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# Safety Analysis Report For Packaging, Y-12 National Security Complex, Model ES-3100 Package with Bulk HEU Contents

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Prepared by
Consolidated Nuclear Security, LLC
Management & Operating Contractor
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**CONTENTS**


APPROVALS ..... v

FIGURES ..... xiii

TABLES ..... xvii

ABBREVIATIONS ..... xxi

REVISION LOG ..... xxiii

ACKNOWLEDGMENTS ..... xxvii

1. GENERAL INFORMATION ..... 1-1
- 1.1 INTRODUCTION ..... 1-1
- 1.2 PACKAGE DESCRIPTION ..... 1-2
  - 1.2.1 Packaging ..... 1-2
  - 1.2.2 Contents ..... 1-8
  - 1.2.3 Special Requirements for Plutonium ..... 1-25
  - 1.2.4 Operational Features ..... 1-25
- 1.3 APPENDICES ..... 1-27
  - Appendix 1.3.1 Package Certification Drawing ..... 1-29
  - Appendix 1.3.2 Equipment Specification JS-YMN3-801580-A002, *ES-3100 Drum Assembly* ..... 1-37
  - Appendix 1.3.3 Equipment Specification JS-YMN3-801580-A001, *ES-3100 Containment Vessel* ..... 1-47
  - Appendix 1.3.4 Equipment Specification JS-YMN3-801580-A003, *Manufacturing Process Specification for Casting Kaolite 1600™ into the ES-3100 Shipping Package* ..... 1-61
  - Appendix 1.3.5 Equipment Specification JS-YMN3-801580-A005, *Casting Catalog No. 277-4 Neutron Absorber for the ES-3100 Shipping Package* ..... 1-81
  - Appendix 1.3.6 Package Category Determination ..... 1-123
  - Appendix 1.3.7 ES-3100 Design Drawings ..... 1-127
  - Appendix 1.3.8 Pyrophoricity of Uranium Metal ..... 1-177
  - Appendix 1.3.9 Equipment Specification SPC-M801580-0001, *ES-3100 Fluorocarbon Elastomer (Viton) Containment Vessel (CV) O-rings* ..... 1-197
  - Appendix 1.3.10 Equipment Specification SPC-M801580-0002, *ES-3100 Ethylene Propylene Diene Monomer (EPDM) Containment Vessel (CV) O-rings* ..... 1-213
- SECTION 1 REFERENCES ..... 1-231

2. STRUCTURAL EVALUATION ..... 2-1
- 2.1 DESCRIPTION OF STRUCTURAL DESIGN ..... 2-2
  - 2.1.1 Discussion ..... 2-2
  - 2.1.2 Design Criteria ..... 2-6
  - 2.1.3 Weights and Centers of Gravity ..... 2-13
  - 2.1.4 Identification of Codes and Standards for Package Design ..... 2-13
- 2.2 MATERIALS ..... 2-17
  - 2.2.1 Material Properties and Specifications ..... 2-17
  - 2.2.2 Chemical, Galvanic, or Other Reactions ..... 2-17
  - 2.2.3 Effects of Radiation on Materials ..... 2-28

2.3 FABRICATION AND EXAMINATION....2-29
2.3.1 Fabrication....2-29
2.3.2 Examination....2-31
2.4 GENERAL REQUIREMENTS FOR ALL PACKAGES....2-34
2.4.1 Minimum Package Size—10 CFR 71.43(a)....2-34
2.4.2 Tamper-Indicating Feature—10 CFR 71.43(b)....2-34
2.4.3 Positive Closure—10 CFR 71.43(c)....2-34
2.5 LIFTING AND TIE-DOWN STANDARDS FOR ALL PACKAGES....2-35
2.5.1 Lifting Devices....2-35
2.5.2 Tie-Down Devices....2-35
2.6 NORMAL CONDITIONS OF TRANSPORT....2-36
2.6.1 Heat....2-40
2.6.2 Cold....2-43
2.6.3 Reduced External Pressure....2-44
2.6.4 Increased External Pressure....2-48
2.6.5 Vibration....2-48
2.6.6 Water Spray....2-50
2.6.7 Free Drop....2-51
2.6.8 Corner Drop....2-52
2.6.9 Compression....2-53
2.6.10 Penetration....2-54
2.7 HYPOTHETICAL ACCIDENT CONDITIONS....2-55
2.7.1 Free Drop....2-59
2.7.2 Crush....2-70
2.7.3 Puncture....2-79
2.7.4 Thermal....2-84
2.7.5 Immersion—Fissile Material....2-89
2.7.6 Immersion—All Packages....2-91
2.7.7 Deep Water Immersion Test (for Type B Packages Containing More than $10^5$ $A_2$)....2-91
2.7.8 Summary of Damage....2-91
2.8 ACCIDENT CONDITIONS FOR AIR TRANSPORT OF PLUTONIUM....2-104
2.9 ACCIDENT CONDITIONS FOR FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT....2-104
2.10 SPECIAL FORM....2-104
2.11 FUEL RODS....2-104
SECTION 2 REFERENCES....2-105

3. THERMAL EVALUATION....3-1
3.1 DESCRIPTION OF THERMAL DESIGN....3-1
3.1.1 Design Features....3-2
3.1.2 Content's Decay Heat....3-3
3.1.3 Summary Tables of Temperatures....3-4
3.1.4 Summary Tables of Maximum Pressures....3-8
3.2 MATERIAL PROPERTIES AND COMPONENT SPECIFICATIONS....3-11
3.2.1 Material Properties....3-11
3.2.2 Component Specifications....3-11

3.3 THERMAL EVALUATION UNDER NORMAL CONDITIONS OF TRANSPORT.....3-17
3.3.1 Heat and Cold.....3-18
3.3.2 Maximum Normal Operating Pressure.....3-27
3.3.3 Maximum Thermal Stresses.....3-28
3.4 THERMAL EVALUATION UNDER HYPOTHETICAL ACCIDENT CONDITIONS.....3-29
3.4.1 Initial Conditions.....3-29
3.4.2 Fire Test Conditions.....3-30
3.4.3 Maximum Temperatures and Pressure.....3-33
3.4.4 Maximum Thermal Stresses.....3-43
3.4.5 Accident Conditions for Fissile Material Packages for Air Transport.....3-43
3.5 APPENDICES.....3-45
Appendix 3.5.1 Containment Vessel Pressure due to Normal Conditions of Transport for the Proposed Contents.....3-47
Appendix 3.5.2 Containment Vessel Pressure due to Hypothetical Accident Conditions for the Proposed Contents.....3-57
Appendix 3.5.3 Silicone Rubber Thermal Properties from Therm 1.2 Database.....3-65
Appendix 3.5.4 Estimates of Hydrogen Buildup in the ES-3100 Package Containing Highly Enriched Uranium.....3-67
SECTION 3 REFERENCES.....3-81

4. CONTAINMENT.....4-1
4.1 DESCRIPTION OF THE CONTAINMENT SYSTEM.....4-4
4.1.1 Containment Boundary.....4-4
4.1.2 Special Requirements for Plutonium.....4-7
4.2 CONTAINMENT UNDER NORMAL CONDITIONS OF TRANSPORT.....4-7
4.3 CONTAINMENT UNDER HYPOTHETICAL ACCIDENT CONDITIONS.....4-9
4.4 LEAKAGE RATE TESTS FOR TYPE B PACKAGES.....4-11
4.5 APPENDICES.....4-13
Appendix 4.5.1 Determination of $A_2$ for the ES-3100 Package with HEU Contents.....4-15
Appendix 4.5.2 Calculation of the ES-3100 Containment Vessel's Regulatory Reference Air Leakage Rates.....4-23
SECTION 4 REFERENCES.....4-41

5. SHIELDING EVALUATION.....5-1
5.1 DESCRIPTION OF SHIELDING DESIGN.....5-1
5.1.1 Design Features.....5-1
5.1.2 Codes and Standards.....5-1
5.1.3 Summary Table of Maximum Radiation Levels.....5-1
5.2 SOURCE SPECIFICATION.....5-4
5.2.1 Gamma Source.....5-4
5.2.2 Neutron Source.....5-4
5.3 SHIELDING MODEL.....5-4
5.3.1 Configuration of Source and Shielding.....5-6
5.3.2 Material Properties.....5-14
5.4 SHIELDING EVALUATION.....5-14
5.4.1 Methods.....5-14
5.4.2 Input and Output Data.....5-15
5.4.3 Flux-to-Dose-Rate Conversion.....5-15
5.4.4 External Radiation Levels.....5-15

5.5 APPENDICES ..... 5-19
Appendix 5.5.1 Origen Input Data from Table 5.3 ..... 5-21
Appendix 5.5.2 MCNP Input Files ..... 5-23
SECTION 5 REFERENCES ..... 5-43

6. CRITICALITY EVALUATION ..... 6-1
6.1 DESCRIPTION OF THE CRITICALITY DESIGN ..... 6-1
6.1.1 Design Features ..... 6-1
6.1.2 Codes and Standards ..... 6-2
6.1.3 Summary of the Criticality Evaluation ..... 6-4
6.1.4 Criticality Safety Index ..... 6-39
6.2 PACKAGE CONTENTS ..... 6-40
6.2.1 Fissile Material Contents ..... 6-40
6.2.2 Convenience Cans, Teflon and Polyethylene Bottles, and 277-4 Canned Spacers ..... 6-42
6.2.3 Packing Materials ..... 6-42
6.2.4 Package Content Loading Restrictions ..... 6-43
6.3 GENERAL CONSIDERATIONS ..... 6-44
6.3.1 Model Configuration ..... 6-45
6.3.2 Material Properties ..... 6-62
6.3.3 Computer Codes and Cross-Section Libraries ..... 6-75
6.3.4 Demonstration of Maximum Reactivity ..... 6-77
6.4 SINGLE PACKAGE EVALUATION ..... 6-79
6.4.1 Solid HEU Metal of Specified Geometric Shapes ..... 6-80
6.4.2 HEU Broken Metal; Solid HEU Metal with Unspecified Geometric Shape and Characterized as Broken Metal; or Turnings, Fines, or Powder ..... 6-88
6.4.3 HEU Oxide ..... 6-90
6.4.4 UNH Crystals ..... 6-92
6.5 EVALUATION OF PACKAGE ARRAYS UNDER NORMAL CONDITIONS OF TRANSPORT ..... 6-94
6.5.1 Solid HEU Metal of Specified Geometric Shapes ..... 6-94
6.5.2 HEU Broken Metal; Solid HEU Metal of Unspecified Geometric Shape and Characterized as Broken Metal; or Turnings, Fines, or Powder ..... 6-97
6.5.3 HEU Oxide ..... 6-99
6.5.4 UNH Crystals ..... 6-100
6.6 EVALUATION OF PACKAGE ARRAYS UNDER HYPOTHETICAL ACCIDENT CONDITIONS ..... 6-101
6.6.1 Solid HEU Metal of Specified Geometric Shapes ..... 6-101
6.6.2 HEU Broken Metal; Solid HEU Metal of Unspecified Geometric Shape and Characterized as Broken Metal; or Turnings, Fines, or Powder ..... 6-102
6.6.3 HEU Oxide ..... 6-104
6.6.4 UNH Crystals ..... 6-105
6.7 FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT ..... 6-105
6.7.1 Results for HEU Metal (Excluding TRIGA Fuel Elements) ..... 6-105
6.7.2 Results for TRIGA Fuel Elements, Three Pieces per Convenience Can ..... 6-109
6.7.3 Results for HEU Broken Metal, Turnings, Fines, or Powder ..... 6-115
6.7.4 Conclusions ..... 6-118

6.8 BENCHMARK EXPERIMENTS....6-119
6.8.1 Applicability of Benchmark Experiments....6-119
6.8.2 Details of Benchmark Calculations....6-119
6.8.3 Bias Determination....6-119
6.9 APPENDICES....6-121
Appendix 6.9.1 Fissile Content and Packaging Models....6-123
Appendix 6.9.2 HAC Package Model....6-153
Appendix 6.9.3 Package Material Compositions....6-165
Appendix 6.9.4 Qualification of a Neutron-absorber Material for the ES-3100....6-197
Appendix 6.9.5 Miscellaneous Information and Data....6-209
Appendix 6.9.6 Abridged Summary Tables of Criticality Calculation Results....6-213
Appendix 6.9.7 Input Listings of ES-3100 Calculation Models for Select Cases....6-363
Appendix 6.9.8 Criticality Evaluation of Additional/New Contents....6-651
Appendix 6.9.9 Criticality Evaluation of HEU Oxide Product Content for Air Transportation....6-705
Appendix 6.9.10 Analysis of HEU Oxide ($U_3O_8$) with Carbon Concentrations for Shipment in the ES-3100....6-723
SECTION 6 REFERENCES....6-733

7. PACKAGE OPERATIONS....7-1
7.1 PACKAGE LOADING....7-3
7.1.1 Preparation for Loading....7-3
7.1.2 Loading of Contents....7-8
7.1.3 Preparation for Transport....7-12
7.2 PACKAGE UNLOADING....7-14
7.2.1 Receipt of Package from Carrier....7-15
7.2.2 Removal of Contents....7-16
7.3 PREPARATION OF EMPTY PACKAGE FOR TRANSPORT....7-17
7.4 OTHER OPERATIONS....7-20
7.5 APPENDICES....7-21
Appendix 7.5.1 Records and Reporting Requirements....7-23
Appendix 7.5.2 Example Leak-Test Procedure, Y-12 Product Specification Procedure Y51-01-B2-R-074, *Shipping Container Leak Test*....7-25
SECTION 7 REFERENCES....7-35

8. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM....8-1
8.1 ACCEPTANCE TESTS....8-3
8.1.1 Visual Inspections and Measurements....8-3
8.1.2 Weld Examinations....8-7
8.1.3 Structural and Pressure Tests....8-7
8.1.4 Leakage Tests....8-8
8.1.5 Component and Material Tests....8-8
8.1.6 Shielding Tests....8-9
8.1.7 Thermal Tests....8-9
8.1.8 Miscellaneous Tests....8-9
8.2 MAINTENANCE PROGRAM....8-9
8.2.1 Structural and Pressure Tests....8-10
8.2.2 Leakage Tests....8-10
8.2.3 Component and Material Tests....8-12

8.2.4 Thermal Tests....8-12
8.2.5 Miscellaneous Tests....8-13
8.3 APPENDIX....8-15
Appendix 8.3.1 Example Leak-test Procedure, Y-12 Product Specification Procedure Y51-01-B2-R-140, *He Leak Testing in B2*....8-17
SECTION 8 REFERENCES....8-29
9. QUALITY ASSURANCE....9-1
9.1 INTRODUCTION....9-1
9.2 SCOPE....9-2
9.3 QUALITY ASSURANCE PLAN....9-3
9.3.1 Quality Assurance Organization....9-3
9.3.2 Quality Assurance Program....9-5
9.3.3 Package Design Control....9-11
9.3.4 Procurement Document Control....9-11
9.3.5 Instructions, Procedures, and Drawings....9-12
9.3.6 Document Control....9-12
9.3.7 Control of Purchased Material, Equipment, and Services....9-13
9.3.8 Identification and Control of Materials, Parts, and Components....9-13
9.3.9 Control of Special Processes....9-14
9.3.10 Internal Inspection....9-14
9.3.11 Test Control....9-15
9.3.12 Control of Measuring and Test Equipment....9-15
9.3.13 Handling, Storage, and Shipping Control....9-15
9.3.14 Inspection, Test, and Operating Status....9-16
9.3.15 Nonconforming Materials, Parts, or Components....9-16
9.3.16 Corrective Action....9-17
9.3.17 Quality Assurance Records....9-17
9.3.18 Audits....9-18
9.3.19 Software Quality Assurance....9-19
SECTION 9 REFERENCES....9-21

## FIGURES


Fig. 1.1. Schematic of the ES-3100 shipping package. ..... 1-3
Fig. 1.2. Exploded view of the ES-3100 package with bulk HEU contents. ..... 1-4
Fig. 1.3. Containment boundary of the ES-3100 shipping package. ..... 1-9
Fig. 1.4. Typical shipping configurations inside the ES-3100 containment vessel. ..... 1-13
Fig. 2.1. Containment vessel calculated stress locations. ..... 2-9
Fig. 2.2. ES-3100 shipping package center of gravity locations. ..... 2-14
Fig. 2.3. ES-3100 vibration testing arrangement. ..... 2-49
Fig. 2.4. Water spray test arrangement for TU-4. ..... 2-51
Fig. 2.5. NCT free drop test on TU-4. ..... 2-53
Fig. 2.6. Compression test on TU-4. ..... 2-54
Fig. 2.7. Penetration test damage on TU-4. ..... 2-55
Fig. 2.8. 9-m drop test arrangement for all test units. ..... 2-60
Fig. 2.9. 9-m drop test damage on TU-4. ..... 2-61
Fig. 2.10. Cumulative damage from 9-m drop and crush testing on TU-2. ..... 2-63
Fig. 2.11. TU-3 (top) and TU-8 (bottom) damage from 1.2- and 9-m drop tests. ..... 2-65
Fig. 2.12. 1.2- and 9-m drop test damage on TU-1. ..... 2-67
Fig. 2.13. 1.2- and 9-m drop test damage to TU-5. ..... 2-69
Fig. 2.14. Cumulative damage following 9-m crush on TU-1. ..... 2-72
Fig. 2.15. Cumulative damage following 9-m crush test on TU-3. ..... 2-74
Fig. 2.16. Cumulative damage from 9-m drop and crush testing on TU-4. ..... 2-75
Fig. 2.17. Cumulative damage from 9-m drop and crush testing on TU-5. ..... 2-77
Fig. 2.17a. Cumulative damage from 9-m drop and crush testing on TU-8. ..... 2-78
Fig. 2.18. 28° oblique and horizontal puncture tests on TU-1. ..... 2-80
Fig. 2.19. 40° oblique puncture test on TU-1. ..... 2-80
Fig. 2.20. Horizontal puncture test over TU-1's containment vessel flange. ..... 2-81
Fig. 2.21. Horizontal CG puncture test on TU-2. ..... 2-81
Fig. 2.22. 24.6° oblique puncture test on TU-3. ..... 2-82
Fig. 2.23. Vertical puncture test on TU-4. ..... 2-82
Fig. 2.24. Horizontal puncture test over TU-5's containment vessel flange. ..... 2-83
Fig. 2.24a. 25.5° oblique puncture test on TU-8. ..... 2-83
Fig. 2.25. Visual comparison of the cumulative damage on the crush side surface after the three drop tests (from top to bottom: TU-1, analytical results with BoroBond, analytical results with Cat 277-4). ..... 2-94
Fig. 2.26. Visual comparison of the cumulative damage on the rigid surface side after the four drop tests (from left to right: TU-2, analytical results with BoroBond, analytical results with Cat 277-4). ..... 2-96
Fig. 2.27. Visual comparison of the cumulative damage on the crush plate side after the three drop tests (from left to right: TU-2, analytical results with BoroBond, analytical results with Cat 277-4). ..... 2-96
Fig. 2.28. Visual comparison of the cumulative bottom damage after the three drop tests (from top to bottom: TU-3, analytical results with BoroBond, analytical results with Cat 277-4). ..... 2-98
Fig. 2.29. Visual comparison of the cumulative lid damage after the three drop tests (from top to bottom: TU-3, analytical results with BoroBond, analytical results with Cat 277-4). ..... 2-99
Fig. 2.30. Visual comparison of the cumulative damage after the three drop tests (from left to right: TU-4, analytical results with BoroBond, analytical results with Cat 277-4). ..... 2-101
Fig. 2.31. Containment vessel markings at assembly (swivel hoist ring removed prior to testing). ..... 2-103
Fig. 2.32. Containment vessel marking after compliance testing. ..... 2-103

Fig. 3.1. MSC.Patran axisymmetric finite element model of the ES-3100 shipping container with BoroBond 4—nodal locations of interest (elements representing air not shown for clarity). ..... 3-19
Fig. 3.2. ANSYS axisymmetric finite element model of the ES-3100 shipping container with Cat 277-4. ..... 3-20
Fig. 3.3. ANSYS axisymmetric finite element model of the ES-3100 shipping container with Cat 277-4 (upper portion detail). ..... 3-21
Fig. 3.4. ANSYS axisymmetric finite element model of the ES-3100 shipping container with Cat 277-4 (lower portion detail). ..... 3-21
Fig. 3.5. TU-1 through TU-5 preheat arrangement. ..... 3-32
Fig. 3.6. Test unit insertion into furnace. ..... 3-32
Fig. 3.7. Test unit removal from furnace. ..... 3-34
Fig. 3.8. Test unit cool down and monitoring arrangement. ..... 3-34
Fig. 5.1. Cylindrical calculational model of the ES-3100 shipping package for NCT. ..... 5-7
Fig. 5.2. ES-3100 HEU metal content radial (top view) geometric models. ..... 5-12
Fig. 6.1. R/Z section view of ES-3100 single-unit packaging model. ..... 6-47
Fig. 6.2. R/Z section view at bottom of ES-3100 single-unit packaging showing KENO V.a geometry units 1001–1003, and 1006 (partial). ..... 6-48
Fig. 6.3. R/Z section view at center of the ES-3100 single-unit packaging showing KENO V.a geometry units 1006 (partial), 1007, and 1008 (partial). ..... 6-49
Fig. 6.4. R/Z section view of near top of the ES-3100 single-unit packaging showing KENO V.a geometry units 1008 (partial) and 1010–1016. ..... 6-50
Fig. 6.5. R/Z section view at the top of the ES-3100 single-unit packaging showing KENO V.a geometry units 1016–1019. ..... 6-51
Fig. 6.6. R/Z section view of ES-3100 array packaging model with a 7% reduction in the drum's inner diameter. ..... 6-52
Fig. 6.7. R/Z section view at the bottom of the ES-3100 array packaging showing KENO V.a geometry units 1001–1003, and 1006 (partial). ..... 6-53
Fig. 6.8. R/Z section view at the center of the ES-3100 array packaging showing KENO V.a geometry units 1006 (partial), 1007, and 1008 (partial). ..... 6-54
Fig. 6.9. R/Z section view of near top of the ES-3100 array packaging showing KENO V.a geometry units 1008 (partial) and 1010–1016. ..... 6-55
Fig. 6.10. R/Z section view at the top of the ES-3100 array packaging showing KENO V.a geometry units 1016–1019. ..... 6-56
Fig. 6.11. Model 1. ..... 6-61
Fig. 6.12. Model 2. ..... 6-61
Fig. 6.13. Model 3. ..... 6-61
Fig. 6.14. Model 4. ..... 6-62
Fig. 6.15. Model 5. ..... 6-62
Fig. 6.16. Model 6. ..... 6-62
Fig. 6.17. $k_{eff} + 2\sigma$ versus pitch for triangular arrangement of content in the containment vessel. ..... 6-83
Fig. 6.18. $k_{eff} + 2\sigma$ versus triangular pitch over range of containment vessel moderation. ..... 6-84
Fig. 6.19. $k_{eff} + 2\sigma$ as a function of uranium weight fraction and moderation. ..... 6-84
Fig. 6.20. $k_{eff}$ vs enrichment (wt % 235U) for HEU ranging from 7 to 10 kg. ..... 6-106
Fig. 6.21. $k_{eff}$ vs stainless steel shell radius (cm) for 7 kg HEU with enrichments ranging from 19 to 100 wt % $^{235}U$. ..... 6-107
Fig. 6.22. $k_{eff}$ vs wet Kaolite shell radius (cm) for 7 kg HEU with enrichments ranging from 19 to 100 wt % $^{235}U$. ..... 6-108
Fig. 6.23. $k_{eff}$ vs shell radius for wet and dry Kaolite for 7 kg HEU at 100% enrichment. ..... 6-109
Fig. 6.24. $k_{eff}$ vs shell radius (cm) for 10.4 kg core of UZrHx with stainless steel or wet Kaolite shell. ..... 6-110

Fig. 6.25. $k_{eff}$ vs water content (g) for homogenized core of UZrHx, 500 g polyethylene and Kaolite where the Kaolite water content ranges from the dry to the wet condition. ..... 6-112
Fig. 6.26. $k_{eff}$ vs excess water (g) from wet Kaolite for fissile core blanketed with a variable thickness Kaolite shell. ..... 6-113
Fig. 6.27. $k_{eff}$ vs excess water (g) from wet Kaolite for fissile material core blanketed with a variable thickness Kaolite shell. ..... 6-114
Fig. 6.28. $k_{eff}$ vs excess water (g) from wet Kaolite for fissile material core blanketed with a variable thickness Kaolite shell. ..... 6-114
Fig. 6.29. $k_{eff}$ vs water content (g) for homogenized core of HEU with 7 kg $^{235}U$, 500 g polyethylene, and Kaolite where the Kaolite water content ranges from the dry to the wet condition. ..... 6-116
Fig. 6.30. $k_{eff}$ vs excess water (g) from wet Kaolite for fissile core blanketed with a variable thickness Kaolite shell. ..... 6-117
Fig. 6.31. $k_{eff}$ vs water (g) in Kaolite for homogenized core of HEU at 100% enrichment, 500-g polyethylene, and wet Kaolite encompassed by shell of $^{235}U$. ..... 6-118
Fig. 8.1. Example label for use on the exterior surface of the containment vessel and the drum. .... 8-12
Fig. 9.1. Y-12 Packaging and Transportation Engineering organizational support. ..... 9-4

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## TABLES


Table 1.1. Uranium concentration limits....1-9
Table 1.2. Bounding uranium isotopic concentrations in oxide....1-11
Table 1.2a. Maximum impurities in uranium silicide....1-16
Table 1.3. Authorized content and fissile mass loading limits for ground transport....1-18
Table 1.3a. Uranyl nitrate crystal content loading limits for ground transport....1-21
Table 1.3b. Authorized content and fissile mass loading limits for air transport....1-21
Table 2.1. Proposed HEU contents for shipment in the ES-3100....2-2
Table 2.2. Category designations for Type B packages....2-6
Table 2.3. Summary of load combinations for normal and hypothetical accident conditions of transport....2-8
Table 2.4. Containment vessel allowable stress....2-9
Table 2.5. Allowable stress intensity ($S_m$) for the containment vessel materials of construction....2-10
Table 2.6. ES-3100 containment vessel design evaluation allowable stress comparisons....2-11
Table 2.7. ES-3100 packaging material specifications....2-12
Table 2.8. Packaging weights for various ES-3100 shipping package arrangements....2-15
Table 2.9. Compliance test unit weights....2-17
Table 2.10. Calculated center of gravity for the various ES-3100 shipping arrangements....2-18
Table 2.11. Applicable codes and standards for Category I packaging....2-19
Table 2.12. Mechanical properties of the metallic components of the drum assembly....2-20
Table 2.13. Mechanical properties of the lid fastening components for the drum assembly....2-21
Table 2.14. Mechanical properties of the cast refractory insulation....2-22
Table 2.15. Mechanical properties of containment vessel O-rings....2-22
Table 2.16. Mechanical properties of the metallic components of the containment vessel....2-23
Table 2.17. Mechanical properties of the cast neutron absorber....2-24
Table 2.18. Summary of NCT—10 CFR 71.71 tests for ES-3100 package....2-37
Table 2.19. Summary of HAC—10 CFR 71.73 tests for the ES-3100 package....2-38
Table 2.20. Summary of temperatures and pressures for NCT....2-39
Table 2.21. ES-3100 containment vessel evaluation for both hot and cold conditions....2-45
Table 2.21a. ES-3100 containment vessel evaluation for internal pressure developed during air transport in accordance with TS-R-1 Paragraph 618....2-46
Table 2.22. NCT ES-3100 containment vessel stress compared to the allowable stress at reduced and increased external pressures....2-47
Table 2.23. Test and analysis summary for the ES-3100 package....2-56
Table 2.24. Recorded height damage to TU-4 from 1.2- and 9-m drop tests....2-61
Table 2.25. Recorded diametrical damage to TU-4 from 1.2- and 9-m drop tests....2-61
Table 2.26. Recorded diametrical damage to TU-2 from NCT and HAC drop testing....2-62
Table 2.27. Recorded flat contour damage to TU-2 from NCT and HAC drop tests....2-62
Table 2.28. Recorded height damage to TU-2 from NCT and HAC drop tests....2-63
Table 2.29. Recorded height damage to TU-3 from 1.2- and 9-m drop tests....2-64
Table 2.30. Recorded diametrical damage to TU-3 from 1.2- and 9-m drop tests....2-64
Table 2.31. Recorded height damage to TU-1 from 1.2- and 9-m drop tests....2-66
Table 2.32. Recorded diametrical damage to TU-1 from 1.2- and 9-m HAC drop tests....2-66
Table 2.33. Recorded flat contour damage to TU-1 from 1.2- and 9-m drop tests....2-67
Table 2.34. Recorded height damage to TU-5 from 1.2- and 9-m drop tests....2-68
Table 2.35. Recorded diametrical damage to TU-5 from 1.2- and 9-m HAC drop tests....2-68
Table 2.36. Recorded flat contour damage to TU-5 from 1.2- and 9-m drop testing....2-69
Table 2.37. Recorded height damage to TU-1 from the 9-m crush test....2-71
Table 2.38. Recorded diametrical damage to TU-1 from the 9-m crush test....2-71

Table 2.39. Recorded flat contour damage to TU-1 from the 9-m crush test ..... 2-71
Table 2.40. Recorded height damage to TU-3 from the 9-m crush test ..... 2-73
Table 2.41. Recorded flat contour damage to TU-3 from the 9-m crush test ..... 2-73
Table 2.42. Recorded diametrical damage to TU-3 from the 9-m crush test ..... 2-73
Table 2.43. Recorded height damage to TU-4 from the 9-m crush test ..... 2-74
Table 2.44. Recorded diametrical damage to TU-4 from the 9-m crush test ..... 2-75
Table 2.45. Recorded height damage to TU-5 from the 9-m crush test ..... 2-76
Table 2.46. Recorded diametrical damage to TU-5 from the 9-m crush tests ..... 2-76
Table 2.47. Recorded flat contour damage to TU-5 from the 9-m crush test ..... 2-76
Table 2.47a. Recorded diametrical damage to TU-8 from the 9-m crush test ..... 2-78
Table 2.47b. Recorded height damage to TU-8 from the 9-m crush test ..... 2-78
Table 2.48. 1-m (40-in.) puncture drop test description and results ..... 2-79
Table 2.49. Thermax temperature-indicating patches for test units ..... 2-85
Table 2.50. Maximum HAC temperatures recorded on the test packages' interior surfaces ..... 2-87
Table 2.51. HAC ES-3100 containment vessel stress compared to the allowable stress ..... 2-90
Table 2.52. Diametrical damage comparison of TU-1 with analytical predictions ..... 2-93
Table 2.53. Flat contour damage comparison of TU-1 with analytical results ..... 2-93
Table 2.54. Cumulative analytical 12° slapdown drop tests maximum effective plastic strain results ..... 2-95
Table 2.55. Diametrical damage comparison of TU-2 with analytical predictions ..... 2-95
Table 2.56. Flat contour damage comparison of TU-2 with analytical predictions ..... 2-95
Table 2.57. Cumulative analytical side drop test maximum effective plastic strain results ..... 2-97
Table 2.58. Diametrical damage comparison of TU-3 with analytical predictions ..... 2-97
Table 2.59. Cumulative analytical corner drop test maximum effective plastic strain results ..... 2-100
Table 2.60. Diametrical damage comparison of TU-4 with analytical predictions ..... 2-100
Table 2.61. Cumulative analytical top drop test maximum effective plastic strain results ..... 2-101
Table 2.62. ES-3100 test package weights before and after 10 CFR 71.73(c)(4) HAC testing ..... 2-102
Table 3.1. Isotopic mass and weight percent for the HEU contents ..... 3-4
Table 3.2. Decay heat for 35.2 kg of HEU content ..... 3-5
Table 3.3. Summary of results of evaluation for the ES-3100 under NCT ..... 3-6
Table 3.4. Maximum HAC temperatures recorded on the test packages' interior surfaces ..... 3-7
Table 3.5. Summary of results of evaluation under HAC for the ES-3100 shipping arrangement using bounding case parameters ..... 3-7
Table 3.6. Total pressure inside the containment vessel at 91.93°C (197.48°F) ..... 3-9
Table 3.7. Total pressure inside the containment vessel at 140.36°C (284.64°F) with efflorescence ..... 3-11
Table 3.8. Thermal properties of the materials used in the thermal analysis ..... 3-12
Table 3.9. Mechanical properties of the materials used in the static stress analyses ..... 3-14
Table 3.10. ES-3100 packaging material specifications ..... 3-15
Table 3.11. Component allowable service temperature and pressure ..... 3-17
Table 3.12. Maximum "quasi steady-state" temperatures during NCT for the ES-3100 shipping container with various content heat loads—Kaolite density of 19.4 lb/ft$^3$ and BoroBond4 ..... 3-22
Table 3.13. Maximum "quasi steady-state" temperatures during NCT for the ES-3100 shipping container with various content heat loads—Kaolite density of 30 lb/ft$^3$ and BoroBond4 ..... 3-23
Table 3.14. ES-3100 shipping container maximum steady-state temperatures with Cat 277-4 (no insolation)—Kaolite density of 19.4 lb/ft$^3$ ..... 3-24
Table 3.15. ES-3100 shipping container maximum "quasi steady-state" temperatures during NCT with various content heat loads and Cat 277-4 (100°F ambient temperature, with insolation) ..... 3-25
Table 3.16. ES-3100 test package weights before and after 10 CFR 71.73(c)(4) HAC testing ..... 3-35

Table 3.17. Thermax temperature-indicating patches for test units ..... 3-35
Table 3.18. ES-3100 package HAC maximum temperatures (Kaolite 1600 density of 19.4 lb/ft$^3$ and Cat 277-4 density of 100 lb/ft$^3$) ..... 3-37
Table 3.19. ES-3100 shipping container HAC maximum temperatures (Kaolite 1600 density of 30 lb/ft$^3$ and Cat 277-4 density of 110 lb/ft$^3$) ..... 3-38
Table 3.20. Predicted temperature adjustments (°F) for containment vessel due to HAC ..... 3-41
Table 3.21. Predicted temperatures of the containment vessel due to HAC ..... 3-42
Table 4.1. Containment requirements of transport for Type B packages ..... 4-1
Table 4.2. Summary of the containment vessel design and fabrication acceptance basis ..... 4-1
Table 4.3. Isotopic mass and weight percent for the HEU contents ..... 4-2
Table 4.4. Activity, $A_2$ value, and number of $A_2$ proposed for transport ..... 4-2
Table 4.5. Regulatory leakage criteria for NCT ..... 4-3
Table 4.6. Containment vessel verification tests criteria for NCT ..... 4-3
Table 4.7. Regulatory leakage criteria for HAC ..... 4-10
Table 4.8. Containment vessel design verification tests for HAC ..... 4-11
Table 5.1. Calculated external dose rates for the ES-3100 package with 36 kg of HEU metal contents ..... 5-2
Table 5.2. Calculated external dose rates for the ES-3100 package with 24 kg of HEU oxide contents ..... 5-3
Table 5.3. Radioisotope specification for all ES-3100 package analysis source calculations with HEU content and other nuclides per HEU unit weight ..... 5-5
Table 5.4. Photon source for one gram of HEU for all contents ..... 5-5
Table 5.5. Neutron source for one gram of HEU for all contents ..... 5-6
Table 5.6. Geometric data for the shielding analysis models of the ES-3100 shipping package as shown in Fig. 5.1 for NCT ..... 5-8
Table 5.7. Detector locations relative to the drum for NCT and to the containment vessel for HAC ..... 5-9
Table 5.8. Shielding model material specifications for the ES-3100 package with HEU content ..... 5-10
Table 5.9. ANSI/ANS-1977 photon flux-to-dose-rate conversion factors ..... 5-16
Table 5.10. ANSI/ANS-1977 neutron flux-to-dose-rate conversion factors ..... 5-17
Table 6.1a. Summary of criticality evaluation for solid HEU metal cylinders and bars ..... 6-5
Table 6.1b. Summary of criticality evaluation for solid HEU metal slugs ..... 6-9
Table 6.1c. Summary of criticality evaluation for HEU broken metal or solid HEU metal of unspecified geometric shape and characterized as broken metal ..... 6-12
Table 6.1d. Summary of criticality evaluation for HEU metal turnings, fines, or powder ..... 6-19
Table 6.1e. Summary of criticality evaluation for HEU product and skull oxide ..... 6-25
Table 6.1f. Summary of criticality evaluation for UNX crystals and unirradiated TRIGA reactor fuel elements ..... 6-29
Table 6.2a. HEU fissile material mass loading limits (with case name) for surface-only modes of transportation ..... 6-35
Table 6.2b. HEU fissile material mass loading limits for air mode of transportation ..... 6-38
Table 6.3. Deformation of 18.37-in.-diam ES-3100 drum projected by finite element analysis Case “3100 RUN1HL Lower Bound Kaolite May 2004” ..... 6-58
Table 6.4. Material compositions used in the ES-3100 calculation models ..... 6-65
Table 7.1. Replacement parts for the ES-3100 packaging ..... 7-4
Table 8.1. Acceptance tests for the drum assembly ..... 8-4
Table 8.2. Acceptance tests for the CV assembly ..... 8-5
Table 8.3. Acceptance tests for packing materials ..... 8-5
Table 9.1. Typical level of quality assurance effort by graded quality category ..... 9-7
Table 9.2. Quality category for ES-3100 packaging components ..... 9-10
Table 9.3. Typical quality assurance records ..... 9-18

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## ABBREVIATIONS

| | |
|---|---|
| ALARA | as low as reasonably achievable |
| AM | as-manufactured |
| ANS | American Nuclear Society |
| ANSI | American National Standards Institute |
| AS | allowable stress |
| ASME | American Society of Mechanical Engineers |
| ASNT | American Society for Nondestructive Testing |
| ASTM | American Society for Testing and Materials |
| AWS | American Welding Society |
| CAS | Chemical Abstract Service |
| Cat 277-4 | Thermo Electron Corporation (corporate name changed to Shieldwerx) Catalog No. 277-4™ (or Cat. No. 277-4) |
| CERCA | Compagnie pour l'Étude et la Realisation de Combustibles Atomiques |
| CFR | Code of Federal Regulations |
| CG | center of gravity |
| CMTR | certified material test report |
| CNS | Consolidated Nuclear Security, LLC |
| CoC | Certificate of Compliance |
| CSI | criticality safety index |
| CV | containment vessel |
| CVA | containment vessel arrangement |
| DOE | U.S. Department of Energy |
| DOT | U.S. Department of Transportation |
| ENDF | Evaluated Nuclear Data Files |
| EPDM | ethylene propylene diene monomer |
| ESL | Evaluated Suppliers List |
| ETP | explicit triangular pack |
| FEA | finite element analysis |
| FEP | fluorinated ethylene propylene |
| GMAW | gas metal arc welding |
| GTAW | gas tungsten arc welding |
| HAC | Hypothetical Accident Conditions |
| HEU | highly enriched uranium |
| H/X ratio | hydrogen-to-fissile isotope ratio |
| IAEA | International Atomic Energy Agency |
| $k_{eff}$ | calculated neutron multiplication factor |
| LOD | loss on drying |
| LTL | lower tolerance limit |
| MIT | Massachusetts Institute of Technology |
| MNOP | maximum normal operating pressure |
| MOCFR | moisture fraction inside the containment vessel |
| MOIFR | moisture fraction of the package external to the containment vessel |
| M.S. | margin of safety |
| M&TE | measuring and test equipment |
| NCT | Normal Conditions of Transport |
| NITS | not important to safety |
| NLF | neutron leakage fraction |
| NNSA | National Nuclear Security Administration |
| NRC | U.S. Nuclear Regulatory Commission |
| NTRC | National Transportation Research Center |
| OECD | Organization for Economic Cooperation and Development |

| | |
|---|---|
| ORNL | Oak Ridge National Laboratory |
| PCV | primary containment vessel |
| PGNAA | prompt gamma-ray neutron activation analysis |
| ppb | parts per billion |
| ppm | parts per million |
| QP&A | Quality Performance & Analysis |
| QA | quality assurance |
| RCSB | Rackable Can Storage Box |
| RFID | radio-frequency identification |
| RFWD | request for waiver or deviation |
| SARP | safety analysis report for packaging |
| SCALE | Standardized Computer Analysis for Licensing Evaluation |
| S/CI | suspect/counterfeit item |
| SFA | spectral fatigue analysis |
| SGT | Safeguards Transporter |
| $s_i$ | standard error |
| SNAP | Systems for Nuclear Auxiliary Power |
| SQA | software quality assurance |
| SRNL | Savannah River National Laboratory |
| SS304 | type 304 stainless steel |
| SSC | structures, systems, and components |
| TGA | thermogravimetric analysis |
| TI | transport index |
| TID | tamper-indicating device |
| TRISO | tristructural isotopic |
| TS | test sample |
| TSD | Transportation Safety Document |
| TU | test unit |
| UNH | uranyl nitrate hexahydrate |
| UNX | uranyl nitrate crystals |
| USL | upper subcritical limit |
| VCO | vacuum coupling O-ring |
| VF | volume fraction |
| Y-12 | Y-12 National Security Complex |

## REVISION LOG

| Date | Revision No. | Description | Affected Pages |
|---|---|---|---|
| 9/25/09 | A | Draft for DOE EM review.<br>All revisions to the previous ES-3100 SAR approved by the NRC (Y/LF-717/R3) are shown in red text. Since the revisions to Appendix 3.5.4 and Sects. 7 and 9 were extensive, these sections are shown in black text. Appendices 5.5.2 and 6.9.8 are new, but they are shown in black text. | All |
| 8/12/10 | 0 | Incorporated responses to comments received from DOE EM, Packaging Certification Program SARP Review Team. | All |
| 11/10/10 | 0<br>Page Change 1 | Incorporated minor revisions to make SARP consistent with Rev. 2 of the CoC. | Cover, title page, iii, v, xxiii, 1-2, 1-12, 1-14, 1-16, 1-17, 1-22, 2-1, 3-37, 6-598, 7-13 |
| 2/10/11 | 0<br>Page Change 2 | • Clarified description of U-Zr oxide in "HEU oxide" category (designated as $UO_2$-$ZrO_2$ throughout the SARP)<br>• Added a physical form of oxide under "HEU Oxide" in Sect. 1.2.2 for pellets<br>• In Table 1.3,<br>– Modified "CSI" and "277-4 can spacer" entries for U-Zr in "Research reactor fuel elements and components" category<br>– Added a new content group called "Oxides of U-Zr" under the "Research reactor fuel elements and components" category<br>• Changed the maximum enrichment of TRIGA fuel to ≤70%<br>• Revised CSI entries for air transport in Table 1.3b<br>• Clarified appropriate DOE marking on the drum in Sect. 7.1.2.2<br>• Editorial corrections as necessary | Cover, title page, iii, v, xxiii, 1-10 through 1-12, 1-15 through 1-17, 2-1, 2-2, 4-3, 6-4, 6-30, 6-33, 6-35, 6-598, 7-11 |

| Date | Revision No. | Description | Affected Pages |
|---|---|---|---|
| 6/21/12 | 0<br>Page Change 3 | • Change the U-233 concentration limit in oxide contents to 0.006 g/gU from 200 ppm<br>• Add bulk HEU oxide as an authorized content for air transport<br>• Add uranium silicide as an authorized content for ground transport<br>• Add Viton GLT-S as an optional O-ring material in addition to EPDM and extend the basis for periodic maintenance from 1 to 2 years for packagings with Viton GLT-S O-rings and temperature monitoring<br>• Revise the spacer can drawing (Drawing M2E801580A043) to make the "vibration absorbing silicone can pad" optional<br>• Increase the amount of U-235 in U-Al reactor fuel<br>• Make allowance for convenience cans with diameters >4.25 in. along with a void volume limit for gas expansion and offgassing materials in the CV<br>• Remove the requirement to place empty convenience cans on top of the loaded cans<br>• Revise the wording regarding convenience can use to allow for contents that cannot fit into a convenience can to be bagged only (no convenience can)<br>• Add the option of applying an RFID system to the ES-3100<br>• Editorial corrections as necessary | All |
| 1/10/13 | 0<br>Page Change 4 | Incorporate responses to Q1 comments. | Cover, title page, v, viii, ix, xvii, xxi, xxii, xxiv, 1-11, 1-12, 1-18, 1-19, 1-20, 1-24, 2-39, 2-39a, 2-41, 2-43, 2-44a, 2-56, 2-107, 2-109, 2-110, 3-6, 3-24, 3-54a, 3-54b, 3-80, 3-81, 3-82, 4-7, 4-9, 4-33 through 4-42, 6-30, 6-35, 6-36, 6-598, 6-611 through 6-614, 6-616, 6-629 through 6-633, 7-1, 7-16, 7-26, 7-43, 8-1, 8-31, 9-1, 9-19, 9-20 |
| 9/30/13 | 0<br>Page Change 5 | • Incorporate responses to Q1 comments for shipping HEU metal and alloy turnings, fines, or powder<br>• Clarified the "HEU Metal and Alloy" and "HEU Oxide" shipping configurations including the use of aluminum convenience cans and Teflon bottles<br>• Editorial corrections as necessary | Cover, title page, v, x, xi, xiv, xv, xix, xxiv, 1-2, 1-10, 1-18 through 1-22, 1-24, 1-227, 2-1, 2-5, 2-13, 2-24, 2-25, 2-41, 3-16, 6-1 through 6-688, 7-6 |
| 2/27/14 | 0<br>Page Change 6 | Incorporate responses to Q1 comments for Phase III review documented in RP-801940-0011 with additional editorial changes. | Cover, title page, v, xxiv, 1-10, 1-20, 1-22, 2-28, 2-39a, 2-40, 2-109, 4-6, 4-42, 7-20, 8-9, 9-20 |

| Date | Revision No. | Description | Affected Pages |
|---|---|---|---|
| 6/30/15 | 0<br>Page Change 7 | • Incorporated changes to address the Consolidated Nuclear Security, LLC, (CNS) organization/position titles and procedural requirements<br>• Updated references to the current Quality Assurance Program Plan (QAP-Y-91-273860-1, Rev. 15)<br>• Removed provisions in the SARP that supported the extended periodic maintenance interval for the package including the temperature labels requirements<br>• Updated references to reflect current regulatory and DOE directive requirements | Cover, ii, title page, v, vii, ix, xi, xii, xv, xix, xxi, xxii, xxiv through xxviii, 1-1, 1-6, 1-19, 1-27, 1-29, 1-31, 1-33, 1-125, 1-149, 1-167, 1-213 through 1-232, 2-9, 2-10, 2-31 through 2-33, 2-40, 2-41, 2-105, 2-106, 3-79, 4-41, 5-39, 6-173, 6-193, 6-616, 6-685, 7-2, 7-4, 7-7 through 7-12, 7-14, 7-15, 7-17 through 7-36, 8-4, 8-5, 8-9 through 8-12, 8-19 through 8-29, 8-31, 9-1 through 9-22 |
| 9/3/15 | 1 | • Incorporated Page Changes 1–7 and minor editorial changes<br>• Added provisions in the SARP to address the requirements for samples and small quantities (≤ 50 g) of HEU metal or alloy turnings, fines, or powder<br>• Added App. 6.9.10 as the basis for the HEU oxide carbon limit requirements and revised appropriate footnotes in Tables 1.3 and 6.9.8.2 | All |

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# 1. GENERAL INFORMATION

## 1.1 INTRODUCTION

This safety analysis report for packaging (SARP) presents the results of the safety analysis prepared in support of the Consolidated Nuclear Security, LLC (CNS) request for licensing of the Model ES-3100 package with bulk highly enriched uranium (HEU) contents and issuance of a Type B(U) Fissile Material Certificate of Compliance. This SARP, published in the format specified in the Nuclear Regulatory Commission (NRC) Regulatory Guide 7.9 and using information provided in UCID-21218 and NRC Regulatory Guide 7.10, demonstrates that the Y-12 National Security Complex (Y-12) ES-3100 package with bulk HEU contents meets the established NRC regulations for packaging, preparation for shipment, and transportation of radioactive materials given in Title 10, Part 71, of the Code of Federal Regulations (CFR) [10 CFR 71] as well as U.S. Department of Transportation (DOT) regulations for packaging and shipment of hazardous materials given in Title 49 CFR.

To protect the health and safety of the public, shipments of radioactive materials are made in packaging that is designed, fabricated, assembled, tested, procured, used, maintained, and repaired in accordance with the provisions cited above. Safety requirements addressed by the regulations that must be met when transporting radioactive materials are containment of radioactive materials, radiation shielding, and assurance of nuclear subcriticality.

A general description and a summary of the evaluation of the packaging are presented in this section. Subsequent sections address structural (Sect. 2) and thermal (Sect. 3) responses to Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) and the packaging's ability to contain the radioactive materials (Sect. 4) when subjected to the requirements of 10 CFR 71.71 and 71.73, respectively. A shielding evaluation was prepared to ensure adequate nuclear radiation shielding (Sect. 5). Criticality evaluations that are unique to the contents were prepared to ensure nuclear subcriticality (Sect. 6). Sections 7 and 8 discuss the operating procedures, the new packaging acceptance tests, and the maintenance program for the planned use and refurbishment of the packaging. Section 9 describes the packaging quality assurance requirements as demonstrated by the *Packaging and Transportation Quality Assurance Program Plan* (QAP-Y-91-273860-1).

The ES-3100 package was subjected to verification (analysis, similarity comparisons, tests, or a combination of these) for NCT and HAC. Full-scale packages were used for design verification testing (Sects. 2 and 3). The ES-3100 package with bulk HEU content was verified solely on the ability of the package to meet the requirements of 10 CFR 71. Transport conveyance influence on the package is not required to meet 10 CFR 71 requirements.

The packaging verification activities (Sects. 2, 3, and 4), using content test masses of between 3.6 and 50.3 kg (8 and 111 lb), show that the packaging meets the containment requirements of 10 CFR 71. The shielding evaluations (Sect. 5) show that the packaging meets the NCT requirements of 10 CFR 71.47, *External Radiation Standards for all Packages*, and the HAC requirements of 10 CFR 71.51, *Additional Requirements for Type B Packages*. Based on the results of the thermal and shielding evaluations, the ES-3100 package with bulk HEU content may be shipped as a nonexclusive use package. The criticality evaluation (Sect. 6) shows that the packaging meets the requirements of 10 CFR 71.55, *General Requirements for Fissile Material Packages*, and 10 CFR 71.59, *Standards for Arrays of Fissile Material Packages*.

## 1.2 PACKAGE DESCRIPTION

A schematic of the ES-3100 shipping package is shown in Fig. 1.1, and an exploded view of the packaging components is presented in Fig. 1.2. The packaging design drawings (Appendix 1.3.7) provide material lists, dimensions, safety components, welding requirements, and gasket requirements. The maximum nominal gross shipping weight of the ES-3100 package with bulk HEU content is 187.81 kg (414.05 lb). The maximum authorized gross shipping weight of the ES-3100 package is 190.5 kg (420 lb). The certification drawing of the ES-3100 can be found in Appendix 1.3.1. The ES-3100 as specified in this SARP is classified as a Type B(U) fissile material Category I package (see Appendix 1.3.6).

### 1.2.1 Packaging

The main functions of the packaging are containment, shielding, and nuclear criticality safety. The bulk HEU contents create a maximum decay heat of ~5 W (Sect. 1.2.2.7 and 3.1.2); therefore, the packaging does not require any special design features such as coolant valves or continuous venting to meet the thermal requirements of 10 CFR 71.

#### 1.2.1.1 Drum assembly

The drum assembly consists of a double open-head reinforced stainless-steel 30-gal drum, arched cover that forms the bottom, arched lid, inner liner, and top plug with cast refractory insulation (Kaolite) [Drawing M2E801580A001, Appendix 1.3.7]. The inside diameter of the drum is 46.36 cm (18.25 in.) with an overall height of 110.49 cm (43.5 in.) including the cover and lid (Drawings M2E801580A004 and M2E801580A001, Appendix 1.3.7). The outside diameter of the drum (including the hoops) is 49.2 cm (19.37 in.). The drum and lid are made from 16-gauge [~0.152-cm (0.0598-in.)-thick] Type 304 or 304L stainless steel. A 12-gauge [~0.267-cm (0.105-in.)-thick] stainless-steel arched cover (Drawing M2E801580A005, Appendix 1.3.7) is welded to the double open-head drum to create the bottom of the drum assembly. An inner liner (Drawing M2E801580A003, Appendix 1.3.7) is attached to the drum by an internal flange (angle) that is welded to both the drum and liner. The cavity created by the inner liner for placement of a containment vessel is a three-tier volume. The uppermost tier accommodates the top plug and has an inside diameter of 37.52 cm (14.77 in.) and is 13.26-cm (5.22-in.) deep (Drawing M2E801580A003, Appendix 1.3.7). The second tier, which accommodates the containment vessel flange, has a 21.84-cm (8.60-in.) inside diameter that is 5.59-cm (2.20-in.) deep (Drawing M2E801580A003, Appendix 1.3.7). The third tier, which accommodates the containment vessel body, has a 15.85-cm (6.24-in.) inside diameter that is 78.31-cm (30.83-in.) deep (Drawing M2E801580A003, Appendix 1.3.7). An additional cavity is created between the second and third tier liners. This cavity runs the full length of the third tier height [78.31 cm (30.83 in.)] and is ~3.00-cm (1.18-in.) thick (Drawing M2E801580A003, Appendix 1.3.7). This cavity is filled with a castable refractory (277-4 special dry mix) for neutron attenuation purposes. Aluminum foil tape is applied over the 277-4 cavity fill and vent holes (four places) located on the drum liner lower shelf (Drawing M2E801580A002, Appendix 1.3.7). The additional cavities between the liner and the drum are filled with an inorganic castable refractory material (Kaolite 1600), which acts as both an impact-absorbing and thermal-insulating material.

In accordance with NUREG/CR-3854, Part 4.2 for a Category I shipping package, an acceptable specification for drums used in any of the component safety groups is DOT Specification 17C or better. It should be noted that the Specification 17C package is no longer included in the DOT regulations (49 CFR 178). The drum used in the ES-3100 is fabricated in accordance with the dimensional requirements of Military Standard MS27683 and modified as shown on Drawing M2E801580A004 (Appendix 1.3.7). The fabrication requirements for the ES-3100 drum assembly are shown in Equipment Specification JS-YMN3-801580-A002 (Appendix 1.3.2). Material, fabrication, and quality control

criteria are generally equivalent to those imposed for a DOT Specification 17C drum. Furthermore, the drum of the ES-3100 is part of a performance-based package that has been tested and analyzed to demonstrate its ability to maintain confinement and containment of its contents under both NCT and HAC. By certifying that the outer shell of the drum assembly used in production meets the same specifications as those tested and analyzed, as described in subsequent sections of this SARP, the outer drum shell used for the ES-3100 is acceptable for a Category 1 shipping package.

As previously discussed, the drum has been modified by the attachment of an inner liner connected to the drum by an internal flange welded to both the drum and the liner. Weld studs are attached to the upper face of the internal flange. The body seams are welded. The following items are conducted in accordance with Sect. IX of the *American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code* (ASME Code, Sect. IX): welding procedures qualification and welders certification to these qualified procedures.

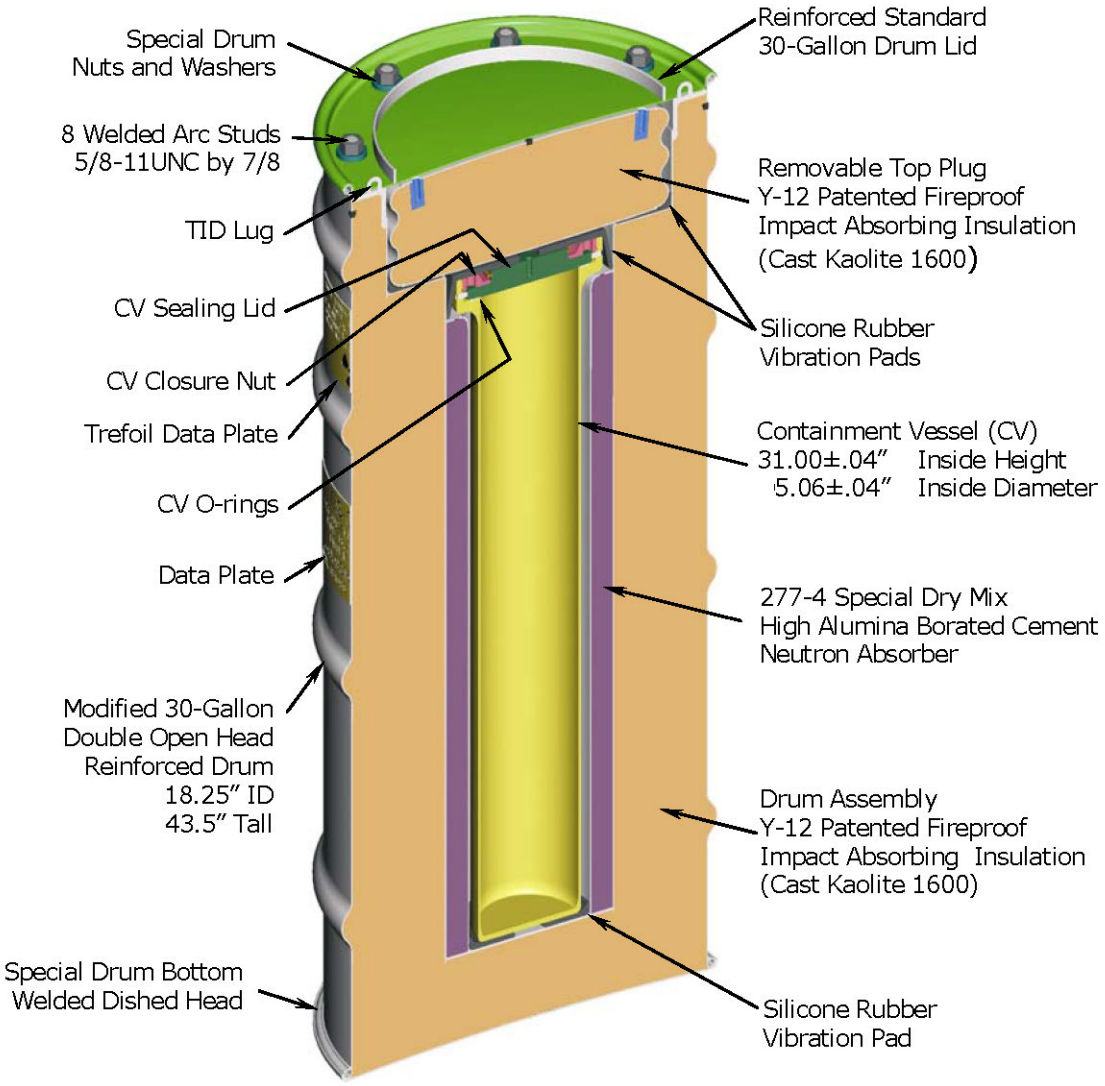



**Fig. 1.1. Schematic of the ES-3100 shipping package.**

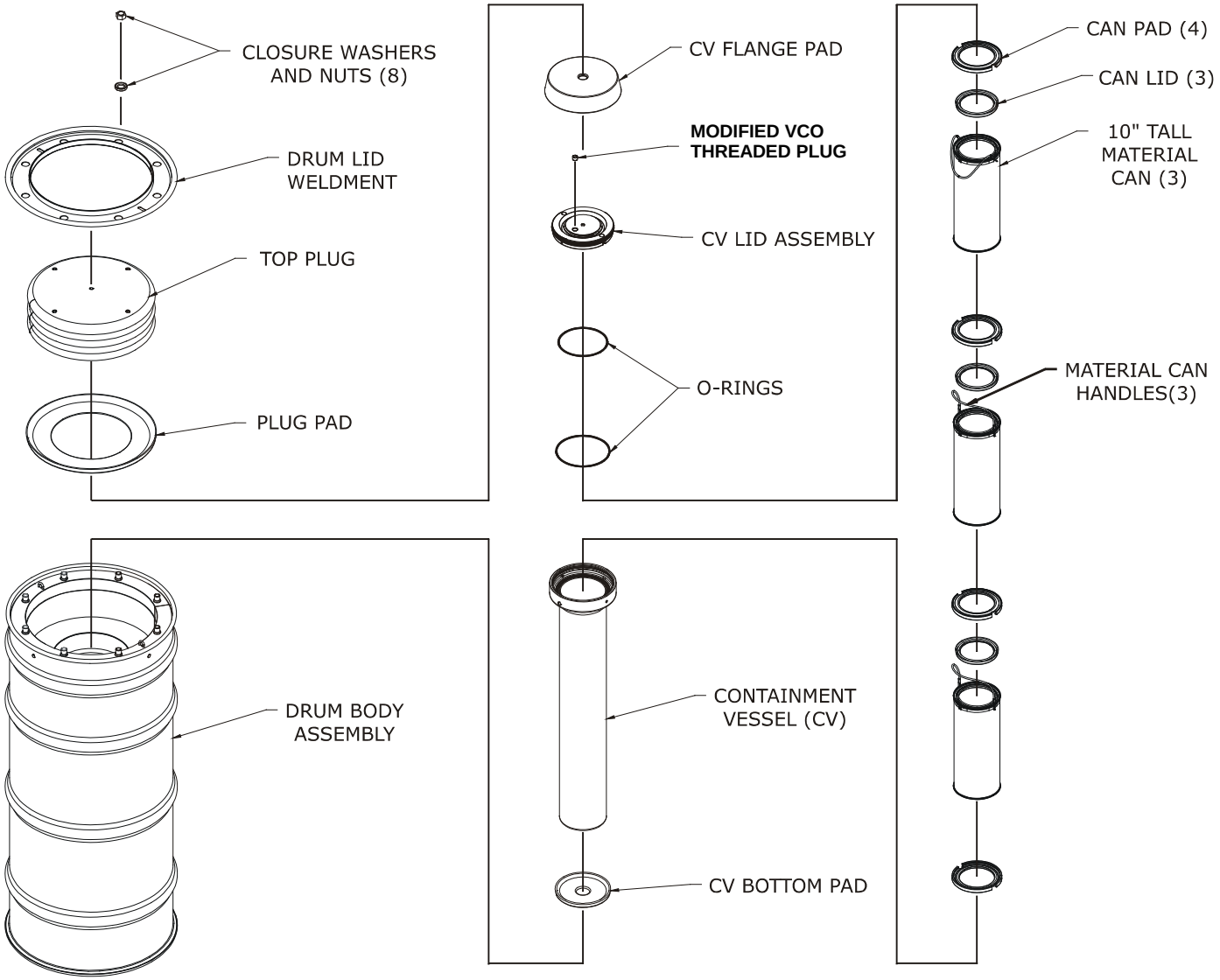



**Fig. 1.2. Exploded view of the ES-3100 package with bulk HEU contents.**

The drum has four circumferential hoops formed into the body. The drum has four 0.795-cm (0.313-in.)-diam holes equally spaced around the circumference ~3.81 cm (1.50 in.) from the top rim to relieve pressure in the drum in the event of a thermal accident (Drawing M2E801580A002, Appendix 1.3.7). Plastic plugs (Nylon 6/6, Micro Plastic, Inc., Item Number 62MP0312) are placed into these holes from the outside to prevent leakage of water into the drum during NCT and storage. The drum is fabricated with a data plate, trefoil data plate, paint, and two lid TID lugs for use with tamper-indicating devices (TIDs). The two electrochemically etched data plates are affixed to the exterior of the drum body in the locations, and with the methods, indicated on Drawing M2E801580A031 (Appendix 1.3.7). The trefoil data plate (M2E8015803A010-1) provides the owner's return address, container model, container serial number, and the trefoil symbol. The other data plate (M2E801580A010-2) provides the required DOT markings—certificate number, maximum gross weight, and "Type B" designation.

The removable lid is attached to the drum body by a flange with eight silicon bronze, 5/8-11-UNC-2B hex-head nuts [C65100, American Society for Testing and Materials (ASTM) F 467] with stainless-steel washers. These nuts are tightened onto the weld studs (Type 304 or 304L stainless steel, 5/8-11-UNC-2A, ASTM A 493 or F 593) to 40.67 ± 6.78 N·m (30 ± 5 ft-lb) of torque with no sequence specified. A radio-frequency identification (RFID) system may be attached to the ES-3100 package if desired. If an RFID is attached to the package using the drum stud and nut assembly, the normal thread engagement of the external nut shall not be reduced when compared to adjacent stud and nut attachments.

The top plug is 36.5 cm (14.37 in.) in diameter and 13.41 cm (5.28 in.) in height at the center. The skin is made from 16 gauge [~0.152-cm (0.0598-in.)-thick] Type 304 or 304L stainless steel and is filled with Kaolite 1600.

The drum assembly also contains three silicone rubber pads. The first pad (CV bottom pad) is placed on the bottom of the innermost liner to support the containment vessel bottom during transport. The second pad (CV flange pad) is placed on top of the containment vessel lid during transport. The third pad (plug pad) is placed on the top shelf of the mid-liner to cushion the top plug during transport. The locations of these three pads are shown on Drawing M2E801580A001 (Appendix 1.3.7), and the dimensions of the pads are shown on Drawing M2E801580A009 (Appendix 1.3.7).

The ES-3100 is handled using industry-standard drum handling equipment. When using a forklift, it can be placed on the tines of the forklift from below, or it is designed for a forklift pincher assembly that can be used to grasp the exterior of the drum assembly. Based on analytical results for a similar package (the Model ES-2100), forklift gripping forces of up to 5400 lb can be used with no detrimental effects on the package (DAC-EA-801376-A003).

No tie-down devices are integral to the package, nor can any features be used for these purposes. The ES-3100 package is designed to be shipped using blocking, bracing, and tie-down equipment that meets industry-standard practices to prevent shifting in the conveyance during NCT.

#### 1.2.1.2 Insulation

The void area formed by the drum and the attached inner liner is filled with an inorganic castable refractory material (Kaolite 1600) made by Thermal Ceramics, Inc., which acts as both a thermal insulating and an impact limiting material. The top plug assembly, which is placed between the containment vessel and the drum lid, is also filled with Kaolite 1600. This material is a mixture of cement and vermiculite and has a nominal cured density of ~358.8 kg/m$^3$ (22.4 lb/ft$^3$). Additional information regarding the characteristics and properties of this material is presented in several supporting documents (Kaolite product data sheet, Kaolite material safety data sheet, Y/DW-1661, ORNL-TM-2003/49, Y/DW-1890, Y/DW-1972, Y/LF-565, Moody 2004). Casting takes place while the

drum is being vibrated in an inverted orientation to ensure that the castable material penetrates into all areas in the void space formed by the drum and the inner liner and that no considerable voids are formed during this process. The Kaolite material is then baked in a furnace at elevated temperatures [~260°C (500°F)] as prescribed in Manufacturing Process Specification JS-YMN3-801580-A003, *Manufacturing Process Specification for Casting Kaolite 1600 into the ES-3100 Shipping Package,* the specification which controls manufacture of Kaolite 1600 for the ES-3100 (Appendix 1.3.4). A thermal ceramic material, such as Kaolite 1600, has been previously used as an impact limiting/thermal insulating material in other Y-12 owned and licensed Type B packages (i.e., ES-2100 and DPP-2). The original decision to use this material was the result of considerable research. This manufacturing process is protected under U.S. Patent 6,299,950 B1 (Byington et al. 2001). The United States Government has rights in this invention pursuant to Contract No. DE-NA0001942 between the National Nuclear Security Administration and CNS.

One of the design goals of Y-12's packaging development program was to build a shipping package entirely of materials that do not char, burn, or thermally decompose when exposed to the temperatures and conditions associated with HAC [800°C (1475°F)]. Cellulosic fiberboard and polyurethane foams, typically used for packaging applications, undergo decomposition when exposed to these HAC thermal conditions. During thermal decomposition, these materials offgas, producing conditions that are potentially detrimental to the performance of the package. The hot gases generated within the packaging can transfer heat to inner regions adjacent to the containment closure seals. Under severe circumstances, this process could lead to loss of containment due to overheating of containment seals. The Kaolite material is nonflammable and will not undergo chemical decomposition at temperatures below 1260°C (2300°F). When Kaolite is heated >100°C (212°F), water vapor from free water contained within the casting will form. Pressurization of the drum and top plug is prevented by pressure-relief holes (vent holes) located near the top of the drum and on the top center of the top plug (Sect. 1.2.1.1 and Drawings M2E801580A002 and M2E801580A008, Appendix 1.3.7). The cured Kaolite 1600 material does not decompose, and thus there are no exothermic chemical reactions that could produce superheated offgasses.

Extensive testing of Kaolite 1600 was performed by the Y-12 Development Division to determine the performance of the material for this type of application (Y/DW-1661). Testing showed that Kaolite 1600 has a tremendous ability to absorb shock over a wide range of material densities, curing temperatures and times, and material temperatures. The 10 CFR 71.73 HAC testing documented in Sect. 2.7 demonstrates that Kaolite 1600 is a robust impact limiter and good thermal insulating material for Type B shipping containers. Post HAC drop testing radiographs of a similar package, the ES-2100, showed some minor cracking of the Kaolite structure in some cases. However, subsequent thermal testing of these ES-2100 packages demonstrated that these cracks were inconsequential to the package's ability to meet regulatory requirements.

Insulation thicknesses within the liner/drum volume adjacent to the side walls of the ES-3100 containment vessel are at least 4.27 cm (1.68 in.), with typical thicknesses of ~12.10 cm (4.77 in.). Below the containment vessel, the minimum thickness of insulation is 10.05 cm (3.96 in.), and the top plug, which is above the containment vessel, includes a 12.55-cm (4.94-in.) thickness of insulation.

#### 1.2.1.3 Shielding

The ES-3100 packaging does not require dedicated shielding materials of specific design to control external radiation levels for the bulk HEU contents. However, the intervening packaging materials of construction (stainless steel of the drum and containment vessel, the Kaolite material, and the 277-4 material) provide some attenuation of the relatively low levels of penetrating radiation emitted by the contents. The amount of shielding modeled for the NCT analysis is represented by the thickness and density of the materials reported in Sects. 1.2.1.1, 1.2.1.2, and 1.2.1.5 and the packaging dimensions

(Appendix 1.3.7). HAC physical testing showed that the containment vessel and insulation remain confined within the drum assembly. However, the HAC shielding evaluation conservatively assumes that only the containment vessel remains for shielding purposes (i.e., no shielding credit is taken for the drum and insulation in the HAC analysis).

### 1.2.1.4 Nuclear criticality safety

The packaging materials of construction in the ES-3100 provide neutron absorption (stainless steel and 277-4) and reflection (stainless steel and insulation). The 277-4 (or Cat 277-4 as it is sometimes referred) material is a noncombustible cast neutron-absorbing material. This material is cast into the innermost liner of the package adjacent to the containment vessel as shown in Fig. 1.1. The material is a high alumina borated concrete composed of aluminum, magnesium, calcium, boron, carbon, silicon, sulfur, sodium, iron, and water. The 277-4 material was manufactured specifically for the ES-3100 package by adding boron carbide to a standard material (Cat No. 277-0) and increasing the boron content from 1.56 wt % to 4.23 wt %. Additional information on the neutron-absorbing characteristics of this material is presented in Appendix 6.9.3. Properties of the 277-4 material are presented in Table 2.17 and several supporting documents (ORNL/TM-2004/290, Y/DW-1987, Y/DZ-2585, COR-NDA-04-93, Y/DV-1914). The cast material has a nominal density of 1681.9 kg/$m^3$ (105 lb/$ft^3$). The procedure for mixing this material and casting it into the ES-3100 shipping package is documented in JS-YMN3-801580-A005, *Casting Catalog No. 277-4 Neutron Absorber for the ES-3100 Shipping Package* (Appendix 1.3.5).

Although shown by tests up to HAC as not being credible, the criticality analysis considers water leakage into the containment vessel in accordance with 10 CFR 71.55(b). Depending on the content being shipped and the shipping configuration being used, criticality safety index (CSI) values for the ES-3100 package may range from 0 to 3.2 (Sect. 1.2.2).

### 1.2.1.5 Containment system

A single containment vessel is used in the ES-3100 shipping package for the transport of bulk HEU contents. The ES-3100 containment boundary (consisting of the containment vessel body, lid assembly, and inner O-ring) is shown in Fig. 1.3.

During fabrication, all ES-3100 containment vessels will be inspected and tested to the requirements specified on the design drawings (Appendix 1.3.7) and equipment specification (Appendix 1.3.3). Certification documents received from the vendor with each component acknowledge the use of these drawings and the specification. These certifications are on file with the Y-12 Quality Organization.

The containment boundary of the ES-3100 package is a pressure vessel that is designed, fabricated, examined, and tested in accordance with the ASME Code, Sect. III, Div. 1, Subsection NB. The ES-3100 containment vessel body is constructed of Type 304L stainless steel and may be fabricated by one of two methods. The first method uses a standard 5-in., schedule 40 stainless-steel pipe (ASME SA-312 Type TP304L), a machined flat-head bottom forging (ASME SA-182 Type F304L), and a machined top flange forging (ASME SA-182 Type F304L). Each of these pieces is joined with circumferential welds as shown on Drawing M2E801580A012 (Appendix 1.3.7). The top flange is machined to provide two concentric half-dove-tailed O-ring grooves in the flat face, to provide locations for two 18-8 stainless steel dowel pins, and to provide the threaded portion for closure using the lid assembly. The second fabrication method for the ES-3100 containment vessel uses flow forming to create the complete body (flat bottom, cylindrical body, and flange) from a single forged billet or bar with final material properties in accordance with ASME SA-182 Type F304L. The top flange area using this fabrication technique is machined identically to that of the welded forging method.

The lid assembly, which completes the containment boundary structure, consists of a sealing lid, closure nut, and external retaining ring (Drawing M2E801580A014, Appendix 1.3.7). The containment vessel sealing lid (Drawing M2E801580A015, Appendix 1.3.7) is machined from Type 304 stainless-steel bar with final material properties in accordance with ASME SA-479. The containment vessel closure nut is machined from a Nitronic 60 stainless-steel bar with material properties in accordance with ASME SA-479. These two components are held together using a WSM-400-S02 external retaining ring made from Type 302 stainless steel. The sealing lid is further machined to accept a ⅜-16 swivel hoist ring bolt, to provide a leak-test port between the elastomeric O-rings, and notched along the perimeter to engage two dowel pins. The swivel hoist ring is only intended for use when loading and unloading the containment vessel. The swivel hoist ring will be removed for shipment. The lid assembly and containment vessel body (with O-rings in place) are joined together by torquing the closure nut to 162.70 ± 6.78 N·m (120 ± 5 ft-lb). The sealing lid portion of the assembly is restrained from rotating during this torquing operation by the two dowel pins installed in the body flange.

The use of a design that includes two O-ring seals permits assembly verification leak testing of the containment vessel by measuring the leak rate from the volume between the inner and outer O-rings. A leak-test port is located between the O-rings in the containment vessel to facilitate a pressure rise or drop leakage test following assembly or 10 CFR 71 compliance testing. This port is sealed during transport using a modified VCO threaded plug. Only the inner O-ring is considered a part of the containment boundary. The O-rings on this containment vessel are either ethylene propylene diene monomer (EPDM) fabricated to ASTM D 2000, M3BA712A14B13F17 or fluorocarbon elastomer (Viton) fabricated to SAE AMS-R-83485. The equipment specifications for the EPDM and Viton O-rings are presented in Appendices 1.3.10 and 1.3.9, respectively.

The inner diameter of the containment vessel is 12.852 cm (5.06 in.) and the usable height inside the containment vessel is 78.74 cm (31.0 in.). The wall thickness of the body excluding the flange is 0.254 cm (0.10 in.). The maximum nominal diameter of the containment vessel body is 19.05 cm (7.50 in.). The nominal thicknesses of the containment vessel's flat bottom is 0.635 cm (0.25 in.). The overall height of the containment vessel without the swivel hoist ring is 82.296 cm (32.40 in.). The containment vessel drawing number, drawing revision, and serial number are electroetched onto the side of the containment vessel body, as well as onto the top of the sealing lid and the closure nut (Drawing M2E801580A011, Appendix 1.3.7). No penetrations, connections, or fittings into this sealed container exist.

### 1.2.2 Contents

The ES-3100 shipping package will be used to ship bulk HEU in the form of oxide ($UO_2$, $UO_3$, $U_3O_8$, $U_3O_8$-Al, $UO_2$-Mg, and $UO_2$-$ZrO_2$), uranium metal and alloy in the form of solid geometric shapes or broken pieces, uranium compounds, uranyl nitrate crystals (UNX), fuel elements from TRIGA reactors, and research reactor fuel elements or fuel components. Actual loading limits are determined in subsequent sections of the SARP. The maximum weight of all contents (including convenience cans or bottles, can spacers, polyethylene bagging and other packing materials) shall not exceed 40.82 kg (90 lb). The maximum concentration of uranium isotopes permitted in the ES-3100 content are listed in Table 1.1. In addition to the uranium isotopes shown in Table 1.1, transuranic isotopes (with the exception of $^{237}Np$) may be present in the HEU metal and alloy contents transported by ground at a maximum concentration of 800.0 µg/gU and at a maximum concentration of 40.0 µg/gU in all other contents. Contents to be transported by air are limited to a maximum transuranic concentration of 40.0 µg/gU, which meets the requirements in 10 CFR 71.88. The concentration of $^{237}Np$ is limited to 0.0250 g/gU. Unless otherwise specified, the contents described in this section pertain to ground transport only. A discussion of contents of air-transport is included in Sect. 1.2.2.1.

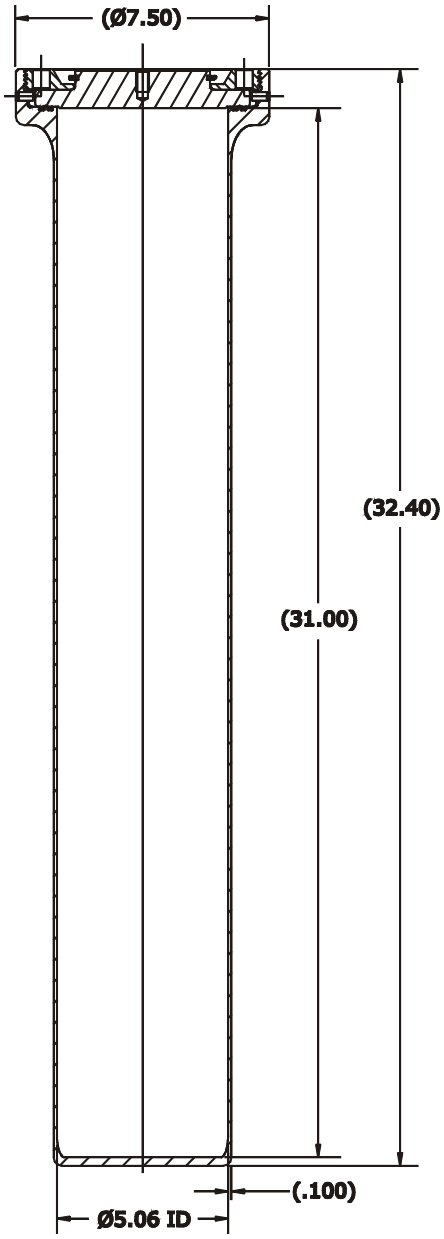



**Fig. 1.3. Containment boundary of the ES-3100 shipping package.**

**Table 1.1. Uranium concentration limits**

| Uranium isotope | Limit |
|---|---|
| $^{232}U$ | 0.040 μg/gU |
| $^{233}U$ | 0.006 g/gU |
| $^{234}U$ | 0.02 g/gU |
| $^{235}U$ | 1.00 g/gU |
| $^{236}U$ | 0.40 g/gU |
| $^{238}U$ | 1.00 g/gU |

**HEU Metal and Alloy**

HEU metal and alloy (alloys of uranium with aluminum, molybdenum, zirconium, stainless steel, titanium, tungsten, niobium, silicon, or vanadium) may be in the form of solid geometric shapes. Solid shapes may include the following:

1. cylinders having a diameter no larger than 4.25 in. (maximum of one cylinder per convenience can);
2. square bars having a cross section no larger than 2.29 in. × 2.29 in. (maximum of one bar per convenience can); and
3. slugs having dimensions of 1.5-in. diam × 2-in. tall (maximum of 10 per convenience can).

HEU bulk metal and alloy contents not covered by the geometric shapes category specified above will be in the broken metal category, and will be so limited.

Alloys of uranium may include aluminum, molybdenum, zirconium, stainless steel, titanium, tungsten, niobium, silicon, or vanadium. Uranium-aluminum alloys are typically 70 to 95% aluminum. Uranium-molybdenum alloys are typically 1 to 12% molybdenum. Uranium/molybdenum alloys may be plated with, clad with, or contain traces of aluminum, gold, stainless steel, nickel and/or chromium. Other uranium alloys may contain up to 50% of the non-uranium constituents.

HEU bulk metal and alloy contents in the broken metal category may be of unspecified geometric form. HEU bulk metal and alloy in this category may also be of a specific shape where one or more of the characteristic dimensions vary from piece to piece (i.e., the height, width, length, radius).

For pyrophoric considerations, HEU metal and alloy must meet the following restrictions (Appendix 1.3.8):

1. Uranium metal and alloy (broken) pieces must have a surface-area-to-mass ratio of not greater than 1 $cm^2/g$ or must not pass through a 3/8-in. (9.5-mm) mesh sieve (or equivalent size-grading method).
2. Particles and small shapes which do not pass the size restriction tests in #1, and powders, foils, turnings, and wires, are not permitted unless they are in a sealed, inerted container. Material meeting this criteria will be in the HEU metal or alloy turnings, fines, or powder category, and will be so limited.

> **Note:** A "sealed, inerted container" is a container with an inert atmosphere that is leaktight as defined in ANSI N14.5-1997.

Metal and alloy may be shipped in tin-plated carbon-steel, stainless-steel, aluminum, or nickel-alloy convenience cans; Teflon convenience bottles; or Teflon bottles inside metal convenience cans. Solid form HEU contents (i.e., spheres, cylinders, bars, slugs) that will not fit in a convenience can may be bagged with no convenience can required around the content. The only hydrogenous packing materials that can be used inside the containment vessel when shipping broken HEU metal are those that have a hydrogen atom density less than or equal to that of water.

**HEU Oxide**

The HEU oxide content in the ES-3100 package includes $UO_2$, $UO_3$, $U_3O_8$, $U_3O_8$-Al, $UO_2$-Mg, and $UO_2$-$ZrO_2$. Maximum overall uranium isotopic weight percents are presented in Table 1.2. The physical form of all contents is dense, loose powder (which may contain clumps) or pellets. Moisture content in oxide is limited to 3 wt % water (Note: Loading Restriction 8 in Sect. 1.2.2.8 also applies). Theoretical densities of $UO_2$, $U_3O_8$, and $UO_3$ are 10.96, 8.30, and 7.29 $g/cm^3$, respectively. Allowable oxide densities are 2.0 to 6.54 $g/cm^3$. Oxide may be shipped in tin-plated carbon-steel, stainless-steel, or nickel-alloy convenience cans; polyethylene or Teflon convenience bottles; or glass ($UO_2$-Mg oxide only), polyethylene, or Teflon bottles inside metal convenience cans.

**Table 1.2. Bounding uranium isotopic concentrations in oxide**

| Isotope | Bounding limit |
|---|---|
| $^{232}U$ | 40 ppb |
| $^{233}U$ | 0.6 wt % |
| $^{234}U$ | 2.0 wt % |
| $^{235}U$ | 100.0 wt % |
| $^{236}U$ | 40.0 wt % |

Uranium oxide shipments must be completed within 12 months after sealing the containment vessel in order to prevent the buildup of hydrogen gas beyond 5 mol %. The time period begins when the containment vessel is sealed. Hydrogen generation calculations are provided in Appendix 3.5.4.

**Research Reactor Fuel Elements and Components**

Research reactor fuel elements or fuel components composed of clad U-Zr, U-Al, $U_3O_8$-Al, $UO_2$, oxides of U-Zr, $UO_2$-Mg, or $U_3Si_2$-Al will be shipped in the ES-3100 package. The fuel elements consist of multiple fuel components in the form of plates, rods, and tubes clad in aluminum, stainless steel, or zircalloy and held together as a single unit by other inert structural components. The fuel components are individual plates, rods, or tubes removed from fuel elements. The uranium in these fuel elements and components is enriched to 10 to 93.5 wt % $^{235}U$.

The U-Al fuel in the research reactor fuel elements and components is an alloy of uranium and aluminum (U-Al) or in the form of $UA1_x$-Al (alloy in an aluminum matrix). The U-A1 fuel contains ~8 to 30 wt % uranium. The $U_3O_8$-Al fuel is in the form of a $U_3O_8$ compound contained in an aluminum metal matrix. The $U_3O_8$-Al contains ~8 to 40 wt % $U_3O_8$. The $UO_2$ fuel is a ceramic compound. The $UO_2$-Mg fuel is a ceramic $UO_2$ compound contained in a magnesium metal matrix. The $UO_2$-Mg fuel contains ~88 wt % $UO_2$.

The research reactor fuel elements and components will be bundled together and placed inside a modified convenience can [a 17.5-in.–tall can (two 8.75-in.–tall cans brazed together) or a 30-in.–tall can (three 10-in.–tall cans brazed together)] or protected on each end with an open-ended convenience can constructed of stainless steel, tin-plated carbon steel, or nickel alloy (see Fig. 1.4).

Intact TRIGA reactor elements and fuel pellets will also be shipped in the ES-3100. The fuel shall be unirradiated. The TRIGA fuel shall be in the form of uranium zirconium hydride ($UZrH_x$), where $x \leq 1.6$. Fuel from three types of TRIGA fuel elements are allowed: TRIGA Standard Fuel Elements, Instrumented TRIGA Standard Fuel Elements, and TRIGA Fuel Follower Control Rods. These fuel elements have three fuel pellets (or sections) per element. The TRIGA Standard Fuel Elements and Instrumented TRIGA Standard Fuel Elements have fissile loadings of 45.33-g $^{235}U$ per pellet (136-g $^{235}U$ per element) and the dimensions are 5 in. in length and 1.44 in. in diameter. The TRIGA Fuel Follower Control Rods have a fissile loading of 37.66-g $^{235}U$ per pellet (113-g $^{235}U$ per element) and the dimensions are 5 in. in length and 1.31 in. in diameter.

TRIGA fuel may be shipped as crimped fuel elements or as $UZrH_x$ fuel pellets (if disassembled), both of which shall be packed into convenience cans prior to shipment. Convenience cans of 4.25-in. diam by various lengths shall be used. Fuel pellets loaded into convenience cans shall be up to 5 in. in length (full-length) and no more than three full-length pellets shall be loaded into a convenience can. Crimped fuel rods are clad fuel pellets and can be up to 15 in. in length (full length of the fuel section from one fuel element). Cladding material is stainless steel or aluminum. Only the fuel section of the TRIGA fuel element is allowed to be shipped; however, there may be residual cladding up to ½ in. in length at either end of the crimped fuel rod. Up to three 15-in.-long crimped fuel elements shall be loaded into a single convenience can for shipping. Maximum loading of bare fuel pellets and crimped fuel elements shall be 3 fuel element

equivalence per ES-3100 containment vessel. TRIGA fuel with enrichments up to 70% has been evaluated. For TRIGA Standard Fuel Elements and Instrumented TRIGA Standard Fuel Elements, the maximum allowable loading is 408-g $^{235}U$ per package, and for TRIGA Fuel Follower Control Rods, the maximum allowable loading is 339-g $^{235}U$ per package. No spacer cans are required.

Fuel elements or pins from the Systems for Nuclear Auxiliary Power (SNAP) reactor will also be shipped in the ES-3100 package. The SNAP reactor fuel pins are composed of $UZrH_x$ ($x \leq 2$) with Hastelloy N cladding. The fuel pins are ~1.25 in. in diameter and ~12.45 in. long. The SNAP reactor fuel pins are enriched to 93 wt % $^{235}U$. The SNAP reactor fuel pins will be packed in appropriate length convenience cans or bundled together and protected on each end with an open-ended can. Up to three fuel elements may be packed into any one convenience can or any one bundle. Up to two loaded convenience cans or two bundles may be shipped in the ES-3100.

**Uranium Compounds**

Several compounds of uranium, including uranium tetrafluoride, uranyl fluoride, uranium carbide, uranium nitride, and uranium silicide, will be shipped in the ES-3100 package. The physical form of these uranium compounds is solid crystalline, granular, or powder. The uranium compounds contain no moisture.

Uranium tetrafluoride ($UF_4$), often called green-salt because of its characteristic color, is generally an intermediate in the conversion of $UF_6$ to either uranium oxide ($U_3O_8$ or $UO_2$) or uranium metal. $UF_4$ is a solid composed of agglomerating particles with a texture similar to baking soda. It is non-volatile and non-hygroscopic, but only slightly soluble in water. After exposure to water, $UF_4$ slowly dissolves and undergoes hydrolysis, forming several possible uranium compounds and hydrogen fluoride (HF). The density of solid $UF_4$ is 6.7 g/cm$^3$.

Uranyl fluoride ($UO_2F_2$) is an intermediate in the conversion of uranium hexafluoride ($UF_6$) to a uranium oxide or metal form and is a direct product of the reaction of $UF_6$ with moisture in the air. It is very soluble in water. Uranyl fluoride is hygroscopic and changes in color from brilliant orange to yellow after reacting with water. Uranyl fluoride is reported to be stable in air to 300°C, above which slow decomposition to $U_3O_8$ occurs. When heated to decomposition, $UO_2F_2$ emits toxic fluoride fumes. The density of $UO_2F_2$ is 6.37 g/cm$^3$.

Uranium carbide is a hard refractive ceramic material. It comes in several stoichiometries such as uranium monocarbide (UC), uranium sesquicarbide ($U_2C_3$), and uranium dicarbide ($UC_2$). Like uranium dioxide and some other uranium compounds, uranium carbide can be used as a nuclear fuel for nuclear reactors, usually in the form of pellets or tablets. Uranium carbide is a dull, dark charcoal-gray or flat black colored powder. The densities of UC, $U_2C_3$, and $UC_2$ are 13.63, 12.7, and 11.3 g/cm$^3$, respectively. Loadings for $U_2C_3$ and $UC_2$ fall under the general category of UC.

Uranium nitride (UN) and uranium sesquinitride ($U_2N_3$) are ceramic compounds used as nuclear fuel in nuclear test reactors whose properties are similar to uranium dioxide or uranium carbide. They can be synthesized by the reaction of nitrogen with uranium at 700 K. Uranium nitride is also formed as a product of uranium combustion in air. The densities of solid UN and $U_2N_3$ are 14.32 and 11.24 g/cm$^3$, respectively. Loadings for $U_2N_3$ fall under the general category of UN.

Uranium silicide, with $U_3Si_2$ as the primary constituent, is produced by melting together uranium metal and high purity silicon. The silicon content of the uranium silicide is ~7.5 wt %. Except for impurities, whose limits are shown in Table 1.2a, the balance of the uranium silicide is uranium. The composition of the uranium in uranium silicide is as follows: 19.75 ± 0.2 wt % $^{235}U$, 0.5 maximum wt % $^{234}U$, 1.0 maximum wt % $^{236}U$, and the balance wt % $^{238}U$. The bulk density range of uranium silicide powder is 5–7 g/cm$^3$.

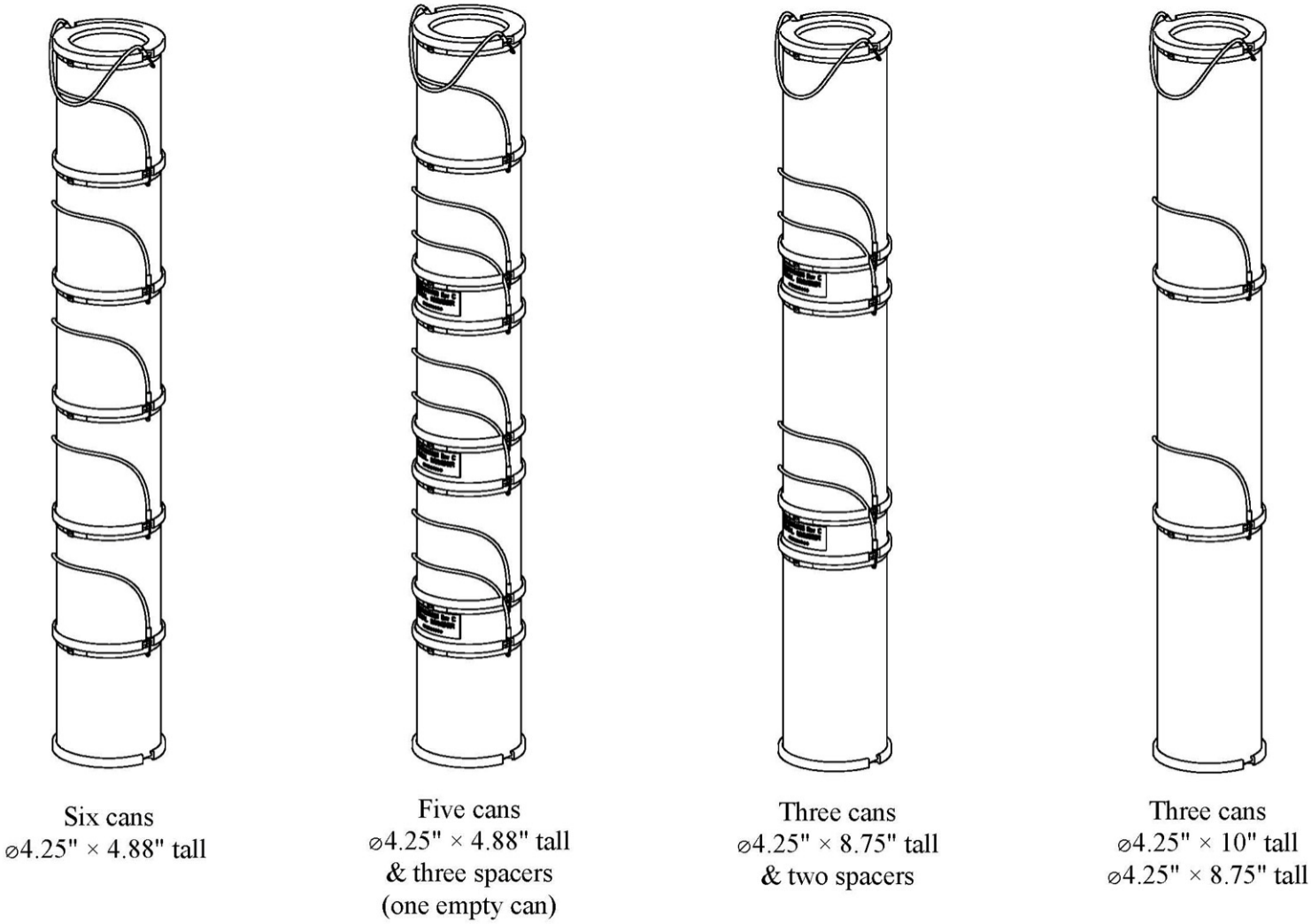



**Fig. 1.4. Typical shipping configurations inside the ES-3100 containment vessel.**

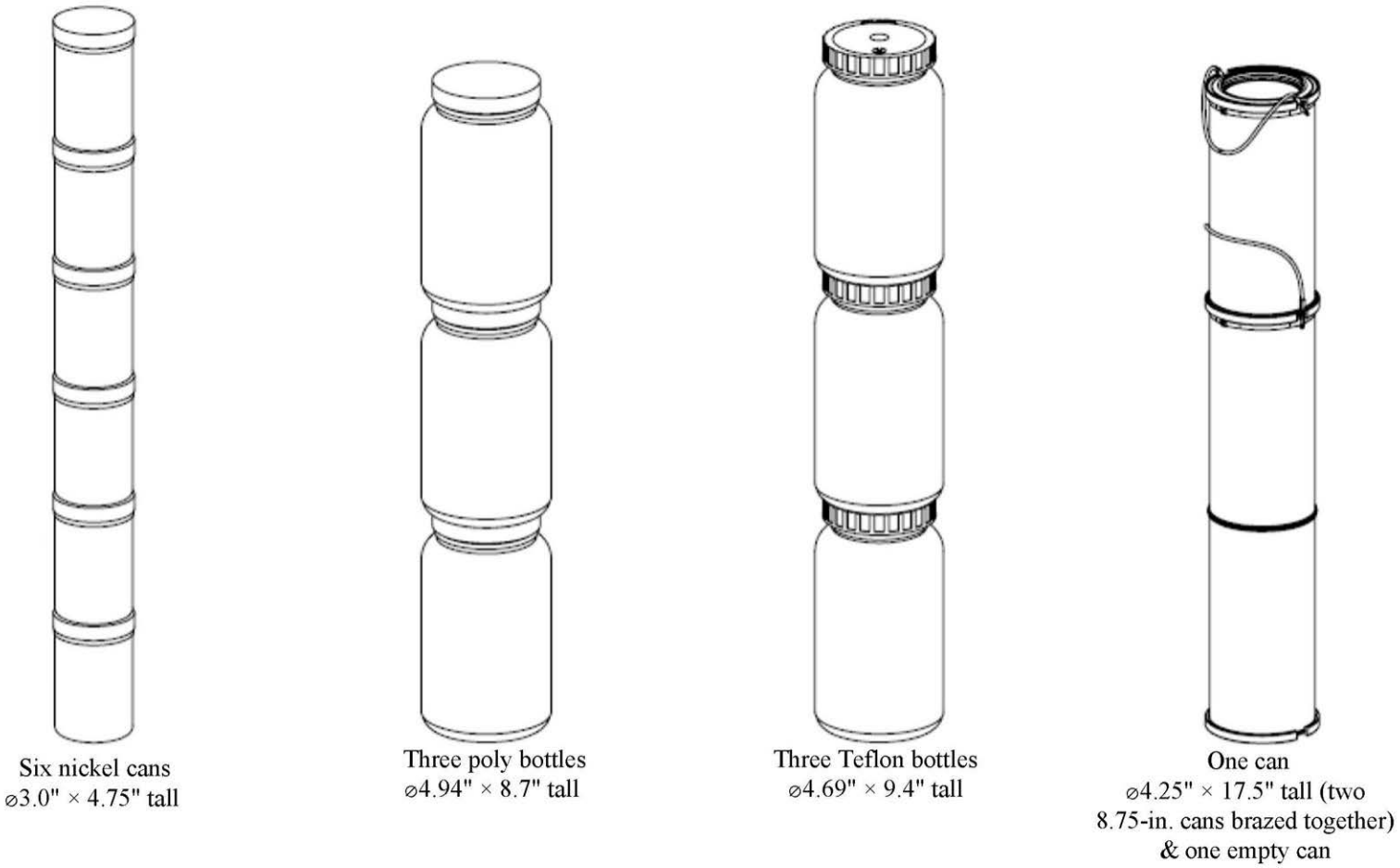
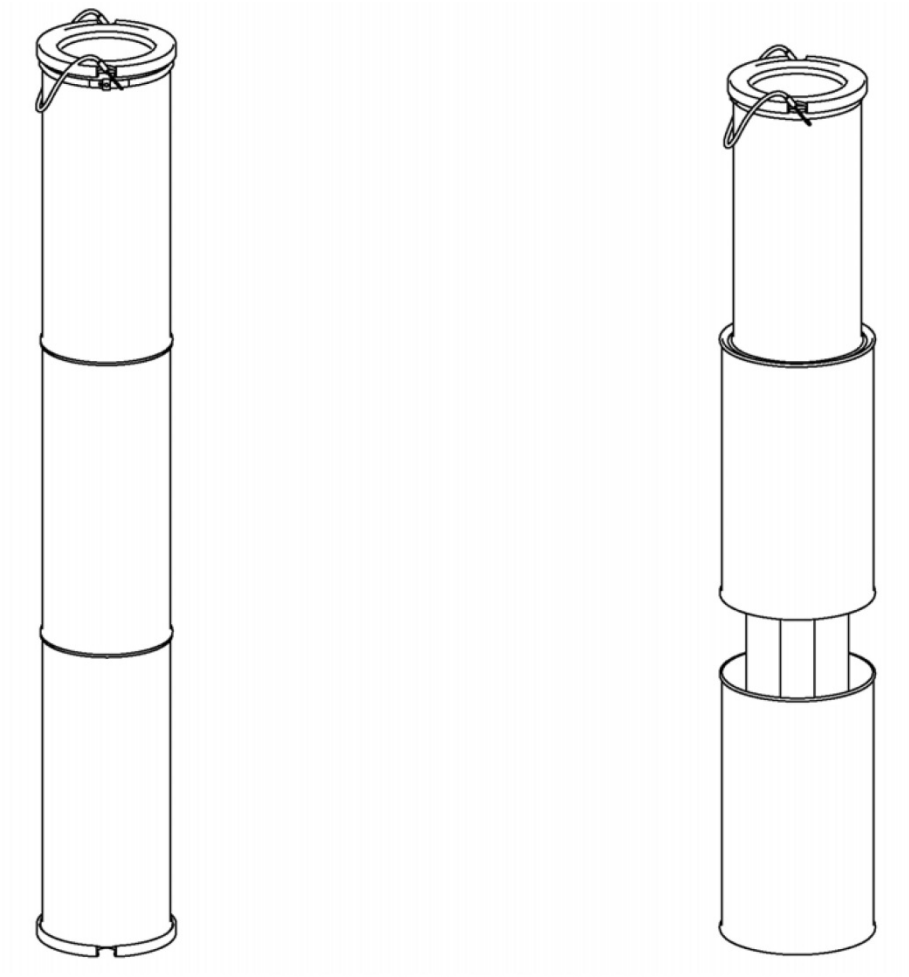



**Fig. 1.4. Typical shipping configurations inside the ES-3100 containment vessel (cont.).**



One can
⌀4.25" × 30" tall
(three 10-in. cans brazed together)

Two cans open ended
⌀≤5" × ≤10" tall
(one empty can or stainless steel scrubbers on top)

**Fig. 1.4. Typical shipping configurations inside the ES-3100 containment vessel (cont.).**

**Table 1.2a. Maximum impurities in uranium silicide [a, b]**

| Element | Parts per million (ppm) |
|---|---|
| Aluminum | 600 |
| Boron | 30 |
| Carbon | 1000 |
| Cadmium | 20 |
| Cobalt | 10 |
| Copper | 100 |
| Iron and nickel | 1000 |
| Hydrogen | 200 |
| Lithium | 10 |
| Nitrogen | 500 |
| Oxygen | 7000 |
| Zinc | 1000 |

[a] Other individual elements not listed in table are limited to a maximum of 500 ppm. The total of all other elements is a maximum of 2500 ppm.

[b] The total impurity content in uranium silicide shall not exceed the equivalent boron content of 30 ppm on a weight basis relative to uranium silicide. The equivalent boron content is calculated as shown in TRTR-14.

Other uranium compounds consist primarily of finished tristructural-isotropic (TRISO) micro fuel particles; however, also included are pure/impure scrap materials generated during various stages of the manufacturing process. These materials have a $^{235}U$ assay $\leq$93.17% and are typically in a solid crystalline or granular form. A finished TRISO fuel particle consists of a kernel composed of $UO_X$ (or sometimes UC or UCO) coated with four exterior layers of three isotropic materials. The four layers are a porous buffer layer made of carbon, followed by a dense inner layer of pyrolytic carbon (PyC), followed by a ceramic layer of SiC to retain fission products at elevated temperatures and to give the TRISO particle more structural integrity, followed by a dense outer layer of PyC.

Uranium compounds may be shipped in tin-plated carbon-steel, stainless-steel, or nickel-alloy convenience cans.

**Uranyl Nitrate Crystals**

Uranyl nitrate crystals are formed by dissolving uranium metal or any of the uranium oxides in nitric acid and the UNX crystalline precipitates are acquired through a variety of extraction, filtration, and purification processes. The UNX crystals are soluble in water, forming a weak solution of nitric acid. Uranyl nitrate hexahydrate (UNH) has a chemical formula of $UO_2(NO_3)_2 \cdot 6H_2O$. This most reactive form is used as the bounding composition for uranyl nitrate crystals in the criticality evaluation. Therefore, for UNX contents, X must be less than or equal to 6. The theoretical density of UNH crystals is 2.79 g/cm$^3$; however, the working densities will be less.

The user of the ES-3100 for UNX shipments will be required to use non-metallic containers only (Teflon bottles) as the convenience container.

Shipments of UNX crystals must be completed within the times shown in Table 1.3a in order to prevent the buildup of hydrogen gas beyond 5 mol %. The time period begins when the containment vessel is sealed. Hydrogen generation calculations are provided in Appendix 3.5.4.

### 1.2.2.1 Radioactive/fissile constituents

For the ES-3100 package with bulk HEU content, the maximum number of $A_2$s is 4752.8 (at 70 years) and the maximum activity is 0.72554 TBq (at 10 years) [Table 4.4].

**Ground Transport**

Fissile material loading limits for ground transport of the various contents of the ES-3100, as determined by criticality analyses, structural analyses, or hydrogen gas generation evaluations, are presented in Tables 1.3 and 1.3a.

**Air Transport**

Contents for air transport of the ES-3100 package are HEU in the form of metal/alloy, research reactor fuel elements and components, and HEU oxide ($UO_2$, $UO_3$, $U_3O_8$, $U_3O_8$-Al, $UO_2$-Mg, and $UO_2$-$ZrO_2$). Fissile material mass loading limits for these contents, as determined by the criticality analyses, are presented in Table 1.3b for air transport.

### 1.2.2.2 Chemical and physical form

The fissile material contents are in solid (HEU metal or alloy, uranium compounds, or research reactor fuel elements and components), crystalline (UNX), or powder (HEU oxide) form. Some moisture (up to 3 wt %) may be present in the HEU oxide material, thereby making the oxide content clump together.

As presented for shipment, the UNX crystals exist as crystalline solids; however, the melting point for uranyl nitrate hexahydrate, trihydrate, and dihydrate is reported as ~60°C, 113°C, and 184°C, respectively (Marshall 1951). Heating of uranyl nitrate hexahydrate crystals up to 200°C results in a stepwise release of water molecules of crystallization (Dash 1999 and Kozlova 2007), which in a closed system results in the partial dissolution of the crystals. During transport of UNH crystals, crystalline solids and a saturated solution of uranyl nitrate will coexist at a temperature above ~60°C (MCW-1424). Given that the NCT maximum containment vessel temperature with insolation is 91.92°C (197.46°F) and the HAC maximum predicted temperature inside the containment vessel at the location near the Teflon bottles is 140.36°C (284.64°F), the uranyl nitrate dihydrate and lower hydrates will remain in a solid phase during transportation. However, the trihydrate and higher hydrate crystals will release water molecules of crystallization upon heating above their melting point, thus converting them into a lower hydrate species, which require a successively higher temperature to release additional water molecules. The melting point for hexahydrate (~60°C) will be exceeded during NCT and HAC; and the melting point for trihydrate (~113°C) crystals will be exceeded during HAC. Upon cooling, the uranyl nitrate hydrate melt will recrystallize to a solid form.

**Table 1.3. Authorized content and fissile mass loading limits for ground transport [a, b, c]**

| Content description | | Enrichment | CSI | No spacers, $^{235}$U (kg) | Basis for limit | 277-4 can spacers, [d] $^{235}$U (kg) | Basis for limit |
|---|---|---|---|---|---|---|---|
| Solid HEU metal or alloy (specified geometric shapes) [e] | Cylinder A | ≤100% | 0.0 | 15.000 | Crit. | 25.000 | Crit. |
| | Cylinder B | ≤100% | 0.0 | 18.000 | Crit. | 30.000 | Crit. |
| | Square bars | ≤100% | 0.0 | 30.000 | Crit. | 35.200 [f] | Struct. |
| | Slugs | ≤95% | 0.0 | 17.374 | Crit. | - | - |
| | Slugs | ≤80% | 0.0 | - | - | 29.318 | Crit. |
| | Slugs | >80%, ≤95% | 0.0 | - | - | 24.324 | Crit. |
| | Slugs | >80%, ≤95% | 0.4 | - | - | 34.749 | Crit. |
| Broken HEU metal or alloy [g] | | >95%, ≤100% | 0.0 | Spacers req'd [d] | | 2.774 | Crit. |
| | | | 0.4 | Spacers req'd | | 5.549 | Crit. |
| | | | 0.8 | Spacers req'd | | 9.248 | Crit. |
| | | | 2.0 | Spacers req'd | | 13.872 | Crit. |
| | | | 3.2 | Spacers req'd | | 24.969 | Crit. |
| | | >90%, ≤95% | 0.0 | Spacers req'd | | 3.516 | Crit. |
| | | | 0.4 | Spacers req'd | | 6.154 | Crit. |
| | | | 0.8 | Spacers req'd | | 10.549 | Crit. |
| | | | 2.0 | Spacers req'd | | 18.461 | Crit. |
| | | | 3.2 | Spacers req'd | | 26.373 | Crit. |
| | | >80%, ≤90% | 0.0 | Spacers req'd | | 3.333 | Crit. |
| | | | 0.4 | Spacers req'd | | 7.500 | Crit. |
| | | | 0.8 | Spacers req'd | | 12.500 | Crit. |
| | | | 2.0 | Spacers req'd | | 20.000 | Crit. |
| | | | 3.2 | Spacers req'd | | 28.334 | Crit. |
| | | >70%, ≤80% | 0.0 | 2.967 | Crit. | 4.450 | Crit. |
| | | | 0.4 | 5.192 | Crit. | 8.900 | Crit. |
| | | | 0.8 | 8.900 | Crit. | 16.317 | Crit. |
| | | | 2.0 | 17.059 | Crit. | 25.218 | Crit. |
| | | | 3.2 | 27.443 | Crit. | 28.184 | Crit. |
| | | >60%, ≤70% | 0.0 | 3.249 | Crit. | 5.198 | Crit. |
| | | | 0.4 | 5.848 | Crit. | 12.996 | Crit. |
| | | | 0.8 | 13.646 | Crit. | 20.793 | Crit. |
| | | | 2.0 | 21.444 | Crit. | 24.692 | Crit. |
| | | | 3.2 | 24.692 | Crit. | 24.692 | Crit. |
| | | ≤60% | 0.0 | 5.576 kg U | Crit. | 11.154 kg U | Crit. |
| | | | 0.4 | 14.872 kg U | Crit. | 28.813 kg U | Crit. |
| | | | 0.8 | 28.814 kg U | Crit. | 35.20 kg U [f] | Struct. |
| | | | 2.0 | 35.20 kg U [f] | Struct. | 35.20 kg U [f] | Struct. |
| | | | 3.2 | 35.20 kg U [f] | Struct. | 35.20 kg U [f] | Struct. |

**Table 1.3. Authorized content and fissile mass loading limits for ground transport [a, b, c]**

| Content description | | Enrichment | CSI | No spacers, $^{235}$U (kg) | Basis for limit | 277-4 can spacers, [d] $^{235}$U (kg) | Basis for limit |
|---|---|---|---|---|---|---|---|
| HEU metal or alloy turnings, fines, or powders [g, h] | | >70%, ≤80% | 0.0 | 2.967 | Crit. | Spacers not req'd | |
| | | | 0.4 | 5.192 | Crit. | Spacers not req'd | |
| | | | 0.8 | 8.900 | Crit. | Spacers not req'd | |
| | | | 2.0 | 17.059 | Crit. | Spacers not req'd | |
| | | | 3.2 | 19.284 | Crit. | Spacers not req'd | |
| | | >60%, ≤70% | 0.0 | 3.249 | Crit. | Spacers not req'd | |
| | | | 0.4 | 5.848 | Crit. | Spacers not req'd | |
| | | | 0.8 | 13.646 | Crit. | Spacers not req'd | |
| | | | 2.0 | 21.444 | Crit. | Spacers not req'd | |
| | | | 3.2 | 24.692 | Crit. | Spacers not req'd | |
| | | ≤60% | 0.0 | 5.576 kg U | Crit. | Spacers not req'd | |
| | | | 0.4 | 14.872 kg U | Crit. | Spacers not req'd | |
| | | | 0.8 | 28.814 kg U | Crit. | Spacers not req'd | |
| | | | 2.0 | 35.20 kg U [f] | Struct. | Spacers not req'd | |
| | | | 3.2 | 35.20 kg U [f] | Struct. | Spacers not req'd | |
| HEU oxide [i, j] ($UO_2$, $UO_3$, $U_3O_8$, $U_3O_8$-Al, $UO_2$-Mg, [k] $UO_2$-$ZrO_2$) | | ≤100% | 0.0 | 15.13 kg oxide<br>9.682 kg $^{235}$U<br>921 g carbon | Crit.,<br>$H_2$ gen. | Spacers not req'd | |
| Research reactor fuel elements and components [l] | $UZrH_x$ (TRIGA) | ≤20% | 0.0 | 0.921 [m] | Crit. | Spacers not req'd | |
| | | >20%, ≤70% | 0.0 | 0.408 [m] | Crit. | Spacers not req'd | |
| | $UZrH_x$ (SNAP) | ≥93% | 0.0 | 0.857 [m] | Crit. | Spacers not req'd | |
| | U-Zr | ≤100% | varies | See limit for broken metal or alloy [g] | Crit. | Spacers as req'd | |
| | U-Al | ≤100% | 0.0 | 7.333 kg U-Al<br>1.117 kg U<br>1.050 kg $^{235}$U | Crit. | Spacers not req'd | |
| | $U_3O_8$-Al | ≤100% | 0.0 | 15.13 kg oxide<br>9.682 kg $^{235}$U [n]<br>921 g carbon | Crit. | Spacers not req'd | |
| | $UO_2$ | ≤100% | 0.0 | 21.937 kg $UO_2$<br>19.308 kg $^{235}$U | Crit. | Spacers not req'd | |
| | Oxides of U-Zr [o] | ≤100% | 0.0 | 15.13 kg oxide<br>9.682 kg $^{235}$U [n]<br>921 g carbon | Crit. | Spacers not req'd | |
| | $UO_2$-Mg | ≤100% | 0.0 | 15.13 kg oxide<br>9.682 kg $^{235}$U [n]<br>921 g carbon | Crit. | Spacers not req'd | |
| | $U_3Si_2$-Al [p] | ≤100% | 0.0 | 5.825 kg $U_3Si_2$-Al<br>2.277 kg U<br>450 g $^{235}$U | Crit. | Spacers not req'd | |

**Table 1.3. Authorized content and fissile mass loading limits for ground transport [a, b, c]**

| Content description | | Enrichment | CSI | No spacers, $^{235}U$ (kg) | Basis for limit | 277-4 can spacers, [d] $^{235}U$ (kg) | Basis for limit |
|---|---|---|---|---|---|---|---|
| Uranium compounds | $UF_4$ | ≤100% | 0.0 | 3 kg $UF_4$<br>2.267 kg $^{235}U$ | Crit. | Spacers not req'd | |
| | $UO_2F_2$ | ≤100% | 0.0 | 3 kg $UO_2F_2$<br>2.067 kg $^{235}U$ | Crit. | Spacers not req'd | |
| | UC | ≤100% | 0.0 | 2 kg UC<br>1.815 kg $^{235}U$ | Crit. | Spacers not req'd | |
| | UN | ≤100% | 0.0 | 2 kg UN<br>1.888 kg $^{235}U$ | Crit. | Spacers not req'd | |
| | TRISO | ≤100% | 0.0 | 2 kg TRISO<br>1.815 kg $^{235}U$ | Crit. | Spacers not req'd | |
| | $U_3Si_2$ [p] | ≥19.7%, <40% | 0.0 | 13 kg $U_3Si_2$ | Crit. | Spacers not req'd | |
| | | ≥40%, ≤60% | 0.0 | 7 kg $U_3Si_2$ | Crit. | Spacers not req'd | |

[a] With the exception of the UNX crystals (Sect. 1.2.2.2), which are loaded in crystalline solid form, HEU in solution form is not permitted for shipment in the ES-3100.
[b] All limits are expressed in kg $^{235}U$ unless otherwise indicated.
[c] Mass loadings cannot be rounded up.
[d] 277-4 can spacers as described on Drawing M2E801580A043 (Appendix 1.3.7).
[e] HEU bulk metal and alloy not covered by these specific geometric shapes must be put into the broken metal category. Geometries of solid shapes are as follows:
- Cylinder A is larger than 3.24-in. diam but no larger than 4.25-in. diam: maximum of 1 cylinder per can.
- Cylinder B is no larger than 3.24-in. diam: maximum of 1 cylinder per can.
- Square bars are no larger than 2.29 in. × 2.29 in. (cross section): maximum of 1 bar per can.
- Slugs are a maximum of 1.5-in. diam × 2.0-in. tall: a maximum of 10 per convenience can where the actual number permitted is restricted by the stated loading limit.

[f] Maximum planned content weight is 35.20 kg. Maximum analyzed for criticality safety is 35.32 kg.
[g] Mass limits for alloys (uranium with aluminum, molybdenum, zirconium, stainless steel, titanium, tungsten, niobium, silicon, or vanadium) must assume that non-uranium portion is $^{235}U$.
[h] If the mass of metal or alloy turnings, fines, or powders is ≤ 50 g, then it may be shipped as the parent form (e.g., broken metal, reactor fuel, etc.).
[i] Seal time must be 12 months or less. Seal time is the length of time after the ES-3100 containment vessel is sealed that the shipment must be complete.
[j] Allowable HEU bulk oxide densities are 2.0–6.54 g/cm$^3$. Non-uranium metallic constituents must be counted as $^{235}U$. Moisture content in oxide is limited to 3 wt % water. As discussed in App. 6.9.10, the carbon limit of 921 g does not apply to HEU oxide in the form of $U_3O_8$ for ground transport.
[k] $UO_2$-Mg will be shipped in a glass bottle inside a metal convenience can under an inert cover gas.
[l] For SNAP $UZrH_x$, $x \leq 2$. For TRIGA $UZrH_x$, $x \leq 1.6$.
[m] Evaluation limit based on specific fuel type as opposed to a maximum calculated limit for $UZrH_x$.
[n] Non-uranium metallic constituents must be counted as $^{235}U$.
[o] Oxides of U-Zr are $UO_2$-Zr and $UO_2$-$ZrO_2$.
[p] The maximum impurities in uranium silicide are shown in Table 1.2a.

**Table 1.3a. Uranyl nitrate crystal content loading limits for ground transport**

| Product [a, b] | Seal time [c] (months) | CSI | Loading limit [d, e] (kg UNX) | U content [f] (wt %) |
|---|---|---|---|---|
| UNX, $0 < X \leq 3$ | 2 | 0.4 | 11.90 | $52 < U \leq 61$ |
| | 4 | 0.4 | 6.70 | $52 < U \leq 61$ |
| UNX, $X > 3$ | 2 | 0.4 | 9.17 | $46 < U \leq 52$ |
| | 4 | 0.0 | 4.75 | $46 < U \leq 52$ |

[a] UNX is uranyl nitrate hydrate $[UO_2(NO_3)_2 \cdot XH_2O]$ where $0 < X \leq 6$.
[b] Must be shipped in Teflon bottles.
[c] Seal time—length of time after the ES-3100 containment vessel is sealed that the shipment must be complete. Seal times listed in this table are much lower than the calculated values shown in Table 3.5.4.1 in Appendix 3.5.4 and have been reduced for additional conservatism.
[d] Total mass of UNX crystals. Spacers are not required for this content type.
[e] Loading limits for uranyl nitrate crystals are based on hydrogen generation calculations presented in Appendix 3.5.4.
[f] Enrichment up to 100%.

**Table 1.3b. Authorized content and fissile mass loading limits for air transport [a, b, c]**

| Content description | Enrichment | CSI | $^{235}U$ (kg) |
|---|---|---|---|
| HEU metal or alloy [d] | ≤100% | — [e] | 7.00 |
| HEU metal or alloy turnings, fines, or powder [d, f] | ≤80% | — [e] | 7.00 |
| Research reactor fuel elements and components ($UZrH_x$, [g] U-Zr, U-Al, $U_3O_8$-Al, $UO_2$, oxides of U-Zr, [h] $UO_2$-Mg, $U_3Si_2$-Al) | ≤20% | — [e] | 0.921 |
| | >20% | — [e] | 0.408 |
| HEU oxide [i, j] ($UO_2$, $UO_3$, $U_3O_8$, $U_3O_8$-Al, $UO_2$-Mg, [k] $UO_2$-$ZrO_2$) | ≤100% | — [e] | 5.281 |

[a] All limits are expressed in kg $^{235}U$ unless otherwise indicated.
[b] Mass loadings cannot be rounded up.
[c] The loading limit for mixed-mode transportation is taken as the most restrictive limit for either ground or air mode of transportation (Table 1.3 or 1.3b).
[d] Mass limits for alloys (uranium with aluminum, molybdenum, zirconium, stainless steel, titanium, tungsten, niobium, silicon, or vanadium) must assume that non-uranium portion is $^{235}U$.
[e] CSI and spacer use are governed by ground transport mode.
[f] If the mass of metal or alloy turnings, fines, or powders is ≤ 50 g, then it may be shipped as the parent form (e.g., broken metal, reactor fuel, etc.).
[g] For SNAP $UZrH_x$, $x \leq 2$. For TRIGA $UZrH_x$, $x \leq 1.6$.
[h] Oxides of U-Zr are $UO_2$-Zr and $UO_2$-$ZrO_2$.
[i] Seal time must be 12 months or less. Seal time is the length of time after the ES-3100 containment vessel is sealed that the shipment must be complete.
[j] Allowable HEU bulk oxide densities are 2.0–6.54 g/cm$^3$. Non-uranium metallic constituents must be counted as $^{235}U$. Moisture content in oxide is limited to 3 wt % water.
[k] $UO_2$-Mg will be shipped in a glass bottle inside a metal convenience can under an inert cover gas.

### 1.2.2.3 Reflectors, absorbers, and moderators

The reflectors, absorbers, and moderators present in the ES-3100 package are those associated with the materials of construction. For example, the thermal insulation acts as a neutron reflector to the contents of a single package and as a neutron moderator in an array of packages. The degree of neutron moderation is a function of the hydrogen content in the Kaolite 1600 and 277-4 materials. The stainless-steel materials of the

containment vessel and the drum also act as neutron reflectors to the contents of a single package but act as neutron absorbers in an array of packages. The nuclear properties of the materials of construction and of the contents are important and have been taken into account in the criticality safety evaluation (Sect. 6). In addition to the materials of construction in the ES-3100 shipping package mentioned above, the 277-4 material has been specifically added to the ES-3100 package for the purpose of enhancing the neutron absorption characteristics for safety purposes (see Sect. 6 for additional discussion of the neutron-absorbing characteristics of this material).

#### 1.2.2.4 Shipping configurations

Authorized content convenience containers for the ES-3100 are cans constructed of stainless steel, tin-plated carbon steel, aluminum, or nickel-alloy (series 200, passivated), and polyethylene and Teflon convenience bottles. Modified convenience cans are constructed by brazing two 8.75-in.–tall cans together to create a 17.5-in.–tall can or by brazing three 10-in.–tall cans together to create a 30-in.–tall can. Research reactor fuel elements and fuel components may also be bundled together and protected on each end with open-ended convenience cans having an outer diameter ≤5 in. Solid form HEU contents (i.e., spheres, cylinders, bars, slugs) that will not fit in a convenience can may be bagged only with no convenience can required around the content. Enriched uranium oxide in the form of $UO_2$-Mg will be packed inside glass bottles, which are placed inside sealed, inerted metal convenience cans. These convenience containers are used to hold the HEU contents for shipment in the ES-3100 package and to assure that the inside of the containment vessel does not become contaminated with HEU under NCT. Convenience containers used in the ES-3100 package must have an outer diameter less than or equal to 12.7 cm (5 in.). The height can vary up to the full internal height of the containment vessel or 78.74 cm (31 in.). Some contents require the use of can spacers (see Table 1.3). These can spacers are thin-walled stainless-steel cans filled with 277-4 material (Drawing M2E801580A043, Appendix 1.3.7). Each convenience can and spacer may be equipped with a stainless-steel band and nylon-coated wire to facilitate loading and unloading operations. Silicone rubber pads may also be used between convenience cans to dampen vibration and minimize contact between metal components. Any combination of convenience containers will be allowed in a single package, as long as the total height of the stack-up (including spacers, if required) does not exceed the inside working height of the containment vessel [78.74 cm (31 in.)]. If can spacers are required, no more than one-third of the total HEU content mass limit shown in Table 1.3 may be placed between any two spacers.

Typical configurations of authorized ES-3100 convenience containers are shown in Fig. 1.4. The shipping configurations shown in Fig. 1.4 utilize convenience cans having ≤5.0-in. diam and various heights [such as 4.75 in., 4.88 in., 8.75 in., 10 in., 17.5 in. (two 8.75-in. cans brazed together), and 30 in. (three 10-in. cans brazed together)], 4.94-in.-diam by 8.7-in.-tall polyethylene bottles, and 4.69-in.-diam by 9.4-in.-tall Teflon bottles. Although any combination of the convenience cans that will fit inside the internal volume of the containment vessel may be used, content forms shall not be mixed in a single package (i.e., HEU oxides may not be packed with HEU metal). Empty cans and/or stainless-steel scrubbers may be used to fill the void space at the top of the containment vessel. If empty cans are shipped, a minimum 0.32-cm (0.125-in.)-diam hole must be placed through the lid to prevent over-pressurization of the can in the event of a thermal accident. These empty cans may be placed above or below the loaded cans. In configurations not requiring can spacers for criticality control, can spacers may be shipped for convenience if placed on top of loaded cans in the containment vessel. The HEU contents may be bagged or wrapped in polyethylene, and the convenience containers may also be wrapped in polyethylene to further reduce the possibility of contamination. If metal cans or polyethylene bottles are used as convenience containers, the total amount of offgassing material (including polyethylene bottles, polyethylene bagging, and lifting slings) is limited to 500 g per package. If Teflon bottles are used as convenience containers, the total amount of offgassing material (including Teflon bottles, polyethylene bagging, and lifting slings) is limited to 1490 g per package (limit established by assuming three 330-g Teflon bottles and 500-g polyethylene bagging). If closed

convenience cans with an outer diameter greater than 4.25 in. are used, at least 55 $in.^3$ of free or void volume must exist inside the containment vessel to allow for gas expansion and offgassing of material at temperatures associated with NCT or HAC. The only hydrogenous materials that can be present in the containment vessel when shipping HEU broken metal are those that have a hydrogen atom density less than or equal to that of water. In some shipping configurations, silicone rubber pads will be placed between the convenience cans to reduce vibration.

### 1.2.2.5 Maximum normal operating pressure

As defined in 10 CFR 71.4, the maximum normal operating pressure is the maximum gauge pressure that would develop in the containment system in one year under an ambient temperature of 38°C (100°F) in still air, with appropriate insolation in the absence of venting, external cooling by an ancillary system, or operational controls during transport. Under these conditions, the maximum normal operating pressure in the ES-3100 containment vessel would be 215.24 kPa (31.218 psia). In comparison, the design internal pressure of the containment vessel is 801.17 kPa (116.2 psia). The design internal pressure is a conservatively assumed value that was assigned for the purpose of the ASME Code calculations in DAC-M900000-0003.

### 1.2.2.6 Maximum and minimum weight

The maximum allowable gross shipping weight for the ES-3100 package is 190.5 kg (420 lb). The largest nominal gross shipping weight of the ES-3100 package with HEU content is 187.81 kg (414.05 lb) [Table 2.8]. The total weight of the tested ES-3100 units ranged from 157.4 to 204.6 kg (347 to 451 lb) [Table 2.9].

The weight of HEU contents in the ES-3100 shipping package is limited to 35.2 kg (77.60 lb). This limit has been established as a bounding case for the maximum structural, thermal, and containment limit for the package. There is no minimum content weight requirement. Actual mass restrictions for the various contents based on the various analyses presented in the SARP are listed in Tables 1.3, 1.3a, and 1.3b. The maximum allowable payload weight of any configuration, including packing components (convenience cans and bottles, polyethylene bags, silicone pads, can spacers, etc.), is 40.82 kg (90 lb). ES-3100 shipping package weights are discussed in greater detail in Sect. 2 and are broken down into individual component weights in Tables 2.8 and 2.9.

The payload weight (including convenience cans, silicone rubber pads, can spacers, and the HEU mockup) used in the ES-3100 package tests ranged from a minimum of 3.6 kg (8 lb) to a maximum of 50.3 kg (111 lb).

### 1.2.2.7 Maximum decay heat

As shown in Sect. 3.1.2, the conservatively calculated maximum heat generation rate of the contents is ~5 W. The ES-3100 package was designed for a maximum heat load of 20 W. Thermal analyses have been performed assuming heat sources of 5, 10, 15, 20, 25 and 30 W in the ES-3100 containment vessel (DAC-PKG-801940-A001).

### 1.2.2.8 Loading restrictions

Loading restrictions based upon the results of the criticality safety calculations presented in Sect. 6.2.4 and additional limitations on packing materials outlined in Sect. 3 are as follows:

(1) HEU fissile material to be shipped in the ES-3100 package must be placed in stainless-steel, tin-plated carbon-steel, aluminum, or nickel alloy convenience cans, polyethylene bottles, or Teflon bottles. Solid form HEU contents (i.e., spheres, cylinders, bars, slugs) that will not fit in a convenience can

may be bagged only with no convenience can required around the content. For contents that are bagged only, stainless-steel metal scrubbers may be placed on the top and bottom of this assembly inside the containment vessel. For these bagged contents, the void volume requirement stated in Loading Restriction 8 must still be satisfied. Enriched uranium oxide in the form of $UO_2$-Mg will be shipped in glass bottles inside a metal convenience can. Convenience containers used in the

ES-3100 package must have an outer diameter less than or equal to 12.7 cm (5 in.). The height can vary up to the full internal height of the containment vessel or 78.74 cm (31 in.). Any closure on the convenience can is allowed.

(2) Any combination of convenience cans is allowed in a single package, as long as the total height (including silicone rubber pads and can spacers, if required) does not exceed the inside working height of the containment vessel (~31 in.).

(3) In situations where empty convenience cans are shipped in the package, they may be placed either above or below the loaded cans, and a minimum 0.32-cm (0.125-in.)-diam hole must be placed through the lid to prevent over pressurization of the can.

(4) The concentration of uranium isotopes in the content is limited as shown in Table 1.1; concentration limits for uranium oxide are shown in Table 1.2.

(5) For pyrophoric considerations, HEU metal or alloy pieces must have a specific area not greater than 1 $cm^2/g$ or must not pass through a 3/8-in. (9.5-mm) mesh sieve (or equivalent size-grading method). Incidental small pieces that do not pass the size restriction tests, and powders, foils, turnings, and wires, may only be shipped if they are in a sealed, inerted container. Glass bottles containing enriched uranium oxide in the form of $UO_2$-Mg must be placed in a sealed, inerted container.

(6) The content shall not exceed "per package" fissile material mass loading limits specified in Tables 1.3, 1.3a, and 1.3b. Where can spacers are required for a "per package" mass loading, the quantity of fissile material located in any vacancy between or adjacent to can spacers shall not exceed one-third of the mass loading limit in Tables 1.3 and 1.3b.

(7) The package content is defined as the HEU fissile material, the convenience cans and can spacers, and the associated packing materials (plastic bags, pads, tape, etc.) inside the ES-3100 containment vessel.

(8) If metal cans are used as convenience containers, the amount of polyethylene bagging and lifting slings is limited to 500 g per package. If Teflon bottles are used as convenience containers, the total amount of offgassing material (including Teflon bottles, polyethylene bagging, and lifting slings) is limited to 1490 g per package. If metal cans or polyethylene bottles are used as convenience containers, the total amount of offgassing material (including polyethylene bottles, polyethylene bagging, and lifting slings) is limited to 500 g per package (see Item 7 in Sect. 6.2.4). If closed convenience cans with an outer diameter greater than 4.25 in. are used, at least 55 $in.^3$ of free or void volume must exist inside the containment vessel to allow for gas expansion and offgassing of material at temperatures associated with NCT or HAC. These mass limits do not include moisture in oxide. Moisture is accounted for in criticality safety calculations (Sect. 6.1.2).

(9) The only hydrogenous packing materials that can be used in the containment vessel when shipping broken HEU metal are those that have a hydrogen atom density less than or equal to that of water.

(10) Shipments of UNX crystals must be completed in the time period noted in Table 1.3a. Shipments of uranium oxide must be completed in 12 months. This time period begins when the containment vessel is sealed.

(11) The mass of any unidentified constituents in content to be shipped in the ES-3100 must be counted against the fissile mass loading limit. Content must not contain unevaluated moderating materials.

(12) Allowable HEU bulk oxide densities are 2.0–6.54 g/cm$^3$.

(13) As noted in Table 1.3, Note e, ground transport of solid HEU metal or alloy of specified geometric shapes is limited to one item per convenience container, with the exception of slugs, which are limited to a maximum of 10 per convenience container.

(14) For air transport, the total free water permitted in the ES-3100 packaging is limited to 12 lb (5,443 g).

### 1.2.3 Special Requirements for Plutonium

The contents to be shipped in the ES-3100 have only trace amounts of transuranic isotopes [<0.74 TBq (20 Ci)]. Therefore, the requirements in 10 CFR 71.63 are not applicable.

### 1.2.4 Operational Features

The ES-3100 package is a Type B(U) fissile material package designed in accordance with DOT and NRC regulations. These regulations require that the package be operated without undue risk to the public, even in the event of a severe accident, and that the dose rate and nonfixed radioactive contamination on the external surface of the package conform with 49 CFR 173.441 and 173.443, respectively. These requirements are translated into the designs for the containment, shielding, and nuclear criticality safety of the contents when subjected to NCT and HAC. Designs for containment, shielding, and nuclear subcriticality safety are supported by operational procedures for loading, unloading, and refurbishing to ensure that those design features are used and maintained in a manner commensurate with their intended function. Drop tests, crush tests, puncture tests, thermal tests, and water immersion tests (Sects. 2.6 and 2.7) show that the drum assembly maintains the insulation and the containment vessel in their intended configurations when subjected to NCT and HAC.

Design features that provide shielding, containment, and nuclear criticality control perform these functions in a passive manner. No valves, connections, gauges, active coolants, or operationally pressurized parts are integral to the ES-3100 package.

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## 1.3 APPENDICES

1.3.1 Package Certification Drawing

1.3.2 Equipment Specification JS-YMN3-801580-A002, *ES-3100 Drum Assembly*

1.3.3 Equipment Specification JS-YMN3-801580-A001, *ES-3100 Containment Vessel*

1.3.4 Equipment Specification JS-YMN3-801580-A003, *Manufacturing Process Specification For Casting Kaolite 1600™ into the ES-3100 Shipping Package*

1.3.5 Equipment Specification JS-YMN3-801580-A005, *Casting Catalog No. 277-4 Neutron Absorber for the ES-3100 Shipping Package*

1.3.6 Package Category Determination

1.3.7 ES-3100 Design Drawings

1.3.8 Pyrophoricity of Uranium Metal

1.3.9 Equipment Specification SPC-M801580-0001, *ES-3100 Fluorocarbon Elastomer (Viton) Containment Vessel (CV) O-rings*

1.3.10 Equipment Specification SPC-M801580-0002, *ES-3100 Ethylene Propylene Diene Monomer (EPDM) Containment Vessel (CV) O-rings*

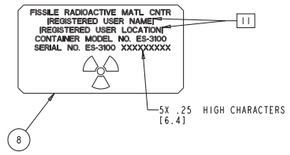
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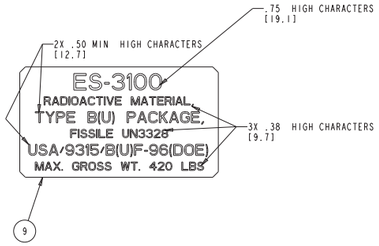
## Appendix 1.3.1

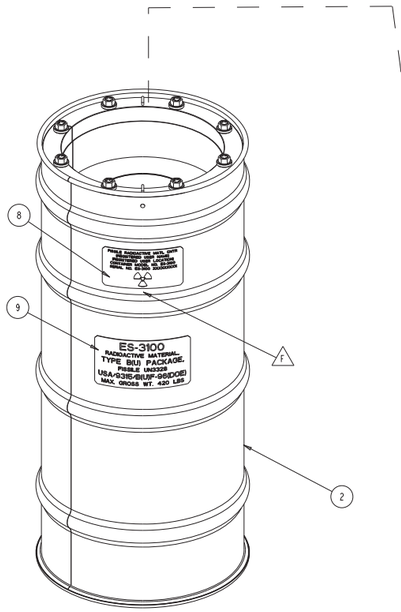
## Package Certification Drawing

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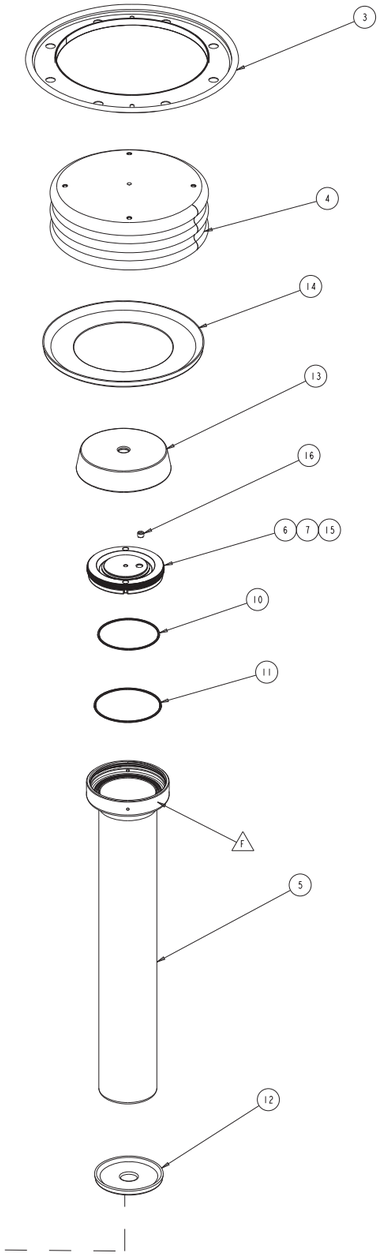
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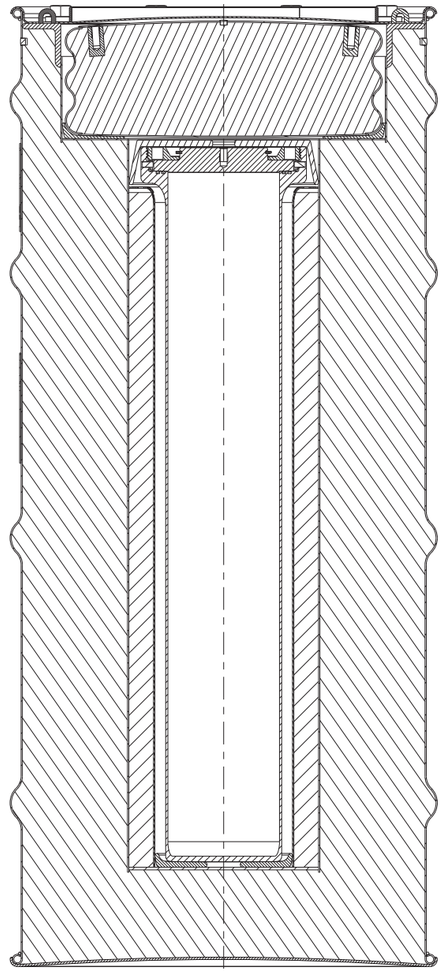



-1 MAIN ASSEMBLY



NOTES

1. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
2. DIMENSIONS ARE IN INCHES [mm].
3. APPROXIMATE WEIGHT: 325 LBS [147.4 Kg] FOR F/N 1 EMPTY.
4. WELDING SYMBOLS SHALL BE INTERPRETED IN ACCORDANCE WITH AWS A2.4.

[5] SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A002 ES-3100 DRUM ASSEMBLY.

[6] SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A001 ES-3100 CONTAINMENT VESSEL.

[7] SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A003 MANUFACTURING PROCESS SPECIFICATION FOR CASTING KAOLITE 1600™ INTO THE ES-3100 SHIPPING PACKAGE.

[8] SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A005 CASTING CATALOG # 277-4 NEUTRON ABSORBER FOR THE ES-3100 SHIPPING PACKAGE.

[9] DURING INSTALLATION OF O-RINGS APPLY A THIN COAT OF SUPER-O-LUBE

[10] DURING INSTALLATION OF CONTAINER VESSEL LID ASSEMBLY, APPLY A LIGHT COAT OF KRYTOX GREASE TO THE THREADS AND UNDER THE NUT.

[11] SEE PROCUREMENT DOCUMENTS FOR PROPER REGISTERED USER NAME AND LOCATION.

F NOTE DELETED

| | | | | | |
|---|---|---|---|---|---|
| | AR | KRYTOX #240AC OR EQUAL THREAD LUBRICANT | FLUORINATED GREASE MILLER-STEPHENSON CHEMICAL CO. | NA | 18 |
| [10] | AR | SUPER-O-LUBE OR EQUAL O-RING LUBRICANT | CLEAR DIMETHYL SILOXANE POLYMER PARKER HANNIFIN CORP | NA | 17 |
| | 1 | MODIFIED VCO THREADED PLUG | BRASS | 3 | 16 |
| [9] | 1 | EXTERNAL RETAINING RING | 302 SST | 3 | 15 |
| | 1 | PLUG PAD | SILICONE RUBBER 22±5 SHORE A COLOR BLACK/GRAY | 1 | 14 |
| | 1 | CV FLANGE PAD | | 1 | 13 |
| | 1 | CV BOTTOM PAD | | 1 | 12 |
| | 1 | OUTER O-RING Ø5.859±.035 ID X Ø.139 ±.004 | ETHYLENE PROPYLENE DIENE MONOMER 70±5 SHORE A COLOR BLACK OR FLUOROCARBON RUBBER, PARKER COMPOUND VM835-75 COLOR BLACK | 1 | 11 |
| | 1 | INNER O-RING Ø5.359±.035 ID X Ø.139±.004 | | 1 | 10 |
| [5] | 1 | ES3100 DATA PLATE | 16 GA 304/304L SST ASTM SA240 | 1 | 9 |
| [5] | 1 | ES3100 TREFOIL DATA PLATE | | 1 | 8 |
| [6] | 1 | CONTAINMENT VESSEL CLOSURE NUT | NITRONIC 60 SST ASME SA-479 UNS-S21800 | 3 | 7 |
| [6] | 1 | CONTAINMENT VESSEL SEALING LID | 304 SST ASME SA-479 | 3 | 6 |
| [6] | 1 | CONTAINMENT VESSEL BODY | 304L SST | 3 | 5 |
| [7] [5] | 1 | TOP PLUG WELDMENT | 16 GA 304/304L SST ASTM SA240 | 2 | 4 |
| [5] | 1 | DRUM LID WELDMENT | | 2 | 3 |
| [8] [7] [5] | 1 | DRUM WELDMENT | | 2 | 2 |
| | | MAIN ASSEMBLY | | 1 | 1 |
| | | NOMENCLATURE OR DESCRIPTION | MATERIAL / SPECIFICATION | SHEET NO | FIND NO |
| | | QTY REQ'D NEXT ASSEMBLY | PARTS LIST | | |

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY ANALYSIS ENGINEERING APPROVAL.

| REVISION | DATE | SAE APPROVAL |
|---|---|---|
| F | 6/11/15 | ALAN WILKINSON |

This document has been reviewed by a Y-12 DC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.

Name: STAN THOMAS Date: 06/11/15

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| PART | REV | DESCRIPTION | DRW | CHKR | DE | DVR | DM | DATE |
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| 000 | F | REMOVED TEMPERATURE LABEL F/N 19 AND DELETED NOTE 12; UPDATED FORMAT | KWJ | MLG | GAB | MLG | JCA | 6/11/15 |
| 000 | E | ADDED OPTIONAL O-RING FOR FIND NO.10 &11, ADDED FIND NO. 19 | CDB | DEW | MLG | DEW | WIN | 6/11/12 |
| 000 | D | REDRAWN TO NEW FORMAT. REVISED ES-3100 DATA PLATE, F/N 9. | MLE | JRJ | MLE | DEW | WIN | 9/10/09 |
| 000 | C | REVISED TREFOIL DATA PLATE, F/N 8, ADDED NOTE 11 | JRJ | RDA | LR | GAB | WIN | 9/9/08 |
| 000 | B | REVISED TREFOIL DATA PLATE, F/N 8 | JRJ | RDA | JRJ | GAB | WIN | 10/16/06 |
| 000 | A | PAGE 1: MODIFIED GENERAL NOTES AND UPDATED FIELD NOTES ADDED TOLERANCES TO ORINGS. PAGE 3: ADDED CORRECT TOLERANCES AND REF. DIMS. PAGE 4. ADDED CORRECT INSPECTION DIMS. AND WELD SYMS. PAGE 5. ADDED CORRECT TOLERANCES AND INSPECTION DIMS. AND ADDED NOTE TO -5 ADDED SHEET 6 RN Y2003-0328 | RDA | JSL | GAB | JRJ | WDS | 3/22/06 |
| 000 | 0 | RN: Y2003-0328 ORTIGINAL ISSUE | JMR | GM | GAB | RBC | MLG | 11/23/05 |

REVISION OR ISSUE PURPOSE

| DRW | CHKR | DE | DVR | DM | DATE |
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REVISION APPROVALS

| PE | DATE | SE | DATE | ME | DATE | NCS | DATE | OM/SO | DATE |
|---|---|---|---|---|---|---|---|---|---|
| JGA | 11/23/05 | JGA | 11/23/05 | | | | | | |

SQUAD CHECK

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|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |

DRAWING APPROVALS

| | | DATE |
|---|---|---|
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| TOLERANCES UNLESS OTHERWISE SPECIFIED | CHKR G MCGINNIS | 1/18/06 |
| | DE GA BYINGTON | 1/23/06 |
| | DVR RB CONATSER | 1/18/06 |
| FRACTIONS | DM ML GOINS | 1/23/06 |
| XX DECIMALS ±.01 | PE RD AIGNER | 1/23/06 |
| XXX DECIMALS ±.005 | SE JG ARBITAL | 1/23/06 |
| ANGLES ±0.5° | OM/SO | |
| BREAK SHARP EDGES .06 MAX | ME N/R | |
| FINISH 125 RMS | | |

Y-12 National Security Complex managed and operated by Consolidated Nuclear Security, LLC for the Department of Energy under U.S. Government contract DE-NA0001942 at Oak Ridge, Tennessee

PROJECT NAME

ES-3100 SHIPPING PACKAGE

CONSOLIDATED ASSEMBLY DRAWING

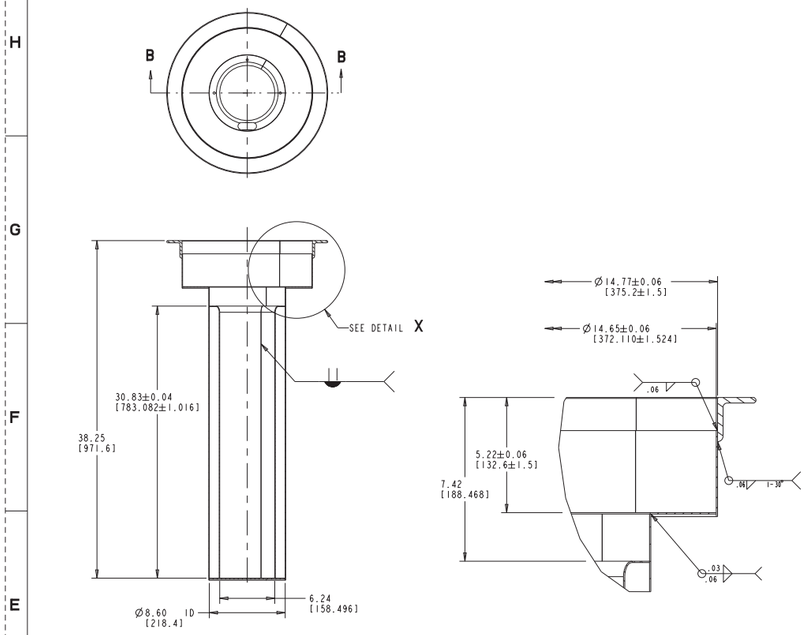
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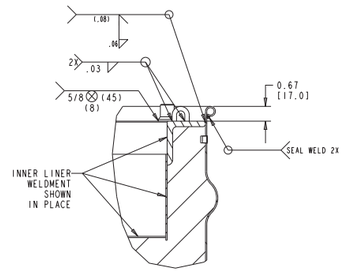
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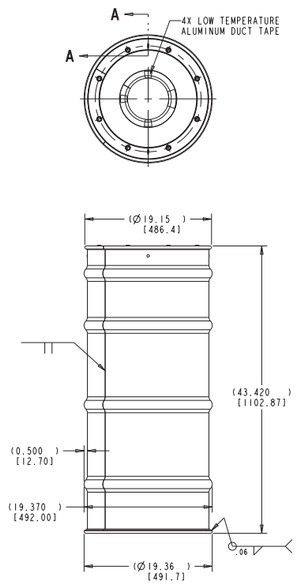

SECTION B-B

DETAIL X

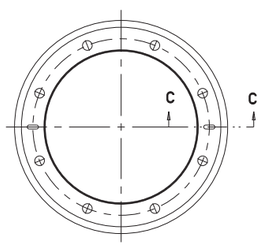
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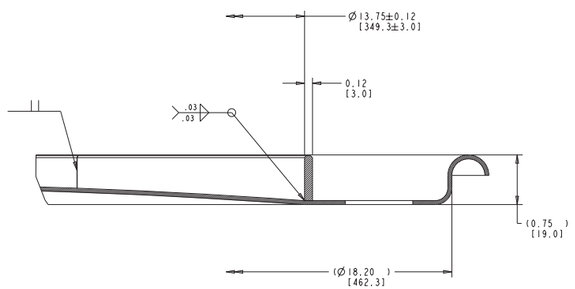

SECTION A-A



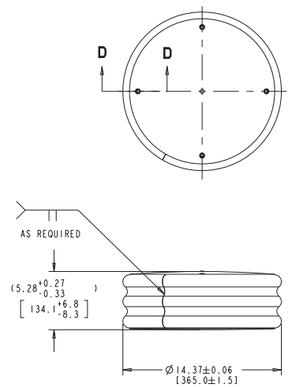

-2 DRUM WELDMENT



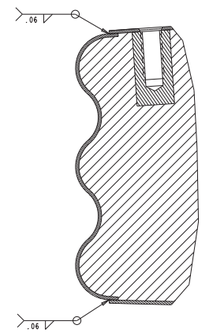

-3 DRUM LID WELDMENT




SECTION C-C




-4 TOP PLUG WELDMENT




SECTION D-D

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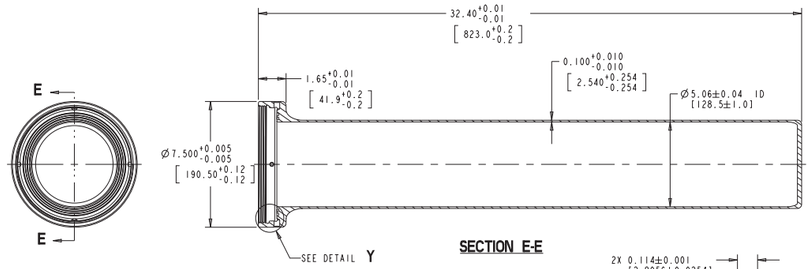
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ES-3100 SHIPPING PACKAGE

CONSOLIDATED ASSEMBLY DRAWING

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|---|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | CM | PKG | IN | E | NA | NA | U |
| SH. OF | TYPE | | | | PART | | | | REV | |
| 2 3 | DD | | | | 000 | | | | F | |

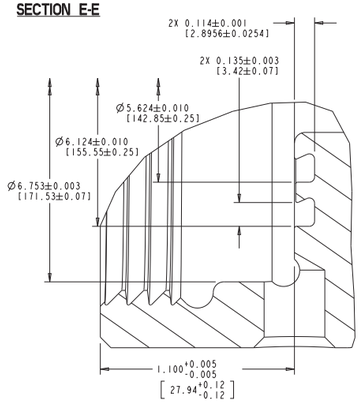
M2E801580A037

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**SECTION E-E**

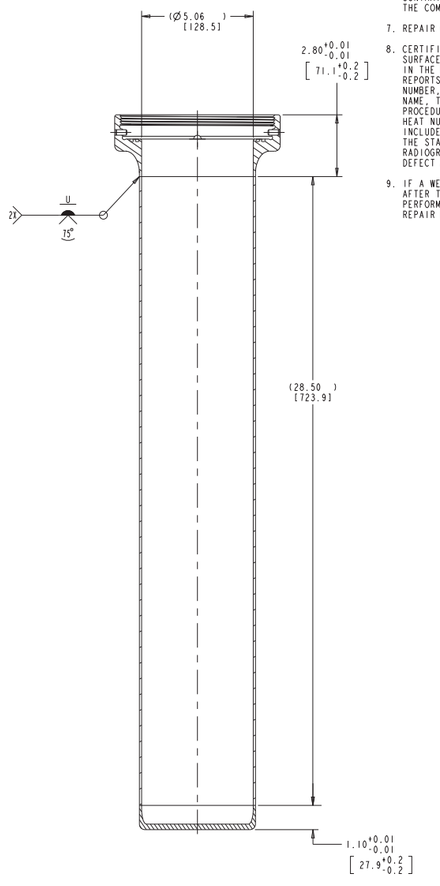
**-5 CONTAINMENT VESSEL BODY**
OPTIONAL WELDED CONSTRUCTION SHOWN ON SHEET 6



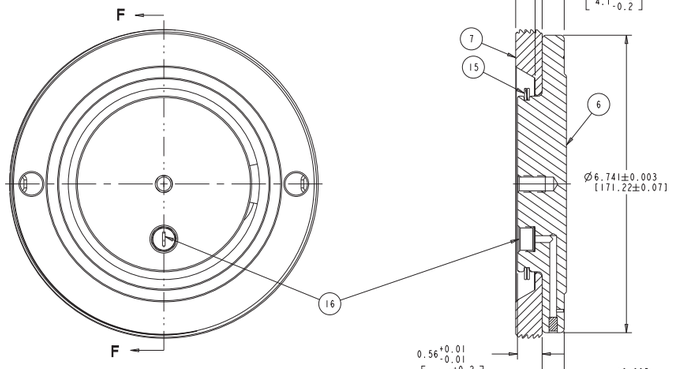

**DETAIL Y**

WELD NOTES:

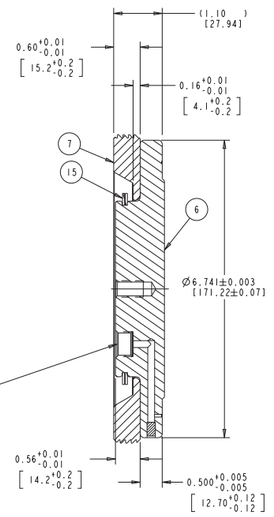
1. ALL WELDS ON THE CONTAINMENT VESSELS SHALL BE DONE EITHER BY THE GTAW OR GMAW PROCESS, MANUAL OR AUTOMATIC, AT THE DISCRETION OF THE SELLER UNLESS SPECIFICALLY CALLED OUT ON THE DRAWINGS. BACKING RINGS, EVEN IF REMOVED AFTER THE WELD HAS BEEN MADE, SHALL NOT BE USED. AS PREVIOUSLY STATED, WELD SYMBOLS ARE PROVIDED ON THE DRAWING INDICATING FOR EACH WELD THE TYPE OF WELD AND DIMENSIONS OF THE WELD.
2. EXCEPT AS LIMITED BY THIS SPECIFICATION, THE APPLICABLE REQUIREMENTS OF NB-4300 AND NB-4400 SHALL APPLY TO THE CONTAINMENT VESSEL.
3. PRIOR TO WELDING, ALL WELD PREPARATION AREAS AND THE SURFACES WITHIN ONE INCH OF THE WELD AREA SHALL BE EXAMINED VISUALLY AND WITH LIQUID PENETRANT. THE ACCEPTANCE CRITERIA FOR THESE EXAMINATIONS ARE THOSE STATED IN NB-5130 (A) THROUGH NB-5130 (D). THE RESULTS OF THESE SURFACE EXAMINATIONS SHALL BE REPORTED TO THE COMPANY TOGETHER WITH THE WELD EXAMINATION REPORTS, SEE SECTION 3.4 OF THIS SPECIFICATION.
4. WELDERS PERFORMING TWO OR MORE WELDS IN ONE DAY THAT ARE REJECTED BASED UPON WELDER TECHNIQUE SHALL BE SUBJECT TO BE RE-QUALIFIED TO THE APPROPRIATE WELDING PROCEDURES, SEE SECTION IX, PARAGRAPH QW-320 OF THE ASME CODE.
5. THE APPLICABLE REQUIREMENTS IN PARAGRAPHS NB-5110, NB-5120, NB-5210, NB-5220, NB-5260, AND NB-5300 SHALL APPLY TO THE CONTAINMENT VESSELS. THE PLUG WELD SHOWN ON DRAWING M2E801580A015 SHALL BE EXAMINED VISUALLY AND WITH PENETRANT. THE APPLICABLE REQUIREMENTS IN PARAGRAPHS NB-5110, AND NB-5350 SHALL APPLY TO THE PLUG WELD. NOTE THAT THE REFERENCE TO THE INSPECTOR IN NB-5112, FOR THE PURPOSES OF THIS SPECIFICATION IS EITHER THE COMPANY'S INSPECTOR OR A SUBCONTRACTOR DESIGNATED BY THE COMPANY.
6. MATERIALS USED IN THE PENETRANT EXAMINATION OF WELDS AND IN THE FINAL SURFACE EXAMINATION OF FINISHED COMPONENTS (SEE SECTION 3.7) SHALL BE SPECIFICALLY RECOMMENDED BY THEIR SUPPLIERS FOR USE WITH AUSTENITIC STAINLESS STEELS, AND COPIES OF THE CERTIFICATION OF CONTAMINANT CONTENT OF MATERIALS USED (SEE SECTION V, ARTICLE 6, T-641) SHALL BE SUPPLIED TO THE COMPANY WITH THE EXAMINATION REPORTS.
7. REPAIR WELDING SHALL MEET THE APPLICABLE REQUIREMENTS OF NB-2500.
8. CERTIFIED WRITTEN WELD EXAMINATION REPORTS TOGETHER WITH THE CORRESPONDING MATERIAL SURFACE EXAMINATION REPORTS, AND WELD MAP SHALL BE SUBMITTED TO THE COMPANY AS STATED IN THE PROCUREMENT SPECIFICATION FOR THE ES-3100 CONTAINMENT VESSEL. WELD EXAMINATION REPORTS FOR ALL WELD AND SURFACE EXAMINATION SHALL INCLUDE: THE CONTAINMENT VESSEL SERIAL NUMBER, A WELD MAP SHOWING THE LOCATION OF THE WELD AND EXAMINATION AREA, THE WELDER'S NAME, THE EXAMINER'S NAME, THE TIME AND DATE OF THE WELD EXAMINATION, THE EXAMINATION PROCEDURE(S) NUMBER USED, THE WPS NUMBER, THE HEAT NUMBERS OF THE MATERIALS JOINED, THE HEAT NUMBER OF THE WELD FILLER, AND EXAMINER'S REMARKS. THE EXAMINER'S REMARKS SHALL INCLUDE THE RESULTS OF THE EXAMINATION AND ACCEPTANCE, OR REJECTION OF THE WELD BASED ON THE STATED CRITERIA. ONE SET OF RADIOGRAPHS SHALL BE PROVIDED TO THE COMPANY WITH RADIOGRAPHIC EXAMINATION REPORTS. IF THE WELD OR SURFACE IS REJECTED, A DESCRIPTION OF THE DEFECT AND SKETCH SHOWING THE LOCATION SHALL BE PROVIDED.
9. IF A WELD IS REJECTED, THE AREA SHALL BE WELD REPAIRED BY THE SELLER AND RE-EXAMINED. AFTER TWO UNSUCCESSFUL REPAIR ATTEMPTS, THE COMPANY SHALL BE NOTIFIED FOR APPROVAL TO PERFORM MORE REPAIR ATTEMPTS. THE COMPANY MAY, AT ITS OPTION, CHOOSE TO REJECT FURTHER REPAIR EFFORTS AND REQUIRE THAT A REPLACEMENT PART BE FABRICATED.




**CONTAINMENT VESSEL BODY ASSEMBLY WELDED OPTION**




**CONTAINMENT VESSEL SEALING LID ASSEMBLY**




**SECTION F-F**

| | | | | |
|---|---|---|---|---|
| 2 | -5 | .2501/.2503 OD DOWEL PIN | ANSI B18.8.2 18-8-SST | 5 |
| 1 | -4 | VESSEL FLANGE | ASME SA-182 TYPE F304L | 4 |
| 1 | -3 | VESSEL END CAP | ASME SA-182 TYPE F304L | 3 |
| 1 | -2 | VESSEL BODY SCH40 PIPE | ASME SA-182 TYPE F304L | 2 |
| X | -1 | CONTAINMENT VESSEL WELDED ASSEMBLY | | 1 |
| — | PART OR IDENTIFYING NO | NOMENCLATURE OR DESCRIPTION | MATERIAL/ SPECIFICATION | FIND NO |
| | ← QTY REQ'D NEXT ASSEMBLY | PARTS LIST | | |

C THIS DRAWING PRODUCED ON CREO PARAMETRIC

THIS DRAWING IS LOANED FOR SOLE USE OF THE INTENDED RECIPIENT AND ONLY FOR THE LIMITED PURPOSES FOR WHICH IT WAS PROVIDED. USE BY OTHER ENTITIES OR FOR OTHER PURPOSES IS PROHIBITED AND AT THE USER'S OWN RISK. DRAWINGS ARE TO BE RETURNED UPON REQUEST OF THE FORWARDING RECIPIENT.

Y-12 National Security Complex managed and operated by Consolidated Nuclear Security, LLC for the Department of Energy under U.S. Government contract DE-NA0001942 Oak Ridge, Tennessee

PROJECT NAME
ES-3100 SHIPPING PACKAGE

CONSOLIDATED ASSEMBLY DRAWING

| USE | DISC | DT | DC | CM | SYSTEM | STAT | SIZE | BLDG | FL | CLASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | CM | PKG | IN | E | NA | NA | U |

| SH. | OF | TYPE | | PART | REV |
|---|---|---|---|---|---|
| 3 | 3 | DD | M2E801580A037 | 000 | F |

M2E801580A037

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## Appendix 1.3.2

## Equipment Specification JS-YMN3-801580-A002, *ES-3100 Drum Assembly*

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# EQUIPMENT SPECIFICATION APPROVAL/REVISION PAGE

| SPECIFICATION NO. | REV. | ISSUE DATE |
|---|---|---|
| JS-YMN3-801580-A002 | D | 10-15-03 |
| PAGE | REVISION DATE | |
| i OF ii | 03/15/06 | |
| PROCURED BY | INSTALLED BY | |
| BWXT L.L.C. | BWXT L.L.C. | |
| PROJECT TITLE | PLANT | BUILDING |
| ES-3100 Shipping Package | Y-12 | AREA |
| JOB TITLE | W.O. OR E.S.O.. | RECORD NUMBER |
| Design Definition | 7RCPCA5A | 2003-0328 |
| SPECIFICATION FOR | | SSC IDENTIFICATION NUMBER |
| ES-3100 DRUM ASSEMBLY | | |

**ENGINEERING AND PLANT APPROVALS**

| SIGNATURE | DATE | SIGNATURE | DATE |
|---|---|---|---|
| PREPARED BY | | PROJECT ENGINEER: | |
| J.L. Heck | 10-21-03 | M.R. Feldman | 10-29-03 |
| DISCIPLINE MANAGER | | OPERATIONS MANAGER/SYSTEM OWNER: | |
| J.C. Walls | 10-29-03 | | |
| DESIGN VERIFICATION | | | |
| Roger Aigner | 10-21-03 | | |

**REVISIONS/ENGINEERING AND PLANT APPROVALS**

| REV. NO. | DESCRIPTION OF REVISION |
|---|---|
| A | Issue Approved |
| B | Change the title of drawing M2E-801580-A001 from Confinement Boundary Assembly to Drum Assembly. Change the title this specification from ES-3100 Confinement Boundary Drums to ES-3100 Drum Assembly. Deleted reference to drawing M2E-801580-A009, Pad Details. Added the reference to drawings M2E-801580-A010, Data Plates and M2E-801580-A031, Main Assembly. Changed the wording in the first paragraph of Section 3.3 |
| C | Revised the third paragraph of Section 3.0 in accordance with REDC PE-06-058. |
| D | Section 3.0, paragraph 3, the phrase "certifying authority's written approval" has been revised to "regulatory authority's written approval." |

| SIGNATURE | DATE | SIGNATURE | DATE |
|---|---|---|---|
| PREPARED BY | | PROJECT ENGINEER | |
| G. A Byington /s/ | 3/14/06 | J. Arbital /s/ | 3/14/06 |
| DISCIPLINE MANAGER | | OPERATIONS MANAGER/SYSTEM OWNER: | |
| C. M. Amonett /s/ | 3/14/06 | | |
| DESIGN VERIFICATION | | | |
| Roger D. Aigner /s/ | 3/14/06 | | |

This document has been has been reviewed by a Y-12 ADC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.

Name: Roger D. Aigner /s/ Date: 3/14/06

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**TABLE OF CONTENTS** **PAGE**


1.0 SCOPE 1

2.0 APPLICABLE CODES AND STANDARDS 1

3.0 DETAILED REQUIREMENTS 2

- 3.1 Materials 3
- 3.2 Welding 3
- 3.3 Weld Examination 4
- 3.4 Cleaning and Passivation 5
- 3.5 Dimensional Inspection Reports 5


## LIST OF COMPANY DRAWINGS

| Drawing Number | Title |
|---|---|
| M2E-801580-A001 | Drum Assembly |
| M2E-801580-A002 | Body Weldment |
| M2E-801580-A003 | Inner Liner Weldment |
| M2E-801580-A004 | Double Open Head Reinforced Drum |
| M2E-801580-A005 | Misc. Details |
| M2E-801580-A006 | Drum Lid Weldment |
| M2E-801580-A007 | Drum Lid |
| M2E-801580-A008 | Top Plug Weldment |
| M2E-801580-A010 | Data Plates |
| M2E-801580-A031 | Main Assembly |

### 1.0 SCOPE

This specification, the Procurement Specification for the ES-3100 Drum Assembly, specifications JS-YMN3-801580-A003 and JS-YMN3-801580-A005, the Company's drawings, and the referenced codes and standards in section 2.0 of this specification state the requirements for the procurement of materials and components, fabrication, inspection, examination, assembly, and testing of the Drum Assembly for the ES-3100 shipping package. If conflicting requirements appear between the Company's documents, and the standards listed in section 2.0 of this document, the Seller shall immediately notify the Company, so that these can be resolved. The Seller shall provide the number of completed assemblies specified in the purchase order.

This specification describes the applicable procedures to be followed in the fabrication, welding, examination, inspection, quality assurance, and documentation requirements for a Drum Assembly used in a Type B nuclear shipping package.

The Drum Assembly shall be manufactured in accordance with those paragraphs of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section VIII, Division 1 that are specified in this document. The Drum Assemblies are not pressure vessels and are not to be hydrostatically tested, nor are they to be stamped. If the Seller does not have certificate of authorization from the ASME to apply the U stamp, the Seller shall be familiar with, and capable of meeting those requirements in Section VIII, Division 1 of the ASME Boiler and Pressure Vessel Code that are referenced in this specification.

Company specification JS-YMN3-801580-A003 gives requirements for casting Kaolite, and JS-YMN3-801580-A005 gives requirements for casting Catalog No. 277-4 in the drum as shown on the Company's drawings.

### 2.0 APPLICABLE CODES AND STANDARDS

The Drum Assembly shall be fabricated, inspected, and tested according to the design drawings, and the portions of the codes, standards, and regulations to the extent described herein.

- American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section VIII, Division 1, 2001 Edition with 2002 and 2003 addenda

- American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section II, Parts A and C, 2001 Edition and 2002 and 2003 addenda

- American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section V, 2001 Edition and 2002 and 2003 addenda

- American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section IX, 2001 Edition and 2002 and 2003 addenda

- American Society For Nondestructive Testing, No. SNT-TC-1A-1992, Recommended Practice for Nondestructive Testing Personnel Qualification and Certification, Dec 1992

- Military Standard, MS27683, Drum, Metal-Shipping and Storage 16 to 80 Gallons

- American Society For Testing Materials, ASTM A 380-99$^{e1}$, Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment and Systems.

All references to the ASME Code in this document are to the ASME Boiler and Pressure Vessel Code, the 2001 Edition with the 2002 and the 2003 addenda.

## 3.0 DETAILED REQUIREMENTS

Detailed dimensional requirements and the materials of construction are called out on the Company's drawings. Additional requirements for materials are given in section 3.1 of this specification. The Seller shall be responsible for determining stock sizes so that the finished machined components meet the dimensions, tolerances and surface features called out on the attached drawings.

Weld symbols are provided on the Company's drawings indicating for each weld the type of weld and dimensions of weld. Additional welding requirements are stated in section 3.2 of this specification

Any material substitution or any other deviation from the requirements shown on the Company's drawings, or stated in the Company's document is not permitted without the Seller submitting a written request for waiver or deviation, Company's written approval, and regulatory authority's written approval (see the Procurement Specification for the ES-3100 Drum Assembly).

The assembled Drum Assembly shall be marked according to the Company's drawings. The Company will assign permanent serial numbers for each Drum Assembly. Drum Assembly's records may be maintained based upon a temporary serial number assigned by the Seller. The temporary serial number for the Drum Assembly shall be cross-referenced to the Drum Assembly's permanent serial number.

The following additional requirements apply as follows:

3.1 Materials

Except for the weld studs, documented Certified Material Test Reports (CMTR's) shall be provided to the Company for all materials used in weldments for the fabrication of the Drum Assembly, including weld filler metal. The CMTR's shall be traceable to heat numbers and shall demonstrate compliance with the SA or SFA material specifications called out. For all other the materials documented Certificates of Compliance shall be provided to the Company certifying that the materials provided comply the requirements stated on the Company's drawings and specifications. See the Procurement Specification for the ES-3100 Drum Assembly for specific documentation requirements.

The markings on the weldment materials shall not be removed until after all weld examination is complete. Note that the heat numbers of base metals and weld filler are required on all weld examination reports (see section 3.3 of this specification).

The weld filler metal used in the fabrication of the Drum Assemblies shall be procured to comply with the SFA specifications of Section II, Part C of the ASME Code that are stated in the Seller's welding procedure specifications. Weld filler metal shall be procured traceable to heat numbers, and Certified Material Test Reports shall be furnished to the Company for each heat of weld wire filler. The control of weld filler by the Seller shall permit a weld examiner to be able to determine the heat number of the weld filler used in any weld on the Drum Assembly.

Prior written approval of the Company shall be obtained for any weld repair on materials, and the weld repair areas shall be noted in a sketch supplied with the CMTR for the material that was weld repaired. Note that depending on the specific defect in a specific material, the Company may or may not approve the weld repair, even if it is permitted by the material specification.

3.2 Welding

All welding shall be done in accordance with welding procedure specifications that are written and performance qualified in accordance with the ASME Code, Section IX. All welders shall be performance qualified to weld using these procedures, and their qualifications documented in accordance with the ASME Code, Section IX. The welding fabrication requirements stated in the ASME Code, Section VIII, Division 1, paragraphs UW-26 through UW-48 shall be met. The Inspector referenced in these paragraphs shall be an individual or individuals that are employed by the Company or subcontractors to the Company.

All butt welds in rolled sheet, pipe and angle joints shall be full penetration butt welds. With the exception of the seam welds in the drum body, all welds shall be done by the GTAW, GMAW, PAW or a Capacitive Discharge (CD) stud welding process.

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Welders performing two or more welds in one day that are rejected shall be subject to be re-qualified to the appropriate welding procedures, see Section IX, and paragraph QW-320 of the ASME Code.

3.3 Weld Examination

A qualified weld examiner using a written weld examination procedure shall visually examine all designated welds. Weld examiners shall be qualified to perform visual weld inspection in accordance with their employer's written practice, which must be in accordance with either SNT-TC-1A (2001 Edition), "Personnel Qualification and Certification in Nondestructive Testing;" or ANSI/ASNT CP-189 (2001 Edition), "ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel;" published by the American Society for Nondestructive Testing. The weld examination procedure shall meet the requirements of the ASME Code, Section V. The weld examination procedures, the weld examiners qualifications, and the weld examination reports shall be submitted to the Company.

Written weld examination reports for all weld examination shall include: the Drum Assembly serial number, a weld map showing the location of the weld, the welder's name, the examiner's name, the time and date of the weld examination, the examination procedure number used, the WPS number, the heat numbers of the materials joined, the heat number of the weld filler, and the examiner's remarks. The examiner's remarks shall include the results of the examination, and acceptance or rejection of the weld based on the stated criteria and include a description and sketch showing the location of any defects found. Weld examination reports shall be submitted to the Company as stated in the Procurement Specification for the ES-3100 Drum Assembly.

The acceptance criteria for joint fit-up and alignment, and for visual examination of welds are given in the ASME Code, Section VIII, Division 1, paragraphs UW-31 through UW-36. In addition, any visible defects such as lack of fusion, lack of penetration, linear or crack like defects, and visible porosity, shall be cause for rejection.

If a weld is rejected, the area may be weld repaired by the Seller and re-examined. After two unsuccessful repair attempts, the Company shall be notified for approval to perform more repair attempts. The Company may, at its option, choose to reject further repair efforts and require that a replacement part be fabricated.

If penetrant examination of welds or materials is performed the materials used in the examination shall be specifically recommended by their suppliers for use with austenitic stainless steels, and copies of the certification of contaminant content of materials used (see Section V, Article 6, T-641) shall be supplied to the Company with the examination reports.

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3.4 Cleaning and Passivation

Cleaning procedures for the stainless steel, including weld areas, shall be submitted to the Company for approval prior to the start of fabrication, see the Procurement Specification for the ES-3100 Drum Assembly. Only non-chloride bearing chemicals shall be used for cleaning (such as trisodium phosphate detergent or acetone). Water used in cleaning shall have a maximum chlorine content of 0.5 parts per million.

Finished components awaiting assembly and assemblies shall be free of dirt, debris, foreign objects, cutting fluids, metal chips, grinding residue, and other foreign substances. The Seller shall clean, cover, and protect parts and subassemblies from becoming dirty while in storage, and to the extent practical, in the shop environment while in work.

After final machining and examination of all welds except the attachment welds for the drum bottom and the closure weld on the top plug, and prior to filling with Kaolite and Catalog No. 277-4 (see JS-YMN3-801580-A003 and JS-YMN3-801580-A005), clean and passivate all stainless steel surfaces of the Drum Assembly in accordance with ASTM A 380. After the closure weld on the top plug weldment and the attachment weld on the drum bottom are examined, clean and locally passivate the weld areas and heat affected zone areas.

3.5 Dimensional Inspection Reports

Straightening, flattening, and forming by mechanical or thermal means of some features and components after welding may be required to ensure proper assembly. The surfaces of areas of the weldment that have been worked shall be visually examined to ensure that no cracks are present or that the weldment has been degraded. Adjacent welds to these areas shall also be visually examined. The acceptance criteria are that no cracks are found. The areas worked and the visual inspections shall be noted on the dimensional inspection report. This work and examination shall be performed prior to the installation of Kaolite or Catalog No. 277-4.

After all testing, inspection and final machining, the Drum Assemblies shall be dimensionally inspected. The dimensions, and features such as flatness, runout, etc, to be inspected are indicated on the Company's drawings. A written inspection report shall be prepared, and submitted to the Company as stated in the Procurement Specification for the ES-3100 Drum Assembly.

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## Appendix 1.3.3

## Equipment Specification JS-YMN3-801580-A001, *ES-3100 Containment Vessel*

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# EQUIPMENT SPECIFICATION APPROVAL/REVISION PAGE

| SPECIFICATION NO. | REV. | ISSUE DATE |
|---|---|---|
| JS-YMN3-801580-A001 | G | 10-15-03 |
| PAGE | REVISION DATE | |
| i OF ii | 06-11-12 | |
| PROCURED BY | INSTALLED BY | |
| B&W Y-12 LLC | B&W Y-12 LLC | |

| PROJECT TITLE | PLANT | BUILDING |
|---|---|---|
| ES-3100 Shipping Package | Y-12 | AREA |
| JOB TITLE | W.O. OR E.S.O. | RECORD NUMBER |
| Production Design Definition | 7RCPCA5A | Y2003-0328 |
| SPECIFICATION FOR | | SSC IDENTIFICATION NUMBER |
| ES-3100 CONTAINMENT VESSEL | | |

## ENGINEERING AND PLANT APPROVALS

| SIGNATURE | DATE | SIGNATURE | DATE |
|---|---|---|---|
| PREPARED BY | | PROJECT ENGINEER: | |
| J.L. Heck | 10-21-03 | M.R. Feldman | 10-29-03 |
| DISCIPLINE MANAGER | | OPERATIONS MANAGER/SYSTEM OWNER: | |
| J.C. Walls | 10-29-03 | | |
| DESIGN VERIFICATION | | | |
| Roger Aigner | 10-21-03 | | |

## REVISIONS/ENGINEERING AND PLANT APPROVALS

| REV. NO. | DESCRIPTION OF REVISION |
|---|---|
| A | Issued Approved |
| B | Included the requirements for a Containment Vessel that was fabricated by welding a forged bottom, a forged top flange and a cylindrical shell as shown on the revised drawing, M2E801580A012, Rev B. |
| C | In all locations removed the references to the Procurement Specification document number OO-PP-1210. Modified the Weld Repair reject and re-qualification requirements in Section 3.3 in the fourth paragraph. In Section 3.9, first, third, and fourth paragraphs changed the units from ref-cm3/sec to cm3/sec helium. Also added new Section 3.6 Welding Documentation Submittals. |
| D | Added two paragraphs to the end of Section 3.1 for reference to ASTM A 262 in accordance with REDC #PE-05-046-A. Added a sentence to the beginning of the first paragraph in Sect. 3.9 in accordance with REDC # PE-06-059. |
| E | Section 3.0, paragraph 3, the phrase "the Company's written approval" has been revised to "the Company's written approval, and regulatory authority's written approval." |
| F | Removed statement about metal spinning in Section 3.1, page 4. Also made many editorial changes on page 9 to support SARP defined in EC-801940-0001. |
| G | Added Viton O-ring drawing as a optional O-ring. Changed Procurement Specification OO-PP-986 to Equipment Specifications SPC-M801580-0001 (for Viton O-ring) and SPC-M801580-0002 (for EPDM O-ring). |

| SIGNATURE | DATE | SIGNATURE | DATE |
|---|---|---|---|
| PREPARED BY | | PROJECT ENGINEER | |
| L. Roberson | 6/11/12 | L. Roberson | 6/13/12 |
| DISCIPLINE MANAGER | | OPERATIONS MANAGER/SYSTEM OWNER: | |
| [signature] | 6/12/12 | N/A | |
| DESIGN VERIFICATION | | Program Mgt. | |
| Monty Harris | 6/12/12 | [signature] | 6/13/12 |

This document has been has been reviewed by a Y-12 ADC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.

Name: Stan Thomas Date: 06/12/12

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**TABLE OF CONTENTS**


**1.0 SCOPE** ..... 1

**2.0 APPLICABLE CODES AND STANDARDS** ..... 1

**3.0 DETAILED REQUIREMENTS** ..... 2

3.1 Materials and Material Examinations ..... 3
3.2 Forming, Fitting and Alignment ..... 5
3.3 Welding and Weld Repair ..... 5
3.4 Weld Examination ..... 6
3.5 NDE Examiner Qualifications ..... 6
3.6 Welding Documentation Submittals ..... 7
3.7 Hydrostatic Testing ..... 7
3.8 Final Examination of Finished Surfaces ..... 8
3.9 Leak Testing ..... 8
3.10 Cleaning, Passivation, and Bead Blasting ..... 9
3.11 Dimensional Inspection Reports ..... 10


**LIST OF COMPANY DRAWINGS**

| Drawing Number | Title |
|---|---|
| M2E-801580-A011 | Containment Vessel Assembly |
| M2E-801580-A012 | Containment Vessel Body Assembly |
| M2E-801580-A013* | Containment Vessel O-ring Details |
| M2E-801580-A014 | Containment Vessel Lid Assembly |
| M2E-801580-A015 | Containment Vessel Sealing Lid |
| M2E-801580-A016 | Containment Vessel Closure Nut |
| M2E-801580-A021 | Containment Vessel Body Test Flange Assembly |
| M2E-801580-A022 | Containment Vessel Lid Test Flange Assembly |
| M2E-801580-A023 | Containment Vessel Leak Test Assemblies |
| M801580-0013* | Containment Vessel Viton O-ring Details |

* Either O-ring set may be used in Containment Vessel Assembly.

## 1.0 SCOPE

This specification, equipment specifications (SPC-M801580-0001, *ES-3100 Fluorocarbon Rubber Elastomer (Viton) O-rings*, and SPC-M801580-0002, *ES-3100 Ethylene Propylene Diene Monomer (EPDM) CV O-rings*), the Company's drawings, and the referenced codes and standards in Sect. 2.0 of this specification state the requirements for the procurement of materials and components, fabrication, inspection, examination, assembly, and testing of the containment vessels for the ES-3100 shipping package. If conflicting requirements appear between the Company's drawings and specifications, the Seller shall immediately notify the Company, so that these can be resolved. The Seller shall provide the number of completed assemblies specified in the purchase order.

The containment vessel will be manufactured in accordance with the applicable requirements stated in the American Society of Mechanical Engineers (ASME) *Boiler and Pressure Vessel Code* (ASME Code), Sect. III, Div. 1, Subsection NB for Class 1 Components as described on the Company's drawings and in this specification. If the Seller does not have certificate of authorization from the ASME to apply the N stamp, the Seller shall be familiar with, and capable of meeting those requirements in Sect. III, Div. 1, Subsections NB and NCA of the ASME Code that are referenced in this specification. The reference to the Inspector in any of the ASME Codes shall in this particular case be that person designated by the Company.

## 2.0 APPLICABLE CODES AND STANDARDS

The Containment Vessel shall be fabricated, inspected, and tested according to the design drawings and the following codes, standards, and regulations as described in this document.

- ANSI N14.5-1997, *American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment,* American National Standards Institute.
- *ASME Boiler and Pressure Vessel Code*, Sect. III, Div. 1 - Subsections NB and NCA, Class 1 Components, 2001 Edition and 2002 and 2003 addenda.
- *ASME Boiler and Pressure Vessel Code*, Sect. II, Parts A and C, 2001 Edition and 2002 and 2003 addenda.
- *ASME Boiler and Pressure Vessel Code*, Sect. V, 2001 Edition and 2002 and 2003 addenda.

- *ASME Boiler and Pressure Vessel Code*, Sect. IX, 2001 Edition and 2002 and 2003 addenda.
- ASTM A 380-99$^{e1}$, *Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment and Systems,* American Society for Testing and Materials.
- SNT-TC-1A-1992, *Recommended Practice for Nondestructive Testing Personnel Qualification and Certification*, American Society for Nondestructive Testing, Dec 1992.
- SSPC SP 5/NACE No. 1, *White Metal Blast Cleaning,* Society for Protective Coatings.

## 3.0 DETAILED REQUIREMENTS

Detailed dimensional requirements and the materials of construction are called out on the Company's drawings. Additional requirements for materials are given in Sect. 3.1 of this specification. The Seller shall be responsible for determining stock sizes so that the finished machined components meet the dimensions, tolerances and surface features called out on the attached drawings.

Weld symbols are provided on the Company's drawings indicating the type of weld and dimensions for each weld. Additional welding and repair welding requirements are stated in Sects. 3.1 and 3.3 of this specification.

Any material substitution or other deviation from the requirements shown on the Company's drawings or stated in the Company's specifications is not permitted without the Seller submitting a written request for waiver or deviation, and Company's written approval, and regulatory authority's written approval.

The term ASME Code in this specification refers to the *ASME Boiler and Pressure Vessel Code*. A paragraph referenced as NB-XXXX or NCA-XXXX, where XXXX is a specific paragraph number, is that paragraph in Sect. III, Subsection NB or Subsection NCA, respectively, of the ASME Code. If a given paragraph is referenced as a requirement, all the paragraphs under the stated paragraph are also to be considered as requirements. For example, if NB-2430 is referenced as a requirement, not only do the applicable requirements of NB-2430 apply, but also those of NB-2431, NB-2431.1, NB-2431.1(a), NB-2432, etc. apply. Note that the Company shall act as the Authorized Inspector, and that the Inspector referenced in the ASME Code shall be a representative of the Company.

The assembled containment vessels shall be marked according to the Company's drawings. Permanent serial numbers for each containment vessel shall be assigned by the Company. Containment vessel records may be maintained based upon a temporary serial number assigned by the Seller. The temporary serial number for the containment vessel shall be cross referenced to the containment vessel's permanent serial number.

The following additional requirements apply as follows:

EXEMPT FROM IO-155

**3.1 Materials and Material Examinations**

The containment vessel body (Drawing M2E-801580-A012), the sealing lid, (Drawing M2E-801580-A015), and the closure nut (Drawing M2E-801580-A016), shall be considered pressure retaining materials as defined in NB-2110, and meet the applicable requirements of NB-2120. Documented Certified Material Test Reports (CMTRs) shall be provided to the Company for the materials used to fabricate these components in accordance with NCA-3860. The suppliers of these materials shall meet the requirements of NCA-3800. Such parts shall be traceable to each containment vessel by means of a serial number assigned by the Company. The Seller shall maintain control of materials to ensure this traceability. Other metallic materials, and the O-ring seals shall be supplied with Certificate of Compliances in accordance with NCA-3862(g) and (h).

Procured materials shall be examined in accordance with NB-2500, and shall meet the stated acceptance criteria. The results of these examinations shall be included with the CMTRs provided to the Company. Prior written approval of the Company shall be obtained for any weld repair on materials, and the weld repair areas shall be both surface and volumetrically examined. The repair area shall be noted in a sketch supplied with the CMTR for the material that was weld repaired and the documented results of the weld examination shall be provided to the Company. Note that depending on the specific defect in a specific material, the Company may or may not approve the weld repair, even if it is permitted by the material specification or by NB-2500.

The weld filler metal used in the fabrication and repair welding as permitted, of the containment vessels shall meet the applicable requirements of NB-2400. It shall be procured to comply with the SFA specifications of Sect. II, Part C of the ASME Code that is stated in the Seller's welding procedure specifications. Weld metal filler shall be procured traceable to heat numbers, and CMTRs shall be furnished to the Company for each heat of weld wire filler used. The results of the delta ferrite determination shall be included in the CMTR for the weld filler metal (see NB-2433). The control of weld filler by the Seller shall permit a weld examiner to be able to determine the heat number of the weld filler used in any weld on the containment vessel.

The Seller shall provide the Company with CMTRs, certified material examination reports and Certificates of Compliance for the materials stated above as required.

There are two containment vessel assemblies shown on Drawing M2E801580A012, Parts M2E801580A012-1 and M2E801580A012-4. The containment vessel assembly(s) to be fabricated will be specified in the Company's purchase order. Note that Part M2E801580A012-4 is fabricated by welding a forged bottom, and forged top flange to a cylindrical shell machined from seamless pipe as shown on the drawing.

The formed containment vessel body, Part M2E801580A012-1, shall be flow formed from a single forged billet or bar. Special requirements for this part are given as follows.

EXEMPT FROM IO-155

Repair welds may be permitted depending on the nature of the defect to be weld repaired, and after receiving the written approval of the Company for such repair welds.

The formed, heat treated, and finished machined containment vessel body, Part M2E801580A012-1, shall meet the applicable requirements of ASME SA-182 for Grade F304L for a forged component. After final forming, parts shall be solution annealed and quenched per the requirements of ASME SA-182 for Grade F304L. In addition, the requirements of NB-2180 shall also apply. A certified heat treatment report shall be provided stating for each furnace charge the following information: the serial numbers of the containment vessel bodies heat treated in the furnace charge, the time and date of the heat treating, the person responsible for the heat treating, the time-temperature profile of the furnace and representative parts of the furnace charge, the quench medium, and all other pertinent details of the heat treating. Such a heat treating report is required for all heat treating, both in process annealing and final heat treatment.

It shall be demonstrated that the formed, heat-treated containment vessel bodies, Part M2E801580A012-1, meet the mechanical property requirements of ASME SA-182 for Grade F304L by mechanical testing of coupons. The test coupons are to be machined from the same heats of materials used to form the containment vessel bodies, and shall have the same or greater amount of cold word (plastic strain) as the containment vessels will have as a result of the forming process. The mechanical tensile testing of coupons shall be done in accordance with ASME SA-370. A minimum of six test coupons shall be tested for each final heat treatment furnace charge. The first set of three test coupons, chosen at random, shall be tested without being heat treated. The second set of three of more test coupons shall be heat treated together with the containment vessel bodies, and then tested. The heating rates and maximum temperatures of the test coupons shall be representative of the entire furnace charge. Test coupons are not required to be heat treated with intermediate processing annealing steps, but are required in the final heat treatment furnace charge.

The results of all the testing of the sample coupons shall be documented, certified and reported to the Company. The mechanical properties test report shall contain the following information: a descriptor of the furnace charge in which the test coupons are to represent; the times and dates of the heat treating and the testing; the person responsible for the testing; a statement that these coupons are prior to or after heat treatment; a description of the testing including a sketch of the tensile test specimen; the make, model, serial number, and current calibration data of the testing machine(s) used in the testing; reference to the written testing procedure used; the resulting measure yield strength, ultimate strength, % elongation and % reduction in area; and any pertinent remarks.

It is permissible to deviate from the liquid quench requirements stated in SA-182 provided that the cooling rates of the alternate quench are such that the heat treated material is not susceptible to intergranular corrosion due to chromium carbide precipitation. This is to be demonstrated by testing according to Practice E of ASTM A 262, and meeting the stated acceptance criteria. This shall be accomplished by obtaining test coupons from each furnace batch that represent the slowest cooling rates of the batch, or by following a heat treating procedure that has been qualified to ensure that the

heat treated batch will not be sensitive to intergranular corrosion. In any case, the requirements of NB-2180 shall apply.

The heat treating procedure must be qualified by measuring the annealing temperatures, soak times and cooling rates of the furnace batch, and then testing heat treated specimens that represent the lowest annealing temperatures, soak times and cooling rates for that furnace batch for sensitivity to intergranular corrosion using Practice E of ASTM A 262. For subsequent annealing operations, the temperatures, soak times, and cooling rates of subsequent furnace batches must be measured and compared to the qualified procedure. Other factors, such as variations of the size and arrangement of the furnace batch that can affect part temperatures and part cooling rates, and the calibration of the furnace temperature sensors must be assessed in the procedure qualification to ensure that minimum temperatures and cooling rates of production heat treating batches can be properly compared to those of the qualified procedure. Such a procedure should be requalified for each individual furnace used, and for significantly different furnace batch sizes. The procedure shall be requalified annually, or if it has not been used for a period of at least three months.

### 3.2 Forming, Fitting and Alignment

The forming, fitting and alignment requirements stated in NB-4200 shall be met in the fabrication of the Containment Vessels unless more stringent requirements are called out on the Company's drawings.

The roundness of cylinders, profile of formed head surfaces, and misalignment or offsets in weld joints shall be included in the dimensional inspection reports for the each containment vessel, see Sect. 3.11 of this specification.

### 3.3 Welding and Weld Repair

All welds on the Containment Vessels shall be done either by the GTAW or GMAW process, manual or automatic, at the discretion of the Seller unless specifically called out on the drawings. Backing rings, even if removed after the weld has been made, shall not be used. As previously stated, weld symbols are provided on the drawing indicating for each weld the type of weld and dimensions of the weld.

Except as limited by this specification, the applicable requirements of NB-4300 and NB-4400 shall apply to the containment vessel.

Prior to welding, all weld preparation areas and the surfaces within one inch of the weld area shall be examined visually and with liquid penetrant. The acceptance criteria for these examinations are those stated in NB-5130 (a) through NB-5130 (d). The results of these surface examinations shall be reported to the Company together with the weld examination reports, see Sect. 3.4 of this specification.

Welders performing two or more welds in one day that are rejected based upon welder technique shall be subject to be re-qualified to the appropriate welding procedures, see Sect. IX, Paragraph QW-320 of the ASME Code.

EXEMPT FROM IO-155

### 3.4 Weld Examination

The applicable requirements in NB-5110, NB-5120, NB-5210, NB-5220, NB-5260, and NB-5300 shall apply to the containment vessels. The plug weld shown on Drawing M2E801580A015 shall be examined visually and with penetrant. The applicable requirements in NB-5110 and NB-5350 shall apply to the plug weld. Note that the reference to the Inspector in NB-5112, for the purposes of this specification is either the Company's inspector or a subcontractor designated by the Company.

Materials used in the penetrant examination of welds and in the final surface examination of finished components (see Sect. 3.7) shall be specifically recommended by their suppliers for use with austenitic stainless steels, and copies of the certification of contaminant content of materials used (see Sect. V, Article 6, T-641) shall be supplied to the Company with the examination reports.

Repair welding shall meet the applicable requirements of NB-2500.

Certified written weld examination reports together with the corresponding material surface examination reports, and weld map shall be submitted to the Company. Weld examination reports for all weld and surface examination shall include: the containment vessel serial number, a weld map showing the location of the weld and examination area, the welder's name, the examiner's name, the time and date of the weld examination, the examination procedure(s) number used, the welding procedure specifications (WPS) number, the heat numbers of the materials joined, the heat number of the weld filler, and examiner's remarks. The examiner's remarks shall include the results of the examination and acceptance, or rejection of the weld based on the stated criteria. One set of radiographs shall be provided to the Company with radiographic examination reports. If the weld or surface is rejected, a description of the defect and sketch showing the location shall be provided.

If a weld is rejected, the area shall be weld repaired by the Seller and re-examined. After two unsuccessful repair attempts, the Company shall be notified for approval to perform more repair attempts. The Company may, at its option, choose to reject further repair efforts and require that a replacement part be fabricated.

### 3.5 NDE Examiner Qualifications

The qualifications of the personnel performing material or weld examination shall be those stated in NB-5500.

EXEMPT FROM IO-155

### 3.6 Welding Documentation Submittals

Submittal of the following are required with the bid unless the current revisions of these submittals have been previously approved by the Company. Submittals that do not demonstrate compliance with this specification will be cause for rejection of the proposal.

- Typical WPS for the applicable code.
- Procedure qualification records (PQR).
- Typical welder performance qualification (WPQ) records for the appropriate code.

Submittal of the following documents are required prior to welding unless the current revisions of these submittals have been previously approved by the Company.

- WPS.
- PQR.
- WPQ records, including evidence of process usage updates.
- Visual examination and nondestructive examination procedures.
- Certification records of examination personnel.
- CMTR.

To facilitate prompt review by the Company of the Seller's weld program, the welding documentation required above shall be submitted electronically in Adobe pdf format either on compact disk (CD) or by email. All information submitted shall reflect the Seller's most current documentation. Upon review and approval of the documentation, the Seller will be notified.

If the latest revision of the Seller's welding documentation required above has been previously submitted electronically and reviewed and approved by the Company, this shall be so stated with the offer. The Seller shall submit a detailed list of the welding documentation to be used for this contract including title, revisions/dates, type components to be used on (i.e., piping, structural, sheet metal, etc.) and indicate the previous contract and approval date. The Company will then review the documentation for applicability on the new contract and approve or comment.

If changes have occurred since the last approval of the welding documentation, in addition to the list of welding documentation that they propose to use the Seller shall submit those documents that have changed. The Company will then review, comment, and/or approve the Seller's documentation.

### 3.7 Hydrostatic Testing

After all machining is complete, the assembled Containment Vessel shall be hydrostatic tested by the Seller in accordance with the applicable sections of NB-6000 at a test pressure of 150 psig +/- 5 psig at ambient temperature (60°F to 90°F). Water with a maximum chlorine content of 0.5 parts per million shall be used as a test medium.

It will be necessary to hydrostatically test the container body assembly separately from the lid assembly. It is recommended that the tooling shown on the Company's Drawings M2E801580A021, M2E801580A022, and M2E801580A023 be used to pressurize the components to be tested. The use of this tooling is not mandatory, but the Seller shall provide suitable fittings to perform the hydrostatic testing.

A written hydrostatic test procedure shall be prepared by the Seller and submitted to the Company for approval prior to testing. Certified written hydrostatic test reports for each containment vessel shall contain the following data: serial number of the containment vessel; time and date of the test; name of person responsible for the hydrostatic testing; the hydrostatic test procedure number; the name, serial number and calibration date of all gages and transducers; and a sketch showing any areas of leakage or any areas where surface defects were observed after hydrostatic testing. Hydrostatic test reports shall be submitted to the Company.

**3.8 Final Examination of Finished Surfaces**

After all finish machining, load testing and hydrostatic testing, all surfaces of the containment vessel body, Drawing M2E801580A012; the containment vessel sealing lid, Drawing M2E801580A015; and the containment vessel closure nut, Drawing M2E801580A016, shall be examined with penetrant in accordance with NB-2546. See Sect. 3.4 for additional requirements for the materials used in the penetrant examination. The results of the final surface examinations shall be documented in a certified examination report and provided to the Company.

If a defect is found, the Company shall be notified in writing. The area may be weld repaired by the Seller only if specifically permitted by the Company in writing, and the area re-examined. After two unsuccessful repair attempts, the Company may, at its option, choose to reject further repair efforts and require that a replacement part be fabricated.

**3.9 Leak Testing**

There are three leak tests to be performed on the ES-3100 containment vessel. The leak testing is to be performed after hydrostatic testing. Following the hydrostatic pressure test and prior to conducting any leak test, the containment vessel and O-ring cavities must be thoroughly dried. The leak testing is to be performed in accordance with the applicable sections of ANSI N14.5-1-1997. A written leak test procedure(s) shall be prepared to perform this testing and submitted to the Company for approval. The written test procedure(s) and leak testing report shall comply with the applicable requirements of Sect. V of the ASME Code. The leak testing for the first two leak tests shall have the sensitivity to detect a leak less than or equal to $5 \times 10^{-8}$ ref-$cm^3$/sec of air, or $1 \times 10^{-7}$ $cm^3$/sec helium and shall use the leak test fixtures shown on the Company's Drawings M2E801580A021, M2E801580A022, and M2E801580A023.

If a leak is found the Company shall be notified in writing. The leak may be weld repaired by the Seller only if specifically permitted by the Company in writing, and the leak test repeated. After two

EXEMPT FROM IO-155

unsuccessful repair attempts, the Company may, at its option, choose to reject further repair efforts, and require that a replacement part be fabricated.

The first leak test shall be performed with the containment vessel body assembled as shown on Drawing M2E801580A023, (Part M2E801580A023-1, *Containment Vessel Body Leak Test Assembly*). Note that the outer O-ring in the containment vessel body is not to be installed for this test. The leak testing acceptance criteria is that the assembly shall not have an integrated leak rate greater than $1 \times 10^{-7}$ ref-cm$^3$/sec of air, or $2 \times 10^{-7}$ cm$^3$/sec helium.

The second leak test shall be performed with the containment vessel lid assembly as shown on Drawing M2E801580A023, (Part M2E801580A023-2, *Containment Vessel Lid Leak Test Assembly*). The leak testing acceptance criteria is that the assembly shall not have an integrated leak rate greater than $1 \times 10^{-7}$ ref-cm$^3$/sec of air, or $2 \times 10^{-7}$ cm$^3$/sec helium.

The third leak test is to be performed with the containment vessel assembled as shown on Drawing M2E801580A011. The leak testing acceptance criteria is that the assembly shall not have an air leak rate greater than $1 \times 10^{-4}$ ref-cm$^3$/sec and the sensitivity of the leak testing procedure shall be less than or equal to $5 \times 10^{-5}$ ref-cm$^3$/sec.

Certified written leak test reports shall be supplied to the Company that describes the leak testing and results. The test report shall identify the containment vessel serial number, identify all standard leaks, gauges, transducers and electronic readouts, give the date on which these instruments were certified, identify the leak detector, give the date on which the leak detector was last certified, the date of the test, time of the start and end of the test, the recorded pressures and leak rates at the start and end of the test, the name of the person conducting the test, the qualifications of the person conducting the test, identify areas of the Containment Vessel where repairs were made and any pertinent remarks. Leak testing reports shall be submitted to the Company.

### 3.10 Cleaning, Passivation, and Bead Blasting

Cleaning procedures for the stainless steel, including weld areas, shall be submitted to the Company for approval prior to the start of fabrication. Only non-chloride bearing chemicals shall be used for cleaning (such as trisodium phosphate detergent or acetone). Water used in cleaning shall have a maximum chlorine content of 0.5 parts per million.

Finished components awaiting assembly and assemblies shall be free of dirt, debris, foreign objects, cutting fluids, metal chips, grinding residue, dye penetrant and developer, and other foreign substances. The Seller shall clean, cover, and protect parts and subassemblies from becoming dirty while in storage, and to the extent practical, in the shop environment while in work.

After final machining, and all examination of welds and surfaces, clean and passivate all stainless steel surfaces of the containment vessel in accordance with ASTM A 380. After passivating is complete, bead

blast all exterior surfaces in accordance with SSPC-SP 5/NACE No. 1, *White Metal Blast Cleaning*, with the exception of all sealing surfaces and threaded surfaces.

**3.11 Dimensional Inspection Reports**

After all testing, inspection and final machining, the containment vessels shall be dimensionally inspected. The dimensions and features to be inspected are indicated on the Company's drawings by a diamond symbol containing an "I". This dimensional inspection includes surface features such as flatness, runout, etc, as called out on the drawings. The dimensional inspection report shall also include the recorded diameter dimensions that show compliance with the requirements of NB-4200. A certified written inspection report shall be prepared and submitted to the Company.

EXEMPT FROM IO-155

## Appendix 1.3.4

**Equipment Specification JS-YMN3-801580-A003,**
***Manufacturing Process Specification for Casting Kaolite 1600™***
***into the ES-3100 Shipping Package***

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# EQUIPMENT SPECIFICATION APPROVAL/REVISION PAGE

| SPECIFICATION NO. | REV. | ISSUE DATE |
|---|---|---|
| JS-YMN3-801580-A003 | C | 11/24/03 |
| PAGE | REVISION DATE | |
| i OF ii | 6/1/06 | |
| PROCURED BY | INSTALLED BY | |
| BWXT L.L.C. | BWXT L.L.C. | |

| PROJECT TITLE | PLANT | BUILDING |
|---|---|---|
| ES-3100 SHIPPING PACKAGE | Y-12 | YAREA-00 |
| JOB TITLE | W.O. OR E.S.O. | RECORD NUMBER |
| Production Design Definition | 7RCPCA08 | 2003-0328 |

SPECIFICATION FOR

MANUFACTURING PROCESS SPECIFICATON FOR CASTING KAOLITE 1600™ INTO THE ES-3100 SHIPPING PACKAGE

SSC IDENTIFICATION NUMBER

**ENGINEERING AND PLANT APPROVALS**

| SIGNATURE | DATE | SIGNATURE | DATE |
|---|---|---|---|
| PREPARED BY | | PROJECT ENGINEER: | |
| R. D. Aigner | 11-25-03 | G. A. Byington | 11-25-03 |
| DISCIPLINE MANAGER | | OPERATIONS MANAGER/SYSTEM OWNER: | |
| J. C. Walls | 11-25-03 | | |
| DESIGN VERIFICATION | | | |
| R. D. Aigner | 11-25-03 | | |

**REVISIONS/ENGINEERING AND PLANT APPROVALS**

| REV. NO. | DESCRIPTION OF REVISION |
|---|---|
| A | Issue for procurement |
| B | Removed the reference to the Prototype Procurement Specification document number OO-PP-1210. Change the equipment reference in Section 3.1.3(c) from a "large mortar mixer or plaster mixer with moving vanes or a smooth wall cement mixer with the fixed vanes removed" to "Whiteman Multiquip's WM700S-H8 plaster/mortar mixer, refereed to as WM700". In Section 3.2 changed the method and time that the water and dry mix were added into the mixer based upon the mixer qualification in Section 3.5. Added Section 3.5, added attachments E and F to determine the proper mixing time and the Mixer Qualification Castings. In section 3.3.1 and 3.3.3 added misting procedure. Section 3.3.2(b) added a circular concave of .32±.10 to the Kaolite before it is baked to match drawing M2E801580A002. Section 3.3.4(b) add a circular convex scrape of .09±.06 to the Kaolite before it is baked to match drawing M2E801580A008. Updated the attachments with general revisions. Section 3.4 has been subdivided into 3.4.1 Baking Instruction and 3.4.2 Baking Documentation and added attachment F to this section. |
| C | Revised patent information in scope. Added recommended "Before Baking" weights for the Body Weldment and Top Plug Weldment based upon a more refined Kaolite 1600™ product code GI80ACCUMD0027 that is produced to the lower side and a smaller range of the manufactures normal tolerance band. This Kaolite 1600™ product code requires using 1.65 times the dry weight for the water weight (instead of 1.5) and generates an acceptable wet mix density of 56.2+/− 5.8 lb/ft$^3$. This additional water requires between 36 to 46 hours of bake time at 500°F. |

| SIGNATURE | DATE | SIGNATURE | DATE |
|---|---|---|---|
| PREPARED BY | | PROJECT MANAGER: | |
| G.A. Byington | 6/1/06 | George Singleton | 6/1/06 |
| DISCIPLINE MANAGER | | CRITICALITY SAFETY: | |
| C.M. Arnold for W.I. North | 6/1/06 | D.F. Clark | 6/1/06 |
| DESIGN VERIFICATION | | QUALITY ASSURANCE: | |
| Monty L Goins | 6/1/06 | D.W. Eckert | 6/1/06 |

This document has been has been reviewed by a Y-12 ADC and UNCI RO and has been determined to be UNCLASSIFIED and not UNCI. This review does not constitute clearance for public release.

Name: R. D. Aigner Date: 06/01/06

EXEMPT FROM IO-155

TABLE OF CONTENTS


| | | Page |
|---|---|---|
| **1** | **Scope** | 3 |
| **2** | **Applicable Documents** | 3 |
| **3** | **Kaolite 1600™ Processing Requirements** | 3 |
| **3.1** | **General** | 3 |
| 3.1.1 | Kaolite 1600™ Receiving and Storage Instructions | 3 |
| 3.1.2 | Cleaning Instructions | 4 |
| 3.1.3 | Mixing Water and Mixing Equipment Requirements | 4 |
| **3.2** | **Mixing of Kaolite 1600™** | 4 |
| **3.3** | **Vibration Casting and Curing of Kaolite 1600™ Into Assemblies** | 5 |
| 3.3.1 | Body Weldment Casting Instructions | 5 |
| 3.3.2 | Body Weldment Curing Instructions | 6 |
| 3.3.3 | Top Plug Assembly Casting Instructions | 6 |
| 3.3.4 | Top Plug Assembly Curing Instructions | 7 |
| **3.4** | **Baking of Assemblies Cast and Cured with Kaolite 1600™ mixture** | 7 |
| 3.4.1 | Baking Instructions | 7 |
| 3.4.2 | Baking Documentation | 8 |
| **3.5** | **Mixer Qualification for Kaolite 1600™ Casting Placement** | 9 |
| 3.5.1 | Wet Density Mixing Test | 9 |
| 3.5.2 | Mixer Baked Density Qualification Castings | 10 |
| **4** | **Quality Assurance Requirements** | 10 |
| **4.1** | **General** | 10 |
| **4.2** | **Material and Equipment Certification** | 11 |
| **4.3** | **Nonconformance Control** | 11 |
| **4.4** | **Operator and Witness Qualifications** | 11 |
| 4.4.1 | Kaolite 1600™ Mixing Process Qualifications | 12 |
| 4.4.2 | Kaolite 1600™ Vibration Casting Process Qualifications | 12 |
| 4.4.3 | Kaolite 1600™ Baking Process Qualifications | 12 |


ATTACHMENTS


| | |
|---|---|
| **A** | **Kaolite Mixing Control** |
| **B** | **Body Weldment** |
| **C** | **Top Plug Assembly Vibration Casting Control** |
| **D** | **Furnace and Baking Control** |
| **E** | **Wet Density Mixer Time Vibration Casting** |
| **F** | **Baked Qualification Density Sample Vibration Casting** |

## 1 Scope

This manufacturing process specification describes the quality assurance and technical requirements that shall be met when weighing, mixing, pouring, vibrating, curing, and baking the Kaolite 1600™ for the ES-3100 shipping container Body Weldment and Top Plug Assemblies. The product produced by following this manufacturing process is protected under U.S. Patent 6,299,950. The United States Government has rights in this invention pursuant to Contract No. DE-AC05-84OR21400, between the U.S. Department of Energy and BWXT Y-12 L.L.C.

This specification describes the instructions that shall be followed for these activities. The components (Body Weldment and Top Plug Assembly) will be fabricated to the design requirements specified on the engineering drawings for the components.

Reference to the Company in this specification shall mean the package certificate holder and reference to the Seller shall mean the supplier of the fabricated Body Weldment and Top Plug Assemblies.

## 2 Applicable Documents

The following documents apply when Casting Kaolite 1600™ Into ES-3100 Shipping Containers.

ES-3100 Drawing Numbers
M2E801580A002, Body Weldment
M2E801580A008, Top Plug Weldment,

Procurement Specification for ES-3100 Confinement Boundary Assembly
JS-YMN3-801580-A002 Equipment Specification for the ES-3100 Drum Assembly

## 3 Kaolite 1600™ Processing Requirements

### 3.1 General

The Kaolite 1600™ material referenced with in this specification shall be provided by Thermal Ceramics, Incorporated or an authorized distributor. The material certification documentation (Certificate of Conformance) for the Kaolite 1600™ must be provided by the supplier for each manufacturer's lot of material to a product code of GI80ACCUMD0027.

#### 3.1.1 Kaolite 1600™ Receiving and Storage Instructions

a. Damaged packages of Kaolite 1600™ shall be rejected by the Seller upon receipt. Damaged packages are those that are wet, those that are visually determined to have been wet, and packages that have been torn.

b. Packages of Kaolite 1600™ must be stored unopened in a dry location and protected from damage. Opened unused and partial used Kaolite 1600™ packages are to be discarded at the end of the work shift. The term work shift shall be defined by the Seller and approved by the Company before commencing operations.

### 3.1.2 Cleaning Instructions

a. Use **NO CHLORINE BLEACH** for cleaning. Potable water shall be used and if required some mild soap (tri-sodium phosphate) may be added to the water to clean all processing equipment and manufactured components before casting. Before the start of any mixing/blending operation, the mixer shall be clean from all foreign materials or previous mixing residues from the inner surface of the mixer. The mixer shall be flushed thoroughly with potable water at the completion of the final mixing operation of the work shift to remove residues. Mixing, and casting shall be performed within a temperature range of 70 (± 25) °F.

b. Fabricated assemblies must be cleaned and protected prior to the casting operation to prevent the introduction of foreign materials into the assemblies. The assemblies shall be inspected and wiped clean prior to casting to ensure no visible contaminants are present inside the casting cavity. This inspection shall be documented in the checklist.

### 3.1.3 Mixing Water and Mixing Equipment Requirements

a. Potable water, that has been filtered through a 20-micron filter and has a chlorine content less than 4 mg/L (4 ppm, 0.0004 percent by mass) for chlorine shall be used for the mixing of Kaolite 1600™. If the potable water is higher then 4 ppm, then use an activated charcoal filter or some other means to reduce the amount of chlorine to at or below 4 ppm. Test the water quality for chlorine weekly during casting operations. Unfiltered potable water may be used for the cleaning of equipment used to process Kaolite 1600™.

b. All weighing operations of assemblies and materials shall be conducted on certified scales with a minimum accuracy of ½ lb.

c. This specification has been developed around the Whiteman Multiquip's WM700S-H8 plaster/mortar mixer, refereed to as WM700. This steel-drum machine mixes 7-cubic feet (193 liters) of material with an 8-horsepower Honda engine running at a slow speed. Other models of plaster/mortar mixers may be used if the speeds and mix times are qualified per section 3.5 and approved by the company.

d. A Heavy Duty Drum Vibrator/Packer(like McMaster-Carr, No. 5809K11, or Company approved equal) shall be used to clamp the Body Weldment, M2E-801580-A002 or Top Plug Weldment, M2E-801580-A008 upside down for vibration casting the Kaolite 1600™ into the welded stainless steel forms.

## 3.2 Mixing of Kaolite 1600™

Mixing shall be performed by operators qualified in accordance with requirements in Section 4.4.

The term batch is defined as a mixture of one bag of Kaolite 1600™ with the appropriate amount of water. The required mix ratio is 1.65 pounds of filtered water per pound of Kaolite 1600™.

The mixing activity shall be recorded on Attachment A, *Kaolite Mixing Control*. Each batch shall be given a mixture control number (MCN) and recorded upon its data Attachment. (A 10-digit control number is recommended consisting of the date and the time format using a 24-hour clock. Example: 1021041515 for October 21, 2004 at 3:15 pm.)

The Kaolite 1600™ mixing shall be performed as follows:

a. Record the weight of the bag of Kaolite 1600™ on the mixing Attachment.

b. The required mix ratio is 1.65 pounds of filtered water per pound of Kaolite 1600™. For a 50 pound bag of Kaolite 1600™, weigh and record 82.5 (± ½) lbs. of filtered water generating an acceptable wet mix density of 56.2±5.8 lb/ft$^3$.

c. Start the mortar mixer motor and when ready to engage the moving vanes, pour the weighed filtered water, pour all of the 50-pound bag of Kaolite 1600™ over the water. Immediately start the WM700 moving vanes for 3.0 (±0.2) minutes.

### 3.3 Vibration Casting and Curing of Kaolite 1600™ into Assemblies

3.3.1 Body Weldment Casting Instructions

Casting operations shall be performed by operators and witnesses qualified in accordance with requirements listed in Section 4.4.

Use Attachment B, *Body Weldment Vibration Casting Control,* to record information gathered during this operation.

Complete the casting of the mixture in less than 70 minutes. This timed procedure starts when the first batch is poured into the vibrating component. The casting and vibrating procedure must be completed within 77 minutes from initial pour for each assembly.

Casting operations shall be performed as follows:

a. Weigh the Body Weldment clean and empty. Record the weight.

b. Fill the Body Weldment with potable water that has been filtered through a 20 micron filter and has a chlorine content of ≤ 4 ppm and weigh it. Record the weight.

c. Remove the water from the assembly as much as is practical.

d. Secure the assembly on the vibration table. Set the vibration table dial indicators to approximately 800 lb-force at 450 vibrations per minute (VPM). Assure that the Body Weldment is properly secured to the table and start the vibration table. The Body Weldment must be vibrated continuously throughout the casting operation.

e. The mixture shall then be poured directly into the assembly after mixing through the fill hole provided.

f. Repeat the mixing operation in Section 3.2 and continue pouring until the mixture overflows the fill hole by ½ to ¾ inch.

g. Mist the top surface of the mixture with a bottle water sprayer if necessary to get the mixture into a solution after the pouring is completed. Do not add more than 8 ounces of water.

h. Vibrate the filled assembly for 5 to 7 minutes after the casting is completed.

### 3.3.2 Body Weldment Curing Instructions

A designated area shall be set aside for curing the assemblies. The temperature of the curing area shall be controlled to 70°F (±25°F) and shall prevent the introduction of foreign materials into the mixture.

Curing operations shall be performed as follows:

a. Remove the Body Weldment from the vibration table and place it in the curing area. Let it rest uncovered for 2½ (±½) hours.

b. Weigh and record the Before Baking weight of the cast assembly. If the weight is outside of 330 to 386 lbs range it is recommended not to cure the casting but to clean out and recast the Kaolite. This Before Baking weight is a recommended process control for the finished baked density. The manufacture may continue with a part outside of this weight range but it has a high chance being rejected for not meeting the finished baked density.

c. After resting, scrape the excess mixture from the fill opening until the Kaolite surface has a circular concave of .32±.10 to match drawing M2E801580A002.

d. Weigh the cast assembly, and photograph the fill opening. Record the weight.

e. Cover the fill opening with plastic sheeting and let the assembly set undisturbed in the curing area for at least 24 hours.

### 3.3.3 Top Plug Assembly Casting Instructions

Use Attachment C, Top Plug Assembly Vibration Casting Control, to record information gathered during this operation.

Complete the casting of the mixture in less than 70 minutes. This timed procedure starts when the first batch is poured into the vibrating component. The casting and vibrating procedure must be completed within 77 minutes from initial pour for each assembly.

Casting operations shall be performed as follows:

a. Weigh the top plug assembly clean and empty. Record the weight.

b. Fill the top plug assembly with potable water that has been filtered through a 20-micron filter and has a chlorine content of ≤ 4 ppm and weigh it. Record the weight.

c. Remove the water from the assembly as much as practical.

d. Place the assembly on the vibration table. Assure that the assembly is properly secured to the table. Set the vibration table dial indicator to approximately 120 lb-force at 450 vibrations per minute and start the vibration table. The top plug assembly must be vibrated continuously throughout the casting operation.

e. The mixture shall then be poured directly into the assembly after mixing through the fill hole provided.

f. Repeat the mixing operation in Section 3.2 and continue pouring until the mixture overflows the fill hole by ½ to ¾ inch.

g. Mist the top surface of the mixture with a bottle water sprayer if necessary to get the mixture into a solution after the pouring is completed. Do not add more than 4 ounces of water.

h. Vibrate the filled assembly for 5 to 10 minutes after the casting is completed.

### 3.3.4 Top Plug Assembly Curing Instructions

Curing operations shall be performed as follows:

a. Remove the top plug assembly from the vibration table and place it in the curing area. Let it rest uncovered for 2½ (±½) hours.

b. Weigh and record the Before Baking weight of the cast assembly. If the weight is outside of 29.2 to 34.2 lbs range it is recommended not to cure the casting but to clean out and recast the Kaolite. This Before Baking weight is a recommended process control for the finished baked density. The manufacture may continue with a part outside of this weight range but it has a high chance being rejected for not meeting the finished baked density.

c. After resting, scrape the excess Kaolite mixture from the fill opening until surfaces are a circular convex shape of .09±.06 before it is baked to match drawing M2E801580A008.

d. Weigh the cast assembly, and photograph the fill opening. Record the weight.

e. Cover the fill opening with plastic sheeting and let the assembly set undisturbed in the curing area for at least 24 hours.

## 3.4 Baking of Assemblies Cast and Cured with Kaolite 1600™ mixture

### 3.4.1 Baking Instructions

Several assemblies may be baked together during each furnace heating cycle. Once the furnace heating cycle has started, no additional assemblies may be inserted into the furnace. The furnace and temperature control requirements to perform the baking operation are as follows:

a. The furnace shall be a gas-fired or a forced convection fresh air circulating electric furnace.

b. The furnace heat zone shall be certified to ±25°F from the furnace set point temperature at each baking temperature process point.

c. Furnace time and temperature strip charts for each furnace heating cycle shall be provided with each completed Attachment D. Alternatively, an ASCII furnace time and temperature data file may be provided for each completed Attachment D.

### 3.4.2 Baking Documentation

Use Attachment D, *Furnace and Baking Control*, to record information gathered during this operation. An Attachment D identified by the Baking Control Number (BCN) shall be generated for each set of assemblies subjected to the furnace baking operations. Record the BCN from Attachment D for each assembly baked during this furnace heating cycle utilizing the proper assembly Casting Attachments B, C, and F. Qualified operators as indicated in Section 4.4 shall perform the baking of the cured assemblies. Movement of the cured assemblies before baking shall be minimized. The time and actual furnace exhaust air temperature shall be recorded at least every 15 minutes for baking control during a furnace heating cycle.

The baking furnace heating cycle shall be completed as follows:

a. Place the assemblies into the furnace.

b. Set the initial set point temperature to 200 (±10) °F.

c. Hold the temperature for 4 hours at a 200 (±10) °F steady state.

d. Increase the furnace set point temperature to 275 (±10) °F.

e. Hold the temperature for 1 hour at a 275 (±10) °F steady state.

f. Increase the furnace set point temperature to 350 (±10) °F.

g. Hold the temperature for 1 hour at a 350 (±10) °F steady state.

h. Increase the furnace set point temperature to 425 (±10) °F.

i. Hold the temperature for 1 hour at a 425 (±10) °F steady state.

j. Increase the furnace set point temperature to 500 (±10) °F.

k. Hold the temperature for 41 (±5) hours at a 500 (±10) °F steady state.

l. Remove assemblies and allow cooling in still air until they reach ambient temperature.

m. Weigh the assemblies after the baking process and record the weights upon the appropriate Attachment (Attachment B or C). Calculate the baked density of the cured mixture using the equation at the bottom of Attachment B or C and record.

EXEMPT FROM 10-155

Acceptance criteria:

An acceptable baking process is defined as the process in which the density of the baked mixture in an assembly is within the acceptance range of 22.4 ±3 lb/ft$^3$ as defined on Attachments B or C. If the density is less than the allowable value, contact the Company for disposition. If the density is greater than the allowable level, then re-bake the assembly using Section 3.4.5.a through k, with the exception of the final hold time which shall be 5 (±0.5) hours. Remove assemblies and allow cooling in still air until they reach ambient temperature. Recalculate and record the density on the appropriate Attachment. If the density still is greater than the allowable level, contact the Company for disposition.

n. Photograph the surface of the baked mixture (digital images are preferred).

o. Following the acceptable baking process, weld the cover plate onto the assemblies in accordance with the appropriate engineering drawing within 24 hours.

p. Weigh the final assembly and record on the appropriate Attachment (Attachment B or C).

### 3.5 Mixer Qualification for Kaolite 1600™ Casting Placement

The mixer qualification process shall verify that the mixer speed and mix time are properly set to mix the Kaolite 1600™. The end result of the mixer qualification is the as-baked density of 22.4±1 lb/ft$^3$ in the Baked Mixer Qualification Samples. This baked density can be estimated by monitoring the wet density. The baked density is approximately 41% of the wet density; therefore, the Target Wet Density is 56.2 lb/ft$^3$ for an average baked density of 22.4±1 lb/ft$^3$. The longer the Kaolite 1600™ is mixed the denser it becomes. The mixer qualification process shall verify the mix time required at a fixed and repeatable speed. The operators shall use the mixer to determine a repeatable speed to operate the mixer for all of the tests. Record the speed setting and assure that the speed setting is repeatable. The mixer qualification tests are a two step process: first is a Wet Density Mixer Time Vibration Casting test used to determine the range of mix time versus wet density; second is the mixer Baked Density Qualification Sample Vibration Casting. It is recommended that a 4-gallon or larger metal pail be used for the testing like the 4-1/2 gallon Tin-Plated Steel Pail (McMaster-Carr 4243T16 or equivalent), 9" Top Dia, 19-3/8" Height.

#### 3.5.1 Wet Density Mixing Test

Use Attachment E, *Wet Density Mixer Time Vibration Casting*, to record information gathered during this operation.

Prepare the Kaolite 1600™ and water for mixing per section 3.2 except for the mix time. A digital stop watch shall be used to monitor the running mix time. The mix time shall vary per Form F from 1 to 15 minutes in 1 minute intervals. Use a quick release attachment to affix the two metal pails (at least 4 gallon) to the vibration table. Start the mixer and run it for one minute, start the vibration table and pour the Kaolite 1600™ into the two pails after filling let them vibrate for 2 minutes, stop the vibration table, scrape them flush, and remove the pails and weigh them. Record the weight, dump the Kaolite 1600™ back into the mixer and start the mixer for another minute and repeat the process.

Plot the wet mix density of the two pails versus the mix time in an Excel file. An Excel file generated by the Company can be provided for this task upon request. Curve fit the data

using a third order polynomial curve and show the equation. Plot the target density of 56.2 lb/ft$^3$ on a chart in Excel along with the wet mix density. Where the curves intersect the target density line is the mixer's target mix time. Consult the Company for verification of this data. Use the Company verified mix time for the Mixer Baked Density Qualification Castings in Section 3.5.2.

### 3.5.2 Mixer Baked Density Qualification Castings

Use Attachment F, *Baked Qualification Density Sample Vibration Casting*, to record information gathered during this operation.

Prepare the Kaolite 1600™ and water for mixing per section 3.2.1 except for the mix time. A digital stop watch shall be used to obtain the Company verified mix time. Start mixer and run it for the Company verified mix time. Start the vibration table and pour the Kaolite 1600™ into the two pails. After filling, let them vibrate for 5 to 7 minutes then stop the vibration table.

Remove the two pails from the vibration table. Place the filled two pails in the curing area, and let them sit uncovered for 2½ (±½) hours. After sitting 2½ (±½) hours, scrape the excess mixture from the fill opening until surfaces are flush. Cover the fill opening with plastic sheeting or a metal lid and let the assembly sit undisturbed in the curing area for at least 24 hours before weighing. Remove the two pails and weigh the cured qualification samples to an accuracy ±1 pounds. Record the as-cured and after-baking weights and follow the baking instructions in section 3.4.

## 4. Quality Assurance Requirements

### 4.1 General

4.1.1 The Seller shall have a quality assurance program that meets the applicable requirements of Title 10 CFR Part 71, Subpart H for packaging and transportation of radioactive material. The quality assurance plan shall be in accordance with the requirements identified in the ES-3100 procurement specification. The Seller shall submit an approved quality assurance program plan that describes the quality assurance policies and practices to be implemented in identifying, controlling and verifying quality of the Kaolite 1600™ processes (weighing, mixing, pouring, vibrating, curing, and baking).

4.1.2 The Seller shall submit a Manufacturing Plan as defined in procurement specification, and shall describe how the Seller will comply with the instructions in this specification. If subcontractors are utilized for any of the processing of the Kaolite 1600™, the Seller shall ensure that the requirements of this specification (including quality assurance requirements) are met by all suppliers and subcontractors. The subcontractor's procedures, approved by the Seller, shall be included in the procedures submitted to the Company for review and approval.

4.1.3 The Seller's quality assurance program plan shall include the requirements for the process controls for the operations, operator and witness' qualifications, and verification records. Operator qualification requirements are identified in Section 4.4.

4.1.4 The Seller shall generate the documentation necessary to show compliance with the approved quality assurance program plan. All records shall be identified based on the assembly serial numbers. The Seller shall maintain quality-related documentation in accordance with requirements in the procurement specification. The Company reserves the right to request any

such documentation and to witness all aspects of the fabrication process in accordance with this specification. The Seller shall ensure that the specified manufacturing and inspection records are generated and supplied to the Company as part of the certification package.

4.1.5 The Seller must ensure all operators are aware of and comply with the quality assurance requirements identified in this specification. The Seller must ensure all operators use and follow written procedures for the respective processes. The Seller shall ensure operators and witnesses are aware of the operational requirements for the common industrial equipment (material handling equipment, mixers, vibration tables, ovens/furnace) used for the processes.

**4.2 Material and Equipment Certification**

4.2.1 Material certification for the Kaolite 1600™ must be provided by the supplier as defined in Section 8.0 of the procurement specification. Bags of Kaolite 1600™ must be identified with the product name and unique lot number. The material certification will be incorporated into the quality assurance records of the certification package.

4.2.3 All weighting, mixing, casting, curing, and baking processes shall be controlled and performed by qualified personnel (see Section 4.4). Written procedures shall be utilized by the operator at each operation and shall identify process hold points where required by the Company.

4.2.4 All process equipment used for mixing, casting, and baking of the Kaolite 1600™ and water mixture must be the model type identified in this specification, and must be in good working condition. Equipment used for measurements must be certified to traceable NIST standards or similar agency. Variation from specified equipment (vibration table, mixer, and furnace) is not allowed without the written approval of the Company before implementation.

**4.3 Nonconformance Control**

4.3.1 The Seller shall have an approved procedure for the control of nonconformances, waivers, and deviation requests during the execution of this manufacturing specification.

4.3.2 Nonconforming components shall not be used unless it has been determined by analysis or assessment by the Company that the nonconformance does not impact the physical properties of the material.

4.2.3 The disposition of nonconforming components shall be documented. Any nonconforming component shall be clearly identified and all nonconformance reports shall be traceable to the actual component affected. Copies of all approved nonconformance reports, except for scrapped components shall be supplied by the Seller to the Company as part of the certification package.

**4.4 Operator and Witness Qualifications**

The Kaolite™ 1600 mixing and vibration casting qualification evaluations shall be sequential. Each operator must mix and cast at least one simulated drum. Mixing and casting operations shall be repeated as necessary to achieve fully cast mock drums. The simulated ES-3100 drums cast during qualification activities shall be baked according to procedure.

### 4.4.1 Kaolite 1600™ Mixing Process Qualifications

Each operator and witness performing Kaolite 1600™ mixing activities must be qualified to perform this activity. This qualification shall be documented. This qualification shall consist of the following:

a. Location and time.

b. Properly identifying a bag of Kaolite 1600™ the bag of material and associated certification data (such as lot numbers)

c. Inspection of the bag for observable damage (such as water damage)

d. Successfully weighing the bag of Kaolite 1600™ on an industrial scale

e. Successfully calculating the required amount of water to be mixed with the Kaolite 1600™ (1.65 pounds of water per pound of Kaolite 1600™)

f. Properly inspecting the mixing equipment for foreign materials (such as oil, grease, free liquids, trash, or evidence of non-Kaolite 1600™ material affixed to the inner surfaces.)

g. Successfully operating the mixing equipment while mixing a complete bag of Kaolite 1600™.

h. Successfully preparing a uniformly mixed batch of Kaolite 1600™. (Uniformly shall be defined as a thoroughly mixed material with no dry material and no free liquids remaining in the mixer.)

### 4.4.2 Kaolite 1600™ Vibration Casting Process Qualifications

Each operator and witness performing Kaolite 1600™ casting activities must be qualified by successfully performing a casting activity. This qualification shall consist of the following.

a. Properly inspecting the inner surfaces of an empty simulated ES-3100 drum body for residues (oil, grease, free liquids) and waste material. (A simulated ES-3100 drum body shall consist of a 55-gallon carbon steel open-head drum which has a 16-gallon carbon steel drum secured to the bottom center. The 16-gallon drum may be secured by tack welding or suitable fasteners. The lid of the 55-gallon drum must have an opening 15" in diameter through which the Kaolite 1600™ can be poured into the drum.)

b. Properly securing an empty simulated ES-3100 drum body to the vibration table.

c. Properly adjusting the vibration table controls to the specified values for drum assemblies.

d. Successfully transferring the Kaolite 1600™ from the mixer into the drum while the drum is vibrating.

### 4.4.3 Kaolite 1600™ Baking Process Qualifications

Each operator and witness performing Kaolite 1600™ baking operations shall review the procedure steps for calculating the as-baked density of the Kaolite 1600™ in the assemblies and perform a sample calculation.

EXEMPT FROM IO-155

| *Attachment A*<br><br>**EQUIPMENT SPECIFICATION**<br>**ES-3100 Shipping Package**<br>**Kaolite Mixing Control** | Specification Number<br>JS-YMN3-801580-A003-1 | | Revision<br>C |
|---|---|---|---|
| | Issue Date<br>11/24/03 | Revision Date<br>6/1/06 | |
| | Plant<br>Y-12 | Page<br>1 | of<br>1 |

| Caster's Company Name | | | Supplier's Company Name | | |
|---|---|---|---|---|---|
| Mixing Start Date | Time | Air Temp. °F | Thermal Ceramics Kaolite 1600™ Certificate of Conformance | | |
| Kaolite 1600™ Mixing and Vibration Casting Information | | | Comments | Operator | Witness |
| 50 lb. Bag ID Number | | | | | |
| Bag Wt. | | | | | |
| 1.65 × Bag Wt. | | | | | |
| Mixing Control Number (MCN) [a] | | | | | |
| Water Wt. ±0.5 lbs. (1.65 times Kaolite Bag Wt.) | | | | | |
| Mix Finish Time | | | | | |

[a] A 10-digit control number is recommended for the Mixing Control Number (MCN) consisting of the date and the time format using a 24-hour clock (i.e. 1021041515 is used for October 21, 2004 at 3:15 pm.)

EXEMPT FROM IO-155

| *Attachment B*<br><br>**EQUIPMENT SPECIFICATION**<br>**ES-3100 Shipping Package**<br>**Body Weldment** | Specification Number<br>JS-YMN3-801580-A003-2 | | Revision<br>C |
|---|---|---|---|
| | Issue Date<br>11/24/03 | Revision Date<br>6/1/06 | |
| | Plant<br>Y-12 | Page<br>1 | of<br>1 |

| Caster's Company Name | | | Seller's Company Name | | | |
|---|---|---|---|---|---|---|
| Part Serial Number | | | Body Weldment Drawing Number<br>M2E801580A002 | | | |
| Measured Weights<br>±0.5 lb | Casting Information<br>Weight | Date | Comments | | Operator | Witness |
| Clean and Empty | | | | | | |
| Filled with Water [a] | | | | | | |
| Before Baking [f] | | | | | | |
| After Baking Cycle 5 | | | | | | |
| After Baking Cycle 5A [d] | | | | | | |
| After Welding | | | | | | |
| Water Information | Water Weight<br>±0.5 lb | Water Temp. | Comments | | Operator | Witness |
| Water Conditions [a] | lb | °F | | | | |
| Casting Start Date | Air Temp. °F | Vibration Settings [b]<br>lbf / VPM | | | | |
| Operation | MCN [c] | Time | Comments | | Operator | Witness |
| Pour Start | | | | | | |
| Pour Start | | | | | | |
| Pour Start | | | | | | |
| Vibration Start | | | | | | |
| Vibration Stop | | | | | | |
| Baking Cycle 5 | Baking Control Num. [c] | Date | Time | Density [d] | Operator | Witness |
| Baking Cycle 5A [d] | Baking Control Num. [c] | Date | Time | Density [d] | Operator | Witness |

[a] Record the water weight and water temperature within 10 minutes from completion of the weighing process.

[b] Recommended Vibration settings are at 450 VPM and twice the total vibrated weight. The total vibrated weight is the finish cast part and fixtures weight, for a setting of approximately 800 pound-force.

[c] A 10-digit Baking Control Number shall be used to define the date and the time of baking using the format with a 24-hour clock (i.e. 1021041515 is used for October 21, 2004 at 3:15 pm.)

[d] Use the above weights to calculate the Density as shown below. If the density is greater, then 25.4 lb/ft$^3$ then proceed with the next Baking Cycle. If the density is less then 19.4 lb/ft$^3$ then contact the Company for disposition.

$$\text{Density} = \frac{(AfterBaking - CleanAndEmpty)}{(WithWater - CleanAndEmpty)} \times 62.3 \text{ lb/ft}^3 \quad @\ 70°\text{F}$$

[f] Recommend Before Baking weight is to be 330 to 386 lb range.

EXEMPT FROM IO-155

| *Attachment C*<br><br>**EQUIPMENT SPECIFICATION**<br>**ES-3100 Shipping Package**<br>**Top Plug Assembly Vibration Casting Control** | Specification Number<br>JS-YMN3-801580-A003-3 | | Revision<br>C |
|---|---|---|---|
| | Issue Date<br>11/24/03 | Revision Date<br>6/1/06 | |
| | Plant<br>Y-12 | Page<br>1 | of<br>1 |

| Caster's Company Name | | | Seller's Company Name | | | |
|---|---|---|---|---|---|---|
| Part Serial Number | | | Top Plug Assembly Drawing Number<br>M2E801580A008 | | | |
| Measured Weights ±0.5 lb | Casting Information | | Comments | | Operator | Witness |
| | Weight | Date | | | | |
| Clean and Empty | | | | | | |
| Filled with Water [a] | | | | | | |
| Before Baking [f] | | | | | | |
| After Baking Cycle 5 | | | | | | |
| After Baking Cycle 5A [d] | | | | | | |
| After Welding | | | | | | |
| Water Information | Water Weight ±0.5 lb | Water Temp. | Comments | | Operator | Witness |
| Water Conditions [a] | lb | °F | | | | |
| Casting Start Date | Air Temp. °F | Vibration Settings [b] lbf / VPM | | | | |
| Operation | MCN | Time | Comments | | Operator | Witness |
| Pour Start | | | | | | |
| Pour Start | | | | | | |
| Vibration Start | | | | | | |
| Vibration Stop | | | | | | |
| Baking Cycle 5 | Baking Control Num. [c] | Date | Time | Density [d] | Operator | Witness |
| Baking Cycle 5A [d] | Baking Control Num. [c] | Date | Time | Density [d] | Operator | Witness |

[a] Record the water weight and water temperature within 10 minutes from completion of the weighing process.

[b] Recommended Vibration settings are at 450 VPM and twice the total vibrated weight. The total vibrated weight is the finish cast part and fixtures weight, for a setting of approximately 120 pound-force.

[c] A 10-digit Baking Control Number shall be used to define the date and the time of baking using the format with a 24-hour clock (i.e. 1021041515 is used for October 21, 2004 at 3:15 pm.)

[d] Use the above weights to calculate the Density as shown below. If the density is greater than 25.4 lb/ft$^3$ then proceed with Baking Cycle 1A. If the density is, less then 19.4 lb/ft$^3$ then contact the Company for disposition.

$$\text{Density} = \frac{(AfterBaking - CleanAndEmpty)}{(WithWater - CleanAndEmpty)} \times 62.3 \text{ lb/ft}^3 \quad @\ 70°\text{F}$$

[f] Recommend Before Baking weight is to be 29.2 to 34.2 lb range.

EXEMPT FROM IO-155

| *Attachment D*<br><br>**EQUIPMENT SPECIFICATION**<br>**ES-3100 Shipping Package**<br>**Furnace and Baking Control** | Specification Number<br>JS-YMN3-801580-A003-4 | | Revision<br>C |
|---|---|---|---|
| | Issue Date<br>11/24/03 | Revision Date<br>6/1/06 | |
| | Plant<br>Y-12 | Page<br>1 | of<br>1 |

| Baking Company Name | | | | Seller's Company Name | | | |
|---|---|---|---|---|---|---|---|
| Baking Control Number [a] | | | | Furnace Serial Number | | | |
| Bake Start Date | | Air Temp. °F | | Computer Data File Name [b] | | | |
| Baking Process Control | Furnace Check or NA | Start Time | Start Date | Stop Time | Stop Date | Operator | Witness |
| Baking Cycle (1) 200°F for 4 hrs. | | | | | | | |
| Baking Cycle (2) 275°F for 1 hrs. | | | | | | | |
| Baking Cycle (3) 350°F for 1 hrs. | | | | | | | |
| Baking Cycle (4) 425°F for 1 hrs. | | | | | | | |
| Baking Cycle (5) 500°F for 36 to 46 hrs. [c] | | | | | | | |
| Baking Cycle (1A) 200°F for 4 hrs. | | | | | | | |
| Baking Cycle (2A) 275°F for 1 hrs. | | | | | | | |
| Baking Cycle (3A) 350°F for 1 hrs. | | | | | | | |
| Baking Cycle (4A) 425°F for 1 hrs. | | | | | | | |
| Baking Cycle (5A) 500°F for 4.5 to 5.5 hrs. [c] | | | | | | | |

[a] Record the Baking Control Number in MMDDYYTIME (with time the 24 hour format i.e. 1021041515 is used for October 21, 2004 at 3:15 pm.) on Casting Forms B, C, and F for each part baked under this furnace heating cycle.

[b] The sample baking cycle time and temperature data could be presented both in a digital and graphical form. For example, an Excel file showing the original data and time verses temperature plots shall be acceptable.

[c] Calculate the density as shown on Forms B or C following this furnace heating cycle phase. If the part density is greater than 25.4 lb/ft$^3$, then proceed with the remaining furnace phases.

EXEMPT FROM IO-155

| *Attachment E* | Specification Number JS-YMN3-801580-A003-5 | | Revision C |
|---|---|---|---|
| **EQUIPMENT SPECIFICATION**<br>**ES-3100 Shipping Package**<br>**Wet Density Mixer Time Vibration Casting** | Issue Date 11/24/03 | Revision Date 6/1/06 | |
| | Plant Y-12 | Page 1 | of 1 |

| Caster's Company Name | | | Seller's Company Name | | |
|---|---|---|---|---|---|
| Mixer Make and Model | | | | | |
| Wet Mix Density Qualification Number [a] | | | Mix Control Number [a] | | |
| Measured Weights ±0.5 lb | Casting Information | | Comments | Operator | Witness |
| | Weight [c, b] (lb) | Date | | | |
| Clean and Empty | | | | | |
| Filled with Water [b] | | | | | |
| Water Information | Water Weight [c, b] ±0.5 lb | Water Temp. | Comments | Operator | Witness |
| Water Conditions | | °F | | | |
| Casting Start Date | Air Temp. °F | Vibration Settings [c] lbf / VPM | Mixer Speed Setting | | |
| Operation | Weight [c, b] (lb) | Time (min) | Wet Density [d] (lb/ft$^3$) | Operator | Witness |
| Wet Cast [c] | | 1.0 | | | |
| Wet Cast [c] | | 2.0 | | | |
| Wet Cast [c] | | 3.0 | | | |
| Wet Cast [c] | | 4.0 | | | |
| Wet Cast [c] | | 5.0 | | | |
| Wet Cast [c] | | 6.0 | | | |
| Wet Cast [c] | | 7.0 | | | |
| Wet Cast [c] | | 8.0 | | | |
| Wet Cast [c] | | 9.0 | | | |
| Wet Cast [c] | | 10.0 | | | |
| Wet Cast [c] | | 11.0 | | | |
| Wet Cast [c] | | 12.0 | | | |
| Wet Cast [c] | | 13.0 | | | |
| Wet Cast [c] | | 14.0 | | | |
| Wet Cast [c] | | 15.0 | | | |
| Curve fit the Time required to generate the target density and contact the Company for confirmation. | | | Target Density 56.2 lb/ft$^3$ | | |

[a] Record the Wet Mix Density Qualification Number **and the** Mix Control Number in MMDDYYTIME (with time the 24 hour format i.e. 1021041515 is used for October 21, 2004 at 3:15 pm.).

[b] Record water weight and water temperature within 10 minutes from completion of the weighing process.

[c] Use both steel pails to calculate the weights and density.

[d] Recommended Vibration settings are at 450 VPM and twice the total vibrated weight. The total vibrated weight is the finish cast part and fixtures weight, for a setting of approximately 120 pound-force.

[e] Use the above weights to calculate the Wet Density as shown below.

$$\text{Wet Density} = \frac{(WetCast - CleanAndEmpty)}{(WithWater - CleanAndEmpty)} \times 62.3 \text{ lb/ft}^3 \quad @\ 70°F$$

EXEMPT FROM IO-155

| *Attachment F*<br><br>**EQUIPMENT SPECIFICATION**<br>**ES-3100 Shipping Package**<br>**Baked Qualification Density Sample Vibration Casting** | Specification Number<br>JS-YMN3-801580-A003-6 | | Revision<br>C |
|---|---|---|---|
| | Issue Date<br>11/24/03 | Revision Date<br>6/1/06 | |
| | Plant<br>Y-12 | Page<br>1 | of<br>1 |

| Caster's Company Name | | | Seller's Company Name | | | |
|---|---|---|---|---|---|---|
| Mixer Make and Model | | | | | | |
| Baked Qualification Density Number [a] | | | Mix Control Number [a] | | | |
| Measured Weights ±0.5 lb | Casting Information<br>Weight ±0.5 lb | Date | Comments | | Operator | Witness |
| Clean and Empty | | | | | | |
| Filled with Water [c] | | | | | | |
| Before Baking | | | | | | |
| After Baking Cycle 5 | | | | | | |
| Water Information | Water Weight ±0.5 lb | Water Temp. | Comments | | Operator | Witness |
| Water Conditions [c] | | °F | | | | |
| Casting Start Date | Air Temp. °F / Vibration Settings [b] lbf | VPM | | | | |
| Operation | MCN | Time | Comments | | Operator | Witness |
| Pour Start | | | | | | |
| Vibration Start | | | | | | |
| Vibration Stop | | | | | | |
| Baking Cycle 5 | Baking Control Num. | Date | Time | Density [d] | Operator | Witness |

[a] Record the Baked Qualification Density Number **and the** Mix Control Number in MMDDYYTIME (with time the 24 hour format i.e. 1021041515 is used for October 21, 2004 at 3:15 pm.).

[b] Recommended Vibration settings are at 450 VPM and twice the total vibrated weight. The total vibrated weight is the finish cast part and fixtures weight, for a setting of approximately 120 pound-force.

[c] Record water weight and water temperature within 10 minutes from completion of the weighing process

[d] Use the above weights to calculate the Qualification Sample Density as shown below. If the density is greater then 23.4 lb/ft$^3$ or less then 21.4 lb/ft$^3$ contact the Company for disposition.

$$\text{Qualification Density} = \frac{(AfterBaking - CleanAndEmpty)}{(WithWater - CleanAndEmpty)} \times 62.3 \text{ lb/ft}^3 \quad @\ 70°\text{F}$$

EXEMPT FROM IO-155

## Appendix 1.3.5

**Equipment Specification JS-YMN3-801580-A005,**
***Casting Catalog No. 277-4 Neutron Absorber for the ES-3100 Shipping Package***

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# EQUIPMENT SPECIFICATION APPROVAL/REVISION PAGE

| SPECIFICATION NO. | REV. | ISSUE DATE |
|---|---|---|
| JS-YMN3-801580-A005 | G | 02-18-05 |
| PAGE | REVISION DATE | |
| i of ii | 08/31/2009 | |
| PROCURED BY | INSTALLED BY | |
| BWXT Y-12 L.L.C. | B&W Y-12 L.L.C. | |

| PROJECT TITLE | PLANT | BUILDING |
|---|---|---|
| ES-3100 Shipping Package | Y-12 | AREA |
| JOB TITLE | W.O. OR E.S.O. | RECORD NUMBER |
| Production Design Definition | 7ADDEQ01 | Y2003-0328 |
| SPECIFICATION FOR | | SSC IDENTIFICATION NUMBER |
| Casting Catalog No. 277-4 Neutron Absorber For The ES-3100 Shipping Package | | NA |

**APPROVALS**

| SIGNATURE | DATE | SIGNATURE | DATE |
|---|---|---|---|
| PREPARED BY<br>G. A. Byington /s/ | 2/18/05 | PROJECT ENGINEER<br>G. A. Byington /s/ | 2/18/05 |
| DESIGN VERIFICATION<br>M. L. Goins /s/ | 2/18/05 | CRITICALITY SAFETY<br>D. A. T. J. F. DeClue /s/ | 2/18/05 |
| DISCIPLINE MANAGER<br>D. P. Sooter /s/ | 11 Feb 05 | | |

**REVISIONS/APPROVALS**

| REV. NO. | DESCRIPTION OF REVISION |
|---|---|
| A | Issued for Procurement. |
| B | Changed the minimum LOD from 25.3% to 30.1% at three locations on page 13 section 4.7.3 and one location on page 23 Form D. |
| C | General changes. Went from an off the shelf item to a two part system of boron carbide plus high alumina cement. |
| D | General revision. Reformatted sections and attachments. Deleted references to drawing numbers. |
| E | The mass limits were changed to account for volume tolerances in the 277-4 annulus. Section 3.3.8, Item l, "inner liner" was replaced with "can". A.3.1 was separated into two sections; the second part of A.3.1 became A.3.1.a with the title "Net Count Rate Time Determination". Section A.6.3 was modified by adding "Define the repeatable accuracy for" before the first sentence. JS-YMN3-801580-A005-5 was expanded to include more approval data requirements. A typo was fixed on JS-YMN3-801580-A005-6. Added Rev level to Forms and headers. |
| F | In Section 3.3.9.3, added maximum and minimum LOD% table based upon cured density and made reference to table on Form F. |
| G | Shieldwerx, supplier of 277-0 was Thermo Electron Corporation. Added Figures 9, 10, & 11 to represent design and procurement changes made to the ES-3100 Heavy Spacer Can Assembly, see drawing M2E801580A043 Rev. 0 for supplementary details. Added additional reference to M2E801580A043. |

| SIGNATURE | DATE | SIGNATURE | DATE |
|---|---|---|---|
| PREPARED BY<br>Michael Ensley /s/ | 09/10/09 | PROJECT ENGINEER<br>Larry Roberson /s/ | 09/10/09 |
| DESIGN VERIFICATION<br>Drew Winder /s/ | 09/10/09 | CRITICALITY SAFETY<br>John DeClue /s/ | 09/10/09 |
| DISCIPLINE MANAGER<br>Walter North /s/ | 09/10/09 | | |

This document has been reviewed by a Y-12 DC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.

Name: Roger D. Aigner /s/ Date: 09/10/09

EXEMPT FROM IO-155 (8-02)

## CONTENTS


1.0 Scope ..... 1

2.0 Applicable Documents ..... 7

3.0 Requirements ..... 8

4.0 Quality Assurance ..... 14

5.0 Preparation For Delivery ..... 15

6.0 Manufacturer's Data ..... 17


## ATTACHMENTS


Appendix A Prompt Gamma-ray Neutron Activation Analysis Testing Setup & Tooling ..... 16

FORM A 277-4 Dry Blend Batch Control

FORM B 277-4 Wet Mix Control (Overcast or Special Batch)

FORM C ES-3100 Body Weldment Casting Control

FORM D ES-3100 Neutron Absorber Form Casting Control

FORM E ES-3100 Heavy Can Spacer Assembly Casting Control

FORM F ES-3100 Companion Sample Casting Control and Tests

FORM AA PGNAA Tooling Setup Control

FORM AB PGNAA Standard Setup

FORM AC PGNAA Daily Standard Setup Control

FORM AD PGNAA Measurements

Offer Apprasial Data - Subcontractor, JS-YMN3-801580-A005-1

Approval Data - Subcontractor, JS-YMN3-801580-A005-2

Certified Data - Subcontractor, JS-YMN3-801580-A005-3

Offer Apprasial Data - PGNAA Subcontractor, JS-YMN3-801580-A005-4

Approval Data - PGNAA Subcontractor, JS-YMN3-801580-A005-5

Certified Data - PGNAA Subcontractor, JS-YMN3-801580-A005-6

1.0 Scope

1.1 This specification describes the requirements for the procurement, preparation, casting, and verification of a neutron absorber material into the ES−3100 shipping package. The neutron absorber material shall be cast into ES−3100 Body Weldment (Figure 1), Neutron Absorber Form (Figures 4 and 5), Heavy Can Spacer Assembly (Figure 6 and 9), and 10 oz. double friction can (Figures 7, 8, 10 and 11) with tooling, i.e., Neutron Absorber Casting Funnel Assembly (Figure 2), and Body Weldment and Casting Funnel Assembly (Figure 3).

1.2 Definitions

**277-0** - Shieldwerx Catalog No. SWX-277-0 or equivalent, Heat Resistant Shielding "Non-Borated" high alumina cement.

**277-4** - A mixture of 277-0 and boron carbide ($B_4C$) powder to form a neutron absorber material.

**Companion Sample Cans** - The 10 oz. double friction cans in Figures 7 and 8 or 10 oz. crimp style cans in Figures 10 and 11 used for sampling.

**Company** – B&W Y-12 L.L.C.

**Dry Batch** - A dry mix of batch size of 277-4.

**Dry Blend Batch** - A thoroughly mixed Dry Batch.

**Heavy Can Spacer Assembly** - The 10 oz. double friction can in Figure 6 or 10 oz. crimp style can in Figure 9.

**Overcast** – Additional cast material required to achieve the fill requirements.

**PGNAA Subcontractor** – Independent testing firm that performs the Prompt Gamma-ray Neutron Analysis on the companion sample cans for the Company.

**Process Procedures** - Dry mixing, wet mixing, casting, sampling, and inspection procedures.

**Subcontractor** - The manufacturer of the ES-3100 Drum Assembly per JS-YMN3-801580-A001.

**Vibration Casting** – Vibration during casting to remove the air bubbles.

**Wet Mix Batch** - A wet mix of Dry Blend Batch and water.

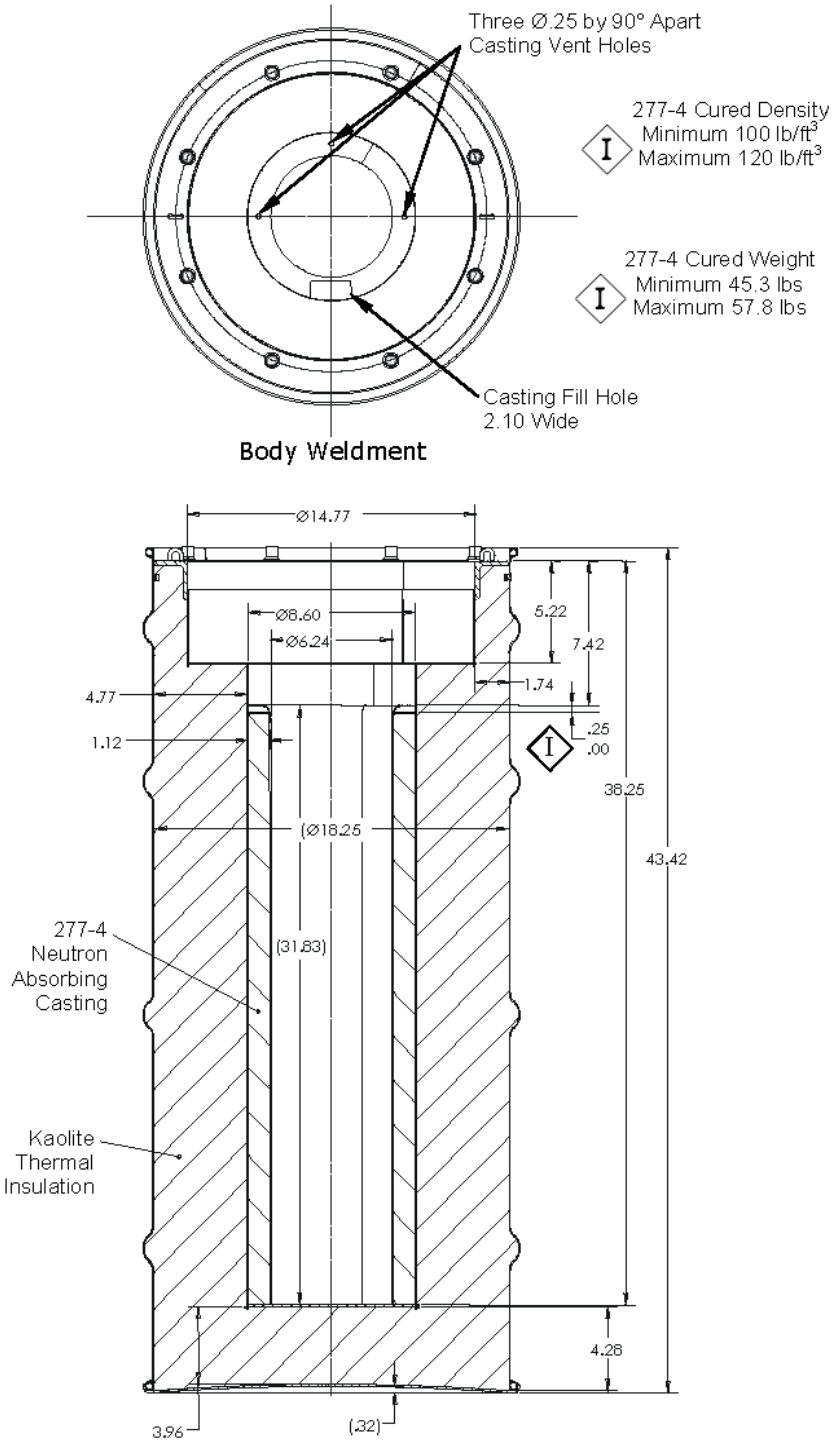
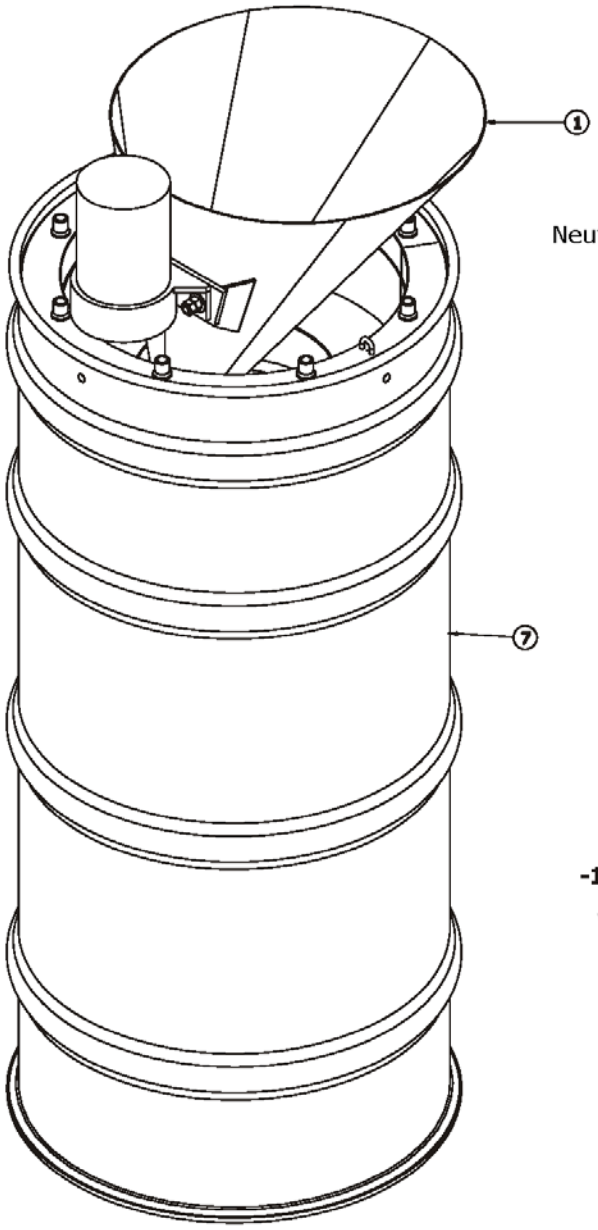


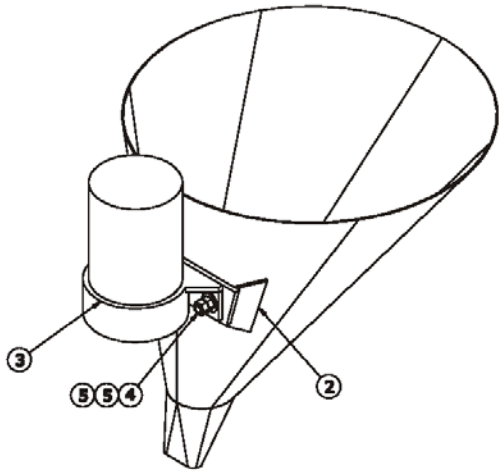

Figure 1 ES-3100 Neutron Absorbing Casting




**-6 BODY WELDMENT AND CASTING FUNNEL ASSEMBLY**

Figure 3

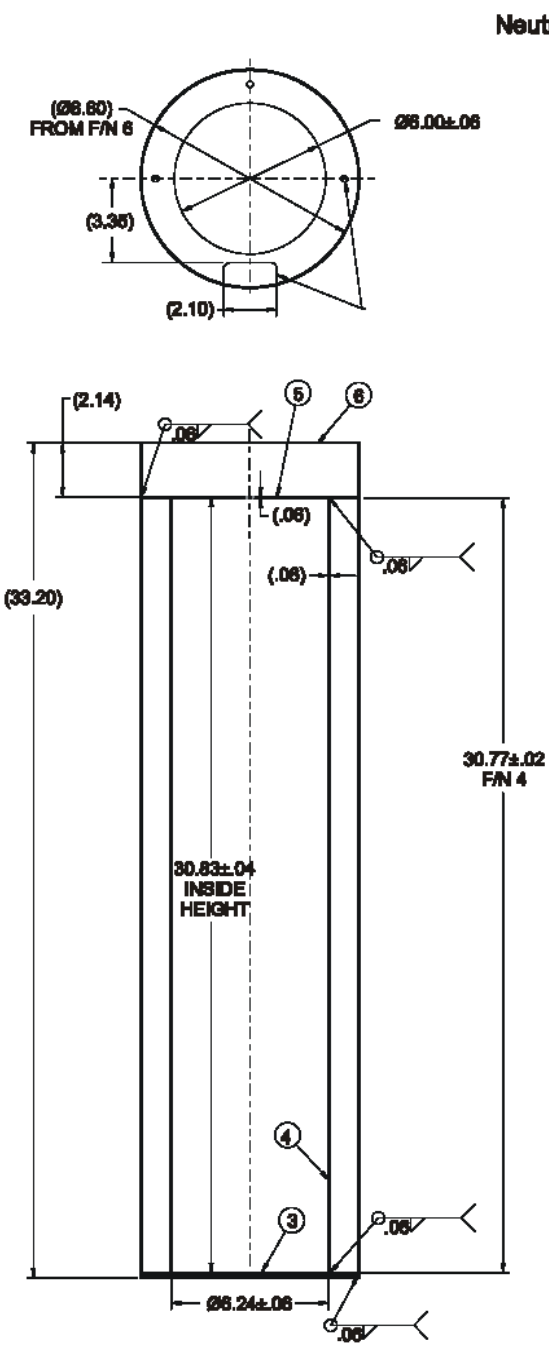
Neutron Absorber Casting Funnel Assembly




**-1 NEUTRON ABSORBER CASTING FUNNEL ASSEMBLY**

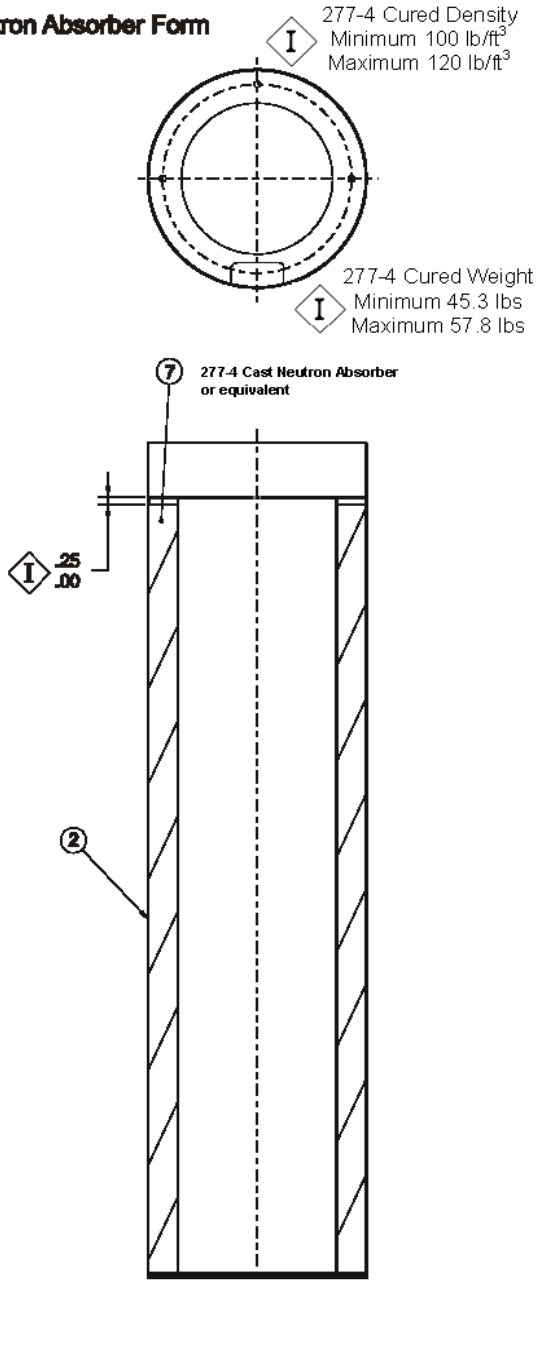
VIBRATOR POWERED CASTING FUNNEL

Figure 2




**-2 NEUTRON ABSORBER FORM WELDMENT**

Figure 4




**-1 NEUTRON ABSORBER FORM ASSEMBLY**

Figure 5



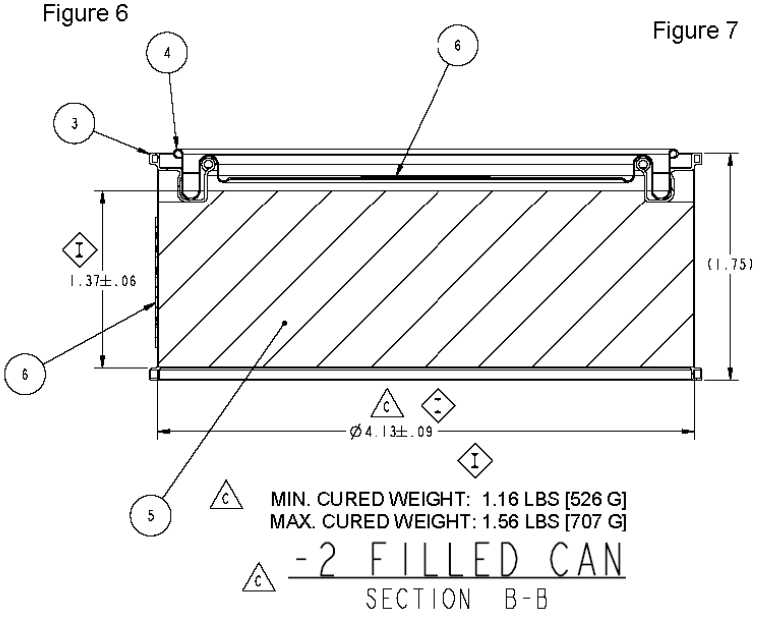

HEAVY CAN SPACER ASSEMBLY

Figure 6




10oz DOUBLE FRICTION CAN
FILLED WITH 277-4

Figure 7




10oz DOUBLE FRICTION CAN
FILLED WITH 277-4

Figure 8



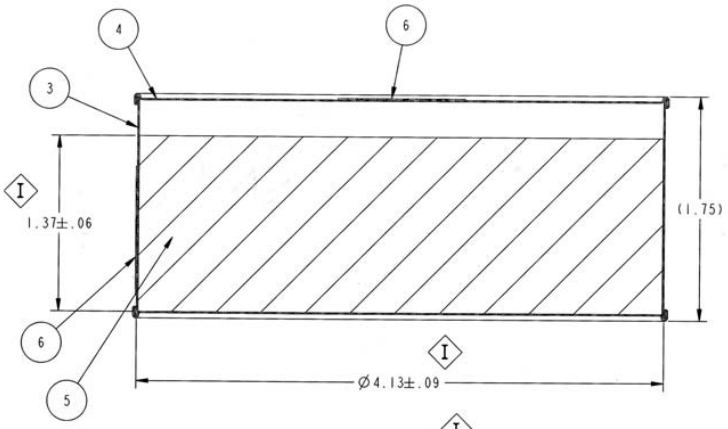

HEAVY CAN SPACER ASSEMBLY

Figure 9




10oz CRIMP STYLE CAN
FILLED WITH 277-4

Figure 10




-2 FILLED CAN
SCALE 2/1

10oz CRIMP STYLE CAN
FILLED WITH 277-4

Figure 11

EXEMPT FROM IO-155 (8-02)

2.0 Applicable Documents

2.1 The following documents are a part of this specification. When there is a conflict between the specification and the applicable documents, the Subcontractor shall bring it to the attention of the Company for resolution.

2.2 Standards

| | |
|---|---|
| ASTM A 380-99 | *Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment and Systems* |
| ASTM C 750-03 | *Specification for Nuclear-Grade Boron Carbide Powder* |
| ASTM C 791-04 | *Test Methods for Chemical, Mass Spectrometric, and Spectrochemical Analysis of Nuclear-Grade Boron Carbide* |
| ASTM E 11-04 | *Standard Specification for Wire Cloth and Sieves for Testing Purposes* |
| 10 CFR 71 Subpart H | *Code of Federal Regulations - Energy - Packaging and Transportation of Radioactive Material - Quality Assurance* |

2.3 Company Documents

| | |
|---|---|
| JS-YMN3-801580-A002 | *ES-3100 Drum Assembly* |
| JS-YMN3-801580-A003 | *Manufacturing Process Specification for Casting Kaolite ™ Into the ES-3100 Shipping Package* |
| M2E801580A026 and M2E801580A043 | *Heavy Can Spacer Assemblies* |

2.4 Referenced Documents (Not Provided with Request for Proposal)

| | |
|---|---|
| DAC-PKG-801624-A001 | *Mixing Weights And Elemental Composition of 277-4 Neutron Poison used in the ES-3100* |
| Ltr. No. COR-NDA-04-93 | Canberra Oak Ridge, LLC, January 5, 2005, *Results of Prompt Gamma-ray Neutron Activation Analysis and Neutron Transmission Measurements on Prototype Confinement Vessel Inner Liners and Spacers.* |
| Ltr. No.: COR-NDA-05-015 | Canberra Oak Ridge, LLC November 3, 2005, *Results of Prompt Gamma-ray Neutron Activation Analysis On 20 Slip Fit Spacer Cans.* |

3.0 Requirements

3.1 General Requirements

The Subcontractor shall be responsible for supplying all materials, services, facilities, and equipment to meet the requirements of this specification unless otherwise noted. Items needed to meet the requirements of this specification that are not identified in this specification shall be specified by the Subcontractor and submitted as Approval Data.

3.2 Equipment Requirements

3.2.1 Certified Scales

All weighing operations of assemblies and materials shall be conducted on certified scales with a minimum accuracy of ±1% of the required measurement or as specified by the measurement tolerance. Scale certification shall be submitted as Approval Data.

3.2.2 Dry Blending the 277-0 and $B_4C$

A small parts tumbler shall be used to dry blend the ingredients. The small parts tumbler shall be a Multi-Barrel Small Parts Tumbler Benchtop Base (McMaster-Carr No. 44235A11) with Multi-Barrel Small Parts Tumbler 8 Gallon Barrel, 15-3/4" Dia X 14-3/4" W (McMaster-Carr No. 44235A24) or Company approved equal.

3.2.3 Mortar or Plaster Mixer

A mortar or plaster type mixer with moving vanes to shear the wet mix shall be used. The batch volume is approximately 0.5 $ft^3$ (15 quarts or 3.8 gallons). Therefore, it is recommended that the mixer volume should be 1.5 to 2 times the mix volume or around 0.75 to 1.0 $ft^3$ (22.5 to 30 quarts, ~6 to 8 gallons). The 277-4 wet mix is thixotropic when mixed and it is recommended that a heavy duty adjustable vibrator mounted to the mixer for both mixing and pouring is used.

3.2.4 Small Plaster Mixer

A drill-powered mortar or plaster mixer and a 5-gallon plastic bucket may be used on small batches of 277-4 instead of the mortar or plaster type mixer. The 5-gallon plastic bucket shall be placed upon the Heavy Duty Drum Vibrator (see Section 3.2.6).

3.2.5 Vibration Powered Funnel Assembly

The Neutron Absorber Casting Funnel Assembly with a vibration- powered funnel (Figures 2 and 3) shall fill both the Body Weldment (Figure 1) and the Neutron Absorber Form (Figure 4). The Casting Funnel Assembly may be modified as required by the Subcontractor to get the wet mix to flow.

3.2.6 Heavy Duty Drum Vibrator

A Heavy Duty Drum Vibrator/Packer shall be used to hold the Body Weldment (Figure 1) or Neutron Absorber Form (Figure 4) for vibration casting the 277-4 into the stainless steel forms. The Heavy Duty Drum Vibrator/Packer shall be McMaster-Carr No. 5809K11, or Company approved equal.

3.2.7 Bench Vibrator

A bench vibrator shall be used during the mixing of the companion sample cans and Heavy Spacer Can Assemblies. The bench vibrator shall be Tabletop Vibration/Mixing Table 10-in. by 7-in. Platform, 10-lb Capacity Continuous Use (McMaster-Carr No. 5714K61) or Company approved equal.

3.3 277-4 Neutron Absorber

3.3.1 Raw Casting Material Requirements and Inspection

3.3.1.1 277-0

Shieldwerx Catalog No. SWX-277-0 Heat Resistant Shielding "Non-Borated" shall be procured. The manufacturer model or catalog number and expiration date shall be clearly indicated on the container. A Certificate of Conformance shall be provided with each lot or batch. The Certificate of Conformance shall include the lot or batch number and the expiration date. The 277-0 shall be sealed and stored in a dry place.

3.3.1.2 Type 1 Nuclear-Grade Boron Carbide Powder

$B_4C$ powder shall be procured as Type 1 Nuclear-Grade Boron Carbide Powder per ASTM C 750. 100% of the powder shall pass through a No. 140 Sieve per ASTM E 11. A Certificate of Conformance and a copy of the chemical and elemental analysis purity in accordance with ASTM C 791 shall be provided.

3.3.1.3 Water

The water shall be potable, filtered through a 20-micron filter and an activated charcoal filter, have a chlorine content of less than 4 ppm, and have a temperature of 65±15°F. Unfiltered potable water may be used for the cleaning of equipment used to cast the neutron absorber system.

3.3.2 Dry Blending Process

3.3.2.1 Dry Batch

A dry batch of 277-4 shall be a mixture of 93.6 wt% 277-0 and 6.4 wt% $B_4C$. It shall be of sufficient quantity to fill one ES-3100 Body Weldment or Neutron Absorber Form, i.e., approximately 0.55 $ft^3$ poured volume and 50 lbs. of dry 277-4 weight. The batch size may be adjusted as necessary based on experience for the ES-3100 Body Weldment or Neutron Absorber Form. The tolerance for 277-0 and $B_4C$ weighting shall be the following:

| 277-4 Dry Batch Size | 277-0 | $B_4C$ |
|---|---|---|
| Equal to or greater than 30 lbs. | ±.2 lbs. | ±.01 lbs. |
| Less than 30 lbs | ±.01 lbs. | ±.01 lbs. |

The data shall be recorded on Form A.

3.3.2.2 Blended Dry Batch

The dry batch of 277-4 shall be thoroughly blended. The data shall be recorded on Form A.

If the blended dry batch is not used immediately, the blended dry batch shall be sealed and stored in a dry place with a Blended Dry Batch control number attached to the container.

The Blended Dry Batch shall not be used if the 277-0 expiration date has expired.

3.3.3 Wet Mixing

The weight of the dry mix and water shall be to the following weight proportions of 100% dry mix and 27±1% water. The 277-4 is thixotropic when mixed. It is recommended to have a heavy duty adjustable vibrator mounted to the mixer for both mixing and pouring. Place the water in the mixer and add the dry mix into the water. Before casting, mix the dry powder and water for at least 3 minutes and less than 60 minutes. Any material in the mixer after 60 minutes shall be discarded. Mix only in a room with a temperature range of 70±25°F.

The data shall be recorded on the appropriate form, i.e., Form B for overcast, Form C for Body Weldment, Form D for Neutron Absorber Form, and Form E for Heavy Can Spacer Assembly/PGNAA Acceptance Standards.

3.3.4 Body Weldment and Neutron Absorber Form Vibration Casting

3.3.4.1 Vibration Casting Requirements for Body Weldment and Neutron Absorber Form

During the vibration casting of the 277-4, record the Body Weldment (Figure 1) casting data on Form C and the Neutron Absorber Form (Figure 5) casting data on Form D. A stainless steel vibration powered funnel (i.e., Neutron Absorber Funnel Assembly shown in Figure 3) fits inside the 2.10-in. wide slotted fill hole shown in Body Weldment and in Neutron Absorber Form.

a. Weigh and record the data on Form C or on Form D.
b. Weigh and record the water weight and temperature data when filled with water to within .25 in. of the top metal surface.
c. Remove the water.
d. Secure the part on the drum vibrator.
e. Plug the 6.24 in. diameter cavity to keep the wet mix from falling into the liner bottom.
f. Place the Neutron Absorber Funnel Assembly in the slot and secure in place. If required, additional vibrators may be added.
g. Prepare the Wet Mix per Section 3.3.3.
h. Start the drum vibrator.
i. Scoop the wet mix into the Neutron Absorber Funnel Assembly.
j. Turn on the vibrating funnel and adjust the vibration force until the wet mix flows.
k. About half way through filling the wet mix in either the Body Weldment or Neutron Absorber Form, cast two companion samples for Section 3.3.7. Record the companion sample data on Form F and either Form C or Form D.
l. Continue filling the wet mix until the part will take no more.
m. After filling is complete, vibrate the container for 45±15 seconds to remove air bubbles.

3.3.4.2 Overcast Requirements for Body Weldment and Neutron Absorber Form

A few hours after casting, the 277-4 will settle in the vertical direction and leave a layer of watery fluid on the top of the casting. Remove this fluid and overcast the top between 4 and 24 hours from the first casting. After the overcast has cured for between 4 and 24 hours inspect the depth of casting to the top metal surface and verify that it is within 0.25 in. If not within the 0.25 in., cast additional 277-4 material and perform the following:

a. Remove the water.
b. Secure the Body Weldment or Neutron Absorber Form on the drum vibrator.
c. Plug the 6.24 in. diameter cavity to keep the wet mix from falling into the liner bottom.
d. Record the Overcast Wet Mix Control Number (WMCN) on the appropriate casting data form.
e. Prepare the Wet Mix per Section 3.3.3.
f. Start the drum vibrator.
g. Scoop the wet mix into the Body Weldment or Neutron Absorber Form Assembly until the vent hole is filled.

The final shrinkage of the 277-4 shall be within 0.25 in. of the metal surface as shown in Figures 1 and 5.

3.3.4.3 Curing Requirements Body Weldment and Neutron Absorber Form

Cover the newly cast wet component with plastic or metal for 7 days. Do not store the cast 277-4 castings in temperatures below 35°F for the first 30 days after casting.

After 7 days, remove the plastic or metal cover and dehydrated using either or both vacuum and heat to create an acceptable density and weight. If heat is used, the maximum temperature of the inner liner shall not exceed 250°F.

Record the diamond I measurements shown on Figures 1 and 5 on the appropriate casting data forms. The acceptable cured height measurement shall be less than 0.25 inches. The acceptable cured casting weight shall be between 45.3 and 57.8 lbs. Cured casting weights shall be used to calculate the cured density. If the cured casting density is greater than 120 $lb/ft^3$, continue the dehydration process. If the cured casting density is less than 100 $lb/ft^3$, the casting shall be unacceptable, the appropriate form shall be completed, and a copy of the form shall be sent to the Company.

3.3.5 Heavy Can Spacer Assembly

The Heavy Can Spacer Assembly shown in Figure 6 or 9 shall be the 10-oz. double friction metal can as shown in Figures 7 and 8, or 10-oz. crimp style metal can as shown in Figures 10 and 11. The cured casting weight for each can shall be measured and the cured casting density recorded on Form E. A cured cast density of 100 to 120 $lb/ft^3$ and a cured weight range of 1.16 to 1.56 lbs shall be acceptable. If the cured casting density is outside the acceptable range, a copy of the form shall be sent to the Company.

Two cans from the middle of the lot on Form E, i.e., a maximum lot of 22 cans, shall be selected and identified as companion sample cans. Cans that are not from the middle of the lot on Form may be selected with Company approval.

3.3.6 PGNAA Acceptance Standards

The PGNAA Acceptance Standards shall be made with a Company representative witnessing the manufacturing processes of weighing, blending, wet mixing, and casting. The PGNAA Acceptance Standards shall be the 10-oz. double friction metal can as shown in Figures 7 and 8, or 10-oz. crimp style metal cans as shown in Figures 10 and 11. The cured casting weight for each can shall be measured and the cured casting density recorded on Form E. A cured casting density of 100 to 120 $lb/ft^3$ and a cured casting weight of 1.16 to 1.56 lbs shall be acceptable. If the cured casting density is outside the acceptable range, a copy of the form shall be sent to the Company.

One can from the middle of the lot on Form E, i.e., a maximum lot of 22 cans, shall be selected and identified as a companion sample can for Loss On Drying (LOD) testing. The remainder of the lot shall be sent to the PGNAA Subcontractor.

3.3.7 Companion Sample Cans

In addition to the companion sample cans selected in Sections 3.3.5 and 3.3.6, two companion sample cans shall be made half way through the casting process for the Body Weldment and the Neutron Absorber Form per Section 3.3.4.1. Companion sample can data shall be recorded on Test Form F.

a. The cured casting density of all companion sample cans shall be calculated per Section 3.3.9.2 and recorded on Form F. If the cured casting density is outside the acceptable range, a copy of the form shall be sent to the Company. A low cured casting density of a companion sample can shall not be a reason to reject the Body Weldment, Neutron Absorber Form, Heavy Can Spacer Assembly casting lot, or PGNAA Acceptance Standards casting lot.
b. The odd serial number companion sample cans for the Body Weldment, Neutron Absorber Form, Heavy Can Spacer Assembly casting lot, or PGNAA Acceptance Standards casting lot shall be LOD tested to verify the hydrogen content per Section 3.3.9.3.
c. The even serial number companion sample cans for the Body Weldment, Neutron Absorber Form, or Heavy Can Spacer Assembly casting lot shall be PGNAA tested to verify the $^{10}B$ content per Section 3.3.9.4.

3.3.8 Casting the 10 oz. Double Friction Metal Cans or 10 oz. Crimp Style Cans

a. Select a labeled can which has a drawing and serial number per drawings M2E801580A026 or M2E801580A043.
b. Weigh the empty labeled can and lid and record the casting can data on Forms C, D, or E. It is acceptable to weigh ten cans with ten lids for each purchase order of cans and to use the average can and lid weight on each form.
c. Weigh the water and measure the water temperature. Record this data on Form C, D, or E. Fill with water only up to the bottom of the inside rim. The can lid shall be on the scale. It is acceptable to weigh the water weight of the first ten cans with ten lids of the same lot of cans and to use the average water weight for each of the following cans if the measurements are consistent.
d. Remove the water from the cans.
e. Prepare the Wet Mix Batch following Section 3.3.3.
f. Hold the can on the bench vibrator during filling with the 277-4 wet mix. Quickly vibrate and continue to add wet mix to the can lip.
g. Once all of the cans are full of wet mix, return the first can back to the vibrator for at least 3 minute at a high frequency setting. During the 3 minutes of vibration, continue to add 277-4 wet mix until the can stays full. Repeat this process for all the cans in the casting lot.
h. Between 1 to 24 hours after casting, scrape the top of the casting to meet 1.37±0.06 dimension from bottom of can noted on Figures 8 and 11.

EXEMPT FROM IO-155 (8-02)

i. Clean the can rim around the edge per Section 3.4.2.
j. Perform an in-process measurement of the scraped casting height to ensure that the casting height parameters are met shown in Figures 8 and 11.
k. Cover the casting by placing the properly labeled can lid on the can for 7 days.
l. Remove the can lid and let the can air dry or use either or both vacuum and heat to create an acceptable density and weight. If heat is used, the maximum temperature of the can shall not exceed 250°F.
m. Measure casting height and weigh the can with lid. Record this data on Forms C, D, or E.
n. Record the final Companion Sample Can casting density, weight, or casting height measurements data on Form F.
o. Crimp lid onto crimp style can, as applicable.

3.3.9 Verification

All verification shall be completed after the casting is cured.

3.3.9.1 Cured Casting Density Verification

The density of cured casting in the Body Weldment, Neutron Absorber Form, Heavy Can Spacer Assembly, and PGNAA Acceptance Standards shall be determined by weighing the casting container before casting, while filled with water, after casting, and when cured.

Since the density of water is known, a simple relationship between the weight differences shall determine the cured casting density.

$$Density = \left( \frac{Cured - Empty}{WithWater - Empty} \right) \times 62.3 \text{ lb/ft}^3$$

3.3.9.2 Companion Sample Can Cured Casting Density Verification

The density of cured casting in each companion sample can shall be determined by weighing the can before casting, while filled with water, after casting, and when cured.

Since the density of water is known, a simple relationship between the weight differences shall determine the cured casting density.

$$Density = \left( \frac{Cured - Empty}{WithWater - Empty} \right) \times 62.3 \text{ lb/ft}^3$$

3.3.9.3 Companion Sample LOD Verification

The companion sample cans identified in Section 3.3.7.b shall be LOD tested. The acceptable LOD percent range shall be based upon the companion sample can cured casting density in Section 3.3.9.2. The Acceptable Maximum and Minimum LOD% at Density is in this table developed from data in DAC-PKG-801624-A001 Table 7, 277-4 Composition @ Extreme Densities and LOD% and compared to the average values as manufactured.

| Acceptable Maximum and Minimum LOD% at Density | | |
|---|---|---|
| Density ($lb/ft^3$) | Maximum LOD% | Minimum LOD% |
| 100 | 31.80% | 28.61% |
| 101 | 32.47% | 28.33% |
| 102 | 33.12% | 28.06% |
| 103 | 33.77% | 27.79% |
| 104 | 34.40% | 27.52% |
| 105 | 35.03% | 27.26% |
| 106 | 35.64% | 27.00% |
| 107 | 36.25% | 26.75% |
| 108 | 36.84% | 26.50% |
| 109 | 37.42% | 26.25% |
| 110 | 37.99% | 26.01% |
| 111 | 38.56% | 25.78% |
| 112 | 39.11% | 25.55% |
| 113 | 39.65% | 25.32% |
| 114 | 40.18% | 25.10% |
| 115 | 40.70% | 24.88% |
| 116 | 41.21% | 24.66% |
| 117 | 41.71% | 24.45% |
| 118 | 42.20% | 24.25% |
| 119 | 42.68% | 24.05% |
| 120 | 43.15% | 23.85% |

a. The lid shall have the serial number permanently transferred by vibro etch or other method.
b. The lid shall have a small vent hole in it. It is recommended that a nail be used to punch a hole 0.12±0.06 in. diameter in the metal lid from the inside surface of the lid.
c. Match the can serial numbers and place the lid on the can.
d. The weight of the can shall be recorded on Form F.
e. The cans shall be placed in an oven at 1500±150°F (800°C) for 4 hours.
f. The weight of the can shall be recorded on Form F with the can temperature not below 100°F.
g. Calculate the LOD% using the equation below and record it on Form F. Due to can oxidizing and gaining weight during the heating cycle, a 0.024 lb correction factor is included in the following LOD% calculation.

$$\text{LOD\%} = \left[1 - \frac{(LODWeight - Empty - 0.024lb)}{(Cured\ \&\ Clean - Empty)}\right] \times 100\%$$

h. Verify that the LOD% is within the acceptable range. If water content is outside the acceptable range, a copy of the form shall be sent to the Company.

3.3.9.4 PGNAA Verification

The companion sample cans identified testing in Section 3.3.7.c shall be sent to the PGNAA Subcontractor. The PGNAA Subcontractor will test to the requirements in Appendix A and record the data on Forms AA to AD. The PGNAA Subcontractor will send copies of the completed Forms AC and AD to the Subcontractor and Company.

The PGNAA testing acceptance results on From AD shall be transferred to Form F.

3.4 Cleaning Requirements

3.4.1 Contact with Chlorides or Fluorides

The stainless steel material shall be protected from contact with chlorides in accordance with ASTM A380, paragraph 8.5, during all operations including packaging. The Material Safety Data Sheet (MSDS) for all cleaning solutions or products used on the ES-3100 shall be submitted as Approval Data to verify that no chlorides or fluorides are present.

3.4.2 Satisfactory Cleanliness

Cleaning procedures for the stainless steel per Section 3.4 of equipment specification JS-YMN3-801580-A002 shall be submitted as Approval Data. Only non-chloride-bearing chemicals shall be used for cleaning (e.g., trisodium phosphate detergent or acetone). Water used in cleaning shall have a maximum chlorine content of 4 parts per million.

After casting but prior to packaging, stainless steel components of the forms and cans shall be cleaned per the approved cleaning procedures. Satisfactory cleanliness shall be determined by visual inspection as can be observed by a person with normal visual acuity (natural or corrected) and without magnification. Light intensity of at least 100 ft-candles shall be provided on the surface to be inspected.

4.0 Quality Assurance

4.1 Quality Assurance Program

The subcontractors shall have in place and maintain a Quality Assurance (QA) Program and inspection system that meets the requirements of 10 CFR 71 Subpart H. If not previously submitted, an uncontrolled copy of the subcontractor's QA Program shall be submitted as Offer Appraisal Data.

4.2 ES−3100 Casting Quality Assurance Requirements

4.2.1 ES−3100 Documentation Package

All records shall be identified based on the ES−3100 serial numbers. The ES-3100 Documentation Package shall be provided as Certified Data with each ES-3100 casting. The ES-3100 Documentation Package shall be complete, legible, indexed, and traceable to the material supplied and include the following:

a. Material measuring, dry blending, wet mixing, casting, sampling, and inspection forms, i.e, Forms A through F.
b. A Certificate of Compliance for each lot of the 277-0 Heat Resistant Shielding "Non-Borated" dry mix documentation with the expiration date identified on each container.

c. A Certificate of Compliances for $B_4C$ powder to Type 1 Nuclear-Grade Boron Carbide Powder per ASTM C 750, chemical and elemental analysis per ASTM C 791, and 100% of the powder passes through a No. 140 Sieve per ASTM E 11.

d. A Certificate of Compliance signed by an officer of the Subcontractor confirming that the cast neutron absorber in ES−3100 shipping package meets the subcontract requirements.

4.2.2 Batch Processes

Batch processes such as mixing, pouring, curing, sampling, inspection, etc., shall be performed in accordance with detailed written procedures. These procedures shall specifically describe the exact manner in which these processes are to be performed. All records shall be traceable to the ES−3100 Shipping Package, Neutron Absorber Form, Heavy Spacer Can Assembly, PGNAA Acceptance Stands or Companion can serial numbers.

4.2.3 Materials Traceability

A manufacturing lot or batch number shall identify material furnished to make up the neutron absorber system. Materials shall be identified by material type; applicable specification and revision number, and be traceable to their lot numbers. Traceability records shall be available for review by the Company's representative.

4.2.4 Procedures

Preparation, installation, sample collection, and inspection processes shall be controlled and performed by qualified personnel. The procedures must incorporate a mechanism to identify process step completion. Procedures shall be submitted as Approval Data. The approved procedures shall be provided as Certified Data prior to the start of casting.

4.2.5 Training and Qualification of Personnel

The Subcontractor shall provide for the training and qualification of personnel to ensure their competence in the use of process procedures and specifications. Records of personnel qualifications shall be made available to the Company upon request. Only those personnel who have been qualified to perform a specific batch process used in the casting of Kaolite per equipment specification JS-YMN3-801580-A003 shall be used to perform work in this process.

4.2.6 The Company reserves the right to request any documentation and to witness any of the processes performed in accordance with this specification.

## 5.0 Preparation for Delivery

After cleaning of stainless steel surfaces per Section 3.4, aluminum foil duct tape shall be applied over the fill and vent holes in the Body Weldment (Figure 1) and the Neutron Absorber Form (Figure 5).

6.0 Manufacturer's Data

6.1 Offer Appraisal Data shall be submitted with the offer. This data shall become part of the subcontract requirements.

6.2 Approval Data will be reviewed and approved by the Company. Subcontractor shall not proceed with the casting activity until Company approval is given for all the Approval Data. The Approval Data shall be transmitted to the Company by the dates agreed to by the Subcontractor and the Company Subcontractor Administrator.

6.3 Certified Data will be used by the Company as the record for the ES-3100 shipping packages. The Certified Data shall be transmitted as noted.

6.4 A request for Company approved equal shall be submitted as Approval Data. Adequate information shall be provided with the request for Company approved equal so that the Company can determine if the item is equivalent.

ATTACHMENT A -
**Prompt Gamma-ray Neutron Activation Analysis Testing Setup & Tooling**
**(Page 1 of 4)**

**A.1 Prompt Gamma-ray Neutron Activation Analysis Can Testing**

Prompt Gamma-ray Neutron Activation Analysis (PGNAA) of boron performs one of the acceptances of the ES-3100 277-4 casting. Specifically, $^{10}B$ gives rise to a 478-keV gamma-ray produced by the recoil of the lithium nucleus from the neutrons captured in $^{10}B$. The gamma-ray is Doppler broadened by 10–15 keV. The PGNAA shall be performed upon a companion sample can cast made during the drum casting in accordance with JS-YMN3-801580-A005 and Body Weldment (Figure 1), Neutron Absorber Form (Figure 5), Heavy Can Spacer Assembly (Figure 6 or 9), and the cast companion samples in the same 10-oz. double friction metal can on (Figures 7 and 8), or 10-oz. crimp style metal cans as shown in (Figures 10 and 11). PGNAA is a relative measurement therefore daily baselines are required to define the acceptance values.

Canberra Industries to perform the PGNAA testing.

Canberra Industries, Inc.
Linda C. Ostrowski
1133-C Oak Ridge Turnpike Suite 260
Oak Ridge, TN 37830-6442
865-241-3963 fax 865-241-3965

**A.2 PGNAA Quality Assurances**

The equipment and software used in the PGNAA shall be certified to a national standard.

**A.3 PGNAA Measurements Setup**

A PGNAA measurement setup number shall be required for each unique setup recording the pertinent data of the setup on Form AA. A new setup is required from previous prototypical work. Several setups may be tried to determine the most efficient testing setup. These changes shall be documented using Form AA. Once the setup is defined on Form AA reference the setup number each time it is used. Measure the PGNAA acceptance standards using the defined setup to verify the setup distances are repeatable within ±0.13-in.

**A.3.1 Net Count Rate Measurements**

Time shall be consistently applied throughout all of the PGNAA testing. For the prototype system setup, a time of at least 15 minutes (900 seconds) for each spectrum measurement was found to be satisfactory. A net count rate (NCR) in counts per second shall be used throughout with a set target standard time limit of around 900 seconds. Record both the count and time in seconds for that count on Form AA and calculate the count rate to three decimal places (i.e., 34.245 counts/sec).

**A.3.1.a Net Count Rate Time Determination**

The time of the measurement shall be determined by performing the Tooling Setup on Form AA at different times like 300, 600, 900, 1800, and 72000 seconds. Determine the accuracy effect of the total counting time on the counting statistics, based upon at least a 72000 seconds (20 hour) count. The testing time shall be re-evaluated when a significant change in the source system occurs.

**A.3.2 Neutron Source**

A spontaneous fission neutron source similar to the 1.8-μg $^{252}Cf$ prototype shall be used to perform the tests. This source was rated at $4.4\times10^6$ neutrons/sec on November 15, 2004. The neutron source is sealed in a 32.5-mm-long, 9.4-mm-diameter stainless steel cylinder and placed in a collimator.

ATTACHMENT A
**(Page 2 of 4)**

**A.3.3 Collimator and Neutron Source Setup**

A collimator similar to the prototype collimator shall be used to hold the source. The prototype collimator was a 3-in. cube of high-density polyethylene covered on five sides with 2 mm of cadmium as a neutron shield with at least 0.5-in. of lead on six sides as a gamma shield. The center of the sixth side of the polyethylene cube has a 9.5-mm hole into which the source was pressed. The sixth side is covered with cadmium except for a 1-in. square in the center. A 1-in. diameter hole in the cadmium at the source location shall be provided in the collimator to generate a better shaped neutron source for the sample can tests. The location of the collimator and source shall be defined in a fixture and shall be inspected to be repeatable to within ±0.13-in. to locate the collimator, can, detector, and other materials, e.g., polyethylene.

Record the setup and the results in the net detector count rate on Form AA. Record the setup source distance (SD) ±0.13-in. from the sample can lid. Move the filled sample can further away from the source, and repeat the process, increasing the distance in increments to identify the setup distance that maximizes the NCR for that source arrangement. Record the setup information on Form AA.

**A.3.4 Detector**

A detector system similar to the prototype shall be used. The prototype was a Canberra Model BE3825 Broad Energy Germanium (BEGe) detector, which was a gamma-ray detector, in a 2-in. thick lead shield with a Canberra Model 7935SL-7 cryostat and Canberra Model 2002CSL preamplifier to capture the gamma spectrum for the PGNAA measurements. This detector has a side lead shield but no shielding in the front to collimate the field-of-view. An Inspector 2000 along with the Genie2K gamma-ray analysis software package from Canberra was used for distinguishing the $^{10}B$ peak from the rest of the gamma-ray spectrum. It is recommended that a fixture be made to locate the collimator, can, and detector. Document the method used to determine the Compton boundary end points.

**A.3.5 Detector Net Count Rate Determination**

Use software equivalent to the Genie2K gamma-ray analysis software package from Canberra for performing the gamma-ray spectrum collection and analysis. The peak fitting routine in Genie2K does not expect a peak as broad as 10–15 keV; therefore, a region-of-interest (ROI) was set around the broad boron neutron activation peak of 478 keV. The data gathered has three components. The gross count is the total count of the gamma-rays detected with an energy that falls within the ROI. The Compton background is the portion of the gross count that is caused by scattered gamma-rays. The NCR is the portion of the total count that is from the boron in a period of time. The NCR is the difference between the gross and the Compton counts.

**A.3.6 Detector Location Setup**

The setup distance of the prototype detector setup was as close as possible using about 1-in. thick lead as a gamma shield to keep the detector noise signal low. This thickness was applied during the PGNAA documented in Ltr. No.: COR-NDA-05-015; Canberra Oak Ridge, LLC November 3, 2005, *Results of Prompt Gamma-ray Neutron Activation Analysis On 20 Slip Fit Spacer Cans*. Figure A.1 shows the direction this development work was heading. Document and verify that the detector setup distance (DD) from the sample can generates a maximum NCR by adjusting the detector setup distance and repeating this test. It is recommended that a fixture be made to locate the collimator, can, and detector.

**ATTACHMENT A**
**(Page 3 of 4)**

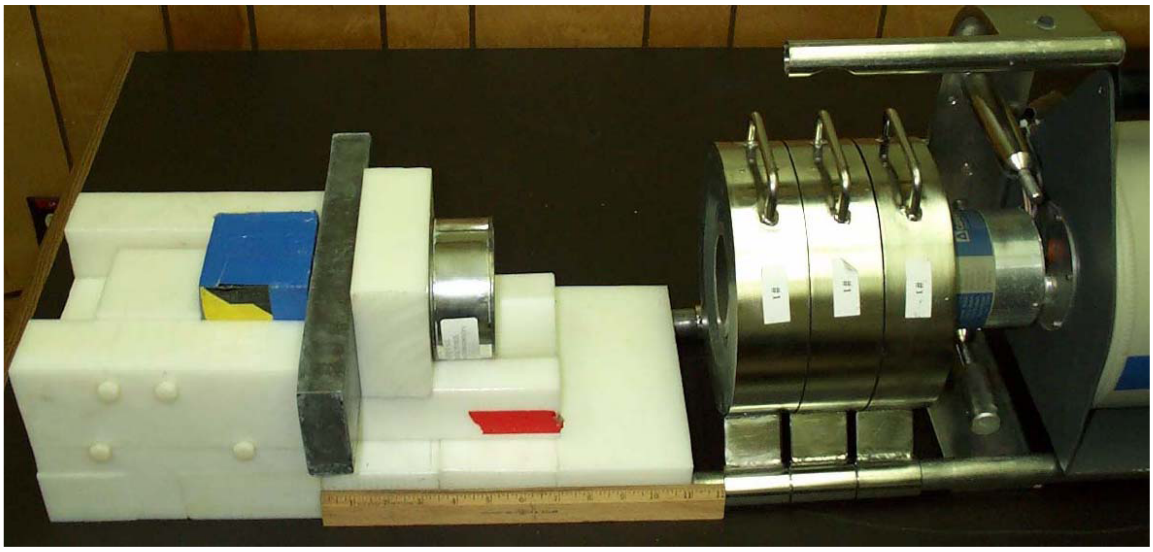


Figure A.1 Preliminary Tooling Generated for PGNAA

**A.3.7 Detector Operation Setup**

Set the detector setup distance (DD) ±0.13-in. and the setup source distance (SD) ±0.13-in. from the filled sample can. Record the set detector setup distance, setup source distance, 277-4 sample serial number, NCR value, and the day and time of the measurement in the setup form. Repeat this final test measurement in 30 minutes to verify the stability of the detector and this shall become the setup standard test measurement on Form AA. The repeatable measurement tolerances shall be part of the testing fixture certification inspection.

**A.3.8 Net Count Rate Baseline Measurements**

Once the setup is completed and the fixture dimensions are certified, Form AB shall be used to record the NCR for the twenty acceptance standards using the 10-oz. double friction metal cans or 10 oz. crimp style cans. The baseline acceptance 277-4 NCR shall be set daily using five of the twenty acceptance standards using the 10-oz. double friction metal cans or 10 oz. crimp style cans and recorded on Form AC. The twenty acceptance standards cans shall be inspected with a Company representative as a witness.

Select five PGNAA acceptance standards from Form AB as the Daily Standard Setup that generate approximately the same average and standard deviation as on Form AB. The baseline acceptance 277-4 NCR shall be set daily using five of the twenty acceptance standards using the 10-oz. double friction metal cans or 10 oz. crimp style cans and recorded on Form AC. Verify the Daily Standard cans selection with the Company. The Body Weldment (Drum), Neutron Absorber Form (From), and Heavy Can Spacer Assembly (Lot) acceptance criteria for the $^{10}B$ interaction is based upon this test. The Minimum acceptable standard NCR shall be set daily using the following formula.

Minimum Acceptable NCR = Can Five NCR Average − 3 × Standard Deviation Can Five NCR

ATTACHMENT A
**(Page 4 of 4)**

**A.4 Net Count Rate Acceptance Measurements**

The NCR acceptance measurement shall be made following the Daily Standard Setup using Form AC and calculating a Pass Rate. Record the PGNAA setup number, day and start time of the measurement, the associated Body Weldment, Neutron Absorber Form, Heavy Can Spacer Assembly Lot's serial number, companion sample can serial number, actual net count, acceptable net count, and testing results on the inspection form. For the testing results, if the actual NCR is equal or above the Pass Rate, then record a PASS; if less than, enter FAIL in the test Form AD. It is acceptable to group the test results for several sample cans on one form following one testing setup.

Once a 277-4 sample can NCR failure has occurred verify that the setup has not shifted by rerunning the Daily Standard Setup using Form AC and calculate a new Pass Rate. If the Pass Rate has changed more then 1% than perform a new detector operation setup and NCR baseline measurements and verify the test failure rate by retesting the failed can. If the companion sample can receives two failures in a row, the associated parts shall be rejected from service, the Company Subcontract Administrator notified, and the testing continued.

**A.5 Documentation of the Acceptance or Rejection Measurements**

Documentation of the acceptance or rejection NCR measurements shall be made with the Forms AA through AD plus a detailed description of the active NCR measurement hardware and software that was used.

**A.6 Results**

**A.6.1 Equipment and Software Quality Assurances**

The national standard used in the PGNAA (see Section A.2) shall be provided as Certified Data.

**A.6.2 Certified Tooling Setup and Repeatable Dimensions**

The final tooling setup shall be manufactured and certified that the placement of the source, detector, sample can, and tooling materials are dimensional stable and repeatable to ±0.13-in.

**A.6.3 Measurement Time and Repeatable Accuracy**

Define the repeatable accuracy for the Nate Rate Count time selection for the production certification inspections. The Nate Rate Count time justification (see Section A.3.1.a) shall be submitted as Approval Data.

**A.6.4 Measurement Software and Methodology**

For the final setup the measurement software and methodology method used to generate the net counts (see Section A.3.4) shall be documented and provided as Certified Data.

**A.6.5 Forms AA through AD**

Forms AA, AB, and AC shall be submitted as Approval Data.

After the process is approved, filled-in Forms AC and AD shall be provided as Certified Data to the Company and the casting company.

**A.6.6 Can Disposition**

After PGNAA testing is completed on a lot of companion sample can lot, the cans shall be returned to the Company. The PGNAA Acceptance Standards cans shall be stored for the life of the subcontract.

EXEMPT FROM IO-155 (8-02)

**FORM A 277-4 Dry Blend Batch Control Rev G Page 1 of 1**

| | | | |
|---|---|---|---|
| Casting Company Name | Certificate of Conformance of the 277-0 dry mix | | |
| Blended Dry Batch Control Number [a] | Record the expiration date of the 277-0 dry mix [b] | | |
| Certificate of Conformance of the $B_4C$ dry mix | 277-0 Heat Resistant Shielding Drum ID Number | | |
| Planning | 277-4 Weight | Units | Operator |
| Batch Size | | lb | |
| Operation | Measurement | Units | Operator |
| 277-0 Weight (Target = 277-4 Weight x 93.6 wt%) | | lb | |
| $B_4C$ Weight (Target = 277-4 Weight x 6.4 wt%) | | lb | |
| Dry Blending Time | | min. | |
| Comments | | | |

[a] A 10-digit Blended Dry Batch Control Number shall be used to define the date and the time of mixing the casting batch using the format with a 24-hour clock (i.e. 1021041515 is used for October 21, 2004 at 3:15 pm.)

[b] Record the expiration date of the Blended Dry Batch and confirm that it is still acceptable to be cast following this specification.

EXEMPT FROM O-155 (8-02)

**FORM B 277-4 Wet Mix Control (Overcast or Special Batch) Rev G Page 1 of 1**

| Casting Company Name | | Blended Dry Batch Control Number | | |
|---|---|---|---|---|
| Wet Mix Control Number (WMCN) [a] | | Record the expiration date of the Dry Blend Batch | | |
| Water Temperature °F | Air Temperature °F | Measurement | Units | Operator |
| 277-4 Weight | | | lb | |
| Water Weight (Target = 277-4 Weight × 27±1 wt%) | | | lb | |
| Mix Time | | | min. | |
| Mix Finish Time | | | min. | |
| Comments | | | | |

[a] A 10-digit Wet Mix Control Number (WMCN) shall be used to define the date and the time of mixing the casting batch using the format with a 24-hour clock (i.e. 1021041515 is used for October 21, 2004 at 3:15 pm.)

EXEMPT FROM O-155 (8-02)

**FORM C ES-3100 Body Weldment Casting Control** **Rev G Page 1 of 1**

| Casting Company Name | | | Body Weldment Casting Control # [a] | | |
|---|---|---|---|---|---|
| Part Serial Number | | | Drawing Number M2E801580A002 | | |
| Measured Weights ±0.5 lb | Casting Information Weight | Date | Comments | | Operator |
| Clean and Empty | | | | | |
| Filled with Water [b] | | | | | |
| Water Information | Water Weight ±0.5 lb | Water Temp. [b] | Comments | | Operator |
| Water Conditions [b] | lb | °F | | | |
| Vibration Settings [c] | lbf | VPM | | | |
| Wet Mix Control | Blended Dry Batch Control No. | | Dry Blend Batch Expiration Date | | |
| (Target Water = 277-4 Weight × 27±1 wt%) | 277-4 Weight | lb | Water Weight | lb | |
| | Air Temperature | °F | Water Temperature | °F | |
| | Mix Time | | Mix Finish Time | | |
| Companion Samples [d] | −1 | | −2 | | |
| | Time | Date | Comments | | Operator |
| Vibration Start | | | | | |
| Vibration Stop | | | | | |
| Overcast WMCN | | | | | |
| After Casting | lb | Date | | | |
| After Cured and Clean | lb | Date | | | |

| Measurements (I) | Height [e] (in) | Pass or Fail Height | Cured Weight (lb) | Pass or Fail Cured Weight [e] | Cured Density [f] (lb/ft$^3$) | Pass or Fail 100−120 (lb/ft$^3$) |
|---|---|---|---|---|---|---|
| Body Weldment | | | | | | |

[a] A 10-digit Body Weldment Casting Control Number shall be used to define the date and the time of mixing the casting batch using the format with a 24-hour clock (i.e., 1021041515 is used for October 21, 2004 at 3:15 pm).

[b] Record the water weight and water temperature within 10 minutes from completion of the weighing process.

[c] Recommended vibration settings are at 450 VPM and three times the total vibrated weight. The total vibrated weight is the finish cast part and fixtures weight, for a setting of approximately 800 pound-force.

[d] Use Form F, for ES-3100 Companion Sample Casting Control and Tests to control the companion sample castings.

[e] The acceptable cured height measurement is less than 0.25 inches. The Body Weldment cured casting weight shall be between 45.3 and 57.8 lbs.

[f] Use the above weights to calculate the density as shown below. $Density = \left( \frac{Cured - Empty}{WithWater - Empty} \right) \times 62.3 \text{ lb/ft}^3$

EXEMPT FROM IO-155 (8-02)

**FORM D ES-3100 Neutron Absorber Form Casting Control Rev G Page 1 of 1**

| Casting Company Name | Body Weldment Casting Control # [a] |
|---|---|
| Part Serial Number | Drawing Number M2E801580A034 |

| Measured Weights ±0.5 lb | Casting Information | | Comments | Operator |
|---|---|---|---|---|
| | Weight | Date | | |
| Clean and Empty | | | | |
| Filled with Water [b] | | | | |

| Water Information | Water Weight ±0.5 lb | Water Temp. [b] | Comments | Operator |
|---|---|---|---|---|
| Water Conditions [b] | lb | °F | | |
| Vibration Settings [c] | lbf | VPM | | |

| Wet Mix Control | Blended Dry Batch Control No. | | Dry Blend Batch Expiration Date | | |
|---|---|---|---|---|---|
| (Target Water = 277-4 Weight × 27±1 wt%) | 277-4 Weight | lb | Water Weight | lb | |
| | Air Temperature | °F | Water Temperature | °F | |
| | Mix Time | | Mix Finish Time | | |

| Companion Samples [d] | −1 | −2 |
|---|---|---|

| | Time | Date | Comments | Operator |
|---|---|---|---|---|
| Vibration Start | | | | |
| Vibration Stop | | | | |
| Overcast WMCN | | | | |
| After Casting | lb | Date | | |
| After Cured and Clean | lb | Date | | |

| Measurements ◇I | Height [e] (in) | Pass or Fail Height | Cured Weight (lb) | Pass or Fail Cured Weight [e] | Cured Density [f] (lb/ft$^3$) | Pass or Fail 100−120 (lb/ft$^3$) |
|---|---|---|---|---|---|---|
| Neutron Absorber Form | | | | | | |

[a] A 10-digit Body Weldment Casting Control Number shall be used to define the date and the time of mixing the casting batch using the format with a 24-hour clock (i.e., 1021041515 is used for October 21, 2004 at 3:15 pm).

[b] Record the water weight and water temperature within 10 minutes from completion of the weighing process.

[c] Recommended vibration settings are at 450 VPM and three times the total vibrated weight. The total vibrated weight is the finish cast part and fixtures weight, for a setting of approximately 800 pound-force.

[d] Use Form F, for ES-3100 Companion Sample Casting Control and Tests to control the companion sample castings.

[e] The acceptable cured height measurement is less than 0.25 inches. The Neutron Absorber Form cured casting weight shall be between 45.3 and 57.8 lbs.

[f] Use the above weights to calculate the density as shown below. $Density = \left( \frac{Cured - Empty}{With Water - Empty} \right) \times 62.3 \text{ lb/ft}^3$

EXEMPT FROM IO-155 (8-02)

**FORM E ES-3100 Heavy Can Spacer Assembly Lot Casting Control Rev G Page 1 of 1**

| Casting Company Name | Can Lot Serial Number [a] | Drawing Number M2E801580A026 or M2E801580A043 |
|---|---|---|
| Average 10 Can and Lid **Empty** Weight | Temperature of Water Weight (°F) | Average 10 Can and Lid **Water** Weight |

| Wet Mix Control | Blended Dry Batch Control No. | | Dry Blend Batch Expiration Date | |
|---|---|---|---|---|
| (Target Water = 277-4 Weight × 27±1 wt%) | 277-4 Weight | lb | Water Weight | lb |
| | Air Temperature | °F | Water Temperature | °F |
| | Mix Time | | Mix Finish Time | |

Wet Mix Control Number (Overcast), if required

| Can Serial # | After Casting Weight (lb) | Cured Weight (lb) | Pass or Fail Cured Weight [b] | Cured Height (in) | Pass or Fail Cured Height [b] | Cured Density (lb/ft$^3$) | Pass or Fail Cured Density [c] |
|---|---|---|---|---|---|---|---|
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| | | | | | | | |
| Companion Samples [d] | | −1 | | | −2 | | |

| Operator | Comments |
|---|---|
| | |

[a] A 10-digit Can Lot Serial Number shall be used to define the date and the time of setup using the format with a 24-hour clock (i.e., 1021041515 is used for October 21, 2004 at 3:15 pm).

[b] Heavy Can Spacer Assembly acceptable weight is 1.16 to 1.56 lbs and height 1.37±0.06 as shown in Figure 8.

[c] Use this equation for the; $Density = \left( \frac{Cured - Empty}{WithWater - Empty} \right) \times 62.3$ lb/ft$^3$. Acceptable 100 to 120(lb/ft$^3$).

[d] Use Form F, for ES-3100 Companion Sample Casting Control and Tests for Heavy Can Spacer Assembly companion samples..

EXEMPT FROM O-155 (8-02)

**FORM F ES-3100 Companion Sample Casting Control and Tests** **Rev G Page 1 of 1**

| Casting Company Name | | Ave. 10 Can and Lid Empty Weight [a] | | Ave. 10 Can and Lid Water Wgt. [a] | | Temp. of Water Weight (°F) | | Drawing Number M2E801580A026 or M2E801580A043 | |
|---|---|---|---|---|---|---|---|---|---|
| Serial Numbers | | Can Measurement Weights ±0.01 (lb) | | | For Record Only | Loss On Drying (Odd Serial Numbered Cans) | | PGNAA (Even Serial Numbered Cans) | |
| Part # or Can Lot# | Companion Sample Can [b] | After Casting Weight | Cured Weight | LOD Weight | Cured Density (lb/ft³) | Calculated LOD% | Pass Or Fail per Sec. 3.3.9.3 | PGNAA (PMN) [c] | Pass Or Fail |
| | | | | | | | | | |
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| Complied by | | | | | Comments | | | | |

a For the same lot of sample cans, it is acceptable to use an average weight of ten can bodies and ten can lids.

b Recommended vibration settings are at 450 VPM and three times the total vibrated weight. The total vibrated weight is the finish cast part and fixtures weight, for a setting of approximately 5 pound-force.

c Record the PGNAA Measurement Number (PMN) from Form AD for each Companion Sample Can tested.

$$Density = \left( \frac{Cured - Empty}{WithWater - Empty} \right) \times 62.3 \ lb/ft^3$$

$$LOD\% = \left[ 1 - \frac{(LODWeight - Empty - 0.024)}{(Cured\ \&\ Clean - Empty)} \right] \times 100\%$$

EXEMPT FROM 10 155 (§ 02)

**FORM AA PGNAA Tooling Setup Control** **Rev G Page 1 of 1**

| Inspecting Company Name | Casting Company Name |
|---|---|
| PGNAA Tooling Setup Number [a] | 277-4 Baseline Can Serial Number |

| Setup Distance [b] | | | Counts | | | Count Time (sec) | Net Count Rate (Net Counts/Sec) |
|---|---|---|---|---|---|---|---|
| # | Collimator | Detector | Gross | Compton | Net | | |
| | | | | | | | |
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Describe the source and the amount of cadmium, lead and polyethylene surrounding the source for each Setup Number.

Describe the Software used and method to generate the net counts.

Operator

[a] A 10-digit PGNAA Tooling Setup Number shall be used to define the date and the time of setup using the format with a 24-hour clock (i.e., 1021041515 is used for October 21, 2004 at 3:15 pm). A −# will define the setup used for testing.

[b] The 10-oz. double friction metal lid or crimp style can lid shall face the source. The setup distances shall be measured from the can lid to the collimator face and from the can lid to the detector front face and must be documented to be repeatable to ±0.13". Also define all thickness of lead and polyethylene surrounding the source measurement to ±0.13".

[c] Use one 277-4 cast 10-oz. double friction metal can per drawing M2E801580A026 or 10-oz. crimp style can per drawing M2E801580A043 as the PGNAA reference to verify the Tooling Setup.

EXEMPT FROM IC-755 (8-02)

**FORM AB PGNAA Standard Setup** **Rev G Page 1 of 1**

| Inspecting Company Name | Casting Company Name |
|---|---|
| PGNAA Standard Setup [a] | PGNAA Tooling Setup Number (with –# ) |

| | 277-4 Standard Can Serial Numbers | Counts | | | Count Time (sec) | Net Count Rate (Net Counts/Sec) |
|---|---|---|---|---|---|---|
| | | Gross | Compton | Net | | |
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| 6 | | | | | | |
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| 14 | | | | | | |
| 15 | | | | | | |
| 16 | | | | | | |
| 17 | | | | | | |
| 18 | | | | | | |
| 19 | | | | | | |
| 20 | | | | | | |
| Average Values | | | | | | |

Comments

Operator

a A 10-digit PGNAA Standard Setup Number shall be used to define the date and the time of setup using the format with a 24-hour clock (i.e., 1021041515 is used for October 21, 2004 at 3:15 pm).

b The 10-oz. double friction metal can lid or 10-oz. crimp style can lid shall face the source following the PGNAA Standard Setup.

EXEMPT FROM IC-755 (8-02)

**FORM AC PGNAA Daily Standard Setup Control** **Rev G** **Page 1 of 1**

| Inspecting Company Name | | Casting Company Name | | | | |
|---|---|---|---|---|---|---|
| PGNAA Daily Standard Setup [a] | | PGNAA Tooling Setup Number (with –# ) | | | | |
| 277-4 Standard Can Serial Numbers [b] | | Counts | | | Count Time (sec) | Net Count Rate (Net Counts/Sec) |
| | | Gross | Compton | Net | | |
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| Average Values | | | | | | |
| Standard Deviation | | | | | | |
| 3 × Standard Deviation | | | | | | |
| (Pass Rate) Minimum Acceptable Net Count Rate = Average − 3 × Standard Deviation = | | | | | | |
| Comments | | | | | | |
| Operator | | | | | | |

[a] A 10-digit PGNAA Daily Standard Setup (DSS) shall be used to define the date and the time of setup using the format with a 24-hour clock (i.e., 1021041515 is used for October 21, 2004 at 3:15 pm).

[b] Select five PGNAA acceptance standards from Form AB as the Daily Standard Setup that generate approximately the same average and standard deviation as on Form AB.

EXEMPT FROM IC-755 (8-02)

**FORM AD PGNAA Measurements** **Rev G Page 1 of 1**

| Inspecting Company Name | Casting Company Name | |
|---|---|---|
| PGNAA Measurement Number (PMN) [a] | PGNAA Daily Standard Setup Num. | PGNAA Pass Rate (Net Cnt/Sec) |

| Even Serial Numbers [b] | | Counts (Cnt) | | | Count Time (sec) | Net Cnt Rate (NetCnt/Sec) | Pass or Fail |
|---|---|---|---|---|---|---|---|
| Drum/Neutron Absorber Form/Lot# | Sample # | Gross | Compton | Net | | | |
| | | | | | | | |
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| EQUIPMENT SPECIFICATION | Specification Number<br>JS-YMN3-801580-A005-1 | Revision<br>G |
|---|---|---|
| | Issue Date<br>2/17/2005 | Revision Date<br>08/31/2009 |
| | | Page 1 of 1 |

*MANUFACTURER'S DATA REQUIREMENTS*

| Item No. | Data Submittal—Purpose and Description | Specification or Reference | Number of Copies | Form[a] | |
|---|---|---|---|---|---|
| | | | | | |
| | **OFFER APPRAISAL DATA - Subcontractor** | | | | |
| | | | | | |
| | The Offerer shall submit the following data with the offer. | | | | |
| | | | | | |
| 1 | Subcontractor's quality assurance program manual | 4.1 | 1 | E | |

[a]Indicate the following:

A Full-size prints
B—Full-size reproducibles
C Microfilm aperture card
D Manual (booklet, brochure, report, etc.)
E—Other (Specify) Subcontractor's standard form
F Other (Specify) Specimen

EXEMPT FROM IC-755 (8-02)

| EQUIPMENT SPECIFICATION | Specification Number<br>JS-YMN3-801580-A005-2 | | Revision<br>G |
|---|---|---|---|
| | Issue Date<br>2/17/2005 | Revision Date<br>08/31/2009 | |
| | | Page 1 of 1 | |

*MANUFACTURER'S DATA REQUIREMENTS*

| Item No. | Data Submittal—Purpose and Description | Specification or Reference | Number of Copies | Form[a] | |
|---|---|---|---|---|---|
| | | | | | |
| | APPROVAL DATA - Subcontractor | | | | |
| | | | | | |
| | The Subcontractor shall provide the following data prior to the start of production casting. | | | | |
| | | | | | |
| 1 | Process equipment approval | 3.1 | 1 | E | |
| 2 | Scale Certifications | 3.2.1 | 1 | E | |
| 3 | Request for Company approved equal | 3.2.2, 3.2.6, 3.2.7, 6.4 | 1 | E | |
| 4 | MSDS for cleaning products | 3.4.1 | 1 | E | |
| 5 | Procedures | 4.2.4 | 1 | E | |
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[a]Indicate the following:

A—Full-size prints
B—Full-size reproducibles
C—Microfilm aperture card
D—Manual (booklet, brochure, report, etc.)
E—Other (Specify) Subcontractor's standard form
F—Other (Specify)
S—Sample of Workmanship

EXEMPT FROM IC-755 (8-02)

| EQUIPMENT SPECIFICATION | Specification Number<br>JS-YMN3-801580-A005-3 | | Revision<br>G |
|---|---|---|---|
| | Issue Date<br>2/17/2005 | Revision Date<br>08/31/2009 | |
| | | Page 1 of 1 | |

*MANUFACTURER'S DATA REQUIREMENTS*

| Item No. | Data Submittal—Purpose and Description | Specification or Reference | Number of Copies | Form[a] | |
|---|---|---|---|---|---|
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| | **CERTIFIED DATA - Subcontractor** | | | | |
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| | Item 1 shall be provided prior to the start of production casting. | | | | |
| 1 | Approved procedures | 4.2.4 | 1 | E | |
| | | | | | |
| | Item 2 shall be provided with each ES-3100 unit. | | | | |
| 2 | ES−3100 Documentation Package | 4.2.1 | 1 | E | |
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[a]Indicate the following:

A Full-size prints
B—Full-size reproducibles
C Microfilm aperture card
D Manual (booklet, brochure, report, etc.)
E—Other (Specify) Subcontractor's standard form
F Other (Specify)
S—Sample of Workmanship

EXEMPT FROM IC-755 (8-02)

| EQUIPMENT SPECIFICATION | Specification Number JS-YMN3-801580-A005-4 | Revision G |
|---|---|---|
| | Issue Date 2/17/2005 | Revision Date 08/31/2009 |
| | | Page 1 of 1 |

*MANUFACTURER'S DATA REQUIREMENTS*

| Item No. | Data Submittal—Purpose and Description | Specification or Reference | Number of Copies | Form[a] | |
|---|---|---|---|---|---|
| | | | | | |
| | **OFFER APPRAISAL DATA – PGNAA Subcontractor** | | | | |
| | | | | | |
| | The Offerer shall submit the following data with the offer. | | | | |
| | | | | | |
| 1 | Subcontractor's quality assurance program manual | 4.1 | 1 | E | |

[a]Indicate the following:

A—Full-size prints
B Full-size reproducibles
C—Microfilm aperture card
D—Manual (booklet, brochure, report, etc.)
E Other (Specify) Subcontractor's standard form
F—Other (Specify) Specimen

EXEMPT FROM IC-1558-021

| EQUIPMENT SPECIFICATION | Specification Number<br>JS-YMN3-801580-A005-5 | | Revision<br>G |
|---|---|---|---|
| | Issue Date<br>2/17/2005 | Revision Date<br>08/31/2009 | |
| | | Page 1 of 1 | |

*MANUFACTURER'S DATA REQUIREMENTS*

| Item No. | Data Submittal—Purpose and Description | Specification or Reference | Number of Copies | Form[a] | |
|---|---|---|---|---|---|
| | | | | | |
| | **APPROVAL DATA – PGNAA Subcontractor** | | | | |
| | | | | | |
| | The Subcontractor shall provide the following data prior to the start of production inspection. | | | | |
| | | | | | |
| 1 | Source, detector, and software must be certified to a national standard. | A.6.1 | 1 | E | |
| 2 | Final tooling setup shall be manufactured<br>- Results of final tooling setup dimensional inspection shall be provided showing repeatability to +/- 0.13"<br>- As built drawing of final tooling setup that was manufactured shall be provided showing setup distances and materials of construction | A.6.2 | 1 | E | |
| 3 | Results of Net Count Rate Measurements performed on manufactured final tooling setup per section A.3.1.a of specification, based upon at least a 20 hour PGNAA measurement count and time justification. | A.6.3 | 1 | E | |
| 4 | Software used to determine net count rate and methodology used to determine net count rate shall be identified and documented | A.6.4 | 1 | E | |
| 5 | Completed Forms AA | A.6.5 | 1 | E | |
| 6 | Completed Forms AB, and AC | A.6.5 | 1 | E | |
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[a]Indicate the following:

A—Full-size prints
B—Full-size reproducibles
C—Microfilm aperture card
D—Manual (booklet, brochure, report, etc.)
E—Other (Specify) Subcontractor's standard form
F—Other (Specify)
S—Sample of Workmanship

EXEMPT FROM IC-755 (8-02)

| EQUIPMENT SPECIFICATION | Specification Number<br>JS-YMN3-801580-A005-6 | Revision<br>G |
|---|---|---|
| | Issue Date<br>2/17/2005 | Revision Date<br>08/31/2009 |
| | | Page 1 of 1 |

*MANUFACTURER'S DATA REQUIREMENTS*

| Item No. | Data Submittal—Purpose and Description | Specification or Reference | Number of Copies | Form[a] | |
|---|---|---|---|---|---|
| | | | | | |
| | **CERTIFIED DATA - PGNAA Subcontractor** | | | | |
| | | | | | |
| | | | | | |
| | Item 1 and 2 shall be provided prior to the start of production PGNAA inspection. | | | | |
| 1 | PGNAA national standard | A.6.1 | 1 | E | |
| 2 | PGNAA measurement software and methodology | A.6.4 | 1 | E | |
| | | | | | |
| | Item 3 shall be provided after each companion can lot is inspected. | | | | |
| 3 | Forms AC and AD | A.6.5 | 2 (1 copy going to Casting Company) | E | |
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[a]Indicate the following:

A—Full-size prints
B—Full-size reproducibles
C—Microfilm aperture card
D—Manual (booklet, brochure, report, etc.)
E—Other (Specify) Subcontractor's standard form
F—Other (Specify)
S—Sample of Workmanship

EXEMPT FROM IC-755 (8-02)

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# Appendix 1.3.6

# Package Category Determination

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## Appendix 1.3.6

## Package Category Determination

**The ES-3100 with HEU content package has a maximum activity of 0.72554 TBq (19.6092 Ci) at 10 y after initial fabrication; the maximum number of A2s carried is 4752.8 at 70 y after initial fabrication (Table 4.4). Based on the guidance from Nuclear Regulatory Commission Regulatory Guide 7.11, *Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m)*, this package is classified in Table 1.1 of NUREG-1609 as a Category I package.**

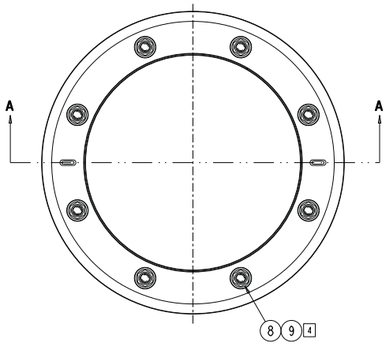
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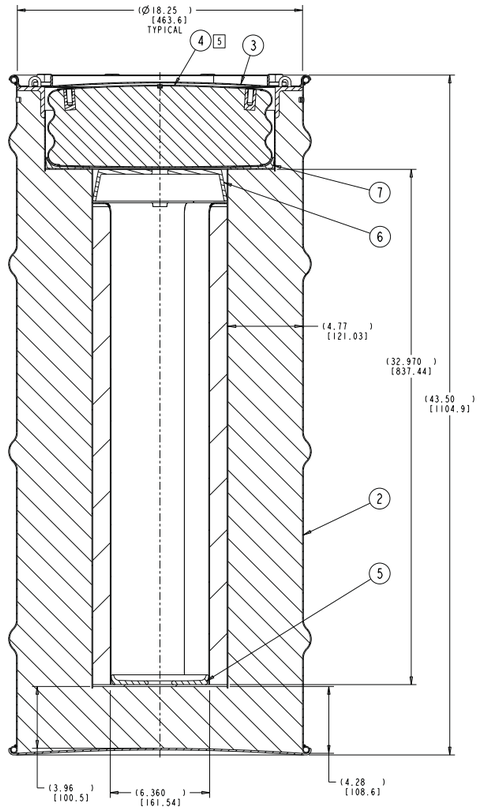
## Appendix 1.3.7

## ES-3100 Design Drawings

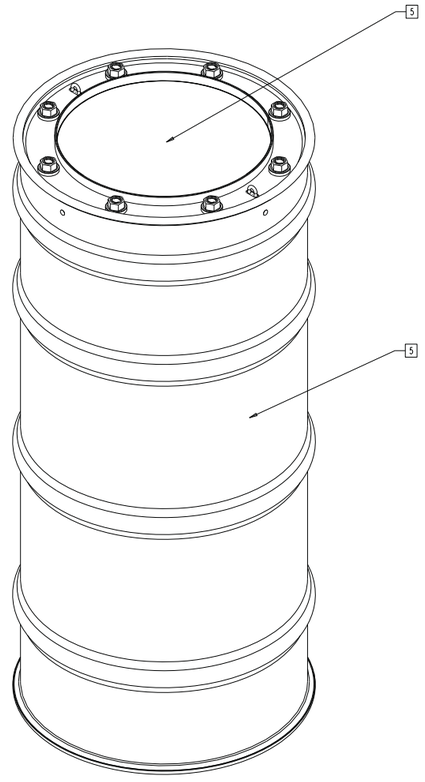
| Drawing No. | Rev. | Title |
|---|---|---|
| M2E801580A001 | C | Drum Assembly |
| M2E801580A002 | B | Body Weldment |
| M2E801580A003 | B | Inner Liner Weldment (2 sheets) |
| M2E801580A004 | B | Double Open Head Reinforced Drum |
| M2E801580A005 | D | Misc. Details |
| M2E801580A006 | B | Drum Lid Weldment |
| M2E801580A007 | B | 18.25" Diameter Drum Lid |
| M2E801580A008 | B | Top Plug Weldment |
| M2E801580A009 | D | Pad Details |
| M2E801580A010 | E | Data Plate Details |
| M2E801580A011 | F | Containment Vessel Assembly |
| M2E801580A012 | C | Containment Vessel Body Assembly (2 sheets) |
| M2E801580A013 | D | Containment Vessel O-ring Details |
| M2E801580A014 | B | Containment Vessel Lid Assembly |
| M2E801580A015 | C | Containment Vessel Sealing Lid |
| M2E801580A016 | B | Containment Vessel Closure Nut |
| M2E801580A023 | D | Containment Vessel Leak Test Assemblies |
| M2E801580A024 | C | Containment Vessel Vibration Absorbing Silicone 4.25” Can Pads |
| M2E801580A031 | G | Main Assembly |
| M2E801580A043 | A | Heavy Can Spacer Assembly (SST) |
| T2E801827A008 | A | Leak Check Flange Assembly |
| M801580-0013 | 0 | Containment Vessel Viton O-ring Details |

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SECTION A-A




ISOMETRIC VIEW

-1 DRUM ASSEMBLY 8 C
SCALE 3/8

NOTES

1. INTERPRET DRAWING PER ENGINEERING DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES [mm]. THE [mm] ARE ONLY FOR REFERENCE.
4. TORQUE HEX NUTS TO 30±5 ft-lb AT ASSEMBLY.
5. IN APPROXIMATE LOCATIONS SHOWN, USING BLACK ENAMEL PAINT (F/N 10), PAINT DRAWING NUMBER, REVISION LETTER AND FIVE DIGIT SERIAL NUMBER IN 1.00" HIGH CHARACTERS ON F/N 2, F/N 3, AND F/N 4.
6. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A002.
7. FOR REF. ONLY APPROXIMATE WEIGHT: 289.2 LBS [131.2 Kg].
8. REFERENCE CONFIGURATION CONTROL EQUIPMENT DATA SHEET DS-PKG-801580-A001.

PARTS LIST

| | | | PART OR IDENTIFYING NO. | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | FIND NO |
|---|---|---|---|---|---|---|---|
| 5 | | AR | | PAINT, BLACK ENAMEL | | FED SPEC 595B-17038 | 10 |
| 4 | | 8 | M2E801580A005-3 | DRUM HEX NUT | | | 9 |
| | | 8 | M2E801580A005-4 | DRUM WASHER | | | 8 |
| | | 1 | M2E801580A009-3 | PLUG PAD | | | 7 |
| | | 1 | M2E801580A009-2 | CV FLANGE PAD | | | 6 |
| | | 1 | M2E801580A009-1 | CV BOTTOM PAD | | | 5 |
| | | 1 | M2E801580A008-1 | TOP PLUG WELDMENT | | | 4 |
| | | 1 | M2E801580A006-1 | DRUM LID WELDMENT | | | 3 |
| | | 1 | M2E801580A002-1 | BODY WELDMENT | | | 2 |
| C | 8 | AR | -1 | DRUM ASSEMBLY | | | 1 |

M2E801580A001 -1 — QTY REQ'D NEXT ASSEMBLY

| REV | DESCRIPTION | DRW | CHKR | DE | DVR | DM | DATE | PE | DATE | PM | DATE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C | ADDED REFERENCE NOTE 8. | MLE | JRJ | MLE | DEW | WIN | 9/10/09 | LR | 9/10/09 | JGA | 9/14/09 |
| B | GEN REV: TORQUE IN NOTE 4 WAS 10 +/- 1 REVISED NOTES 4 & 7; F/N 8 & 9 WAS VENDOR SUPPLIED MOVED NUT & WASHER DETAILS TO A005. | JRP | SMM | GAB | RDA | DPS | 8/18/09 | GAB | 7/10/09 | JGA | 7/10/09 |
| A | ISSUED FOR PROTOTYPE PROCUREMENT | JRJ | JSL | GAB | JLH | JCW | 8/29/08 | MRF | 8/29/08 | DBM | 8/29/08 |

REVISION OR ISSUE PURPOSE — REVISION APPROVALS — SQUAD CHECK: AR CV ST HV CM FP PD EE IC H NP — DRAWING APPROVALS

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY ANALYSIS ENGINEERING APPROVAL.

| REVISION | DATE | SAE APPROVAL |
|---|---|---|
| C | 09/10/09 | J.F. DECLUE |

This document has been reviewed by a Y-12 DC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.

Name: R.D. AIGNER Date: 09/10/09

SCALE: NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS
XX DECIMALS
XXX DECIMALS
ANGLES
BREAK SHARP EDGES .06 MAX
FINISH

| | | |
|---|---|---|
| DRW | JR JACKSON | 10/29/03 |
| CHKR | JS LOWERY | 10/29/03 |
| DE | GA BYINGTON | 10/29/03 |
| DVR | JL HECK | 10/29/03 |
| DM | JC WALLS | 10/29/03 |
| PE | MR FELDMAN | 10/29/03 |
| PM | DB MILLER | 10/29/03 |

BWXT Y-12, L.L.C. — Y-12 National Security Complex managed by BWXT Y-12, L.L.C. for the Department of Energy under U.S. Government contract DE-AC05-00OR22800 a Oak Ridge, Tennessee a

PROJECT NAME: ES-3100 SHIPPING PACKAGE

DRUM ASSEMBLY

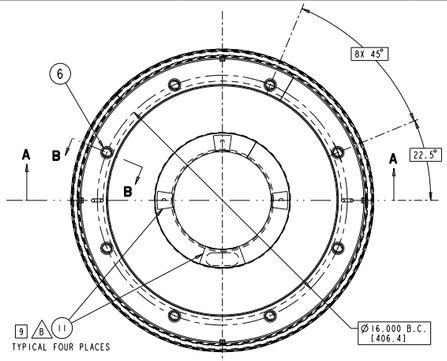
| 1 | 48 | 49 | 50 | PLANT | BLDG | FL | SH. OF | TYPE | CLASS |
|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | Y-12 | NA | NA | 1 1 | A | U |

| 51 | 52 | 53 | |
|---|---|---|---|
| CM | PKG | IN | M2E801580A001 REV C |

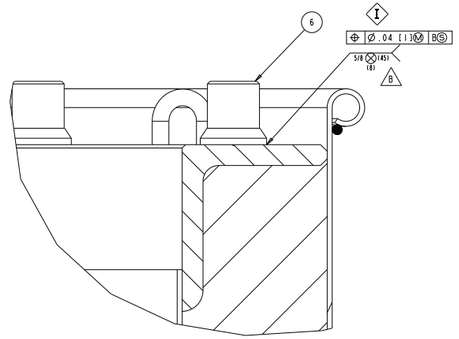
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P THIS DRAWING PRODUCED ON PRO/ENGINEER

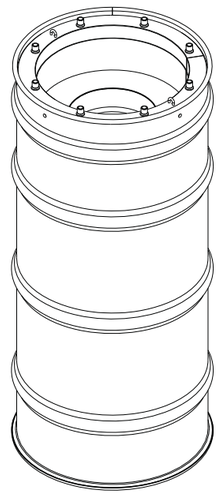
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-1 BODY WELDMENT
SCALE 3/8




SECTION B-B
SCALE 2/1



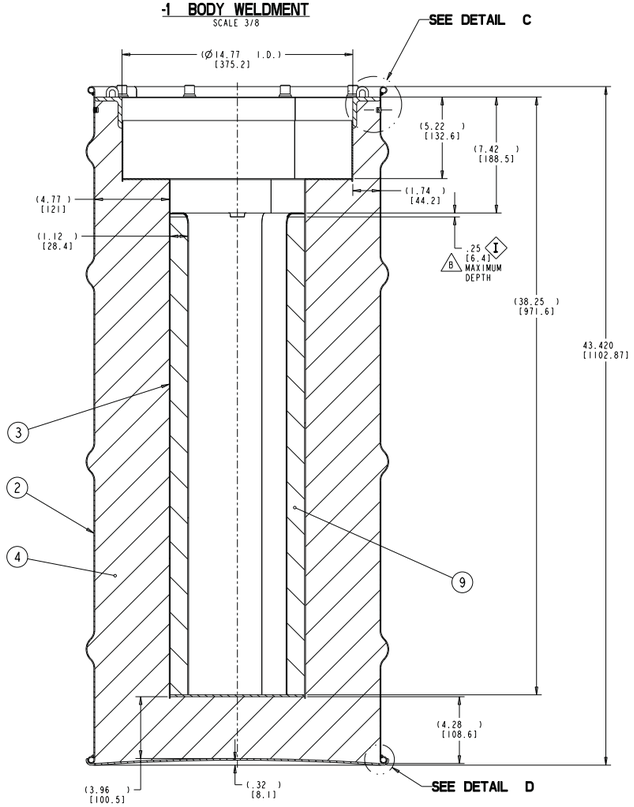
ISOMETRIC VIEW
SCALE 1/4

NOTES

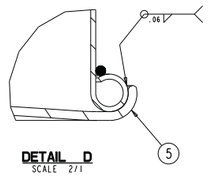
1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES [mm].
4. OD OF ANGLE TURNED TO ID OF DRUM AT ASSEMBLY.
5. WELDING SYMBOLS SHALL BE INTERPRETED IN ACCORDANCE WITH AWS A2.4.
6. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A002.
7. DIMENSIONS AND FEATURES FLAGGED BY A I SYMBOL SHALL BE INSPECTED AND DOCUMENTED.
8. SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A003 FOR REQUIREMENTS OF KAOLITE PROCESSING.
9. SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A005 FOR REQUIREMENTS OF CATALOG 277-4 PROCESSING AND APPLYING THE F/N 11 OVER FILL/VENT HOLES.
10. FOR REFERENCE ONLY APPROXIMATE WEIGHT: 259.7 LBS [117.8 Kg]

KAOLITE:
VOLUME: 4.82 CU. FT.
DENSITY: 22.4 LBS/CU. FT.
WEIGHT: 108.0 LBS [49.0 Kg]

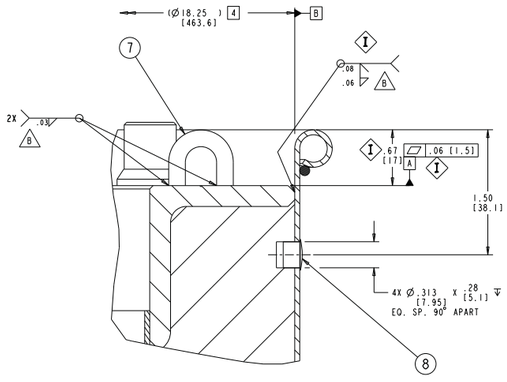
CATALOG 277-4:
VOLUME: 0.466 CU. FT.
DENSITY: 105.0 LBS/CU. FT.
WEIGHT: 48.89 LBS [22.18 Kg]




SECTION A-A
SCALE 3/8




DETAIL D
SCALE 2/1




DETAIL C
SCALE 2/1

| | | | | | | |
|---|---|---|---|---|---|---|
| B 9 | AR | 7616A21 OR EQUAL | LOW TEMPERATURE (-40° to +250°F) | ALUMINUM FOIL DUCT TAPE 2" WIDE | McMASTER- CARR ATLANTA, GA | 11 |
| | AR | | WELD FILLER METAL | PER WELD PROCEDURES | | 10 |
| B 9 | AR | -9 | CATALOG NO. 277-4 | THERMO ELECTRON CORP., THERMOREAX, 504 AIRPORT ROAD, SANTA FE, NM 87507 PHONE 505-428-3508, FAX 505-428-3535 | | 9 |
| | 4 | 62MP0312 OR EQUAL | PLUG, NYLON 6/6 | MICRO PLASTIC INC. FLIPPIN, AR 72634 | | 8 |
| | 2 | M2E801580A005-2 | TID LUG | | | 7 |
| | 8 | ARC FT 5/8-11 X 7/8 LG | ARC WELD STUD | 304 / 304L SST | ASTM A493 OR ASTM F593 | 6 |
| | 1 | M2E801580A005-1 | DRUM FLAT COVER | | | 5 |
| 8 | AR | -4 | KAOLITE 1600 VIBRATED CAST | THERMAL CERAMICS AUGUSTA, GA 30903-0923 | | 4 |
| | 1 | M2E801580A003-1 | INNER LINER WELDMENT | | | 3 |
| | 1 | M2E801580A004-1 | DOUBLE OPEN HEAD REINFORCED DRUM | | | 2 |
| AR | X | -1 | BODY WELDMENT | | | 1 |
| M2E801580 2001 | -1 | PART OR IDENTIFYING NO | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | FIND NO |
| | | QTY REQ'D NEXT ASSEMBLY | PARTS LIST | | | |

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.

| REVISION | DATE | NCSD APPROVAL |
|---|---|---|
| B | 2/10/05 | JF DECLUE |

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Name: ROGER D. AIGNER Date: 2/10/05

| REV | DESCRIPTION | DRW | CHKR | DE | DVR | DM | DATE | PE | DATE | PM | DATE | WE | DATE | AR | CV | ST | HV | EM | FP | PD | EE | IE | M | NP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B | GEN REV ADDED F/N 11, 5/8 WAS 1/2, F/N 9 WAS BOROBOND 4; MOD. GEN. NOTE 9; MOD. WELD SYMS. IN DET. C; MOD. MTS AND VOLS. IN NOTE 10 | JRP | SMM | GAB | RDA | DPS | 11/17/05 | GAB | 2/10/05 | JGA | 2/10/05 | DJE | 2/11/05 | | | | | | | | | | | |
| A | ISSUED FOR PROTOTYPE PROCUREMENT | JRJ | JSL | GAB | JLH | JCW | 10/29/03 | MRF | 10/29/03 | DBM | 10/29/03 | | | | | | | | | | | | | |

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK

| DRAWING APPROVALS | | |
|---|---|---|
| | DATE | |
| DRW J.R. JACKSON | 10/29/03 | |
| CHKR J.S. LOWERY | 10/29/03 | |
| DE G.A. BYINGTON | 10/29/03 | |
| DVR J.L. HECK | 10/29/03 | |
| DM J.C. WALLS | 10/29/03 | |
| PE W.R. FELDMAN | 10/29/03 | |
| PM D.B. MILLER | 10/29/03 | |

SCALE: NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS
XX DECIMALS ±.03
XXX DECIMALS ±.005
ANGLES ±0.5°
BREAK SHARP EDGES .06 MAX
FINISH 125 RMS

BWXT Y-12 National Security Complex managed by BWXT Y-12, L.L.C. for the Department of Energy under U.S. Government contract DE-AC05-00OR22800 a Oak Ridge, Tennessee a PROJECT NAME

ES-3100 SHIPPING PACKAGE

BODY WELDMENT

| 1 | 48 | 49 | 50 | PLANT | BLDG | FL | SH. | OF | TYPE | CLASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | Y-12 | NA | NA | 1 | 1 | A | U |

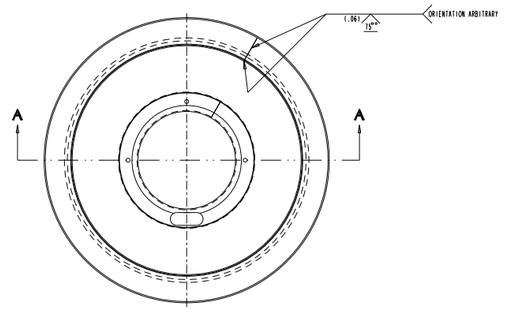
| 51 | 52 | 53 | | REV |
|---|---|---|---|---|
| CM | PKG | IN | M2E801580A002 | B |

M2E801580A002

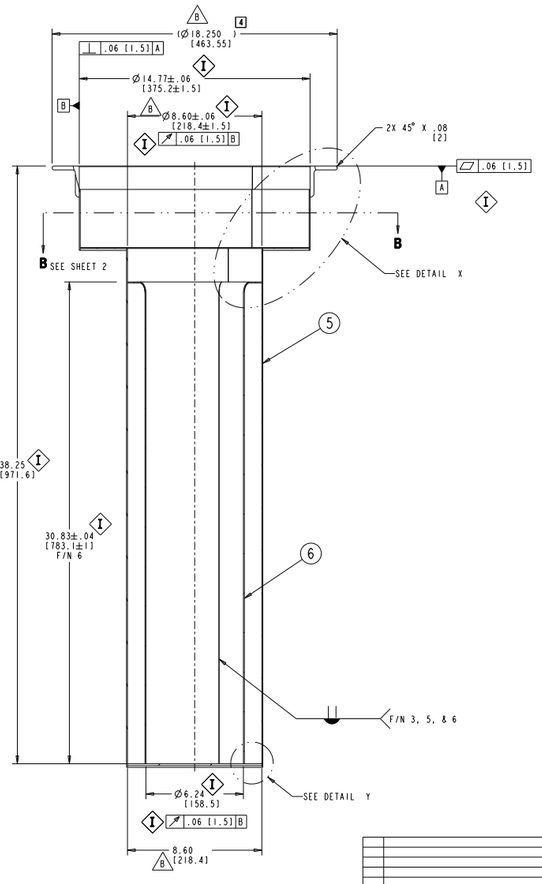
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PTHIS DRAWING PRODUCED ON PRO/ENGINEER

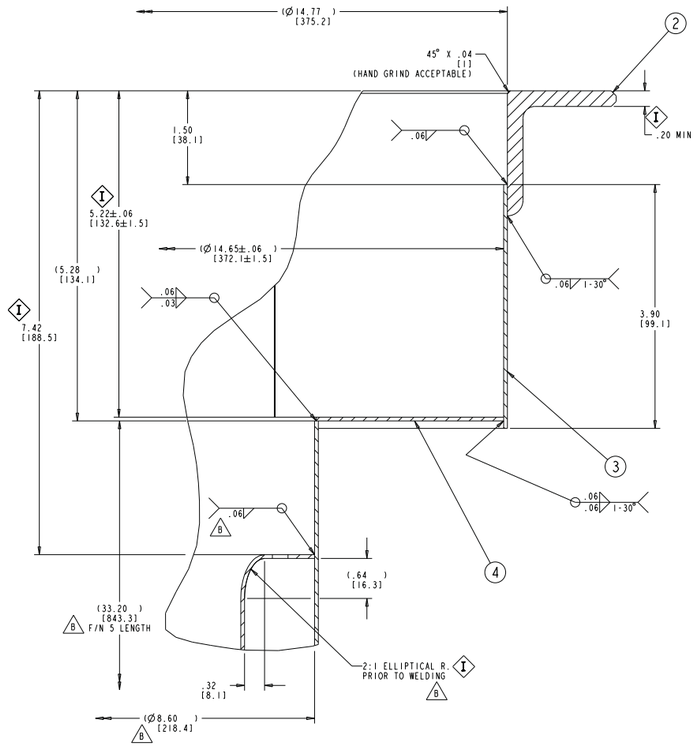
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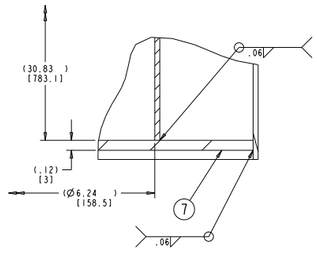

## -1 INNER LINER WELDMENT
SCALE 3/8




## SECTION A-A




## DETAIL X
SCALE 3/2




## DETAIL Y
SCALE 2/1

NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES [mm].
4. FINAL DIAMETER SET BY DRUM INSIDE DIAMETER, -.01 TO -.06 TOLERANCE.
5. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A002.
6. DIMENSIONS AND FEATURES FLAGGED BY A I SYMBOL SHALL BE INSPECTED AND DOCUMENTED.
7. WELDING SYMBOLS SHALL BE INTERPRETED IN ACCORDANCE WITH AWS A2.4.

| FIND NO | PART OR IDENTIFYING NO. | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | QTY REQ'D NEXT ASSEMBLY |
|---|---|---|---|---|---|
| 8 | | WELD FILLER METAL | | | AR |
| 7 | -7 | BOTTOM PLATE | 11 GAGE SHEET 304/304L SST | ASME SA240 | 1 |
| 6 | -6 | LOWER INNER RING | 16 GAGE SHEET 304/304L SST | | 1 |
| 5 | -5 | LOWER OUTER RING | | | 1 |
| 4 | -4 | UPPER FLOOR PLATE | | | 1 |
| 3 | -3 | UPPER OUTER RING | | | 1 |
| 2 | -2 | 2 X 2 X 1/4 ANGLE MODIFIED | 304/304L SST | ASME SA479 | 1 |
| 1 | -1 | INNER LINER WELDMENT | | | AR |

PARTS LIST

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.

| REVISION | DATE | NCSD APPROVAL |
|---|---|---|
| B | 2/10/05 | JF DECLUE |

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Name: ROGER D. AIGNER Date: 2/10/05

| REV | DESCRIPTION | REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK |
|---|---|---|---|---|
| B | DELETED F/N 7, RENUMBERED F/N 8 TO 7 AND F/N 9 TO 8. CHANGED F/N 5 Ø8.80 TO Ø8.60, LENGTH 2.14 TO 33.20. F/N 6 OD WAS Ø9.13 NOW Ø8.60. REMOVED NOTE #8 | JRP | SMM GAB RDA DPS 1/18/05 | GAB 2/10/05 JGA 2/10/05 DJE 2/11/05 |
| A | ISSUED FOR PROTOTYPE PROCUREMENT | JRJ | JSL GAB JLH JCW 10/29/03 | MRF 10/29/03 DBM 10/29/03 |

| DRAWING APPROVALS | | DATE |
|---|---|---|
| DRW | J.R. JACKSON | 10/29/03 |
| CHKR | J.S. LOWERY | 10/29/03 |
| DE | G.A. BYINGTON | 10/29/03 |
| DVR | J.L. HECK | 10/29/03 |
| DM | J.C. WALLS | 10/29/03 |
| PE | M.R. FELDMAN | 10/29/03 |
| PM | D.B. MILLER | 10/29/03 |

SCALE: NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS ±.03
XX DECIMALS ±.03
XXX DECIMALS ±.005
ANGLES ±0.5°
BREAK SHARP EDGES .04 MAX
FINISH 125 RMS

Y-12 National Security Complex managed by BWXT Y-12, L.L.C. for the Department of Energy under U.S. Government contract DE-AC05-00OR22800 at Oak Ridge, Tennessee

PROJECT NAME: ES-3100 SHIPPING PACKAGE

INNER LINER WELDMENT

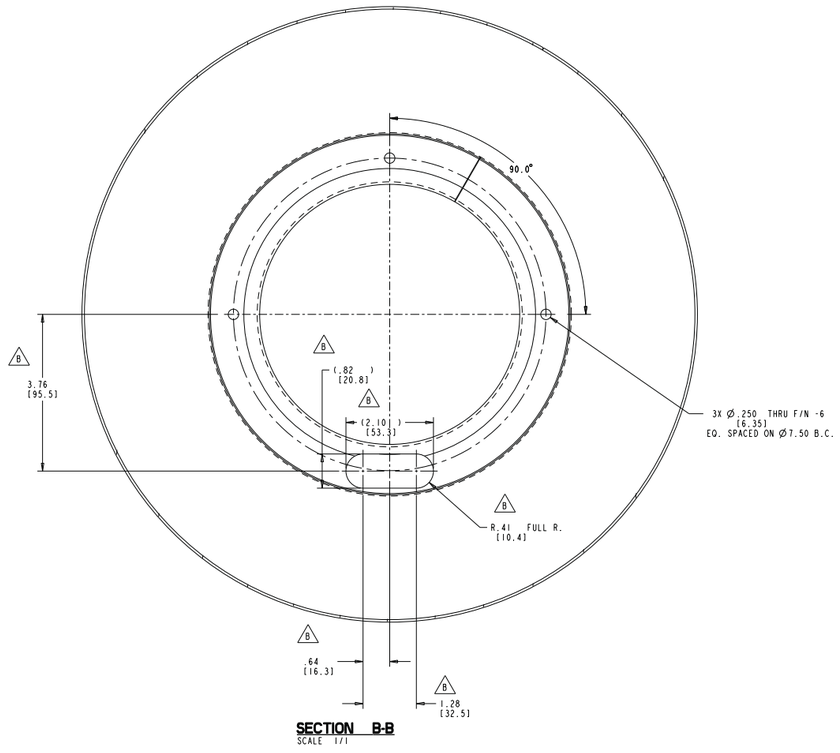
| SIZE | FSCM NO | PLANT | BLDG | FL | SH. OF | TYPE | CLASS | REV |
|---|---|---|---|---|---|---|---|---|
| D | 06 49 | L F | Y-12 | NA | NA 1 2 | S | U | B |
| SCALE | CM | PKG | IN | M2E801580A003 | | | | |

M2E801580A003

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THIS DRAWING PRODUCED ON PRO/ENGINEER

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**SECTION B-B**
SCALE 1/1

NEXT ASS'Y: FINAL ASS'Y: 1

M2E801580A003

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THIS DRAWING PRODUCED ON PRO/ENGINEER

Y-12 National Security Complex managed by BWXT Y-12, L.L.C. for the Department of Energy under U.S. Government contract DE-AC05-00OR22800 • Oak Ridge, Tennessee •

PROJECT NAME
ES-3100 SHIPPING PACKAGE

INNER LINER WELDMENT

| 1 | 48 | 49 | 50 | PLANT | BLDG | FL | SH. | OF | TYPE | CLASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | Y-12 | NA | NA | 2 | 2 | S | U |

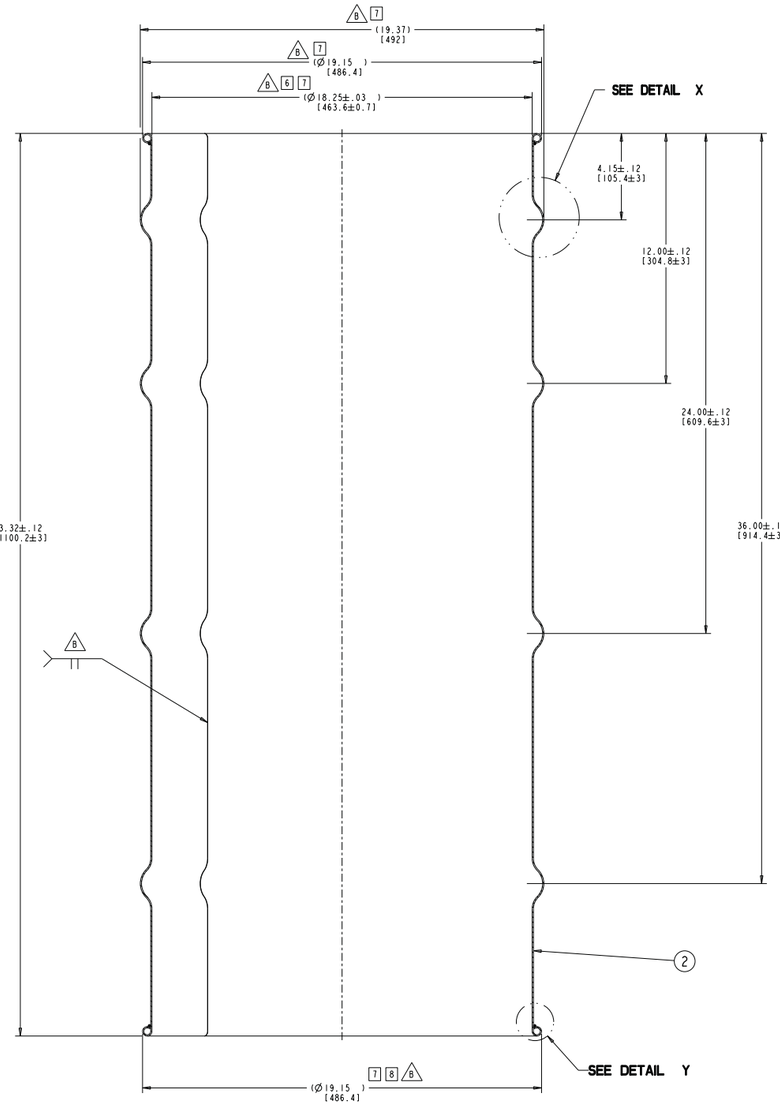
| 51 | 52 | 53 | | |
|---|---|---|---|---|
| CM | PKG | IN | M2E801580A003 | REV B |

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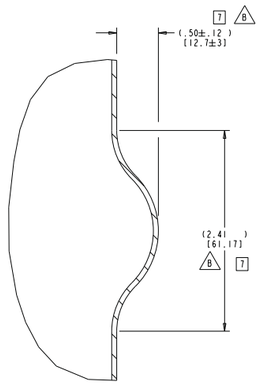
NEXT ASS'Y: FINAL ASS'Y:

NOTES

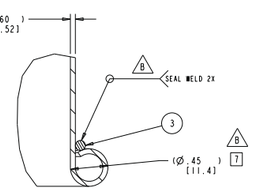
1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES.[mm].
4. WELDING SYMBOLS SHALL BE INTERPRETED IN ACCORDANCE WITH AWS A2.4.
5. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A002.
6. INSPECT THE I.D. OF THE DRUM TO DETERMINE THE ACTUAL DIAMETER DIMENSION FOR FABRICATION INTERFACE WITH M2E801580A003. REFERENCE NOTE 4 ON DWG. M2E801580A002.
7. DRUM DIAMETERS, CORRUGATIONS, AND MANUFACTURING SHALL MEET THE REQUIREMENTS OF MILITARY STANDARD, MS27683-7 (DRUM, METAL SHIPPING AND STORAGE (6 TO 80 GALLS). THE SEAM WELD OF THE DOUBLE OPEN-HEAD DRUM SHALL BE TESTED BY APPLYING AN INTERNAL AIR PRESSURE TO 10 PSIG (MIL-D-6054F, PARAGRAPH 4.6.1 PROCEDURE B) AND BY CONDUCTING A ROUGH HANDLING TEST (MIL-D-6054F, PARAGRAPH 4.6.2).
8. INSPECT THE O.D. OF THE DRUM FOR INTERFACE DIMENSION WITH M2E801580A005-1, DRUM FLAT COVER. REFERENCE NOTE 5 ON DRAWING M2E801580A005.



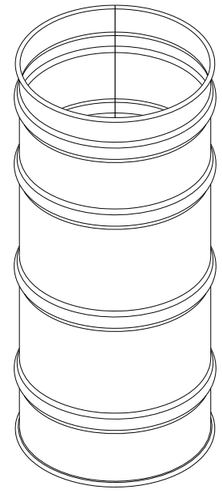

-1 DOUBLE OPEN HEAD REINFORCED DRUM
SCALE 1/2




DETAIL X
SCALE 2/1
(4X)




DETAIL Y
SCALE 2/1
(2 X)



ISOMETRIC VIEW
SCALE 1/4

| | | | | | |
|---|---|---|---|---|---|
| | AR | | WELD FILLER METAL | PER WELD PROCEDURES | 4 |
| | AR | Ø1/8 | WELD WIRE | ER308L | ASME SFA 5.9 3 |
| 7 | 1 | -2 | DRUM 16 GA (.0595) | 304/304L SST | ASME SA240 2 |
| | AR | -1 | DOUBLE OPEN HEAD REINFORCED DRUM | | 1 |
| MATERIAL CODE | QTY | PART OR IDENTIFYING NO | NOMENCLATURE OR DESCRIPTION | MATERIAL SPECIFICATION | FIND NO |
| | | QTY REQ'D NEXT ASSEMBLY | PARTS LIST | | |

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| REVISION | DATE | NCSD APPROVAL |
|---|---|---|
| B | 2/10/05 | JF DECLUE |

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Name: ROGER D. AIGNER Date: 2/10/05

| REV | DESCRIPTION | REVISION OR ISSUE PURPOSE | DRW | CHKR | DE | DVR | DM | DATE | PE | DATE | PM | DATE | ME | DATE | AR | CV | ST | HV | EM | FP | PQ | EC | IE | M | NP | REVISION APPROVALS | SQUAD CHECK | DRAWING APPROVALS | DATE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B | GEN REV REMOVED TOL ON 18.25 DIA. REMOVED (I) ON 19.15 DIA. REMOVED BOX 9 DIM. UPDATED NOTE NUM. 6 TO 8. REVISED NOTE 7. MOD. WELD SYMBOLS. ADDED REF DIMENSIONS IN DETAIL X | | JRP | SMM | GAB | RDA | DPS | 11/18/05 | GAB | 2/10/05 | JGA | 2/10/05 | | | | | | | | | | | | | | | | | |
| A | ISSUED FOR PROTOTYPE PROCUREMENT | | JRJ | JSL | GAB | JLH | JCW | 10/29/03 | MRF | 10/29/03 | DBM | 10/29/03 | | | | | | | | | | | | | | | | | |

| | |
|---|---|
| SCALE: | NOTED |
| TOLERANCES UNLESS OTHERWISE SPECIFIED | |
| FRACTIONS | |
| XX DECIMALS | ±.03 |
| XXX DECIMALS | ±.010 |
| ANGLES | ±0.5° |
| BREAK SHARP EDGES | .06 MAX |
| FINISH | 125 RMS |

| | | |
|---|---|---|
| DRW | J.R. JACKSON | 10/29/03 |
| CHKR | J.S. LOWERY | 10/29/03 |
| DE | G.A. BYINGTON | 10/29/03 |
| DVR | J.L. HECK | 10/29/03 |
| DM | J.C. WALLS | 10/29/03 |
| PE | M.R. FELDMAN | 10/29/03 |
| PM | D.B. MILLER | 10/29/03 |

BWXT Y-12 National Security Complex managed by BWXT Y-12, L.L.C. for the Department of Energy under U.S. Government contract DE-AC05-00OR22800 a Oak Ridge, Tennessee a

PROJECT NAME: ES-3100 SHIPPING PACKAGE

DOUBLE OPEN HEAD REINFORCED DRUM

| 1 | 48 | 49 | 50 | PLANT | BLDG | FL | SH. | OF | TYPE | CLASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | Y-12 | NA | NA | 1 | 1 | S | U |

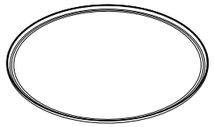
| 51 | 52 | 53 | | REV |
|---|---|---|---|---|
| CM | PKG | IN | M2E801580A004 | B |

M2E801580A004

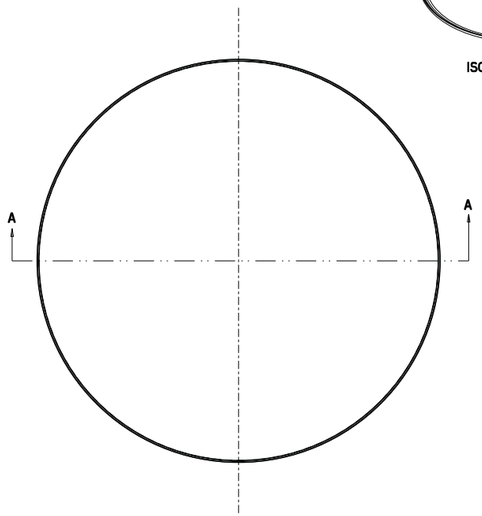
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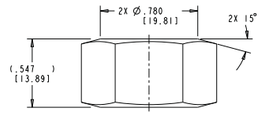
PTHIS DRAWING PRODUCED ON PRO/ENGINEER

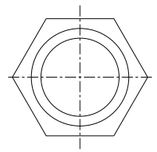
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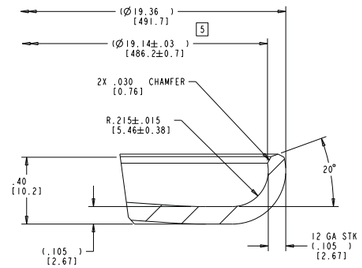
ISOMETRIC VIEW
SCALE 1/4



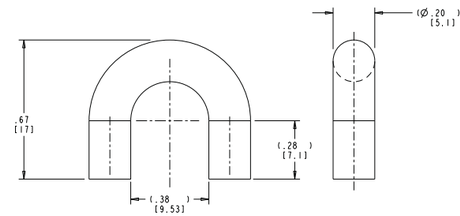



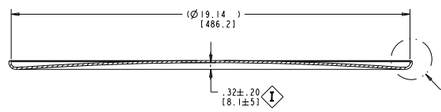
-3 MODIFIED DRUM NUT [7] [8] [D]
SCALE 3/1




DETAIL Z
SCALE 4/1

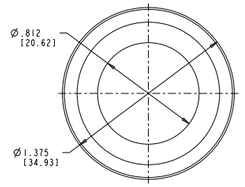


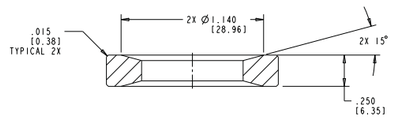

-2 TID LUG
SCALE 4/1




SECTION A-A

-1 DRUM FLAT COVER
SCALE 1/2




-4 DRUM WASHER
SCALE 3/1

NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES.[mm].
4. DIMENSIONS AND FEATURES FLAGGED BY A I SYMBOL SHALL BE INSPECTED AND DOCUMENTED.
5. DRUM FLAT COVER SHALL BE FABRICATED TO INTERFACE WITH DOUBLE OPEN HEAD REINFORCED DRUM DIMENSION. TOLERANCE SHALL BE -.01 TO -.04. REFERENCE NOTE 9 ON DRAWING M2E801580A004.
6. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A002.
7. REFERENCE CONFIGURATION CONTROL EQUIPMENT DATA SHEET DS-PKG-801580-A003.
8. [D] THE DRUM NUT MECHANICAL PROPERTY MARKING, F467K, SHALL BE FULLY VISIBLE AFTER MODIFICATION.

| [D] [8] [7] | | | | | | |
|---|---|---|---|---|---|---|
| 8 | | -4 | DRUM WASHER | 300 SERIES SST | ASTM A240 OR A276 | 4 |
| 8 | | -3 | MODIFIED DRUM NUT | C65100 SILICON BRONZE | ASTM F-467 ANSI B18.2.2 | 3 |
| | 2 | MODIFIED 3392751 OR EQUAL | TID LUG | 304L SST CHAIN 3/16" TRADE SIZE, .20 DIA. MATERIAL, INSIDE LINK SIZE .38 WD, 95L | McMASTER-CARR SUPPLY CO. ATLANTA, GA 30374 | 2 |
| | 1 | -1 | DRUM FLAT COVER | 12 GA 304/304L SST | ASME SA240 | 1 |
| DELETED SEE DCN 0001 | | PART OR IDENTIFYING NO | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | FIND NO |
| DELETED SEE DCN 0002 | | QTY REQ'D NEXT ASSEMBLY | PARTS LIST | | | |

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY ANALYSIS ENGINEERING APPROVAL.

| REVISION | DATE | SAE APPROVAL |
|---|---|---|
| D | 03/17/2010 | J.F. DeCLUE |

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Name: STAN THOMAS Date: 3/17/2010

| REV | DESCRIPTION | DRW | CHKR | DE | DVR | DM | DATE | PE | DATE | PM | DATE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D | ADDED NOTE 8 | JRJ | JRF | GAB | MLG | WIN | 3/17/10 | LR | 3/17/10 | JGA | 3/17/10 |
| C | ADDED REFERENCE NOTE 7. | MLE | JRJ | MLE | DEW | WIN | 9/18/09 | LR | 9/18/09 | JGA | 9/18/09 |
| B | REVISED F/N 2; ADDED F/N 3 & 4 REMOVED TOL FROM DETAIL Z DIM. | JRP | SMM | GAB | RDA | DPS | 11/03/05 | GAB | 2/19/05 | JGA | 2/19/05 |
| A | ISSUED FOR PROTOTYPE PROCUREMENT | JRJ | JSL | GAB | JLH | JCW | 10/29/03 | MRF | 10/29/03 | DBM | 10/29/03 |

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK

| DRAWING APPROVALS | DATE |
|---|---|
| AR CV ST HV EM FP PD EE IE W NP | |
| DRW J.R. JACKSON | 10/29/03 |
| CHKR J.S. LOWERY | 10/29/03 |
| DE G.A. BYINGTON | 10/29/03 |
| DVR J.L. HECK | 10/29/03 |
| DM J.C. WALLS | 10/29/03 |
| PE M.R. FELDMAN | 10/29/03 |
| PM D.B. MILLER | 10/29/03 |

SCALE: NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS ±.03
XX DECIMALS ±.03
XXX DECIMALS ±.010
ANGLES ±0.5°
BREAK SHARP EDGES .06 MAX
FINISH 125 RMS

BWXT Y-12 National Security Complex managed by BWXT Y-12, L.L.C. for the Department of Energy under U.S. Government contract DE-AC05-00OR22800 a Oak Ridge, Tennessee a

PROJECT NAME: ES-3100 SHIPPING PACKAGE

MISC. DETAILS

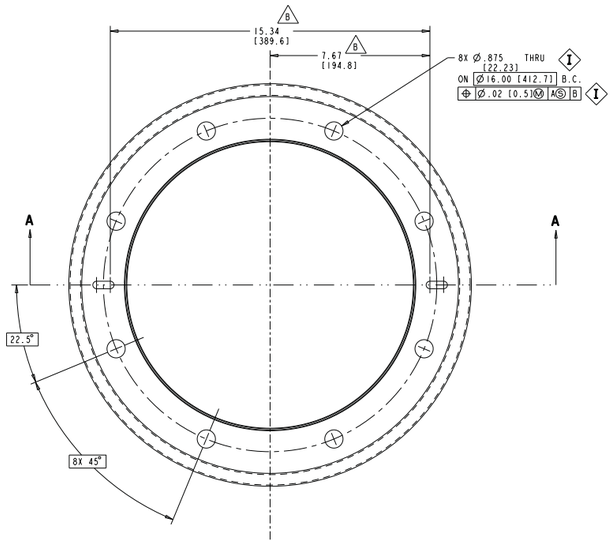
| I | 48 | 49 | 50 | PLANT | BLDG | FL | SH. | OF | TYPE | CLASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | Y-12 | NA | NA | 1 | 1 | S | U |
| 51 | | 52 | | 53 | | | | | | |
| CM | | PKG | | IN | M2E801580A005 | | | | | REV D |

M2E801580A005

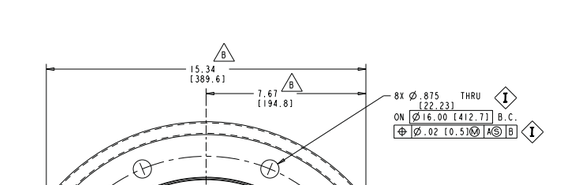
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PTHIS DRAWING PRODUCED ON PROVENGINEER

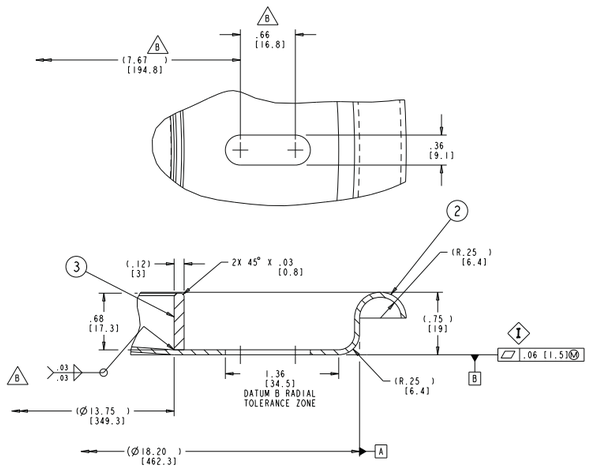
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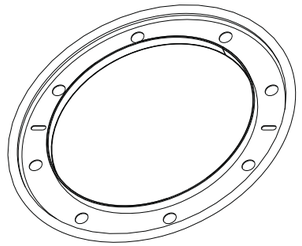

## -1 DRUM LID WELDMENT
SCALE 1/2




## SECTION A-A




## DETAIL Z
SCALE 2/1



## ISOMETRIC VIEW
SCALE 3/8

NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES.[mm].
4. (B) WELDING SYMBOLS SHALL BE INTERPRETED IN ACCORDANCE WITH AWS A2.4.
5. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A002.
6. DIMENSIONS AND FEATURES FLAGGED BY A (I) SYMBOL SHALL BE INSPECTED AND DOCUMENTED.
7. FOR REFERENCE ONLY APPROXIMATE WEIGHT: 9.1 LBS [4.1 Kg]

| | | | | | |
|---|---|---|---|---|---|
| | AR | | WELD FILLER METAL | PER WELD PROCEDURES | 4 |
| | 1 | -3 | 11 GA (.1197) SHEET | 304/304L SST ASME SA240 | 3 |
| | 1 | M2E801580A007-1 | 18.25" DIA. DRUM LID | | 2 |
| AR | X | -1 | DRUM LID WELDMENT | | 1 |
| M2E801580A001 | | PART OR IDENTIFYING NO | NOMENCLATURE OR DESCRIPTION | MATERIAL SPECIFICATION | FIND NO |
| | | QTY REQ'D NEXT ASSEMBLY | PARTS LIST | | |

| REV | DESCRIPTION | DRW | CHKR | DE | DVR | DM | DATE | PE | DATE | PM | DATE | ME | DATE | AR | CV | ST | HV | EM | FP | PD | EC | IE | W | NP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B | REPLACED HOLE WITH SLOT; ADDED TOL TO 13.75 DIM; ADDED (I) ;MOD WELD; GEN REV NOTE 4 WAS 5 | JRP | SMM | GAB | RDA | DPS | 11/03/05 | GAB | 2/10/05 | JGA | 2/10/05 | DTE | 2/11/05 | | | | | | | | | | | |
| A | ISSUED FOR PROTOTYPE PROCUREMENT | JRJ | JSL | GAB | JLH | JCW | 10/29/03 | MRF | 10/29/03 | DBM | 10/29/03 | | | | | | | | | | | | | |

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.

| REVISION | DATE | NCSD APPROVAL |
|---|---|---|
| B | 2/10/05 | JF DECLUE |

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Name: ROGER D. AIGNER Date: 2/10/05

| | | |
|---|---|---|
| SCALE: NOTED | DRW | J.R. JACKAON 10/29/03 |
| TOLERANCES UNLESS OTHERWISE SPECIFIED | CHKR | J.S. LOWERY 10/29/03 |
| | DE | G.A. BYINGTON 10/29/03 |
| FRACTIONS ±.03 | DVR | J.L. HECK 10/29/03 |
| XX DECIMALS ±.03 | DM | J.C. WALLS 10/29/03 |
| XXX DECIMALS ±.010 | PE | M.R. FELDMAN 10/29/03 |
| ANGLES ±0.5° | PM | D.B. MILLER 10/29/03 |
| BREAK SHARP EDGES .06 MAX | | |
| FINISH 125 RMS | | |

BWXT Y-12 National Security Complex managed by BWXT Y-12, L.L.C. for the Department of Energy under U.S. Government contract DE-AC05-00OR22800. a Oak Ridge, Tennessee a

PROJECT NAME: ES-3100 SHIPPING PACKAGE

DRUM LID WELDMENT

| I | 48 | 49 | 50 | PLANT | BLDG | FL | SH. | OF | TYPE | CLASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | Y-12 | NA | NA | 1 | 1 | S | U |

| 51 | 52 | 53 | | REV |
|---|---|---|---|---|
| CM | PKG | IN | M2E801580A006 | B |

M2E801580A006

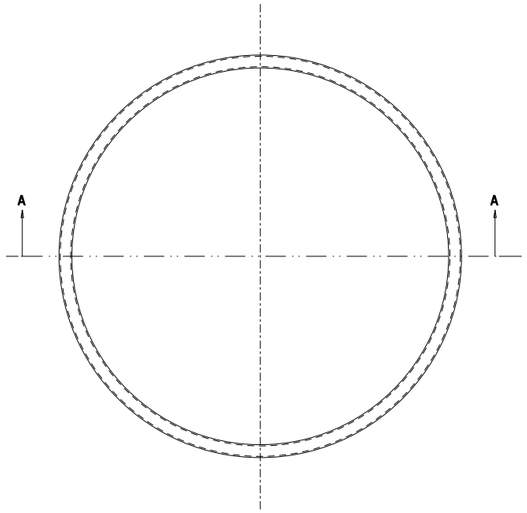
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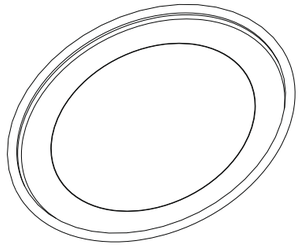
PTHIS DRAWING PRODUCED ON PRO/ENGINEER

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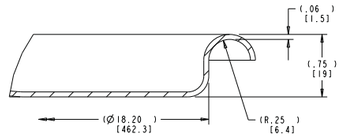
NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES.[mm].
4. FOR ADDITIONAL INFORMATION SEE EQUIPMENT SPECIFICATION DS-YMN3-801580A002.
5. LID SHALL BE FABRICATED IN ACCORDANCE WITH MILITARY SPECIFICATION MS27683-61, COVER STYLE 1.

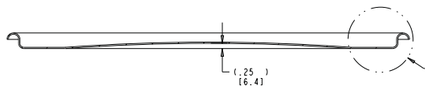


ISOMETRIC VIEW
SCALE 3/8




DETAIL Z
SCALE 2/1




SECTION A-A

-1 18.25" DIAMETER DRUM LID
SCALE 1/2

| AR | -1 | 18.25" DIA. DRUM LID | 16 GA 304/304L SST | ASME SA240 | 1 |
|---|---|---|---|---|---|
| | PART OR IDENTIFYING NO. | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | FIND NO. |
| M2E801580A006 | QTY REQ'D NEXT ASSEMBLY | PARTS LIST | | | |

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| REVISION | DATE | NCSD APPROVAL |
|---|---|---|
| B | 2/10/05 | JF DECLUE |

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Name: ROGER D. AIGNER Date: 2/10/05

| REV | DESCRIPTION | DRW | CHKR | DE | DVR | DM | DATE | PE | DATE | PM | DATE | AR | CV | ST | HV | EM | FP | PD | EE | IE | M | NP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B | GENERAL REVISION | JRP | SMM | GAB | RDA | DPS | 1/31/05 | GAB | 2/10/05 | JGA | 2/10/05 | | | | | | | | | | | |
| A | ISSUED FOR PROTOTYPE PROCUREMENT | JRJ | JSL | GAB | JLH | JCW | 10/29/03 | MRF | 10/29/03 | DBM | 10/29/03 | | | | | | | | | | | |

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK

| | | |
|---|---|---|
| SCALE: NOTED | DRW | J.R. JACKSON 10/29/03 |
| TOLERANCES UNLESS OTHERWISE SPECIFIED | CHKR | J.S. LOWERY 10/29/03 |
| | DE | G.A. BYINGTON 10/29/03 |
| FRACTIONS | DVR | J.L. HECK 10/29/03 |
| XX DECIMALS | DM | J.C. WALLS 10/29/03 |
| XXX DECIMALS | PE | M.R. FELDMAN 10/29/03 |
| ANGLES | PM | D.B. MILLER 10/29/03 |
| BREAK SHARP EDGES MAX | | |
| FINISH | | |

DRAWING APPROVALS | DATE

BWXT Y-12 National Security Complex managed by BWXT Y-12, L.L.C. for the Department of Energy under U.S. Government contract DE-AC05-00OR22800 • Oak Ridge, Tennessee •

PROJECT NAME: ES-3100 SHIPPING PACKAGE

18.25" DIAMETER DRUM LID

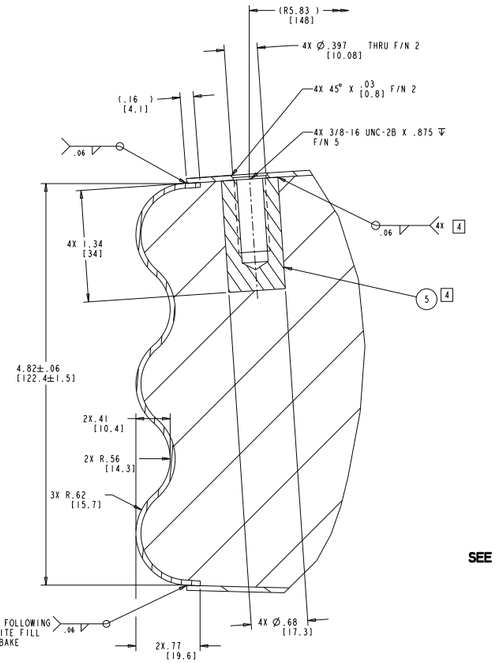
| I | 48 | 49 | 50 | PLANT | BLDG | FC | SH. OF | TYPE | CLASS |
|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | Y-12 | NA | NA | 1 1 | S | U |
| 51 | | 52 | | 53 | M2E801580A007 | | | | REV B |
| CM | | PKG | | IN | | | | | |

M2E801580A007

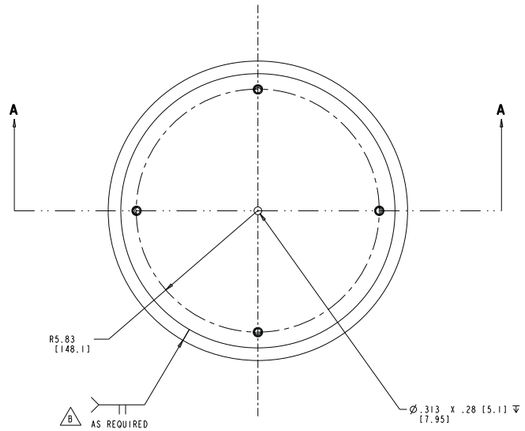
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P THIS DRAWING PRODUCED ON PRO/ENGINEER

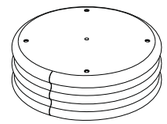
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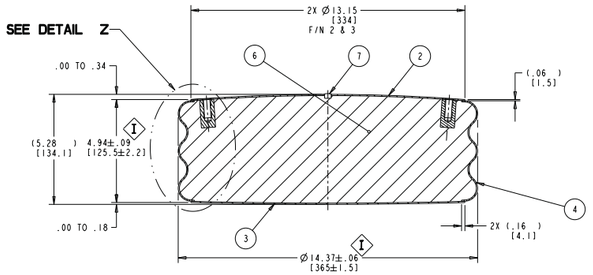

**DETAIL Z**
SCALE 2/1




**SECTION A-A**



**ISOMETRIC VIEW**
SCALE 1/4




**-1 TOP PLUG WELDMENT**
SCALE 1/2

NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES.[mm].
4. WELD LIFTING INSERTS (F/N 5) IN PLACE BEFORE FILLING WITH KAOLITE (F/N 6).
5. WELDING SYMBOLS SHALL BE INTERPRETED IN ACCORDANCE WITH AWS A2.4.
6. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATIONS JS-YMN3-801580-A002 AND A003.
7. DIMENSIONS AND FEATURES FLAGGED BY A ⟨I⟩ SYMBOL SHALL BE INSPECTED AND DOCUMENTED.
8. FOR REFERENCE ONLY:
   APPROXIMATE WEIGHT 19.6 LBS [8.8 Kg] WITH
   KAOLITE VOLUME 0.43 CU.FT.
   KAOLITE DENSITY 22.4 LBS/CU. FT.
   KAOLITE WEIGHT: 9.6 LBS [4.7 Kg]

| | | | | | | |
|---|---|---|---|---|---|---|
| | AR | | WELD FILLER METAL | PER WELD PROCEDURES | | 8 |
| | 1 | 62MP0312 OR EQUAL | PLUG, NYLON 6/6 | MICRO PLASTIC INC. FLIPPIN, AR 72634 | | 7 |
| | 1 | -6 | KAOLITE 1600 TM VIBRATED CAST | THERMAL CERAMICS AUGUSTA, GA 30903-0923 | | 6 |
| | 4 | -5 | LIFTING INSERT | 11/16 ROUND 304/304L SST | ASME SA479 | 5 |
| | 1 | -4 | PLUG RIM | 16 GA SHT 304/304L SST | ASME SA240 | 4 |
| | 1 | -3 | BOTTOM SHEET | | | 3 |
| | 1 | -2 | TOP SHEET | | | 2 |
| AR | X | -1 | TOP PLUG WELDMENT | | | 1 |
| M2E801580 A001 | | PART OR IDENTIFYING NO | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | FIND NO |
| | | QTY REQ'D NEXT ASSEMBLY | PARTS LIST | | | |

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.

| REVISION | DATE | NCSD APPROVAL |
|---|---|---|
| B | 2/10/05 | JF DECLUE |

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Name: ROGER D. AIGNER Date: 2/10/05

| REV | DESCRIPTION | DRW | CHKR | DE | OVR | DM | DATE | PE | DATE | PM | DATE | WE | DATE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B | GENERAL REVISION ADDED WELD SYMBOL | JRP | SMM | GAB | RDA | DPS | 11/17/05 | JGA | 2/11/05 | GAB | 2/11/05 | DJE | 2/11/05 |
| A | ISSUED FOR PROTOTYPE PROCUREMENT | JRJ | JSL | GAB | JLH | JCW | 10/29/03 | MPF | 10/29/03 | DEB | 10/29/03 | | |

REVISION OR ISSUE PURPOSE | REVISION APPROVALS

| SQUAD CHECK | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| AR | CV | ST | HV | EM | FP | PD | EE | IE | M | NP |
| | | | | | | | | | | |

SCALE: NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS
XX DECIMALS ±.03
XXX DECIMALS ±.005
ANGLES ±0.5°
BREAK SHARP EDGES .06 MAX
FINISH 125 RMS

DRAWING APPROVALS

| | | DATE |
|---|---|---|
| DRW | J.R. JACKSON | 10/29/03 |
| CHKR | J.S. LOWERY | 10/29/03 |
| DE | G.A. BYINGTON | 10/29/03 |
| OVR | J.L. HECK | 10/29/03 |
| DM | J.C. WALLS | 10/29/03 |
| PE | M.R. FELDMAN | 10/29/03 |
| PM | D.B. MILLER | 10/29/03 |

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PROJECT NAME: ES-3100 SHIPPING PACKAGE

TOP PLUG WELDMENT

| I | 48 | 49 | 50 | PLANT | BLDG | FL | SH. | OF | TYPE | CLASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | Y-12 | NA | NA | 1 | 1 | S | U |
| | 51 | | 52 | 53 | M2E801580A008 | | | | | REV |
| DATE | CM | | PKG | IN | | | | | | B |

M2E801580A008

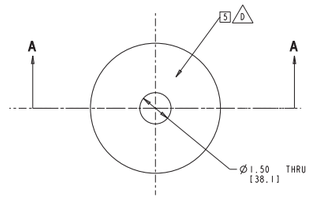
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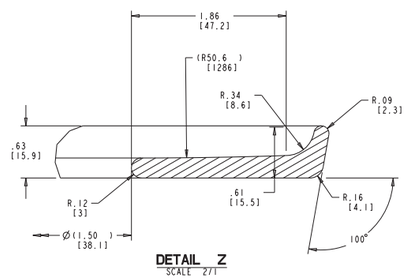
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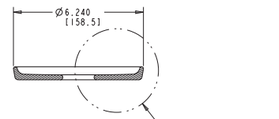
NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER "RMA" RUBBER HANDBOOK (RMA-392) CLASS "A2 PRECISION."
3. DIMENSIONS ARE IN INCHES.
4. MANUFACTURER/SUPPLIER TO PROVIDE CERTIFICATE OF COMPLIANCE FOR ALL FEATURES OF THESE ITEMS.
5. IN APPROXIMATE LOCATION SHOWN, ENGRAVE DRAWING NUMBER AND REVISION LETTER IN 1/4" HIGH CHARACTERS IN THE MOLD TO MAKE A LEGIBLE RAISED MARKINGS IN THE PART.
6. FOR ADDITIONAL INFORMATION SEE EQUIPMENT DATA SHEET DS-801580-0002.



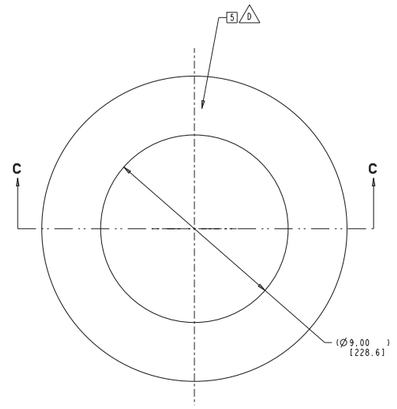



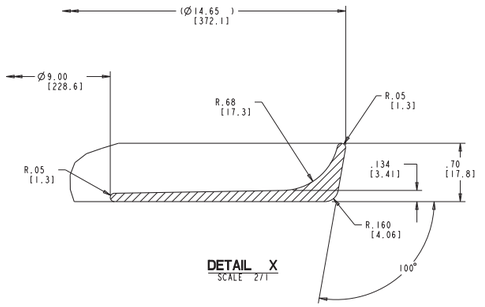

DETAIL Z
SCALE 2/1



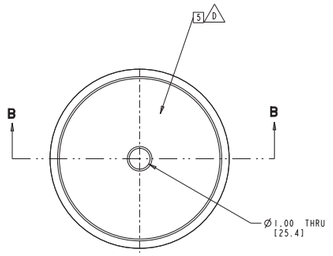

SECTION A-A

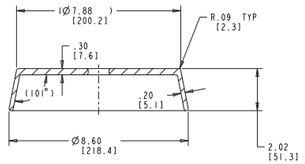
-1 CV BOTTOM PAD
SCALE 1/2
APPROXIMATE WEIGHT- 0.37 LB




DETAIL X
SCALE 2/1

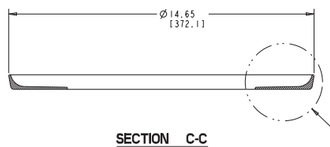



SECTION B-B

-2 CV FLANGE PAD
SCALE 1/2

APPROXIMATE WEIGHT - 1.15 LB




SECTION C-C

-3 PLUG PAD
SCALE 1/2

APPROXIMATE WEIGHT 0.77 LB

| ITEM NO | QTY REQ'D NEXT ASSEMBLY | PART OR IDENTIFYING NO. | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | FIND NO |
|---|---|---|---|---|---|---|
| | | PARTS LIST | | | | |
| 3 | AR | -3 | PLUG PAD | SILICONE RUBBER 22±5 SHORE A COLOR BLACK/GRAY | SEE NOTE 6 | 3 |
| 2 | AR | -2 | CV FLANGE PAD | | | 2 |
| 1 | AR | -1 | CV BOTTOM PAD | | | 1 |

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY ANALYSIS ENGINEERING APPROVAL.

| REVISION | DATE | SAE APPROVAL |
|---|---|---|
| D | 6/05/2012 | J.F. DeCLUE |

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Name: DREW WINDER Date: 06/06/12

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| PART | REV | DESCRIPTION | DRW | CHKR | DE | DVR | DM | DATE | PE | DATE | SE | DATE | WE | DATE | WCS | DATE | OM/SD | DATE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 000 | D | DELETED FIND NO 4, ADDED NOTE 6, CHANGED NOTE 5, REMOVED VENDOR FROM PARTS LIST | CDB | DEW | MLG | DEW | WIN | 6/11/12 | WIN | 6/11/12 | JGA | 6/18/12 | | | | | | |
| 000 | C | GEN REV: REDESIGNED F/N 1; ADDED APPROXIMATE WEIGHT TO F/N 1, 2 AND 3 | JRP | SMM | GAB | RDA | DPS | 11/13/06 | GAB | 7/10/05 | JGA | 7/10/05 | | | | | | |
| 000 | B | MODIFIED DIMENSIONING ON -3 | GAB | RA | GAB | JLH | JCW | 11/27/04 | GAB | 11/27/04 | JGA | 11/27/04 | | | | | | |
| 000 | A | ISSUED FOR PROTOTYPE PROCUREMENT | JRJ | JSL | GAB | JLH | JCW | 08/29/03 | MRF | 08/29/03 | DBM | 08/29/03 | | | | | | |

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK | DRAWING APPROVALS

| SQUAD CHECK | AR | CV | ST | HV | EM | FP | PD | EE | IE | W | NP |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DATE | | | | | | | | | | | |

SCALE: NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS
XX DECIMALS
XXX DECIMALS
ANGLES
BREAK SHARP EDGES MAX
FINISH

| DRAWING APPROVALS | | |
|---|---|---|
| DRW | J.R. JACKSON | 10/29/03 |
| CHKR | J.S. LOWERY | 10/29/03 |
| DE | G.A. BYINGTON | 10/29/03 |
| DVR | J.L. HECK | 10/29/03 |
| DM | J.C. WALLS | 10/29/03 |
| PE | M.R. FELDMAN | 10/29/03 |
| SE | | |
| OM/SD | D.B. MILLER | 10/29/03 |
| WE | N/R | |

Y-12 National Security Complex managed by B & W Technical Services Y-12, LLC for the Department of Energy under U.S. Government contract DE-AC 05-00OR22800 • Oak Ridge, Tennessee •

PROJECT NAME: ES-3100 SHIPPING PACKAGE

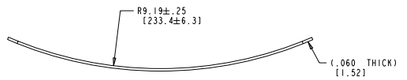
PAD DETAILS

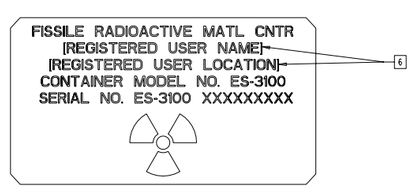
| USE | DISC | DT | DC | CM | SYSTEM | STAT | SIZE | BLDG | FL | CLASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | CM | PKG | IN | E | NA | NA | U |

| SH. | OF | TYPE | PART | REV |
|---|---|---|---|---|
| 1 | 1 | DD | M2E801580A009 | 000 D |

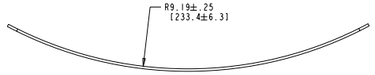
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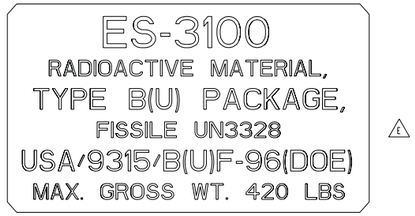
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-1 ES-3100 TREFOIL DATA PLATE
FORMED

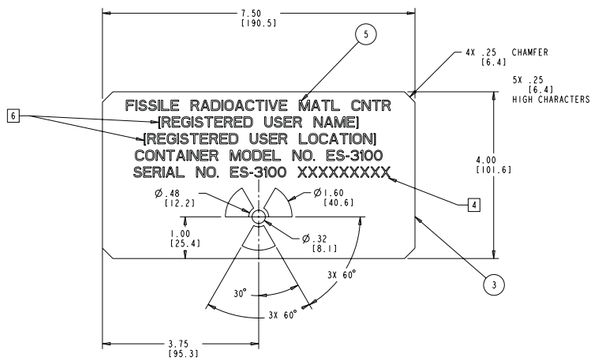


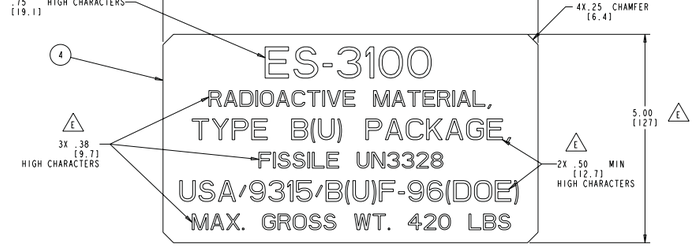

-2 ES-3100 DATA PLATE
FORMED

NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES [mm].
4. CONTAINER SERIAL NUMBER SHOWN "XXXXXXXXX" IS A GENERIC REPRESENTATION, ACTUAL SERIAL NUMBERS SHALL BE SPECIFIED IN PURCHASE ORDER, OR PROCUREMENT CONTRACT.
5. ALL CHARACTERS AND SYMBOLS SHALL BE ELECTROCHEMICALLY ETCHED .003-.005 DEEP AND FILLED WITH BLACK ENAMEL PAINT (F/N 5).
6. SEE PROCUREMENT DOCUMENTS FOR PROPER REGISTERED USER NAME AND LOCATION.




-1 ES-3100 TREFOIL DATA PLATE
SCALE 1/1
FLAT PATTERN




-2 ES-3100 DATA PLATE
SCALE 1/1
FLAT PATTERN

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | AR | AR | -5 | PAINT, BLACK ENAMEL | | FED SPEC 595b-17038 | 5 |
| | | 1 | -4 | 16 GA, SHEET | 304/304L SST | ASME SA240 | 4 |
| | | 1 | -3 | | | | 3 |
| E | AR | | -2 | ES-3100 DATA PLATE | | | 2 |
| | AR | | -1 | ES-3100 TREFOIL DATA PLATE | | | 1 |
| MATERIAL ASSY | QTY REQ'D NEXT ASSEMBLY | | PART OR IDENTIFYING NO | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | FIND NO |

PARTS LIST

E THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY ANALYSIS ENGINEERING APPROVAL.

| REVISION | DATE | SAE APPROVAL |
|---|---|---|
| E | 09/10/09 | J.E. DECLUE |

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Name: R.D. AIGNER Date: 09/10/09

| REV | DESCRIPTION | DRW | CHKR | DE | DVR | DM | DATE | PE | DATE | PM | DATE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| E | REVISED DATA PLATE F/N 2 & 4, UPDATED SAE BLOCK. | MLE | JRJ | ML | E | DEW | W I N | 9/10/09 | LR | 9/10/09 | JGA 9/10/09 |
| D | REVISED TREFOIL DATA PLATE, F/N 1, ADDED NOTE 6 | JRJ | RDA | LR | GAB | W I N | 9/9/08 | LR | 9/9/08 | JGA | 9/9/08 |
| C | REVISED TREFOIL DATA PLATE, F/N 1, AND NOTE 4 | JRJ | RDA | JRJ | GAB | W I N | 8/16/06 | MAR | 8/16/06 | JGA | 8/17/06 |
| B | GEN REV: REMOVED RIVIT HOLES F/N 1 & 2; ADDED CHAMFERS F/N 1 & 2; ADDED NEW FLAT PATTERN VIEWS; REMOVED NOTE 5; CHANGED NOTE 6 TO NOTE 5; REMOVED NOTE 7; REMOVED INDEX NOTE BOX 5; CHANGED INDEX NOTE BOX 7 TO 4 | JRP | SMM | GAB | RDA | DPS | 11/18/05 | GAB | 2/10/05 | JGA | 2/10/05 |
| A | ISSUED FOR PROTOTYPE PROCUREMENT | JRJ | JSL | GAB | JLH | JCW | 8/29/03 | MRF | 10/29/03 | DBM | 10/29/03 |

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK

| | AR | CV | ST | HV | EM | FP | PD | EE | IE | W | NP |
|---|---|---|---|---|---|---|---|---|---|---|---|

DRAWING APPROVALS

SCALE: NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS
XX DECIMALS ±.03
XXX DECIMALS ±.005
ANGLES ±0.5°
BREAK SHARP EDGES .06 MAX
FINISH 125 RMS

| | | DATE |
|---|---|---|
| DRW | J.R. JACKSON | 10/29/03 |
| CHKR | J.S. LOWERY | 10/29/03 |
| DE | G.A. BYINGTON | 10/29/03 |
| DVR | J.L. HECK | 10/29/03 |
| DM | J.C. WALLS | 10/29/03 |
| PE | M.R. FELDMAN | 10/29/03 |
| PM | D.B. MILLER | 10/29/03 |

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PROJECT NAME: ES-3100 SHIPPING PACKAGE

DATA PLATE DETAILS

| 1 | 48 | 49 | 50 | PLANT | BLDG | FL | SH. | OF | TYPE | CLASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | Y-12 | NA | NA | 1 | 1 | S | U |

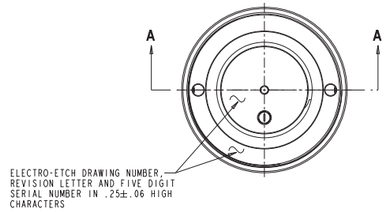
| 51 | 52 | 53 | | REV |
|---|---|---|---|---|
| CM | PKG | IN | M2E801580A010 | E |

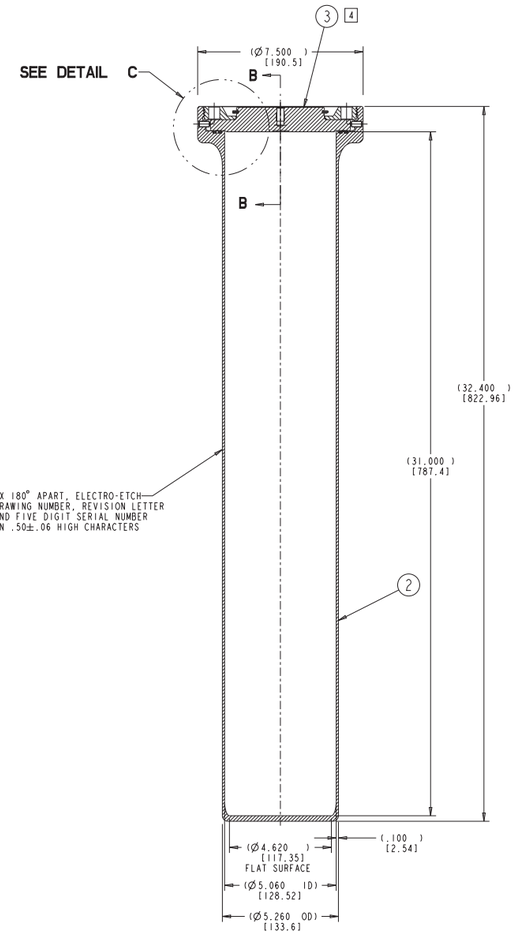
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P THIS DRAWING PRODUCED ON PRO/ENGINEER

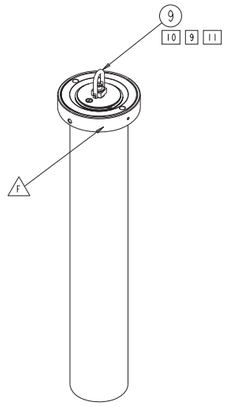
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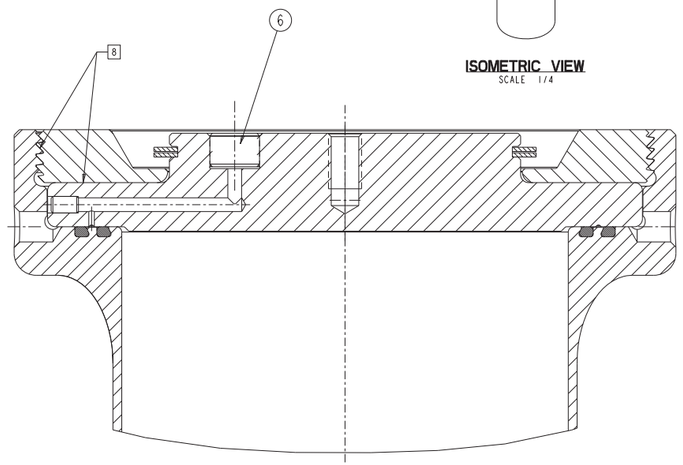




SECTION A-A

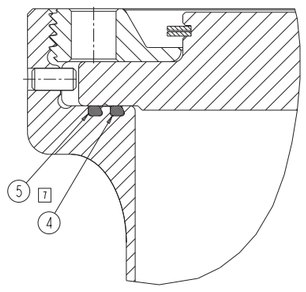
-1 CONTAINMENT VESSEL ASSEMBLY
SCALE 1/2



ISOMETRIC VIEW
SCALE 1/4



SECTION B-B
SCALE 2/1



DETAIL C
SCALE 2/1

NOTES

1. INTERPRET DRAWING PER ENGINEERING DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994. PERFECT ORIENTATION AT MMC FOR INTERRELATED FEATURES REQUIRED.
3. DIMENSIONS ARE IN INCHES [mm].
4. INSTALL THE LID NUT AND TORQUE TO 120 ±5 FT-LBS AS SHOWN ON M2E801580A020-3 AND A020-4.
5. APPROXIMATE WEIGHT: 32.98 LBS. [14.96 KG].
6. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPEC. DS-YMN3-801580-A001.
7. DURING INSTALLATION OF O-RINGS APPLY A THIN COAT OF SUPER-O-LUBE.
8. DURING INSTALLATION OF CONTAINER VESSEL LID ASSEMBLY, APPLY A LIGHT COAT OF KRYTOX GREASE TO THE THREADS AND UNDER THE NUT.
9. SWIVEL HOIST RING FOR USE WHEN LOADING AND UNLOADING CONTAINMENT VESSEL ONLY. NOT FOR SHIPMENT.
10. TORQUE SWIVEL HOIST RING TO 12 ±1 FT.LBS. PER MFGR'S SPEC.
11. THE SWIVEL HOIST RING, THREAD LUBRICANT AND O-RING LUBRICANTS ARE REQUIRED AT EACH LOADING AND MAINTENANCE STATION.

F NOTE DELETED

| | | | | | | |
|---|---|---|---|---|---|---|
| F | | | | | | |
| 11 10 9 | AR | 3052T56 OR EQUAL | SWIVEL HOIST RING | ALLOY STEEL | McMASTER- CARR ATLANTA, GA | 9 |
| 11 10 9 | AR | KRYTOX 8240AC OR EQUAL | THREAD LUBRICANT | FLUORINATED GREASE | MILLER-STEPHENSON CHEMICAL CO. DANBURY, CT 06810 | 8 |
| 11 8 | AR | SUPER-O-LUBE OR EQUAL | O-RING LUBRICANT | CLEAR DIMETHYL SILOXANE POLYMER | PARKER HANNIFIN CORP. O-RING DIV.PO BOX 11751 LEXINGTON, KY 40512 | 7 |
| 11 7 | 1 | PART # 04-2126 | MODIFIED VCO THREADED PLUG | BRASS | VOLUNTEER INDUSTRIAL P. O. BOX 30371 KNOXVILLE, TN 37930 PHONE 865-660-2617 | 6 |
| | 1 | M2E801580A013-2 OR M801580-0013-2 | O-RING, OUTER | | | 5 |
| | 1 | M2E801580A013-1 OR M801580-0013-1 | O-RING, INNER | | | 4 |
| | 1 | M2E801580A014-1 | CONTAINMENT VESSEL LID ASSEMBLY | | | 3 |
| | 1 | M2E801580A012-1 OR A012-4 | CONTAINMENT VESSEL BODY ASSEMBLY | | | 2 |
| AR | X | -1 | CONTAINMENT VESSEL ASSEMBLY | | | 1 |
| M2E801580 A001 -1 | | PART OR IDENTIFYING NO | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | FIND NO |
| | | QTY REQ'D NEXT ASSEMBLY | PARTS LIST | | | |

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY ANALYSIS ENGINEERING APPROVAL.

| REVISION | DATE | SAE APPROVAL |
|---|---|---|
| F | 6/11/15 | ALAN WILKINSON |

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Name: STAN THOMAS Date: 06/11/15

C THIS DRAWING PRODUCED ON CREO PARAMETRIC

THIS DRAWING IS LOANED FOR SOLE USE OF THE INTENDED RECIPIENT AND ONLY FOR THE LIMITED PURPOSES FOR WHICH IT WAS PROVIDED. USE BY OTHER ENTITIES OR FOR OTHER PURPOSES IS PROHIBITED AND AT THE USER'S OWN RISK. DRAWINGS ARE TO BE RETURNED UPON REQUEST OF THE FORWARDING RECIPIENT.

| PART | REV | DESCRIPTION | DRW | CHKR | DE | DVR | DM | DATE | PE | DATE | PM | DATE | WE | DATE | NCS | DATE | QM/SO | DATE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 000 | F | REMOVED TEMPERATURE LABEL F/N 10 AND DELETED NOTE 13; UPDATED FORMAT | KWJ | MLG | GAB | MLG | JCA | 6/11/15 | JCA | 6/11/15 | JGA | 6/18/15 | | | | | | |
| 000 | E | DELETED NOTE 12. ADDED NEW PART NUMBERS FOR F/N 4 AND F/N 5. ADDED F/N 10 TO PARTS LIST AND ADDED NOTE 13 TO NOTES | CDB | DEW | MLG | DEW | WIN | 6/11/12 | WIN | 6/11/12 | JGA | 6/18/12 | | | | | | |
| 000 | D | ADDED REFERENCE NOTE 12. | MLE | JRJ | MLE | DEW | WIN | 5/18/09 | LR | 5/18/09 | JGA | 5/14/09 | | | | | | |
| 000 | C | GENERAL REVISION DELETED F/N 9; RENUMBERED F/N 10 TO NEW F/N 9; ADDED NOTE 11; NOTE 4 TORQUE WAS 100 | JRP | SMM | GAB | RDA | DPS | 11/13/05 | GAB | 11/10/05 | JGA | 11/10/05 | | | | | | |
| 000 | B | -6 WAS A FABRICATED PART, ADDED A012-4 WELDED CV OPTION | | GAB | RA | GAB | JLH | JCW | 01/22/04 | GAB | 01/22/04 | JGA | 01/22/04 | | | | | |
| 000 | A | ISSUED FOR PROTOTYPE PROCUREMENT | | JRJ | JSL | GAB | JLH | JCW | 08/29/03 | MRF | 08/29/03 | DBM | 08/29/03 | | | | | |

REVISION APPROVALS: AR CV ST HV EM FP PD EE IE M NP

SQUAD CHECK

| DRAWING APPROVALS | | DATE |
|---|---|---|
| SCALE: NOTED | DRW JRJ/S.W. SPARKS | 10/29/03 |
| TOLERANCES UNLESS OTHERWISE SPECIFIED | CHKR J.S. LOWERY | 10/29/03 |
| | DE G.A.BYINGTON | 10/29/03 |
| | DVR J.L. HECK | 10/29/03 |
| FRACTIONS | DM J.C. WALLS | 10/29/03 |
| XX DECIMALS ±.01 | PE M.R. FELDMAN | 10/29/03 |
| XXX DECIMALS ±.005 | SE | |
| ANGLES ±0.5° | QM/SO D.B. MILLER | 10/29/03 |
| BREAK SHARP EDGES .06 MAX | WE N/R | |
| FINISH 125 RMS | | |

Y-12 National Security Complex managed and operated by Consolidated Nuclear Security, LLC for the Department of Energy under U.S. Government contract DE-NA0001942 a Oak Ridge, Tennessee a

PROJECT NAME: ES-3100 SHIPPING PACKAGE

CONTAINMENT VESSEL ASSEMBLY

| USE | DISC | DT | DC | CM | SYSTEM | STA | SIZE | BLDG | FL | CLASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | CM | PKG | IN | E | NA | NA | U |

| SH. | OF | TYPE | PART | REV |
|---|---|---|---|---|
| 1 | 1 | DD | M2E801580A011 | 000 F |

M2E801580A011

8 | 7 UNCLASSIFIED | 6 | 5 | 4 | 3 | 2 UNCLASSIFIED | 1

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NOTES

1 INTERPRET DRAWING PER ENGINEERING DRAFTING STANDARD ES-3.1.

2 INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994. PERFECT ORIENTATION AT MMC FOR INTERRELATED FEATURES REQUIRED.

3 DIMENSIONS ARE IN INCHES [mm].

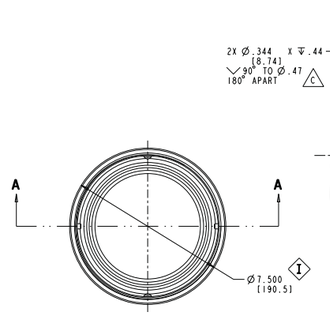
4 APPROXIMATE WEIGHT: 22.44 LBS [10.18 Kg].

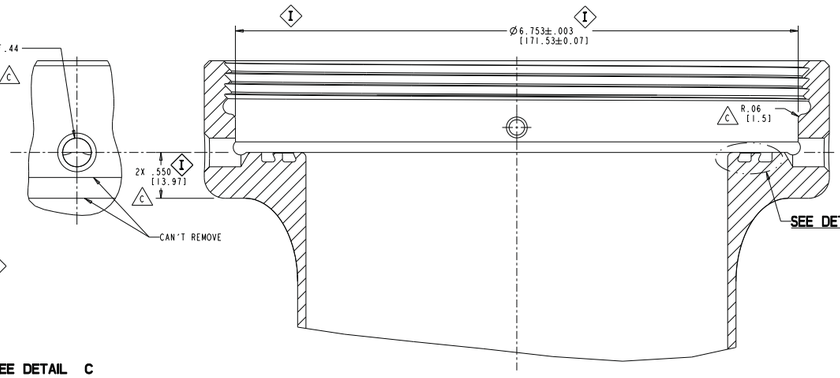
5 FOR ADDITIONAL REQUIREMENTS SEE JS-YMN3-801580-A001.

6 DIMENSIONS AND FEATURES FLAGGED BY A (I) SYMBOL SHALL BE INSPECTED AND DOCUMENTED.

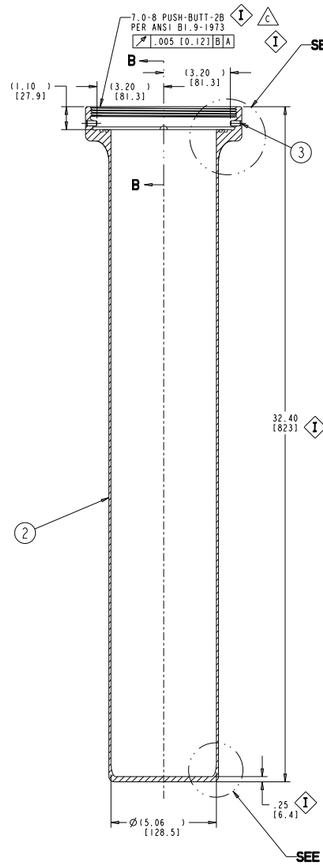
7 VERIFY THE CONTAINMENT VESSEL INTERNAL DIAMETER BY USING THE MINIMUM CVID GAGE. THE CVID GAGE SHALL BE 10.30 +/- 0.03 LONG BY 5.020 +/- .001 EXTERNAL DIAMETER WITH A 20 DEGREE CHAMFER FROM THE CYLINDER TO A 4.52 +/- .03 DIAMETER ON THE BOTTOM. THE BOTTOM SHALL BE FINISHED WITH A .25 THICK YELLOW BRASS PLATE.

8 THE FORMED BODY CONSTRUCTION SHOWN IN PART -2 IS PREFERED. THE ALTERNATIVE WELDED OPTION SHOWN IN PART -4 ON SHEET 2 IS ALSO ACCEPTABLE. PART -4 SHALL CONFORM TO THE PART -1 DIMENSIONS.

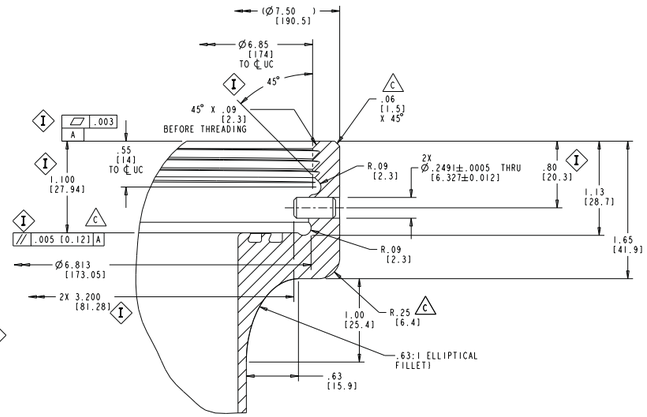


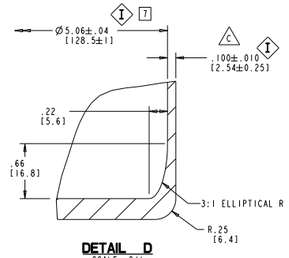

SECTION B-B
SCALE 2/1



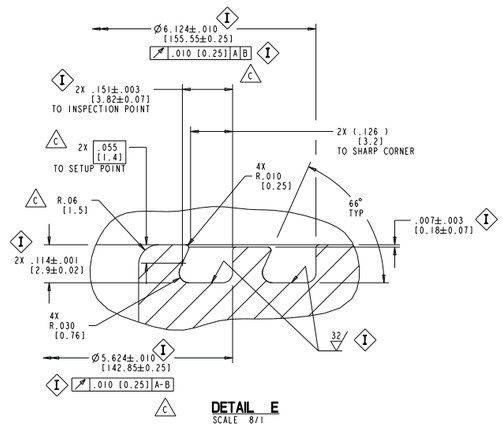

SECTION A-A



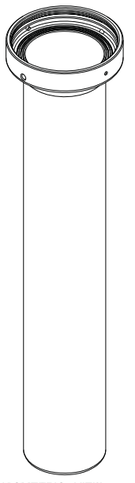

DETAIL C
SCALE 2/1




DETAIL D
SCALE 2/1




DETAIL E
SCALE 8/1



ISOMETRIC VIEW
SCALE 3/8

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1 | -7 | CONTAINMENT VESSEL END CAP | SST | ASME SA-182 TYPE F304L | 7 |
| | | | 1 | -6 | CV PIPE BODY SIPS SCH40 | | ASME SA-312 TYPE TP304L | 6 |
| | | | 1 | -5 | CONTAINMENT VESSEL FLANGE | | ASME SA-182 TYPE F304L | 5 |
| 7 8 | AR | AR | X | -4 | CONTAINMENT VESSEL BODY ASSEMBLY WELDED OPTION | | | 4 |
| C | | | 2 2 | -3 | DOWEL PIN, .50 LONG Ø0.2501/0.2503 OD | 18-8-SST | ANSI B18.8.2 | 3 |
| | | | 1 | -2 | CONTAINMENT VESSEL FORMED BODY | 304L SST | SEE NOTE 5 | 2 |
| 7 8 | AR | AR | X | -1 | CONTAINMENT VESSEL BODY ASSEMBLY | | | 1 |
| M2E801580 A002 / M2E801580 A003 | | -4 | - | PART OR IDENTIFYING NO / QTY REQD / NEXT ASSY | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | FIND NO |

PARTS LIST

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.

| REVISION | DATE | NCSD APPROVAL |
|---|---|---|
| C | 2/10/05 | JF DECLUE |

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Name: ROGER D. AIGNER Date: 2/10/05

-1 CONTAINMENT VESSEL BODY ASSEMBLY

| REV | DESCRIPTION | DRW | CHKR | DE | DVR | DM | DATE | PE | DATE | PM | DATE | ME | DATE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C | GEN REV; REMOVED ALL MMC & RFS SYMS FROM GEO TOLS; MODIFIED GEO TOLS TO PRIMARY & SECONDARY DATUM REF ADDED VIEW ZONE G-6; ADDED .06 X 45° CHAM; ADDED TOL TO DIM IN DETAIL D; ADDED ANSI SPEC TO BOM; CHNG G TO U IN WELD SYM SHT 2 | JRP | SMM | GAB | RA | GAB | RDA | DPS | 1/11/05 | GAB | 2/1/05 | JGA | 2/1/05 | DJE | 2/11/05 |
| B | ADDED PARTS -4,-5,-6, AND -7 ON SHEET 2 ALSO, GENERAL REVISIONS TO SHEET 1. | GAB | RA | GAB | JLH | JCW | 11/22/04 | GAB | 11/22/04 | JGA | 11/22/04 | | | | |
| A | ISSUED FOR PROTOTYPE PROCUREMENT | DWS | JSL | GAB | JLH | JCW | 10/29/03 | MRF | 10/29/03 | DBM | 10/29/03 | | | | |

REVISION OR ISSUE PURPOSE / REVISION APPROVALS

| SQUAD CHECK | AR | CV | ST | HV | EM | FP | PD | EE | IE | M | NP |
|---|---|---|---|---|---|---|---|---|---|---|---|

SCALE: NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS
XX DECIMALS ±.01
XXX DECIMALS ±.005
ANGLES ±0.5°
BREAK SHARP EDGES .06 MAX
FINISH 125 RMS

| DRAWING APPROVALS | | DATE |
|---|---|---|
| DRW | JRJ for D.W. SPARKS | 10/29/03 |
| CHKR | J.S. LOWERY | 10/29/03 |
| DE | G.A. BYINGTON | 10/29/03 |
| DVR | J.L. HECK | 10/29/03 |
| DM | J.C. WALLS | 10/29/03 |
| PE | M.R. FELDMAN | 10/29/03 |
| PM | D.B. MILLER | 10/29/03 |

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PROJECT NAME
ES-3100 SHIPPING PACKAGE

CONTAINMENT VESSEL BODY ASSEMBLY

| I | 48 | 49 | 50 | PLANT | BLDG | FL | SH. | OF | TYPE | CLASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | Y-12 | NA | NA | 1 | 2 | S | U |

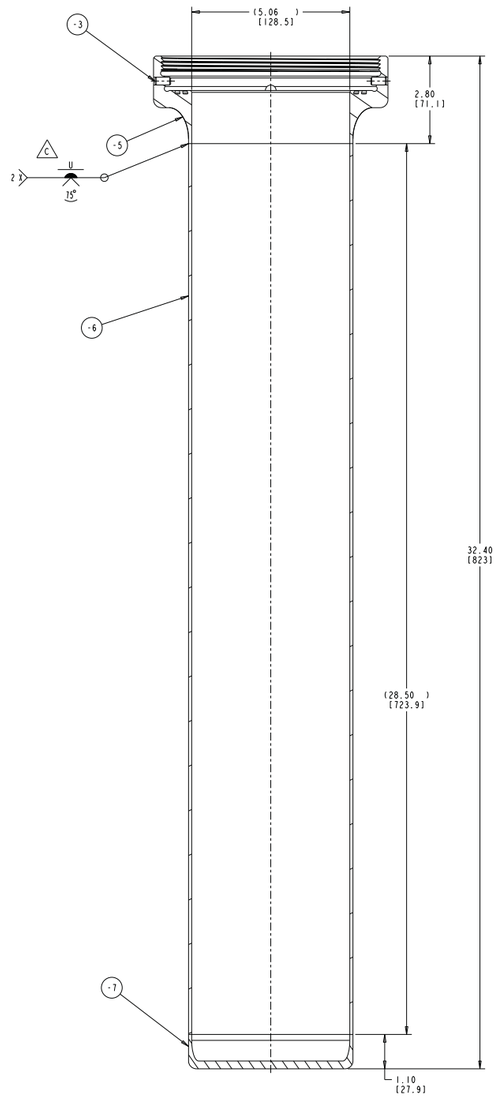
| 51 | 52 | 53 | | REV |
|---|---|---|---|---|
| CM | PKG | IN | M2E801580A012 | C |

M2E801580A012

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**-4 CONTAINMENT VESSEL BODY ASSEMBLY WELDED OPTION**

SCALE 3/4

NEXT ASS'Y: FINAL ASS'Y:

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PTHIS DRAWING PRODUCED ON PRO/ENGINEER

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PROJECT NAME
ES-3100 SHIPPING PACKAGE

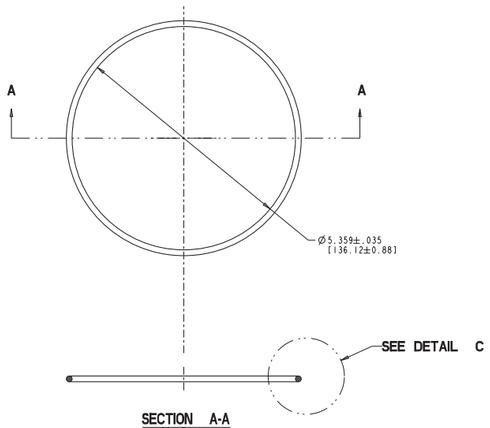
CONTAINMENT VESSEL BODY ASSEMBLY

| 1 | 48 | 49 | 50 | PLANT | BLDG | FL | SH. OF | TYPE | CLASS |
|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | Y-12 | NA | NA | 2 2 | S | U |
| 51 | | 52 | 53 | | M2E801580A012 | | | | REV |
| CM | | PKG | IN | | | | | | C |

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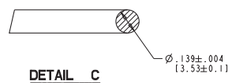
NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES.[mm].
4. (D) O-RING SHALL MEET THE REQUIREMENTS SPECIFIED IN EQUIPMENT SPECIFICATION SPC-M801580-0002.

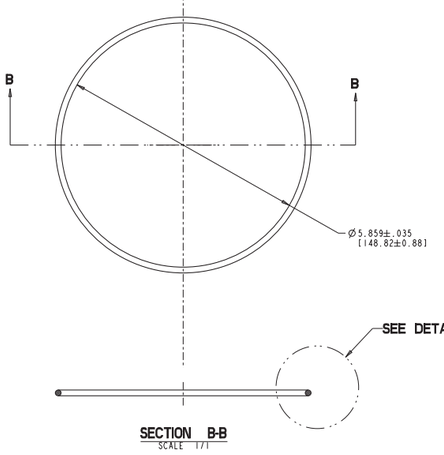



SECTION A-A
SCALE 1/1

-1 INNER O-RING

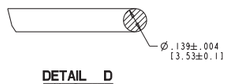



DETAIL C
SCALE 4/1




SECTION B-B
SCALE 1/1

-2 OUTER O-RING




DETAIL D
SCALE 4/1

| | | | | | |
|---|---|---|---|---|---|
| | AR | -2 | OUTER O-RING | SEE NOTE 4 | 2 |
| AR | AR | -1 | INNER O-RING | | 1 |
| M2E801580-A013-2 M2E801580-A013-1 | | PART OR IDENTIFYING NO | NOMENCLATURE OR DESCRIPTION | MATERIAL / SPECIFICATION | FIND NO |
| | | QTY REQ'D NEXT ASSEMBLY | PARTS LIST | | |

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| REVISION | DATE | SAE APPROVAL |
|---|---|---|
| D | 06/05/2012 | J.F. DeCLUE |

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Name: DREW WINDER Date: 6/06/2012

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| PART | REV | DESCRIPTION | DRW | CHKR | DE | DVR | DM | DATE | PE | DATE | SE | DATE | WE | DATE | MCS | DATE | OM/SO | DATE | AR | CV | ST | HV | EN | FP | PD | EE | IE | W | NP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | REVISION OR ISSUE PURPOSE | REVISION APPROVALS | | | | | | | | | | | | | | | | SQUAD CHECK | | | | | | | | | | |
| 000 | D | RESPECIFIED MATERIAL COMPOSITION AND SPECIFICATION FOR O-RINGS | CDB | DEW | MLG | DEW | WLN | 6/11/12 | WLN | 6/11/12 | JGA | 6/18/12 | | | | | | | | | | | | | | | | | |
| 000 | C | ADDED REFERENCE NOTE 5. | MLE | JRJ | MLE | >< | CMA | 6/15/09 | LLB | 6/15/09 | CMA | 6/15/09 | | | | | | | | | | | | | | | | | |
| 000 | B | GEN REV; -1 WAS 2-253; -2 WAS 2-257;302°F WAS 300°F | JRP | SMM | GAB | RDA | DPS | 7/18/05 | GAB | 7/18/05 | JGA | 7/18/05 | | | | | | | | | | | | | | | | | |
| 000 | A | ISSUED FOR PROTOTYPE PROCUREMENT | DWS | JSL | GAB | JLH | JCW | 8/29/03 | MRF | 8/29/03 | DBM | 8/29/03 | | | | | | | | | | | | | | | | | |

| | |
|---|---|
| SCALE: | NOTED |
| TOLERANCES UNLESS OTHERWISE SPECIFIED | |
| FRACTIONS | |
| XX DECIMALS ±.01 | |
| XXX DECIMALS ±.005 | |
| ANGLES ±0.5° | |
| BREAK SHARP EDGES .06 MAX | |
| FINISH 125 RMS | |

| DRAWING APPROVALS | | |
|---|---|---|
| DRW | JRJ/D.B. SPARKS | 10/26/03 |
| CHKR | J.S. LOWERY | 10/29/03 |
| DE | GAB | 10/29/03 |
| DVR | J.L. HICKS | 10/29/03 |
| DM | J.C. WALLS | 10/29/03 |
| PE | M.R. FELDMAN | 10/29/03 |
| SE | | |
| OM/SO | D.B. MILLER | 10/29/03 |
| WE | N/R | |
| DATE | | |

Y-12 National Security Complex managed by B & W Technical Services Y-12, LLC for the Department of Energy under D.E. Government contract DE-AC-05-00OR22800 • Oak Ridge, Tennessee •

PROJECT NAME: ES-3100 SHIPPING PACKAGE

CONTAINMENT VESSEL O-RING DETAILS

| USE | DISC | DT | DC | CM | SYSTEM | STAT | SIZE | BLDG | FL | CLASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | CM | PKG | IN | E | NA | NA | U |

| SH. | OF | TYPE | PART | REV |
|---|---|---|---|---|
| 1 | 1 | DD | 000 | D |

M2E801580A013

M2E801580A013

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NOTES

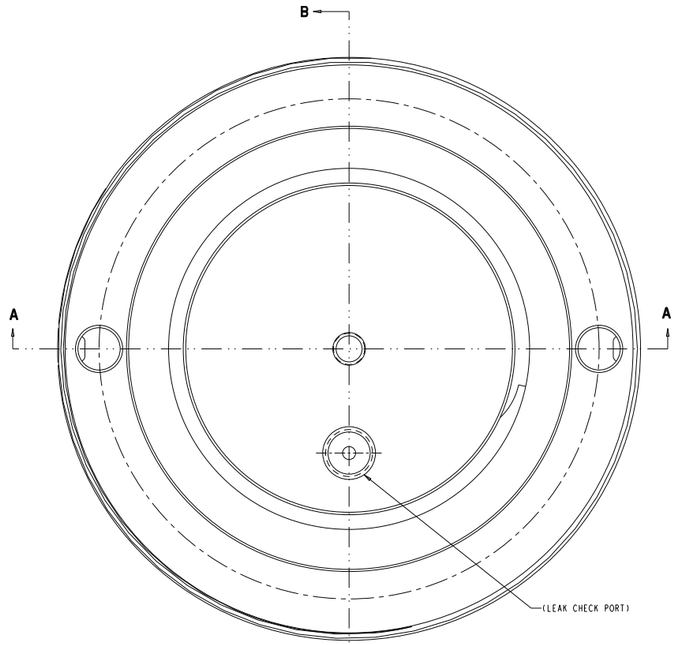
1 INTERPRET DRAWING PER ENGINEERING DRAFTING STANDARD ES-3.1.

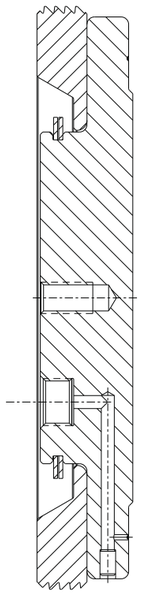
2 INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994. PERFECT ORIENTATION AT MMC FOR INTERRELATED FEATURES REQUIRED.

3 DIMENSIONS ARE IN INCHES [mm].

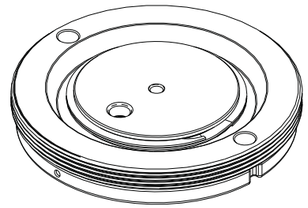
4 APPROXIMATE WEIGHT: 10.54 LBS [4.78 Kg].

5 FOR ADDITIONAL REQUIREMENTS SEE JS-YMN3-801580-A001.

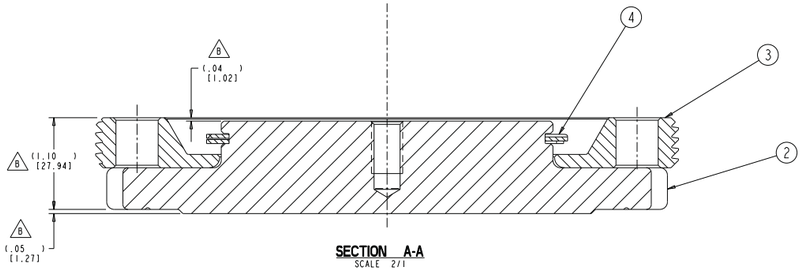


SECTION B-B



ISOMETRIC VIEW
SCALE 1/1




SECTION A-A
SCALE 2/1

-1 CONTAINMENT VESSEL LID ASSEMBLY

| | | | | | |
|---|---|---|---|---|---|
| | 1 | WSM-400-S02 | EXTERNAL RETAINING RING | SMALLEY STEEL RING CO. 385 GILMAN AVE. WHEELING, IL 60090 | 4 |
| | 1 | M2E801580A016-1 | CONTAINMENT VESSEL CLOSURE NUT | | 3 |
| | 1 | M2E801580A015-1 | CONTAINMENT VESSEL SEALING LID | | 2 |
| AR | AR | -1 | CONTAINMENT VESSEL LID ASSEMBLY | | 1 |
| M2E801580 A013 M2E801580 A001 | | PART OR IDENTIFYING NO / QTY REQD / NEXT ASSY | NOMENCLATURE OR DESCRIPTION | MATERIAL / SPECIFICATION | FIND NO |

PARTS LIST

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.

| REVISION | DATE | NCSD APPROVAL |
|---|---|---|
| B | 2/10/05 | JF DECLUE |

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Name: ROGER D. AIGNER Date: 2/10/05

| REV | DESCRIPTION | DRW | CHKR | DE | DVR | DM | DATE | PE | DATE | PM | DATE | AR | CV | ST | HV | EM | FP | PD | EE | IE | M | NP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B | GEN. REV. THREAD RELIEF IN SECTION B-B; DIMS WERE 3 PLACE | JRP | SMM | GAB | RDA | DPS | 1/17/05 | GAB | 2/10/05 | JGA | 2/10/05 | | | | | | | | | | | |
| A | ISSUED FOR PROTOTYPE PROCUREMENT | DWS | JSL | GAB | JLH | JCW | 10/29/03 | MRF | 10/29/03 | DBM | 10/29/03 | | | | | | | | | | | |

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK | DRAWING APPROVALS

SCALE: NOTED

TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS
XX DECIMALS
XXX DECIMALS
ANGLES
BREAK SHARP EDGES MAX
FINISH

| | | |
|---|---|---|
| DRW | JRJ for D.W. SPARKS | 10/29/03 |
| CHKR | J.S. LOWERY | 10/29/03 |
| DE | G.A. BYINGTON | 10/29/03 |
| DVR | J.L. HECK | 10/29/03 |
| DM | J.C. WALLS | 10/29/03 |
| PE | M.R. FELDMAN | 10/29/03 |
| PM | D.B. MILLER | 10/29/03 |

Y-12 National Security Complex managed by BWXT Y-12, L.L.C. for the Department of Energy under U.S. Government contract DE-AC05-00OR22800 at Oak Ridge, Tennessee

PROJECT NAME: ES-3100 SHIPPING PACKAGE

CONTAINMENT VESSEL LID ASSEMBLY

| 1 | 48 | 49 | 50 | PLANT | BLDG | FL | SH. | OF | TYPE | CLASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | Y-12 | NA | NA | 1 | 1 | S | U |

| 51 | 52 | 53 | | REV |
|---|---|---|---|---|
| CM | PKG | IN | M2E801580A014 | B |

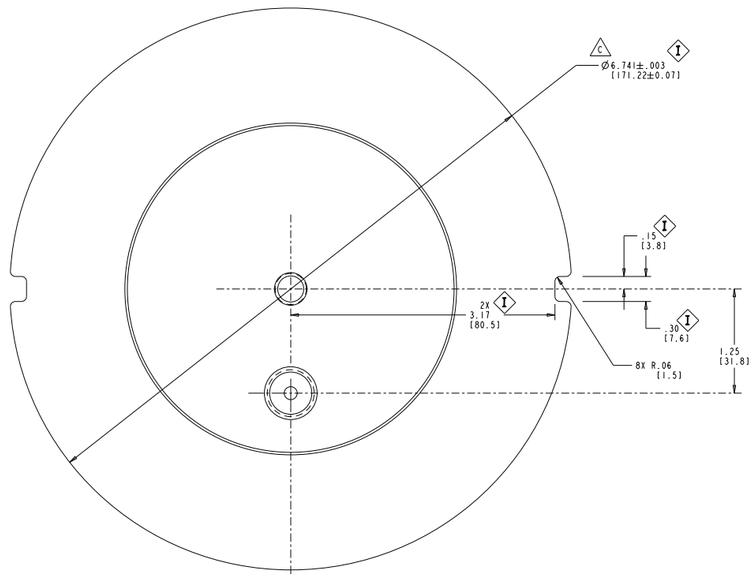
DATE

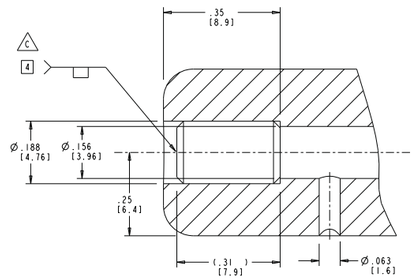
M2E801580A014

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PTHIS DRAWING PRODUCED ON PRO/ENGINEER

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DETAIL C
SCALE 8/1

NOTES

1 INTERPRET DRAWING PER ENGINEERING DRAFTING STANDARD ES-3.1.

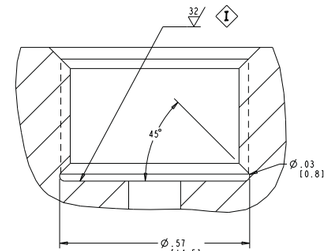
2 INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994. PERFECT ORIENTATION AT MMC FOR INTERRELATED FEATURES REQUIRED.

3 DIMENSIONS ARE IN INCHES [mm].

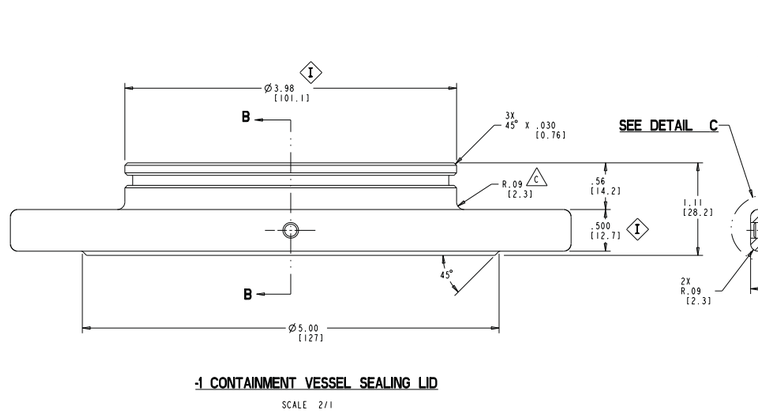
C 4 WELD BAR (F/N 3) TO CONTAINER LID (F/N 2) BEFORE FINAL MACHINING.

5 FOR ADDITIONAL REQUIREMENTS SEE JS-YMN3-801580-A001.

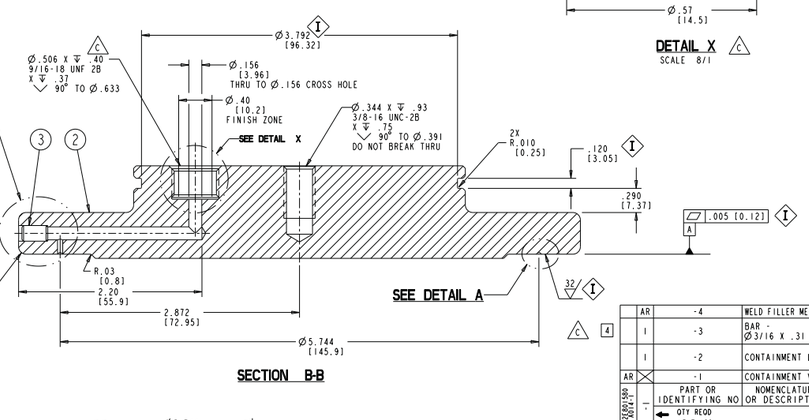
6 DIMENSIONS OR FEATURES FLAGGED BY A (I) SYMBOL SHALL BE INSPECTED AND DOCUMENTED.



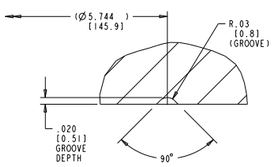

DETAIL X
SCALE 8/1




-1 CONTAINMENT VESSEL SEALING LID
SCALE 2/1




SECTION B-B




DETAIL A
SCALE 8/1

| | AR | -4 | WELD FILLER METAL | PER WELD PROCEDURES | | 4 |
|---|---|---|---|---|---|---|
| | 1 | -3 | BAR - Ø3/16 X .31 LONG | SST 304 | ASME SA-479 | 3 |
| | 1 | -2 | CONTAINMENT LID | | | 2 |
| | AR | -1 | CONTAINMENT VESSEL SEALING LID | | | 1 |
| MATERIAL SPECIFICATION | | PART OR IDENTIFYING NO | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | FIND NO |
| | | QTY REQD NEXT ASSY | PARTS LIST | | | |

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| REVISION | DATE | NCSD APPROVAL |
|---|---|---|
| C | 2/10/05 | JF DECLUE |

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Name: ROGER D. AIGNER Date: 2/10/05

| REV | DESCRIPTION | DRW | CHKR | DE | DVR | DM | DATE | PE | DATE | PM | DATE | WE | DATE | AR | CV | ST | HV | EM | FP | PD | EE | IE | M | NP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C | MOVED Ø6.741 DIM TO ZONE H6; ZONE D6 ADDED DIM R.09; ZONE D5 CHANGED DIM .38 TO .37; ADDED DET. X MOVED 32 FINISH SYM & (I) FROM SEC B-B | JRP | SMM | GAB | RDA | DPS | 11/8/05 | GAB | 11/10/05 | JGA | 11/10/05 | DJE | 11/11/05 | | | | | | | | | | | |
| B | REDUCED ORING FINISH AND LEAKCHECK DEPTH | GAB | RA | GAB | JLH | JCW | 8/12/04 | GAB | 8/12/04 | JGA | 8/12/04 | | | | | | | | | | | | | |
| A | ISSUED FOR PROTOTYPE PROCUREMENT | DWS | JSL | GAB | JLH | JCW | 8/26/03 | MRF | 8/26/03 | DBM | 8/26/03 | | | | | | | | | | | | | |

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK

| | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DRAWING APPROVALS | DRW | JRJ for D.W. SPARKS | 10/29/03 | CHKR | J.S. LOWERY | 10/29/03 | DE | G.A. BYINGTON | 10/29/03 | DVR | J.L. HECK | 10/29/03 | DM | J.C. WALLS | 10/29/03 | PE | M.R. FELDMAN | 10/29/03 | PM | D.B. MILLER | 10/29/03 | | | |

SCALE: NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS ±.01
XX DECIMALS ±.005
XXX DECIMALS ±0.5°
ANGLES
BREAK SHARP EDGES .06 MAX
FINISH 125 RMS

Y-12 National Security Complex managed by BWXT Y-12, L.L.C. for the Department of Energy under U.S. Government contract DE-AC05-00OR22800 a Oak Ridge, Tennessee a

PROJECT NAME
ES-3100 SHIPPING PACKAGE

CONTAINMENT VESSEL SEALING LID

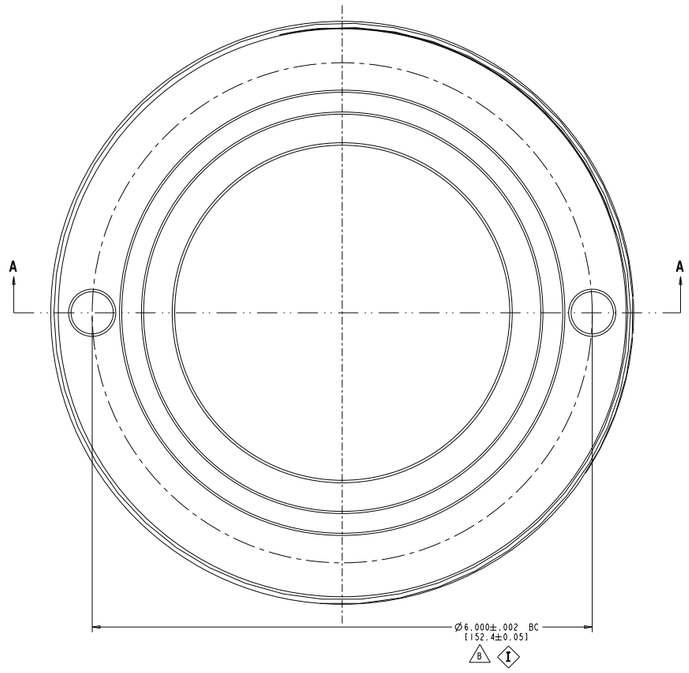
| J | 4B | 4S | 5D | PLANT | BLDG | FL | SH. | OF | TYPE | CLASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | Y-12 | NA | NA | 1 | 1 | S | U |
| SI | | AI | | SI | | | | | | REV |
| CM | | PKG | | IN | M2E801580A015 | | | | | C |

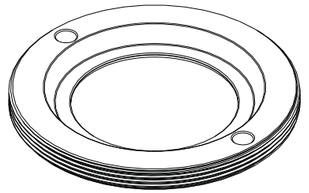
M2E801580A015

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P THIS DRAWING PRODUCED ON PRO/ENGINEER

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**ISOMETRIC VIEW**
SCALE 1/1

NOTES

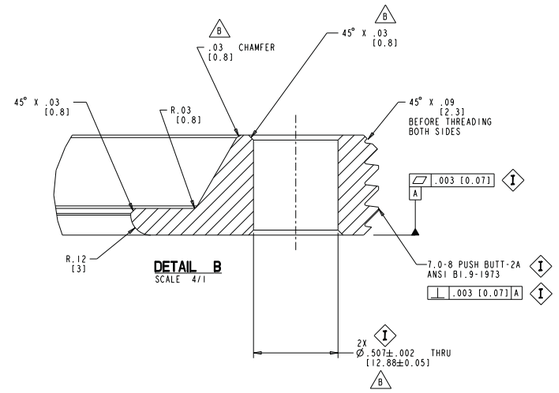
1 INTERPRET DRAWING PER ENGINEERING DRAFTING STANDARD ES-3.1.

2 INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994. PERFECT ORIENTATION AT MMC FOR INTERRELATED FEATURES REQUIRED.

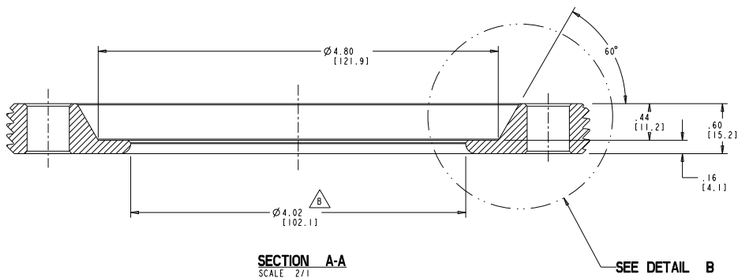
3 DIMENSIONS ARE IN INCHES [mm].

C 4 FOR ADDITIONAL REQUIREMENTS SEE JS-YMN3-801580-A001.

5 DIMENSIONS AND FEATURES FLAGGED BY A I SYMBOL SHALL BE INSPECTED AND DOCUMENTED.1




**DETAIL B**
SCALE 4/1




**SECTION A-A**
SCALE 2/1

**-1 CONTAINMENT VESSEL CLOSURE NUT**

| AR | AR | -1 | CONTAINMENT VESSEL CLOSURE NUT | NITRONIC 60 SST | ASME SA-479 UNS-S21800 | 1 |
|---|---|---|---|---|---|---|
| M2E801580 A001-1 | M2E801580 A001-1 | PART OR IDENTIFYING NO | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | FIND NO |
| | | ← QTY REQD NEXT ASSY | PARTS LIST | | | |

M2E801580A016

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| REVISION | DATE | NCSD APPROVAL |
|---|---|---|
| B | 2/10/05 | JF DECLUE |

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Name: ROGER D. AIGNER Date: 2/10/05

| REV | DESCRIPTION | DRW | CHKR | DE | DVR | DW | DATE | PE | DATE | PM | DATE | AR | CV | ST | HV | EM | FP | PD | EE | IC | M | NP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B | ADDED CHAMFER IN DETAIL B; MOD. HOLE TOL. REMOVED NOTE 4; RENUMBERED NOTES IN GEN NOTES | JRP | SMM | GAB | RDA | DPS | 11/18/05 | GAB | 2/10/05 | JGA | 2/10/05 | | | | | | | | | | | |
| A | ISSUED FOR PROTOTYPE PROCUREMENT | DWS | JSL | GAB | JLH | JCW | 10/29/03 | MRF | 10/29/03 | DBM | 10/29/03 | | | | | | | | | | | |

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK | DRAWING APPROVALS | DATE

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P THIS DRAWING PRODUCED ON PRO/ENGINEER

| | |
|---|---|
| SCALE: | NOTED |
| TOLERANCES UNLESS OTHERWISE SPECIFIED | |
| FRACTIONS | |
| XX DECIMALS | ±.01 |
| XXX DECIMALS | ±.005 |
| ANGLES | ±0.5° |
| BREAK SHARP EDGES | .06 MAX |
| FINISH | 125 RMS |

| | | |
|---|---|---|
| DRW | JRJ for D.W. SPARKS | 10/29/03 |
| CHKR | J.S. LOWERY | 10/29/03 |
| DE | G.A. BYINGTON | 10/29/03 |
| DVR | J.L. HECK | 10/29/03 |
| DW | J.C. WALLS | 10/29/03 |
| PE | M.R. FELDMAN | 10/29/03 |
| PM | D.B. MILLER | 10/29/03 |

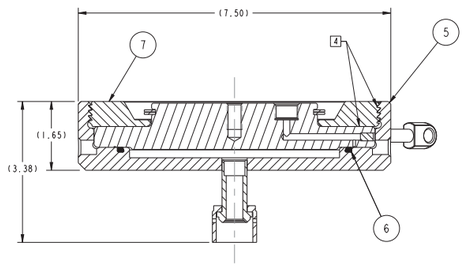
BWXT Y-12 National Security Complex managed by BWXT Y-12, L.L.C. for the Department of Energy under U.S. Government contract DE-AC05-00OR22800 a Oak Ridge, Tennessee a PROJECT NAME

ES-3100 SHIPPING PACKAGE

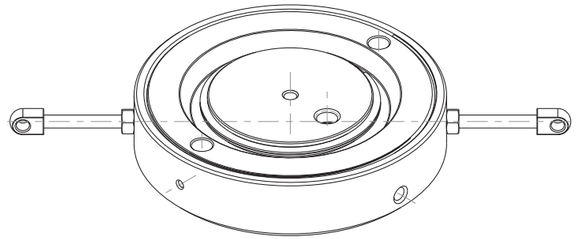
CONTAINMENT VESSEL CLOSURE NUT

| 1 | 48 | 49 | 50 | PLANT | BLDG | FL | SH. | OF | TYPE | CLASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | Y-12 | NA | NA | 1 | 1 | S | U |
| | 51 | 52 | | 53 | | | | | REV | |
| CM | | PKG | | IN | M2E801580A016 | | | | B | |

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-2 CONTAINMENT VESSEL LID LEAK TEST ASSEMBLY
SCALE: 1/1



ISO VIEW
SCALE: 1/1

NOTES

1 INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.

2 INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.

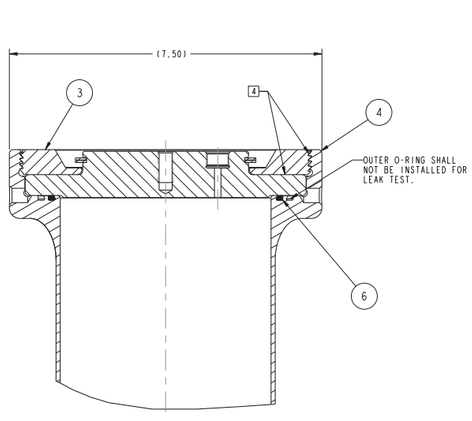
3 DIMENSIONS ARE IN INCHES.

4 APPLY A LIGHT COAT OF THREAD LUBRICANT, F/N 8, TO THREADS OF CLOSURE NUT, F/N 7; AND ON SURFACES BETWEEN CLOSURE NUT, F/N 3 AND TEST FLANGE, F/N 2.

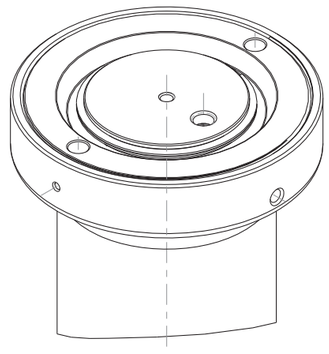
5 APPLY A LIGHT COAT OF THREAD LUBRICANT, F/N 8, TO THREADS OF CONTAINMENT VESSEL LID ASSEMBLY, F/N 7; AND ON SURFACES BETWEEN CONTAINMENT VESSEL LID TEST FLANGE, F/N 5 AND CONTAINMENT VESSEL LID ASSEMBLY, F/N 7.

6 APPLY A LIGHT COAT OF SUPER O-LUBE, F/N 9, TO SURFACE OF INNER O-RING, F/N 6.

7 FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATION JS-1MN3-801580-A001




-1 CONTAINMENT VESSEL BODY LEAK TEST ASSEMBLY
SCALE: 1/1



ISO VIEW
SCALE: 1/1

| | | | | | | |
|---|---|---|---|---|---|---|
| AR | AR | -9 | SUPER O-LUBE | CLEAR DIMETHYL SILOXANE POLYMER | PARKER HANNIFIN O-RING DIVISION 2360 PALUMBO DR. LEXINGTON, KY. | 9 |
| 6 AR | AR | KRYTOX # 240 AC | THREAD LUBRICANT | FLUORINATED GREASE | MILLER-STEPHENSON CHEMICAL CO. DANBURY, CT 06810! | 8 |
| 4 5 | 1 | M2E801580A014-1 | CONTAINMENT VESSEL LID ASSEMBLY | | | 7 |
| D 6 | 1 | M2E801580A013-1 OR M801580-0013-1 | INNER O-RING | | | 6 |
| | 1 | M2E801580A022-1 | CONTAINMENT VESSEL LID TEST FLANGE | | | 5 |
| | 1 | M2E801580A012-1 OR A012-4 | CONTAINMENT VESSEL BODY ASSEMBLY | | | 4 |
| | 1 | M2E801580A021-1 | CONTAINMENT VESSEL BODY TEST FLANGE ASSEMBLY | | | 3 |
| X | | -2 | CONTAINMENT VESSEL LID LEAK TEST ASSEMBLY | | | 2 |
| X | X | -1 | CONTAINMENT VESSEL BODY LEAK TEST ASSEMBLY | | | 1 |
| -2 | - | PART OR IDENTIFYING NO | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | FIND NO |
| | | ← QTY REQ'D NEXT ASSEMBLY | PARTS LIST | | | |

M2E801580A023

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Name: DREW WINDER Date: 6/06/2012

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| PART | REV | DESCRIPTION | DRW | CHKR | DE | DVR | DM | DATE |
|---|---|---|---|---|---|---|---|---|
| 000 | D | ADDED OPTIONAL O-RING FOR F/ND NO.6 | CDB | DEW | MLG | DEW | WIN | 6/11/12 |
| 000 | C | GEN REV; REPLACED REF TO PROCURER; CLEARED TOLERANCE BLOCK;ADDED OR EQUAL TO F/N 8 & 9 IN BOM | JRP | SMM | GAB | RDA | DPS | 1/17/05 |
| 000 | B | ADDED A012-4 WELDED CV OPTION | GAB | RA | GAB | JLH | JCW | 11/22/04 |
| 000 | A | ISSUED FOR PROTOTYPE PROCUREMENT | RDA | JSL | GAB | JLH | JCW | 11/09/03 |

REVISION OR ISSUE PURPOSE

| PE | DATE | SE | DATE | WE | DATE | WCS | DATE | OM/SO | DATE |
|---|---|---|---|---|---|---|---|---|---|
| GAB | 6/11/12 | WIN | 6/11/12 | GAB | 11/22/04 | GAB | 11/22/04 | JGA | 6/08/12 |
| GAB | 1/17/05 | GAB | 1/17/05 | GAB | 11/22/04 | JGA | 11/22/04 | | |
| GAB | 11/22/04 | GAB | 11/22/04 | GAB | 11/09/03 | GAB | 11/09/03 | | |
| GAB | 11/09/03 | GAB | 11/09/03 | GAB | 11/09/03 | GAB | 11/09/03 | | |

REVISION APPROVALS

| AR | CV | ST | HV | EM | FP | PD | EC | IE | M | NP |
|---|---|---|---|---|---|---|---|---|---|---|

SQUAD CHECK

DRAWING APPROVALS

SCALE: NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS
XX DECIMALS ±.01
XXX DECIMALS ±.005
ANGLES ±0.5°
BREAK SHARP EDGES .06 MAX
FINISH 125 RMS

| | | |
|---|---|---|
| DRW | ROAF J.B. JACKSON | 11/26/03 |
| CHKR | J.S. LOWERY | 11/26/03 |
| DE | G.A. BYINGTON | 11/26/03 |
| DVR | J.L. HECK | 11/26/03 |
| DM | J.C. WALLS | 11/26/03 |
| PE | G.A. BYINGTON | 11/26/03 |
| SE | | |
| OM/SO | G.B. SINGLETON | 11/26/03 |
| WE | N/R | |
| DATE | | |

Y-12 National Security Complex managed by B & W Technical Services Y-12, LLC for the Department of Energy under U.S. Government contract DE-AC-05-00OR22800 a Oak Ridge, Tennessee a

PROJECT NAME: ES-3100 SHIPPING CONTAINER

CONTAINMENT VESSEL LEAK TEST ASSEMBLIES

| USE D/SC | DT | DC | CM | SYSTEM | STAT/SIZE | BLDG | FL | CLASS |
|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | NC | PKG | IN | E | NA | NA | U |

SH. OF TYPE 1 1 DD

M2E801580A023 PART 000 REV D

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NOTES

1 INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.

2 INTERPRET DIMENSIONS AND TOLERANCES PER "RMA" RUBBER HANDBOOK (RMA-392) CLASS "A2 PRECISION."

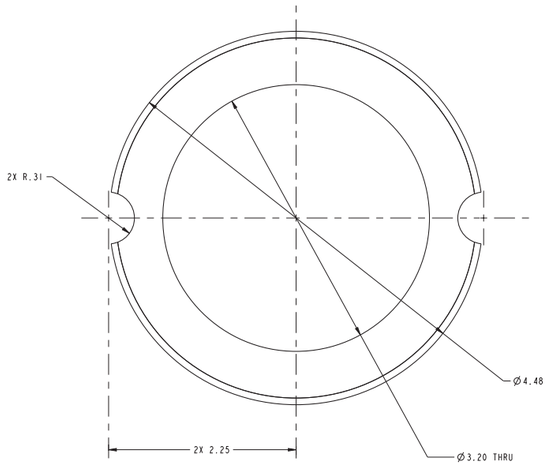
3 DIMENSIONS ARE IN INCHES.

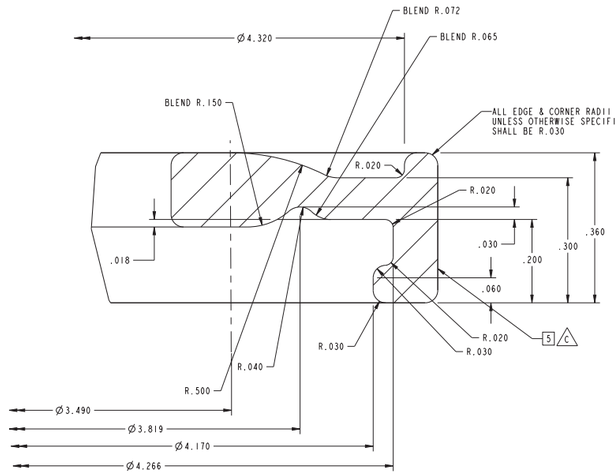
[4] MANUFACTURER/SUPPLIER TO PROVIDE CERTIFICATE OF COMPLIANCE FOR ALL FEATURES OF THESE ITEMS.

C [5] IN APPROXIMATE LOCATION SHOWN, ENGRAVE DRAWING NUMBER AND REVISION LETTER IN 1/4" HIGH CHARACTERS IN THE MOLD TO MAKE A LEGIBLE RAISED MARKING IN THE PART.

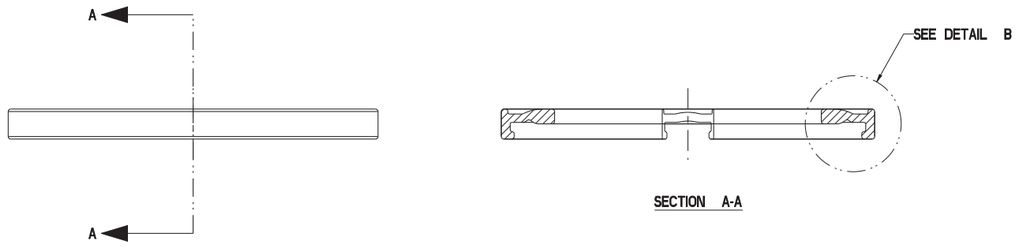
C [6] FOR ADDITIONAL INFORMATION SEE EQUIPMENT DATA SHEET DS-801580-0002.

7 FOR REFERENCE ONLY:
WEIGHT: 0.0588 LBS [26.7 g]




DETAIL B
SCALE 10/1




SECTION A-A

| C [4] [6] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| M2E801580 A024 | AR | AR | AR | AR | CONTAINMENT VESSEL VIBRATION ABSORBING SILICONE 4.25" CAN PAD | CONTAINMENT VESSEL VIBRATION ABSORBING SILICONE 4.25" CAN PAD | SILICONE RUBBER A50-83B, SILICA FILLED, LOW HYDROGEN AND LOW VOLATILE VAPORS, POST CURED HARDNESS 75+/- 5 SHORE A | SEE NOTE 6 | 1 |
| M2E801580 A024 | -1 | | | | PART OR IDENTIFYING NO | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | FIND NO |
| | | | | | QTY REQ'D NEXT ASSEMBLY | PARTS LIST | | | |

-1 CONTAINMENT VESSEL VIBRATION ABSORBING SILICONE 4.25" CAN PAD
SCALE 2/1

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY ANALYSIS ENGINEERING APPROVAL.

| REVISION | DATE | SAE APPROVAL |
|---|---|---|
| C | 06/05/2012 | J.F. DeCLUE |

This document has been reviewed by a Y-12 DC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.

Name: DREW WINDER Date: 06/06/12

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| PART | REV | DESCRIPTION | DRW | CHKR | DE | DVR | DM | DATE | PE | SE | DATE | WE | DATE | MCS | DATE | OM/SO | DATE | AR | CV | ST | HV | EM | FP | PD | EE | IE | M | NP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 000 | C | REVISED NOTES 5 & 6 | CDB | DEW | MLG | DEW | WIN | 6/11/12 | WIN | 6/11/12 | JGA | 6/18/12 | | | | | | | | | | | | | | | | |
| 000 | B | DELETED NOTE 8; ADDED NEXT ASS'Y TO BOM CHNG LOCATION OF INDEX NOTE 5 TO DET. B | JRP | SMM | GAB | RDA | DPS | 11/28/11 | GAB | 2/16/12 | JGA | 2/16/12 | | | | | | | | | | | | | | | | |
| 000 | A | ISSUED FOR DESIGN REVIEW | RDA | JSL | GAB | JLH | JCW | 11/29/10 | GAB | 11/29/10 | GBS | 11/29/10 | | | | | | | | | | | | | | | | |
| | | REVISION OR ISSUE PURPOSE | | | | | | | | | | REVISION APPROVALS | | | | | | | | | SQUAD CHECK | | | | | | | |

| DRAWING APPROVALS | | |
|---|---|---|
| DRW | R.D. AIGNER | 11/26/03 |
| CHKR | J.S. LOWERY | 11/26/03 |
| DE | G.A. BYINGTON | 11/26/03 |
| DVR | J.L. HECK | 11/26/03 |
| DM | J.C. WALLS | 11/26/03 |
| PE | G.A. BYINGTON | 11/26/03 |
| SE | | |
| OM/SO | G.B. SINGLETON | 11/26/03 |
| WE | N/R | |

SCALE: NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS
XX DECIMALS
XXX DECIMALS
ANGLES
BREAK SHARP EDGES MAX
FINISH

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PROJECT NAME

ES-3100 SHIPPING PACKAGE

CONTAINMENT VESSEL VIBRATION ABSORBING SILICONE 4.25 CAN PADS

| USE | DISC | DT | DC | CM | SYSTEM | STATE/ZIP | BLDG | FL | CLASS |
|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | CM | PKG | IN E | NA | NA | U |

| SH. | OF | TYPE | PART | REV |
|---|---|---|---|---|
| 1 | 1 | DD | M2E801580A024 | 000 C |

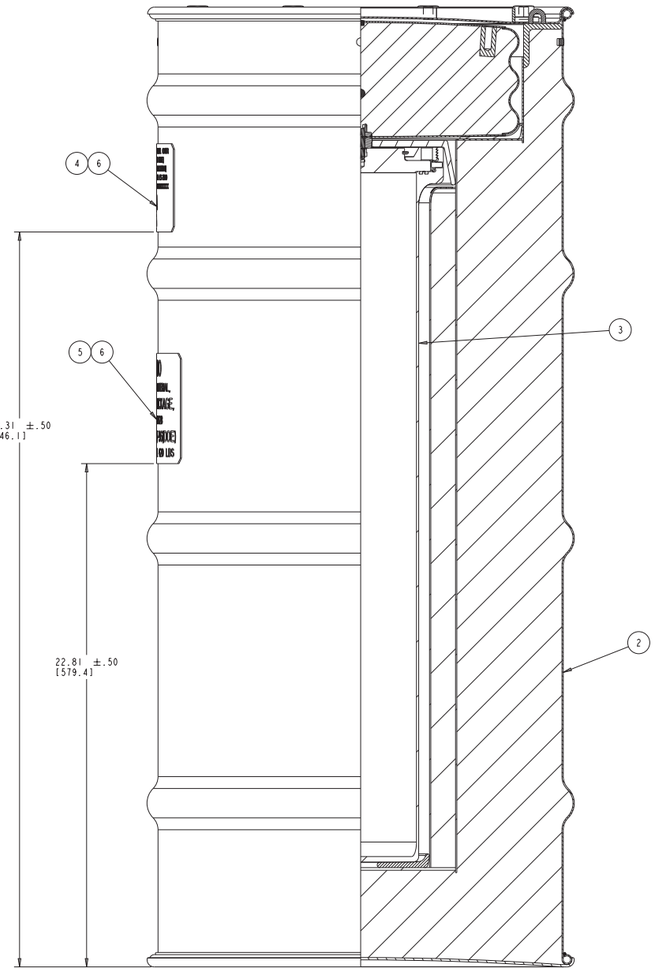
M2E801580A024

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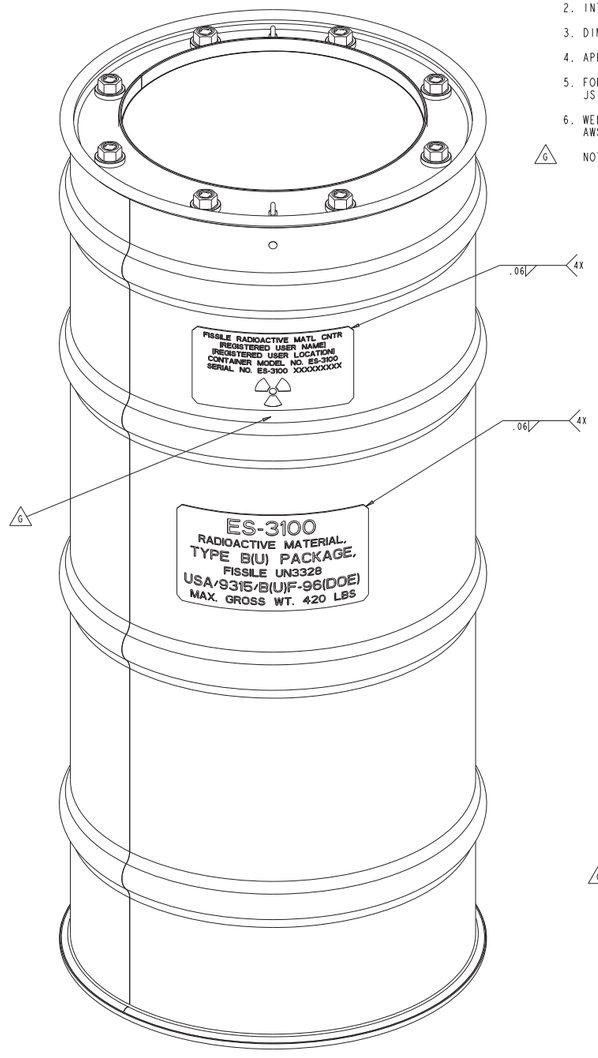
NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES [mm].
4. APPROXIMATE WEIGHT: 323.8 LBS [146.9 Kg]
5. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A002.
6. WELDING SYMBOLS SHALL BE INTERPRETED IN ACCORDANCE WITH AWS A2.4.

G NOTE DELETED




-1 MAIN ASSEMBLY
SCALE 1/2




ISOMETRIC VIEW
SCALE 1/2

G

| AR | -6 | WELD FILLER METAL | | | 6 |
|---|---|---|---|---|---|
| 1 | M2E801580A010-2 | ES-3100 DATA PLATE | | | 5 |
| 1 | M2E801580A010-1 | ES-3100 TREFOIL DATA PLATE | | | 4 |
| 1 | M2E801580A011-1 | CONTAINMENT VESSEL ASSEMBLY | | | 3 |
| 1 | M2E801580A001-1 | DRUM ASSEMBLY | | | 2 |
| X | -1 | MAIN ASSEMBLY | | | 1 |
| | PART OR IDENTIFYING NO | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | FIND NO |
| | QTY. REQ'D NEXT ASSEMBLY | PARTS LIST | | | |

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| REVISION | DATE | SAE APPROVAL |
|---|---|---|
| G | 6/11/15 | ALAN WILKINSON |

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Name: STAN THOMAS Date: 06/11/15

C THIS DRAWING PRODUCED ON CREO PARAMETRIC

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| PART | REV | DESCRIPTION | DRW | CHKR | DE | DVR | DM | DATE | PE | DATE | SE | DATE | WE | DATE | NCS | DATE | OM/SO | DATE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 000 | G | REMOVED TEMPERATURE LABEL F/N 7 AND DELETED NOTE 7; UPDATED FORMAT | KWJ | MLG | GAB | MLG | JCA | 6/11/15 | JCA | 6/11/15 | JGA | 6/18/15 | | | | | | |
| 000 | F | ADDED NOTE 7 ALONG WITH F/N 7 TO PARTS LIST AND DRAWING FIELD | CDB | DEW | MLG | DEW | WIN | 6/11/12 | WIN | 6/11/12 | JGA | 6/18/12 | | | | | | |
| 000 | E | REVISED ES-3100 DATA PLATE. | MLE | JRJ | MLE | DEW | WIN | 9/10/09 | LR | 9/10/09 | JGA | 9/14/09 | NA | NA | | | | |
| 000 | D | REVISED TREFOIL DATA PLATE | JRJ | RDA | LR | GAB | WIN | 9/9/08 | LR | 9/9/08 | JGA | 9/9/08 | NA | NA | | | | |
| 000 | C | REVISED TREFOIL DATA PLATE | JRJ | RDA | JRJ | GAB | WIN | 10/16/06 | 10/16/06 | 10/17/06 | JGA | 10/12/06 | NA | NA | | | | |
| 000 | B | GEN REV;CHG. NOTE 4;ADDED NOTES 5 & 6; CHG. F/N 6 WAS BLIND RIVIT;WEIGHTS & VOLS IN NOTE 10 UPDATED TO REFLECT NEW MAT'L. | JRP | SMM | GAB | RDA | DPS | 11/18/05 | GAB | 2/10/05 | JGA | 2/10/05 | DJE | 2/11/05 | | | | |
| 000 | A | | JRJ | JSL | GAB | JLH | JCW | 10/29/03 | MRF | 10/29/03 | DBM | 10/29/03 | | | | | | |

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK

| AR | CV | ST | HV | EM | FF | PD | EE | IE | M | NP |
|---|---|---|---|---|---|---|---|---|---|---|

SCALE: NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS
XX DECIMALS ±.01
XXX DECIMALS ±.005
ANGLES ±0.5°
BREAK SHARP EDGES .06 MAX
FINISH 125 RMS

DRAWING APPROVALS

| | | |
|---|---|---|
| DRW | J.R. JACKSON | 10/29/03 |
| CHKR | J.S. LOWERY | 10/29/03 |
| DE | G.A. BYINGTON | 10/29/03 |
| DVR | J.L. HECK | 10/29/03 |
| DM | J.C. WALLS | 10/29/03 |
| PE | M.R. FELDMAN | 10/29/03 |
| SE | | |
| OM/SO | D.B. MILLER | 10/29/03 |
| WE | N/R | |

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Oak Ridge, Tennessee

PROJECT NAME
ES-3100 SHIPPING PACKAGE

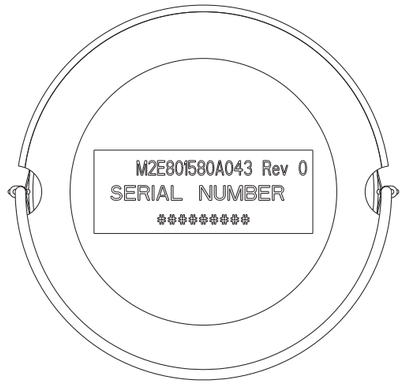
MAIN ASSEMBLY

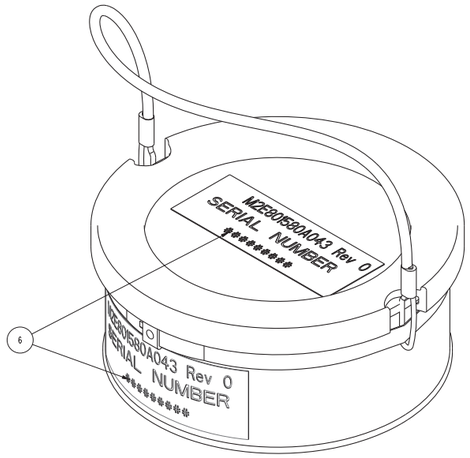
| USE | DISC | DT | DC | CM | SYSTEM | STA | SIZE | BLDG | FL | CLASS |
|---|---|---|---|---|---|---|---|---|---|---|
| G | M | L | F | CM | PKG | INE | | NA | NA | U |

SH. OF | TYPE | PART | REV
1 1 | DD | M2E801580A031 | 000 | G

M2E801580A031

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NOTES

1 INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.

2 INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.

3 DIMENSIONS ARE IN INCHES.

[4] FOR FURTHER INFORMATION, SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A005, CASTING CATALOG NO. 277-4 NEUTRON ABSORBER.

[5] FOR PURCHASE OF F/N 8, SEE DOCUMENT #DS-YMN3-801580-A001.

[6] USE THE BAND-IT TIE-LOCK II HAND TOOL "A920" TO ATTACH THE STAINLESS STEEL BANDS AND CABLE ASSEMBLIES TO THE MATERIAL CANS. THE TOOL'S TENSION SETTING SHALL BE SET BETWEEN 4 AND 8.

7 REFERENCE DOCUMENT #DAC-YMN3-801580-A001.

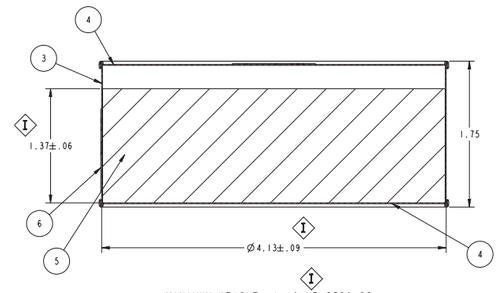
8 FOR REFERENCE ONLY FIND NO 1; NOMINAL WEIGHT: 1.38 LBS [0.626 KG]

9 DIMENSIONS AND FEATURES FLAGGED BY SYMBOL Ⓘ SHALL BE INSPECTED AND DOCUMENTED. THESE DIMENSIONS ARE OF CRITICALITY SAFETY CONCERNS AND SHALL NOT BE DEVIATED WITHOUT PRIOR APPROVAL.

[10] MARK WITH PERMANENT LABELS F/N 6 DRAWING NUMBER, REVISION LETTER AND SIX DIGIT SERIAL NUMBER IN .18±.03 HIGH CHARACTERS.

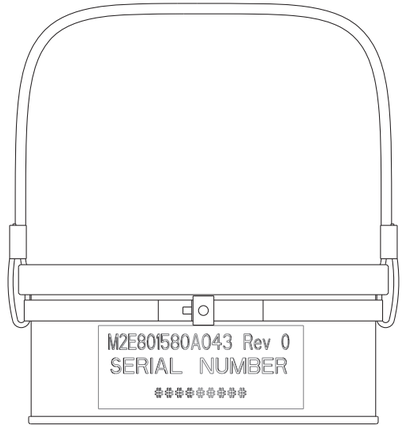
[11] SUPPLIED BY COMPANY.

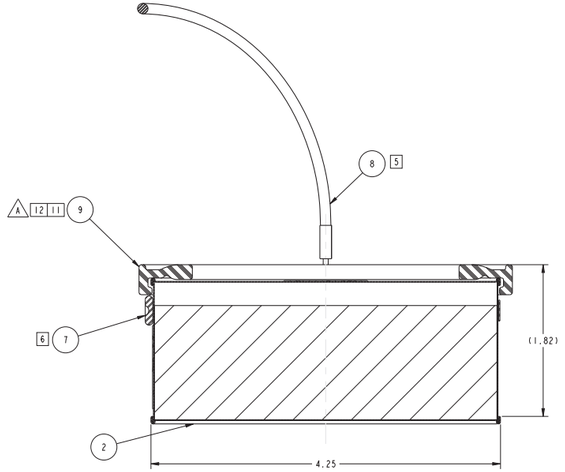
A [12] FOR SHIPMENTS, THE USE OF VIBRATION PAD, FIND NO.9 WITH HEAVY CAN SPACER, IS OPTIONAL.




MINIMUM WEIGHT: 1.16 LB [526 G]
MAXIMUM WEIGHT: 1.56 LB [707 G]

**-2 FILLED CAN**
SCALE 2/1




**-1 HEAVY CAN SPACER ASSEMBLY (SST)**
SCALE 2/1

| A 12 | 11 | | | | | |
|---|---|---|---|---|---|---|
| | 5 | AR | M2E801580A024-1 | VIBRATION ABSORBING SILICONE 4.25" CAN PAD | | 9 |
| | 6 | 1 | -8 | CABLE LANYARD | REFERENCE NOTE 5 | 8 |
| | 10 | 1 | AS213 | BAND CLAMP | 304 SST | BAND-IT-IDEX, INC. DENVER, CO 80216 | 7 |
| | 4 | 2 | WL-OL875WJ OR EQUAL | 2.625" BY 1" VINYL COATED WEATHERPROOF WHITE PRINTER LABELS | | WORLDLABEL.COM 336 CONVENT AVE,STE 2A NEW YORK NY 10031 SALES (866) 226-8669 | 6 |
| | | AR | -5 | 277-4 FILLER | | JS-YMN3-801580-A005 | 5 |
| | | 2 | -4 | CAN END COVER | 304/304L STAINLESS STEEL 30 GA. (0.012) | ASTM A240 | 4 |
| | | 1 | -3 | CAN BODY | | | 3 |
| | | 1 | -2 | FILLED CAN | | | 2 |
| | | | -1 | HEAVY CAN SPACER ASSEMBLY (SST) | | | 1 |
| -2 | -1 | PART OR IDENTIFYING NO | | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | FIND NO |
| | | QTY REQ'D NEXT ASSEMBLY | | PARTS LIST | | | |

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| REVISION | DATE | SAE APPROVAL |
|---|---|---|
| A | 06/05/2012 | J.F. DeCLUE |

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Name: DREW WINDER Date: 6/06/12

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| PART | REV | DESCRIPTION | DRW | CHKR | DE | DVR | DM | DATE | PE | DATE | SE | DATE | WE | DATE | WCS | DATE | OM/SO | DATE | AR | CV | ST | HV | EM | FP | PD | EC | IE | W | NP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 000 | A | REVISED NOTES AND ADDED NOTE 12 FOR FIND NO.9 | CDB | DEW | MLG | DEW | WIN | 6/11/12 | WIN | 6/11/12 | JGA | 6/18/12 | | | | | | | | | | | | | | | | | |
| 000 | 0 | ORIGINAL ISSUE. | MLE | JRJ | MLE | DEW | WIN | 11/8/09 | LR | 11/8/09 | JGA | 11/4/09 | | | | | | | | | | | | | | | | | |

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK | DRAWING APPROVALS

| | |
|---|---|
| SCALE: | NOTED |
| TOLERANCES UNLESS OTHERWISE SPECIFIED | |
| FRACTIONS | |
| XX DECIMALS | ±.01 |
| XXX DECIMALS | ±.005 |
| ANGLES | ±0.5° |
| BREAK SHARP EDGES | .06 MAX |
| FINISH | 125 RMS |

| | | |
|---|---|---|
| DRW | M.L. ENSLEY | 05/07/09 |
| CHKR | JR JACKSON | 05/07/09 |
| DE | M.L. ENSLEY | 05/07/09 |
| DVR | D.E. WINDER | 05/10/09 |
| DM | W.I. NORTH | 05/10/09 |
| PE | L. ROBERSON | 05/10/09 |
| SE | | |
| OM/SO | J.G. ARBITAL | 05/14/09 |
| WE | N/R | |

Y-12 National Security Complex managed by B & W Technical Services Y-12, LLC for the Department of Energy under U.S. Government contract DE-AC-05-00OR22800 • Oak Ridge, Tennessee •

PROJECT NAME
ES-3100 SHIPPING PACKAGE

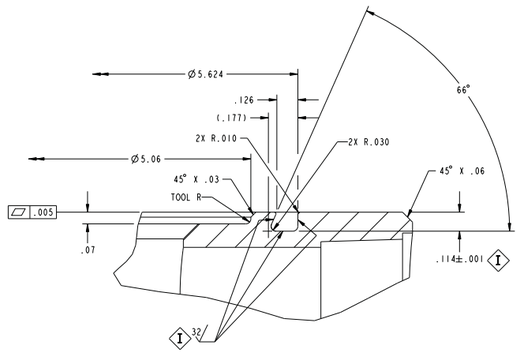
HEAVY CAN SPACER ASSEMBLY (SST)

| USE | DISC | DT | DC | CM | SYSTEM | BTA | SIZE | BLDG | FL | CLASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | CM | PKG | IN | E | NA | NA | U |

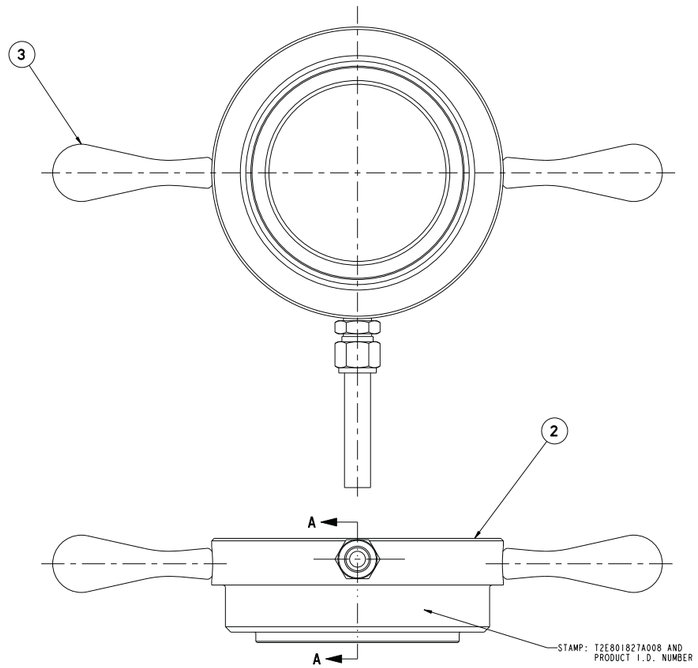
| SH. | OF | TYPE | | PART | REV |
|---|---|---|---|---|---|
| 1 | 1 | | M2E801580A043 | 000 | A |

M2E801580A043

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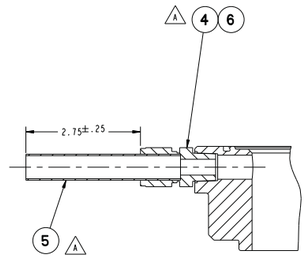



**DETAIL X**
SCALE 4/1

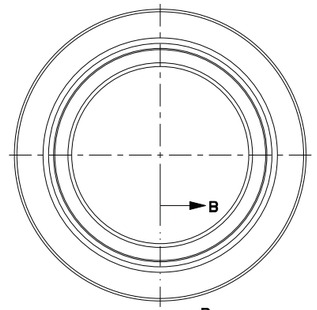



**-1 LEAK CHECK FLANGE ASSEMBLY**
SCALE 1/1

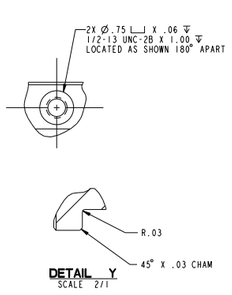
NOTES
1 INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2 INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M - 1994.
3 DIMENSIONS ARE IN INCHES.
4 DIMENSIONS OR FEATURES FLAGGED BY ◇I SHALL BE INDEPENDENTLY VERIFIED.



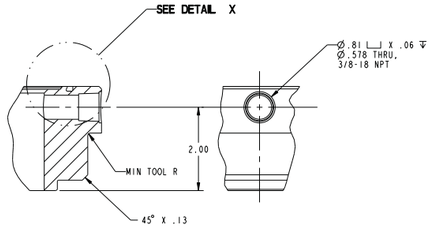

**SECTION A-A**
SCALE 1/1




**-2 LEAK CHECK FLANGE**
SCALE 1/1




**DETAIL Y**
SCALE 2/1




**SECTION B-B**
SCALE 1/1

| | | | | | | |
|---|---|---|---|---|---|---|
| A | AR | -6 | TEFLON PIPE TAPE | | | 6 |
| A | 1 | -5 | 5/8 OD X .035 WALL OR 5/8 OD X .060 WALL TUBE | 304 S.S. OR 316 S.S. | ASTM A269 | 5 |
| A | 1 | SS-1010-1-6 | MALE CONNECTOR | 316 S.S. | SWAGELOK COMPANY | 4 |
| | 2 | TH-7 | MACHINE HANDLE | STEEL | REID TOOL SUPPLY CO MUSKEGON, MI 49444 | 3 |
| | 1 | -2 | LEAK CHECK FLANGE | 304 S.S. | | 2 |
| AR AR | X | -1 | LEAK CHECK FLANGE ASSEMBLY | | | 1 |
| M2E801893 A028-1 M2E801827 A008-1 | | PART OR IDENTIFYING NO | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | FIND NO |
| A | | ← NEXT ASSEMBLY | PARTS LIST | | | |

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PTHIS DRAWING PRODUCED ON PRO/ENGINEER

| REV | DESCRIPTION | DRW | CHKR | DE | DVR | DM | DATE | PE | DATE | SE | DATE | ME | DATE | QM/SQ | DATE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | ADDED M2E801893A028-1, ADDED F/N 4, F/N 5 | JR | JML | EL | LR | RDA | 4-18-06 | WIN | 4-18-06 | WIN | 5-28-08 | LR | 5-28-08 | | |
| | AND F/N 6 TO PARTS LIST | | | | | | | | | | | | | | |
| 0 | ORIGINAL ISSUE, RN Y2003-0328 | SMW | GAB | EL | RDA | LEG | 4-18-06 | JL | 4-18-06 | MDW | 4-18-06 | | | | |

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK | DRAWING APPROVALS

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AR | CV | ST | HV | CW | FP | PD | EE | IC | M | NP | | | | | | | |

SCALE: NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS
XX DECIMALS ±.01
XXX DECIMALS ±.005
ANGLES ±0.5°
BREAK SHARP EDGES .06 MAX
FINISH 125 RMS

| | | |
|---|---|---|
| DRW | McTEER/JOHNSON | 4/12/06 |
| CHKR | GA BYINGTON | 4-18-06 |
| DE | E LOZYNIAK | 4-18-06 |
| DVR | RD AIGNER | 4-18-06 |
| DM | LE GALYON | 4-18-06 |
| PE | JACK LAFFERTY | 4-18-06 |
| SE | MD WALDROP | 4-18-06 |
| QM/SQ | NR | NR |

This document has been reviewed by a Y-12 DC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.

Name: R.D. AIGNER Date: 5/28/09

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PROJECT NAME: TOOLING

LEAK CHECK FLANGE ASSEMBLY

| 1 | 48 | 49 | 50 | PLANT | BLDG | FL | SH. | OF | TYPE | CLASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | M | U | D | Y-12 | | | 1 | 1 | S | U |

| 51 | 52 | 53 | REV |
|---|---|---|---|
| NC | TOOL | IN | A |

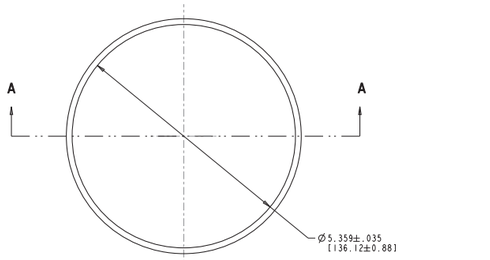
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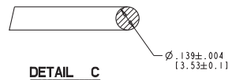
NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES.[mm].
4. O-RING SHALL MEET THE REQUIREMENTS SPECIFIED IN EQUIPMENT SPECIFICATION SPC-M801580-0001.

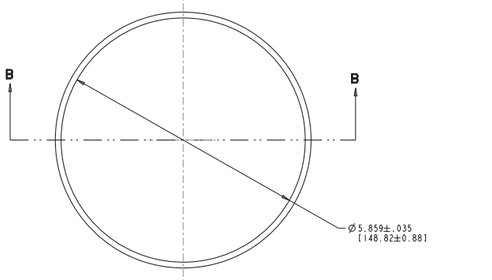



SECTION A-A
SCALE 1/1

-1 INNER O-RING

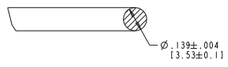



DETAIL C
SCALE 4/1




SECTION B-B
SCALE 1/1

-2 OUTER O-RING




DETAIL D
SCALE 4/1

| | | | | | |
|---|---|---|---|---|---|
| | AR | -2 | OUTER O-RING | SEE NOTE 4 | 2 |
| AR | AR | -1 | INNER O-RING | SEE NOTE 4 | 1 |
| M2301580-0001 M2301581-0001 | PART OR IDENTIFYING NO | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | FIND NO |
| | QTY REQ'D NEXT ASSEMBLY | PARTS LIST | | | |

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY ANALYSIS ENGINEERING APPROVAL.

| REVISION | DATE | SAE APPROVAL |
|---|---|---|
| 0 | 6/05/2012 | J.F. DeCLUE |

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Name: DREW WINDER Date: 6/5/12

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| PART | REV | DESCRIPTION | DRW | CHKR | DE | DVR | DM | DATE | PE | DATE | SE | DATE | WE | DATE | WCS | DATE | OM/SO | DATE | AR | CV | ST | HV | EM | FP | PD | EE | IE | W | NP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 000 | 0 | ORIGINAL ISSUE | CDB | DEW | MLG | DEW | WIN | 6/11/12 | WIN | 6/11/12 | JGA | 6/18/12 | | | | | | | | | | | | | | | | | |
| | | REVISION OR ISSUE PURPOSE | REVISION APPROVALS | | | | | | | | | | | | | | | | SQUAD CHECK | | | | | | | | | | |

| | |
|---|---|
| SCALE: | NOTED |
| TOLERANCES UNLESS OTHERWISE SPECIFIED | |
| FRACTIONS | |
| XX DECIMALS | ±.01 |
| XXX DECIMALS | ±.005 |
| ANGLES | ±0.5° |
| BREAK SHARP EDGES | .06 MAX |
| FINISH | 125 RMS |

| | | |
|---|---|---|
| DRW | C.D. BROWN | 06/05/12 |
| CHKR | D.E. WINDER | 06/05/12 |
| DE | M.L. GOINS | 06/07/12 |
| DVR | D.E. WINDER | 06/07/12 |
| DM | W.I. NORTH | 06/11/12 |
| PE | W.I. NORTH | 06/11/12 |
| SE | NR | |
| OM/SO | J.G. ARBITAL | 06/18/12 |
| WE | N/R | |

DRAWING APPROVALS

Y-12 National Security Complex managed by B & W Technical Services Y-12, LLC for the Department of Energy under U.S. Government contract DE-AC-05-00OR22800 • Oak Ridge, Tennessee •

PROJECT NAME: ES-3100 SHIPPING PACKAGE

CONTAINMENT VESSEL VITON O-RING DETAILS

| USE | DISC | DT | DC | CM | SYSTEM | STAT | SIZE | BLDG | FL | CLASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | M | L | F | CM | PKG | IN | E | NA | NA | U |

| SH. | OF | TYPE |
|---|---|---|
| 1 | 1 | DD |

M801580-0013

| PART | REV |
|---|---|
| 000 | 0 |

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## Appendix 1.3.8

## Pyrophoricity of Uranium Metal

Prepared by: Russell W. Schmidt
BWXT Y-12
November 2006
Revised June 2007

Reviewed by: Sanford G. Bloom
BWXT Y-12
November 2006
Re-reviewed June 2007

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## Appendix 1.3.8

## Pyrophoricity of Uranium Metal

### I. Introduction

The ES-3100 is a new shipping container designed for safe and efficient transportation of highly enriched uranium in a wide range of material forms. The ES-3100 has been certified for use with a variety of contents, including enriched uranium metal and alloy. However, the current size limitations on uranium contents in the form of broken metal are unnecessarily restrictive. The size limits exist because under certain conditions uranium metal and some uranium alloys are pyrophoric – they have the potential to spontaneously ignite. The size restrictions are intended to eliminate the possibility of spontaneous ignition during transport.

The purpose of this analysis is to evaluate the potential for uranium metal pieces to spontaneously ignite under the conditions expected for shipment in the ES-3100 shipping container, and to identify limits on the uranium metal content that will prevent spontaneous ignition during transport, while still allowing a high degree of flexibility and utility.

It is important to remember that the content limits developed for the ES-3100 must be implemented in the field. Therefore the criteria derived from this evaluation must be simple, robust, and readily applied in all of the facilities using this package.

This evaluation does not include new laboratory tests of uranium metal ignition parameters. Such tests have been performed and well documented in the past. This evaluation draws on the extensive body of existing data and proven storage and transport practice to identify the bounds within which uranium metal and alloys can be safely transported in the ES-3100 shipping container.

### II. Proposed Definition of Pyrophoricity

The Certificate of Compliance (CoC), gives the definition of broken metal in Paragraph 5(b)(1)(ii), as follows:

> *For metal or alloy defined as broken metal, mass limits are specified in Table 2. Uranium metal and alloy pieces must have a surface-area-to-mass ratio of not greater than 1 cm²/g or must have a mass not less than 50 g, whichever is most restrictive. Powders, foils, turnings, wires, and incidental small particles are not permitted, unless they are restricted to not more than 1 percent by weight of the content per convenience can, and they are either in a sealed, inerted container or are stabilized to an oxide prior to shipment.*

It is suggested that the definition of broken metal in Paragraph 5(b)(1)(ii) be revised to the following:

> *For metal and alloy defined as broken metal, mass limits are specified in Table 2. Uranium metal and alloy pieces must have a surface-area-to-mass ratio of not greater than 1 cm²/g or must not pass freely through a 3/8-inch (0.0095 m) mesh sieve. Particles and small shapes that do not pass this size restriction, as well as powders, foils, turnings, and wires, are not permitted, unless they are either in a sealed container under an inert cover gas.*

## III. Rational for Proposed Changes

The proposed text makes the following changes:

- The 50 g minimum piece size is eliminated.
- A 3/8-in. mesh limit is added.
- The phrase "whichever is most restrictive" is deleted.
- Remove oxidation as a treatment for pyrophoric uranium, in this context.
- The 1% limit on inerted material is eliminated.

The 1-$cm^2/g$ maximum specific surface area limit is the most significant limit in the original text, and that limit is retained unchanged. Specific surface area is the most significant parameter in determining if a given piece of uranium is at risk of spontaneous ignition under a given set of conditions, and therefore it is appropriate that this restriction should control any other restrictions to the package contents. The discussion section below will demonstrate that the 1 $cm^2/g$ maximum allowable specific surface area is adequate to prevent spontaneous ignition in the ES-3100.

The 50-g minimum piece size is overly restrictive and is inconsistent with the 1-$cm^2/g$ upper limit on specific surface area. Smooth uranium metal pieces can have a mass of less than 0.5 g and still have a specific surface area less than 1 $cm^2/g$ (see Example 1). This makes the 50-g limit two orders of magnitude too large. The 50-g limit is nearly an order of magnitude too large even considering metal pieces with the rough surface of broken metal instead of a smooth cast or polished surface.

**Example 1.**
Consider a smooth uranium metal sphere with a diameter of 0.32 cm (0.126 in.).
The radius of the sphere is 0.16 cm. The density of uranium metal is 19 $g/cm^3$.

| | |
|---|---|
| The volume is | $V = (4 / 3) \times Pi \times r^3 = (4 / 3) \times Pi \times (0.16)^3 = 0.01716\ cm^3$ |
| The mass is | $M = Density \times V = 19\ g/cm^3 \times 0.01716\ cm^3 = 0.3260\ g$ |
| The surface area is | $A = 4 \times Pi \times r^2 = 4 \times Pi \times (0.16)^2 = 0.3217\ cm^2$ |
| The specific surface area is | $SA = A / M = 0.3217\ cm^2 / 0.3260\ g = 0.9868\ cm^2/g$ |

This specific surface area is just within the 1 $cm^2/g$ upper limit.

If instead of a smooth surface the sphere has a rough surface characteristic of broken uranium metal, a larger size is needed to ensure that the 1 $cm^2/g$ limit is maintained. For a roughness factor of three (meaning that the rough surface has an actual surface area that is three times the surface area calculated from the radius), the radius would need to be three times the above example to give the same specific area. In this case:
$r = 3 \times 0.16\ cm = 0.48\ cm$; $V = (4 / 3) \times Pi \times (0.48)^3 = 0.463\ cm^3$;
$M = 19\ g/cm^3 \times 0.463\ cm^3 = 8.802\ g$; $A = 4 \times Pi \times (0.48)^2 \times 3$ (roughness factor) $= 8.686\ cm^2$
And so the specific surface area is $8.686\ cm^2 / 8.802\ g = 0.9868\ cm^2/g$ as above.

Depending on the surface roughness, a sphere with a mass between 0.33 and 8.8 g will meet the 1 $cm^2/g$ specific surface area limit

The 1 $cm^2/g$ specific surface area limit controls the parameter that is most important in terms of preventing spontaneous ignition, but it is not easy to measure or to use in the field. A mass limit (similar to the 50-g limit in the existing certificate, but more consistent with the 1-$cm^2/g$ specific area limit) could be used, but it is very time-consuming to weigh every piece of metal in a package. An approach that is both effective at enforcing the 1-$cm^2/g$ specific surface area limit and quick and easy to use in the field is to separate large pieces from small ones in a sieve. The recommended text stipulates a 3/8-in. mesh sieve to quickly remove small particles (with a large specific surface area) from large particles which have a small specific surface area.

As demonstrated in Example 1, rough-surfaced spheres 3/8 in. (0.95 cm) in diameter meet the 1 $cm^2/g$ specific surface area limit (a smooth-surfaced sphere of this size has a specific surface area of 0.33 $cm^2/g$). Therefore, a sphere which does not pass freely through the 3/8-in. mesh sieve will meet the 1 $cm^2/g$ specific surface area limit. Other simple shapes such as cubes and rods are also effectively controlled by the 3/8-in. sieve. Foils, turnings, and wires are explicitly forbidden in both the current and proposed text, unless they are packed in an inert atmosphere.

The phrase "whichever is most restrictive" has been deleted from the proposed text since the sieve test has been sized to effectively enforce the 1-$cm^2/g$ specific surface area limit.

The option of converting pyrophoric uranium to an oxide is removed, since metals need to be shipped as metals for maximum usefulness at the receiver site. In addition, if oxides are produced, packing limits for oxides have been explicitly given in the CoC.

The final change in the proposed text is to eliminate the 1% of content weight limit on inerted material. This limit is unnecessary for uranium metal sealed in a container containing an inert atmosphere. If the metal has been sealed in a container containing an inert atmosphere, there is no oxygen available to the metal and therefore no chance of combustion.

Uranium metal packaged for transport in the ES-3100 is first placed inside a convenience can or other container. These cans are then placed into the ES-3100 containment vessel (CV). The convenience cans will displace most of the oxygen from the CV, leaving only enough to react with a few grams of metal. If a sealed container containing an inert atmosphere somehow came open in transport (an unlikely scenario given the very limited amount of movement possible inside a properly loaded CV), this small amount of oxygen is not enough to support spontaneous ignition. The CV has been shown to retain its structural integrity and remain leak tight under hypothetical accident conditions (HAC), so no additional oxygen can enter.

## IV. Discussion

In his 1995 review,[1] Terry Totemeier explains pyrophoricity this way: "Pyrophoricity refers to the tendency of certain metals to ignite and burn in a self-sustaining oxidation reaction. The pyrophoric nature of metals is usually defined in terms of an ignition temperature, which is the temperature at which a metal will ignite and burn in a self-sustained fashion for a given set of conditions." ASTM C-1454[2] defines pyrophoric as "capable of igniting spontaneously under temperature, chemical, or physical/mechanical conditions specific to the storage, handling, or transportation environment."

This evaluation will demonstrate that uranium metal with a specific surface area of 1 $cm^2/g$ will not spontaneously ignite under the conditions existing in the ES-3100 during packaging and transport.

The primary factors determining if the conditions for spontaneous ignition exist are specific surface area and temperature. Totemeier explains, "Because oxidation is a surface reaction, the amount of area available for reaction is a critical factor in the determination of the heat generated in oxidation. Specific area is the best parameter to describe the effect of area, as it also accounts for the amount of material not reacting which can serve as a heat sink." Temperature is critical because the amount of heat generated by the reaction is a function of the reaction rate, which is in turn a function of the temperature. Higher temperatures give higher reaction rates.

An additional safety factor in the case of the ES-3100 is the small amount of oxygen available in the sealed inner CV. This serves to limit the total amount of uranium that can oxidize, and therefore prevents any potential heat build-up from reaching the ignition point of uranium metal.

*Ignition Temperature and Transport Conditions*

In Figs. 4 and 5 of his review, Totemeier plots two separate tests of uranium ignition temperatures as a function of specific surface area. For a specific surface area of 1 $cm^2/g$ these two plots give values of 390°C (663 K)[1] and 340°C (613 K), respectively. Using the lower value and rounding down gives a conservative value of 600 K for the ignition temperature of uranium metal in the ES-3100.

The ES-3100 thermal analysis determined that the temperature at the CV wall would not exceed 190°F (361 K) for normal conditions of transport (NCT) and 255°F (397 K) for HAC. These values, particularly the HAC temperature, are very conservative. The actual results from six separate package tests showed that the CV wall temperature was typically around 210°F (372 K), with the highest recorded value of 241°F (389 K). Note that all of these temperatures are well below the 600 K ignition temperature of the uranium metal contents.

*Maximum Temperature from Oxidation – Basic Equations*

Uranium metal readily reacts with oxygen to form uranium dioxide ($UO_2$). This reaction is exothermic. The heat released by the reaction warms the uranium metal, increasing the reaction rate. Under normal conditions for storage and transport, the reaction rate is slow enough that the small amount of heat generated by the reaction is lost to the environment, and a stable steady-state is achieved. If the reaction rate is fast enough, and the metal is relatively well insulated, the temperature of the uranium metal can build, slowly at first but at an increasing rate, until the ignition temperature is reached and the metal ignites and burns.

The task at hand is to evaluate the balance between heat generation and heat loss in the ES-3100 under HAC to verify that a stable steady state is reached, and that the steady-state condition is safely below the ignition point of uranium metal. A recent paper by Epstein, Malinovic, and Plys[3] lays out a useful approach, which will be followed here without the approximations used in their paper.

---

[1] The curve in Totemeier Fig. 4 is discontinuous, with a transition from a lower curve to an upper curve shown at a specific surface area of 6 $cm^2/g$. At a specific surface area of 1 $cm^2/g$, the upper curve would give an ignition temperature of 550ºC, while extrapolation of the lower curve gives 390ºC. The original reference from which Totemeier drew Fig. 4 explains that the transition from the lower curve to the upper curve is influenced by many factors, including the metallurgy of the uranium, any alloying metals or impurities, and the oxygen content of the gas involved. Therefore, this analysis uses the lower curve value of 390ºC.

For uranium metal packed in cylindrical cans, the generation of heat throughout the can and the associated transfer of heat to the can wall is mathematically identical to the generation of heat within a wire due to electrical resistance. In their text "Transport Phenomena"[4] Bird, Stewart & Lightfoot develop the desired relation (Equation 9.2-14):

$$Tcenter - Twall = (S \times R^2) / (4 \times Kth) \quad \text{(Equation 1)}$$

where

Tcenter is the temperature at the center of the can (K)
Twall is the temperature at the can wall (K)
S is the heat production per unit volume ($W/cm^3$)
R is the radius of the can (cm)
Kth is the thermal conductivity of the uranium contents (W/cm K)

The heat production per unit volume is a function of the reaction rate and the heat of reaction. Since the oxidation reaction occurs at the surface of the uranium, the reaction rate is typically stated as a mass reacted per second per unit area. The specific surface area, the uranium metal density, and the packing density are applied to convert the rate per unit uranium surface area to a rate per unit can volume. The result is:

$$S = Rho \times Phi \times SArea \times dHrxn \times RxnRate \quad \text{(Equation 2)}$$

where

Rho is the density of the uranium metal ($g/cm^3$)
Phi is the packing density of the uranium in the can ($cm^3$ U/$cm^3$ can volume)
SArea is the specific surface area of the uranium ($cm^2/g$)
dHrxn is the heat of reaction (J/g uranium)
RxnRate is the reaction rate [g uranium / ($s \cdot cm^2$)]

The reaction rate of uranium metal with oxygen has been evaluated by many researchers over the years. The general form of the rate equation used is:

$$RxnRate = K0 \times P^n \times e^{(-Te/T)} \quad \text{(Equation 3)}$$

where

K0 is the reaction rate coefficient [g uranium / ($s \cdot cm^2$)]
P is the partial pressure of water vapor (kPa)
n is the exponential coefficient on the partial pressure of water vapor
Te is the activation energy (K)
T is the temperature of the reactants (K)

For the case at hand, the temperature of the reactants is the highest at the can center (Tcenter) and the lowest at the can wall (Twall). The average temperature of the reactants is midway between these two values. For conservatism the reaction rate of the entire contents is evaluated at the maximum temperature, which occurs at the center of the can (Tcenter). This analysis considers heat transfer only through the can walls, and ignores heat transfer through the top and bottom of the can. This is also a conservative assumption.

Equations 1, 2, and 3 are combined to yield:

$$Tcenter - Twall = (R^2 \times Rho \times Phi \times SArea \times dHrxn \times K0 \times P^n \times e^{(-Te/Tcenter)}) / (4 \times Kth) \quad \text{(Equation 4)}$$

Note that Kth is a property of the can contents (that is, for the bed of uranium metal particles with air in between), and not a property of solid uranium metal. The thermal conductivity of uranium metal is much higher than the thermal conductivity of a bed of uranium metal pieces.

P is the partial pressure of $H_2O$ present in the CV at the center-line temperature. This value is calculated by assuming that the ES-3100 was loaded at ambient conditions of T0 and 100% relative humidity, which yields a water vapor pressure of P0. When the temperature in the CV increases the partial pressure of water vapor increases according to the ideal gas law, which in this case reduces to:

$$P = P0 \times (Tcenter/T0) \qquad \text{(Equation 5)}$$

In this evaluation, the maximum possible rate of heat generation due to the oxidation of the uranium metal is also of interest since this heat must be carried away by the package, even at HAC. The maximum rate of heat generation is the heat generated by the oxidation of uranium metal at the highest temperature reached during HAC, assuming the maximum allowable load of uranium metal. This is:

$$Qmax = Mmax \times SArea \times dHrxn \times K0 \times P^n \times e^{(-Te/Tcenter)} \qquad \text{(Equation 6)}$$

where

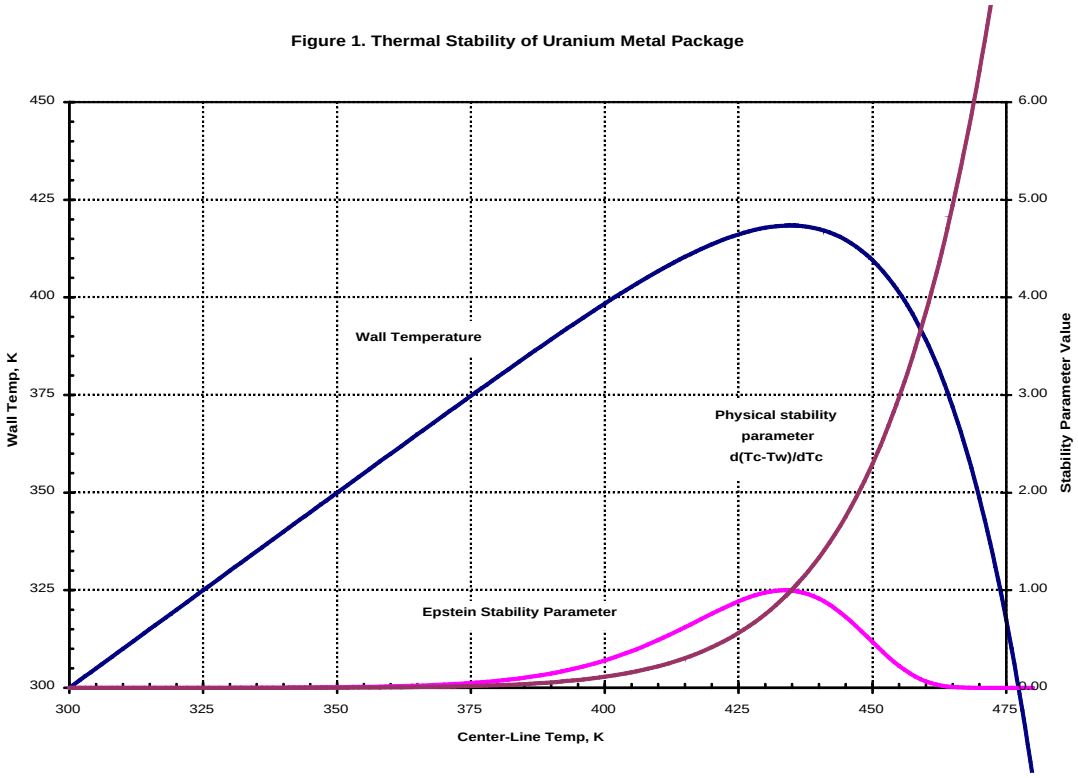
Qmax = the maximum rate of heat generation (W)
Mmax = the maximum uranium metal loading (g)

*Evaluation of Thermal Stability*

Equation 4 provides the means to evaluate the maximum temperature reached in the uranium metal. It does not by itself validate the stability of the system. This system does present a simple means to evaluate stability – both numerical stability and more importantly physical stability (meaning that the temperature cannot build to spontaneous ignition).

Solving Equation 4 for Twall over a range of Tcenter values and plotting the results produces Fig. 1:

Figure 1. Thermal Stability of Uranium Metal Package




The wall temperature calculated from Equation 4 and plotted here is the temperature needed in order to provide enough heat transfer to maintain the given center-line temperature. The wall temperature initially tracks the center-line temperature – the rate of heat generation is low, so a very small temperature difference is sufficient to remove that heat. As the center-line temperature (and therefore the amount of heat generated) increases, the temperature difference needed to keep the center-line temperature steady at the given value increases exponentially. At some point (~435 K in Fig. 1) the required temperature difference gets so large that the wall temperature would have to decrease in order to maintain a stable center-line temperature. In an actual package there is no cooling mechanism to do this, and once the center-line temperature exceeds this point the amount of heat generated will exceed the ability to carry off that heat, and the center-line temperature will increase until either the reaction runs out of oxygen or the ignition point is reached. The point at which the required wall temperature stops increasing, marks the maximum stable center-line temperature for the package. The required wall temperature stops increasing at the point where the rate of increase in the needed temperature difference [d(Tcenter-Twall)] equals the rate of increase of the center-line temperature (dTcenter). Stated mathematically, when d(Tcenter-Twall)/dTcenter is less than 1 the required Twall increases along with Tcenter, and stability is maintained. When d(Tcenter-Twall)/dTcenter is greater than 1 Twall would have to drop to maintain stability as Tcenter increases. Since this is not possible in a real package, the temperature in the package would steadily increase to either ignition or consumption of all available oxygen. The value of d(Tcenter−Twall)/dTcenter = 1 marks the maximum stable point for a given package.

Equation 4 is

$$Tcenter - Twall = (R^2 \times Rho \times Phi \times SArea \times dHrxn \times K0 \times P^n \times e^{(-Te/Tcenter)}) / (4 \times Kth)$$

Taking the first derivative of this equation with respect to Tcenter yields an equation for the stability parameter derived above:

$$d(Tcenter-Twall)/dTcenter = (Tcenter-Twall) \times Te/Tcenter^2 \quad \text{(Equation 7)}$$

The thermal stability of the system is maintained as long as $(Tcenter-Twall) \times Te/Tcenter^2 \leq 1$. This parameter is equivalent to the stability parameter "B" developed in Epstein et al., without the simplifying assumptions made in that paper. The value of d(Tcenter−Twall)/dTcenter is plotted in Fig. 1, along with the Epstein "B" parameter.

*Input Parameters*

The key values used to evaluate Equations 4, 5, 6, and 7 are shown in Table 1.

**Table 1. Key input parameters**

| Parameter | Value | Units |
|---|---|---|
| R | 5.27 | cm |
| Rho | 19 | g/cm³ |
| Phi | 0.26 | cm³/cm³ |
| SArea | 1 | cm²/g |
| dHrxn | 4559 | J/g Uranium |
| K0 | 76086 | gU/(s·cm²) |
| P0 | 3.53 | kPa |
| T0 | 300 | K |
| n | 0.3 | |
| Te | 11490 | K |
| Kth | 0 | W/(cm·K) |

The sources of these parameters are:

R is the inside radius of a convenience can. The typical can used has an outside diameter of 4.25 in., and an inside diameter of 4.15 in. (10.54 cm).

Rho is the density of uranium metal.

Phi is the packing density of uranium metal when packed into the convenience cans. Operator experience at Y-12 is that a maximum of 5 kg U of broken metal will fit into a 4.25-in. OD by 4.875-in. high can, which has an internal volume of 1000 cm³. This yields a packing density of 0.26 cm³/cm³. The effects of variations on this value are discussed below.

SArea is the specific surface area, which is limited by the package certification to 1 cm²/g.

dHrxn is the heat of reaction, on a uranium basis. This value came from Totemeier, page 17 (1089 cal/gU = 4559 J/gU).

K0, n, and Te are parameters for the reaction rate equation. As noted above, a number of researchers have analyzed the reaction rate of uranium metal with various combinations of oxygen and water vapor. Numerous models have been developed from this data. This analysis used the published model that best fit the conditions present. Many of the published rate models are only valid up to 100 to 130°C. This evaluation requires evaluation beyond 140°C. Many of the models are for either pure oxygen or pure water vapor. McGillivray[5] notes that the reaction rate at a given temperature varies with both the oxygen concentration and the partial pressure of water vapor. The published model that best matches the conditions of this evaluation (reaction in air at temperatures exceeding 140°C, with a small water vapor partial pressure) is the Pearce model (Pearce, <100% RH, in Air, T <192°C) as reported in the Epstein paper.

P0 and T0 are used to calculate P, the partial pressure of $H_2O$ vapor present in the CV at the center-line temperature. This value is calculated by assuming that the ES-3100 was loaded at ambient conditions of T0 = 300 K (80°F) and 100% relative humidity. P0 is therefore the vapor pressure of water at 300 K, which is P0 = 3.53 kPa. When the temperature in the CV increases, the partial pressure of water vapor increases according to equation 5.

Kth is the thermal conductivity of the uranium particle bed. The value here was taken from Epstein et al., page 6. Because of the air-filled void spaces, the bed thermal conductivity is much lower than the uranium metal value of 0.3 W/(cm·K).

*Results*

The set of equations (4, 5, 6, and 7) was evaluated using a commercial software package named Tk!Solver, which has the advantage of being able to automatically iterate to solutions as needed. This is necessary when solving equation 4 for a fixed wall temperature to determine Tcenter. Attachment 1 shows the rules, input and output for the TK!Solver model for the HAC and NCT cases.

The HAC evaluation gave a maximum CV temperature (Twall) of 255°F (397 K). Evaluating Equations 4–7 for these conditions yields a Tcenter of 398.4 K (257.5°F), with a maximum heat output (assuming a full load of 36 kgU) of 5.9 Watts, and a stability parameter d(Tcenter-Twall)/dTcenter of 0.102, well below the critical value of 1.0.

The 255°F HAC temperature was based on a uranium heat generation of 0.4 W. The 5.9-W maximum heat generated from the oxidation reaction under those conditions would heat the CV wall above that temperature. The thermal analysis evaluated the HAC for heat generation rates of 20 W and 30 W as well as the 0.4-W standard value. Table 3.7 in the thermal analysis shows that for an assumed 20 W heat generation in the uranium metal contents, the peak CV wall temperature is 277°F (409.3 K). Using this value ensures that the heat transfer from the uranium contents to the CV wall and to the rest of the package is conservatively addressed.

For the revised HAC wall temperature of 277°F (409.3 K), Equations 4–7 yield the following results:

Tcenter = 413.3 K (284.4°F) [well below the ignition temperature of 600 K]
MaxQ = 17.0 Watts (below the 20 W assumption)
d(Tcenter-Twall)/dTcenter = 0.272 (well below the critical value of 1.0)

At the NCT wall temperature of 190°F (360.9 K) the results are:

Tcenter = 361.0 K (190.1°F) [well below the ignition temperature of 600 K]
MaxQ = 0.289 Watts (below the 0.4 W assumption)
d(Tcenter-Twall)/dTcenter = 0.006 (well below the critical value of 1.0)

These values clearly show that uranium metal with a specific surface area of no more than 1 $cm^2/g$ will not spontaneously ignite under any anticipated transport conditions.

*Variation in Input Packing Density*

The density with which uranium metal is packed into the convenience cans limits the surface area available to oxidize. Operator experience at Y-12 is that a maximum of 5 kg U of broken metal will fit into a 4.25-in.-OD by 4.875-in.-high can, which has an internal volume of 1000 $cm^3$. This yields a packing density of 0.26 $cm^3/cm^3$.

A search of the literature on packing densities reveals a lot of work on smooth spheres, and very little on anything else. Scott and Kilgour[6] experimented with packing smooth steel spheres in cylinders, and reported a maximum packing density of 0.6366 after extensive vibration to compact the steel spheres as much as possible. The steel balls used in this experiment had a coefficient of friction of 0.2, well below the value for smooth uranium metal of 1.0. Subsequent analysis by Kong and Lannutti[7] considering the effects of friction between particles gives packing fractions in the range of 0.41 to 0.46, with higher friction coefficients producing lower packing fractions.

The broken metal routinely packed at Y-12 consists of large, rough, irregular pieces. The reported packing density of 0.26 for this material is consistent with the literature reviewed, particularly Kong and Lannutti. Therefore, the value of 0.26 was used as the base value in the analyses reported above.

To bound the metal contents of the ES-3100 two additional cases have been analyzed under HAC: rough broken metal at a packing density of 0.46 (the upper end of the range reported by Kong & Lannutti); and smooth cast spheres at a packing density of 0.64 (consistent with Scott & Kilgour).

For rough broken metal at a packing density of 0.46 the maximum center temperature at HAC was 422 K, well below the ignition temperature of 600 K. For smooth cast 3/8" spheres at a packing density of 0.64 the maximum center temperature at HAC was 412 K, well below the ignition temperature of 600 K.

*Oxygen Limitation in the Containment Vessel*

The analysis above placed no restriction on the amount of oxygen available to react with the uranium metal contents. In reality, the ES-3100 CV has a finite volume, which restricts the amount of oxygen available for reaction.

The CV is a cylinder with inside dimensions of 31.00-in. (78.74-cm) tall and 5.06 in. (12.85 cm) in diameter. This produces a volume of 10,215 $cm^3$, or 10.215 liters. At ambient conditions of 300 K (80.3°F) and 100% relative humidity, 10.215 liters of humid air contains 2.78 g of oxygen from the air, and another 0.23 grams of oxygen in the $H_2O$. These 3.01 grams of oxygen can react with 22.40 g of uranium metal. This is 0.06% of the ES-3100's capacity.

A mass of 22.4 g of U metal when reacted with 3.01 g of oxygen will produce a maximum total heat output of 102 kJ (96.8 BTU), spread out over the time required for the reaction to take place. This total amount of oxygen could sustain the NCT maximum heat output of 0.289 W for 4.1 days, or the HAC peak heat output for 1.7 hours. If somehow released all at once, the 102 kJ would only raise the temperature of 36 kg of uranium by 24.5 K. More realistically, as shown by the calculations above, any reaction will be slow, with enough time for the heat generated to flow to the CV and the rest of the package.

The ES-3100 CV is 15.1 kg of stainless steel, with a heat capacity of 0.515 J/(g·K). The 102 kJ maximum produced by the oxidation reaction could only raise the temperature of the CV (ignoring contents) by 13.1 K. This heat sink, plus the heat sinks offered by the CV contents, ensures that the oxidation reaction will not be able to build to the 600 K ignition temperature required for spontaneous ignition.

In practice there will less than 3 g of oxygen available to react with the uranium metal inside the closed CV. A full load of uranium will, by itself, displace nearly 20% of the air in the CV. The convenience cans, spacer cans, and other packing materials will displace even more air, further reducing the amount of uranium that could possibly react. Also, the uranium metal is packed inside closed convenience cans. These cans limit the oxygen available to react with the contents to the oxygen in the convenience can itself. Finally, part of the available oxygen will react with the uranium before the peak HAC conditions are reached. Figure 22b in Sect. 3 shows that it will take ~4 hours for the CV wall to reach the maximum temperature in the HAC fire. During this four-hour temperature ramp-up 0.9 grams of oxygen would be consumed by reaction with the uranium, leaving only 2.1 grams available to react once the HAC temperature was reached. Even if the uranium surface area was uncontrolled, lack of oxygen would snuff out any increase in the uranium reaction rate before it could reach the ignition point.

*Specific Surface Area Implementation via Sieve*

As noted above, the 1 $cm^2/g$ specific surface area limit is not easy to measure or to use in the field. A screening method that is simple and easy to use in the field will reduce the potential for packaging mistakes. The recommended approach is to separate large pieces from small ones in a sieve. The recommended text stipulates a 3/8-in. mesh sieve to quickly remove small particles (with a large specific surface area) from large particles which have a small specific surface area.

Example 1 above showed that the minimum size of a metal sphere meeting the 1 $cm^2/g$ specific surface area limit varies with the degree of surface roughness. In Example 1 a smooth sphere 1/8 in. in diameter and a rough sphere 3/8 in. in diameter both had specific surface areas just below the 1 $cm^2/g$ limit. The 3/8-in. mesh is stipulated in the recommended text in order to accommodate both smooth and rough metal.

The actual metal contents of the ES-3100 will include both smooth-surfaced and rough-surfaced metal. The smooth-surfaced items include a variety of cast and machined shapes. The rough-surfaced items are “broken metal” – large castings that have been fractured into smaller pieces. These broken metal pieces will typically have two or three cast surfaces with the remaining 3 or 4 surfaces of fractured metal.

The 3/8-in. mesh recommendation is based on a surface roughness factor of three, meaning that the rough surface has an actual surface area available to react with oxygen that is three times that of a smooth-surface of the same gross dimensions. This roughness factor of three was derived from an evaluation of fracture surfaces for cast uranium metal. Roughness factors ranged from 1.1 to 2.7, with a mean value of 2.0. A roughness factor of three was selected to bound the highest value observed. The

3/8-in. mesh screening is therefore suitable for metal that is fractured on all surfaces. Since as noted above even broken metal will have several smooth faces the 3/8-in. mesh screening should be quite conservative.

As demonstrated above, a rough-surfaced sphere which does not pass freely through the 3/8-in. mesh sieve will meet the 1 $cm^2/g$ specific surface area limit. Other simple shapes such as cubes and rods are also effectively controlled by the 3/8-in. sieve. Foils, turnings, and wires are explicitly forbidden in both the current and proposed text, unless they are packaged in an inert atmosphere. Attachment 2 shows the dimensions of a variety of shapes that have a specific surface area of 1 $cm^2/g$. All of these items will fall through a 3/8-in. sieve, demonstrating that the sieve will effectively enforce the 1 $cm^2/g$ specific surface area limit.

Most foils and wires will not fall through a sieve of any reasonable size. The current 50 g test would likewise not reliably exclude these materials, which is why foils, turnings, and wires are explicitly forbidden in both the current and proposed text, unless they are packed in an inert atmosphere. Operator training will be required under either the current or the proposed text to ensure that these items are properly packaged.

*Operator Training*

As part of the transition to using the new shipping container, training materials are being prepared to instruct the field operations personnel on the proper way to use the ES-3100. As noted above, the training for the operators packing uranium metal into the convenience cans for shipment in the ES-3100 will be important in ensuring that potentially pyrophoric materials are properly categorized and inerted as necessary. This training will cover the following points:

- All metal pieces must be evaluated to ensure that their smallest dimension is larger than the 3/8-in. mesh size.
  - Single solid-metal pieces that are clearly larger than the 3/8-in. mesh in every dimension do not require sieving.
  - Items which are obviously unacceptable, such as foils, wires, and turnings, may be removed before the sieving
  - Any item that is not obviously larger than the 3/8-in. mesh in every dimension and which has not been rejected must be sieved.
  - Any item that falls through the sieve must be rejected.
- Operators need to be alert to items which may not fall through the sieve but which are too small:
  - Long, thin shapes such as wires and turnings may not fall through the sieve when shaken. If the wire or turning could be picked up and poked through the mesh it must be rejected, even if it did not fall through unassisted.
  - Wires or turnings may form a tangled ball which will not fall through. The above criterion applies: if the wire or turning could be separated and poked through the mesh it must be rejected.

- No distinction is made between wires and rods – if the item could be picked up and poked through the mesh it must be rejected.
- Foils, thin chips or shards - any item less than 1/8-in. thick – must be rejected.
- Metal showing visible moisture or signs of having been stored in water must be rejected.

- Rejected items must be separated for proper handling:
  - Rejected items can be shipped if packed under an inert cover gas.
  - An acceptable cover gas must be an inert gas or mixture of inert gases with a high-purity (≥99%) and low moisture (≤5 ppm moisture).

## V. Conclusion

The evaluations performed show that uranium metal conforming to the 1-$cm^2/g$ limit on specific surface area will not spontaneously ignite under any anticipated transport conditions. Spontaneous ignition is independently prevented by both the 1-$cm^2/g$ limit on the uranium metal and by the limited amount of oxygen available in the sealed ES-3100 CV.

The 3/8-in. sieve specified in the revised text effectively applies the 1-$cm^2/g$ specific surface area limit to broken uranium metal in a manner that is quick and easy to use in the field.

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**Attachment 1. TK!Solver Model and Results**

Rules

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Tcenter-Twall=((R^2*rho*phi*SArea*dHrxn*K0*P^n)/(4*Kth))*exp(-Te/Tcenter)
P=P0*(Tcenter/T0)
Deriv=(Tcenter-Twall)*Te/Tcenter^2
HRate=SArea*dHrxn*K0*P^n*exp(-Te/Tcenter)
MaxQ=HRate*MaxM
RRate=SArea*MaxM*K0*P^n*exp(-Te/Tcenter)
ORate=RRate*32/238
OTime=MaxO/ORate

---

HAC—277°F Wall Temperature

| Input | Name | Output | Unit | Comment |
|---|---|---|---|---|
| | Tcenter | 413.348 | K | Temperature at the center of the can |
| 409.3 | Twall | | K | Temp at the can wall |
| | HRate | .000472 | W/gU | Rate of heat production (w/unlimited O2) |
| | MaxQ | 16.9945 | W | Maximum heat production (from max KgU) |
| 36000 | MaxM | | gU | Maximum ES-3100 contents |
| 3.01 | MaxO | | gO | Maximum ES-3100 Oxygen Content |
| | RRate | .003728 | gU/s | Reaction Rate at given Conditions |
| | ORate | .000501 | gO/s | Oxygen Use rate at given conditions |
| | OTime | 1.66822 | hr | Oxygen time to run-out |
| 5.27 | R | | cm | Can radius |
| 1 | SArea | | cm^2/gU | Specific Surface Area of U particles |
| | Deriv | .272221 | | d(Tcenter-Twall)/dTcenter |
| 19 | rho | | gU/cm^3 | Density of uranium |
| .26 | phi | | | Packing density, U cm^3 / Can cm^3 |
| 4559 | dHrxn | | J/gU | Heat of Reaction |
| 76086 | K0 | | gU/(s*cm^2) | Reaction rate coefficient - Pearce <100% |
| 11490 | Te | | K | Reaction rate coefficient - Pearce <100% |
| .3 | n | | | Reaction rate coefficient - Pearce <100% |
| 3.53 | P0 | | kPa | Vapor pressure of water at T0 |
| 300 | T0 | | K | Temperature for P0 |
| | P | 4.86373 | kPa | Vapor Pressure of Water at Tcenter |
| .004 | Kth | | W/cm*K | Thermal Conductivity of U particle bed |

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---

NCT - 190℉ Wall Temperature

| Input | Name | Output | Unit | Comment |
|---|---|---|---|---|
| | Tcenter | 360.969 | K | Temperature at the center of the can |
| 360.9 | Twall | | K | Temp at the can wall |
| | HRate | 8.03E-6 | W/gU | Rate of heat production (w/unlimited O2) |
| | MaxQ | .288991 | W | Maximum heat production (from max KgU) |
| 36000 | MaxM | | gU | Maximum ES-3100 contents |
| 3.01 | MaxO | | gO | Maximum ES-3100 Oxygen Content |
| | RRate | 6.34E-5 | gU/s | Reaction Rate at given Conditions |
| | ORate | 8.52E-6 | gO/s | Oxygen Use rate at given conditions |
| | OTime | 98.1015 | hr | Oxygen time to run-out |
| 5.27 | R | | cm | Can radius |
| 1 | SArea | | cm^2/gU | Specific Surface Area of U particles |
| | Deriv | .00607 | | d(Tcenter-Twall)/dTcenter |
| 19 | rho | | gU/cm^3 | Density of uranium |
| .26 | phi | | | Packing density, U cm^3 / Can cm^3 |
| 4559 | dHrxn | | J/gU | Heat of Reaction |
| 76086 | K0 | | gU/(s*cm^2) | Reaction rate coefficient - Pearce <100% |
| 11490 | Te | | K | Reaction rate coefficient - Pearce <100% |
| .3 | n | | | Reaction rate coefficient - Pearce <100% |
| 3.53 | P0 | | kPa | Vapor pressure of water at T0 |
| 300 | T0 | | K | Temperature for P0 |
| | P | 4.2474 | kPa | Vapor Pressure of Water at Tcenter |
| .004 | Kth | | W/cm*K | Thermal Conductivity of U particle bed |

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## Attachment 2. Pyrophoric Size Limits on Small Uranium Metal Pieces

| | | |
|---|---|---|
| Specific Surface Area: | 1.0 | cm^2/g |
| Uranium Metal Density: | 19.0 | g/cm^3 |
| Surface Area Multiplier: | 3.0 | |

*The surface area multiplier is the ratio of the actual surface area divided by the simple geometeric surface area.*

### Spheres - Minimum Safe Diameter

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Limiting diameter | | 0.9474 | cm | or | 0.3730 | in | 8.459 | grams |

### Rods - Minimum Safe Diameter

| Length | | Diameter | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0.9 | cm | 0.9474 | cm | or | 0.3730 | in | 12.688 | grams |
| 1.0 | cm | 0.9231 | cm | or | 0.3634 | in | 12.715 | grams |
| 1.5 | cm | 0.8000 | cm | or | 0.3150 | in | 14.326 | grams |
| 2.0 | cm | 0.7500 | cm | or | 0.2953 | in | 16.788 | grams |
| 2.5 | cm | 0.7229 | cm | or | 0.2846 | in | 19.495 | grams |
| Infinite | | 0.6316 | cm | or | 0.2487 | in | | |

### Cubes - Minimum Safe Side Length

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Limiting side length | | 0.9474 | cm | or | 0.3730 | in | 16.155 | grams |

### Square Cross-Section Rods - Minimum Safe Side Length

| Length | | Side | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0.9 | cm | 0.9474 | cm | or | 0.3730 | in | 16.155 | grams |
| 1.0 | cm | 0.9231 | cm | or | 0.3634 | in | 16.189 | grams |
| 1.5 | cm | 0.8000 | cm | or | 0.3150 | in | 18.240 | grams |
| 2.0 | cm | 0.7500 | cm | or | 0.2953 | in | 21.375 | grams |
| 2.5 | cm | 0.7229 | cm | or | 0.2846 | in | 24.822 | grams |
| Infinite | | 0.6316 | cm | or | 0.2487 | in | | |

### Chips & Shards - Minimum Safe Thickness

| Length | | Width | | Thickness | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.0 | cm | 0.5 | cm | 6.0000 | cm | or | 2.3622 | in | 57.000 | grams |
| 1.5 | cm | 0.5 | cm | 2.0000 | cm | or | 0.7874 | in | 28.500 | grams |
| 2.0 | cm | 0.5 | cm | 1.5000 | cm | or | 0.5906 | in | 28.500 | grams |
| 2.5 | cm | 0.5 | cm | 1.3043 | cm | or | 0.5135 | in | 30.978 | grams |
| 3.0 | cm | 0.5 | cm | 1.2000 | cm | or | 0.4724 | in | 34.200 | grams |
| Infinite | | 0.5 | cm | 0.8571 | cm | or | 0.3375 | in | | |
| 1.0 | cm | 0.6 | cm | 2.0000 | cm | or | 0.7874 | in | 22.800 | grams |
| 1.5 | cm | 0.6 | cm | 1.2000 | cm | or | 0.4724 | in | 20.520 | grams |
| 2.0 | cm | 0.6 | cm | 1.0000 | cm | or | 0.3937 | in | 22.800 | grams |
| 2.5 | cm | 0.6 | cm | 0.9091 | cm | or | 0.3579 | in | 25.909 | grams |
| 3.0 | cm | 0.6 | cm | 0.8571 | cm | or | 0.3375 | in | 29.314 | grams |
| Infinite | | 0.6 | cm | 0.6667 | cm | or | 0.2625 | in | | |
| Infinite | | Infinite | | 0.3158 | cm | or | 0.1243 | in | | |

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## Appendix 1.3.9

## Equipment Specification SPC-M801580-0001,
## *ES-3100 Fluorocarbon Elastomer (Viton) Containment Vessel (CV) O-rings*

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# EQUIPMENT SPECIFICATION APPROVAL/REVISION PAGE

| SPECIFICATION NO. | REV. |
|---|---|
| SPC-M801580-0001 | 0 |
| ISSUE DATE | REVISION DATE |
| 6/11/2012 | |
| PROCURED BY | INSTALLED BY |
| B&W Y-12 LLC | B&W Y-12 LLC |

| PROJECT TITLE | QUALITY LEVEL | BUILDING |
|---|---|---|
| ES-3100 | Q | YAREA-00 |

JOB TITLE
ES-3100 Shipping Container

SPECIFICATION FOR
ES-3100 Fluorocarbon Elastomer (Viton) Containment Vessel (CV) O-rings

UNID

## REVISIONS

| REV. NO. | DESCRIPTION OF REVISION |
|---|---|
| 0 | Issued approved. |

## APPROVALS

| SIGNATURE | DATE | SIGNATURE | DATE |
|---|---|---|---|
| PREPARED BY<br>L. Roberson | 6/11/12 | PROJECT ENGINEER<br>L. Roberson | 6/13/12 |
| DESIGN VERIFICATION<br>Monty L Goins | 6/12/12 | Program Mgr.<br>D.R. | 6/13/12 |
| DISCIPLINE MANAGER<br>W. D. Cash | 6/12/12 | | |

EXEMPT FROM IO-155 (8-02)

For Y-12 use only, the O-rings shall be stored in accordance with procedure Y60-503, Level B.

This document has been has been reviewed by a Y-12 DC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.

Name: Jon Thomas Date: 06/12/12

# EQUIPMENT SPECIFICATION
# ES-3100 VITON CV O-RINGS

| SPECIFICATION NO. | REV. |
|---|---|
| SPC-M801580-0001 | 0 |
| ISSUE DATE | REVISION DATE |
| 6/11/2012 | |
| PLANT | PAGE |
| Y-12 | ii of iii |

**TABLE OF CONTENTS**


**1.0 SCOPE ..... 1**
**2.0 APPLICABLE DOCUMENTS ..... 1**
**3.0 DEFINITIONS ..... 1**
**4.0 REQUIREMENTS ..... 2**
4.1 Materials ..... 2
4.2 Properties ..... 2
4.3 Fabrication ..... 2
4.4 Packaging and Marking Requirements ..... 2
4.5 Inspection ..... 3
**5.0 NUMBERS OF PARTS ..... 3**
**6.0 FIRST ARTICLE EVALUATION (FAE) ..... 3**
6.1 Primary Objective ..... 3
6.2 FAE Document Requirements ..... 3
6.3 Verification Testing ..... 4
6.4 Onsite Evaluation ..... 4
6.5 Results Notification ..... 4
6.6 Documentation ..... 4
**7.0 MANUFACTURING PLAN ..... 4**
7.1 General ..... 4
7.2 Manufacturing Procedures ..... 5
7.3 Equipment ..... 5
**8.0 QUALITY ASSURANCE PROVISIONS ..... 5**
8.1 General ..... 5
8.2 Material Control ..... 5
8.3 Inspection Requirements ..... 5
8.4 Acceptance Criteria ..... 6
**9.0 CERTIFICATION DATA ..... 7**
9.1 Conforming Product ..... 7
9.2 Nonconforming Product ..... 7
9.3 Test Material ..... 7
9.4 Cause for Rejection ..... 7
9.5 Distribution and Number of Copies ..... 7
**10.0 CLEANING ..... 8**
**11.0 PART MARKING ..... 8**
**12.0 SHIPMENT ..... 8**
**13.0 FINAL ACCEPTANCE ..... 8**
**ATTACHMENT 1 REQUEST FOR WAIVER OR DEVIATION FORM ..... 9**
**ATTACHMENT 2 CERTIFIED DATA – MANUFACTURER ..... 11**

**LIST OF COMPANY DRAWINGS**

| Drawing Number | Title |
|---|---|
| M801580-0013 | Containment Vessel Viton O-Ring Details |

**ATTACHMENTS**

**MANUFACTURER'S DATA REQUIREMENTS**

| | |
|---|---|
| Attachment 1 | Request for Waiver or Deviation Form |
| Attachment 2 | Certified Data – Manufacturer |

# EQUIPMENT SPECIFICATION
# ES-3100 VITON CV O-RINGS

| SPECIFICATION NO. | REV. |
|---|---|
| SPC-M801580-0001 | 0 |
| ISSUE DATE | REVISION DATE |
| 6/11/2012 | |
| PLANT | PAGE |
| Y-12 | 1 of 11 |

## 1.0 SCOPE

This specification, the Company's drawings, and the documents referenced herein provide requirements for the materials, fabrication, inspection, examination, documentation, and testing of ES-3100 O-rings.

If conflicting requirements appear in these documents, the Manufacturer shall immediately notify the Company for resolution.

The Seller shall not deviate from the requirements of this specification without prior written consent from the Company. Requests for changes or deviations shall be submitted on the Request for Waiver or Deviation, Attachment 1.

## 2.0 APPLICABLE DOCUMENTS

The ES-3100 O-rings shall be fabricated, inspected, and tested according to the design drawings and the applicable referenced documents.

- ASTM D 412, *Test Methods for Vulcanized Rubber and Thermoplastic Elastomers – Tension*
- ASTM D 1329, *Standard Test Method for Evaluating Rubber Property Retraction at Lower Temperatures (TR Test)*
- ASTM D 2240, *Test Method for Rubber Property – Durometer Hardness*
- MIL-STD-413C Notice 1, June 19, 1987, *Visual Inspection Guide for Elastometric O-Rings*
- SAE AMS-R-83485, *Rubber, Fluorocarbon Elastomer, Improved Performance at Low Temperature, Type 1*
- SAE AMS-R-83485/1, *Rubber, Fluorocarbon Elastomer, Improved Performance at Low Temperatures, O-rings, Sizes, and Tolerances*
- Title 10 Code of Federal Regulations, Part 71, Subpart H, *Quality Assurance*

## 3.0 DEFINITIONS

Batch—A batch is defined as a homogeneous quantity of material compound mixed at one time.

LOT—A lot shall be a quantity of product of the same identity, cured in the same production run, and from the same batch.

First Article—Product that is submitted to Y-12 for evaluation prior to the seller being released to manufacture the remaining quantities in the subcontract. This product must be representative of production items by virtue of having been produced and inspected using the same facilities, testing, processes, and type of personnel planned for use in production.

First Article Evaluation (FAE)—An evaluation by Y-12 of the first article unit manufactured and the facilities, tooling, processes, etc. concerned with the manufacture and inspection.

## 4.0 REQUIREMENTS

### 4.1 Materials

4.1.1 The Manufacturer shall be responsible for supplying all materials, services, facilities, and equipment to meet the requirements of this specification and Company drawings unless otherwise noted.

4.1.2 The O-rings shall meet the requirements of SAE AMS-R-83485, Parker O-ring Compound VM835-75.

4.1.3 The O-ring material shall be fluorocarbon rubber, SAE AMS-R-83485, Parker O-ring Compound VM835-75.

4.1.4 The O-ring color shall be black.

**NOTE:** The use for the O-rings is a static face seal.

### 4.2 Properties

4.2.1 The O-rings shall have a normal temperature service range of 302°F to -40°F. The low temperature capability of the O-ring shall be determined by conducting a TR-10 test specified in ASTM D 1329. A quantitative test report certifying this low temperature capability shall be submitted for each lot of O-rings as Certified Data; see Attachment 2.

4.2.2 The O-rings shall have a Shore A hardness of 75A ± 5 per ASTM D 2240. A quantitative test report certifying this hardness shall be submitted for each lot of O-rings as Certified Data; see Attachment 2.

4.2.3 The O-rings shall have a minimum elongation of 100% per ASTM D 412. A quantitative test report certifying this elongation shall be submitted for each lot of O-rings as Certified Data; see Attachment 2.

### 4.3 Fabrication

4.3.1 The O-rings shall be molded as a single piece.

4.3.2 Each O-ring's surface shall be smooth, non-porous, and free of skin defects and impregnated material to the requirements of MIL-STD-413C.

### 4.4 Packaging and Marking Requirements

4.4.1 O-ring packaging shall be accomplished under conditions which will ensure freedom from contamination by dust, oil, grease, and other extraneous matter.

4.4.2 Individual O-rings shall be packaged one to a sealed package.

4.4.3 The O-ring package marking shall be in accordance with Sect. 11.0.

4.4.4 O-ring packages, if packed in an outer container, shall be packed in such a manner that during shipment and storage, they will not be permanently distorted, and will be protected against damage from exposure to weather or any other normal hazard. Unless otherwise specified in the Purchase Order, the outer container shall be marked with no less that the following information:

- Purchase Order Number
- Manufacturer's Identification
- Part Number
- Date of Shipment
- Number of parts per container

### 4.5 Inspection

4.5.1 Dimensional requirements are specified on the Company Drawing M801580-0013.

4.5.2 The Manufacturer's inspection shall include, as a minimum, the following.

4.5.2.1 All dimensions and tolerances require 100% inspection. In the event that inspection of a dimension or tolerance is not practical, the Manufacturer shall submit for approval an alternate plan for ensuring the features will meet requirements.

4.5.2.2 The O-rings shall be 100% visually inspected per MIL-STD-413C.

4.5.3 A certified written inspection report(s) shall be prepared and submitted to the Company in accordance with Sect. 9.1 and Attachment 2.

4.5.4 Where inspection or test equipment yields quantitative readings, actual measurements and deviation from nominal readings shall be recorded.

4.5.5 A representative sample for each batch of material per paragraph 9.3 shall be provided to the Company for verification testing.

4.5.6 The seal material composition shall be verified by Fourier Transform Infrared (FTIR) Spectroscopy on a sample of two units taken from each batch of material. A report shall be provided to the Company.

## 5.0 NUMBERS OF PARTS

The total number of parts to be manufactured for First Article Evaluation (FAE) and production shall be specified in the Company's purchase order.

## 6.0 FIRST ARTICLE EVALUATION (FAE)

### 6.1 Primary Objective

The primary objective of a FAE is to verify that the product conforms to its requirements and that the facilities tooling, processes, controls, personnel, acceptance methods, etc. can consistently furnish product of the required quality and quantity. The FAE is conducted in two phases. The first phase is an evaluation at the Seller's site of all critical manufacturing, inspection, and testing operations and equipment. The second phase is an independent evaluation by Y-12 of the FAE parts of material received by Y-12.

### 6.2 FAE Document Requirements

The Seller shall manufacture first article quantities that are representative of production units. All parts shall be produced, tested, and inspected using the same facilities, tools, processes, procedures, and type of personnel planned for use during production. It is the responsibility of the Seller to:

6.2.1 Notify the Company sufficiently in advance of the fabrication of the First Article Unit to permit the Company to witness the manufacture and inspection. Normally 10 days notice is required.

6.2.2 Furnish for review/approval copies of all procedures, follow sheets, data forms, processing records, etc., used by the Seller to define or control those aspects of the manufacturing and inspection operations that influence the quality of the finished product. These documents are to be furnished not later than the notification of the date of First Article production.

6.2.3 Furnish for each First Article Unit copies of all inspection and certification data required to be supplied for the production parts.

### 6.3 Verification Testing

The Seller shall be released for fabrication of production quantities when Stage II customer verification testing of the FAE is successfully completed.

### 6.4 Onsite Evaluation

The Company will perform an FAE of the first parts manufactured by production process and personnel. This evaluation shall be conducted on the FAE parts as received by the Company.

### 6.5 Results Notification

The Seller shall not proceed to manufacture parts beyond the initial FAE quantities until a successful FAE has been completed and notification to proceed has been received from the Company. The Seller shall be notified in writing by Y-12 of the results of the First Evaluation Article Evaluation. The FAE results will be reported in one of the following three categories:

6.5.1 **Acceptable:** Seller is released to initiate manufacture of production quantities.

6.5.2 **Conditionally Acceptable:** Y-12 will specify actions which the Seller must complete before being released for production quantities.

6.5.3 **Not Acceptable:** The First Article units have serious deficiencies, or the ability of the Seller to consistently furnish product of the required quality and quantity is subject to major uncertainty. The Company will specify the required action.

### 6.6 Documentation

The Seller shall provide the documentation as specified in Sect. 6.2.2. All process procedures as described by the above reference shall be submitted for review by the Company prior to the manufacture of FAE parts. Final approval of these procedures shall be made on successful completion of Company's evaluation of parts received. Any subsequent changes to these approved documents or processes will require notification be made to the Company. The Company shall then determine if a new FAE is warranted.

## 7.0 MANUFACTURING PLAN

### 7.1 General

The Seller shall manufacture parts in accordance with SAE AMS-R-83485, Type 1; this specification; and the requirements standard set forth in Sect. 4.0 of this document.

### 7.2 Manufacturing Procedures

The Seller shall develop and implement written procedures, follow sheets, data forms, and processing records as required to document and control the manufacturing processes and to ensure consistency of all operations. In addition, the Seller shall prepare an inspection procedure as specified by Sect. 8.3.2 of this document for submittal to the Company for review and approval.

### 7.3 Equipment

The Seller shall have adequate manufacturing and test equipment to ensure compliance of the dimensional configuration and physical properties specified by the specifications referenced.

## 8.0 QUALITY ASSURANCE PROVISIONS

### 8.1 General

The Seller shall implement and maintain a quality control system that meets and ensure that the requirements listed in this document and 10 CFR Part 71, Subpart H are met.

### 8.2 Material Control

The Seller shall maintain an effective material control program which meets the requirements of this document and ensures that the following material controls are implemented and maintained:

8.2.1 Ensures that only material meeting the specified requirements is used in the fabrication of this product.

8.2.2 Provides for obtaining the supplier's certification of raw material called out in this specification and/or purchase order as necessary to meet the requirements of Sect. 4.0 of this document.

8.2.3 Ensures that all mechanical testing of specimens representative of the cured material has been done and quantitative test results obtained.

8.2.4 Provides traceability from as-shipped parts to the lot run and the batch of stock from which the parts were manufactured.

### 8.3 Inspection Requirements

8.3.1 The Seller's Quality Control program shall develop the necessary procedures and data record forms, and implement an inspection and test program which meets all the requirements specified below.

8.3.2 The Seller shall submit an Inspection procedure for Company approval a minimum of ten (10) days prior to manufacture of FAE parts. This procedure shall contain, as a minimum, a listing of inspection equipment used to inspect each dimension and all features and requirements specified by Sect. 8.3.4.

8.3.3 Prior to performing final inspection, the Seller shall perform all cleaning operations required to ensure parts are free of all fabrication and handling defects and that no foreign materials are present on the part's surface or features.

8.3.4 The Seller shall visually and dimensionally inspect all parts 100 percent. The Seller's inspection shall include, as a minimum, the following:

8.3.4.1 **Part identification:** Part identification as specified by Sect. 12.0 of this document.

8.3.4.2 **Cleanliness:** All parts submitted to the Company shall be inspected by the Seller to be free of all foreign materials. This shall include dirt, grease, curing compound, etc., which are attached to or adhere to the part surface or features.

8.3.4.3 **Workmanship:** The seals shall meet the workmanship requirements of MIL-STD-413C. There must be no defects or foreign materials in the rubber which will alter its ability to form a seal or endanger longevity by chemical interactions.

8.3.4.4 **Dimensions:** Inside diameter and width (cross-section) as specified by the purchase order shall be inspected.

8.3.5 The Seller shall establish and implement a plan to sample and test the physical properties of each batch of cured molding compound used for manufacture. The Seller shall test to ensure compliance to all criteria specified.

8.3.6 The Seller shall document the results of the inspection and/or testing on appropriate data record forms. Where inspection or test equipment yields quantitative readings, actual measurements or deviation from nominal readings shall be recorded.

8.3.7 Documentation of all inspection and test results shall be maintained by the Seller for a minimum of one (1) year after completion of the contract. The Company shall reserve the option to retrieve and review this data as deemed necessary to ensure compliance with all product specifications.

8.3.8 The Seller shall not ship nonconforming parts without prior approval by the Company. (Ref. Sect. 9.2.)

**8.4 Acceptance Criteria**

8.4.1 Batch Acceptance

8.4.1.1 **Certification:** The supplier shall certify that each batch meets the physical properties per SAE AMS-R-83485, Type 1, of compound called out in this specification in Sect. 4.1.

8.4.1.2 **Environment:** Test specimen preparation and testing may be done at 18 to 30°C and 10 to 65% relative humidity (applies to Sects. 8.4.1.3–8.4.1.4).

8.4.1.3 **Composition:** The seal material composition shall be verified by Fourier Transform Infrared (FTIR) Spectroscopy on a sample of two units taken from each batch of material. A report shall be provided to the Company.

8.4.1.4 **Density:** The density (specific gravity) of the material shall be verified on a sample of two units taken from each batch of material.

8.4.2 Lot Acceptance

8.4.2.1 **Inspection Report:** The seals shall meet the inspection requirements as specified by paragraph 8.3.4.

8.4.2.2 **Cure Certification:** The supplier shall certify that each lot was cured according to the temperature and time parameter specified in the Seller's approved manufacturing plan.

## 9.0 CERTIFICATION DATA

### 9.1 Conforming Product

With each shipment of O-rings, the Seller shall submit the following certification data:

9.1.1 two (2) copies of a signed certification which identifies, by batch and lot numbers, all O-rings included in the shipment and attest that all parts conform to all criteria of the purchase order and this specification;

9.1.2 two (2) copies of the quantitative test results for physical property tests per Sect. 8.4.1.1;

9.1.3 two (2) copies of the FTIR Spectroscopy per Sect. 8.4.1.3;

9.1.4 two (2) copies of the quantitative test results for density per Sect. 8.4.1.4;

9.1.5 two (2) copies of the inspection report per Sect. 8.4.2.1; and

9.1.6 two (2) copies of the cure certification per Sect. 8.4.2.2.

### 9.2 Nonconforming Product

9.2.1 The Seller shall not ship nonconforming parts without prior approval by the Company. Any nonconforming product approved for shipment shall be documented on the Certificate of Conformance (C of C) or a Nonconforming Material Report attached to the C of C. This documentation shall include, as a minimum, the following information:

- Identification of part(s) by lot and serial number.
- The nonconforming feature(s) on each part.
- Identification of the Company representative who granted approval.
- The date that the approval was granted.

### 9.3 Test Material

For each lot of material used to fabricate, the Seller shall supply to the Company one piece of stock that is a minimum of 6" x 6" x 0.070” – 0.090” thick and has been cured with the parts from each batch. This piece shall be from the same material as the parts in the lot run. This test material shall be identified with the batch number of the material compound used and the production lot number represented, and shall be forwarded to the Company with the first shipment of parts fabricated from the material represented.

### 9.4 Cause for Rejection

Material certifications and/or any supporting test data as specified above cannot be waived. Failure to supply the required data may be cause for rejection.

### 9.5 Distribution and Number of Copies

Certification data shall be forwarded for each shipment of parts to the Company. One (1) copy shall be included with the shipment of O-rings and one (1) copy to be forwarded to the subcontract administrator.

## 10.0 CLEANING

Each part shall be thoroughly cleaned after the completion of all processing and prior to shipment.

## 11.0 PART MARKING

Each O-ring package shall be marked to identify the following information:

- Master Batch Number
- Lot Number
- Vendor or Company Part Number or Part Name
- Size or Code
- Compound
- Cure Date (Date of Mfg.)
- Expiration Date (4 years from date of manufacture)

## 12.0 SHIPMENT

The Seller shall ship parts in accordance with the delivery schedule as specified in the Company's Purchase Order.

## 13.0 FINAL ACCEPTANCE

Final acceptance of each part shall be based on inspection and testing performed by the Company at the receiving site. Any parts not meeting the requirements set forth in this specification or applicable part drawing will be returned to the Seller for rework or replacement. Any shipment that contains a nonconforming product may be returned to the Seller without a 100 percent inspection by the Company

**ATTACHMENT 1**
**REQUEST FOR WAIVER OR DEVIATION FORM**

# REQUEST FOR WAIVER OR DEVIATION

| 1. WAIVER DEVIATION | 2. SHEET 1 OF 1 |
|---|---|
| | 3. NO. |

| 4. COMPONENT NAME | 5. VENDOR | 6. PART OR IDENTIFYING NUMBER | 7. DOCUMENT NUMBER | REV |
|---|---|---|---|---|
| | | | | |

| 8. PURCHASE ORDER NUMBER | ITEM NO. | 9. PROGRAM | 10. SERIAL OR LOT NUMBER | 11. LOT SIZE |
|---|---|---|---|---|
| | | | | |

| 12. CHARACTERISTIC | 13. DESCRIPTION OF WAIVER/DEVIATION | 14. SPECIFICATION REQUIREMENTS | 15. RESULTS |
|---|---|---|---|
| | | | |

16. VENDOR'S PLAN FOR CORRECTIVE ACTION

| 17. INITIATED BY | 18. TITLE | 19. DATE |
|---|---|---|
| | | |

COMPANY EVALUATION

| 20. CHARACTERISTIC | 21. EVALUATION COMMENTS |
|---|---|
| | |

| 22. EVALUATOR/DATE | | | 23. ACCEPT | 24. REJECT |
|---|---|---|---|---|
| NCS REVIEWER | | DATE | | |
| QUALITY ENGINEER | | DATE | | |
| DESIGN ENGINEER | | DATE | | |
| | | DATE | | |
| | | DATE | | |

| PACKAGING MANAGER | DATE |
|---|---|
| | |

This document has been reviewed by a Y-12 Derivative Classifier / UCNI Reviewing Official and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for Public Release.

Name: _____ Date: _____

| **ATTACHMENT 2**<br>**CERTIFIED DATA – MANUFACTURER**<br>EQUIPMENT SPECIFICATION | Specification Number<br>SPC-M801580-0001 | Revision<br>00 |
|---|---|---|
| | Issue Date<br>6/11/2012 | Revision Date |
| | | Page 1 of 1 |

***Manufacturer's Data Requirements***

| Item No. | Data Submittal—Purpose and Description | Specification or Reference | | | |
|---|---|---|---|---|---|
| | | | | | |
| | **CERTIFIED DATA – Manufacturer** | | | | |
| | | | | | |
| | | | | | |
| | Items shall be supplied as specified in Sect. 9.5 | | | | |
| | | | | | |
| 1. | Certificate of Conformance | 9.2.1 | | | |
| 2. | TR-10 Test Report | 4.2.1 | | | |
| 3. | Hardness Test Report | 4.2.2 | | | |
| 4. | Elongation Test Report | 4.2.3 | | | |
| 5. | Inspection Reports | 4.5.3 | | | |
| 6. | FTIR Report | 4.5.6 | | | |
| 7. | Request for Waiver or Deviation Forms (if applicable) | 1.0 | | | |
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## Appendix 1.3.10

## Equipment Specification SPC-M801580-0002,
## *ES-3100 Ethylene Propylene Diene Monomer (EPDM) Containment Vessel (CV) O-rings*

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# EQUIPMENT SPECIFICATION FOR ES-3100 ETHYLENE PROPYLENE DIENE MONOMER (EPDM) CONTAINMENT VESSEL (CV) O-RINGS

## TABLE OF CONTENTS

**1. SCOPE** ..... **2**
**2. APPLICABLE DOCUMENTS** ..... **2**
**3. DEFINITIONS** ..... **2**
**4. REQUIREMENTS** ..... **2**
4.1 Materials ..... 2
4.2 Properties ..... 3
4.3 Fabrication ..... 3
4.4 Packaging and Marking Requirements ..... 3
4.5 Inspection ..... 3
**5. NUMBERS OF PARTS** ..... **4**
**6. FIRST ARTICLE EVALUATION (FAE)** ..... **4**
6.1 Primary Objective ..... 4
6.2 FAE Document Requirements ..... 4
6.3 Verification Testing ..... 4
6.4 Onsite Evaluation ..... 4
6.5 Results Notification ..... 4
6.6 Documentation ..... 5
**7. MANUFACTURING PLAN** ..... **5**
7.1 General ..... 5
7.2 Manufacturing Procedures ..... 5
7.3 Equipment ..... 5
**8. QUALITY ASSURANCE PROVISIONS** ..... **5**
8.1 General ..... 5
8.2 Material Control ..... 5
8.3 Inspection Requirements ..... 6
8.4 Acceptance Criteria ..... 6
**9. CERTIFICATION DATA** ..... **7**
9.1 Conforming Product ..... 7
9.2 Nonconforming Product ..... 7
9.3 Test Material ..... 7
9.4 Cause for Rejection ..... 8
9.5 Distribution and Number of Copies ..... 8
**10. CLEANING** ..... **8**
**11. PART MARKING** ..... **8**
**12. SHIPMENT** ..... **8**
**13. FINAL ACCEPTANCE** ..... **8**
**ATTACHMENT A. REQUEST FOR WAIVER OR DEVIATION FORM** ..... **9**
**ATTACHMENT B. CERTIFIED DATA – MANUFACTURER** ..... **14**
**ATTACHMENT C. CERTIFICATE OF CONFORMANCE REQUIREMENTS** ..... **15**
**ATTACHMENT D. CV O-RING DETAILS DRAWING** ..... **16**

## 1. SCOPE

This specification, the Company's drawings, and the documents referenced herein provide requirements for the materials, fabrication, inspection, examination, documentation, and testing of ES-3100 O-rings.

If conflicting requirements appear in these documents, the Manufacturer shall immediately notify the Company for resolution.

The Seller shall not deviate from the requirements of this specification without prior written consent from the Company. Requests for changes or deviations shall be submitted on the Request for Waiver or Deviation form, Attachment A.

## 2. APPLICABLE DOCUMENTS

The ES-3100 EPDM O-rings shall be fabricated, inspected, and tested according to the design drawings and the applicable referenced documents.

- ASTM D412, *Test Methods for Vulcanized Rubber and Thermoplastic Elastomers – Tension*
- ASTM D1329, *Standard Test Method for Evaluating Rubber Property Retraction at Lower Temperatures (TR Test)*
- ASTM D2000, *Standard Classification System for Rubber Products in Automotive Applications*
- ASTM D2240, *Test Method for Rubber Property – Durometer Hardness*
- MIL-STD-413C Notice 1, June 19, 1987, *Visual Inspection Guide for Elastometric O-Rings*
- Title 10 Code of Federal Regulations, Part 71, Subpart H, *Quality Assurance*

## 3. DEFINITIONS

Batch—A batch is defined as a homogeneous quantity of material compound mixed at one time.

LOT—A lot shall be a quantity of product of the same identity, cured in the same production run, and from the same batch.

First Article—Product that is submitted to the Company for evaluation prior to the seller being released to manufacture the remaining quantities in the subcontract. This product must be representative of production items by virtue of having been produced and inspected using the same facilities, testing, processes, and type of personnel planned for use in production.

First Article Evaluation (FAE)—An evaluation by the Company of the first article unit manufactured and the facilities, tooling, processes, etc. concerned with the manufacture and inspection.

## 4. REQUIREMENTS

### 4.1 Materials

4.1.1 The Manufacturer shall be responsible for supplying all materials, services, facilities, and equipment to meet the requirements of this specification and Company drawings unless otherwise noted.

4.1.2 The O-rings shall meet the requirements of ASTM D2000 specification M3BA 712 A14 B13 F17.

4.1.3 The O-ring material shall be ethylene propylene diene monomer (EPDM) rubber.

4.1.4 The O-ring color shall be black.

**NOTE:** The use for the O-rings is a static face seal.

**4.2 Properties**

4.2.1 The O-rings shall have a normal temperature service range of 302°F to -40°F. The low temperature capability of the O-ring shall be determined by conducting a TR-10 test specified in ASTM D1329. A quantitative test report certifying this low temperature capability shall be submitted for each lot of O-rings as Certified Data; see Attachment B.

4.2.2 The O-rings shall have a Shore A hardness of 70A ± 5 per ASTM D2240. A quantitative test report certifying this hardness shall be submitted for each lot of O-rings as Certified Data; see Attachment B.

4.2.3 The O-rings shall have a minimum elongation of 100% per ASTM D412. A quantitative test report certifying this elongation shall be submitted for each lot of O-rings as Certified Data; see Attachment B.

**4.3 Fabrication**

4.3.1 The O-rings shall be molded as a single piece.

4.3.2 Each O-ring's surface shall be smooth, non-porous, and free of skin defects and impregnated material to the requirements of MIL-STD-413C.

**4.4 Packaging and Marking Requirements**

4.4.1 O-ring packaging shall be accomplished under conditions which will ensure freedom from contamination by dust, oil, grease, and other extraneous matter.

4.4.2 Individual O-rings shall be packaged one to a sealed package.

4.4.3 The O-ring package marking shall be in accordance with Sect. 11.

4.4.4 O-ring packages, if packed in an outer container, shall be packed in such a manner that during shipment and storage, they will not be permanently distorted, and will be protected against damage from exposure to weather or any other normal hazard. Unless otherwise specified in the Purchase Order, the outer container shall be marked with no less that the following information:

- Purchase Order Number
- Manufacturer's Identification
- Part Number
- Date of Shipment
- Number of parts per container

**4.5 Inspection**

4.5.1 Dimensional requirements are specified on the Company Drawing M2E801580A013.

4.5.2 The Manufacturer's inspection shall include, as a minimum, the following.

4.5.2.1 All dimensions and tolerances require 100% inspection. In the event that inspection of a dimension or tolerance is not practical, the Manufacturer shall submit for approval an alternate plan for ensuring the features will meet requirements.

4.5.2.2 The O-rings shall be 100% visually inspected per MIL-STD-413C.

4.5.3 A certified written inspection report(s) shall be prepared and submitted to the Company in accordance with Sect. 9.1 and Attachment B.

4.5.4 Where inspection or test equipment yields quantitative readings, actual measurements and deviation from nominal readings shall be recorded.

4.5.5 A representative sample for each batch of material per paragraph 9.3 shall be provided to the Company for verification testing.

4.5.6 The seal material composition shall be verified by Fourier Transform Infrared (FTIR) Spectroscopy on a sample of two units taken from each batch of material. A report shall be provided to the Company.

## 5. NUMBERS OF PARTS

The total number of parts to be manufactured for First Article Evaluation (FAE) and production shall be specified in the Company's purchase order.

## 6. FIRST ARTICLE EVALUATION (FAE)

### 6.1 Primary Objective

The primary objective of a FAE is to verify that the product conforms to its requirements and that the facilities tooling, processes, controls, personnel, acceptance methods, etc. can consistently furnish product of the required quality and quantity. The FAE is conducted in two phases. The first phase is an evaluation at the Seller's site of all critical manufacturing, inspection, and testing operations and equipment. The second phase is an independent evaluation by the Company of the FAE parts of material received by the Company.

### 6.2 FAE Document Requirements

The Seller shall manufacture first article quantities that are representative of production units. All parts shall be produced, tested, and inspected using the same facilities, tools, processes, procedures, and type of personnel planned for use during production. It is the responsibility of the Seller to:

6.2.1 Notify the Company sufficiently in advance of the fabrication of the First Article Unit to permit the Company to witness the manufacture and inspection. Normally 10 days notice is required.

6.2.2 Furnish for review/approval copies of all procedures, follow sheets, data forms, processing records, etc., used by the Seller to define or control those aspects of the manufacturing and inspection operations that influence the quality of the finished product. These documents are to be furnished not later than the notification of the date of First Article production.

6.2.3 Furnish for each First Article Unit copies of all inspection and certification data required to be supplied for the production parts.

### 6.3 Verification Testing

The Seller shall be released for fabrication of production quantities when Stage II customer verification testing of the FAE is successfully completed.

### 6.4 Onsite Evaluation

The Company will perform an FAE of the first parts manufactured by production process and personnel. This evaluation shall be conducted on the FAE parts as received by the Company.

### 6.5 Results Notification

The Seller shall not proceed to manufacture parts beyond the initial FAE quantities until a successful FAE has been completed and notification to proceed has been received from the Company. The Seller shall be notified in writing by the Company of the results of the First Evaluation Article Evaluation. The FAE results will be reported in one of the following three categories:

6.5.1 Acceptable: Seller is released to initiate manufacture of production quantities.

6.5.2 Conditionally Acceptable: The Company will specify actions which the Seller must complete before being released for production quantities.

6.5.3 Not Acceptable: The First Article units have serious deficiencies, or the ability of the Seller to consistently furnish product of the required quality and quantity is subject to major uncertainty. The Company will specify the required action.

**6.6 Documentation**

The Seller shall provide the documentation as specified in Sect. 6.2.2. All process procedures as described by the above reference shall be submitted for review by the Company prior to the manufacture of FAE parts. Final approval of these procedures shall be made on successful completion of Company's evaluation of parts received. Any subsequent changes to these approved documents or processes will require notification be made to the Company. The Company shall then determine if a new FAE is warranted.

## 7. MANUFACTURING PLAN

**7.1 General**

The Seller shall manufacture parts in accordance with ASTM D2000, this specification, and the requirements standard set forth in Sect. 4 of this document.

**7.2 Manufacturing Procedures**

The Seller shall develop and implement written procedures, follow sheets, data forms, and processing records as required to document and control the manufacturing processes and to ensure consistency of all operations. In addition, the Seller shall prepare an inspection procedure as specified by Sect. 8.3.2 of this document for submittal to the Company for review and approval.

**7.3 Equipment**

The Seller shall have adequate manufacturing and test equipment to ensure compliance of the dimensional configuration and physical properties specified by the specifications referenced.

## 8. QUALITY ASSURANCE PROVISIONS

**8.1 General**

The Seller shall implement and maintain a quality control system that meets the requirements of this document.

**8.2 Material Control**

The Seller shall maintain an effective material control program which meets the requirements of this document and ensures that the following material controls are implemented and maintained:

8.2.1 Ensures that only material meeting the specified requirements is used in the fabrication of this product.

8.2.2 Provides for obtaining the supplier's certification of raw material called out in this specification and/or purchase order as necessary to meet the requirements of Sect. 4 of this document.

8.2.3 Ensures that all mechanical testing of specimens representative of the cured material has been done and quantitative test results obtained.

8.2.4 Provides traceability from as-shipped parts to the lot run and the batch of stock from which the parts were manufactured.

**8.3 Inspection Requirements**

8.3.1 The Seller's Quality Control program shall develop the necessary procedures and data record forms, and implement an inspection and test program which meets all the requirements specified below.

8.3.2 The Seller shall submit an Inspection procedure for Company approval a minimum of ten (10) days prior to manufacture of FAE parts. This procedure shall contain, as a minimum, a listing of inspection equipment used to inspect each dimension and all features and requirements specified by Sect. 8.3.4.

8.3.3 Prior to performing final inspection, the Seller shall perform all cleaning operations required to ensure parts are free of all fabrication and handling defects and that no foreign materials are present on the part's surface or features.

8.3.4 The Seller shall visually and dimensionally inspect all parts 100 percent. The Seller's inspection shall include, as a minimum, the following:

8.3.4.1 Part marking: Part marking as specified by Sect. 11 of this document.

8.3.4.2 Cleanliness: All parts submitted to the Company shall be inspected by the Seller to be free of all foreign materials. This shall include dirt, grease, curing compound, etc., which are attached to or adhere to the part surface or features.

8.3.4.3 Workmanship: The seals shall meet the workmanship requirements of MIL-STD-413C. There must be no defects or foreign materials in the rubber which will alter its ability to form a seal or endanger longevity by chemical interactions.

8.3.4.4 Dimensions: Inside diameter and width (cross-section) as specified by the purchase order shall be inspected.

8.3.5 The Seller shall establish and implement a plan to sample and test the physical properties of each batch of cured molding compound used for manufacture. The Seller shall test to ensure compliance to all criteria specified.

8.3.6 The Seller shall document the results of the inspection and/or testing on appropriate data record forms. Where inspection or test equipment yields quantitative readings, actual measurements or deviation from nominal readings shall be recorded.

8.3.7 Documentation of all inspection and test results shall be maintained by the Seller for a minimum of one (1) year after completion of the contract. The Company shall reserve the option to retrieve and review this data as deemed necessary to ensure compliance with all product specifications.

8.3.8 The Seller shall not ship nonconforming parts without prior approval by the Company. (Ref. Sect. 9.2.)

**8.4 Acceptance Criteria**

8.4.1 Batch Acceptance

8.4.1.1 Certification: The supplier shall certify that each batch meets the physical properties per ASTM D2000 of compound called out in this specification in Sect. 4.1.

8.4.1.2 Environment: Test specimen preparation and testing may be done at 18 to 30°C and 10 to 65% relative humidity (applies to Sects. 8.4.1.3–8.4.1.4).

8.4.1.3 Composition: The O-ring material composition shall be verified by Fourier Transform Infrared (FTIR) Spectroscopy on a sample of two units taken from each batch of material. A report shall be provided to the Company.

8.4.1.4 Density: The density (specific gravity) of the material shall be verified on a sample of two units taken from each batch of material.

8.4.2 Lot Acceptance

8.4.2.1 Inspection Report: The O-rings shall meet the inspection requirements as specified by Sect. 8.3.4.

8.4.2.2 Cure Certification: The supplier shall certify that each lot was cured according to the temperature and time parameter specified in the Seller's approved manufacturing plan.

## 9. CERTIFICATION DATA

### 9.1 Conforming Product

With each shipment of O-rings, the Seller shall submit the following certification data:

9.1.1 two (2) copies of a signed certification (Certificate of Conformance per Attachment C) that identifies, by batch and lot numbers, all O-rings included in the shipment and attest that all parts conform to all criteria of the purchase order and this specification;

9.1.2 two (2) copies of TR-10 test results per Sect. 4.2.1.

9.1.3 two (2) copies of the quantitative test results for physical property tests per Sect. 8.4.1.1;

9.1.4 two (2) copies of the FTIR Spectroscopy per Sect. 8.4.1.3;

9.1.5 two (2) copies of the quantitative test results for density per Sect. 8.4.1.4;

9.1.6 two (2) copies of the inspection report per Sect. 8.4.2.1; and

9.1.7 two (2) copies of the cure certification per Sect. 8.4.2.2.

### 9.2 Nonconforming Product

9.2.1 The Seller shall not ship nonconforming parts without prior approval by the Company. Any requested exceptions, deviations, or proposed changes to the requirements of a procurement specification by the Supplier after award and before acceptance shall be submitted using UCN-13816B, *Request for Waiver or Deviation (RFWD)*.

The Supplier shall contact the Subcontract Administrator to obtain a UCN-13816B form and submit a request for waiver and deviation to the Subcontract Administrator when one of the following nonconforming conditions is identified.

- Requirements in Supplier documents approved by the Company are violated.
- Nonconformances cannot be corrected by continuing the original manufacturing process except by reworking or repairing the item.
- The item does not meet original requirements, even though it can be restored to a fully functional condition.

See Attachment A for a sample form and instructions.

### 9.3 Test Material

For each lot of material used to fabricate, the Seller shall supply to the Company one piece of stock that is a minimum of 6" x 6" x 0.070" – 0.090" thick and has been cured with the parts from each batch. This piece shall be from the same material as the parts in the lot run. This test material shall be identified with the batch number of the material compound used and the production lot number represented, and shall be forwarded to the Company with the first shipment of parts fabricated from the material represented.

### 9.4 Cause for Rejection

Material certifications and/or any supporting test data as specified above cannot be waived. Failure to supply the required data may be cause for rejection.

### 9.5 Distribution and Number of Copies

Certification data shall be forwarded for each shipment of parts to the Company. One (1) copy shall be included with the shipment of O-rings and one (1) copy to be forwarded to the subcontract administrator.

## 10. CLEANING

Each part shall be thoroughly cleaned after the completion of all processing and prior to shipment.

## 11. PART MARKING

Each O-ring package shall be marked to identify the following information:

- Master Batch Number
- Lot Number
- Vendor or Company Part Number or Part Name
- Size or Code
- Compound
- Cure Date (Date of Mfg.)
- Expiration Date (4 years from date of manufacture)

## 12. SHIPMENT

The Seller shall ship parts in accordance with the delivery schedule as specified in the Company's Purchase Order.

## 13. FINAL ACCEPTANCE

Final acceptance of each part shall be based on inspection and testing performed by the Company at the receiving site. Any parts not meeting the requirements set forth in this specification or applicable part drawing will be returned to the Seller for rework or replacement. Any shipment that contains a nonconforming product may be returned to the Seller without a 100 percent inspection by the Company.

## ATTACHMENT A. REQUEST FOR WAIVER OR DEVIATION FORM

CNS | consolidated nuclear security, llc

CLICK HERE FOR INSTRUCTIONS

### REQUEST FOR WAIVER OR DEVIATION (RFWD)

| 1. REQUEST TYPE | 2. SHEET 1 OF ___ |
|---|---|
| ☐ DEVIATION (Supplier Initiated)<br>☐ WAIVER (Supplier Initiated)<br>☐ Change (CNS Initiated) | 3a. NUMBER<br>3b. SAP DMS NUMBER |

| 4. SUPPLIER | 5. P.O. NO. / ITEM NO. | 6. PROGRAM / PROJECT | 7. DOCUMENT NO. / REV. |
|---|---|---|---|
| 8. COMPONENT NAME | 9. PART OR IDENTIFY NO. | 10. ☐SERIAL or ☐ LOT NO. | 11. LOT SIZE |

| 12. SPEC. REF. NO. | 13. SPECIFICATION REQUIREMENTS | 14. DESCRIPTION OF WAIVER/DEVIATION/CHANGE | 15. SUPPLIER PLAN FOR CORRECTIVE ACTION |
|---|---|---|---|
| 1) | | | |
| 2) | | | |
| 3) | | | |
| 4) | | | |

| 16. INITIATING ENTITY REPRESENTATIVE (print /sign) | 17. TITLE | 18. COMPANY | 19. DATE |
|---|---|---|---|
| | | | |

**RESPONDING ENTITY EVALUATION (TO BE COMPLETED BY RESPONDING ENTITY EVALUATOR)**

| 20. SPEC. REF. NO. | 21. EVALUATION COMMENTS | 22. EVALUATOR (print/sign) / DATE | 23. RECOMMENDED DISPOSITION |
|---|---|---|---|
| 1) | | | ☐ ACCEPT ☐ REJECT |
| 2) | | | ☐ ACCEPT ☐ REJECT |
| 3) | | | ☐ ACCEPT ☐ REJECT |
| 4) | | | ☐ ACCEPT ☐ REJECT |

24. ARE DESIGN DRAWING(S), SPECIFICATION(S), DATA SHEET(S), INSPECTION PLANS(S), OR SURVEILLANCE PLAN(S), ETC. CHANGES REQUIRED? ☐ YES ☐ NO
IF YES, LIST DOCUMENTS REQUIRING CHANGES (TO BE COMPLETED BY CNS REPRESENTATIVE)

| | | |
|---|---|---|
| | | |

SAMPLE

Y60-015, 4.2.4.3.4.7.4.8 & 4.11
UCN-13816B (01-15)

CLICK HERE FOR AN ADDITIONAL PAGE

SHEET ___ OF ___

| APPPOVALS (CNS Approvals Require Same Affected Functions/Organizations Approval As Original Document) | | | |
|---|---|---|---|
| 25. ENTITY | 26. NAME (Print/ sign) | 27. DATE | 28. APPROVE/REJECT RECOMMENDED DISPOSITIONS |
| CNS Customer/Program Manager: | | | ☐ APPROVED ☐ REJECTED |
| CNS Technical Representative: | | | ☐ APPROVED ☐ REJECTED |
| CNS Design Authority Representative: | | | ☐ APPROVED ☐ REJECTED |
| CNS Project Representative: | | | ☐ APPROVED ☐ REJECTED |
| CNS Quality Engineer: | | | ☐ APPROVED ☐ REJECTED |
| Design Engineering: | | | ☐ APPROVED ☐ REJECTED |
| Product/Packaging Engineering: | | | ☐ APPROVED ☐ REJECTED |
| Procurement Representative: | | | ☐ APPROVED ☐ REJECTED |
| CNS Other (List): | | | ☐ APPROVED ☐ REJECTED |
| Supplier Representative: | | | ☐ APPROVED ☐ REJECTED |

SAMPLE

*Y60-015, 4.2, 4.3, 4.7, 4.8 & 4.11*
UCN-13816B (01-15)

## RFWD Completion Instructions

**INITIATING ENTITY**

The following fields are to be completed by the INITIATING ENTITY. The purpose of Block No.1 through 20 is the identification of the Waiver/Deviation/Change. For Waivers and Deviations, the Initiating Entity is the Supplier. For Changes, the Initiating Entity is Y-12.

1. **REQUEST TYPE** – Check the appropriate block:
   - DEVIATION (Supplier initiated, prior to production)
   - WAIVER (Supplier initiated, during or after production)
   - CHANGE (Y-12 initiated, after award of contract)

2. **SHEET/FORM PAGES** – Complete Page of Page(s), including any attachments or supporting documents. Each page's Sheet/Form block must be completed (i.e., Page 1 of 2; Page 2 of 2; Page 3 of 3; Pages 10 of 10, etc.).

3. **3.a NUMBER** – An identifying, sequential numbering system acceptable to supplier and Y-12 (e.g., Purchase Order Number + sequential number – [examples 430001234-1, 430001234-2,etc].
   **3.b SAP DMS NUMBER – Y-12**

4. **SUPPLIER** – Supplier Name associated with the Waiver, Deviation, or Change.

5. **PURCHASE ORDER (P.O.) NUMBER/ITEM NUMBER** – From the Y-12 issued P.O. and the item number associated with the P.O.

6. **PROGRAM/PROJECT** – Program or project name, if applicable.

7. **DOCUMENT NUMBER and REVISION** – Drawing or Specification Number and Revision.

8. **COMPONENT NAME** – Name take from Y-12 design document(s).

9. **PART OR IDENTIFYING NUMBER** – Part Name or unique reference number.

10. **SERIAL OR LOT NUMBER** – Check the appropriate box and enter the Serial Number or Lot Number, if applicable.

11. **LOT SIZE** – Total quantity of parts affected by the WAIVER/DEVIATION/CHANGE.

12. **SPECIFICATION REFERENCE NUMBER** – Paragraph number or drawing reference/location of characteristic(s) to be waived/deviated/changed (each characteristic requires individual line).

13. **SPECIFICATION REQUIREMENT** – Requirement(s) extracted from the specification/drawing.

14. **DESCRIPTION OF WAIVER/DEVIATION/CHANGE** – Written explanation of what characteristic is to be waived/deviated/changed (e.g., technical or material requirement is violated, requirement in supplier document is violated, nonconformance cannot be corrected by continuing the original process or rework, item does not conform to the original requirement, but can be restored to condition that it will function unimpaired, Y-12 is directing the Supplier to make a change to what is specified in the contract document(s), etc.).

*Y60-015, 4.2,4.3,4.7,4.8 & 4.11*
UCN-13816B INST (01-15)

## RFWD Completion Instructions (continuation)

15. **SUPPLIER PLAN FOR CORRECTIVE ACTION** – Written explanation of corrective action(s) taken or planned to address each waiver/deviation characteristic identified which may include disposition recommendations such as accept/use-as-is, rework to specification, repair to usable condition, return to vendor, reject/scrap, etc., if applicable. This block does not apply to Y-12 initiated changes. (NOTE: If more SPEC. REF. NOs. are needed , a TAB key at the last entry of Block No.15 will insert an additional line, else "mouse click" to Block No. 16).

16. **INITIATING ENTITY REPRESENTATIVE** – Name (print/signature) of the authorized representative of the Initiator (Supplier or Y-12) submitting the Waiver/Deviation/Change.

17. **TITLE** – Title of the Initiating Entity Representative from Block No.16.

18. **COMPANY** – Company affiliation of the Initiator (Y-12 or Supplier).

19. **DATE** – Date Waiver/Deviation/Change initiated.

**Responding Entity Evaluation**

The following fields are to be completed by the RESPONDING ENTITY EVALUATOR. The purpose of Block 20 through 23 is the evaluation of the proposed Waiver/Deviation/Change. For Waivers and Deviations, the Responding Entity is Y-12. For Changes, the Responding Entity is the Supplier.

20. **SPECIFICATION REFERENCE NUMBER** – Item(s) transposed from Block No.12 above, to be evaluated.

21. **EVALUATION COMMENTS** – Written evaluation of each Waiver/Deviation/Change requested by the Initiating Entity.

22. **EVALUATOR/DATE** – Name (print/signature) of the Evaluator for the responding Entity and the Date of the evaluation. The Evaluator is one who is technically qualified to evaluate the proposed Waiver/Deviation/Change.

23. **RECOMMENDED DISPOSITION** – Based on the evaluation and the comments provided in Block 21, the Evaluator's recommendation to either Accept or Reject each Waiver/Deviation/Change Item. For Waivers and Deviations, this represents the Y-12 Evaluator's intended recommendation to other Y-12 functions/organizations for acceptance or rejection of each proposed waived/deviated item. For Changes, this represents the Supplier's intended acceptance or rejection of each proposed change initiated by Y-12.

**Y-12 Representative**

24. **ARE DESIGN DRAWINGS(S), SPECIFICATIONS, OR DATA SHEET(S) CHANGES REQUIRED** – Indicate (Yes or No) if changes to the original contract documents or supporting/operational documents are warranted because of the Waiver/Deviation/Change.

*Y60-015, 4.2,4.3,4.7,4.8 & 4.11*
UCN-13816B INST (01-15)

## RFWD Completion Instructions (continuation)

**Approvals**

Y-12 approvals require the same affected functions/organizational approval as the original document (Applicability is determined by the original document approvals and the governing document procedures). The Technical Representative is responsible for identifying and obtaining the appropriate approvals and processing the RFWDC form.

25. **ENTITY –** The required list of approvers may include:
    - Y-12 Customer/Program Manager (i.e., end user)
    - Y-12 Technical Representative
    - Y-12 Design Authority Representative, as applicable (otherwise, N/A)
    - Y-12 Project Representative, as applicable (otherwise, N/A)
    - Y-12 Quality Engineer, as applicable (otherwise, N/A)
    - Design Engineering, as applicable (otherwise, N/A)
    - Product/Packaging Engineering, as applicable (otherwise, N/A)
    - Procurement Representative, as applicable (otherwise, N/A)
    - Y-12 Other – List additional function positions required to approve, if applicable.
    - Supplier Representative – Person with overall responsibility and authority to approve information and dispositions as documented on this form.

26. **NAME –** Name (print/signature) of each person fulfilling the roles denoted in Block No. 25.

27. **DATE –** Date of approval signature.

28. **APPROVE/REJECT RECOMMENDED DISPOSITION –** Based on the information provided in Block No. 21, each Approver is to approve or reject the Recommended Disposition noted in Block No. 23. Checking the Approved block means the Approver accepts all recommended dispositions provided in Block No. 23. Checking the Rejected block means the Approver rejects one or more of the recommended dispositions provided in Block No. 23.

Note: Communication between the supplier and Y-12 for RFWDC's must be handled by the Y-12 Subcontract Administrator.

*Y60-015, 4.2,4.3,4.7,4.8 & 4.11*
UCN-13816B INST (01-15)

| ATTACHMENT B.<br>CERTIFIED DATA – MANUFACTURER<br>EQUIPMENT SPECIFICATION | | Page 1 of 1 |
|---|---|---|
| ***Manufacturer's Data Requirements*** | | |
| **Item No.** | **Data Submittal—Purpose and Description** | **Specification or Reference** |
| | | |
| | **CERTIFIED DATA – Manufacturer** | |
| | | |
| | | |
| | Items shall be supplied as specified in Sect. 9.1 | |
| | | |
| 1. | TR-10 test report | 4.2.1 |
| 2. | Hardness test report | 4.2.2 |
| 3. | Elongation test report | 4.2.3 |
| 4. | Inspection reports | 4.5.3 |
| 5. | FTIR report | 4.5.6 |
| 6. | Cure certificate | 8.4.2.2 |
| 7. | Certificate of Conformance | 9.1.7 |
| 8. | Request for Waiver or Deviation forms (if applicable) | 9.2.1 |
| 9. | 6" x 6" material sample | 9.3 |
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## ATTACHMENT C. CERTIFICATE OF CONFORMANCE REQUIREMENTS

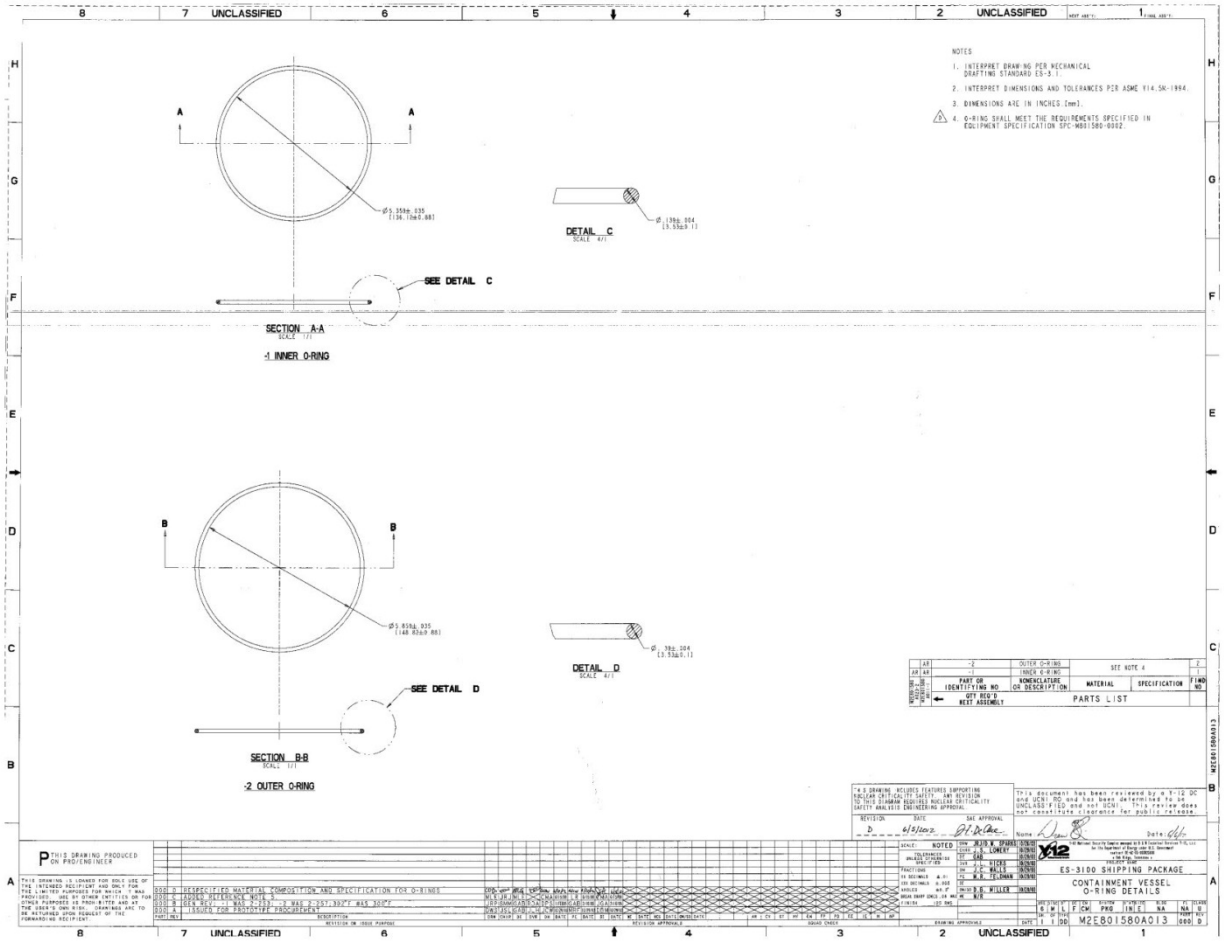
A Certificate of Conformance (CoC) shall be submitted after completion of project. The CoC shall conform as follows:

1. The CoC shall identify the purchased material or equipment, by the purchase order number.
2. The CoC shall identify the specific procurement requirements met by the purchased material or equipment, such as codes, standards, and other specifications. This may be accomplished by including a list of the specific requirements or by providing to Y-12 a copy of the purchase order and the procurement specifications or drawings, together with a suitable CoC.
3. The CoC shall identify any approved changes, waivers, or deviations applicable to the subject material or equipment.
4. The CoC shall identify any procurement requirements that have not been met, together with an explanation and the means for resolving the request for waiver or deviation.
5. The CoC shall be signed or otherwise authenticated by a person who is responsible for this quality assurance function and whose function and position are described in the quality assurance program of the Supplier.
6. The Supplier's certification system, including the procedures to be followed in filling out a CoC and the administrative procedures for review and approval of the certificates, shall be described in their quality assurance program.
7. If the CoC is for Commercial Grade Survey (CGS), the certificate shall identify the programs, process, and controls, including revision level evaluated and approved by the company, and attest to the implementation thereof.

   - QMS Manual, Rev J
   - P720-01, Rev C, *Planning of Product Realization*
   - P753-01, Rev B, *Handle, Store and Issue Materials*
   - W720-01, Rev D, *Create Production Plans (Work Orders)*

   If any document revisions differ from those listed, the Company shall review and approve through RFWD process prior to use.

## ATTACHMENT D. CV O-RING DETAILS DRAWING



## SECTION 1 REFERENCES


10 CFR 71, *Packaging and Transportation of Radioactive Material*, January 2015.

49 CFR, *Transportation*, October 2014.

ANSI N14.5-1997, *Radioactive Materials-Leakage Tests on Packages for Shipment*, American Natl. Standards Institute, Feb. 5, 1998.

*ASME Boiler and Pressure Vessel Code*, Sect. III, Div. 1, Subsection NB, *Class 1 Components*, American Society of Mechanical Engineers, New York, 2001 ed. with 2002 and 2003 addenda.

*ASME Boiler and Pressure Vessel Code*, Sect. IX, *Qualification Standard for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators*, American Society of Mechanical Engineers, New York, 2001 ed. with 2002 and 2003 addenda.

ASME SA-182/SA-182M, *Specification for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service*, American Society of Mechanical Engineers, New York, revision at time of fabrication. This specification is from the *ASME Boiler and Pressure Vessel Code*, Sect. II, Part A.

ASME SA-312/SA-312M, *Specification for Seamless and Welded Austenitic Stainless Steel Pipes*, American Society of Mechanical Engineers, New York, revision at time of fabrication. This specification is from the *ASME Boiler and Pressure Vessel Code*, Sect. II, Part A.

ASME SA-479/SA-479M, *Specification for Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels*, American Society of Mechanical Engineers, New York, revision at time of fabrication. This specification is from the *ASME Boiler and Pressure Vessel Code*, Sect. II, Part A.

ASTM A 493, *Standard Specification for Stainless Steel Wire and Wire Rods for Cold Heading and Cold Forging*, ASTM International, *Annual Book of ASTM Standards*, Sect. 1, Vol. 01.03, West Conshohocken, Pa., revision at time of fabrication.

ASTM D 2000, *Standard Classification System for Rubber Products in Automotive Applications*, ASTM International, *Annual Book of ASTM Standards*, Sect. 9, Vol. 09.02, West Conshohocken, Pa., revision at time of procurement.

ASTM F 467, *Standard Specification for Nonferrous Nuts for General Use*, ASTM International, *Annual Book of ASTM Standards*, Sect. 1, Vol. 01.08, West Conshohocken, Pa., revision at time of procurement.

ASTM F 593, *Standard Specification for Stainless Steel Bolts, Hex Cap Screws, and Studs*, ASTM International, *Annual Book of ASTM Standards*, Sect. 1, Vol. 01.08, West Conshohocken, Pa., revision at time of fabrication.

Byington, G. A. et al., "Fireproof Impact Limiter Aggregate Package Inside Shipping Containers," U.S. patent 6,299,950 B1, Oct. 9, 2001.

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DAC-EA-801376-A003, K. D. Handy, *Structural Analysis of Forklift Gripper on the ES-2100*, Lockheed Martin Energy Systems, Inc., Oak Ridge Y-12 Plant, February 2000.

DAC-M900000-0003, C. R. Hammond, *Stress Analysis of ES-3100 Containment Vessel with Viton O-rings*, B&W Y-12, Y-12 National Security Complex, May 23, 2012.

DAC-PKG-801940-A001, Rev. 1, D. L. Lowe, *Thermal Analyses (ANSYS) of the ES-3100 Shipping Container for NCT and HAC*, B&W Y-12, Y-12 National Security Complex, November 2012.

Dash, S., et al, "Temperature Programmed Decomposition of Uranyl Nitrate Hexahydrate," *Journal of Nuclear Materials*, **264**, No. 3, 271–82, 1999.

Kozlova, R. D., V. A. Matyukha, and N. V. Dedov, "Mechanism and Kinetics of Thermal Decomposition of Uranyl Nitrate Hexahydrate under the Nonisothermal Conditions," *Radiochemistry*, **49**, No. 2, 130–34, 2007.

Marshall, W. L., Jr., J. S. Gill, and C. H. Secoy, "The Uranyl Nitrate-Water System Above 60°," *Journal of the American Chemical Society*, **73**, No. 4, 1867–69, 1951.

MCW-1424, G. P. Lang and M. O. Nethaway, *Some Physical Properties of Uranyl Nitrate Solutions*, Mallinckrodt Chemical Works, Dec. 15, 1958.

Moody, K., Thermal Ceramics, Inc., *Coefficient of thermal expansion for Kaolite 1600*, e-mail communication to P. A. Bales, BWXT Y-12, Dec. 9, 2004.

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# 2. STRUCTURAL EVALUATION

The ES-3100 package is used to ship highly enriched uranium (HEU) in the following forms: oxide; bulk and broken metal shapes; uranyl nitrate crystals (UNX); and unirradiated research reactor fuel elements and components, and uranium compounds. Content will be packed in various size convenience cans made of stainless, tin-plated carbon steel, aluminum, or nickel alloy, and polyethylene, glass, or Teflon fluorinated ethylene propylene (FEP) bottles. The cans shall have a diameter of ≤ 12.7 cm (5 in.) and heights of ≤ 25.4 cm (10 in.). Two or more cans having a diameter of ≤ 12.7 cm (5 in.) and a maximum height of ≤ 25.4 cm (10.0 in.) may be brazed together to form a can assembly of up to 76.2 cm (30 in.) in height (Fig. 1.4). Any combination of these cans shall be allowed in a single package, as long as the total length of the can stack (with spacers when required) does not exceed the inside working height of the containment vessel. Any closure on the convenience can is allowed. Containment vessel arrangements that utilize closed metal cans with diameters >10.8 cm (4.25 in.) will provide for at least 55 $in.^3$ of free or void volume for gas expansion and offgassing of material at temperatures associated with Normal Conditions of Transport (NCT) or Hypothetical Accident Conditions (HAC). The contents that cannot be packaged in the proposed cans due to the contents' overall dimensions, such as the unirradiated research reactor fuel elements and components, will be bundled together and protected on each end with an open-ended can (Fig. 1.4). When space is available inside the containment vessel, stainless-steel metal scrubbers will be placed on the top and bottom of this partially canned assembly, or an empty convenience can will be placed on the top or bottom of this assembly inside the containment vessel. Solid form HEU contents that will not fit in a convenience can may be bagged only with no convenience can required around the content. However, the usage of convenience cans for these contents is not prohibited. Stainless-steel metal scrubbers may be placed on the top and bottom of this assembly inside the containment vessel. Additionally, glass bottles with enriched uranium oxide may be packed inside metal convenience cans. These glass bottles with enriched uranium oxide containing $UO_2$-Mg will be treated as pyrophoric material and packaged in a sealed and inerted container. Polyethylene bags may be used inside or outside any convenience can as long as the loading restrictions in Sect. 1.2.2.8 are met. If Teflon bottles are used as convenience containers, the total amount of offgassing material (including Teflon bottles, polyethylene bagging, and lifting slings) is limited to 1490 g per package. If metal cans, polyethylene bagging or polyethylene bottles are used as convenience containers, the total amount of offgassing material (including polyethylene bottles, polyethylene bagging, and lifting slings) is limited to 500 g per package (see Item 7 in Sect. 6.2.4). The maximum payload inside the containment vessel will be as follows and as shown in Table 2.1: (1) 24-kg oxide or compounds (up to 100% enrichment in $^{235}U$); (2) HEU oxide shall be in the form of $U_3O_8$-Al, $UO_2$-Mg, $UO_2$-$ZrO_2$, $UO_2$, $UO_3$, or $U_3O_8$; (3) 24 kg of UNX crystals; (4) 35.2 kg of uranium metal and alloy (up to 100% enrichment in $^{235}U$); (5) HEU metal and alloy may be in the form of broken pieces, ingots, buttons, small castings, or fuel elements (rods, plates, or tubes); and (6) the maximum weight of all contents, including nuclear material, convenience containers, polyethylene bags, spacers, slings, etc., shall not exceed 40.82 kg (90 lb). Uranium and transuranic isotopic allowances are defined in Sect. 4. Mass limits and total weights for each shipping arrangement are defined and described in Sect. 2.1.3. The 40.82-kg (90-lb) maximum containment vessel content weight and 35.2-kg (77.60-lb) HEU content weight limits have been established as a bounding case for the maximum structural, thermal, and containment limit for the shipping package. There is no minimum content weight requirement. The content masses and forms used for the proposed content do not take into consideration limits based on shielding and subcriticality.

**Table 2.1. Proposed HEU contents for shipment in the ES-3100**

| Form | Chemical or physical description | Total weight of HEU contents kg (lb) |
|---|---|---|
| HEU oxide | $U_3O_8$-Al, $UO_2$-Mg, $UO_2$-$ZrO_2$, $UO_2$, $UO_3$, $U_3O_8$ | 24 (52.91) |
| Uranyl nitrate crystals | $UO_2(NO_3)_2 + 6H_2O$ | 24 (52.91) |
| HEU metal and alloy | Specific geometric shapes (spheres, cylinders, square bars or slugs) or broken metal pieces, rods, plates, or tubes | 35.2 (77.60) |

As described in the following sections, design analysis, similarity, drop simulations, and the full-scale testing documented herein demonstrates that the ES-3100 package is in compliance with the requirements of Title 10 Code of Federal Regulations (CFR) 71 and Title 49 CFR 100–178 when it is used to ship contents described above. The maximum bounding activity of the contents (35.2 kg of HEU) is $7.2554 \times 10^{-1}$ TBq (19.6092 Ci) and occurs 10 years after initial fabrication. When the maximum activity-to-$A_2$ value is reached at ~70 years from material fabrication, the corresponding activity is $7.2456 \times 10^{-1}$ TBq (19.5827 Ci). The corresponding maximum number of $A_2$s carried is $4.7528 \times 10^{3}$. This information is further discussed in Sect. 4.

## 2.1 DESCRIPTION OF STRUCTURAL DESIGN

### 2.1.1 Discussion

The principal structural members of the shipping package consist of the following: the drum assembly, the containment vessel, packaging material, and the contents. Each of these will be described and discussed in the following sections.

#### 2.1.1.1 Drum assembly

The drum assembly of the shipping package is defined as the structure that maintains the position of and provides protection to the impact and thermal barrier surrounding the containment vessel. Preserving the location of the containment vessel within the packaging prevents reduction of the shielding and subcriticality effectiveness. The drum assembly for the ES-3100 consists of an internally flanged Type 304 or 304L stainless-steel 30-gal modified drum with two Type 304 or 304L stainless-steel inner liners, one filled with noncombustible cast refractory insulation and impact limiter (Kaolite) and one filled with noncombustible cast neutron absorber (Cat 277-4), a stainless-steel top plug with cast refractory insulation, silicone rubber pads, silicon bronze hex-head nuts, and a stainless-steel lid and bottom (Drawing M2E801580A031, Appendix 1.3.7). The nominal weight of these components is 131.89 kg (290.76 lb).

The drum's diameters (inner diameter of 18.25 in.) and corrugations meet the requirements of Military Standard MS27683. All other dimensions are controlled by Drawing M2E801580A004 (Appendix 1.3.7). Modifications to the drum from MS27683 include the following: (1) the overall height was increased; (2) the drum was fabricated with two false wire open ends; and (3) a 0.27-cm (12-gauge, 0.1046-in.)–thick concave cover was welded to the bottom false wire opening (Drawing M2E801580A005, Appendix 1.3.7). Four 0.795-cm (0.313-in.)–diam equally spaced holes are drilled in the top external

sidewall to prevent a pressure buildup between the drum and inner liner. The holes are sealed with a plastic plug to provide a moisture barrier for the cast refractory insulation during NCT. The cavity created by the inner liner for placement of a containment vessel is a three-tiered volume. The uppermost tier accommodates the top plug and has an inside diameter of 37.52-cm (14.77-in.) and is 13.26-cm (5.22-in.) deep. The second tier has an inside diameter of 21.84-cm (8.60-in.) that is 5.59-cm (2.20-in.) deep. The third tier has a 15.85-cm (6.24-in.) inside diameter that is 78.31-cm (30.83-in.) deep.

The volume between the mid liner and the drum and the top plug's internal volume is completely filled with the noncombustible cast refractory insulation called Kaolite 1600 from Thermal Ceramics, Inc. Kaolite properties, such as mechanical, thermal conductivity, and impact, are presented in Y/DW-1661, ORNL-TM-2003/49, Y/DW-1890, and Y/DW-1972. The volume inside the center liner tube is filled with a noncombustible cast neutron poison (absorber) material called Cat 277-4, which is created by mixing Cat 277-0 material from Shieldwerx (SWX-277-0) and boron carbide ($B_4C$). The material is composed of aluminum, magnesium, calcium, boron, carbon, silicon, sulfur, sodium, iron, and water. The final mixture will have an average density of 110 lb/ft$^3$. Cat 277-4 properties, such as thermophysical, mechanical, and neutron activation, are presented in ORNL/TM-2004/290, Y/DW-1987, Y/DZ-2585, COR-NDA-04-93, and Y/DV-1914. BoroBond4, another noncombustible neutron absorber, was used only in prototype test packages instead of Cat 277-4. The drum body, inner liners, and lid are fabricated from 0.15-cm (16-gauge, 0.0598-in.)–thick Type 304 or 304L stainless-steel sheet. A rolled stainless-steel flange with a 5.08 × 5.08 × 0.64-cm (2 × 2 × 0.25-in.)–thick modified stainless-steel structural angle is welded around the top of the mid inner liner. The mid inner liner is then welded to the inside surface of the drum along this flange. Eight ⅝-11-UNC-2A studs welded to the drum and silicon bronze nuts provide the structural attachment for the drum lid, and are torqued to 40.67 ± 6.78 N·m (30 ± 5 ft-lb) at assembly. The drum lid's diameter and shape meet the requirements of Military Standard MS27683. All other dimensions are controlled by Drawings M2E801580A006 and M2E801580A007, Appendix 1.3.7. The stiffener ring (Find Number 3 on Drawing M2E801580A006, Appendix 1.3.7) provides the lid with an inner flange. The stiffener ring was incorporated in the ES-3100 package for use during handling and transport to protect the lid closure studs and nuts. During transport, the stiffener ring helps position drum tie-down adapters that are used for tie-down of a single unit configuration in Safeguards Transporters (SGTs) in accordance with the National Nuclear Security Administration (NNSA) Technical Manual. The drum is marked by two stainless-steel data plates. The data plate lettering and mounting requirements on the drum are shown on Drawings M2E801580A010 and M2E801508A031 (Appendix 1.3.7), respectively. Painting and marking requirements for the drum are shown on Drawing M2E801580A001 (Appendix 1.3.7). Two lugs are welded to the mid inner liner and project through the drum lid at assembly. Each lug has a 0.953-cm (0.38-in.)–diam hole through which a tamper-indicating device (TID) can be threaded.

The volume between the drum and mid-liner is filled with a lightweight noncombustible cast refractory material called Kaolite 1600. The top plug is also filled with this material and represents the thermal insulation and impact-limiting barrier. The material is composed of portland cement, water, and vermiculite and has an average density of 358.8 kg/m$^3$ (22.4 lb/ft$^3$). The procedure for manufacturing and documenting the installation of this material, JS-YMN3-801580-A003 (Appendix 1.3.4), is referenced on Drawings M2E801580A002 and M2E801580A008 (Appendix 1.3.7) for the drum assembly weldment and top plug weldment, respectively. The insulation has a maximum continuous service temperature limit of 871°C (1600°F) due to the presence of the vermiculite and portland cement.

The volume between the most inward liner and the mid-liner is filled with a noncombustible cast neutron-absorber (poison) material from Thermo Electronic Corp. called Cat 277-4. The material is a high alumina borated concrete composed of aluminum, magnesium, calcium, boron, carbon, silicon, sulfur, sodium, iron, and water. The final mixture has an average density of 1681.9 kg/m$^3$ (105 lb/ft$^3$). The procedure for manufacturing and documenting the installation of this material, JS-YMN3-801580-A005

(Appendix 1.3.5), is referenced on Drawing M2E801580A002 (Appendix 1.3.7). This neutron-absorber material has a maximum continuous service temperature limit of 150°C (302°F) in order to retain the bound mass of water in the final cured mixture for subcriticality control.

The top plug is fabricated in accordance with Drawing M2E801580A008 with an overall diameter of 36.50 cm (14.37 in.) and a height of 13.41 cm (5.28 in.). The plug's rim, bottom sheet, and top sheet are fabricated from 0.15-cm (16-gauge, 0.0598-in.)–thick Type 304 or 304L stainless-steel sheet per American Society of Mechanical Engineers (ASME) SA-240. Four lifting inserts are welded into the top sheet for loading and unloading operations. The internal volume of the top plug is filled with Kaolite 1600 in accordance with JS-YMN3-801580-A003, Appendix 1.3.4.

Three silicone rubber pads complete the drum assembly. One pad is placed on the bottom of the most inward liner to support the containment vessel during transport. Another pad is placed on the top shelf of the mid-liner to support the top plug during transport. The final pad is placed over the top of the containment vessel during transport. The pads are molded to the shapes as defined on Drawing M2E801580A009 (Appendix 1.3.7). The material is silicone rubber with a Shore A durometer reading of 22 ± 5.

#### 2.1.1.2 Containment boundary

The containment vessel's body, lid assembly, and inner O-ring provide the containment boundary (Fig. 1.3). The O-ring material is either an ethylene propylene diene monomer (EPDM) or a fluorocarbon elastomer (Viton) [see Tables 2.7 and 2.15]. Two methods of fabrication may be used to fabricate the containment vessel body of the ES-3100 package as shown on Drawing M2E801580A012 (Appendix 1.3.7). The first method uses a standard 5-in., schedule 40 stainless-steel pipe per ASME SA-312 Type TP304L, a machined flat-head bottom forging per ASME SA-182, Type F304L, and a machined top flange forging per ASME SA-182, Type F304L. The nominal outside diameter of the 5-in. schedule 40 pipe is machined to match the nominal wall thickness of 0.100 in. Each of these pieces is joined with circumferential welds as shown on Sheet 2 of Drawing M2E801580A012 (Appendix 1.3.7). The top flange is machined to match the schedule 5-in. pipe, to provide two concentric half-dovetailed O-ring grooves in the flat face, to provide locations for two 18-8 stainless-steel dowel pins, and to provide the threaded portion for closure using the lid assembly. The second method of fabrication uses flow forming to create the complete body (flat bottom, cylindrical body, and flange) from a single forged billet or bar with final material properties in accordance with ASME SA-182, Type F304L. The top flange area using this fabrication technique is machined identically to that of the welded forging method. The lid assembly, which completes the containment boundary structure, consists of a sealing lid, closure nut, and external retaining ring (Drawing M2E801580A014, Appendix 1.3.7). The containment vessel sealing lid (Drawing M2E801580A015, Appendix 1.3.7) is machined from Type 304 stainless-steel bar with final material properties in accordance with ASME SA-479. The containment vessel closure nut (Drawing M2E801580A016, Appendix 1.3.7) is machined from a Nitronic 60 stainless-steel bar with material properties in accordance with ASME SA-479. These two components are held together using an external retaining ring made from Type 302 stainless steel. A weld is used to seal around a plug that is inserted inside the hole used for machining the pathway for leak testing between the O-rings. Since this plug and weld are outside the containment boundary, the weld is not important to safety. However, it is important to operation because its sealing capability is needed to properly conduct the preshipment leak test. This weld is addressed in Paragraph 3.4 of the containment vessel equipment specification (JS-YMN3-801580-A001, Appendix 1.3.3). In this specification, the weld is inspected visually and using dye penetrant. The requirements of Subsections NB-5110 and NB-5350 of the *ASME Boiler and Pressure Vessel Code* (ASME Code) also apply. The sealing lid is further machined to accept a ⅜-16 swivel hoist ring bolt to facilitate loading and unloading, to provide a leak-check port between the elastomeric O-rings, and notched along the perimeter to engage two dowel pins. The lid assembly, with the O-rings in place on the body, are joined together by torquing the closure nut and sealing lid assembly

to 162.70 ± 6.78 N·m (120 ± 5 ft-lb). The sealing lid portion of the assembly is restrained from rotating during this torquing operation by the two dowel pins installed in the body flange. A leak-check port is located between the O-rings in the containment vessel to facilitate a pressure rise or drop leakage test following assembly or 10 CFR 71 compliance testing. This port is sealed during transport using a modified VCO threaded plug. Only the inner O-ring is considered a part of the containment boundary.

There are no penetrations of, connections to, or fittings for the sealed containment boundary. To meet the requirements for package certification, the containment boundary must remain intact during all conditions of transport. This integrity must be demonstrated by test or other acceptable methodology for NCT and HAC as described in 10 CFR 71.

### 2.1.1.3 Packaging materials

Contents may be packed in four ways: first, various size convenience cans made of stainless steel, tin-plated carbon steel, aluminum, or nickel-alloy, and polyethylene bottles or Teflon FEP bottles may be used (including bottles inside metal cans); second, contents that cannot be packaged in the proposed cans due to the contents' overall dimensions, such as the unirradiated research reactor fuel elements, will be bundled together and protected on each end with an open-ended can (Fig. 1.4); third, solid form contents that will not fit in a convenience can may be bagged only with no convenience can required around content (however, usage of convenience can is allowed); fourth, glass bottles with enriched uranium oxide ($UO_2$-Mg) will be packed inside a sealed and inerted container and treated as pyrophoric contents.

The convenience cans shall have a diameter of ≤ 12.7 cm (5 in.) and a height of ≤ 76.2 cm (30 in.). Any combination of these cans shall be allowed in a single package, as long as the total length of the can stack (with spacers and pads as required) does not exceed the inside working height of the containment vessel (~31 in.). Any closure on the convenience can is allowed. Multiple short cans may be brazed together. Containment vessel arrangements that utilize closed metal cans with diameters >10.8 cm (4.25 in.) will provide for at least 55 $in.^3$ of free or void volume for gas expansion and offgassing of material at temperatures associated with NCT or HAC. The polyethylene bottles have a diameter of ~12.54 cm (4.94 in.) and a height of ~22.1 cm (8.7 in.). A total of three polyethylene bottles may be loaded into the containment vessel. The Teflon FEP bottles have a diameter of ~11.91 cm (4.69 in.) and a height of ~23.88 cm (9.4 in.). A total of three Teflon FEP bottles may be loaded into the containment vessel. Polyethylene bags may be used inside or outside any convenience can or bottle. In some packing arrangements, silicone rubber pads may be used between convenience cans. Also, some arrangements will require can spacers between cans (see Table 1.3). These spacers are thin stainless-steel cans filled with the noncombustible cast neutron poison. Each convenience can and spacer is equipped with a stainless-steel band clamp and nylon coated wire for loading and unloading operations. The spacers are ~10.49 cm (4.13 in.) in diameter by 4.45 cm (1.75 in.) in height and have a maximum weight of ~0.71 kg (1.56 lb). In order to minimize displacement of convenience containers during transport, stainless-steel scrubbers or polyethylene bags may be added on the top or bottom of the last can or bottle in the containment vessel.

When bundling fuel elements, stainless-steel metal scrubbers will be placed on the top and bottom of this partially canned assembly, or an empty convenience can will be placed on the top or bottom of this assembly inside the containment vessel.

If partial loading configurations are employed and empty cans or bottles are used, these empty cans or bottles will require a minimum 0.32-cm (⅛-in.)–diam hole to be placed through the lid.

### 2.1.2 Design Criteria

The ES-3100 packaging/content combination addressed in this safety analysis report for packaging (SARP) is intended to ship contents with a maximum activity of $7.2554 \times 10^{-1}$ TBq (19.6092 Ci) at 10 years from initial fabrication; the maximum number of $A_2$s carried is $4.7528 \times 10^{3}$ at 70 years following initial fabrication (Table 4.4). Based on the guidance from Nuclear Regulatory Commission (NRC) Regulatory Guide 7.11, *Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m)*, this package is classified in NUREG-1609 (Table 1.1) and Table 2.2 as a Category I shipping package. Therefore, the containment vessel is designed (using nominal dimensions for each component), fabricated, and inspected in accordance with the ASME Code, Sect. III, Div. 1, Subsection NB. The design and subsequent verification comply with the requirements of 10 CFR 71. The structural requirements for the packaging under NCT are addressed in Sect. 2.6. The structural requirements for the packaging under HAC are addressed in Sect. 2.7.

**Table 2.2. Category designations for Type B packages**

| Contents form | Category I | Category II | Category III |
|---|---|---|---|
| Special form | >3000 $A_1$ or >1.11 PBq (30,000 Ci) | Between 3000 $A_1$ and 30 $A_1$, and not >1.11 PBq (30,000 Ci) | <30 $A_1$ and <1.11 PBq (30,000 Ci) |
| Normal form | >3000 $A_2$ or >1.11 PBq (30,000 Ci) | Between 3000 $A_2$ and 30 $A_2$, and not >1.11 PBq (30,000 Ci) | <30 $A_2$ and <1.11 PBq (30,000 Ci) |

The drum assembly of the shipping package is defined as the structure that maintains the position of and provides protection to the impact barrier, thermal barrier, and neutron poison surrounding the containment vessel. Because the location of the containment vessel in the packaging is stable, the shielding and subcriticality effectiveness of the package is not reduced. The drum assembly for the ES-3100 consists of an internally flanged Type 304 or 304L stainless-steel 30-gal modified drum with two Type 304 or 304L stainless-steel inner liners, one filled with noncombustible cast refractory insulation and impact limiter and one filled with noncombustible cast neutron absorber; a stainless-steel top plug with cast refractory insulation, silicone rubber pads, silicon bronze hex-head nuts, and a stainless-steel lid and bottom (Drawing M2E801580A001, Appendix 1.3.7). The drum assembly is maintained when there are no breaches in the drum surface, the lid remains attached, the relative position of the containment vessel is not altered significantly, and no substantial amount of insulation is exposed following testing stipulated in 10 CFR 71.71 and 73. The drum assembly's design requirements for compliance testing are as follows:

1. The drum lid shall remain attached to the drum under all loading conditions.

2. No opening in the drum shall occur large enough to pass a 10-cm cube [10 CFR 71.43(a)].

3. The outer drum's effective diameter shall exceed requirements to maintain subcriticality and shielding effectiveness.

4. The drum assembly shall provide the structural and thermal protection needed to ensure the containment vessel meets the test leakage criteria for both NCT and HAC of $\leq 1.0 \times 10^{-7}$ ref-cm$^3$/s.

5. Neutron poison remains in place and retains the amount of water needed to maintain subcriticality.

In accordance with NUREG/CR-3854, Part 4.2 for a Category I shipping package, an acceptable specification for a drum used in any of the component safety groups is U.S. Department of Transportation (DOT) Specification 17C or better. It should be noted that the Specification 17C package is no longer included in the DOT regulations (49 CFR 178). The drum used in the ES-3100 is fabricated in accordance with the dimensional requirements of MS27683 and modified as shown on Drawing M2E801580A004 (Appendix 1.3.7). The fabrication requirements for the ES-3100 drum assembly are shown in JS-YMN3-801580-A002 (Appendix 1.3.2). Material, fabrication, and quality control criteria are generally equivalent to those imposed for a DOT Specification 17C drum. The drum weld seam is pressure tested to 68.95 kPa (10 psi) gauge and a rough handling test in accordance with MIL-D-6054F is conducted. As discussed in Sect. 1.2.1.1, the drum used for the ES-3100 is equivalent to or better than that stipulated by NUREG/CR-3854 for a Category I shipping package. In accordance with DOE, a performance-based package is an approved, quality-controlled, hazardous material container that has been tested or analyzed to demonstrate its ability to maintain confinement and/or containment of its contents under both normal use and credible accident conditions as stipulated in 10 CFR 71. The drum assembly and containment vessel have been maintained for the ES-3100 shipping package as demonstrated by test results documented in the test reports (ORNL/NTRC-013 and ORNL/NTRC-047) and the analytical comparisons discussed in Sects. 2.6 and 2.7.

The codes and standards used for design, analysis, and fabrication of the containment vessel's components are satisfied by complying with the appropriate paragraphs in Sect. III, Div. 1, Subsection NB, and Sect. IX of the ASME Code. Nominal dimensions, not minimum dimensions, were used in the design analysis of the containment vessel components. Though not explicitly expressed, the load combinations and tests stated in NRC Regulatory Guide 7.8, *Load Combinations for the Structural Analysis of Shipping Casks*, are used in the structural evaluation of the containment vessel for both NCT and HAC as depicted in Table 2.3. Acceptance criteria for the containment vessel stresses are shown in Table 2.4 and locations are depicted in Fig. 2.1.

The design internal pressure of 699.82 kPa (101.5 psi) gauge for the containment vessel was determined based on its stress capability before the ASME Code evaluation shown in DAC-M900000-0003 was started. The containment vessel is tested with an internal pressure of 1034.21 kPa (150 psi) gauge or 1.48 times the design pressure, which exceeds the requirement stipulated in Sect. III, Paragraph NB-6221 (a minimum hydrostatic test pressure of 1.25 times the design pressure) and the regulatory requirement of 10 CFR 71.85(b) (1.5 times the maximum normal operating pressure). As shown in Table 2.6, the containment vessel design stresses are well below the allowable stresses (see Fig. 2.1 for stress locations). Therefore, this ES-3100 containment vessel is capable of shipping at a higher internal pressure. The external pressure requirement from 10 CFR 71.73(c)(6) is 150 kPa (21.7 psi) gauge. These design and operating pressures were used to calculate the stresses (DAC-M900000-0003) in all components of the containment vessel, which are well below the allowable limits at all operating conditions. The maximum normal operating pressure calculated for NCT in accordance with 10 CFR 71.4 and 10 CFR 71.71(c)(1) for the bounding load case is 215.24 kPa (31.218 psia). For conservatism and for use in subsequent analyses in Sects. 2 and 4 during NCT, the maximum gas temperature and the maximum normal operating pressure in the containment vessel are rounded up to 93.33°C (200.0°F) and 215.46 kPa (31.25 psia), respectively. The maximum internal gauge pressure calculated for NCT is 190.46 kPa (27.63 psi), which is the maximum normal operating pressure minus the reduced external pressure condition of 10 CFR 71.71(c)(3) [215.46−25.00 kPa] (Sect. 2.6.3). A summary of the package's design, NCT, and HAC pressures and temperatures is presented in Appendices 3.5.1 and 3.5.2. Allowable stress intensity limits and calculated stresses at the design evaluation conditions for the containment vessel are summarized in Tables 2.4–2.6. The stresses used in the design of all metal containment vessel components are in the elastic range of the material properties. For conditions addressed by analysis, the margin of safety (M.S.) is calculated and defined as:

$$\text{Margin of Safety} = \text{Allowable Stress} / \text{Actual Stress} - 1.$$

**Table 2.3. Summary of load combinations for normal and hypothetical accident conditions of transport**

| Normal or accident condition | Applicable initial condition | | | | | | | | Fabrication stresses | SARP reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ambient temperature | | Insolation | | Decay heat | | Internal pressure | | | |
| | 38°C | -29°C | Max | 0 | Max | 0 | Max | Min | | |
| **Normal conditions (analyze separately)** | | | | | | | | | | |
| Hot environment (38°C ambient temperature) | | | X | | X | | X | | X | Sect. 2.6.1 |
| Cold environment (−40°C ambient temperature) | | | | X | | X | | X | X | Sect. 2.6.2 |
| Increased external pressure (20 psia) | | X | | X | | X | | X | X | Sect. 2.6.4 |
| Minimum external pressure (3.5 psia) | X | | X | | X | | X | | X | Sect. 2.6.3 |
| Vibration and shock: | X | | X | | X | | X | | X | Sect. 2.6.5 [a] |
| Normally incident to the mode of transport | | X | | X | | X | | X | X | |
| Free drop | X | | X | | X | | X | | X | Sect. 2.6.7 [b] |
| 1.2-m drop | | X | | X | | X | | X | X | |
| Compression test | X | | X | | X | | X | | X | Sect. 2.6.9 [a] |
| | | X | | X | | X | | X | X | |
| Penetration test | X | | X | | X | | X | | X | Sect. 2.6.10 [a] |
| | | X | | X | | X | | X | X | |
| **Accident conditions (apply sequentially)** | | | | | | | | | | |
| Free drop: 9-m drop | X | | X | | X | | X | | X | Sect. 2.7.1 [c] |
| | | X | | X | | X | | X | X | |
| Crush: 9-m drop | X | | X | | X | | X | | X | Sect. 2.7.2 [c] |
| | | X | | X | | X | | X | X | |
| Puncture: 1-m drop onto bar | X | | X | | X | | X | | X | Sect. 2.7.3 [c] |
| | | X | | X | | X | | X | X | |
| Thermal: fire accident | X | | X | | X | | X | | X | Sect. 2.7.4 |

[a] This condition was conducted at room temperature with atmospheric pressure inside the containment vessel.

[b] This condition was conducted at ambient temperature at the time of the test except for Test Unit-2 (TU-2). The containment vessel was at atmospheric pressure except for TU-2. Justification for compliance with the environmental requirements of NRC Regulatory Guide 7.8 is provided in Sect. 2.6.

[c] This condition was conducted at ambient temperature at the time of the test except for TU-2. The containment vessel was at atmospheric pressure except for TU-2. Justification for compliance with the environmental requirements of NRC Regulatory Guide 7.8 is provided in Sect. 2.7.

**Table 2.4. Containment vessel allowable stress**

| Stress category | Maximum allowable stress | |
|---|---|---|
| | **Level A (NCT)** | **Level D (HAC)** |
| Primary membrane stress intensity | $S_m$ | Lesser of 2.4 $S_m$ and 0.7 $S_u$ |
| Primary membrane + primary bending stress intensity | 1.5 $S_m$ | Lesser of 3.6 $S_m$ and $S_u$ |
| Range of primary + secondary stress intensity | 3.0 $S_m$ | Not applicable |
| Fatigue stress range | $S_a$ @ $10^6$ cycles | < 2 $S_a$ @ 10 cycles |
| Buckling | No buckling | No buckling |

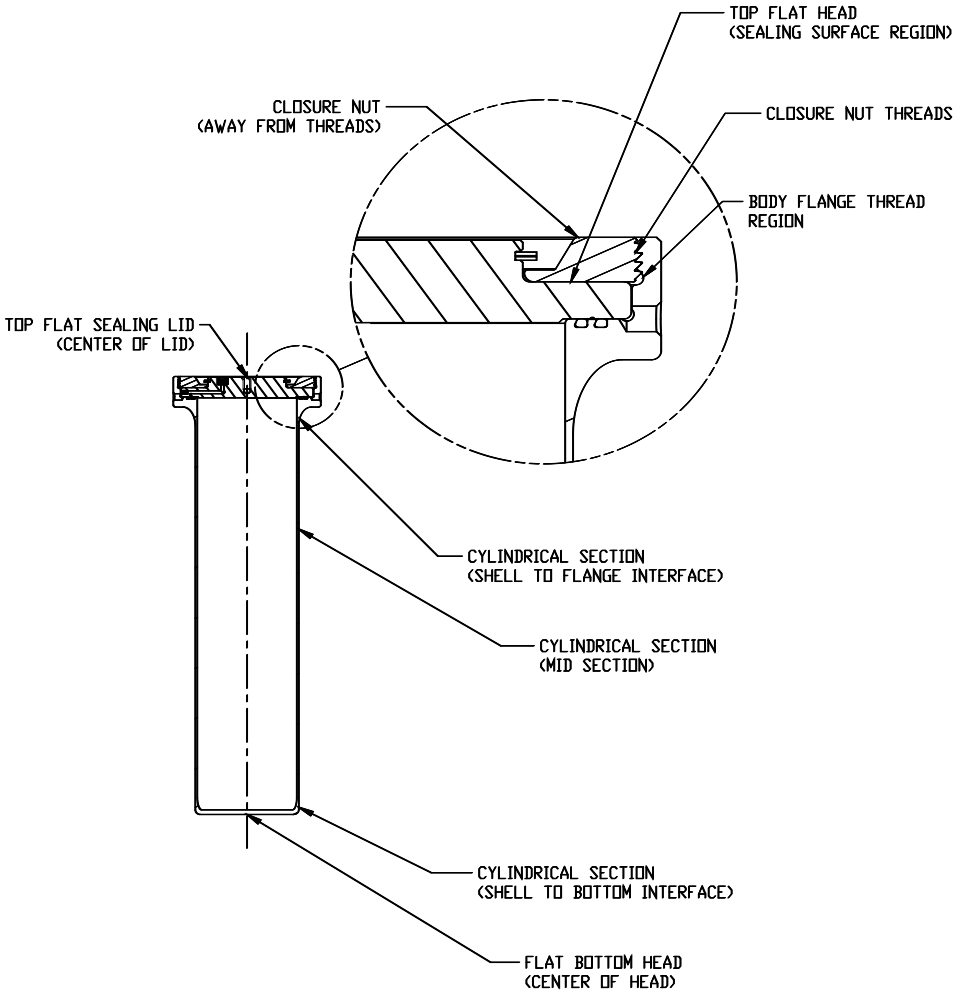



**Fig. 2.1. Containment vessel calculated stress locations.**

**Table 2.5. Allowable stress intensity ($S_m$) for the containment vessel materials of construction [a]**

| Description | Specification | $S_m$ (up to 148.9°C) | $S_m$ [b] (up to 176.7°C) |
|---|---|---|---|
| Pipe body (Method 1) | ASME SA-312 seamless pipe, Type TP304L stainless steel | 1.151 × 105 kPa (16,700 psi) | 1.120 × 105 kPa (16,250 psi) |
| Formed body, end cap, and flange (Method 2) | ASME SA-182, Type F304L stainless steel | 1.151 × 105 kPa (16,700 psi) | 1.120 × 105 kPa (16,250 psi) |
| Flange and end cap (Method 1) | ASME SA-182 forging, Type F304L stainless steel | 1.151 × 105 kPa (16,700 psi) | 1.120 × 105 kPa (16,250 psi) |
| Containment vessel sealing lid | ASME SA-479, Type 304 stainless steel | 1.379 × 105 kPa (20,000 psi) | 1.331 × 105 kPa (19,300 psi) |
| Containment vessel closure nut (as ASME SA-193 bolting) | ASME SA-479, UNS-S21800, Nitronic 60 stainless steel | 7.584 × 104 kPa (11,000 psi) | 7.205 × 104 kPa (10,450 psi) |

[a] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Table 4 at 148.9°C (300°F) and 176.7°C (350°F).
[b] The values shown at 176.7°C (350°F) have been interpolated.

**Table 2.6. ES-3100 containment vessel design evaluation allowable stress comparisons [a]**

| Stress locations shown in Fig. 2.1 | Internal pressure design evaluation containment boundary stress @ 699.82 kPa (101.5 psi) gauge | | External pressure design evaluation containment boundary stress @ −149.62 kPa (−21.7 psi) gauge | | Allowable pressure, stress, or shear capacity |
|---|---|---|---|---|---|
| | kPa (psi) or kg (lb) | M.S. [b] | kPa (psi) or kg (lb) | M.S. [b] | kPa (psi) or kg (lb) |
| Top flat portion of sealing lid (center of lid) | $1.142 \times 10^4$ (1656) | 18 | $2.441 \times 10^3$ (354) | 82 | $1.999 \times 10^5$ (29,000) [c] |
| Closure nut ring (away from threaded portion) | $3.420 \times 10^4$ (4960) | 4.2 | $1.902 \times 10^4$ (2759) [d] | 7.6 | $1.441 \times 10^5$ (20,900) |
| Top flat head (sealing surface region) | $2.897 \times 10^4$ (4202) | 6.9 | $7.087 \times 10^3$ (1028) [d] | 28 | $1.999 \times 10^5$ (29,000) [c] |
| Cylindrical section (middle) internal pressure | $1.948 \times 10^4$ (2825) | 5.8 | | | $1.120 \times 10^5$ (16,250) [e] |
| Cylindrical section (middle) external pressure | | | $1.496 \times 10^2$ (21.7) | 5.1 | $7.584 \times 10^2$ (110) [f] |
| Cylindrical section (shell-to-flange interface) | $2.697 \times 10^4$ (3912) | 6.2 | $5.766 \times 10^3$ (836) | 29 | $1.682 \times 10^5$ (24,400) [c] |
| Cylindrical section (shell-to-bottom interface) | $5.856 \times 10^4$ (8493) | 2.9 | $1.252 \times 10^4$ (1816) | 13 | $1.682 \times 10^5$ (24,400) [c] |
| Body flange thread load, kg (lb) | $1.696 \times 10^3$ (3740) | 15 | $9.072 \times 10^2$ (2000) [d] | 29 | $2.608 \times 10^4$ (57,500) [g] |
| Body flange thread region (under cut region) | $5.689 \times 10^4$ (8251) | 3.0 | $2.839 \times 10^4$ (4117) [d] | 5.9 | $1.682 \times 10^5$ (24,400) [c] |
| Flat bottom head (center) | $4.895 \times 10^4$ (7100) | 3.4 | $1.047 \times 10^4$ (1518) | 16 | $1.682 \times 10^5$ (24,400) [c] |
| Closure nut thread load, kg (lb) | $1.696 \times 10^3$ (3740) | 20 | $9.072 \times 10^2$ (2000) [d] | 37 | $3.353 \times 10^4$ (73,911) [g] |

[a] Stresses are calculated using pressures, gasket and closure nut preload, and nominal dimensions for all containment vessel components (DAC-M900000-0003). Calculated stresses for external pressure were determined by multiplying the stress at the design conditions by a factor equal to the ratio of external pressure to design pressure plus the contribution from preload. Allowable stress values are taken from Table 2.5 up to 176.7°C (350°F).

[b] Margin of safety = allowable stress/actual stress.

[c] Stress interpreted as the sum of $P_l + P_b$; allowable stress intensity value is $1.5 \times S_m$.

[d] Stress and shear load in these areas is dominated by the 162.7 ± 6.8 N·m (120 ± 5 ft-lb) preload. Pressure ignored.

[e] Stress interpreted as the primary membrane stress ($P_m$); allowable stress intensity value is $S_m$.

[f] Allowable external pressure [kPa (psi)].

[g] Allowable shear capacity is defined as $0.6 \times S_m \times$ thread shear area for the body material. Thread shear area = 38.026 $cm^2$ (5.894 $in.^2$). Allowable shear capacity is defined as $1.2 \times S_m \times$ thread shear area for the closure nut material.

In NRC Regulatory Guide 7.11, below Table 1, the following quote is found: "Although NUREG/CR-1815 (Ref. 2) addresses the use of ferritic steels only, it does not preclude the use of austenitic stainless steels. Since austenitic stainless steels are not susceptible to brittle failure at temperatures encountered in transport, their use in containment vessels is acceptable to the staff and no tests are needed to demonstrate resistance to brittle failure." According to NRC Regulatory Guide 7.11, because the containment vessel is manufactured from Type 304L stainless steel (which is an austenitic stainless steel), "no tests are needed to demonstrate resistance to brittle failure." Therefore, brittle or fatigue failures are not anticipated under any design, transport, accident, or storage condition (Sects. 2.6 and 2.7). Material specifications for the ES-3100 packaging components are listed in Table 2.7.

**Table 2.7. ES-3100 packaging material specifications**

| Component | Specifications |
|---|---|
| | **Drum assembly** |
| Drum washers | 1.375 OD × 0.812 ID × 0.25 in. thick, 300 Series stainless steel |
| Drum threaded weld studs | 5/8-11 × 7/8 long, ARC FT, Type 304 or 304L stainless-steel studs |
| Drum hex nuts | ⅝-11 UNC-2B, silicon bronze C65100 |
| Drum lid weldment | Modified 30-gal, 16-gauge (MS27683) lid, Type 304 or 304L stainless steel; and an 11-gauge-thick sheet, Type 304 or 304L stainless steel, ASME SA-240 |
| Drum weldment | Modified 30-gal, 16-gauge (MS27683), Type 304 or 304L stainless steel, ASME SA-240, manufactured per Drawing M2E801580A004 (Appendix 1.3.7) |
| Drum plugs | Nylon plastic plug, Micro Plastic, Inc. |
| | **Impact limiter, insulation enclosure, neutron absorber, and drum packing material** |
| Insulation and impact limiter (not removable) | Lightweight cast refractory insulation, Kaolite 1600, 358.8 ±48.1 kg/m$^3$ (22.4 ±3 lb/ft$^3$) density, cast in stainless-steel shells in the drum and top plug |
| Neutron absorber | Cat 277-4, 1681.9 + 240.3/−80.1 kg/m$^3$ (105 + 15/−5 lb/ft$^3$) density |
| Top plug (removable) | Type 304 or 304L stainless steel, ASME SA-240 (body), ASME SA-479 (lifting inserts) |
| Inner liners | Type 304 or 304L stainless steel, ASME SA-240 (body), ASME SA-479 (modified angle) |
| Silicone pads | Silicone rubber, 22 ±5 Shore A, color black/gray |
| Aluminum foil duct tape | McMaster Carr Part # 7616A21, temperature range −40 to 121°C (−40 to 250°F) |
| | **Containment vessel** |
| Containment vessel plug | Part # 04-2126, Modified VCO threaded plug with O-ring, brass |
| Containment vessel hoist ring | 3052T56, Swivel hoist ring, alloy steel (not used for shipment) |
| Containment vessel | Method 1: Type TP304L stainless steel ASME SA-312 (seamless pipe body); Type F304L, stainless steel, ASME SA-182 (flange and end cap); Type 304, stainless steel, ASME SA-479 (sealing lid), Nitronic 60 stainless steel per ASME SA-479, UNS-S21800 (closure nut)<br>Method 2: Type F304L stainless-steel ASME SA-182 (body, flange, and end cap); Type 304, stainless steel, ASME SA-479 (sealing lid), Nitronic 60 stainless steel per ASME SA-479, UNS-S21800 (closure nut)<br>All components per *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Table 2A |

**Table 2.7. ES-3100 packaging material specifications**

| Component | Specifications |
|---|---|
| Containment vessel O-rings | Elastomer, ethylene propylene diene monomer, Specification M3BA712A14B13F17 in ASTM D 2000 per SPC-M801580-0002 (Appendix 1.3.10); or fluorocarbon elastomer (Parker Compound VM835-75), SAE AMS-R-83485 per SPC-M801580-0001 (Appendix 1.3.9) |
| Containment vessel lid assembly retaining ring | Smalley Steel Ring Co., Part #WSM-400-S02, Type 302 stainless steel |
| Containment vessel O-ring lubricant | Clear dimethyl siloxane polymer |
| Containment vessel closure nut lubricant | Krytox #240AC |
| Containment vessel body dowel pins | 0.2501/0.2503-in. OD × 0.50-in. long, 18-8 stainless steel |
| | **Containment vessel packing material** |
| Convenience cans | Stainless steel, aluminum, or tinned carbon steel with stainless-steel can handles and nylon-coated stainless-steel wire; nickel-alloy (200 series, passivated) in nylon mesh bag |
| Convenience bottles | Polyethylene, glass, or Teflon FEP |
| Silicone rubber pads | Silicone rubber, 22 ±5 Shore A, color black/gray |
| Can spacers | Stainless-steel can filled with Cat 277-4 |
| Bagging | Polyethylene |
| Metal scouring scrubbers | Stainless steel, McMaster Carr Part #7361T13 |

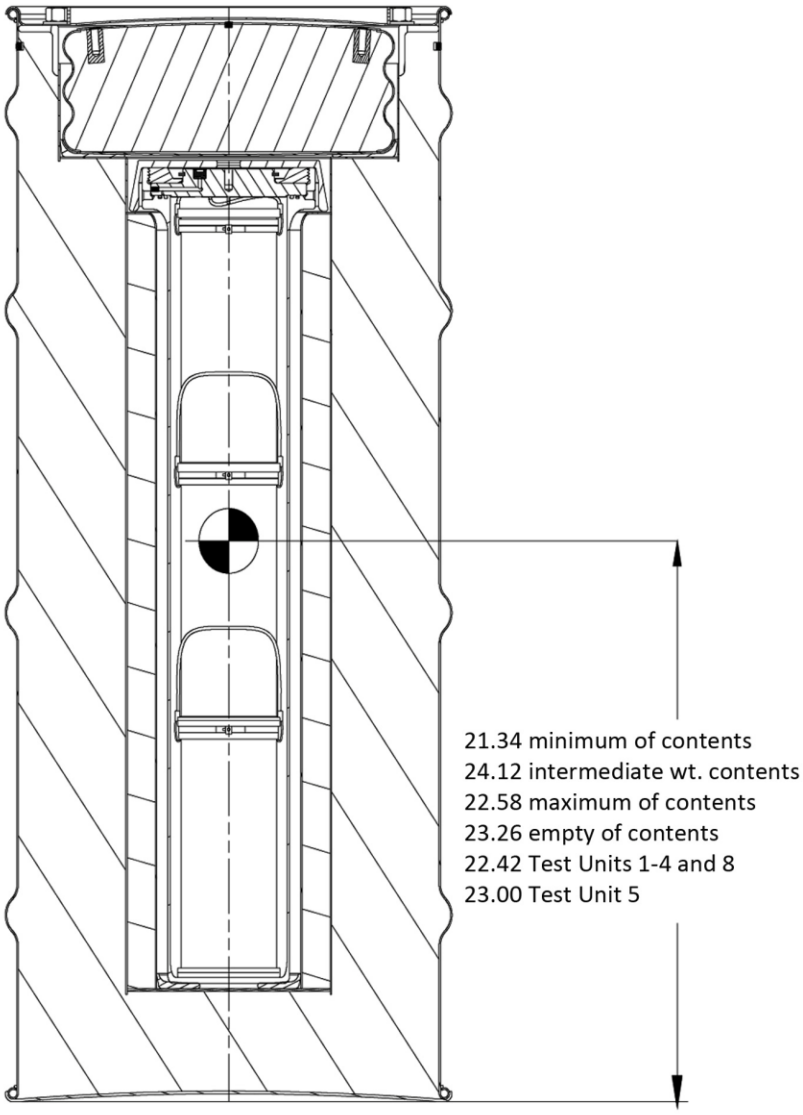
### 2.1.3 Weights and Centers of Gravity

The weights of the packaging components for the actual proposed contents ready for shipment and the test units are provided in Tables 2.8 and 2.9. The values listed for the test weights are the actual data recorded during compliance testing. The remaining weights listed for the shipping package are calculated weights. Nominal dimensions and densities were used in the calculations. Miscellaneous parts (nuts and washers) are included.

The range of the centers of gravity for the ES-3100 shipping package with the various HEU arrangements and the test packages is shown in Fig. 2.2. A summary of the calculations is provided in Table 2.10.

### 2.1.4 Identification of Codes and Standards for Package Design

Based on the discussion in Sect. 2.1.2, the shipping package has been designed and analyzed and will be fabricated, tested and maintained to the requirements of a Category I package. In accordance with the references from NUREG/CR-1815, Table 2.11 describes the appropriate codes and standards that are and will be used to comply with Category I packaging. These requirements have been extracted from NUREG/CR-3854 and NUREG/CR-3019.




**Note:** Dimensions are in inches.

**Fig. 2.2. ES-3100 shipping package center of gravity locations.**

**Table 2.8. Packaging weights for various ES-3100 shipping package arrangements [a, b]**

| Item | Three 10-in. tall can configuration [kg (lb)] [c, d] | Six 4.875-in. tall can configuration [kg (lb)] | Five 4.875-in. tall can configuration [kg (lb)] | Six 4.75-in. tall can configuration [kg (lb)] | Three 8.75-in. tall can configuration [kg (lb)] [e] | Three 8.7-in. tall bottle configuration [kg (lb)] | Three 9.4-in. tall bottle configuration [kg (lb)] | Empty containment vessel configuration [kg (lb)] | ES-3100 with maximum weight contents [kg (lb)] |
|---|---|---|---|---|---|---|---|---|---|
| **Drum assembly** | | | | | | | | | |
| Drum assembly (drum body, lid, bottom, mid liner, inner liner, cast refractory insulation, cast neutron absorber, nuts, washers, and data plates) f | 121.96 (268.87) | 121.96 (268.87) | 121.96 (268.87) | 121.96 (268.87) | 121.96 (268.87) | 121.96 (268.87) | 121.96 (268.87) | 121.84 (268.61) | 121.96 (268.87) |
| Top plug | 8.9 (19.6) | 8.9 (19.6) | 8.9 (19.6) | 8.9 (19.6) | 8.9 (19.6) | 8.9 (19.6) | 8.9 (19.6) | 8.9 (19.6) | 8.9 (19.6) |
| Silicone support pads | 1.04 (2.29) | 1.04 (2.29) | 1.04 (2.29) | 1.04 (2.29) | 1.04 (2.29) | 1.04 (2.29) | 1.04 (2.29) | 1.04 (2.29) | 1.04 (2.29) |
| **Total drum assembly weight** | **131.89 (290.76)** | **131.89 (290.76)** | **131.89 (290.76)** | **131.89 (290.76)** | **131.89 (290.76)** | **131.89 (290.76)** | **131.89 (290.76)** | **131.78 (290.50)** | **131.89 (290.76)** |
| **Containment vessel** | | | | | | | | | |
| Containment vessel (flange, dowel pins, cylindrical body, and end cap) | 10.18 (22.44) | 10.18 (22.44) | 10.18 (22.44) | 10.18 (22.44) | 10.18 (22.44) | 10.18 (22.44) | 10.18 (22.44) | 10.18 (22.44) | 10.18 (22.44) |
| Lid assembly (sealing lid, VCO plug, retaining ring, closure nut and O-rings) | 4.92 (10.85) | 4.92 (10.85) | 4.92 (10.85) | 4.92 (10.85) | 4.92 (10.85) | 4.92 (10.85) | 4.92 (10.85) | 4.92 (10.85) | 4.92 (10.85) |
| **Total containment vessel weight** | **15.10 (33.29)** | **15.10 (33.29)** | **15.10 (33.29)** | **15.10 (33.29)** | **15.10 (33.29)** | **15.10 (33.29)** | **15.10 (33.29)** | **15.10 (33.29)** | **15.10 (33.29)** |

**Table 2.8. Packaging weights for various ES-3100 shipping package arrangements [a, b]**

| Item | Three 10-in. tall can configuration [kg (lb)] [c, d] | Six 4.875-in. tall can configuration [kg (lb)] | Five 4.875-in. tall can configuration [kg (lb)] | Six 4.75-in. tall can configuration [kg (lb)] | Three 8.75-in. tall can configuration [kg (lb)] [e] | Three 8.7-in. tall bottle configuration [kg (lb)] | Three 9.4-in. tall bottle configuration [kg (lb)] | Empty containment vessel configuration [kg (lb)] | ES-3100 with maximum weight contents [kg (lb)] |
|---|---|---|---|---|---|---|---|---|---|
| **Contents** | | | | | | | | | |
| Convenience cans with handles | 0.72 (1.59) | 1.0 (2.22) | 0.84 (1.85) | -- | 0.67 (1.47) | -- | -- | -- | -- |
| Silicone vibration pads | 0.11 (0.23) | 0.l8 (0.41) | 0.16 (0.353) | -- | 0.11 (0.23) | -- | -- | -- | -- |
| Nickel cans | -- | -- | -- | 1.84 (4.07) | -- | -- | -- | -- | -- |
| Polyethylene bottles | -- | -- | -- | -- | -- | 0.345 (0.76) | -- | -- | -- |
| Teflon FEP bottles | -- | -- | -- | -- | -- | -- | 0.99 (2.18) | -- | -- |
| Spacers with handles | -- | -- | 1.88 (4.14) | -- | 1.25 (2.76) | -- | -- | -- | -- |
| Polyethylene bagging or lifting sling | 0.5 (1.10) | 0.5 (1.10) | 0.5 (1.10) | 0.5 (1.10) | 0.5 (1.10) | 0.155 (0.34) | 0.50 (1.10) | -- | -- |
| Metal scouring pads | -- | -- | -- | -- | 0.14 (0.30) | -- | -- | -- | -- |
| HEU or HEU/Alloy content | 35.2 (77.60) | 35.2 (77.60) | 35.2 (77.60) | 24 (52.91) | 35.2 (77.60) | 24.0 (52.91) | 24.0 (52.91) | -- | -- |
| **Total proposed content weight** | **36.52 (80.52)** | **36.89 (81.33)** | **38.57 (85.04)** | **26.34 (58.08)** | **37.86 (83.46)** | **24.50 (54.01)** | **25.49 (56.19)** | **0** | **40.82 (90)** |
| **Total shipping package weight** | **183.51 (404.57)** | **183.88 (405.38)** | **185.56 (409.09)** | **173.33 (382.13)** | **184.84 (407.51)** | **171.49 (378.07)** | **172.47 (380.24)** | **146.88 (323.79)** | **187.81 (414.05)** |

[a] Calculated weight using Pro/ENGINEER software with nominal dimensions and densities.
[b] Shipping weight increases by ~2.5 lb if a radio-frequency identification tag is included.
[c] The weight of this configuration bounds the weight of the bundled fuel rods, tubes, or plates with open-ended cans on either end.
[d] The weight of this configuration bounds the weight of the three 25.4-cm (10-in.)–high cans brazed together containing fuel rods, tubes, or plates.
[e] The weight of this configuration bounds the weight of the two 22.2-cm (8.75-in.)–high cans that are brazed together containing the TRIGA fuel elements.
[f] Weight excluding tamper indicating device.

**Table 2.9. Compliance test unit weights [a]**

| Item | Test Unit [kg (lb)] | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **8** |
| Drum body assembly [b] | 126.6 (279) | 127.9 (282) | 127.9 (282) | 127.9 (282) | 128.8 (284) | -- | 128.4 (283) |
| Top plug | 9.5 (21) | 9.5 (21) | 9.53 (21) | 8.6 (19) | 9.5 (21) | -- | 10.9 (24) |
| Drum silicone support pads | 0.9 (2) | 0.9 (2) | 0.9 (2) | 0.5 (1) | 0.9 (2) | -- | 1.3 (2.8) |
| Containment vessel [c] | 15.4 (34) | 15.0 (33) | 15.0 (33) | 14.5 (32) | 15.0 (33) | 15.0 (33) | 14.5 (32) |
| Mock-up test contents [d] | 49.9 (110) | 49.9 (110) | 50.3 (111) | 49.9 (110) | 3.6 (8) | | 49.9 (110) |
| Contents | | | | | | 6.3 (14) [e] | |
| **Total test unit weight** | **202.3 (446)** | **202.8 (447)** | **203.7 (449)** | **201.8 (445)** | **157.4 (347)** | **21.3 (47)** | **204.6 (451)** |

[a] Total weight may be different from sum of individual component weights due to scale tolerance of ±0.45 kg (1 lb).
[b] This weight includes the drum, mid liner, inner liner, cast refractory, cast neutron absorber, bottom, lid, washers and nuts.
[c] This weight includes containment vessel cylindrical body, end cap, flanged top, and lid assembly.
[d] This weight includes convenience cans, silicone rubber pads, can handles, spacers (if required), and HEU mockup.
[e] This weight was added to reduce buoyancy of containment vessel during 15-m (50-ft) immersion test.

## 2.2 MATERIALS

### 2.2.1 Material Properties and Specifications

The mechanical properties and specifications of the packaging materials are presented in Tables 2.12–2.17. See the drawings in Appendix 1.3.7 for details of all components. Design temperature ranges are listed where they are required to establish the allowable stresses used in the design calculations for the containment vessel (DAC-M900000-0003). Service temperature ranges for the remaining shipping container components were obtained from the references shown in Tables 2.12–2.17.

Kaolite 1600 property values are presented in Table 2.14, and additional Kaolite property and source information is presented in the Kaolite material safety data sheet, ORNL-TM-2003/49, Y/DW-1890, Y/LF-565, and the e-mail communication from Moody to Bales (Moody 2004). ORNL/TM-2004/290, Y/DW-1987, Y/DZ-2585, COR-NDA-04-93, and Y/DV-1914 contain the Cat 277-4 property and source information. Y/DW-1968 contains detailed technical data on strength and thermal expansion of BoroBond4. (BoroBond4 was used in the prototype test units, but it is not used in the package to be certified.)

### 2.2.2 Chemical, Galvanic, or Other Reactions

A package must be of materials and construction to ensure that there will be no significant chemical, galvanic, or other reaction among the packaging components, among package contents, or between the packaging components and the package contents, including a possible reaction resulting from inleakage of water, to the maximum credible extent. Account must be taken for the behavior of materials under irradiation.

**Table 2.10. Calculated center of gravity for the various ES-3100 shipping arrangements**

| Content description | Distance from drum's bottom (in.) |
|---|---|
| **Cylinders, bars, slugs, broken metal—35,200 g (77.60 lb) maximum—no can spacers** | |
| 3 full 4.88-in. cans + 3 empty 4.88-in. cans | 21.139 |
| 2 full 4.88-in. cans + 4 empty 4.88-in. cans | 21.405 |
| 1 full 4.88-in. can + 5 empty 4.88-in. cans | 22.066 |
| 3 full 10-in. cans | 22.071 |
| 2 full 10-in. cans + 1 empty 10-in. can | 21.762 |
| 1 full 10-in. can + 2 empty 10-in. cans | 22.075 |
| 3 full 8.75-in. cans | 21.875 |
| 2 full 8.75-in. cans + 1 empty 8.75-in. can | 21.662 |
| 1 full 8.75-in. can + 2 empty 8.75-in. cans | 22.060 |
| **Cylinders, bars, slugs, broken metal—35,200 g (77.60 lb) maximum—with can spacers** | |
| 3 full 8.75-in. cans + 2 spacers | 22.245 |
| 2 full 8.75-in. cans + 1 empty 8.75-in. can + 2 spacers | 21.802 |
| 1 full 8.75-in. can + 2 empty 8.75-in. cans + 2 spacers | 22.072 |
| 3 full 4.88-in. cans + 2 empty 4.88-in. cans + 3 spacers | 21.471 |
| 2 full 4.88-in. cans + 3 empty 4.88-in. cans + 3 spacers | 21.500 |
| 1 full 4.88-in. can + 4 empty 4.88-in. cans + 3 spacers | 22.028 |
| **UNX crystals 24,000 g (52.91 lb) maximum—with no spacers** | |
| 3 full 8.94-in.–high Teflon FEP bottles + bagging | 22.674 |
| 2 full 8.94-in.–high Teflon FEP bottles + 1 empty 8.94-in.–high Teflon FEP bottle + bagging | 22.383 |
| 1 full 8.94-in.–high Teflon FEP bottle + 2 empty 8.94-in.–high Teflon FEP bottles + bagging | 22.543 |
| **Oxide—24,000 g (52.91 lb) maximum—with no spacers** | |
| 6 full 4.75-in.–high nickel cans + bagging | 22.631 |
| 5 full 4.75-in.–high nickel cans + 1 empty 4.75-in.–high nickel can + bagging | 22.434 |
| 4 full 4.75-in.–high nickel cans + 2 empty 4.75-in.–high nickel cans + bagging | 22.343 |
| 3 full 4.75-in.–high nickel cans + 3 empty 4.75-in.–high nickel cans + bagging | 22.366 |
| 2 full 4.75-in.–high nickel cans + 4 empty 4.75-in.–high nickel cans + bagging | 22.511 |
| 1 full 4.75-in.–high nickel can + 5 empty 4.75-in.–high nickel cans + bagging | 22.787 |
| **Oxide—24,000 g (52.91 lb) maximum—with no spacers** | |
| 3 full 8.7-in.–high polyethylene bottles + bagging | 22.372 |
| 2 full 8.7-in.–high polyethylene bottles + 1 empty 8.7-in.–high polyethylene bottle + bagging | 22.210 |
| 1 full 8.7-in.–high polyethylene bottle + 2 empty 8.7-in.–high polyethylene bottles + bagging | 22.480 |

**Table 2.11. Applicable codes and standards for Category I packaging**

| | Containment<br>*ASME Boiler and Pressure Vessel Code*, Sect. III, Subsection NB | Criticality [a] |
|---|---|---|
| Materials | | Cat 277-4 [a] |
| Base materials | NB-2000 (except NB-2300) and NB-4100 | |
| Welding materials | NB-2400 | |
| Fabrication | | |
| Forming, fitting, aligning, and joint preparation | NB-4200 | |
| Welding | NB-4400 | |
| Qualification of procedures and personnel | NB-4300 | |
| Examination | NB-5000 | [b] |
| Acceptance testing | NB-6000 | [c] |
| Quality assurance | Subpart H in Title 10, CFR, Part 71 | |

[a] NUREG/CR-3854 states, "The designer may specify a neutron-absorber material by a commercial trade name or as a mixture of elements or common compounds. When appropriate, qualification data should be included to demonstrate that the material functions as specified. When special absorber materials are used to control criticality, an acceptance test should be performed for each container to ensure that the absorber material has been properly installed."

[b] NUREG/CR-3854 states, "Packages designed to transport fissile material which contain neutron-absorber material should be tested to demonstrate the presence of the neutron-absorber material. The test description should include information similar to that requested for gamma shield testing 3.2.1. Fabrication records of the absorber material and its installation and testing should be maintained."

[c] NUREG/CR-3854 states, "Gamma scanning or probing may be used to demonstrate the soundness of the neutron absorber. Alternatively, ultrasonic testing may be used. Whatever method is used, the following information should be provided in the test procedure:

(1) Description of the measuring technique including the electronics;
(2) The source type and strength used to measure the neutron absorber effectiveness;
(3) The standards and methods used to calibrate the source, sensors, and other pertinent equipment;
(4) The grid pattern used to check the neutron absorber;
(5) The type of gamma sensor used to measure the neutron absorber effectiveness;
(6) The specific test requirements and measurements;
(7) The acceptance criteria."

**Table 2.12. Mechanical properties of the metallic components of the drum assembly [a]**

| | | |
|---|---|---|
| Drum, bottom cover, and lid | ASME SA-240 Type 304 or 304L, stainless-steel plate | |
| Inner liners | ASME SA-240 Type 304 or 304L, stainless-steel plate | |
| Top plug weldment | ASME SA-240 Type 304 or 304L, stainless-steel plate | |
| Materials of construction | ASME SA-240 Type 304 | ASME SA-240 Type 304L |
| Design stress intensity, MPa (ksi) at: | | |
| −40°C (−40°F) | 137.9 (20) | 115.1 (16.7) |
| 37.78°C (100°F) | 137.9 (20) | 115.1 (16.7) |
| 93.33°C (200°F) | 137.9 (20) | 115.1 (16.7) |
| 148.89°C (300°F) | 137.9 (20) | 115.1 (16.7) |
| Ultimate strength, MPa (ksi) at: | | |
| −40°C (−40°F) | 517.1 (75) | 482.6 (70) |
| 37.78°C (100°F) | 517.1 (75) | 482.6 (70) |
| 93.33°C (200°F) | 489.5 (71) | 455.7 (66.1) |
| 148.89°C (300°F) | 456.4 (66.2) | 422.0 (61.2) |
| Yield strength, MPa (ksi) at: | | |
| −40°C (−40°F) | 206.8 (30) | 172.4 (25) |
| 37.78°C (100°F) | 206.8 (30) | 172.4 (25) |
| 93.33°C (200°F) | 172.4 (25) | 147.5 (21.4) |
| 148.89°C (300°F) | 154.4 (22.4) | 132.4 (19.2) |
| Elongation in 5.08 cm (2 in.) (%) | 40 [b] | 40 [b] |
| Coefficient of thermal expansion, cm/cm/°C (in./in./°F) at: | | |
| −40°C (−40°F)[c] | 0.00001476 (0.0000082)[c] | 0.00001476 (0.0000082)[c] |
| 37.78°C (100°F) | 0.00001548 (0.0000086) | 0.00001548 (0.0000086) |
| 93.33°C (200°F) | 0.00001602 (0.0000089) | 0.00001602 (0.0000089) |
| 148.89°C (300°F) | 0.00001656 (0.0000092) | 0.00001656 (0.0000092) |
| Modulus of elasticity, GPa (Mpsi) at: | | |
| −40°C (−40°F) | 197.2 (28.6) | 197.2 (28.6) |
| 37.78°C (100°F) | 194.0 (28.14) | 194.0 (28.14) |
| 93.33°C (200°F) | 190.3 (27.6) | 190.3 (27.6) |
| 148.89°C (300°F) | 186.2 (27.0) | 186.2 (27.0) |

[a] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Subpart 1, Tables 2A, U, and Y-1; and Subpart 2, Tables TE-1, Column B, and TM-1.
[b] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part A, for ASME SA-240 material.
[c] MIL-HDBK-5H.

**Table 2.13. Mechanical properties of the lid fastening components for the drum assembly**

| Drum weld studs | Specification |
|---|---|
| Material | ASTM A 493 Type 304/304L stainless steel |
| Fabrication standard | ASTM F 593 |
| Service temperature range, °C (°F) | −40 to 816 (−40 to 1500) [a] |
| Maximum allowable stress, S, MPa (ksi) at temperatures [a] | |
| −29°C to 38°C (−20 to 100°F) | 129.6 (18.8) |
| 93.3°C (200°F) | 115.1 (16.7) |
| 148.9°C (300°F) | 103.4 (15.0) |
| Coefficient of thermal expansion, cm/cm/°C (in./in./°F) [a] | |
| 21.1°C (70°F) | $1.53 \times 10^{-5}$ ($8.5 \times 10^{-6}$) |
| 93.3°C (200°F) | $1.60 \times 10^{-5}$ ($8.9 \times 10^{-6}$) |
| 148.9°C (300°F) | $1.66 \times 10^{-5}$ ($9.2 \times 10^{-6}$) |
| **Drum hex-head nuts** | **Specification** |
| Material | silicon bronze |
| Fabrication standard | ASTM F 467 |
| UNS designation | C65100 [b] |
| Minimum proof stress, MPa (ksi) | 485 (70) [b] |
| **Drum washer** | **Specification** |
| Drum | 1.375-in. OD × 0.812-in. ID × 0.25 in. thick, Series 300 stainless steel |

[a] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Subpart 1, Table 3; and Subpart 2, Table TE-1, Group 3, B value.
[b] ASTM F 467.

**Table 2.14. Mechanical properties of the cast refractory insulation**

| | |
|---|---|
| Material composition | Cast refractory, Kaolite 1600 |
| Flexural tensile strength, kPa (psi)<br>Standard deviation | 133 (19.4) [a]<br>32 (4.7) |
| Average coefficient of thermal expansion, cm/cm/°C (in./in./°F) | $9.07 \times 10^{-6}$ ($5.04 \times 10^{-6}$) [b] |
| Average modulus of rupture per ASTM C 133, kPa (psi) | 258.6 (37.5) [c] |
| Normal operating temperature, °C (°F) | −40 to 871 (−40 to 1600) [c] |
| Density after curing, kg/m$^3$ (lb/ft$^3$) | 358.8 (22.4) [c] |
| Force/deflection curves | Y/DW-1972 [d] |

[a] Y/DW-1661.
[b] Moody 2004.
[c] Kaolite product data sheet.
[d] Y/DW-1972.

**Table 2.15. Mechanical properties of containment vessel O-rings**

| | |
|---|---|
| **Ethylene propylene diene monomer** | |
| Specification | ASTM D 2000, M3BA712A14B13F17 [a, b] |
| Normal service temperature range, °C (°F) | −40 to 150 (−40 to 302) [b, c] |
| Permissible exposure time at 150°C (302°F), h | 1000 [c] |
| Hardness durometer, Shore A | 70 ± 5 [b] |
| Minimum elongation, % | 100 [b] |
| Fabrication method | Molded [b] |
| **Fluorocarbon elastomer** | |
| Specification | SAE AMS-R-83485, Type 1 [d, e] |
| Parker compound | VM835-75 |
| Normal service temperature range, °C (°F) | −40 to 204 (−40 to 400) [c, e] |
| Permissible exposure time at 204°C (400°F), h | 1000 [c] |
| Hardness durometer, Shore A | 75 ± 5 [e] |
| Minimum elongation, % | 120 [e] |
| Fabrication method | Molded [e] |

[a] ASTM D 2000.
[b] SPC-M801580-0002 (Appendix 1.3.10).
[c] *Parker O-Ring Handbook*, Sect. 2.13.2 and Fig. 2-28, p. 2-27.
[d] SAE AMS-R-83485.
[e] SPC-M801580-0001 (Appendix 1.3.9).

**Table 2.16. Mechanical properties of the metallic components of the containment vessel**

| Containment vessel: body, flange, and seal lid | Specification |
|---|---|
| Material of construction: stainless steel, Type 304L | ASME SA-312 (pipe); ASME SA-182 (flange, formed body, or end cap); ASME SA-479 (seal lid) |
| Design temperature range, °C (°F) | −40 to 176.67 (−40 to 350) |
| Minimum ultimate strength, MPa (ksi) | 482.6 (70) [a] |
| Yield strength, 0.2% offset, MPa (ksi) at temperatures | |
| 37.8°C (100°F) | 172 (25) [a] |
| 149°C (300°F) | 132 (19.2) [b] |
| 176.67°C (350°F) | 126.52 (18.35) [b] |
| Elongation in 5.08 cm (2 in.), % | 30 [c] |
| Modulus of elasticity, GPa (Mpsi) at temperature [b] | |
| −40°C (−40°F) | 197.2 (28.60) |
| 37.78°C (100°F) | 194.0 (28.14) |
| 93.33°C (200°F) | 190.3 (27.60) |
| 121.11°C (250°F) | 188.2 (27.30) |
| 148.89°C (300°F) | 186.2 (27.00) |
| 176.67°C (350°F) | 184.4 (26.75) |
| Allowable stresses ($S_m$) [d] at 149°C (300°F) | |
| Welded pipe, MPa (ksi) | |
| 149°C (300°F) | 115.14 (16.7) |
| 176.67°C (350°F) | 112.03 (16.25) |
| Forged flanges, lids, end caps, MPa (ksi) | |
| at 149°C (300°F) | 115.14 (16.7) |
| 176.67°C (350°F) | 112.03 (16.25) |
| Coefficient of thermal expansion, cm/cm/°C (in./in./°F) at temperatures [e] | |
| −40°C (−40°F) | 0.00001476 (0.00000820) |
| 37.78°C (100°F) | 0.00001548 (0.00000860) |
| 93.33°C (200°F) | 0.00001602 (0.00000890) |
| 121.11°C (250°F) | 0.00001638 (0.00000910) |
| 148.89°C (300°F) | 0.00001656 (0.00000920) |
| 176.67°C (350°F) | 0.00001674 (0.00000930) |

| Containment vessel closure nut | Specification |
|---|---|
| Material of construction | Nitronic 60, UNS-S21800 |
| Elongation, % | 10–12 [f] |
| Design temperature range, °C (°F) | −40 to 176.67 (−40 to 350) |
| Ultimate strength, MPa (ksi), room temperature | 1655–1813 (240–263) [f] |
| Yield strength, 0.2% offset, MPa (ksi), room temperature | 1344–1496 (195 − 217) [f] |
| Coefficient of thermal expansion, cm/cm/°C (in./in./°F) at temperatures [e] | |
| 93.33°C (200°F) | 0.0000158 (0.0000088) |
| 204.40°C (400°F) | 0.00001660 (0.0000092) |

[a] Listed in the appropriate material specification identified under materials of construction.
[b] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Tables Y-1 and TM-1.
[c] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part A for ASME SA-312, SA-182, or SA-479 material.
[d] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Table 2A.
[e] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Subpart 2, Table TE-1, Column B, except that −40°C is from MIL-HDBK-5H, Table 2.7.1.0.
[f] Value presented in ARMCO NITRONIC 60 Stainless Steel Product Data Bulletin, S-56b.

**Table 2.17. Mechanical properties of the cast neutron absorber**

| Material | Cat 277-4 |
|---|---|
| Service temperature range, °C (°F) | −40 to 150 (−40 to 302) |
| Modulus of elasticity in tension, GPa (Mpsi) at temperatures [a] | |
| −40°C (−40°F) | 13.72 (1.991) |
| 21.11°C (70°F) | 4.72 (0.684) |
| 37.78°C (100°F) | 2.78 (0.403) |
| Coefficient of thermal expansion, cm/cm/°C (in./in./°F) at temperatures [b] | |
| −40°C (−40°F) | $12.700 \times 10^{-6}$ ($7.056 \times 10^{-6}$) |
| −20°C (−4°F) | $13.000 \times 10^{-6}$ ($7.222 \times 10^{-6}$) |
| 0°C (32°F) | $13.000 \times 10^{-6}$ ($7.222 \times 10^{-6}$) |
| 40°C (104°F) | $12.600 \times 10^{-6}$ ($7.000 \times 10^{-6}$) |
| 60°C (140°F) | $11.599 \times 10^{-6}$ ($6.444 \times 10^{-6}$) |
| 80°C (176°F) | $10.400 \times 10^{-6}$ ($5.778 \times 10^{-6}$) |
| 100°C (212°F) | $9.700 \times 10^{-6}$ ($5.389 \times 10^{-6}$) |
| 120°C (248°F) | $9.101 \times 10^{-6}$ ($5.056 \times 10^{-6}$) |
| Poisson's ratio | |
| −40°C (−40°F) | 0.33 [a] |
| 21.11°C (70°F) | 0.28 |
| 37.78°C (100°F) | 0.25 |
| Density, g/cm$^3$ (lb/in.$^3$) | 1.682 (0.0608) |

[a] Y/DW-1987.
[b] ORNL/TM-2004/290.

**Analysis.** Starting with the outer components, the packaging consists of the drum (austenitic Type 304 stainless steel), weld studs (austenitic stainless steel), nuts (silicon bronze), insulation (cast refractory), neutron absorber (Cat 277-4), silicone support pads, containment vessel (austenitic Type 304L stainless steel), closure nut (Nitronic 60), silicone support pads, can spacers (stainless steel and Cat 277-4), stainless-steel scrubbers, convenience cans (stainless steel, tin-plated carbon steel, aluminum, or nickel-alloy [series 200, passivated]), polyethylene or Teflon FEP bottles, glass bottles inside convenience can, polyethylene bags, and the HEU contents.

The cast refractory insulation (Kaolite) is contained between the drum and mid-liner and within the top plug assembly's stainless-steel sheet metal. Due to the alkaline nature of this material, greater permanence of the surrounding structure is assured. Also, this material has been used successfully for years as an insulation heat treatment liner adjacent to metal surfaces of furnaces.

The cast neutron absorber (Cat 277-4) is contained between the most inward liner and mid-liner. During the casting process, the chlorine content is limited to 100 parts per million. The small quantity of chlorine will not affect the stainless-steel liners.

The nuts used to attach the drum to the lid are silicon bronze. All other metal components of the packaging are stainless steel, Nitronic 60, or tinned steel. All stainless-steel components are passivated per ASTM A 380, Paragraph 6.4, and Table A2.1, Part II. Prior to assembly, the packaging will be kept inside a building or transported between buildings in an enclosed truck. The assembled components are protected from the weather and inspected at the time of packaging; therefore, the package will not contain any free water (other than absorbed water in the encapsulated Kaolite) at the time it is loaded

for transport. Under NCT, the only moisture present will be the relative humidity or moisture absorbed by the cast refractory or neutron-absorber materials. When the package is subjected to a water-spray type environment, some water may leak into the cavity formed by the inner liner and occupied by the containment vessel. To minimize the possibility of any potentially corrosive situation, a visual examination of the interior surface of the inner liner and the exterior surface of the containment vessel shall be conducted prior to packing and following transport of the shipping package (see Sect. 7). Any free water present and any corrosion discovered shall be promptly removed.

The ES-3100 containment vessel is fabricated from ASME SA-182, Type 304L stainless steel that is solution annealed and quenched, cleaned, and passivated (JS-YMN3-801580-A001, Appendix 1.3.3). This low carbon (<0.03 wt % carbon) grade of austenitic stainless steel is more resistant to the precipitation of chromium carbide precipitation along the grain boundaries, due to its low carbon content. The solution anneal relieves residual stresses resulting from the method of fabrication and it ensures that the alloy is not susceptible to intergranular corrosion as demonstrated by testing in accordance with ASTM A 262. Cleaning and passivation treatments in accordance with ASTM A 380 enhance the thin, chromium-oxide film that forms on the alloy surface. During content loading operations (Sect. 7.1.1.2) and periodic maintenance (Sect. 8.2.5.2) the interior and exterior surfaces of the containment vessel are routinely inspected for signs of moisture, corrosion, and physical damage.

During immersion under HAC, water can enter the holes at the top of the drum, be absorbed into the cast refractory material, and fill all void spaces within the drum and inner liner. The insulating value of the insulation material may be decreased, and an overall weight increase would occur. The most important consideration is that the containment boundary remain intact and leaktight. This situation has been evaluated by completely immersing the containment vessel in a tank simulating 0.9- and 15-m (3- and 50-ft) immersion depths. The containment vessel remained intact and water tight, as demonstrated by the analysis and testing discussed in Sect. 2.7.

Physical contact between the convenience cans and the containment vessel wall, bottom, or top is minimized when the silicone support pads are used. The polyethylene or Teflon FEP bottles may be in contact with the stainless steel of the containment vessel, but will not react. During normal shipping operations, the cans and bottles will provide separation of the HEU contents from the containment vessel walls. The contents that cannot be packaged in the proposed cans due to the contents' overall dimensions, such as the unirradiated research reactor fuel elements, will be bundled together and protected on each end with an open-ended can (Fig. 1.4). When space is available inside the containment vessel, stainless-steel metal scrubbers will be placed on the top and bottom of this partially canned assembly, or an empty convenience can will be placed on the top or bottom of this assembly inside the containment vessel. Some solid form content may only be packed inside polyethylene bagging only. The bagging will prevent the uranium material from contacting the stainless-steel containment vessel. Stainless-steel metal scrubbers may be placed on the top and bottom of this assembly. Additionally, glass bottles with enriched uranium oxide ($UO_2$-Mg) will be packed inside sealed and inerted containers and treated as a pyrophoric content. The passivated nickel-alloy cans are galvanically similar to the stainless steel of the containment vessel and thus will not react. Aluminum clad components, alloys, and convenience cans oxidize quickly when exposed to moisture in the air. Therefore, there will not be any galvanic reaction between the aluminum and the containment vessel materials. Additionally, polyethylene bagging may be used around the convenience container as required by packaging personnel (in some cases the HEU is bagged inside the convenience container). Therefore, galvanic corrosion between the containment vessel wall and convenience containers or contents is highly unlikely. In addition, with the exception of UNX crystals, the environment inside the containment vessel is free of electrolytic solutions, further ensuring that there will be no galvanic reactions occurring inside the containment vessel.

For pyrophoric considerations, broken metal and alloy pieces shall be of a size that: (a) the specific surface area does not exceed 1 $cm^2/g$, or (b) will not pass freely through a mesh size of ⅜ in. (9.53 mm). Incidental small particles which do not pass the size restriction tests, and powders, foils, turnings, and wires may only be shipped if they are in a sealed, inerted container. Enriched uranium oxide in glass bottles ($UO_2$-Mg) will be shipped in a sealed, inerted container.

The material testing documented in Y/DZ-2720 does not identify the composition of the volatiles or gases generated during testing. Since Teflon FEP, a fluorine-containing polymer, is used to transport uranyl nitrate crystals and one of the uranium compounds is uranium tetrafluoride ($UF_4$), the possible development of a corrosive environment inside the containment vessel is investigated. Based on the following literature, FEP is notable among polymers for its high thermal stability. It decomposes at temperatures above ~260°C (500°F). In air or in oxygen, FEP decomposes in one way at lower temperatures and in another at higher temperatures. In this discussion, "oxygen" implies oxygen at a pressure of 300 torr. In air, the partial pressure of oxygen is near 150 torr. Below ~525°C, the decomposition of FEP is first order, and the main decomposition product is hexafluoropropylene ($C_3F_6$), although tetrafluoroethylene ($C_2F_4$) is a near second in abundance (Leidecker, Teflon thermal decomposition). The carbon-fluorine compound is one of the strongest compounds found in organic chemistry (its dissociation energy is 460 kJ/mol). The carbon chain is nearly completely covered by fluorine atoms and is, therefore, protected against external influences. This results in the exceptionally high chemical resistance of FEP (Daikin America). Based on the preceding statements, it is reasonable to conclude that most, if not all, of the gas coming from any decomposition of the Teflon FEP bottles would be hexafluoropropylene and tetrafluoroethylene rather than fluorine gas. The maximum temperature predicted (NCT or HAC) inside the ES-3100 containment vessel at the location near the Teflon FEP bottles is 140.56°C (285.00°F). This temperature is considerably below the lower limit of the FEP decomposition temperature [260°C (500°F)]. Due to the difference between the decomposition temperature of FEP [260°C (500°F)] and the maximum predicted temperature from testing [140.56°C (285.00°F)], essentially no $C_3F_6$ or $C_2F_4$ and no fluorine is expected to form during transport. Uranium tetrafluoride is a solid composed of agglomerating particles with a texture similar to baking soda. It is nonvolatile, nonhydroscopic, and only slightly soluble in water. A corrosive environment with fluorine as the base is not anticipated for either the uranium tetrafluoride compound or the Teflon bottles. It should be noted that the offgassing rate and quantity used for Teflon FEP at lower temperatures in Appendices 3.5.1 and 3.5.2 are very conservative estimates. The actual values shown for the Teflon bottle sample in Y/DZ-2720 may have resulted from the cumulative tolerance in the testing setup and data recording and not from actual offgassing.

Uranyl nitrate crystals are formed by dissolving uranium metal or any of the uranium oxides in nitric acid and the UNX crystalline precipitates are acquired through a variety of extraction, filtration, and purification processes. The UNX crystals are soluble in water, forming a weak nitric acid solution. Anhydrous uranyl nitrate [Formula: $UO_2(NO_3)_2$; molecular weight: 394.0; Chemical Abstract Service (CAS) Registry No. 10102-06-4] dissolves in water and when exposed to moist air it forms a mixture of the uranyl nitrate hydrates. Uranyl nitrate hexahydrate (UNH) [Formula: $UO_2(NO_3)_2 \cdot 6H_2O$; molecular weight: 502.1; CAS Registry No. 13520-83-7] separates out of solutions of uranyl nitrate at room temperature. The formation of uranyl nitrate hydrates in solution can be influenced by the addition of nitric acid. The higher the nitric acid concentration, the less water molecules take part in the hydrate formation (e.g., triyhydrates, dihydrates). Thermal decomposition of UNX crystals has been studied in detail in support of nuclear fuel reprocessing. As presented for shipment, the UNX crystals exist as crystalline solids; however, the melting point for UNH, trihydrate, and dihydrate is reported as ~60°C, 113°C, and 184°C, respectively (Marshall 1951). Heating of UNH crystals up to 200°C results in a stepwise release of water molecules of crystallization (Dash 1999 and Kozlova 2007), which in a closed system results in the partial dissolution of the crystals. During transport of UNH crystals, crystalline solids and a saturated solution of uranyl nitrate will coexist at a temperature above ~60°C (MCW-1424).

Given that the NCT maximum containment vessel temperature with insolation is 91.92°C (197.46°F) and the HAC maximum predicted temperature inside the containment vessel at the location near the Teflon bottles is 140.56°C (285.00°F), the uranyl nitrate dihydrate and lower hydrates will remain in a solid phase during transportation. However, the trihydrate and higher hydrate crystals will release water molecules of crystallization upon heating above their melting point, thus converting them into a lower hydrate species, which require a successively higher temperature to release additional water molecules. The melting point for hexahydrate (~60°C) will be exceeded during NCT and HAC, and the melting point for trihydrate (~113°C) crystals will be exceeded during HAC. The solubility of uranyl nitrate is reported in ARH-724 ADD to be 55.9 and 81.1 lb $UO_2(NO_3)_2$ per 100 lb of saturated solution at 77 and 191°F, respectively. Released water molecules will partially dissolve the UNX crystals forming a weak nitric acid solution (<5% $HNO_3$). Upon cooling, the uranyl nitrate hydrate melt will recrystallize to a solid form.

While the Teflon bottles have proven to be fully capable of containing UNX crystals during normal shipping operations, there has been no effort to qualify these convenience containers under NCT and HAC testing conditions stipulated in 10 CFR 71.71 and 10 CFR 71.73, respectively. Consequently, solid/liquid UNX contents are therefore assumed to be in contact with the containment vessel internals. The general bulk corrosion can be estimated with published corrosion data for Type 304L stainless steel in nitric acid. Conservatively assuming an exposure to 5% nitric acid for 51 weeks at 200°F (NCT) and 1 week at 300°F (HAC) with corrosion rate data from NiDI Technical Series No. 10 075 (corrosion rate ranges of 0.000–0.005 and 0.005–0.020 in. per year at 200°F and 300°F, respectively), the estimated general corrosion would be 0.0001–0.0053 in. per 12-month exposure. However, given the conservative seal times stipulated in Table 1.3a, these corrosion rates would be reduced to 0.0001–0.0020 in. per 4-month exposure and to 0.0001–0.0012 in. per 2-month exposure. For comparison purposes, using corrosion rate data (0.0000–0.0039 and 0.0039–0.0394 in. per year at 212°F and 302°F, respectively) from the Outokumpu Corrosion Handbook, the estimated general corrosion rates would be 0.0001–0.0046 in. per 12-month exposure, 0.0001–0.0021 in. per 4-month exposure, and 0.0001–0.0014 in. per 2-month exposure. The average general corrosion would be 0.0025 in. per 12-month exposure, 0.0011 in. per 4-month exposure, and 0.0007 in. per 2-month exposure. Under the maximum seal time limit authorized (4 months in Table 1.3a), the average corrosion rate of ~0.001 in. or even the maximum corrosion rate of ~0.002 in. would not have a significant impact on the containment vessel integrity. It should be noted that these calculated corrosion rates are conservative given that the nitric acid concentration will progressively decrease during the exposure interval (i.e., as the nitric acid reacts) and that the maximum HAC temperature was imposed for 1 week with the maximum NCT temperature imposed for the remaining balance of the exposure interval.

As opposed to general corrosion in which all parts of the exposed surface corrode at approximately the same rate, pitting corrosion occurs when discrete areas of the alloy undergo localized attack while the bulk material remains virtually unaffected. Pitting corrosion can occur under acidic conditions involving a high concentration of chlorides, aeration, and moderately high temperatures. It can be inhibited by approaches commonly used to reduce corrosion in general: environment, alloy composition and structure, potential, and temperature. Various inorganic chemicals, including nitrates, will inhibit pitting when added to corrosive solutions. Type B and fissile material packages of UNX solutions with free acid are routinely transported in accordance with NRC requirements [e.g., NRC Certificate of Compliance Nos. 9250 and 9291 for the Model No. 5X22 Package and Liqui-Rad (LR) Transport Unit Package, respectively]. UNX crystals have been routinely transported in stainless-steel containment vessels in accordance with NRC requirements [e.g., NRC Certificate of Compliance Nos. 9250 and 9315 for the Model No. 5X22 Package and ES-3100 Package, respectively]. There have been no reported occurrences of pitting corrosion issues related to the transportation of UNX crystals or solutions in these referenced packages. Routine visual inspections of the ES-3100 containment vessel internals during loading and maintenance operations will identify general or pitting corrosion problems before they would present any significant impact on the containment vessel integrity.

Laboratory tests have been ongoing at the Savannah River National Laboratory (SRNL) since 2003 studying the performance of Viton GLT O-rings in the K-Area Materials Storage facility at the Savannah River Site. Data from these tests indicate that negligible degradation to the Viton GLT O-rings occurs at temperatures of 200°F or less, for a period of 5 years (SRNL-MST-2008-00127). No impact on the ability of the seal on the 9975 primary containment vessel (PCV) is expected. A −40°F cold test was performed on a prototype PCV (9965) at minimum internal pressure. The PCV was helium leak-rate tested per NRC Regulatory Guide 7.4, *Leakage Tests on Packages for Shipment of Radioactive Materials,* and the bell jar method in ANSI N14.5-1997. The PCV was fitted with two Viton GLT O-rings and cooled to −40°F. The bell jar was evacuated and the PCV was pressurized to 15 psig helium internal pressure. The test showed that the PCV remained leaktight to a sensitivity $<1 \times 10^{-7}$ ref cc/sec for 10 min. Repeating the above test confirmed the results (SRL-PTG-90-0047). O-rings made from Viton GLT-S (Parker compound VM835-75) are acceptable replacements for Viton GLT O-rings as there is no technical basis to suspect the thermal resistance and long-term aging behavior will be significantly different (SRNL-EES-2006-00056). The design of the 9975 PCV and the 9977 6-in. containment vessel is essentially the same, with the 6-in. containment vessel being a scaled up version of the PCV (a 5-in.-diam containment vessel). Secondary effects due to long-term storage or use, such as compression set, thermal set, etc., are also captured under the surveillance program results. O-rings are captured inside the containment vessel of the ES-3100 in a static face seal (axial) method as opposed to the conical (radial) mating surfaces of the 9975 containment vessel. Both designs (ES-3100 and 9975) use the same cross-sectional diameter and durometer O-rings. The half-dovetail O-ring groove design of the ES-3100 provides a nominal 18% compression when metal-to-metal contact of the body and lid is achieved at closure (*Parker O-Ring Handbook,* Design Chart 4-5). The basic design of the ES-3100 O-ring groove detail requires no stretching of the O-ring unlike the requirement of the conical (radial) sealing surfaces for the 9965, 9975, and 9977 containment vessels. Assuming the conical surfaces react like an industrial static seal, the nominal stretch required for this design will provide ~16 to 23% compression of the O-ring. As shown in SRNS-TR-2009-00259, Table 1, the percent compression of the 9975 O-ring may vary from 8 to 23.4% under various stretch, size, and gap conditions. Whereas, the ES-3100 design provides a range of 15 to 21% based on O-ring size and groove depth variations. Because the O-ring compressions are similar between designs and the O-ring compounds and sizes are comparable, the surveillance program data should be applicable for Viton GLT-S O-ring use in the ES-3100 containment vessel.

The containment boundary remains intact even when the drum and inner liner are filled with water; therefore, the package is acceptable to the maximum credible extent from the standpoint of chemical, galvanic, or other reactions.

### 2.2.3 Effects of Radiation on Materials

All materials are affected to some extent by ionizing radiation, although low exposure levels do not typically cause appreciable effects (i.e., changes in the physical and mechanical properties). Upon exposure to ionizing radiation, a fraction of the incident energy is dissipated by interactions with the orbital electrons or nuclei of individual atoms. In sufficient quantities, the cumulative effects of these interactions may result in properties that differ from those of the unirradiated material. The radiation effects in a given material are proportional to the dose (amount of radiation absorbed), irrespective of the type of radiation.

The contents of the ES-3100 package are not irradiated, and the calculated total dose rates (Sect. 5) are well below those required to significantly damage any of the package materials by radiolytic interactions. The safety-related packaging components most vulnerable to radiation-induced degradation are the containment vessel EPDM or fluorocarbon elastomer O-rings. According to the *Parker O-Ring Handbook,* practically all elastomers suffer no change of their physical properties at a cumulative dose up to $1 \times 10^6$ rad. In addition, select EPDM and fluorocarbon elastomer compounds have been successfully tested at $1 \times 10^7$ rad of gamma radiation. Based on the calculated dose rate of 0.5 rad/h (Sect. 5.4.4), the maximum cumulative dose for the containment boundary O-ring location

would be $<5 \times 10^3$ and $<1 \times 10^4$ rad for an exposure period of 1 or 2 years, respectively. Since the maximum absorbed dose is well below the $1 \times 10^6$ rad threshold, there will be no significant degradation of the O-ring material properties due to irradiation. Also, no significant degradation or activation of the other packaging materials of construction is expected at the calculated total dose rates.

Section 4.5.2.3 of NUREG-1609 requires the applicant to demonstrate that any combustible gases generated in the package during a period of one year do not exceed 5% (by volume) of the free gas volume in any confined region of the package. No credit should be taken for getters, catalysts, or other recombination devices. Appendix 3.5.4 evaluates the various packaging arrangements for the generation of hydrogen gas due to the radiolysis of water vapor, free water, interstitial water, polyethylene bags, and polyethylene or Teflon bottles. When the content mass and the material composition are limited as shown in Appendix 3.5.4, the combustible gas concentration limit stated in NUREG-1609 is not exceeded. Getters, catalysts, or other recombination devices are not employed in any of the containment vessel packaging arrangements.

## 2.3 FABRICATION AND EXAMINATION

### 2.3.1 Fabrication

#### 2.3.1.1 Drum assembly fabrication

The drum assembly is fabricated in accordance with JS-YMN3-801580-A002 (Appendix 1.3.2), JS-YMN3-801580-A003 (Appendix 1.3.4), and JS-YMN3-801580-A005 (Appendix 1.3.5). The latter two specifications control the casting of the Kaolite 1600 and Cat 277-4 materials inside the liners, spacer cans, and the top plug.

The drum assembly and top plug are fabricated according to the design drawings (Appendix 1.3.7), and the portions of the codes, standards, and regulations to the extent described below:

1. *ASME Boiler and Pressure Vessel Code*, Sect. VIII, Div. 1, 2001 ed. with 2002 and 2003 addenda;

2. *ASME Boiler and Pressure Vessel Code*, Sect. II, Parts A and C, 2001 ed. with 2002 and 2003 addenda;

3. *ASME Boiler and Pressure Vessel Code*, Sect. IX, 2001 ed. with 2002 and 2003 addenda;

4. Military Standard MS27683, *Drum, Metal—Shipping and Storage 16 to 80 Gallons*; and

5. ASTM A 380, *Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems*.

Detailed dimensional requirements and the materials of construction are called out on the drawings in Appendix 1.3.7. Except for the weld studs, documented Certified Material Test Reports (CMTRs) are provided for all materials used in weldments for the fabrication of the drum, including weld filler metal. The CMTRs are traceable to heat numbers and demonstrate compliance with the SA or SFA Series material specifications called out. For all other materials, documented Certificates of Compliance (CoCs) are provided certifying that the materials provided comply with the requirements stated on the drawings and specifications. All welding is done in accordance with welding procedure specifications that are written and performance qualified in accordance with the ASME Code, Sect. IX. All welders are performance qualified to weld using these procedures, and their qualifications are documented in accordance with the ASME Code, Sect. IX. The welding fabrication requirements stated in the

ASME Code, Sect. VIII, Div. 1, Paragraphs UW-26–UW-48, are met. All butt welds in rolled sheet, pipe, and angle joints are full penetration butt welds. With the exception of the seam welds in the drum body, all welds shall be done by the gas tungsten arc welding (GTAW), gas metal arc welding (GMAW), plasma arc welding, or a capacitor discharge stud welding process. The weld filler metal used in the fabrication of the drum assembly is procured to comply with the SFA specifications of Sect. II, Part C, of the ASME Code that are stated in the welding procedure specifications. Weld filler metal is traceable to heat numbers, and CMTRs are furnished for each heat of weld wire filler. The control of weld filler permits a weld examiner to be able to determine the heat number of the weld filler used in any weld on the drum assembly. Weld symbols are provided on the drawings, indicating for each weld the type of weld and the dimensions of weld. These weld symbols are interpreted in accordance with AWS A2.4.

#### 2.3.1.2 Containment boundary fabrication

The containment boundary consists of the containment vessel, lid assembly, and inner O-ring. The containment vessel is manufactured in accordance with the applicable requirements in the ASME Code, Sect. III, Div. 1, Subsection NB, for Class 1 Components as described on the drawings in Appendix 1.3.7 and JS-YMN3-801580-A001 (Appendix 1.3.3). The containment vessel is fabricated according to the design drawings and the following codes, standards, and regulations as described in JS-YMN3-801580-A001.

1. *ASME Boiler and Pressure Vessel Code*, Sect. III, Div. 1, Subsections NB and NCA, Class 1 Components, 2001 ed. with 2002 and 2003 addenda;

2. *ASME Boiler and Pressure Vessel Code*, Sect. II, Parts A and C, 2001 ed. with 2002 and 2003 addenda;

3. *ASME Boiler and Pressure Vessel Code*, Sect. IX, 2001 ed. with 2002 and 2003 addenda; and

4. ASTM A 380, *Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems*.

Detailed dimensional requirements and the materials of construction are called out on the drawings in Appendix 1.3.7. CMTRs are provided for the materials used to fabricate these components in accordance with NCA-3860 of the ASME Code. The suppliers of these materials will meet the requirements of NCA-3800 of the ASME Code. Such parts are traceable to each containment vessel by means of a serial number. The fabricator maintains control of materials to ensure this traceability. Other metallic materials and the O-ring seals are supplied with CoCs in accordance with NCA-3862(g) and (h) of the ASME Code. The weld filler metal used in the fabrication, and repair welding as permitted, of the containment vessels meets the requirements of ASME Code, Sect. III, Subsection NB, Paragraph NB-2400. It is procured to comply with the SFA specifications of Sect. II, Part C, of the ASME Code that is stated in the fabricator's welding procedure specifications. Weld metal is procured traceable to heat numbers, and CMTRs are furnished for each heat of weld wire filler used. The results of the delta ferrite determination are included in the CMTR for the weld filler metal (see Paragraph NB-2433). There are two containment vessel assemblies shown on Drawing M2E801580A012 (Appendix 1.3.7), Parts M2E801580A012-1 and M2E801580A012-4. Part M2E801580A012-4 is fabricated by welding a forged bottom and forged top flange to a cylindrical shell machined from seamless pipe as shown on the drawing. All welds on the containment vessels are accomplished by either the GTAW or GMAW process, manual or automatic, at the discretion of the fabricator unless specifically called out on the drawings. Backing rings, even if removed after the weld has been made, are not used. As previously stated, weld symbols are provided on the drawings, indicating the type of weld and dimensions of the weld. These weld symbols are interpreted in accordance with AWS A2.4. The forming, fitting, and alignment requirements stated in

Paragraph NB-4200 are met in the fabrication of the containment vessels unless more stringent requirements are called out on the design drawings.

The preferred fabrication method for the containment vessel body (Part M2E801580A012-1) is from a single forged billet or bar by any process that meets the requirements stated in JS-YMN3-801580-A001 (Appendix 1.3.3) and shown on the design drawings. The formed, heat treated, and finished machined containment vessel body shall meet the applicable requirements of ASME SA-182 for Grade F304L for a forged component. After final forming, parts are solution annealed and quenched per the requirements of ASME SA-182 for Grade F304L. A certified heat treatment report is provided stating the following information for each furnace charge: the serial numbers of the containment vessel bodies heat treated in the furnace charge, the time and date of the heat treating, the person responsible for the heat treating, the time-temperature profile of the furnace and representative parts of the furnace charge, the quench medium, and all other pertinent details of the heat treating. Such a heat treating report is required for all heat treating, both in-process annealing and final heat treatment.

### 2.3.2 Examination

#### 2.3.2.1 Examination of the drum assembly fabrication

The drum and top plug assemblies are examined and tested according to the design drawings and the applicable portions of the codes, standards, and regulations described below:

1. *ASME Boiler and Pressure Vessel Code*, Sect. VIII, Div. 1, 2001 ed. with 2002 and 2003 addenda;

2. *ASME Boiler and Pressure Vessel Code*, Sect. V, 2001 ed. with 2002 and 2003 addenda; and

3. SNT-TC-1A-1992, *Recommended Practice for Nondestructive Testing Personnel Qualification and Certification*, American Society for Nondestructive Testing, December 1992.

All welded or weld-repair surfaces shall be visually examined by a qualified weld examiner for indications of inclusions, cracks, or porosity using a written weld examination procedure. Weld examiners are qualified to perform visual weld inspections in accordance with SNT-TC-1A, *Personnel Qualification and Certification in Nondestructive Testing*, or ANSI/ASNT CP-189, *Qualification and Certification of Nondestructive Testing Personnel*, published by the American Society for Nondestructive Testing. The ASME Code, Sect. IX, is to be employed as the applicable requirement. Section VIII of the ASME Code is invoked for acceptance criteria for Code-specified examinations, which are to be performed in accordance with the provisions of ASME Code, Sect. V. Any indication of inclusions, cracks, or porosity in the welds is cause for rejection. The item may be reworked to meet the specifications. The weld examination procedures, the weld examiners' qualifications, and the weld examination reports are submitted to Consolidated Nuclear Security, LLC (CNS) for record keeping. The acceptance criteria for joint fit-up and alignment or for visual examination of welds are given in the ASME Code, Sect. VIII, Div. 1, Paragraphs UW-31 through UW-36. In addition, any visible defects such as lack of fusion, lack of penetration, linear or crack-like defects, and visible porosity, are cause for rejection. Straightening, flattening, and forming by mechanical or thermal means of some features and components after welding may be required to ensure proper assembly. The surfaces of areas of the weldment that have been reworked are visually examined to ensure that no cracks are present or that the weldment has not been degraded. Welds that are adjacent to these areas are also visually examined. The acceptance criterion is that no cracks are found. The areas worked and the visual inspections are noted on the dimensional inspection report. The external seam weld of the drum assembly is pressure tested by attaching removable lids on both the top and bottom false wire locations and injecting water and air inside the assembly up to the final pressure of 170.30 kPa (24.7 psia). After all testing, inspection, and final machining are complete, the drum assembly and top plug are dimensionally inspected. The dimensions

and features such as flatness and run-out to be inspected are indicated on the design drawings. A written inspection report is prepared, submitted, and maintained for each ES-3100 drum assembly.

The above examination criteria address the stainless-steel components. However, the drum assembly also consists of the Kaolite 1600 material and the Cat 277-4 neutron poison. Acceptance criteria for the installation of the Kaolite 1600 material are addressed by JS-YMN3-801580-A003 (Appendix 1.3.4). This specification controls and documents the raw materials used for mixing, casting and vibration methodology, and the baking of the material inside the drum assembly. The final acceptance criterion is achieved by producing a cast Kaolite 1600 material density of 358.8 ± 48 kg/$m^3$ (22.4 ± 3 lb/$ft^3$). Acceptance criteria for the installation of Cat 277-4 neutron poison are addressed in JS-YMN3-801580-A005 (Appendix 1.3.5). This specification also controls and documents the raw materials used for mixing, casting, and vibration methodology, and the final density of the casting [1682 +240/−80 kg/$m^3$ (105 +15/−5 lb/$ft^3$)]. Further examination criteria to verify the concentration and homogeneity of the Cat 277-4 in each drum assembly are also provided in JS-YMN3-801580-A005. The various parameters specified in NUREG/CR-3854 and in Table 2.11 for a neutron poison are addressed in detail in this specification.

#### 2.3.2.2 Examination of the containment vessel fabrication

The containment vessel is examined and tested according to the design drawings and applicable portions of the following codes, standards, and regulations as described below:

1. *ASME Boiler and Pressure Vessel Code*, Sect. III, Div. 1, Subsections NB and NCA, Class 1 Components, 2001 ed. with 2002 and 2003 addenda;

2. ANSI N14.5-1997, *American National Standard for Radioactive Materials—Leakage Tests on Packages for Shipment*;

3. *ASME Boiler and Pressure Vessel Code*, Sect. V, Subsection A, Article 10, Appendix IX, "Helium Mass Spectrometer Test—Hood Technique," 2001 ed., and 2002 and 2003 addenda;

4. *ASME Boiler and Pressure Vessel Code*, Sect. V, Article 6, "Liquid Penetrant Examination," 2001 ed., and 2003 addenda; and

5. SNT-TC-1A-1992, *Recommended Practice for Nondestructive Testing Personnel Qualification and Certification*, American Society for Nondestructive Testing, December 1992.

Procured materials are examined in accordance with the applicable paragraphs of NB-2500 and meet the stated acceptance criteria. The results of these examinations are included with the CMTRs provided to CNS. All welded or weld-repair surfaces are visually examined by a qualified weld examiner for indications of inclusions, cracks, or porosity. The ASME Code, Sect. IX, provides the applicable requirements. Section III of the ASME Code is invoked for acceptance criteria for Code-specified examinations, which are to be performed in accordance with ASME Code, Sect. V. Prior written approval is obtained for any weld repair on materials, and the weld repair areas are both surface and volumetrically examined. The repair area is noted in a sketch supplied with the CMTR for the material that was weld repaired, and the documented results of the weld examination are provided to CNS. The markings on the weldment materials are not removed until after all weld examination is complete. The heat numbers of base metals and weld filler are required on all weld examination reports. Control of

weld filler by the fabricator makes it possible for a weld examiner to determine the heat number of the weld filler used in any weld on the containment vessel.

As previously stated, the containment vessel body may be fabricated by two different methods (Appendix 1.3.7, Drawing M2E801580A012). Part M2E801580A012-4 is fabricated by welding a forged bottom and forged top flange to a cylindrical shell machined from seamless pipe as shown on the drawing. Prior to welding these components, all weld preparation areas and the surfaces within one inch of the weld are examined visually and with liquid penetrant. The acceptance criteria for these examinations are those stated in Paragraphs NB-5130(a) through NB-5130(d). The requirements in ASME Code, Paragraphs NB-5110, NB-5120, NB-5210, NB-5220, NB-5260, and NB-5300 apply to the containment vessels. The plug weld shown on Drawing M2E801580A015 (Appendix 1.3.7) shall be examined visually and with penetrant. The requirements in Paragraphs NB-5110 and NB-5350 apply to the plug weld. Materials used in the penetrant examination of welds and in the final surface examinations of finished components shall be specifically recommended by their suppliers for use with austenitic stainless steels, and copies of the certification of contaminant content of materials used shall be supplied with the examination reports (ASME Code, Sect. V, Article 6, T-641). Repair welding shall meet the applicable requirements of NB-2500. Certified written weld examination reports together with the corresponding material surface examination reports and weld map shall be submitted as stated in the procurement specification for the containment vessel. Weld examination reports for all weld and surface examinations shall include the containment vessel serial number, a weld map showing the location of the weld and examination area, the welder's name, the examiner's name, the time and date of the weld examination, the examination procedure number(s) used, the WPS number, the heat numbers of the joined materials, the heat number of the weld filler, and examiner's remarks. The examiner's remarks shall include the results of the examination and the acceptance or rejection of the weld based on the stated criteria. One set of radiographs shall be provided with the radiographic examination reports. If a weld or surface is rejected, a description of the defect and a sketch showing the location shall be provided.

The nonwelded containment vessel body, Part M2E801580A012-1, shall be formed from a single forged billet or bar by any process that meets the requirements stated in JS-YMN3-801580-A001 (Appendix 1.3.3) and shown on the design drawings (Appendix 1.3.7). The formed, heat treated, and finished machined containment vessel body shall meet the applicable requirements of ASME SA-182 for Grade F304L for a forged component. Mechanical properties are verified by testing of coupons. The test coupons are to be machined from the same heats of materials used to form the containment vessel bodies and shall have the same or greater amount of cold work (plastic strain) as the containment vessels will have as a result of the forming process. The mechanical tensile testing of coupons shall be done in accordance with ASME SA-370. A minimum of six test coupons shall be tested for each final heat treatment furnace charge. The first set of three test coupons, chosen at random, shall be tested without being heat treated. The second set of three or more test coupons shall be heat treated together with the containment vessel bodies and then tested. The heating rates and maximum temperatures of the test coupons shall be representative of the entire furnace charge. Test coupons are not required to be heat treated with intermediate processing annealing steps but are required in the final heat treatment furnace charge. The results of all the testing of the sample coupons shall be documented, certified, and reported to CNS. The mechanical properties test report shall contain the following information: a descriptor of the furnace charge which the test coupons are to represent; the times and dates of the heat treating and the testing; the person responsible for the testing; a statement that these coupons are tested prior to or after heat treatment; a description of the testing, including a sketch of the tensile test specimen; the make, model, serial number, and current calibration data of the machine(s) used in the testing; reference to the written testing procedure that was used; the resulting measured yield strength, ultimate strength, percent elongation and percent reduction in area; and any pertinent remarks.

## 2.4 GENERAL REQUIREMENTS FOR ALL PACKAGES

The general design standards for all packages in accordance with 10 CFR 71.43(a) through (c) are addressed in the following paragraphs.

### 2.4.1 Minimum Package Size—10 CFR 71.43(a)

**Requirement:** The smallest overall dimension of a package shall not be <10 cm (4 in.).

**Compliance:** The drum's outside diameter over the rolled rings is 49.20 cm (19.37 in.), and the outside height including the lid is 110.49 cm (43.50 in.). The minimum outside diameter of the ES-3100 containment vessel is 13.36 cm (5.26 in.), and the overall height is 82.30 cm (32.40 in.). Therefore, the packaging meets this requirement.

### 2.4.2 Tamper-Indicating Feature—10 CFR 71.43(b)

**Requirement:** The outside of the package must incorporate a feature, such as a seal, that is not readily breakable and that, while intact, would be evidence that the package has not been opened by unauthorized persons.

**Compliance:** The removable drum head is attached to the body by eight ⅝-11-UNC-2B silicon bronze nuts and ⅝-in. nominal washers. Two 0.51-cm (0.20-in.)–thick lugs with 0.953-cm (0.38-in.)–diam holes (Drawing M2E801580A005, Appendix 1.3.7) project through slots in the drum lid and provide attachment for TIDs. These TIDs consist of a stainless-steel cable with an aluminum crimp closure or equivalent. The requirement is satisfied by the TIDs, which are installed as specified in Sect. 7.1.2.2. The TID is only required when the containment vessel has HEU in the package. It is not required for empty shipments, but may be installed if required by site-specific requirements.

### 2.4.3 Positive Closure—10 CFR 71.43(c)

**Requirement:** Each package must include a containment system securely closed by a positive fastening device that cannot be opened unintentionally or by pressure that may arise within the package.

**Compliance:** The fastened lid on the drum with tamper-indicating features provides assurance that the drum assembly will not be unintentionally breached. The containment vessel is sealed using the lid assembly and closure nut to ensure that it will be breached only through a deliberate effort, and then only after the drum assembly has been breached. The design of the containment vessel is analyzed in DAC-M900000-0003 for a differential pressure of 699.82 kPa (101.5 psi) internal and 150 kPa (21.7 psi) external. The internal design pressure exceeds the maximum differential pressure of 190.46 kPa (27.63 psi) [215.46 − 25] and 674.31 kPa (97.80 psi) attained during NCT (Sect. 2.6.3) and HAC (Appendix 3.5.2), respectively. In addition, calculation results are provided in Sects. 2.6.1 and 2.7.4.3 to demonstrate that the stresses in the containment vessel and closure nut threads do not exceed the stress limits established by the ASME Code for NCT and HAC. Therefore, the containment boundary will not be breached during any mode of transport due to pressurization of the containment boundary.

## 2.5 LIFTING AND TIE-DOWN STANDARDS FOR ALL PACKAGES

This section addresses the requirements of 10 CFR 71.45, "Lifting and Tie-Down Standards for All Packages."

### 2.5.1 Lifting Devices

**Requirement.** Any lifting attachment that is a structural part of a package must be designed with a minimum safety factor of three against yielding when used to lift the package in the intended manner, and it must be designed so that failure of any lifting device under excessive load would not impair the ability of the package to meet other requirements of 10 CFR 71, Subpart E. Any other structural part of the package that could be used to lift the package must be capable of being rendered inoperable for lifting the package during transport, or must be designed with strength equivalent to that required for lifting attachments.

**Analysis.** The ES-3100 packages, as delivered for transport, have no lifting devices or structural parts that can be used for lifting. Therefore, the lifting devices requirements of 10 CFR 71.45 are not applicable.

### 2.5.2 Tie-Down Devices

**Requirement.** If there is a system of tie-down devices that is a structural part of the package, the system must be capable of withstanding, without generating stress in any material of the package in excess of its yield strength, a static force applied to the center of gravity of the package having a vertical component of two times the weight of the package with its contents, a horizontal component along the direction in which the vehicle travels of ten times the weight of the package with its contents, and a horizontal component in the transverse direction of five times the weight of the package with its contents. Any other structural part of the package that could be used to tie down the package must be capable of being rendered inoperable for tying down the package during transport, or must be designed with strength equivalent to that required for tie-down devices. Each tie-down device that is a structural part of a package must be designed so that failure of the device under excessive load would not impair the ability of the package to meet other requirements of this part.

**Analysis.** The ES-3100 package, as delivered for transport, has no tie-down devices that are structural parts of the package. Therefore, the tie-down requirements of 10 CFR 71.45 are not applicable. The package is secured in the conveyance using blocking, bracing, and tie-down equipment that meets industry-standard practices to prevent shifting during NCT. When using a Safeguards Transporter (SGT), safe tie-down and transport of the package is accomplished by methods explained in the NNSA Technical Manual. For single-unit tie-down, a drum tie-down adapter is positioned on top of the drum and two chains, passing through the adapter, are attached to equipment positioned on the floor of the transport vehicle. The welded ring on the drum lid helps to initially position this drum tie-down adapter as well as prevent inadvertent assembly damage to the studs and nuts. Another method of securing the ES-3100 package is by the use of a Cargo-Restraint Transporter or Cargo Pallet Assembly. In these methods, a frame is positioned around the base and top of either five or six packages. These frames are then chained or locked to the floor as depicted in the NNSA Technical Manual. Tension is applied to the chains to eliminate any slack. The downward load resulting from the chain tensioning is insignificant when compared to the compression loading as specified in 10 CFR 71.71(c)(9).

## 2.6 NORMAL CONDITIONS OF TRANSPORT

This section demonstrates compliance with 10 CFR 71.43(f) and with 10 CFR 71.51(a)(1) and (b) following the tests and NCT conditions stipulated in 10 CFR 71.71. Package structural evaluation is performed by the combination of full-scale testing, similarity, and analysis as described in the following sections. A summary of 10 CFR 71.71 tests for the ES-3100 package is shown in Table 2.18. The essentially unyielding surface used for the 1.2-m (4-ft) drop test was the indoor drop test pad at the National Transportation Research Center (NTRC). All 9-m (30-ft) drop and crush tests were conducted at the outside drop pad at NTRC. The indoor pad consists of a 5.08-cm (2-in.)–thick steel plate embedded inside a reinforced concrete pad ~127-cm (50-in.) thick. The outside drop pad consists of a 10.16-cm (4-in.)–thick steel plate embedded inside a reinforced concrete pad ~167.6-cm (66-in.) thick. An article has been prepared by the NTRC staff to describe the integrity of these test pads (Shappert 1991). It is shown that the package will not experience any loss in shielding effectiveness or spacing and will not release any radioactive content or undergo leakage of water into the containment vessel during exposure to NCT. The four tests (water spray, free drop, compression, and penetration) made on Test Unit-4 (TU-4) were conducted in the 20.8 to 22.4°C (69.4 to 72.4°F) range, with the 1.2-m drop test conducted at 22.4°C (72.4°F). The maximum regulatory reference air leakage rate is $\leq 1.3792 \times 10^{-4}$ ref-cm$^3$/s. Compliance with this permitted activity release limit is not dependent on filters or mechanical cooling systems. Following NCT compliance testing, the package was subjected to the sequential HAC test battery.

The ES-3100 package was tested in accordance with test plans developed by the NTRC at the Oak Ridge National Laboratory (ORNL) [ORNL/NTRC-013 and ORNL/NTRC-047]. Testing of ES-3100 prototype units was performed at the NTRC facility, except as noted below. Six full-scale test units were assembled with content weights ranging from 3.6 kg (8 lb) to 50.3 kg (111 lb). One of these test units (TU-4) was subjected to the tests specified in 10 CFR 71.71(c)(5) through (c)(10) excluding (c)(8) prior to the HAC sequential tests stipulated in 10 CFR 71.73 and shown in Table 2.18. Tables 2.18 and 2.19 summarize the testing procedure and the drop orientations for each ES-3100 test unit. The contents used as surrogate payloads for the test units are shown on Drawings M2E801580A029 and M2E801580A027. In the light-weight configuration, the contents consist of three 25.4-cm (10-in.)-high convenience cans with handles, and four silicone rubber pads. These convenience cans, handles and silicone rubber pads are identical to those proposed for transport. The bottom convenience can was filled with steel grit until the convenience can and grit assembly weighed ~3 kg (6.6 lb). The actual weight of the steel grit was 2.77 kg (6.11 lb). The total content weight for the light-weight content configuration including the convenience cans, silicone rubber pads, can handles, and steel grit was ~3.6 kg (8 lb). In the heavy-weight configurations, the surrogate payload consists of three steel cylindrical shaped components with handles, two can spacers filled with neutron-absorbing material and handles, and six silicone rubber pads. These components weighed a total of ~50 kg (110.2 lb). These different weight assemblies bound the range of possible content configurations and structural deformation resulting from compliance testing.

Title 10 CFR 71.71(b) specifies that the tests for NCT be conducted at the most unfavorable ambient temperature within the range of −29 to 38°C (−20 to 100°F). The drum is fabricated from Type 304 stainless steel, and the containment vessel is fabricated from Type 304L stainless steel, which is particularly suitable for low-temperature service. The Izod impact strength for the stainless steel used in the package components remains constant over a large range [specifically, from 21.11 to −195.5°C (70 to −320°F)] (*Stainless Steel Handbook*). Tensile strength increases from a minimum of $4.826 \times 10^5$ to $1.696 \times 10^6$ kPa (70,000 to 246,000 psi), and the yield strength increases ~10% over the same temperature range. The EPDM O-rings in the containment vessel have a normal service temperature range of −40 to 150°C (−40 to 302°F) [Table 2.15]. The fluorocarbon elastomer O-rings have a normal service temperature range of −40 to 204°C (−40 to 400°F) [Table 2.15]. The normal service temperature range of the drum and containment vessel is −40 to 426.7°C (−40 to 800°F) [ASME Code, Sect. II, Part D]. At −29°C (−20°F), the impact-limiting material has been shown by tests to be stiffer than at 22.4°C (72.4°F).

**Table 2.18. Summary of NCT—10 CFR 71.71 tests for ES-3100 package [a]**

| Test | TU-1 (heavy) 12° slap-down | TU-2 (heavy) side drop | TU-3 (heavy) CG over top corner | TU-4 (heavy) top down | TU-5 (light) 12° slap-down | TU-8 [b] (heavy) CG over top corner |
|---|---|---|---|---|---|---|
| Operational leak test (CALT5 or VTI Smart Station) | 1 | 1 | 1 | 1 | 1 | 1 |
| NCT— 10 CFR 71.71(c)(5) Vibration | | | | 5 | | |
| NCT— 10 CFR 71.71(c)(6) Water spray | | | | 2 | | |
| NCT— 10 CFR 71.71(c)(7) 1.2 m (4 ft) free drop | 2 | 2 | 2 | 3 | 2 | 2 |
| NCT— 10 CFR 71.71(c)(9) Compression | | | | 6 | | |
| NCT— 10 CFR 71.71(c)(10) Penetration | | | | 4 | | |

[a] The numbers 1 through 6 indicate the sequence of the tests.
[b] TU-8 used Viton GLT-S O-rings and Cat 277-4 for the neutron-absorbing material. This unit was also pre-chilled to −40°F prior to free drop testing. Test report ORNL/NTRC-047, Rev. 1, discusses the testing conducted on TU-8.

This condition has been evaluated by the compliance testing conducted on TU-2. TU-2 was chilled prior to being subjected to any structural testing (i.e., 1.2-m NCT drop, 9-m HAC drop, HAC crush, and HAC puncture tests). This unit was chilled to a nominal temperature of −40°C (−40°F). This was accomplished by placing the unit in an environmental chamber in Building 5800 at ORNL with initially setting of the chamber at ~ −57°C (−70°F) for 24 h. After this initial period, the control on the environmental chamber was set to ~ −43°C (−45°F) for another 48 h. Prior to the initiation of structural testing of this unit, it was removed from the environmental chamber and placed in an insulated box. Once transported to the NTRC, sequential structural testing as shown in Table 2.19 was performed as quickly as possible. The other test units were first subjected to the free drop from 1.2 m (4 ft) test prior to the HAC testing of 10 CFR 71.73. These additional tests were conducted to show that the NCT testing would not reduce the effectiveness of the package to withstand HAC testing. The reduction in tensile strength of the stainless steel from 22.4 to 38°C (73 to 100°F) is only ~2%, and the impact-limiting material test trends show that the impact-limiting material may become slightly softer. However, these slight reductions in tensile strength and absorption characteristics should not affect the results significantly compared to those conducted at 38°C (100°F).

**Table 2.19. Summary of HAC—10 CFR 71.73 tests for the ES-3100 package [a]**

| Test | TU-1 (heavy) 12° slap-down | TU-2 (heavy) side drop | TU-3 (heavy) CG over top corner | TU-4 (heavy) top down | TU-5 (light) 12° slap-down | TU-6 [b] 15-m immersion | TU-8 [c] (heavy) CG over top corner |
|---|---|---|---|---|---|---|---|
| 10 CFR 71.73(c) (1) Free drop 9 m (30 ft) | 1 | 1 | 1 | 1 | 1 | | 1 |
| 10 CFR 71.73(c)(2) Crush 9 m (30 ft) | 2 | 2 | 2 | 2 | 2 | | 2 |
| 10 CFR 71.73(c)(3) Puncture 1 m (40 in.) | 3, 4, 5, 6 | 3 | 3 | 3 | 3 | | 3 |
| Preheat to >38°C (100 °F) before thermal test | 7 | 4 | 4 | 4 | 4 | | 4 |
| 10 CFR 71.73(c)(4) Thermal 800°C (1475°F) | 8 | 5 | 5 | 5 | 5 | | 5 |
| Operational leak test of containment vessel (CALT5or VTI Smart Station) | 9 | 6 | 6 | 6 | 6 | 1 | 6 |
| Full containment boundary leak test (He Leak Test) | 10 | 7 | 7 | 7 | 7 | | 7 |
| 10 CFR 71.73(c)(5) Immersion test fissile materials—0.9 m (3 ft) | 11 | 8 | 8 | 8 | 8 | | 8 |
| 10 CFR 71.73(c)(6) Immersion test—all packages 15 m (50 ft) | | | | | | 2 | |

[a] The numbers 1–11 indicate the sequence of the tests.
[b] TU-6 is only a containment vessel with ballast to ensure nonbuoyancy.
[c] TU-8 used Viton GLT-S O-rings and Cat 277-4 for the neutron-absorbing material. This unit was also pre-chilled to −40°F prior to free drop testing. Test report ORNL/NTRC-047, Rev. 1, discusses the testing conducted on TU-8.

Title 10 CFR 71.71(b) also states that the initial internal pressure within the containment system during NCT drop testing shall be considered as the maximum normal operating pressure. The maximum normal operating pressure is defined in 10 CFR 71.4 as the maximum gauge pressure that would develop in the containment system in a period of 1 year under the heat conditions specified in 10 CFR 71.71(c)(1). The internal pressure developed under these conditions in the ES-3100 containment vessel is calculated in Appendix 3.5.1 and discussed in Sects. 2.6.1.1 and 3.3.2. As noted in these sections, the internal pressure is calculated and rounded up to 215.46 kPa (31.25 psia). Since the decay heat of the proposed contents is ~5 W, little or no impact on the pressure or temperature of the package components will result during NCT. As shown in DAC-M900000-0003, the design absolute pressure of the containment vessel is 801.17 kPa (116.2 psia), and the hydrostatic test pressure stipulated in JS-YMN3-801580-A001 is 1135.57 kPa (164.7 psia). Thus, increasing the internal pressure of the containment vessel to a maximum of 215.46 kPa (31.25 psia) during NCT would have no detrimental effect. Table 2.20 provides a summary of the pressures and temperatures in the various shipping configurations. As discussed in Sect. 2.6.1.4, the containment vessel and the closure nut stresses for this pressure condition are well below the allowable stress values.

**Table 2.20. Summary of temperatures and pressures for NCT**

| Average gas evaluation temperature °C (°F) | Containment vessel absolute internal pressure kPa (psia) |
|---|---|
| −40 (−40) [a] | 76.74 (11.13) |
| 25.0 (77) [b] | 101.35 (14.70) |
| 91.92 (197.46) [c] | 134.15 (19.457) [d] |
| 91.92 (197.46) [c] | 215.24 (31.218) [e] |
| 93.33 (200.00) [f] | 215.46 (31.25) [f] |

[a] Analysis conducted with no decay heat load in accordance with 10 CFR 71.71(c)(2).
[b] Assembly temperature and pressure.
[c] These values have been calculated in DAC-PKG-801940-A001 with 5-W decay heat and insolation.
[d] This value has been calculated in Appendix 3.5.1 for containment vessel arrangement Number 1.
[e] This value has been calculated in Appendix 3.5.1 for containment vessel arrangement Number 7.
[f] The values have been calculated in either DAC-PKG-801940-A001 or Appendix 3.5.1 and rounded up for conservatism.

Title 10 CFR 71.71(c) specifies that the package service temperature must extend from −40 to 38°C (−40 to 100°F) with insolation. As shown in Sect. 3.3.1 and calculated in DAC-PKG-801940-A001, the upper service temperature with insolation is calculated and rounded up to 93.33°C (200.00°F) for an empty ES-3100 containment vessel. Thermal cycling of the packages from 93.33°C (200.00°F) to −40°C (−40°F) is considered an unlikely event, and the change would occur over a long period of time.

In any event, the 133.33°C (240.00°F) thermal cycle would not result in brittle fracture or fatigue failure in the packaging. The acceptability of the packaging against brittle fracture is discussed in Sect. 2.6.2. The only concern for fatigue or endurance failure is related to the cyclic pressure changes in the containment vessel as the temperature varies from low to high. A 25°C (77°F) ambient temperature normally exists for the containment vessel during assembly. The containment vessel is sealed at an absolute pressure of ~101.35 kPa (14.70 psi). The internal absolute pressure at an average gas temperature of 93.33°C (200.0°F) is 215.46 kPa (31.25 psi) for the ES-3100 containment vessel (Table 2.20). The absolute internal pressure at −40°C or −40°F is 76.74 kPa (11.13 psi) for the containment vessel. Therefore, the maximum cyclic pressure differential for the containment vessel from low to high temperatures is (215.46 − 76.74) kPa or 138.72 kPa (20.12 psi). This cyclic pressure is insignificant when considering the integrity of the containment vessel as shown by the stress levels discussed in Sect. 2.6.1.3.

The ES-3100 package has been tested to determine the effectiveness of the package following a sequential NCT 1.2-m (4-ft) drop test and an HAC test battery. Testing conducted on TU-4 showed that there would be no loss or dispersal of radioactive contents, no significant increase in external surface radiation levels if the actual contents had been subjected to these tests, and no substantial reduction in the effectiveness of the packaging to survive the HAC testing. Thus, the requirements of 10 CFR 71.43(f) are satisfied.

Because some contents may be transported by air, the following criteria and guidance have been incorporated into various sections of this SARP.

1. International Atomic Energy Agency (IAEA) TS-R-1, Paragraph 619 states: “Packages containing radioactive material, to be transported by air, shall be capable of withstanding, without leakage, an internal pressure that produces a pressure differential of not less than the maximum normal operating pressure plus 95 kPa.”

2. In order to also comply with 49 CFR 173.410(i)(2), the range of temperature evaluated will be from −40 to 55°C (ambient temperature).

3. According to IAEA TS-G-1.1, Paragraph 619.3, the evaluation at an ambient temperature of 55°C does not consider the solar radiation input; however, self-heating of the package is taken into account.

A thermal analysis has been conducted that predicts various temperatures of the shipping package evaluated at an ambient temperature of 55°C (131°F) with no insolation but does include 5 W of internal decay heating. The results are shown in Table 3.14 for this condition. The maximum temperature predicted for the containment vessel is 63.39°C (146.11°F). This temperature will be used in subsequent analyses as the maximum average gas temperature inside the containment vessel during air transport. An analysis has been conducted in Appendix 3.5.1 to determine the maximum normal operating pressure (MNOP) for air transport. Table 9 in Appendix 3.5.1 shows the results of this analysis, where the MNOP is determined to be 198.42 kPa (28.778 psia) for air transport. This value of 198.42 kPa (28.778 psia) is bounded by the value determined for ground transportation shown in Table 2.20. Therefore, the MNOP of 215.46 kPa (31.25 psia) is used in further analyses. To comply with TS-R-1, Paragraph 619, an analysis is shown in Appendix 4.5.2 using an upstream pressure of 310.47 kPa (45.03 psia) and a downstream pressure of 0 kPa (0 psia). This provides the maximum pressure differential of 215.46 kPa + 95 kPa (31.250 + 13.78 psia). The analysis in Appendix 4.5.2 for air transport shows that the leaktight criteria obtained on test units is substantially below the calculated results for air transport. Therefore, the requirements of 10 CFR Part 71.51(a)(1) are satisfied. The containment vessel has also been evaluated at the maximum pressure differential shown in Table 9 of Appendix 3.5.1. The margin of safety for each component is significantly large enough to conclude that this maximum pressure differential determined for air transport does not degrade the structural integrity of the containment vessel (Table 2.21a).

### 2.6.1 Heat

**Requirement.** An ambient temperature of 38°C (100°F) in still air and insolation, as stated in 10 CFR 71.71(c)(1).

**Analysis.** An increase in ambient temperature to 38°C (100°F) with insolation will have no effect on the ability of the containment vessel to provide containment.

The maximum normal operating pressure is defined in 10 CFR 71.4 as the maximum gauge pressure that would develop in the containment system in a period of 1 year under the heat conditions specified in 10 CFR 71.71(c)(1). The internal pressure developed under these conditions in the ES-3100 containment vessel is calculated in Appendix 3.5.1 and discussed in Sects. 2.6.1.1 and 3.3.2. As noted in these sections, the internal pressure varies with temperature. Based on the isotopic determination of the proposed contents, a conservative maximum decay heat of 5 W is used for the maximum internal heat load in evaluating the package for NCT (Sect. 3.1.2). The maximum calculated and rounded internal absolute pressure in the containment vessel with insolation and using the bounding case parameters is 215.46 kPa (31.25 psia). The design absolute pressure of the containment vessel is 801.17 kPa (116.20 psia), and the hydrostatic test pressure is 113.55 kPa (164.7 psia). Thus, increasing the internal pressure of the containment vessel to a maximum of 215.46 kPa (31.25 psia) during NCT would have no detrimental effect. Table 2.20 provides a summary of the pressures and temperatures for the various shipping configurations. As discussed in Sect. 2.6.1.4, the containment vessel and closure nut stresses for

these pressure conditions are well below the allowable stress values. If the package is exposed to solar radiation at 38°C (100°F) in still air, the conservatively calculated temperatures at the top of the drum, on the top surface of the containment vessel, and on the containment vessel near the O-ring sealing surfaces are 118.86°C (245.94°F), 91.92°C (197.46°F), and 91.87°C (197.36°F), respectively (Sect. 3.3.1). Nevertheless, these temperatures are within the service limits of all packaging components, including the O-rings. The normal service temperature range of the O-rings used in the containment vessel is −40 to 150°C (−40 to 302°F) for the EPDM O-rings and −40 to 204°C (−40 to 400°F) for the fluorocarbon elastomer O-rings [Table 2.15]. Radioactive material packages require periodic maintenance per NRC Regulatory Guide 7.9, Sect. 8.2.2, *Leakage Tests*. In general, this specifies that elastomeric seals should be replaced and leak tested within the 12-month period before shipment. Testing done at SRNL for materials stored in the K-Area Material Storage has demonstrated that GLT (GLT-S) Viton O-rings, which are made from fluorocarbon elastomer, demonstrate no significant loss of seal capability for a period of up to 5 years when maintained at a temperature of 93°C (200°F) or less. O-rings are captured inside the containment vessel of the ES-3100 in a static face seal (axial) method as opposed to the conical (radial) mating surfaces of the 9975 containment vessel. Both designs (ES-3100 and 9975) use the same cross-sectional diameter and durometer O-rings. The half-dovetail O-ring groove design of the ES-3100 provides a nominal 18% compression when metal-to-metal contact of the body and lid is achieved at closure (*Parker O-Ring Handbook*, Design Chart 4-5). The basic design of the ES-3100 O-ring groove detail requires no stretching of the O-ring unlike the requirement of the conical sealing surfaces for the 9965, 9975, and 9977 containment vessels. Assuming the conical surfaces react like an industrial static seal, the nominal stretch required for this design will provide ~16 to 23% compression of the O-ring. As shown in SRNS-TR-2009-00259, Table 1, the percent compression of the 9975 O-ring may vary from 8 to 23.4% under various stretch, size, and gap conditions. Whereas, the ES-3100 design provides a range of 15 to 21% based on O-ring size and groove depth variations. Because the O-ring compressions are similar between designs and the O-ring compounds and sizes are comparable, the surveillance program data (See Sect. 2.2.2) should be applicable for Viton GLT-S O-ring use in the ES-3100 containment vessel.

#### 2.6.1.1 Summary of pressures and temperatures

An ambient temperature of 25°C (77°F) is assumed for the packaging at assembly. Since there are four ventilation holes near the top of the drum, and holes in the liner encapsulating the neutron poison material that are not hermetically sealed, the drum assembly will not become pressurized as the temperature increases. The containment vessel is sealed; thus, the internal pressure will change with temperature. Maximum calculated pressures at various temperatures (Sect. 3.3.1) are listed in Table 2.20.

#### 2.6.1.2 Differential thermal expansion

The drum, inner liners, and containment vessel are all constructed of Type 304 or 304L stainless steel. Radial and vertical expansion among these components will not cause any interferences or thermally induced stresses due to design clearances at assembly. Due to similarities of the coefficient of thermal expansion between Type 304/304L and the containment vessel closure nut material (ASME SA-479), the compression of the O-rings does not change appreciably during the temperature excursion from 25°C (77°F) to the maximum adjusted temperature of 93.33°C (200.00°F).

The Kaolite 1600 insulation and Cat 277-4 material is poured and cast in place during the fabrication of the drum weldment (Drawing M2E801580A002, Appendix 1.3.7). Although some contraction of these materials may occur during curing, it is assumed for analysis purposes that a zero gap will exist between the Kaolite and the bounding drum and mid liner, and a zero gap exists between the Cat 277-4 and the two liners. Due to differences in coefficients of thermal expansion, some radial and axial interferences are expected due to thermal growth of the inner liners. These radial and axial interferences and induced stresses are calculated in DAC-PKG-801940-A002. A maximum stress intensity of $6.604 \times 10^4$ kPa (9579 psi) was calculated for the inner liners. This stress value is well below the allowable yield strength of $1.324 \times 10^5$ kPa (19200 psi) at 148.9°C (300°F). A maximum stress intensity of $6.550 \times 10^2$ kPa (95.0 psi) and $9.329 \times 10^2$ kPa (135.3 psi) occurs in the Cat 277-4 and Kaolite 1600 materials, respectively. Based on tabulated data and curves presented in Y/DW-1987 and the curves presented in Y/DW-1890 at 38°C (100°F), these compressive stresses are well below the failure limit of ~$4.826 \times 10^3$ kPa (700 psi) and $5.171 \times 10^3$ kPa (750 psi) for the Cat 277-4 and Kaolite 1600 materials, respectively. Therefore, these thermally induced stresses will not reduce the effectiveness of the drum assembly.

The effects of differences in coefficient of thermal expansion between the HEU contents and their associated convenience cans, polyethylene or Teflon FEP bottles are not addressed. No credit is taken for the ability of the convenience can or bottle to maintain its structural integrity during transport. Section 4 of this document assumes the HEU content is in the form of an aerosol and all is available for release; therefore, no credit for the convenience can, polyethylene bagging, or bottle is taken. Based on assembly clearances and the flexibility of the polyethylene or Teflon FEP bottles, no radial or vertical interferences will develop during NCT. Based on assembly clearances and insignificant differences in the coefficient of thermal expansion between the stainless-steel, tin-plated carbon steel, aluminum, or nickel-alloy convenience cans and the stainless-steel containment vessel, no radial or vertical interferences will develop during NCT testing.

### 2.6.1.3 Stress calculations

During normal conditions, stresses are only imposed by changes in internal pressure of the containment vessel as the temperature varies slowly over the operating range (Table 2.20). Stress levels imposed on the package during NCT are insignificant, as shown in Tables 2.21, 2.21a, and 2.22. These tabulated stresses were determined by multiplying the stress at the design conditions (DAC-M900000-0003 and Table 2.6) by a factor equal to the ratio of operating pressures to design pressures and adding any contribution from the closure nut preload. This methodology is based on linear elastic material behavior. As shown in Sect. 2.6.1.4, all stresses in the containment vessel components are well below the ASME Code allowable stress intensity limits.

### 2.6.1.4 Comparison with allowable stresses

NCT containment vessel stresses are calculated in accordance with the load combinations listed in Table 2.3 and their values are shown in Tables 2.21, 2.21a, and 2.22. The hot environment, cold environment, reduced external pressure, increased external pressure condition, and vibration normally incident to transport are addressed in Sects. 2.6.1, 2.6.2, 2.6.3, 2.6.4, and 2.6.5, respectively. The fatigue or endurance limits for austenitic stainless steel are normally assumed to be about one-half the ultimate tensile strength (*Design Guidelines for the Selection and Use of Stainless Steel*, pp. 17–18). For Type 304 stainless steel, one-half the ultimate tensile strength is $2.4 \times 10^5$ kPa (35,000 psi). Tensile and compressive hoop stresses of the magnitude shown in Tables 2.21, 2.21a, and 2.22 are insignificant compared to the endurance limit of $2.4 \times 10^5$ kPa (35,000 psi). As shown in Tables 2.21, 2.21a, and 2.22, the containment vessel stresses during NCT are insignificant. Even at the maximum test temperature and internal pressure (Sect. 3.4.3), the stresses in the containment boundaries were insignificant when compared with the

allowable stress intensities shown in Tables 2.4 and 2.5. Corresponding calculated stress regions are shown in Fig. 2.1. Thermal expansion or contraction issues are addressed in Sects. 2.6.1.2 and 2.6.2.

### 2.6.2 Cold

**Requirement.** An ambient temperature of −40°C (−40°F) in still air and shade, as required by 10 CFR 71.71(c)(2).

**Analysis.** The drum is fabricated from Type 304 stainless-steel sheet (Table 2.7). As discussed in Sect. 2.6, stainless steel is excellent for low-temperature service, particularly regarding tensile and impact strength. The thermal insulation (Kaolite) is a lightweight noncombustible cast refractory made from portland cement and vermiculite. The only moisture available for freezing at −40°C (−40°F) would be moisture that had not been removed during the curing and cool-down phase of fabrication. Because there will be no free water present for freezing and the insulation is a bonded mass of random fibers and cement, the properties of the insulation will not change appreciably. The matrix may become less flexible when subjected to the cold temperature, but the inner liner will remain in the position in which it was placed at the time of fabrication. The Kaolite 1600 insulation and Cat 277-4 materials are poured and cast in place during the fabrication of the drum weldment (Drawing M2E801580A002, Appendix 1.3.7). Although some contraction of these material may occur during curing, it is assumed for analysis purposes that a zero gap will exist between the Kaolite and the bounding drum and mid liner and a zero gap exists between the Cat 277-4 and the two liners. Due to differences in the coefficient of thermal expansion, some radial and axial interference is expected due to contraction of the outer drum and inner liners. These radial and axial interferences and induced stresses are calculated in DAC-PKG-801940-A002. A maximum stress intensity of $3.855 \times 10^4$ kPa (5591.9 psi) was calculated for the inner liners. This stress value is well below the allowable yield strength of $1.724 \times 10^5$ kPa (25000 psi) at −40°C (−40°F). A maximum stress intensity of 164.8 kPa (23.9 psi) and 163.4 kPa (23.7 psi) occurs in the Cat 277-4 and Kaolite 1600 materials, respectively. Based on tabulated data and curves presented in Y/DW-1987 and the curves presented Y/DW-1972 at −40°C (−40°F), these compressive stresses are well below the failure limit of ~$6.895 \times 10^3$ kPa (1000 psi) and $5.308 \times 10^3$ kPa (770 psi) for the Cat 277-4 and Kaolite 1600 materials, respectively. Therefore, these thermally induced stresses will not reduce the effectiveness of the drum assembly.

The containment vessel is fabricated from Type 304L stainless steel, which is suitable for low-temperature service, particularly regarding impact resistance. This material does not show a transition from ductile to brittle failure at this temperature [−40°C (−40°F)]. The ASME Code, Sect. III, Subsection NB-2311, exempts impact testing of Type 304L stainless steels. The Izod impact strength for Type 304 stainless steel is 149.14 N·m (110 ft-lb) from 21.11 to −195.5°C (70 to −320°F). The tensile strength increases from ~$4.826 \times 10^5$ to $1.696 \times 10^6$ kPa (70,000 to 246,000 psi) between 21.11 and −195.5°C (70 and −320°F), and the yield strength increases ~10% over the same range. NRC Regulatory Guide 7.6, Part B, states, “these designs were made of austenitic stainless steel which is ductile even at low temperatures. Thus, this guide does not consider brittle fracture.” The drum, inner liner, top plug, and containment vessel are made from austenitic stainless steel. Similarly, the containment vessel closure nut material is a galling and wear resistant austenitic stainless steel. Therefore, brittle fracture of these structural materials at −40°C (−40°F) is not possible.

The specified O-rings used in the containment vessel have a continuous service temperature range of −40 to 150°C (−40 to 302°F) for the EPDM O-rings and −40 to 204°C (−40 to 400°F) for the fluorocarbon elastomer O-rings (Table 2.15). The low temperature extreme has been verified by compliance testing of TU-2 and TU-8 (Sect. 2.7.1.2). TU-2 and TU-8 were pre-chilled to a nominal temperature of −40°C (−40°F). This was accomplished by placing the units in an environmental chamber in Building 5800 at ORNL and initially setting the chamber control to −56.7°C (−70°F) for 24 h. After this initial period, the control on the environmental chamber was set to −42.8°C (−45°F) for at least 48 h. Prior to the initiation of structural testing of these units, they were removed from the environmental chamber and placed in an insulated box and transported to NTRC for testing.

As previously noted, the containment vessels will be assembled for shipment in a temperature environment of ~25°C (77°F). If the package should be exposed to −40°C (−40°F) for an extended period, all components will equalize near this low temperature. The absolute internal pressure inside the containment vessel would decrease to a pressure of 76.74 kPa (11.13 psi), assuming no decay heating (Table 2.20). Therefore, the pressure differential across the containment vessel at −40°C (−40°F) is −24.61 kPa (−3.57 psia) {[76.739 − 101.35 kPa] (11.13 − 14.7 psia)}. Due to similarities between the coefficient of thermal expansion for Type 304 or 304L stainless steel and the containment vessel closure nut material (ARMCO NITRONIC, ASME SA-479), the compression of the O-rings does not change appreciably during the temperature excursion from 25°C (77°F) to −40°C (−40°F). The calculated stresses shown in Tables 2.21 and 2.21a were determined by multiplying the stress at the design conditions (DAC-M900000-0003 and Table 2.6) by a factor equal to the ratio of operating pressure to design pressure and adding any contribution from the closure nut preload. This methodology is based on linear elastic material behavior. As shown in Sect. 2.6.1.4, all stresses in the containment vessel components are well below the ASME Code allowable stress intensity limits. As demonstrated by the information presented above, the packaging is acceptable for NCT at −40°C (−40°F).

### 2.6.3 Reduced External Pressure

**Requirement.** An absolute external pressure of 25 kPa (3.5 psi) is required by 10 CFR 71.71(c)(3).

**Analysis.** Reducing the absolute external pressure from ambient pressure to 25 kPa (3.5 psi) will have no effect on the drum assembly because the plastic plugs and aluminum tape covering the ventilation holes for the Cat 277-4 will allow the internal pressure of the drum assembly to equalize. This reduced pressure and a maximum internal pressure produces the maximum pressure differential across the containment vessel of 190.46 kPa (27.63 psi) [215.46 − 25]. The containment vessel is designed and fabricated in accordance with Sects. III and IX of the ASME Code for an internal pressure differential of 699.82 kPa (101.5 psi) as shown in DAC-M900000-0003. A summary of the resulting stress intensities at various locations identified in Fig. 2.1 on the containment vessel in comparison with the ASME Code allowable limits for this condition is shown in Table 2.22. These tabulated stresses were determined by multiplying the stress at the design conditions (DAC-M900000-0003 and Table 2.6) by a factor equal to the ratio of operating pressures to design pressures and adding any contribution from the closure nut preload. This methodology is based on linear elastic material behavior. As shown in Table 2.22, all stresses in the containment vessel components are well below the ASME Code allowable stress intensity limits. Therefore, the ES-3100 packaging is acceptable for NCT at an absolute external pressure of 25 kPa (3.5 psi).

**Table 2.21. ES-3100 containment vessel evaluation for both hot and cold conditions [a]**

| Stress locations shown in Fig. 2.1 | Hot conditions [10 CFR 71.71(c)(1)] containment vessel stress @ 114.10 kPa (16.55 psi) gauge | | Cold conditions [10 CFR 71(c)(2)] containment vessel stress @ −24.61 kPa (−3.57 psi) gauge | | Allowable pressure, stress, or shear capacity |
|---|---|---|---|---|---|
| | kPa (psi) or kg (lb) | M.S. [b] | kPa (psi) or kg (lb) | M.S. [b] | kPa (psi) or kg (lb) |
| Top flat portion of sealing lid (center of lid) | $1.862 \times 10^3$ (270) | 107 | $4.015 \times 10^2$ (58) | 498 | $1.999 \times 10^5$ (29,000) [c] |
| Closure nut ring (away from threaded portion) | $5.576 \times 10^3$ (809) | 26 | $1.902 \times 10^4$ (2759) [d] | 7.6 | $1.441 \times 10^5$ (20,900) |
| Top flat head (sealing surface region) | $4.724 \times 10^3$ (685) | 42 | $7.088 \times 10^3$ (1028) [d] | 28 | $1.999 \times 10^5$ (29,000) [c] |
| Cylindrical section (middle) internal pressure | $3.176 \times 10^3$ (461) | 35 | | | $1.120 \times 10^5$ (16,250) [e] |
| Cylindrical section (middle) external pressure | | | $2.461 \times 10^1$ (3.57) | 31 | $7.584 \times 10^2$ (110) [f] |
| Cylindrical section (shell to flange interface) | $4.398 \times 10^3$ (638) | 38 | $9.483 \times 10^2$ (138) | 177 | $1.682 \times 10^5$ (24,400) [c] |
| Cylindrical section (shell to bottom interface) | $9.548 \times 10^3$ (1385) | 18 | $2.060 \times 10^3$ (299) | 82 | $1.682 \times 10^5$ (24,400) [c] |
| Body flange threads load, kg (lb) | $9.072 \times 10^2$ (2000) [d] | 29 | $9.072 \times 10^2$ (2000) [d] | 29 | $2.608 \times 10^4$ (57,500) [g] |
| Body flange thread region (under cut region) | $2.839 \times 10^4$ (4117) [d] | 5.9 | $2.839 \times 10^4$ (4117) [d] | 5.9 | $1.682 \times 10^5$ (24,400) [c] |
| Flat bottom head (center) | $7.982 \times 10^3$ (1158) | 21 | $1.722 \times 10^3$ (250) | 98 | $1.682 \times 10^5$ (24,400) [c] |
| Closure nut thread load, kg (lb) | $9.072 \times 10^2$ (2000) [d] | 37 | $9.072 \times 10^2$ (2000) [d] | 37 | $3.353 \times 10^4$ (73,911) [g] |

[a] Stresses are calculated using pressures, gasket and closure nut preload, and nominal dimensions for all containment vessel components (DAC-M900000-0003). Calculated stresses for external pressure were determined by multiplying the stress at the design conditions by a factor equal to the ratio of external pressure to design pressure plus the contribution from preload. Allowable stress values are taken from Table 2.5 up to 176.7°C (350°F).

[b] Margin of safety = allowable stress/actual stress.

[c] Stress interpreted as the sum of $P_l + P_b$; allowable stress intensity value is $1.5 \times S_m$.

[d] Stress and shear load in these areas is dominated by the 162.7 ± 6.8 N·m (120 ± 5 ft-lb) preload. External pressure component is ignored.

[e] Stress interpreted as the primary membrane stress ($P_m$); allowable stress intensity value is $S_m$.

[f] Allowable external pressure [kPa (psi)].

[g] Allowable shear capacity is defined as $0.6 \times S_m \times$ thread shear area for the body material. Thread shear area = 38.026 $cm^2$ (5.894 $in.^2$). Allowable shear capacity is defined as $1.2 \times S_m \times$ thread shear area for the closure nut material.

**Table 2.21a. ES-3100 containment vessel evaluation for internal pressure developed during air transport in accordance with TS-R-1 Paragraph 618 [a]**

| Stress locations shown in Fig. 2.1 | Containment vessel stress @ 293.43 kPa (42.558 psi) gauge | | Allowable pressure, stress, or shear capacity |
|---|---|---|---|
| | kPa (psi) or kg (lb) | M.S. [b] | kPa (psi) or kg (lb) |
| Top flat portion of sealing lid (center of lid) | $4.787 \times 10^3$ (694.35) | 23.9 | $1.999 \times 10^5$ (29,000) [c] |
| Closure nut ring (away from threaded portion) | $1.434 \times 10^4$ (2079.68) | 10.0 | $1.441 \times 10^5$ (20,900) |
| Top flat head (sealing surface region) | $1.215 \times 10^4$ (1761.86) | 16.5 | $1.999 \times 10^5$ (29,000) [c] |
| Cylindrical section (middle) internal pressure | $8.167 \times 10^3$ (1184.50) | 13.7 | $1.120 \times 10^5$ (16,250) [e] |
| Cylindrical section (shell to flange interface) | $1.131 \times 10^4$ (1640.27) | 14.9 | $1.682 \times 10^5$ (24,400) [c] |
| Cylindrical section (shell to bottom interface) | $2.455 \times 10^4$ (3561.04) | 6.9 | $1.682 \times 10^5$ (24,400) [c] |
| Body flange threads load, kg (lb) | $1.566 \times 10^4$ (2270.81) [d] | 25.3 | $2.608 \times 10^4$ (57,500) [f] |
| Body flange thread region (under cut region) | $3.383 \times 10^4$ (4906.11) [d] | 5.0 | $1.682 \times 10^5$ (24,400) [c] |
| Flat bottom head (center) | $2.053 \times 10^4$ (2976.96) | 8.2 | $1.682 \times 10^5$ (24,400) [c] |
| Closure nut thread load, kg (lb) | $1.566 \times 10^4$ (2270.81) [d] | 32.5 | $3.353 \times 10^4$ (73,911) [f] |

[a] Calculated stresses were determined by multiplying the stress at the design conditions (Table 2.6) by a factor equal to the ratio of operating pressures to design pressures (independent of pressure direction) plus contributions from preload. Allowable stress values are taken from Table 2.5 up to 176.7°C (350°F).

[b] Margin of safety = allowable stress/actual stress.

[c] Stress interpreted as the sum of $P_l + P_b$; allowable stress intensity value is $1.5 \times S_m$.

[d] Stress and shear load in these areas are dominated by the 162.7 ± 6.8 N·m (120 ± 5 ft-lb) preload.

[e] Stress interpreted as the primary membrane stress ($P_m$); allowable stress intensity value is $S_m$.

[f] Allowable shear capacity is defined as $0.6 \times S_m \times$ thread shear area for the body material. Thread shear area = 38.026 $cm^2$ (5.894 $in.^2$). Allowable shear capacity is defined as $1.2 \times S_m \times$ thread shear area for the closure nut material.

**Table 2.22. NCT ES-3100 containment vessel stress compared to the allowable stress at reduced and increased external pressures [a]**

| Stress locations shown in Fig. 2.1 | Reduced external pressure [10 CFR 71.71(c)(3)] containment boundary stress @ 190.46 kPa (27.63 psi) gauge | | Increased external pressure [10 CFR 71.71(c)(4)] containment boundary stress @ −63.26 kPa (−9.18 psi) gauge | | Allowable pressure, stress, or shear capacity |
|---|---|---|---|---|---|
| | kPa (psi) or kg (lb) | M.S. [b] | kPa (psi) or kg (lb) | M.S. [b] | kPa (psi) or kg (lb) |
| Top flat portion of sealing lid (center of lid) | $3.108 \times 10^3$ (451) | 64 | $1.033 \times 10^3$ (150) | 194 | $1.999 \times 10^5$ (29,000) [c] |
| Closure nut ring (away from threaded region) | $9.309 \times 10^3$ (1350) | 15 | $1.902 \times 10^4$ (2759) [d] | 7.6 | $1.441 \times 10^5$ (20,900) |
| Top flat head (sealing surface region) | $7.887 \times 10^3$ (1144) | 25 | $7.088 \times 10^3$ (1028) [d] | 28 | $1.999 \times 10^5$ (29,000) [c] |
| Cylindrical section (middle) internal pressure | $5.302 \times 10^3$ (769) | 21 | | | $1.120 \times 10^5$ (16,250) [e] |
| Cylindrical section (middle) external pressure | | | $6.329 \times 10^1$ (9.18) | 12 | $7.584 \times 10^2$ (110) [f] |
| Cylindrical section (shell-to-flange interface) | $7.342 \times 10^3$ (1065) | 23 | $2.438 \times 10^3$ (354) | 69 | $1.682 \times 10^5$ (24,400) [c] |
| Cylindrical section (shell-to-bottom interface) | $1.594 \times 10^4$ (2312) | 11 | $5.297 \times 10^3$ (768) | 32 | $1.682 \times 10^5$ (24,400) [c] |
| Body flange threads load, kg (lb) | $9.072 \times 10^2$ (2000) [d] | 29 | $9.072 \times 10^2$ (2000) [d] | 29 | $2.608 \times 10^4$ (57,500) [g] |
| Body flange thread region (under cut region) | $2.839 \times 10^4$ (4117) [d] | 5.9 | $2.839 \times 10^4$ (4117) [d] | 5.9 | $1.682 \times 10^5$ (24,400) [c] |
| Flat bottom head (center) | $1.333 \times 10^4$ (1933) | 13 | $4.428 \times 10^3$ (642) | 38 | $1.682 \times 10^5$ (24,400) [c] |
| Closure nut thread load, kg (lb) | $9.072 \times 10^2$ (2000) [d] | 37 | $9.072 \times 10^2$ (2000) [d] | 37 | $3.353 \times 10^4$ (73,911) [g] |

[a] Stresses are calculated using pressures, gasket and closure nut preload, and nominal dimensions for all containment vessel components (DAC-M900000-0003). Calculated stresses for external pressure were determined by multiplying the stress at the design conditions by a factor equal to the ratio of external pressure to design pressure plus the contribution from preload. Allowable stress values are taken from Table 2.5 up to 176.7°C (350°F).

[b] Margin of safety = allowable stress/actual stress.

[c] Stress interpreted as the sum of $P_l + P_b$; allowable stress intensity value is $1.5 \times S_m$.

[d] Stress and shear load in these areas is dominated by the 162.7 ± 6.8 N·m (120 ± 5 ft-lb) preload. External pressure component is ignored.

[e] Stress interpreted as the primary membrane stress ($P_m$); allowable stress intensity value is $S_m$.

[f] Allowable external pressure [kPa (psi)].

[g] Allowable shear capacity is defined as $0.6 \times S_m \times$ thread shear area for the body material. Thread shear area = 38.026 $cm^2$ (5.894 $in.^2$). Allowable shear capacity is defined as $1.2 \times S_m \times$ thread shear area for the closure nut material.

### 2.6.4 Increased External Pressure

**Requirement.** An absolute external pressure of 140 kPa (20 psi) is required by 10 CFR 71.71(c)(4).

**Analysis.** Increasing the absolute external pressure from ambient pressure to 140 kPa (20 psi) would have no effect on the drum assembly because the plastic plugs and aluminum tape covering the ventilation holes for the Cat 277-4 will allow the internal pressure of the drum assembly to equalize. At this increased external pressure, the maximum pressure differential across the containment vessel would be −63.26 kPa (76.74 − 140 kPa) [−9.18 psi], assuming the vessel's absolute pressure and temperature to be 76.74 kPa (11.13 psi) and −40°C (−40°F), respectively. Each containment vessel is designed and fabricated in accordance with Sects. III and IX of the ASME Code for a minimum external pressure of 150 kPa (21.7 psi) gauge. A comparison of the resulting stress intensities at various locations on the containment vessel (Fig. 2.1) with the ASME Code allowable limits for this condition is shown in Table 2.22. These tabulated stresses were determined by multiplying the stress at the design conditions (DAC-M900000-0003 and Table 2.6) by a factor equal to the ratio of operating pressures to design pressures and adding any contribution from the closure nut preload. This methodology is based on linear elastic material behavior. As shown in Table 2.22, all stresses in the containment vessel components are well below the ASME Code allowable stress intensity limits. Therefore, the ES-3100 packaging is acceptable for NCT at an external absolute pressure of 140 kPa (20 psi).

### 2.6.5 Vibration

**Requirement.** Vibration normally incident to transportation is required by 10 CFR 71.71(c)(5).

**Analysis.** Vibration testing on a prototypical ES-3100 package (TU-4) was conducted in accordance with the ES-3100 test plan and documented in the test report (ORNL/NTRC-013). Testing was conducted with the package restrained as shown in Fig. 2.3. The containment vessel was assembled with the mock-up content weighing 49.90 kg (110 lb). The total weight of the test unit was 201.8 kg (445 lb). The unit was subjected to an endurance test with random vibrations modeled after the power spectral density plot for the SGT vibration envelope in the vertical axis (Cap 2002). At this level of vibration intensity, the test compares with MIL-STD-810F. MIL-STD-810F is a standard random vibration test for basic transportation vibrations generated by a large truck or tractor-trailer combination. MIL-STD-810F defines 60 min of testing as equal to 1609 km (1000 miles) of common carrier transportation. Assuming that the two random vibration tests are similar in intensity, TU-4 had ~6436 km (4000 miles) of simulated random vibration testing. Based on a nominal shipping distance of 3218 km (2000 miles), TU-4 was subjected to a test that was approximately two times more severe than that required by 10 CFR 71.71(c)(5). As shown by the following paragraphs, containment, shielding effectiveness, and subcriticality were maintained even when the package was subjected to such an arduous environment.

The test was run at ~22.8°C (73°F) rather than at the high or low temperatures specified for NCT. This was reasonable because the thermal coefficients of expansion of the flange and closure nut materials are very close. Therefore, the temperature extremes would not have a significant effect on the closure tightness.




**Note:** MD-1 test unit removed during actual testing.

**Fig. 2.3. ES-3100 vibration testing arrangement.**

Summarizing 10 CFR 71.43(f), the tests and conditions of NCT shall not substantially reduce the effectiveness of the packaging to withstand HAC sequential testing. The effectiveness of the ES-3100 to withstand HAC sequential testing is not diminished through application of the tests and conditions stipulated in 10 CFR 71.71. The justification for this statement is provided by physical testing of both the ES-2M (GAB1296-2) and ES-3100 (ORNL/NTRC-013) test packages. Due to the similarities in design, fabrication, and construction materials of the ES-2M and the ES-3100 packages, the physical characteristics of the Kaolite 1600 will hold true for both designs. The integrity of the Kaolite 1600 is not significantly affected by the NCT vibration and 1.2-m drop tests. Prior to testing the ES-2M design, each test unit was radiographed to determine the integrity of the Kaolite 1600 impact and insulation material. Following casting of the material inside the drum, some three-dimensional curving cracks were seen in some packages near the thinner top sections from the bottom of the liner to the bottom drum edge. After vibration testing, radiography of the ES-2M TU-4 showed that the lower half of the impact limiter was broken into small pieces. In order to evaluate these findings, TU-4 was reassembled and subjected to HAC sequential testing. After vibration and impact testing, many three-dimensional curving cracks were seen around the impact areas, and the inner liner was visibly deformed. Nevertheless, TU-4 maintained the adequate spacing required for shielding effectiveness and subcriticality. Temperatures at the containment boundary were also similar to other packages not subjected to vibration testing prior to HAC

testing. No inleakage of water was recorded following immersion. Additionally, TU-4 of the ES-3100 test series was subjected to tests and conditions stipulated in 10 CFR 71.71(c)(5) through (c)(10), excluding (c)(8). Following completion of both the NCT and HAC tests, the containment vessel was removed, and a full-body helium leak test was conducted to the leaktight criterion ($\leq 2 \times 10^{-7}$ $cm^3/s$) in accordance with ANSI N14.5-1997.

Following compliance testing of the ES-3100 shipping package, minor changes were incorporated into the proposed design as described in Sect. 2.7.1.5. During the vibration test, the shipping package is restrained from movement in the vertical direction with a tie-down arrangement similar to that used on an SGT for a single package. Based on the acceleration spectral density presented in the letter from J. S. Cap to G. W. Crowder (Cap 2002), the largest contributor to shipping package motion is in the vertical direction. Since the containment vessel and contents are not restrained within the inner liner cavity, the containment vessel is free to bounce up and down. In the vertical direction, the top plug and the bottom of the inner liner restrict the movement of this vessel. Because the inner liner contour has not changed with respect to the containment vessel, and there are clearances between the containment vessel flange and the inner liner in the vertical direction, the cast neutron poison and inner liner are not directly impacted by the movement of the containment vessel. Therefore, changes in the neutron poison and minor radial dimension changes in the mid liner will not affect the outcome of vibration testing. Based on the success of the previously tested units and the fact that these proposed changes will have little or no effect on testing, vibration normally incident to transport does not reduce the effectiveness of the packaging during HAC testing. Thus, the requirements of 10 CFR 71.43(f) are satisfied.

Procedures will be followed to ensure that the packaging is assembled as specified (Sect. 7). The drum, lid, and fasteners are refurbished as required before each use. The ⅝-in.–diam flange nuts on the drum are torqued to 40.67 N·m (30 ft-lb) nominal. The closure nut on the containment vessel is torqued to 162.7 N·m (120 ft-lb) nominal. The package is acceptable for vibration normally incident to transport in an SGT.

### 2.6.6 Water Spray

**Requirement.** A water spray that simulates exposure to rainfall of ~5.08 cm (2 in.) per hour for at least 1 h is required by 10 CFR 71.71(c)(6).

**Analysis.** A water spray of 5.08 cm (2 in.) per hour was directed from above and around the periphery of the ES-3100 TU-4 for a minimum of 1 h as shown in Fig. 2.4. The drum had four plastic plug-sealed ventilation holes near the top that prevent water from entering the insulation cavity. Aluminum duct tape covering the installation holes in the mid liner prevents water from entering the neutron poison cavity. There was evidence of water leakage into the volume between the containment vessel and the inner liner at the conclusion of the test. Water entered this cavity through the holes provided in the lid for the TID lugs, but none penetrated the containment boundary. The criticality analysis shown in Sect. 6 was conducted with moderation by water to the most reactive credible extent and close full reflection of the containment system by water on all sides. Because the package remained subcritical under these conditions, the ES-3100 package is acceptable for use under the water spray conditions of NCT.




**Fig. 2.4. Water spray test arrangement for TU-4.**

### 2.6.7 Free Drop

**Requirement.** A free drop of 1 m (4 ft) onto a flat, essentially unyielding, horizontal surface in a position for which maximum damage is expected is required by 10 CFR 71.71(c)(10). This test shall be made between 1½ and 2½ h after the conclusion of the water spray test (Sect. 2.6.6).

**Analysis.** The ES-3100 test package, TU-4, previously sprayed with water (Sect. 2.6.6) with a measured gross weight of 201.85 kg (445 lb) and containing a content weight of 49.90 kg (110 lb), was tested in accordance with 10 CFR 71.71(c)(7). The temperature and pressure at the time of the drop test was 22.8°C (73°F) and ~101.35 kPa (14.70 psi), respectively. As discussed in Sect. 2.6, the response of the test package would not have been significantly different if it had been tested at the extremes of the temperature range dictated by 10 CFR 71.71(b) with the containment vessel at the maximum normal operating pressure.

The essentially unyielding surface used for this test was the indoor drop test pad at the NTRC. All 9-m (30-ft) drop and crush tests were conducted at the outside drop pad at the NTRC. The indoor pad consists of a 5.08-cm (2-in.)–thick steel plate embedded inside a reinforced concrete pad ~127-cm (50-in.) thick. The outside drop pad consists of a 10.16-cm (4-in.)–thick steel plate embedded inside a reinforced concrete pad ~167.6-cm (66-in.) thick. An article has been prepared by the NTRC staff to describe the integrity of these test pads (Shappert 1991).

TU-4 was dropped from 1.2 m (4 ft) in a vertical position, with the drum's top initially striking the unyielding surface (Fig. 2.5). This attitude was assumed to be the most vulnerable orientation for producing damage to the sealing surfaces of the containment vessel and for introducing buckling into the cylindrical portion of the containment vessel body. The long axis of the drum was 0° from vertical. The test package made a free fall, with initial contact on the drum's lid. Damage consisted of shortening the drum height from 110.81 cm (43⅝ in.) to 110.49 cm (43½ in.) There were no breaks in the drum assembly. Additional details and sketches can be obtained from the test report (ORNL/NTRC-013). Based on the HAC analytical structural deformation results shown in Sect. 2.7.8, the drop test damage would be nearly identical had this test been conducted on the proposed configuration using the Cat 277-4 neutron absorber. On this basis, the ES-3100 package meets the requirements of 10 CFR 71.71(c)(7).

In addition to the tests conducted on TU-4, all test units (except TU-6) were initially subjected to a free drop of 1.2 m (4 ft) onto a flat, essentially unyielding horizontal surface. As shown in Table 2.18, the orientations for these drops were two drops bottom to lid slapdown with the long axis of the drum ~12° from parallel to the drop pad; one drop with the long axis of the test unit parallel to the drop pad; two drops with the center of gravity drop over the drum/lid interface with the long axis of the drop rotated ~24.6° from perpendicular to the drop pad; and one with the long axis of the drum perpendicular to the drop pad. Package description, damage from testing, and drop orientation concerns are discussed in Sect. 2.7.1 for each test unit. Following the 1.2-m (4-ft) drop, each of these test units was subjected to the full HAC sequential test battery. The robustness of the ES-3100 containment vessel was demonstrated through whole boundary helium leak testing to $\leq 2.0 \times 10^{-7}$ $cm^3/s$ (leaktight). This helium leak test eclipses the required criteria for both NCT and HAC based on the bounding case contents. Visual inspection of the containment boundaries showed no distortion or deformation from testing. Therefore, based on the various drop orientations, the severity of the HAC test sequence, and the testing conducted on TU-4, the ES-3100 shipping package has been shown to meet the requirements of 10 CFR 71.43, 71.51(a)(1), and 71.71(c)(7).

### 2.6.8 Corner Drop

**Requirement.** 10 CFR 71.71(c)(8) requires a free drop onto each corner of the package in succession, or in the case of a cylindrical package, onto each quarter of each rim, from a height of 0.3 m (1 ft) onto a flat, essentially unyielding, horizontal surface. This test applies only to fiberboard, wood, or fissile material rectangular packages not exceeding 50 kg (110 lb) and fiberboard, wood, or fissile material cylindrical packages not exceeding 100 kg (220 lb).

**Analysis.** This test is not applicable because the range of package weights for the ES-3100 [146.88 kg (323.79 lb) to 187.81 kg (414.05 lb)] exceeds the weight restrictions defined in the preceding paragraph for fissile material cylindrical packages.

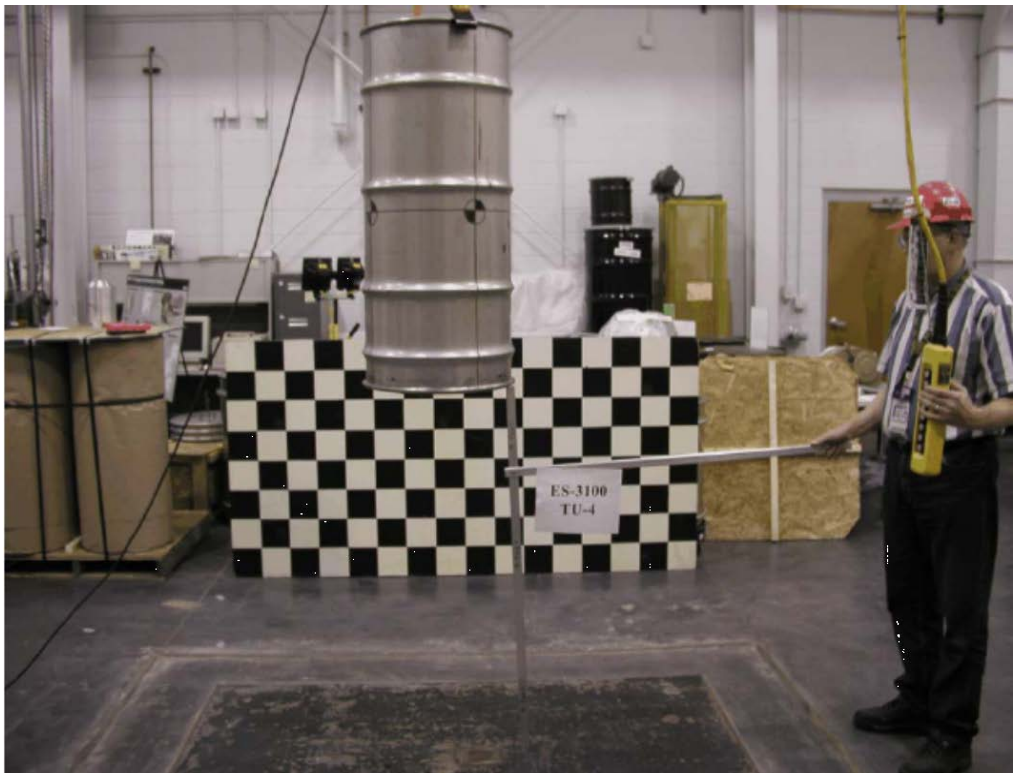



**Fig. 2.5. NCT free drop test on TU-4.**

### 2.6.9 Compression

**Requirement.** Title 10 CFR 71.71(c)(9) requires that packages weighing up to 5000 kg (11,000 lb) must be subjected for a period of 24 h to a compressive load applied uniformly to the top and bottom of the package in the position in which the package would normally be transported. The compressive load must be the greater of the following:

1. the equivalent of five times the weight of the package or

2. the equivalent of 13 kPa (2.0 psi) multiplied by the vertically projected area of the package.

**Analysis.** The proposed maximum weight of the ES-3100 shipping package is calculated to be 187.81 kg (414.05 lb) [Table 2.8]. As shown on Drawing M2E801580A010 (Appendix 1.3.7), the data plate states that the maximum gross weight of the ES-3100 shipping package is 190.51 kg (420 lb). In accordance with Item 1 above, the minimum compressive load would be 5 × 190.51 kg or 952.55 kg (2100 lb). The vertically projected area of the package is 1891 $cm^2$ (293.16 $in.^2$) or the area of the lid weldment. Based on Item 2 above, the minimum compressive load would be 13 kPa × 1891 $cm^2$ or 250.72 kg (552.75 lb). Therefore, the approach stipulated in Item 1 above represents the greatest compressive load for this configuration. A conservative 1043 kg (2300 lb) compressive load was uniformly applied to the top and bottom of TU-4 for at least 24 h (Fig. 2.6). The test package had been sprayed with water as noted in Sect. 2.6.6. No change in height or diameter of the test unit resulted from the test.

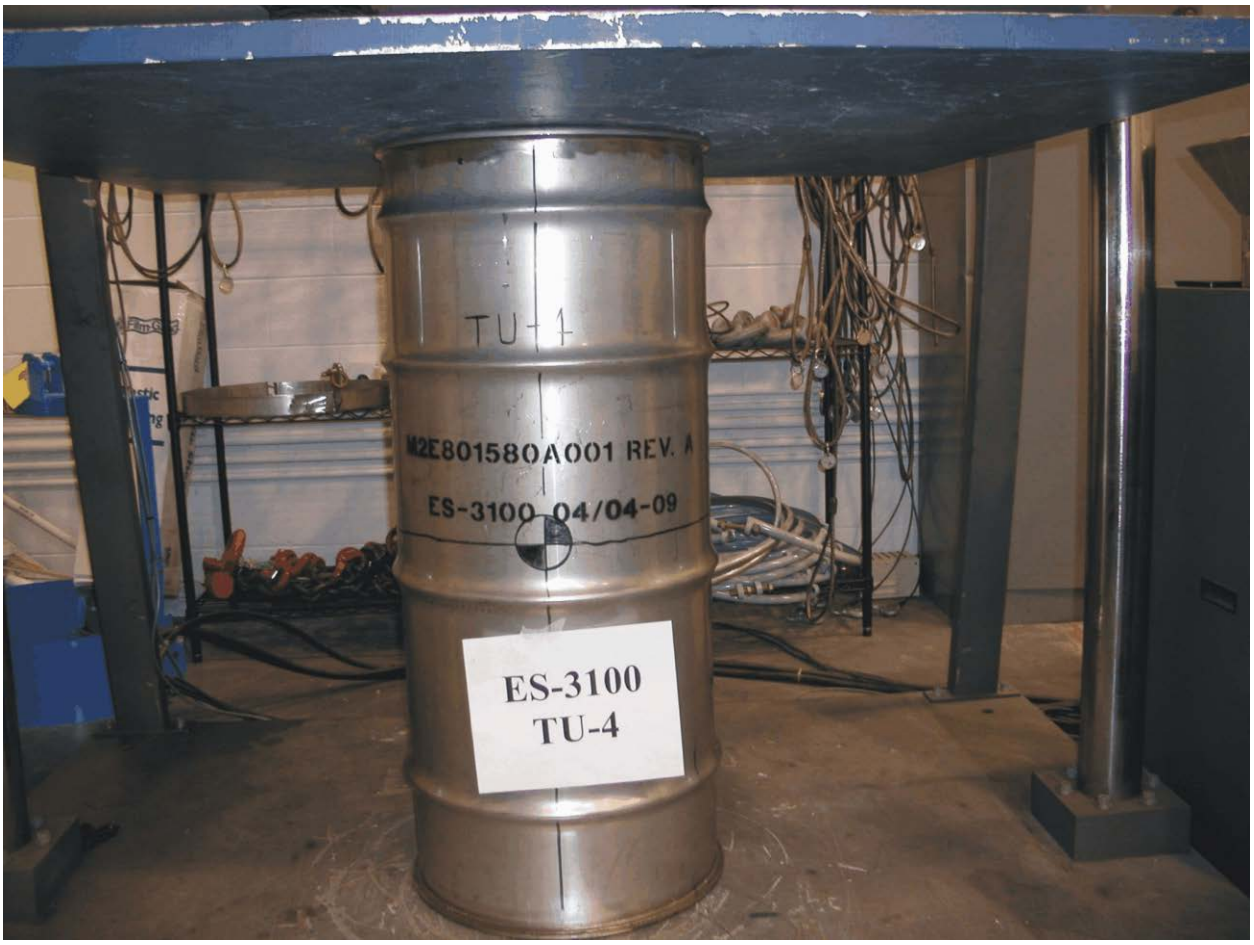



**Fig. 2.6. Compression test on TU-4.**

Due to the design of the ES-3100 drum lid, the applied compressive load was distributed equally around the lid and supported primarily through the outer drum contour and Kaolite 1600 substrate. Little or no load is transferred to the neutron poison (BoroBond4 in TU-4) and internal liners. Therefore, the changes in the design of the liners and neutron poison proposed for this shipping package should not impact the outcome resulting from compression testing. Based on the results of compliance testing of TU-4 and the insignificant changes in the design, the ES-3100 package meets the requirements of 10 CFR 71.71(c)(9).

### 2.6.10 Penetration

**Requirement.** Impact of the hemispherical end of a vertical steel cylinder of 3.2-cm (1.25-in.) diam and 6-kg (13-lb) mass dropped from a height of 1 m (40 in.) onto the exposed package surface that is expected to be most vulnerable to puncture is required by 10 CFR 71.71(c)(10). The long axis of the cylinder must be perpendicular to the package surface.

**Analysis.** A 6-kg (13-lb) steel cylinder was dropped from 1 m (40 in.) onto the surface of TU-4, which was previously subjected to water spray, free drop, vibration and compression tests. The penetration bar impacted the side of the drum at the welded seam near the package's center of gravity. The bar did not penetrate the drum, but an indentation 0.64-cm (0.25-in.) deep was recorded at the drum seam weld as shown in Fig. 2.7. The magnitude of this indentation is insignificant. Based on the HAC analytical structural deformation results shown in Sect. 2.7.8, the magnitude of indentation would be nearly identical had this test been conducted on the proposed configuration using the Cat 277-4 neutron absorber. On this basis, the ES-3100 package meets the requirements of 10 CFR 71(c)(10).




**Fig. 2.7. Penetration test damage on TU-4.**

## 2.7 HYPOTHETICAL ACCIDENT CONDITIONS

This section demonstrates compliance with 10 CFR 71.73, "Hypothetical Accident Conditions." It shows that the package will experience no loss in shielding effectiveness or spacing and no release of radioactive content or leakage of water into the containment vessel during HAC. A summary of the tests and analyses conducted on the ES-3100 configuration is shown in Table 2.23.

**Table 2.23. Test and analysis summary for the ES-3100 package [a]**

| Container | NCT water spray, compression, penetration, vibration | 1.2-m (4-ft) drop | 9-m (30-ft) drop and crush test | | | | 1.2-m (4-ft) puncture drop | Preheat >38°C (100°F) | HAC thermal burn test | O-ring cavity leak check (operational) | Full-body helium leak test [b] | 0.9-m (3-ft) immer. test | 15-m (50-ft) immer. test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Top drop | CG over lid corner | Bottom to lid slapdown | Side drop | | | | | | | |
| TU-1 | | 1—YES | | | 12°<br>2—YES | | 3—YES [c] | 4—YES | 5—YES | 6−YES<br>$\leq 1.0 \times 10^{-4}$ ref. $cm^3/s$ | 7—YES<br>$1.6 \times 10^{-7}$ $cm^3/s$ | 8—YES | |
| TU-2 | | 1—YES | | | | 2—YES | 3—YES | 4—YES | 5—YES | 6−YES<br>$\leq 1.0 \times 10^{-4}$ ref. $cm^3/s$ | 7—YES<br>Pulsing between $1.0 \times 10^{-9}$ to $1.4 \times 10^{-6}$ $cm^3/s$ | 8—YES | |
| TU-3 | | 1—YES | | 24.6°<br>2—YES | | | 3—YES | 4—YES | 5—YES | 6−YES<br>$\leq 1.0 \times 10^{-4}$ ref. $cm^3/s$ | 7—YES<br>$1.0 \times 10^{-7}$ $cm^3/s$ | 8—YES | |
| TU-4 | YES | 1—YES | 2—YES | | | | 3—YES | 4—YES | 5—YES | 6−YES<br>$\leq 1.0 \times 10^{-4}$ ref. $cm^3/s$ | 7—YES<br>$2.0 \times 10^{-7}$ $cm^3/s$ | 8—YES | |
| TU-5 | | 1—YES | | | 12°<br>2—YES | | 3—YES | 4—YES | 5—YES | 6−YES<br>$\leq 1.0 \times 10^{-4}$ ref. $cm^3/s$ | 7—YES<br>$3.1 \times 10^{-8}$ $cm^3/s$ | 8—YES | |
| TU-6 | | | | | | | | | | 1−YES<br>$\leq 1.0 \times 10^{-4}$ ref. $cm^3/s$ | | | 2—YES |
| TU-8 | | 1—YES | | 2—YES | | | 3—YES | 4—YES | 5—YES | 6−YES<br>$\leq 1.0 \times 10^{-4}$ ref. $cm^3/s$ | 7-YES [e]<br>$1.6 \times 10^{-7}$ $cm^3/s$ | 8—YES | |
| Impact analysis | | YES | YES | YES | YES | YES | | | | | | | |
| Thermal analysis | YES [d] | | | | | | | YES | YES [d] | | | | |

[a] Numbering refers to sequence of activities.
[b] Full-body helium leak test conducted following HAC testing. Leakage value recorded after 20 min of the test period.
[c] TU-1 was puncture tested in four different orientations.
[d] Thermal analysis was conducted to determine time for cooling to −40°C and to evaluate the application of decay heating and insolation during the cool-down phase.
[e] Full-body helium leak test conducted following HAC testing. Leakage value recorded after 16 min of testing.

Title 10 CFR 71.51 requires that the ES-3100 package satisfy the standards under HAC specified in 10 CFR 71.73. For the tests specified in 10 CFR 71.73, six test packages were subjected to the five sequential tests: free drop, crush, puncture, thermal, and immersion. The configuration for TU-1 through TU-4 and TU-8 used full-scale shipping packages with steel mock-ups similar to the maximum contents to be shipped in the ES-3100 configuration. TU-5, also a full-scale shipping package, was dropped with a mock-up of the lightest component proposed for shipping at that time. TU-8 was equipped with a containment vessel using fluorocarbon elastomer O-rings instead of the EPDM O-rings. TU-8 was a true production unit using the flow forming fabrication method for the containment vessel. However, the drum assembly was rejected based on prompt gamma-ray neutron activation analysis (PGNAA) readings and became available for compliance testing. TU-8 also was equipped with a top plug that was ~3 lb heavier than allowed by Sect. 8.2.3.2. This failed PGNAA reading and the heavy top plug issue have no significant effect on the temperature and structural response of the package when subjected to the compliance tests in accordance with 10 CFR 71.71(c)(7) and 71.73(c)(1) through (c)(5). All test units were first subjected to the NCT free drop from 1.2 m (4 ft). In addition to the 1.2-m (4-ft) drop, TU-4 was also subjected to the full battery of tests in accordance with applicable paragraphs of 10 CFR 71.71(c)(5) through (c)(10) except (c)(8). These preliminary tests were conducted to provide evidence that the ES-3100's ability to withstand HAC testing was not degraded through NCT testing. Demonstration of the ES-3100 package's ability to satisfy the requirements of HAC is provided in the following sections. A summary of the test results is provided in each area of Sect. 2.7; details are documented in the test reports (ORNL/NTRC-013 and ORNL/NTRC-047).

Although physical testing of the ES-3100 containers was performed generally at or near room temperature except for TU-2 and TU-8, the effectiveness of the Kaolite insulating material at various temperature extremes was examined through the use of laboratory testing and structural analysis of a similar package, the ES-2LM (DAC-EA-900000-A002). For low-temperature service, Kaolite specimens were tested at −28.89 and −40°C (−20 and −40°F). These tests showed little change in the response of the material as compared to room temperature. Furthermore, structural analyses for bounding soft and stiff material cases were run. The Kaolite 1600 data used in these bounding analyses were from laboratory experiments that used a heavily cured sample (stiff) and a sample to which borax had been added (soft) [Y/DW-1661]. Following the production run for the ES-2100 and DPP-2 shipping containers, new casting specimens were available for compression testing. In order to reduce the total cost of Kaolite testing, specimens were tested to approximately −40°C (−40°F) to cover both the cold conditions stipulated in 10 CFR 71.71(c)(2) and the −29°C (−20°F) temperature stipulated in 10 CFR 71.71(b)(1) and at 38°C (100°F). The results of Kaolite specimen testing are documented in Y/DW-1890 and Y/DW-1972. Upon further review of the data, the new test data was somewhat stiffer in the cold/high-density specimens than the data previously used in Y/DW-1972. Therefore, in order to encompass the extremes of all existing data, additional drop simulation sequences using the new bounding curves have been conducted on the ES-3100 package as documented in DAC-EA-801699-A001 and DAC-EA-801699-A002. In addition to the analytical effort, TU-2 and TU-8 were pre-chilled to a nominal temperature of −40°C (−40°F). This was accomplished by placing the units in an environmental chamber in Building 5800 at ORNL and initially setting the chamber control to −56.7°C (−70°F) for 24 h. After this initial period, the control on the environmental chamber was set to −42.8°C (−45° F) for at least 48 h. Prior to the initiation of structural testing of this unit, the units were removed from the environmental chamber and placed in an insulated box and transported to the NTRC. High-temperature [up to 38°C (100°F)] behavior was not addressed. However, in light of the fact that the insulation material is typically used as a cast refractory insulation in furnace applications and that structural tests were performed in the range of 20.8 to 30.6°C (69.4 to 87°F) or just 7.4 to 17.2°C (13 to 30°F) below the high-temperature limit, it is not anticipated that any decline in impact absorption would be detrimental at 38°C (100°F).

Extensive computer impact simulation and analysis was conducted using LS-DYNA software. The results are documented in DAC-EA-801699-A001 and DAC-EA-801699-A002. Early in the design phase, simulation was used to determine areas of large structural deformation and stress concentrations. Prior to the compliance testing in accordance with 10 CFR 71.71, simulation was used to determine the drop orientation that would cause the most structural damage to the drum assembly and thereby propose a worst-case scenario for potential breeching of the containment vessel. Prior drop test programs have shown the slapdown orientation to cause the most structural degradation of a drum-style container. Computer software LS-DYNA was used to simulate a 9-m (30-ft) drop orientation at a slapdown angle of 12° with a friction factor of $\mu = 0.0$ as calculated using the computer code Slapdown, Version 05.20.93. Slapdown calculated that no matter what friction factor was assumed, the lid-end velocity peaked at ~14° (DAC-EA-801699-A001, Appendix 6.11). The maximum lid-end velocity versus the slapdown angle is presented in Fig. 6.11.6 of DAC-EA-801699-A001, and the logic for the development of this figure is explained in Appendix 6.11 of DAC-EA-801699-A001. Because of the mitigating effects of the length-to-diameter ratios and the relative closeness of the 12° increase in velocity to the maximum values (shown in DAC-EA-801699-A001, Fig. 6.11.6), the 12°slapdown is considered the worst-case slapdown. Based on the correlation of data obtained from preliminary drop tests of the similar ES-2M configuration and computer-simulated drops, several orientations were eliminated from the drop test matrix (Table 2.23). Several other impact simulations have been conducted using a wide range of material properties for the impact limiter material (Kaolite 1600) to determine the variance in structural deformation. Results of these simulations are documented in DAC-EA-900000-A002, Sect. 5.6. Although the analysis shows some variance, the magnitude of difference was not large enough to degrade the performance of the drum assembly and containment boundary. Due to the similarities in design, fabrication, and material used in construction of the shipping packages, these same results would hold true for the ES-3100 package.

Title 10 CFR 71.73(b) requires that the HAC tests, except for the water immersion tests, be conducted at the most unfavorable ambient temperature within the range of −29 to 38°C (−20 to 100°F). This requirement was previously discussed in Sect. 2.6 for NCT, in which it was concluded that the tests performed at 70 to 90°F ambient temperatures should provide essentially the same results, except for thermal, as those made at any ambient temperature between −29 to 38°C (−20 to 100°F). Buckling failures are not anticipated for this package design. This assumption is based on the fact that no evidence of buckling occurred when the package was subjected to the compression test in accordance with 10 CFR 71.71(c)(9); the water immersion tests in accordance with 10 CFR 71.73(c)(5) and 71.73(c)(6); and the 1.2- and 9-m drop test conducted on TU-4. ASME Code calculations further substantiate that buckling failures of the containment vessel are not anticipated for this package design (DAC-M900000-0003).

Title 10 CFR 71.73(b) states that the HAC initial pressure within the containment vessel during testing shall be considered as the maximum internal normal operating pressure. The internal pressures in the ES-3100 containment vessel at various temperatures for NCT are discussed in Sects. 3.3.1 and 3.3.2 and tabulated in Table 2.20. The maximum normal absolute operating pressure due to insolation and the bounding case parameters is 215.46 kPa (31.25 psia) for the containment vessel. This pressure is well below the design internal gauge pressure of 699.82 kPa (101.5 psi). Increasing the internal pressure in the containment vessel to 215.46 kPa (31.25 psia) before free drop (Sect. 2.7.1), crush (Sect. 2.7.2), puncture (Sect. 2.7.3), or water immersion (Sect. 2.7.5) testing would have no detrimental effect on the containment vessel's structural integrity due to the low stresses shown in Tables 2.21 and 2.21a. Temperature and pressure increases in the containment vessel due to the compliance thermal tests are discussed and evaluated in Sects. 2.7.4 and 3.4.3. A summary of these pressures is presented in Appendix 3.5.2.

Summarizing 10 CFR 71.43(f) and 71.55(d)(4), the tests and conditions of NCT will not substantially reduce the effectiveness of the packaging to withstand HAC sequential testing. The effectiveness of the ES-3100 to withstand HAC sequential testing is not diminished through application of the tests and conditions stipulated in 10 CFR 71.71. The justification for this statement is provided by physical testing of both the ES-2M and ES-3100 test packages, and the analytical structural deformation predicted in DAC-EA-801699-A001 and DAC-EA-801699-A002 (summarized in Sect. 2.7.8). Due to the similarities in design, fabrication, and material used in construction of both the ES-2M and the ES-3100 package, the physical characteristics of the Kaolite 1600 will hold true for both designs. The integrity of the Kaolite 1600 is not significantly affected by the NCT vibration and 1.2-m (4-ft) drop tests. Prior to testing the ES-2M design, each test unit was radiographed to determine the integrity of the Kaolite 1600 impact and insulation material. Following casting of the material inside the drum, some three-dimensional curving cracks were seen in some packages near the thinner top sections from the bottom of the liner to the bottom drum edge. After vibration testing, radiography of the ES-2M TU-4 showed that the lower half of the impact limiter was broken into small pieces. In order to evaluate these findings, TU-4 was reassembled and subjected to HAC sequential testing. After vibration and impact testing, many three-dimensional curving cracks were seen around the impact areas, and the inner liner was visibly deformed. Nevertheless, the ES-2M TU-4 maintained the adequate spacing required for shielding effectiveness and subcriticality. Temperatures at the containment boundary were also similar to other packages not subjected to vibration testing prior to HAC testing. No inleakage of water was recorded following immersion. Additionally, TU-4 of the ES-3100 test series was subjected to tests and conditions stipulated in 10 CFR 71.71(c)(5) through (c)(10), excluding (c)(8). Following completion of these NCT tests, the test unit was subjected to the full HAC test battery. Following these tests, the containment vessel was removed and subjected to a full-body helium leak test. Criteria for a leaktight condition were achieved. Based on the success of these units, vibration normally incident to transport does not reduce the effectiveness of the packaging during HAC testing. Thus, the requirements of 10 CFR 71.43(f) and 71.55(d)(4) are satisfied.

### 2.7.1 Free Drop

**Requirement.** A free drop of 9 m (30 ft) onto a flat, unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected is required by 10 CFR 71.73(c)(1).

**Analysis.** Six test packages were drop tested from 9 m (30 ft) in accordance with 10 CFR 71.73(c)(1) with the setup as shown in Fig. 2.8. A description of the drop pad is presented in Sect. 2.6.7. Four different drop positions were used in the testing based on the analytical results from LS-DYNA drop simulations. The ES-3100 test units were designated as TU-1 through TU-5 and TU-8. TU-4 was subjected to the full NCT testing (water spray, 1.2-m (4-ft) drop, compression, penetration, and vibration) prior to HAC testing. The gross weight of the ES-3100 test units varied between 157.4 kg (347 lb) and 204.6 kg (451 lb). Mock-up components weighing between 3.6 kg (8 lb) [TU-5] and 50.3 kg (111 lb) [TU-3] were used during testing. Discussion of the damage to each test package resulting from the 9-m (30 ft) drop is given in subsequent paragraphs. Rationale for the four drop positions is included in the discussion for each test unit. Minor changes to the mid liner and the substitution of the neutron poison from BoroBond4 to Cat 277-4 are further evaluated in Sect. 2.7.8.



**Fig. 2.8. 9-m drop test arrangement for all test units.**

### 2.7.1.1 End drop

TU-4, weighing 201.8 kg (445 lb), was dropped from 9-m (30 ft) with the long axis of the drum perpendicular to the impact surface within 0.2°. The mock-up components are shown on Drawing M2E801580A027. The concern for this drop orientation was that the containment vessel assembly would crush, buckle or compress the insulation to a thickness that would result in excessive O-ring temperatures during the thermal testing cycle. Following initial impact, the package bounced very little before landing on its side. The damage to the drum consisted of reducing the overall height from 43.5 in. [following the 1.2-m (4-ft) drop] to a minimum 42.63 in. The diameter of the drum was measured at six locations along the long axis of the package and at two radial locations. The measurements and pictorials of the damage are recorded on Test Form 1 of Procedure TTG-PRF-08 shown in the test report data sheets (ORNL/NTRC-013) and are summarized in Tables 2.24 and 2.25 and Fig. 2.9.

**Table 2.24. Recorded height damage to TU-4 from 1.2- and 9-m drop tests (in.)**

| | 0° | 90° | 180° | 270° |
|---|---|---|---|---|
| Predrop height | 43.50 | 43.50 | 43.63 | 43.63 |
| Post 1.2-m drop height | 43.50 | 43.50 | 43.50 | 43.50 |
| Post 9-m drop height | 43.00 | 43.13 | 42.88 | 42.63 |

**Table 2.25. Recorded diametrical damage to TU-4 from 1.2- and 9-m drop tests (in.)**

| Axial measurement location | 0 to 180° | | | 90 to 270° | | |
|---|---|---|---|---|---|---|
| | Predrop test | Post 1.2-m drop test | Post 9-m drop test | Predrop test | Post 1.2-m drop test | Post 9-m drop test |
| Top false wire | 19.25 | 19.25 | 19.25 | 19.38 | 19.38 | 19.38 |
| Top rolling hoop | 19.25 | 19.25 | 19.13 | 19.25 | 19.25 | 19.88 |
| CG & top rolling hoop | 19.25 | 19.25 | 19.81 | 19.25 | 19.25 | 19.38 |
| CG rolling hoop | 19.13 | 19.13 | 19.13 | 19.25 | 19.25 | 19.25 |
| Bottom rolling hoop | 19.13 | 19.13 | 19.25 | 19.25 | 19.25 | 19.25 |
| Bottom false wire | 19.38 | 19.38 | 19.25 | 19.25 | 19.25 | 19.25 |




**Fig. 2.9. 9-m drop test damage on TU-4.**

### 2.7.1.2 Side drop

TU-2, weighing 202.8 kg (447 lb), was chilled to −40°C (−40°F) prior to conducting the drop tests. This unit was sequentially dropped from 1.2 m (4 ft), 9 m (30 ft), crushed from 9 m (30 ft), and puncture tested with the long axis of the drum parallel to the impact surface. The mock-up component used in TU-2 is shown on Drawing M2E801580A027; it weighed 49.9 kg (110 lb). There were two concerns for this drop orientation. The primary concern was that the containment vessel assembly would crush or compress the insulation to a thickness that would result in excessive O-ring temperatures during the thermal testing cycle. Another concern was that the cold temperatures might cause excessive loads and deformation in the containment vessel body during impact. This, in turn, might cause leaking above the regulatory limit to occur. The test package made a free fall with initial contact occurring between the rolling hoops of the drum and the impact surface with the ambient temperature at 24.2°C (75°F). Since it was important to evaluate the package at the regulatory minimum temperature, individual results of each test were not recorded. Time required to measure the package between drops would have allowed the package to further increase in temperature. Tables 2.26, 2.27, and 2.28 and Fig. 2.10 show cumulative results of damage to TU-2 from drop testing.

**Table 2.26. Recorded diametrical damage to TU-2 from NCT and HAC drop testing (in.)**

| Axial measurement location | 0 to 180° | | 90 to 270° | |
|---|---|---|---|---|
| | Predrop test | Post drop test [a] | Predrop test | Post drop test [a] |
| Top false wire | 19.25 | 17.63 | 19.25 | 19.81 |
| Top rolling hoop | 19.25 | 17.38 | 19.25 | 19.75 |
| CG & top rolling hoop | 19.25 | 17.00 | 19.25 | 20.00 |
| CG rolling hoop | 19.25 | 16.00 | 19.25 | 20.25 |
| Bottom rolling hoop | 19.25 | 15.50 | 19.25 | 20.13 |
| Bottom false wire | 19.25 | 18.00 | 19.25 | 19.38 |

[a] Includes cumulative damage from 1.2-m drop, 9-m drop, and crush test.

**Table 2.27. Recorded flat contour damage to TU-2 from NCT and HAC drop tests (in.)**

| Axial measurement location | Flat width @ 0° | Flat width @ 180° |
|---|---|---|
| Top false wire | 8 | 6.25 |
| Top rolling hoop | 9 | 8.88 |
| CG & top rolling hoop | 10.13 | 9.63 |
| CG rolling hoop | 9.88 | 12.00 |
| Bottom rolling hoop | 9.88 | 14.88 |
| Bottom false wire | 9.38 | 0 |
| Crease (see Fig. 2.10 for location) | – | 15.25 |

**Table 2.28. Recorded height damage to TU-2 from NCT and HAC drop tests (in.)**

| | 0° | 90° | 180° | 270° |
|---|---|---|---|---|
| Predrop height | 43.50 | 43.50 | 43.50 | 43.50 |
| Post-drop height [a] | 44.75 | 43.75 | 42.75 | 43.63 |

[a] Includes cumulative damage from 1.2-m drop, 9-m drop, and crush test.




**Fig. 2.10. Cumulative damage from 9-m drop and crush testing on TU-2.**

### 2.7.1.3 Corner drop

Two corner drops were conducted in the same attitude with the maximum content weights with different containment vessel O-rings and neutron poison. TU-3 used the EPDM O-rings and Borobond 4 for the neutron poison. TU-8 used the fluorocarbon elastomer O-rings and the Cat 277-4 neutron poison. Both O-rings are proposed for use in the ES-3100 containment vessel but only the Cat 277-4 neutron poison is used for production units.

#### 2.7.1.3.1 TU-3 corner drop

TU-3, weighing 203.7 kg (449 lb), was dropped from 9 m (30 ft), with the long axis of the drum at an oblique angle of 24.8° (desired angle was 24.6°) from the impact surface. The mock-up component used in TU-3 is shown on Drawing M2E801580A027; it weighed 50.3 kg (111 lb). The primary concern for this drop orientation was that the combination of plastic deformation at impact on the corner of the drum and the crushing or compacting of the adjacent insulation by the containment vessel flange would result in excessive O-ring temperatures during thermal testing. Another concern was that the mock-up contents would be forced against the containment vessel lid at impact. This, in turn, might yield the flange or closure nut, resulting in loss of containment. The test package made a free fall, with initial

contact occurring between the top rim of the drum and the impact surface with the ambient temperature at 28°C (82.4°F). A secondary contact occurred between the bottom drum rim and the impact surface. No drum studs, nuts, or washers were lost due to the impact. The lid was still firmly attached to the drum assembly, with no visible separations or rips; thus, the position of the containment vessel inside the drum (and therefore the contents of the shipping container) was maintained. A general description of damage to TU-3 is summarized in Tables 2.29 and 2.30. A picture of the damage is shown in Fig. 2.11.

**Table 2.29. Recorded height damage to TU-3 from 1.2- and 9-m drop tests**

**(in.)**

| | 0° | 90° | 180° | 270° |
|---|---|---|---|---|
| Predrop height | 43.50 | 43.50 | 43.50 | 43.50 |
| Post 1.2-m drop height | 43.00 | 43.50 | 43.63 | 43.50 |
| Post 9-m drop height | 40.63 | 43.25 | 43.75 | 43.38 |

**Table 2.30. Recorded diametrical damage to TU-3 from 1.2- and 9-m drop tests**

**(in.)**

| Axial measurement location | 0 to 180° | | | 90 to 270° | | |
|---|---|---|---|---|---|---|
| | Predrop test | Post 1.2-m drop test | Post 9-m drop test | Pre drop test | Post 1.2-m drop test | Post 9-m drop test |
| Top false wire | 19.25 | 19.25 | 19.25 | 19.13 | 19.38 | 19.19 |
| Top rolling hoop | 19.13 | 19.13 | 18.63 | 19.13 | 19.25 | 19.88 |
| CG & top rolling hoop | 19.13 | 19.13 | 19.13 | 19.13 | 19.25 | 19.38 |
| CG rolling hoop | 19.13 | 19.13 | 19.13 | 19.13 | 19.25 | 19.38 |
| Bottom rolling hoop | 19.13 | 19.13 | 19.13 | 19.13 | 19.25 | 19.38 |
| Bottom false wire | 19.13 | 19.13 | 19.13 | 19.13 | 19.25 | 19.25 |

#### 2.7.1.3.2 TU-8 corner drop

TU-8, weighing 204.6 kg (451 lb), was chilled to −40°C (−40°F) prior to conducting the drop tests. This unit was dropped from 9 m (30 ft), with the long axis of the drum at an oblique angle of 23.9° (desired angle was 24.6°) from the impact surface. The mock-up component used in TU-8 is shown on Drawing M2E801580A027; it weighed 49.9 kg (110 lb). The primary concern for this drop orientation was that the combination of plastic deformation at impact on the corner of the drum and the crushing or compacting of the adjacent insulation by the containment vessel flange would result in excessive O-ring temperatures during thermal testing. Another concern was that the mock-up contents would be forced against the containment vessel lid at impact. This, in turn, might yield the flange or closure nut, resulting in loss of containment. The test package made a free fall, with initial contact occurring between the top rim of the drum and the impact surface with the ambient temperature at 14.5°C (58.1°F). A secondary contact occurred between the bottom drum rim and the impact surface. No drum studs, nuts, or washers were lost due to the impact. The lid was still firmly attached to the drum assembly, with no visible separations or rips; thus, the position of the containment vessel inside the drum (and therefore the contents of the shipping container) was maintained. A picture of the damage is shown in Fig. 2.11. Because this was a chilled unit, measurements of the damage were not taken until all drop testing was completed.




**Fig. 2.11. TU-3 (top) and TU-8 (bottom) damage from 1.2- and 9-m drop tests.**

### 2.7.1.4 Oblique drops

Two oblique (slapdown) drops were conducted in the same attitude with maximum and minimum content weights to determine the structural response on the package in accordance with NRC Regulatory Guide 7.8. Paraphrasing Regulatory Position 1.6, a local structural response might be greater during an impact test if the weight of the contents were less than the maximum. Therefore, TU-1 and TU-5 contained the maximum and minimum weight configurations, respectively.

#### 2.7.1.4.1 TU-1 slapdown

TU-1, weighing 202.3 kg (446 lb), was dropped from 9 m (30 ft) with the long axis of the unit at an oblique angle of 12.2° (desired angle was 12°) to the essentially unyielding surface. The mock-up component used in TU-1 is shown on Drawing M2E801580A027; it weighed 49.90 kg (110 lb). Based on Sect. 3.1 of NRC Regulatory Guide 7.8, the structural performance of the package must be evaluated for the minimum and maximum weight of the contents. Therefore, this unit was tested above the maximum proposed content weight to see if the containment vessel would react differently from the much lighter mock-up content used in TU-5 in a similar drop orientation. The primary concern was that the orientation would cause greater angular acceleration of the contents near the package top. This in turn would cause the containment vessel to crush or compress the insulation to a thickness that would result in excessive O-ring temperatures during the thermal testing cycle. The test package made a free fall with initial contact occurring between the rolling hoops of the drum and the impact surface with the ambient temperature at 28°C (82.4°F). No drum studs, nuts, or washers were lost due to the impact. The lid was still firmly attached to the drum assembly, with no visible separations or rips; thus, the position of the containment vessel inside the drum (and therefore the contents of the shipping container) was maintained. A general description of damage is provided in Tables 2.31, 2.32, and 2.33 and Fig. 2.12.

**Table 2.31. Recorded height damage to TU-1 from 1.2- and 9-m drop tests (in.)**

| | 0° | 90° | 180° | 270° |
|---|---|---|---|---|
| Predrop height | 43.50 | 43.50 | 43.50 | 43.50 |
| Post 1.2-m drop height | 43.50 | 43.50 | 43.50 | 43.50 |
| Post 9-m drop height | 42.63 | 43.38 | 43.25 | 43.38 |
| Buckle | 44.50 | | | |

**Table 2.32. Recorded diametrical damage to TU-1 from 1.2- and 9-m HAC drop tests (in.)**

| Axial measurement location | 0 to 180° | | | 90 to 270° | | |
|---|---|---|---|---|---|---|
| | Predrop test | Post 1.2-m drop test | Post 9-m drop test | Predrop test | Post 1.2-m drop test | Post 9-m drop test |
| Top false wire | 19.25 | 19.13 | 18.50 | 19.25 | 19.25 | 19.38 |
| Top rolling hoop | 19.25 | 19.00 | 18.50 | 19.25 | 19.25 | 19.38 |
| CG & top rolling hoop | 19.25 | 19.13 | 18.50 | 19.25 | 19.25 | 19.38 |
| CG rolling hoop | 19.25 | 19.13 | 18.63 | 19.25 | 19.25 | 19.38 |
| Bottom rolling hoop | 19.25 | 19.00 | 18.63 | 19.25 | 19.25 | 19.25 |
| Bottom false wire | 19.25 | 19.00 | 17.81 | 19.25 | 19.25 | 19.38 |

**Table 2.33. Recorded flat contour damage to TU-1 from 1.2- and 9-m drop tests (in.)**

| Axial measurement location | Flats width maximum post 1.2-m drop | Flats width maximum post 9-m drop |
|---|---|---|
| Top false wire | 5.25 | 8.00 |
| Top rolling hoop | 4.38 | 7.38 |
| CG & top rolling hoop | 4.50 | 7.13 |
| CG rolling hoop | 3.00 | 6.38 |
| Bottom rolling hoop | 4.00 | 6.75 |
| Bottom false wire | 4.63 | 10 |




**Fig. 2.12. 1.2- and 9-m drop test damage on TU-1.**

#### 2.7.1.4.2 TU-5 slapdown

TU-5, weighing 157.4 kg (347 lb), was dropped from 9 m (30 ft), with the long axis of the drum at an oblique angle of 12.5° (desired angle was 12°) from the impact surface. The mock-up component (Drawing M2E801580A029), weighing 3.6 kg (8 lb), was the hardware; the majority of the mass was located near the bottom of the containment vessel (ORNL/NTRC-013). Based on Sect. 3.1 of NRC Regulatory Guide 7.8, the structural performance of the package must be evaluated for the minimum and maximum weight of the contents. Therefore, this unit was tested at the minimum proposed weight to see if the containment vessel would react differently from the much heavier mock-up content used in TU-1 in a similar drop orientation. The test package made a free fall with initial contact occurring between the bottom rim of the drum and the impact surface with the ambient temperature at 30.6°C (87°F). A secondary contact occurred between the top drum lid and the impact surface. No drum studs, nuts, or washers were lost during this impact test. The lid was still firmly attached to the drum assembly, with no visible separations or rips; thus, the position of the containment vessel inside the drum (and therefore the contents of the shipping container) was maintained. A general description of damage is provided in Tables 2.34, 2.35, and 2.36 and Fig. 2.13.

**Table 2.34. Recorded height damage to TU-5 from 1.2- and 9-m drop tests**

**(in.)**

| | 0° | 90° | 180° | 270° |
|---|---|---|---|---|
| Predrop height | 43.50 | 43.50 | 43.50 | 43.50 |
| Post 1.2-m drop height | 43.88 | 43.50 | 43.50 | 43.50 |
| Post 9-m drop height | 44.50 | 43.50 | 43.38 | 43.50 |

**Table 2.35. Recorded diametrical damage to TU-5 from 1.2- and 9-m HAC drop tests**

**(in.)**

| Axial measurement location | 0 to 180° | | | 90 to 270° | | |
|---|---|---|---|---|---|---|
| | Predrop test | Post 1.2-m drop test | Post 9-m drop test | Predrop test | Post 1.2-m drop test | Post 9-m drop test |
| Top false wire | 19.25 | 18.88 | 18.75 | 19.38 | 19.38 | 19.38 |
| Top rolling hoop | 19.25 | 19.00 | 18.75 | 19.25 | 19.25 | 19.38 |
| CG & top rolling hoop | 19.25 | 19.13 | 18.75 | 19.25 | 19.25 | 19.38 |
| CG rolling hoop | 19.25 | 19.13 | 18.75 | 19.25 | 19.25 | 19.25 |
| Bottom rolling hoop | 19.25 | 19.13 | 18.75 | 19.25 | 19.25 | 19.25 |
| Bottom false wire | 19.25 | 19.13 | 18.44 | 19.25 | 19.25 | 19.31 |

**Table 2.36. Recorded flat contour damage to TU-5 from 1.2- and 9-m drop testing (in.)**

| Axial measurement location | Maximum width of flats post 1.2-m drop | Maximum width of flats post 9-m drop |
|---|---|---|
| Top false wire | 5.38 | 8.38 |
| Top rolling hoop | 4.25 | 8.38 |
| CG & top rolling hoop | 3.88 | 7.63 |
| CG rolling hoop | 2.50 | 7.50 |
| Bottom rolling hoop | 3.25 | 8.25 |
| Bottom false wire | 5.00 | 9.25 |




**Fig. 2.13. 1.2- and 9-m drop test damage to TU-5.**

### 2.7.1.5 Summary of results

Damage resulting from physical testing is quantitatively described including photographs in Sect. 2.7.1. The full-scale test units were fabricated in accordance with drawings created for production hardware. During the procurement process for the full-scale test units, several small changes were suggested by the manufacturer to improve the efficiency and to reduce the cost of fabrication. These changes were incorporated and tested. However, following compliance testing the following changes have been made to the proposed production hardware. First, a change in the neutron poison from BoroBond4 to Cat 277-4 has been adopted; second, the mid liner design has been changed to a continuous shell by reducing the diameter of the step in the inner liner for the containment vessel flange from 22.35 cm (8.8 in.) to 21.84 cm (8.6 in.); and third, the silicone rubber pad thickness on the drum assembly bottom liner was increased by ~0.15 cm (0.06 in.). The second change increased the amount of Kaolite 1600 around the containment vessel flange, increased the final volume of the neutron poison, and slightly decreased the volume of the Kaolite 1600 adjacent to the neutron poison. The third change was made to stiffen the rubber pad so it would remain in place during vibration normally incurred during transport. In order to evaluate the impact of these changes, analytical drop simulations were conducted and documented in DAC-EA-801699-A001 and DAC-EA-801699-A002. The drop simulations were conducted in the same attitude and temperature regime as those conducted during the compliance testing phase for certification. The results of the structural deformation from compliance testing, drop simulation using BoroBond4, and drop simulations using Cat 277-4 material are presented in Sect. 2.7.8. The analytical structural deformation results shown in Tables 2.52–2.61 are nearly identical for the two neutron poisons. The analytical results are also well representative of the results recorded during compliance testing. Analytical strain prediction in the structural components is also compared. Although there are minor differences between simulations, the overall magnitude of the strains is very similar. The thermal aspects of these changes are addressed in Sect. 3. NCT and HAC results predicted for an undamaged package show that the change in neutron poison actually reduces the final temperature of the containment vessel components. Therefore, the substitution of Cat 277-4 material and the minor changes in the inner and mid liners for production hardware should not reduce the effectiveness of the packaging when subjected to the regulatory requirements of 10 CFR 71, and the results of compliance testing would be analogous.

## 2.7.2 Crush

**Requirement.** Title 10 CFR 71.73(c)(2) requires that the specimen be subjected to a dynamic crush test in which the specimen is placed on a flat, essentially unyielding, horizontal surface so as to suffer maximum damage by the drop of a 500-kg (1100-lb) mass from 9 m (30 ft) onto the specimen. The mass must consist of a solid mild steel plate 1 m (40 in.) by 1 m ( 40 in.) and must fall in a horizontal attitude. The crush test is required only when the specimen has a mass $\leq$ 500 kg (1100 lb), an overall density $\leq$ 1000 kg/m$^3$ (62.4 lb/ft$^3$) based on external dimensions, and radioactive contents >1000 $A_2$ not as special form radioactive material. For packages containing fissile material, the radioactive contents >1000 $A_2$ criterion does not apply.

**Analysis.** Six test packages were subjected to the dynamic crush test from 9 m (30 ft) in accordance with 10 CFR 71.73(c)(2). The previously drop-tested packages (described in Sect. 2.7.1) were restrained in the orientation used for drop testing. Discussion of the damage to each test package that resulted from the crush test is given in subsequent paragraphs, with details given in the test reports (ORNL/NTRC-013 and ORNL/NTRC-047). Rationale for the three drop positions is included in Sect. 2.7.1 for each test unit. The impact of the steel plate only increased the overall concern for each orientation.

TU-1, weighing 202.3 kg (446 lb), was positioned in a horizontal attitude with the damaged portion of the test unit, resulting from prior drop tests, placed on the drop pad (0° mark facing down on

test pad). The 500-kg (1100-lb) crush plate was centered over the sealing lid location on the containment vessel and dropped from 9 m (30 ft) and squarely contacted the top false wire of the drum at an ambient temperature of 29°C (84.2°F). Following initial impact, the package bounced very little before landing on its side. No drum studs, nuts, or washers were lost due to the impact. The lid was still firmly attached to the drum, with no visible separation or rips; thus, the position of the thermal barrier and neutron poison was maintained. A summary of the resulting damage is shown in Tables 2.37, 2.38, and 2.39. Since the length of the crush plate did not encompass the entire length of the test package, a crush edge indentation is recorded in Table 2.39. A pictorial of the damage is shown in Fig. 2.14.

**Table 2.37. Recorded height damage to TU-1 from the 9-m crush test (in.)**

| | 0° | 90° | 180° | 270° |
|---|---|---|---|---|
| Pre-crush height | 44.50 | 43.38 | 43.25 | 43.38 |
| Post 9-m crush test height | 44.88 | 43.38 | 44.00 | 43.63 |

**Table 2.38. Recorded diametrical damage to TU-1 from the 9-m crush test (in.)**

| Axial measurement location | 0 to 180° | | 90 to 270° | |
|---|---|---|---|---|
| | Precrush test | Post 9-m crush test | Precrush test | Post 9-m crush test |
| Top false wire | 18.50 | 15.63 | 19.38 | 20.63 |
| Top rolling hoop | 18.50 | 16.00 | 19.38 | 20.43 |
| CG & top rolling hoop | 18.50 | 16.25 | 19.38 | 20.25 |
| CG rolling hoop | 18.63 | 16.50 | 19.38 | 19.88 |
| Bottom rolling hoop | 18.63 | 18.25 | 19.25 | 19.50 |
| Bottom false wire | 17.81 | 17.81 | 19.38 | 19.25 |

**Table 2.39. Recorded flat contour damage to TU-1 from the 9-m crush test (in.)**

| Axial measurement location | Flats width maximum @ 0° | Flats width maximum @ 180° |
|---|---|---|
| Top false wire | 9.00 | 8.50 |
| Top rolling hoop | 10.00 | 10.00 |
| CG & top rolling hoop | 10.00 | 10.13 |
| CG rolling hoop | 9.00 | 10.63 |
| Bottom rolling hoop | 8.25 | -- |
| Bottom false wire | 9.75 | -- |
| Dent where edge of plate struck test unit | -- | 9.13 |




**Fig. 2.14. Cumulative damage following 9-m crush on TU-1.**

TU-2 (chilled package), weighing 202.8 kg (447 lb), was positioned in a horizontal attitude with the long axis of the drum parallel with respect to the drop pad. The damaged portion of the test unit, resulting from prior drop tests, was placed nearest the drop pad (0° mark facing down on pad). The 500-kg (1100-lb) crush plate was centered over the test unit's center of gravity and dropped from 9 m (30 ft) squarely onto the top false wire of the drum at an ambient temperature of 26.8°C (80.4°F). Following initial impact, the package bounced very little before landing on its side. No drum studs, nuts, or washers were lost due to the impact. The lid was still firmly attached to the drum, with no visible separation or rips; thus, the position of the thermal barrier and neutron poison was maintained. A summary of the cumulative damage is shown in Tables 2.26, 2.27, and 2.28 in Sect. 2.7.1.2. Figure 2.10 is a photograph of the damage.

TU-3, weighing 203.7 kg (449 lb), was positioned in the same oblique attitude as previously drop tested from 9 m (30 ft). The long axis of the drum was at an oblique angle of 24.7° (desired angle was 24.6°) from the impact surface with the damaged portion of the lid in contact with the drop pad (0° mark in contact with pad). The 500-kg (1100-lb) crush plate was dropped from 9 m (30 ft) with the center of gravity of both the plate and test unit in line at an ambient temperature of 30.5°C (86.9°F). The initial impact of the plate was with the edge of the drum bottom. A secondary contact occurred between the bottom drum rim and the impact surface. One drum stud was sheared from the test unit; however, the lid was still firmly attached to the drum, with no visible separation or rips. Therefore, the thermal barrier and neutron poison was maintained in position. Tables 2.40, 2.41, and 2.42 describe the measured damage which is recorded on Test Form 3 (ORNL/NTRC-013). A photograph of the damage to TU-3 is shown in Fig. 2.15.

**Table 2.40. Recorded height damage to TU-3 from the 9-m crush test (in.)**

| | 0° | 90° | 180° | 270° |
|---|---|---|---|---|
| Precrush height | 40.63 | 43.25 | 43.75 | 43.38 |
| Post 9-m crush test height | 39.38 | 42.43 | 39.13 | 42.50 |

**Table 2.41. Recorded flat contour damage to TU-3 from the 9-m crush test (in.)**

| Axial measurement location | Flats width maximum precrush | Flats width maximum post-crush |
|---|---|---|
| Top of test unit | 14.00 | 18.38 |
| Bottom of test unit | 0.00 | 17.88 |

**Table 2.42. Recorded diametrical damage to TU-3 from the 9-m crush test (in.)**

| Axial measurement location | 0 to 180° | | 90 to 270° | |
|---|---|---|---|---|
| | Precrush test | Post 9-m crush test | Precrush test | Post 9-m crush test |
| Top false wire | 19.25 | 19.25 | 19.19 | 19.06 |
| Top rolling hoop | 18.63 | 18.75 | 19.88 | 20.25 |
| CG & top rolling hoop | 19.13 | 19.25 | 19.38 | 19.75 |
| CG rolling hoop | 19.13 | 19.13 | 19.38 | 19.25 |
| Bottom rolling hoop | 19.13 | 19.13 | 19.38 | 19.75 |
| Bottom false wire | 19.13 | 18.00 | 19.25 | 19.38 |




**Fig. 2.15. Cumulative damage following 9-m crush test on TU-3.**

TU-4, weighing 201.8 kg (445 lb), was positioned vertically with the previously damaged drum top in contact with the drop pad. The 500-kg (1100-lb) crush plate was dropped from 9 m (30 ft) and squarely contacted the bottom of the test unit. The center of the 500-kg (1100-lb) crush plate was positioned over the radial test unit's center of gravity, in this case over the center of the drum's bottom at an ambient temperature of 29.8°C (85.6°F). Following initial impact, the package bounced very little before landing on its side. No drum studs, nuts, or washers were lost due to the impact. The lid was still firmly attached to the drum, with no visible separation or rips; thus, the position of the thermal barrier and neutron poison was maintained. A summary of the resulting damage is shown in Tables 2.43 and 2.44, and a photograph is shown in Fig. 2.16.

**Table 2.43. Recorded height damage to TU-4 from the 9-m crush test (in.)**

| | 0° | 90° | 180° | 270° |
|---|---|---|---|---|
| Precrush height | 43.00 | 43.13 | 42.88 | 42.63 |
| Post 9-m crush test height | 39.38 | 40.38 | 40.63 | 39.75 |

**Table 2.44. Recorded diametrical damage to TU-4 from the 9-m crush test (in.)**

| Axial measurement location | 0 to 180° | | 90 to 270° | |
|---|---|---|---|---|
| | Precrush test | Post 9-m crush test | Precrush test | Post 9-m crush test |
| Top false wire | 19.25 | 19.25 | 19.38 | 19.38 |
| Top rolling hoop | 19.13 | 20.00 | 19.88 | 20.13 |
| CG & top rolling hoop | 19.81 | 20.00 | 19.38 | 20.06 |
| CG rolling hoop | 19.13 | 19.43 | 19.25 | 19.50 |
| Bottom rolling hoop | 19.25 | 19.94 | 19.25 | 20.00 |
| Bottom false wire | 19.25 | 19.25 | 19.25 | 19.25 |




**Fig. 2.16. Cumulative damage from 9-m drop and crush testing on TU-4.**

TU-5, weighing 157.4 kg (347 lb), was positioned in a horizontal attitude with the damaged portion of the test unit resulting from prior drop tests placed on the drop pad (0° mark facing down on test pad). The 500-kg (1100-lb) crush plate was centered over the test unit's center of gravity and dropped from 9 m (30 ft) squarely onto the top false wire of the drum at an ambient temperature of 29.6°C (85.3°F). Following initial impact, the package bounced very little before landing on its side. No drum studs, nuts, or washers were lost due to the impact. The lid was still firmly attached to the drum, with no visible separation or rips; thus, the position of the thermal barrier and neutron poison was maintained. A summary of the resulting damage is shown in Tables 2.45, 2.46, and 2.47. Figure 2.17 is a photograph of the damage. Since the length of the crush plate did not encompass the entire length of the test package, additional indentations are recorded on Test Form 3 (ORNL/NTRC-013).

**Table 2.45. Recorded height damage to TU-5 from the 9-m crush test**

**(in.)**

| | 0° | 90° | 180° | 270° |
|---|---|---|---|---|
| Precrush height | 44.50 | 43.50 | 43.38 | 43.50 |
| Post 9-m crush test height | 45.00 | 43.50 | 43.75 | 43.88 |

**Table 2.46. Recorded diametrical damage to TU-5 from the 9-m crush tests**

**(in.)**

| Axial measurement location | 0 to 180° | | 90 to 270° | |
|---|---|---|---|---|
| | Precrush test | Post 9-m crush test | Precrush test | Post 9-m crush test |
| Top false wire | 18.75 | 18.69 | 19.38 | 19.38 |
| Top rolling hoop | 18.75 | 17.13 | 19.38 | 19.63 |
| CG & top rolling hoop | 18.75 | 17 | 19.38 | 20 |
| CG rolling hoop | 18.75 | 16.75 | 19.25 | 20 |
| Bottom rolling hoop | 18.75 | 16.50 | 19.25 | 19.75 |
| Bottom false wire | 18.44 | 17.00 | 19.31 | 19.38 |

**Table 2.47. Recorded flat contour damage to TU-5 from the 9-m crush test**

**(in.)**

| Axial measurement location | Flats width maximum @ 0° | Flats width maximum @ 180° |
|---|---|---|
| Top false wire | 8.88 | 0.00 |
| Top rolling hoop | 8.50 | 12.50 |
| CG & top rolling hoop | 8.00 | 12.00 |
| CG rolling hoop | 8.75 | 11.38 |
| Bottom rolling hoop | 10.25 | 11.38 |
| Bottom false wire | 11.38 | 10.50 |




**Fig. 2.17. Cumulative damage from 9-m drop and crush testing on TU-5.**

TU-8, weighing 204.6 kg (451 lb), was positioned in the same oblique attitude as previously drop tested from 9 m (30 ft). TU-8 was placed on the drop pad with the previously damaged portion of the package in contact with the drop pad and was held in place with twine anchoring the package in the correct position. The intended orientation of TU-8 on the drop pad was 24.6° ± 2°. The test unit was oriented with its lid in contact with the drop pad (inverted) at a measured angle of 23.4° from vertical such that the crush plate would impact the package in a center of gravity over corner orientation. The 500-kg (1100-lb) crush plate was dropped from 9 m (30 ft) with the center of gravity of both the plate and test unit in line at an ambient temperature of 14.6°C (58.3°F). The initial impact of the plate was with the edge of the drum bottom. A secondary contact occurred between the bottom drum rim and the impact surface. One drum stud was sheared from the test unit; however, the lid was still firmly attached to the drum, with no visible separation or rips. Therefore, the thermal barrier and neutron poison was maintained in position. Tables 2.47a and 2.47b describe the measured damage which is recorded on Test Form 3 (ORNL/NTRC-047). A photograph of the damage to TU-8 is shown in Fig. 2.17a.

**Table 2.47a. Recorded diametrical damage to TU-8 from the 9-m crush test (in.)**

| Axial measurement location | 0 to 180° | | 90 to 270° | |
|---|---|---|---|---|
| | Precrush test | Post 9-m crush test | Precrush test | Post 9-m crush test |
| Top false wire | 19.25 | 19.25 | 19.19 | 19.19 |
| Top rolling hoop | 19.13 | 19.06 | 18.93 | 19.93 |
| CG and top rolling hoop | 19.13 | 19.13 | 19.19 | 19.31 |
| Centerline | 19.38 | 19.13 | 18.50 | 18.93 |
| CG rolling hoop | 19.00 | 19.12 | 19.06 | 19.00 |
| Bottom rolling hoop | 19.00 | 19.12 | 19.12 | 19.88 |
| Bottom false wire | 19.25 | 19.25 | 18.56 | 19.31 |

**Table 2.47b. Recorded height damage to TU-8 from the 9-m crush test (in.)**

| | 0° | 90° | 180° | 270° |
|---|---|---|---|---|
| Precrush height | 43.63 | 43.50 | 43.50 | 43.56 |
| Post 9-m crush test height | 40.00 | 42.00 | 38.63 | 42.25 |



**Fig. 2.17a. Cumulative damage from 9-m drop and crush testing on TU-8.**

**Conclusion.** As noted in the discussion above, plastic deformation of the drum occurred in all test packages at the impacted areas. However, the position of the impact-limiting material (Kaolite) and neutron poison material (BoroBond in TU-1 through TU-5 and Cat 277-4 in TU-8) was maintained in all test packages. The largest area of deformation along the side of the test packages was a flat measuring 31.75 cm (12.50 in.) wide at the drum's top rolling hoop and ending with a width of 26.67 cm (10.50 in.) at the drum bottom in TU-5.

### 2.7.3 Puncture

**Requirement.** A free drop of 1 m (40 in.) from a position to obtain maximum damage onto the upper end of a solid, vertical, cylindrical, 15-cm (6-in.)–diam mild steel bar mounted on an unyielding horizontal surface, is required by 10 CFR 71.73(c)(3). The bar must be ≥20 cm (8 in.) long with the top end rounded to 6-mm (0.25-in.) maximum radius. The long axis of the bar must be vertical.

**Analysis.** The six units previously dropped and crushed from 9-m (30 ft) [Sects. 2.7.1 and 2.7.2] were dropped from 1 m (40 in.) in accordance with 10 CFR 71.73(c)(3). The puncture bar was bolted to the steel plate of the inside drop pad surface at NTRC (see Sect. 2.6.7 regarding the indoor drop test pad). A description of the drop orientations and results are shown in Table 2.48. Figures 2.18–2.24a show the results of puncture testing.

**Table 2.48. 1-m (40-in.) puncture drop test description and results**

| Test Unit | Test unit's long axis drop orientation | Axial and radial location from drum lid [a] | Recorded damage [indentation depth (in.)] [b] | Photograph |
|---|---|---|---|---|
| 1 | Horizontal | Test unit's CG (0° mark) | 0.63 | Fig. 2.18 |
| 1 | Horizontal | 8 in. down (180° mark) | 0.38 | Fig. 2.20 |
| 1 | 28° oblique from vertical | Drum lid's edge (90° mark) | Three impact locations<br>1. 0.63<br>2. 0.38<br>3. 0.13 | Fig. 2.18 |
| 1 | 40° oblique from vertical | In line with test unit's CG (270° mark) | Two impact locations<br>1. 0.75<br>2. 0.13 | Fig. 2.19 |
| 2 | Horizontal | Test unit's CG (0° mark) | 0.13 | Fig. 2.21 |
| 3 | 24.6° oblique from vertical | In line with test unit's CG (270° mark) | Two impact locations<br>1. Additional flattening of lid<br>2. 0.88 | Fig. 2.22 |
| 4 | Vertical | Center of drum's lid & CG | 0.13 | Fig. 2.23 |
| 5 | Horizontal | 8 in. down (0° mark) | 0.13 | Fig. 2.24 |
| 8 | 25.5° oblique from vertical | In line with test unit's CG (270° mark) | – [c] | Fig. 2.24a |

[a] See detailed description of test units in Sect. 5.4.3 of ORNL/NTRC-013 and Sect. 5.4 of ORNL/NTRC-047.
[b] For detailed description of damaged locations, see Test Form 4 for TU-1, TU-3, TU-4, and TU-5 and Test Form 3 for TU-2 (ORNL/NTRC-013) and test report ORNL/NTRC-047 for TU-8.
[c] Indentation depth not measured for TU-8. See Tables 2.47a and 2.47b and Fig. 2.24a for cumulative damage information.




**Fig. 2.18. 28° oblique and horizontal puncture tests on TU-1.**




**Fig. 2.19. 40° oblique puncture test on TU-1.**




**Fig. 2.20. Horizontal puncture test over TU-1's containment vessel flange.**




**Fig. 2.21. Horizontal CG puncture test on TU-2.**




**Fig. 2.22. 24.6° oblique puncture test on TU-3.**




**Fig. 2.23. Vertical puncture test on TU-4.**




**Fig. 2.24. Horizontal puncture test over TU-5's containment vessel flange.**




**Fig. 2.24a. 25.5° oblique puncture test on TU-8.**

**Conclusion.** Although all test units were deformed by this puncture test, no drum surfaces were breached, thereby maintaining the integrity of the thermal barrier and neutron poison.

### 2.7.4 Thermal

**Requirement.** Exposure of the specimen fully engulfed, except for a simple support system, in a hydrocarbon fuel/air fire of sufficient extent and in sufficiently quiescent ambient conditions to provide an average emissivity coefficient of at least 0.9, with an average flame temperature of at least 800°C (1475°F) for a period of 30 min, or any other thermal test that provides the equivalent total heat input to the package and that provides a time-averaged environmental temperature of 800°C (1475°F). The fuel source must extend horizontally at least 1 m (40 in.) but may not extend more than 3 m (10 ft) beyond any external surface of the specimen, and the specimen must be positioned 1 m (40 in.) above the surface of the fuel source. For purposes of calculation, the surface absorptivity must be either that value which the package may be expected to possess if exposed to the fire specified or 0.8, whichever is greater; and the convective coefficient must be that value which may be demonstrated to exist if the package were exposed to the fire specified. Artificial cooling may not be applied after cessation of external heat input, and any combustion of materials of construction must be allowed to proceed until it terminates naturally.

**Analysis.** The six test units previously subjected to both NCT and HAC drop testing were thermally tested in accordance with 10 CFR 71.73(c)(4). To determine the maximum temperatures reached during thermal testing, temperature-indicating patches were placed at various locations throughout the test packages at assembly. The temperature range for each patch used is identified in Table 2.49. When the temperature of an indicator was reached, the color would change to black (i.e., blackout temperature). The range of possible blackout temperatures of the patches was from 51.67 to 260°C (125 to 500°F). For TU-1 through TU-5, Table 2.49 defines the number and location of the temperature-indicating patches. Since the configuration (except the fluorocarbon elastomer O-rings and the Cat 277-4 neutron poison differences) and the drop orientation of TU-8 had previously been thermally tested (TU-3), no temperature-indicating patches were used internally in TU-8. The use of fluorocarbon elastomer O-rings in this unit would have no effect on the temperature of the package. A temperature adjustment to compensate for conducting the HAC compliance tests with BoroBond4 and substituting Cat 277-4 for the production shipping containers was evaluated. This adjustment was determined by using an undamaged package and subjecting it to a thermal environment representative of that required by 10 CFR 71.73(c)(4). Based on the analytical results shown in DAC-PKG-801699-A001 and DAC-PKG-801940-A001, the containment vessel in a package using Cat 277-4 would be 2.5 to 8°F cooler than a package with BoroBond4. Therefore, the results from TU-3 are used without further adjustment for the above configuration changes in TU-8.

Prior to the beginning of the thermal test, the No. 3 furnace at Timken Steel Company in Latrobe, Pennsylvania, was characterized for temperature and heat recovery times. Oxygen content in stack gases of the furnace was not monitored because it was not anticipated that any of the package's materials of construction were combustible. There was some burning of the silicone pads which are placed between the inner liners and the top plugs of the packages. However, it should be noted that this furnace employs "pulsed" fire burners. This type of burner is unique in that the natural gas flow rate is varied based on furnace controller demands, but the flow of air through the burners is constant, even when no gas is flowing, thereby ensuring a very rich furnace atmosphere capable of supporting any combustion of package materials of construction. The support stand was welded to a large steel plate which had been placed on the floor of the furnace prior to heating. This steel plate acted as the radiating surface at the bottom of the furnace as well as providing the ability to hold the test stand rigidly in place. Before heating the furnace, workers practiced loading and unloading test packages from the cold furnace to assure that the furnace door would not remain open >90 s during each loading. In fact, the maximum time the door was open during any loading was 64 s.

**Table 2.49. Thermax temperature-indicating patches for test units**

| Patch location | Internal surface | External surface | Temperature range °C (°F) | Test report figure [a] |
|---|---|---|---|---|
| Inner liner of drum assembly | | 8 (full range [b])<br>10 (5B & 5C) | 52 to 260 (125 to 500)<br>"B" 77–127 (171–261) [c]<br>"C" 132–182 (270–360) [d] | 5.3 |
| Top plug weldment | | 4 (full range) | 52 to 260 (125 to 500) | 5.31 |
| Containment vessel body flange | 8 (4B & 4C) | 8 (4B & 4C) | "B" 77–127 (171–261)<br>"C" 132–182 (270–360) | 5.28 |
| Containment vessel body (end cap and cylinder) | | 5 (B) | "B" 77–127 (171–261) | 5.28 |
| Containment vessel sealing lid | 4 (B) | 4 (B) | "B" 77–127 (171–261) | 5.29 |
| Test mock-up components | | 6 (B) | "B" 77–127 (171–261) | 5.26 & 5.27 |

[a] ORNL/NTRC-013.
[b] Full range labels consist of two strips; the first strip spans from 1250–3000°F in 250°F increments, and the second strip spans from 3250–5000°F in 250°F increments.
[c] Temperature-indicating labels described as "B" labels read between 1710°F and 2610°F in increments of between 90°F and 110°F.
[d] Temperature-indicating labels described as "C" labels read between 2700°F and 3600°F in increments 90°F and 110°F.

A total of 18 thermocouples was installed on the furnace surfaces and on the test package support stand (ORNL/NTRC-013 and ORNL/NTRC-047). All units were tested in a horizontal attitude with the end of the package facing the right and left side walls of the furnace. The test units were thermally tested with the 0° mark on the drum facing the floor of the furnace.

TU-1 through TU-5 and TU-8 were preheated to >38°C (100°F) by placing the packages in an environmental chamber, which was heated by a torpedo-type kerosene space heater controlled by a mechanical bulb thermostat with a control range of 38 to 93°C (100 to 200°F). The general construction of the environmental chambers was similar: a welded steel frame with fiberglass insulation panels or blankets. The set-point temperature of the environmental chambers was monitored and adjusted for the duration of the preheat cycle. Initially, the thermostat was set to 66°C (150°F) for ~23 h to 24 h. The thermostat set point was then reduced to ≥43°C (110°F) for the remainder of the preheat cycle. All of packages were preheated for at least 47 h. Six thermocouples were attached to the exterior surface of each test package after preheating. Metal retainer clips were welded to the drum to hold the thermocouples in place. The thermocouple tips were inserted underneath the metal clips and the wire was wrapped around the metal clip. To eliminate any radiant heat exchange between the thermocouples and the furnace walls, the tips and metal clips were covered with a ceramic coating.

No test package was loaded into the furnace until all functioning thermocouples on the furnace walls and support stand had a reading of 800°C (1475°F) or higher. All packages were placed in the preheated furnace on the support stand positioned with the long axis horizontal, the package lid facing toward a furnace side wall and oriented as described above. These packages were exposed to the radiation environment for a minimum of 30 min after all functioning furnace thermocouples, and at least

five of the six test package exterior surface thermocouples, reached 800°C (1475°F). During the testing, the thermocouple temperature data were recorded every 15 s.

A minimum of 24 h prior to the beginning of all testing, the furnace was turned on with a set-point temperature of 871°C (1600°F). After each test, the furnace was allowed to reheat for a minimum of 45 min after obtaining the set-point temperature before testing the next unit. The furnace control temperature data recorder ran continuously for the duration of the preheat. No test package was loaded into the furnace until all functioning thermocouples on the furnace walls and support stand had a reading of 800°C (1475°F) or higher.

Each test package was removed from the furnace and placed in an area where it was not exposed to artificial cooling. As the furnace door was opened for each test unit, smoking or flaming was visible from the TID lug hole at 0°. Flaming continued on some packages for 22 min and smoking continued up to 1 h on others. All of the packages were allowed to cool naturally to room temperature. The post-thermal test weights of each unit were recorded on Test Form 1 (ORNL/NTRC-013 and ORNL/NTRC-047). The drums were disassembled, and the damage was photographed. The post-thermal test weight of each loaded containment vessel was also recorded. Each package was visually inspected, and the condition of the package and any observations were recorded.

After the containment vessels were removed from TU-1 through TU-5 and TU-8, two different leak tests were performed on each containment vessel. An operational leak test was conducted between the O-rings using either a CALT5 leak tester or a VTI smart station vacuum decay leak detector. Following this operational leak test, a full body helium leak test was conducted. Details of these leak tests are provided in the test reports (ORNL/NTRC-013 and ORNL/NTRC-047) and the results are summarized in Table 2.23. All six containment vessels were then removed from the drum assembly and immersed under a head of water of at least 0.9 m (3 ft) in a horizontal position for a period of $\geq$8 h. Following the immersion test of 10 CFR 71.73(c)(6), the containment vessels of TU-1 through TU-5 and TU-8 were opened to remove the contents, gather available data, and look for signs of water in-leakage. No water in-leakage was detected in any of the units.

The blackout temperatures on the surface of the containment boundaries, inner liners, and mock-up components used in TU-1 through TU-5 are given in the test report (Test Form 5 for each test unit). Maximum blackout temperatures recorded on the surface of all test units (except TU-8) are tabulated in Table 2.50. These values and temperature adjustments are discussed in Sect. 3.4.3.

**Conclusion**. All six test packages were intact following the 30-min exposure to the high- temperature thermal environment as required in 10 CFR 71.73(c)(4). Examination during disassembly showed that the containment vessel surfaces, flanges, fasteners, sealing surfaces, and O-rings were not damaged by the thermal testing. All six containment vessel assemblies met the subsequent 0.9-m (3-ft) water immersion test and maintained a full-body helium leak rate $\leq 2.0 \times 10^{-7}$ cm$^3$/s. Following compliance testing, minor changes were made to the mid liner, and the neutron poison was changed from BoroBond4 to Cat 277-4. In order to evaluate the impact of these changes, extensive analytical drop simulations were utilized. The models, material properties, and drop orientations are described in DAC-EA-801699-A001 and DAC-EA-801699-A002. Results comparing structural deformation and maximum strains in the various material of construction are shown in Sect. 2.7.8. Based on the HAC analytical structural deformation results shown in Sect. 2.7.8, similar compliance test results would be expected had testing been conducted on packages employing the new proposed Cat 277-4 neutron poison. Therefore, the requirements of 10 CFR 71.73(c)(4) were satisfied, and containment was maintained.

**Table 2.50. Maximum HAC temperatures recorded on the test packages' interior surfaces**

| Temperature patch location [a] | ES-3100 Test Unit | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| | [°C (°F)] | [°C (°F)] | [°C (°F)] | [°C (°F)] | [°C (°F)] |
| Top plug bottom | 149 (300) | 163 (325) | 177 (350) | 177 (350) | 177 (350) |
| Inner liner | | | | | |
| Flange step wall | 135 (275) | 163 (325) | 135 (275) | 135 (275) | 135 (275) |
| BoroBond4 step | 107 (225) | 135 (275) | 107 (225) | 177 (350)[b] | 121 (250) |
| CV body wall high | 99 (210) | 99 (210) | 99 (210) | 99 (210) | 104 (219) |
| CV body wall middle | 99 (210) | 93 (199) | 116 (241)[b] | 93 (199) | 99 (210) |
| Bottom flat portion | 104 (219) | 99 (210) | 99 (210) | 127 (261) | 110 (230) |
| Containment vessel | | | | | |
| Lid (external top) | 116 (241) | 110 (230) | 116 (241) | 127 (261) | 127 (261) |
| Lid (internal) | 104 (219) | 104 (219) | 110 (230) | 110 (230) | 116 (241) |
| Flange (external) | 116 (241) | 110 (230) | 110 (230) | 116 (241) | 121 (250) |
| Flange (internal) | 104 (219) | 99 (210) | 116 (241)[b] | 104 (219) | 116 (241) |
| Body wall mid height | 99 (210) | 88 (190) | 99 (210) | 82 (180) | 93 (199) |
| Bottom end cap (center) | 99 (210) | 99 (210) | 88 (190) | 110 (230) | 99 (210) |
| Mock-up | | | | | |
| Side top | 82 (180) | 77 (171) | 77 (171) | 77 (171) | 99 (210) |
| Side middle | 77 (171) | 77 (171) | 77 (171) | 77 (171) | 93 (199) |
| Side bottom | 77 (171) | 77 (171) | 77 (171) | 77 (171) | 88 (190) |

[a] Refer to figures for exact locations and to Test Form 5 for recorded values (ORNL/NTRC-013).
[b] Temperature-indicating patch may have been damaged due to impact with surrounding structure. See Test Form 5 in ORNL/NTRC-013 for additional information.

### 2.7.4.1 Summary of pressures and temperatures

The ES-3100 shipping packages will typically be loaded at an ambient temperature and absolute pressure of ~25°C (77°F) and 101.35 kPa (14.70 psi), respectively. If the temperature of the package increases during shipment due to external temperature or insolation, the drum will not pressurize because four ventilation holes are drilled near the top of the drum, and the drum is not sealed at the drum lid–flange interface. The containment vessel is sealed at assembly. The internal pressure will increase due to transport temperatures, insolation (Sect. 3.3.1), decay heating, and the temperatures during HAC (Sect. 3.4.3). Temperature and pressures are summarized in Tables 3.5 and 3.7.

The maximum HAC adjusted internal absolute pressure in the containment vessel of the ES-3100 has been calculated and rounded up to 775.66 kPa (112.50 psia). This predicted pressure is based on a conservative maximum rounded average gas temperature of 140.56°C (285.00°F) as shown in Sect. 3.4.3 and Appendix 3.5.2.

### 2.7.4.2 Differential thermal expansion

The drum, inner liner, and containment vessel are all constructed of Type 304 or 304L stainless steel. Because of design clearances used during assembly, radial and vertical expansion among these components will not cause any interferences or thermally induced stresses. Due to similarities of the coefficient of thermal expansion between Type 304 or 304L and the containment vessel closure nut (ASTM A 479 and ARMCO Nitronic 60), the compression of the O-rings and the closure nut and containment vessel thread load do not change appreciably during the temperature excursion from 25°C (77°F) to the maximum adjusted containment vessel temperature of 167.22°C (332.99°F) [Sect. 3.4.3].

The Kaolite 1600 insulation and Cat 277-4 neutron poison are poured and cast in place during the fabrication of the drum assembly weldment (Drawing M2E801580A002, Appendix 1.3.7). This process produces a zero gap between the insulation and the bounding drum and inner liner and zero gap between the neutron poison and the mid and inner liners. Because of differences in coefficients of thermal expansion, some radial and axial interferences are expected from thermal growth of the liners. These radial and axial interferences have been addressed by the HAC thermal test. The results show that the stresses induced are minimal and do not reduce the effectiveness of the drum assembly.

Since there are ample clearances between the various size convenience containers and HEU contents, no induced thermal stresses from differences in coefficient of thermal expansion will exist.

### 2.7.4.3 Stress calculations

The temperature gradient on the containment vessel was essentially uniform from top to bottom during the thermal tests (Table 2.50). The gradient around the periphery of the six test units was also essentially uniform and similar to the vertical gradient. As noted in the ES-3100 test report, the temperatures recorded on the containment vessels of all the test units were fairly uniform, both vertically and circumferentially. The maximum temperature variation on the containment vessels was ~50°F (from the test temperatures reported in Table 2.50). No damage would be expected on the containment vessel from thermal stresses resulting from a temperature differential of this magnitude. This conclusion is based on the guidelines given in the ASME Code, Sect. III, Div. 1. Thermal stress is defined as a self-balancing stress produced by a nonuniform distribution of temperature (ASME Code, Sect. III, Paragraph NB-3213.13). This paragraph further states that there are two types of thermal stresses: general thermal stress and local thermal stress. An example of a general stress is that produced by an axial temperature distribution in a cylindrical shell (ASME Code, Paragraph NB-3213.9). This general stress is further classified as a secondary stress (that is, a normal stress or a shear stress developed by the constraint of adjacent materials or by self-constraint of the structure) [ASME Code, Paragraph NB-3213.9]. Paragraph NB-3213.9 further states that the basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions that cause the stress to occur, and failure from a single application would not be expected. An example of a local thermal stress is a small hot spot in the wall of a pressure vessel (ASME Code, Paragraph NB-3213.13). Local thermal stress is associated with almost complete suppression of the differential expansion and thus produces no significant distortion. Such stresses are considered only from a fatigue standpoint. Fatigue will not result from a one-time cyclic event such as an accidental fire.

The principal effect of the elevated temperature on stress levels is caused by the increase in the internal pressure. The calculated stresses as shown in Table 2.51 were determined by multiplying the stress at the design conditions (DAC-M900000-0003) by a factor equal to the ratio of operating pressures to design pressures and adding any contribution from the closure nut preload. This methodology is based on the application of linear elastic material behavior. As shown in Sect. 2.7.4.4, all stresses in the containment vessel components (based on nominal dimensions for the components) are well below the ASME Code allowable stress intensity limits.

### 2.7.4.4 Comparison with allowable stresses

As noted in Sect. 2.7.4.3, the differential stresses resulting from temperatures recorded during HAC are negligible. Also, as shown in Table 2.51, stresses of this low magnitude do not affect the adequacy of the packaging. Corresponding calculated stress regions are shown in Fig. 2.1.

## 2.7.5 Immersion—Fissile Material

**Requirement.** In those cases for which water leakage into the containment boundary has not been assumed for criticality analysis, the specimen must be immersed under a 0.9-m (3-ft) head of water in an attitude for which maximum leakage is expected, as required by 10 CFR 71.73(c)(5).

**Analysis.** The containment vessels for the ES-3100 test packages (TU-1 through TU-5 and TU-8) were removed from their respective drum assemblies following the thermal tests described in Sect. 2.7.4. After examination for damage (distortion, warpage, heating), the volume between the O-rings was pressurized, and the O-ring seals were leak checked in accordance with either the CALT5 manufacturer's instructions manual using the CALT5 leak tester or the VTI instructions manual using the VTI smart station vacuum decay leak detector. Following the O-ring cavity check, the containment vessel lids were drilled and tapped for a full-body helium leak check. The seals remained functional on all vessels, and the integrity of the containment vessel structure was maintained (indicated by a helium leak rate $\leq 2.0 \times 10^{-7}$ $cm^3/s$). Following these leak tests, each unit was then submerged under a 0.9-m (3-ft) head of water for at least 8 h. No water leakage into the vessel was seen in any of the test units. The results of this test are recorded on the data sheet of Procedure TTG-PRF-14 shown in test report ORNL/NTRC-013 for units TU-1 through TU-5 and on the data sheet of Procedure TTG-PRF-18 shown in test report ORNL/NTRC-047 for TU-8. It should be noted that the criticality analysis does assume water leakage into the ES-3100 containment vessel; however, the 0.9-m (3-ft) immersion tests were performed anyway.

**Table 2.51. HAC ES-3100 containment vessel stress compared to the allowable stress [a]**

| Stress locations shown in Fig. 2.1 | Thermal condition 10 CFR 71.73 (c)(4) containment boundary stress @674.31 kPa (97.80 psi) gauge & 140.56°C (285.0°F) | | Immersion condition 10 CFR 71.73 (c)(6) containment boundary stress @−150 kPa (−21.7 psi) gauge & −2.22°C (28°F) | | Allowable pressure, stress, or shear capacity |
|---|---|---|---|---|---|
| | kPa (psi) | M.S. [b] | kPa (psi) | M.S. [b] | kPa (psi) |
| Top flat portion of sealing lid (center of head) | $1.100 \times 10^4$ (1596) | 18 | $2.441 \times 10^3$ (354) | 82 | $1.999 \times 10^5$ (29,000) [c] |
| Closure nut ring (away from threaded portion) | $3.295 \times 10^4$ (4779) | 4.4 | $1.902 \times 10^4$ (2759) [d] | 7.6 | $1.441 \times 10^5$ (20,900) |
| Top flat head (sealing surface region) | $2.792 \times 10^4$ (4049) | 7.2 | $7.087 \times 10^3$ (1028) [d] | 28 | $1.999 \times 10^5$ (29,000) [c] |
| Cylindrical section (middle) internal pressure | $1.877 \times 10^4$ (2722) | 6.0 | | | $1.120 \times 10^5$ (16,250) [e] |
| Cylindrical section (middle) external pressure | | | $1.496 \times 10^2$ (21.7) | 5.1 | $7.584 \times 10^2$ (110) [f] |
| Cylindrical section (shell-to-flange interface) | $2.599 \times 10^4$ (3769) | 6.5 | $5.766 \times 10^3$ (836) | 29 | $1.682 \times 10^5$ (24,400) [c] |
| Cylindrical section (shell-to-bottom interface) | $5.642 \times 10^4$ (8183) | 3.0 | $1.252 \times 10^4$ (1816) | 13 | $1.682 \times 10^5$ (24,400) [c] |
| Body flange threads load, kg (lb) | $1.655 \times 10^3$ (3648) | 16 | $9.072 \times 10^2$ (2000) [d] | 29 | $2.608 \times 10^4$ (57,500) [g] |
| Body flange thread region (under cut region) | $5.481 \times 10^4$ (7950) | 3.1 | $2.839 \times 10^4$ (4117) [d] | 5.9 | $1.682 \times 10^5$ (24,400) [c] |
| Flat bottom head (center) | $4.717 \times 10^4$ (6841) | 3.6 | $1.047 \times 10^4$ (1518) | 16 | $1.682 \times 10^5$ (24,400) [c] |
| Closure nut thread load, kg (lb) | $1.655 \times 10^3$ (3648) | 20 | $9.072 \times 10^2$ (2000) [d] | 37 | $3.353 \times 10^4$ (73,911) [g] |

[a] Stresses are calculated using pressures, gasket and closure nut preload, and nominal dimensions for all containment vessel components (DAC-M900000-0003). Calculated stresses for external pressure were determined by multiplying the stress at the design conditions by a factor equal to the ratio of external pressure to design pressure plus the contribution from preload. Allowable stress values are taken from Table 2.5 up to 176.7°C (350°F).

[b] Margin of safety = allowable stress/actual stress.

[c] Stress interpreted as the sum of $P_l + P_b$; allowable stress intensity value is $1.5 \times S_m$.

[d] Stress and shear load in these areas is dominated by the 162.7 ± 6.8 N·m (120 ± 5 ft-lb) preload. External pressure component is ignored.

[e] Stress interpreted as the primary membrane stress ($P_m$); allowable stress intensity value is $S_m$.

[f] Allowable external pressure [kPa (psi)].

[g] Allowable shear capacity is defined as $0.6 \times S_m \times$ thread shear area for the body material. Thread shear area = 38.026 $cm^2$ (5.894 $in.^2$). Allowable shear capacity is defined as $1.2 \times S_m \times$ thread shear area for the closure nut material.

### 2.7.6 Immersion—All Packages

**Requirement.** A separate, undamaged specimen must be immersed under water at a pressure equivalent to a 15-m (50-ft) head of water, as required by 10 CFR 71.73(c)(6). This requirement may be satisfied by an external pressure of 150 kPa (21.7 psi) gauge.

**Analysis.** Immersion under a 15-m (50-ft) head of water would result in water entering the drum because the plastic plugs covering the four ventilation holes could fail, and the drum/lid flange is not gasketed. The ES-3100 containment vessel has been designed and tested for an external pressure of 150 kPa (21.7 psi) gauge and an internal gauge pressure of 699.82 kPa (101.5 psi), using nominal dimensions for all vessel components. Each containment vessel design incorporates an O-ring seal of verified integrity to provide assurance that no water will penetrate the containment boundary. The containment vessel of TU-6 was subjected to this 15-m (50-ft) water immersion test. No visible signs of water leakage into the containment boundary were recorded.

### 2.7.7 Deep Water Immersion Test (for Type B Packages Containing More than $10^5$ $A_2$)

The amount of $A_2$s proposed for transport is ~4753. Therefore, the deep water immersion test is not applicable.

### 2.7.8 Summary of Damage

After testing six full scale ES-3100 test packages under HAC, the drum, drum lid, and top plug were damaged as expected. The containment vessel flange, O-ring grooves, and closure nut were not damaged. Plastic deformation occurred in the six drum assemblies in the impact areas from the 1.2-m (3.9-ft) and 9-m (30-ft) drop, crush and subsequent puncture tests. No breaks were noted in the drum assembly, and no insulation was exposed. The resultant damage did not reduce the effective center-to-center package spacing to a point of criticality concern (Sect. 6).

The full-scale test units (TU-1 through TU-6) were fabricated in accordance with drawings created for production hardware. During the procurement process for the full-scale test units, several small changes were suggested by the manufacturer to improve the efficiency and to reduce the cost of fabrication. These changes were incorporated and tested. However, after compliance testing on the first seven test units, the following changes have been made to the proposed production hardware. First, a change in the neutron poison from BoroBond4 to Cat 277-4 has been adopted; second, the mid liner design has been changed to a continuous shell by reducing the diameter of the step in the inner liner for the containment vessel flange from 22.35 cm (8.8 in.) to 21.84 cm (8.6 in.); and third, the silicone rubber pad thickness on the drum assembly bottom liner was increased by ~0.15 cm (0.06 in.). The second change increased the amount of Kaolite 1600 around the containment vessel flange, increased the final volume of the neutron poison, and slightly decreased the volume of the Kaolite 1600 adjacent to the neutron poison. The third change was made to stiffen the rubber pad so it would remain in place during vibration normally incurred during transport. As previously discussed in Sect. 2.7, TU-8 was a true production unit using the flow forming fabrication method for the containment vessel. Because TU-8 was tested much later than the original seven units, the above changes had been incorporated in TU-8 prior to conducting the tests. TU-8 also incorporated the change in O-ring material from EPDM to the fluorocarbon elastomer. In order to evaluate the impact of the above changes on the original HAC test units (TU-1 through TU-5), analytical drop simulations were conducted and documented in DAC-EA-801699-A001 and DAC-EA-801699-A002. The drop simulations were conducted in the same attitude and temperature regime as those conducted during the compliance testing phase for certification. Temperature dependent material properties were used in the analysis. The results of the structural deformation from compliance testing, drop simulation using BoroBond4, and drop simulations using Cat 277-4 material are presented in the following tables and figures. The analytical structural

deformation results shown in Tables 2.52–2.61 are nearly identical for the two neutron poisons. The analytical results are also well representative of the results recorded during compliance testing as depicted in Figs. 2.25–2.30. Analytical strain prediction in the structural components is also compared for the two neutron poisons. Although there are minor differences between the compliance testing and drop simulations, the overall magnitude of the strains is very similar. The thermal aspects of these changes are addressed in Sect. 3. NCT and HAC results predicted for an undamaged package show that the change in neutron poison actually reduces the final temperature of the containment vessel components. Therefore, the substitution of Cat 277-4 material and the minor changes in the inner and mid liners for production hardware should not reduce the effectiveness of the packaging when subjected to the regulatory requirements of 10 CFR 71.71 and 71.73, and the results of compliance testing would be analogous. Some of the test units lost ~0.45 kg (1 lb) of their gross weight due to boiling off of the water trapped in the refractory and BoroBond4 materials (Table 2.62).

Assuming all water loss is from the neutron poison, the BoroBond4 material lost ~9.4% of its water content. Using the temperature data recorded during HAC testing shown in Table 2.50 and applying the temperature adjustments discussed in Sect. 3.4.3, the average temperature of the neutron poison would be ~150°C (302°F). Since the ES-3100 test units were not fabricated packages with Cat 277-4, thermogravimetric analysis (TGA) was used to compare the neutron poison's propensity to lose water. The results of this analysis are shown in Y/DV-1914, *Summary of TGA Testing of Borated Concrete and Adhesive-Backed Silicone Foam*. Samples of both BoroBond4 and Cat 277-4 were TGA tested, and the results were compared at 150°C (302°F). The BoroBond4 samples lost ~ 61.6% of their original water content. The dry Cat 277-4 lost a maximum of only 6.61%. The BoroBond4 TGA samples lost ~6.5 times the amount of water lost by the ES-3100 test units during HAC compliance testing. Assuming comparable results would be expected for the Cat 277-4 material due to similarity in the structural configuration, installation methodology, and LS-DYNA drop simulation structural deformation results, the Cat 277-4 water loss would be only 1.02%. Criticality safety analysis assumes a greater percent loss; therefore, additional conservatism is being applied in this SARP.

The maximum blackout temperature recorded adjacent to the O-rings during testing was 127.22°C (241°F) [Table 2.50]. Using the adjustments discussed in Sect. 3.4.3, the maximum adjusted temperature at the containment boundary O-rings during shipment under HAC was calculated to be 156.19°C (313.14°F). As shown in Fig. 2-24 of the *Parker O-Ring Handbook*, these O-ring materials can survive at the predicted temperature shown in Table 3.21 [156.19°C (313.14°F)] for several hundred hours. Since the predicted temperature is only ~6.1°C (11°F) above the continuous service temperature of 302°F for the EPDM O-ring and less than the continuous service temperature of 400°F for the fluorocarbon elastomer O-ring, the thermally tested packages with insolation would cool to acceptable limits within 24 h. Therefore, these adjusted temperatures would not adversely affect the containment vessel O-rings.

**Table 2.52. Diametrical damage comparison of TU-1 with analytical predictions**

**(in.)**

| Axial measurement location | 0 to 180° | | | 90 to 270° | | |
|---|---|---|---|---|---|---|
| | Test results | Analytical results with BoroBond | Analytical results with Cat 277-4 | Test results | Analytical results with BoroBond | Analytical results with Cat 277-4 |
| Top false wire | 15.63 | 15 | 14.9 | 20.63 | 20.7 | 20.7 |
| Top rolling hoop | 16 | 15.3 | 15.1 | 20.44 | 20.8 | 20.8 |
| CG & top rolling hoop | 16.25 | 15.9 | 15.7 | 20.25 | 20.6 | 20.7 |
| CG rolling hoop | 16.5 | 16.4 | 16.2 | 19.88 | 20.1 | 20.4 |
| Bottom rolling hoop | 18.25 | 18.3 | 18.1 | 19.5 | 19.6 | 19.8 |
| Bottom false wire | 17.81 | 18.1 | 18 | 19.25 | 19.4 | 19.4 |

**Table 2.53. Flat contour damage comparison of TU-1 with analytical results**

**(in.)**

| Axial measurement location | Flats width @ 0° | | | Flats width @ 180° | | |
|---|---|---|---|---|---|---|
| | Test results | Analytical results with BoroBond | Analytical results with Cat 277-4 | Test results | Analytical results with BoroBond | Analytical results with Cat 277-4 |
| Top false wire | 9 | 10.5 | 10.5 | 8.5 | 10.5 | 10.9 |
| Top rolling hoop | 10 | 11 | 11 | 10 | 11 | 11 |
| CG & top rolling hoop | 10 | 10.1 | 10.1 | 10.13 | 10.1 | 10.1 |
| CG rolling hoop | 9 | 8.4 | 8.4 | 10.63 | 10.1 | 10.1 |
| Bottom rolling hoop | 8.25 | 7.6 | 7.6 | --- | 0 | 0 |
| Bottom false wire | 9.88 | 10.1 | 10.1 | --- | 0 | 0 |




**Fig. 2.25. Visual comparison of the cumulative damage on the crush side surface after the three drop tests (from top to bottom: TU-1, analytical results with BoroBond, analytical results with Cat 277-4).**

**Table 2.54. Cumulative analytical 12° slapdown drop tests maximum effective plastic strain results**

| Component | Component material | Effective plastic strain (in./in.) | | | |
|---|---|---|---|---|---|
| | | Offset crush | | Centered crush | |
| | | Model with BoroBond | Model with Cat 277-4 | Model with BoroBond | Model with Cat 277-4 |
| CV body | Type 304L stainless steel | 0.0457 | 0.0564 | 0.0741 | 0.0643 |
| CV lid | Type 304L stainless steel | 0.0005 | 0.0013 | 0.0006 | 0.0018 |
| CV closure nut | SA-479 Nitronic 60 | 0.0000 | 0.0001 | 0.0003 | 0.0000 |
| Angle | Type 304 stainless steel | 0.1045 | 0.1070 | 0.0917 | 0.0944 |
| Drum | Type 304 stainless steel | 0.3972 | 0.3920 | 0.3537 | 0.3443 |
| Drum bottom | Type 304 stainless steel | 0.2877 | 0.2879 | 0.2919 | 0.3000 |
| Liner | Type 304 stainless steel | 0.2702 | 0.2060 | 0.2363 | 0.2846 |
| Lid | Type 304 stainless steel | 1.0797 | 0.9689 | 1.0795 | 0.5828 |
| Lid stiffener | Type 304 stainless steel | 0.0838 | 0.0894 | 0.0303 | 0.0288 |
| Drum lid studs | Type 304 stainless steel | >0.57 | 0.4018 | 0.3174 | 0.2390 |
| Lid hex nut | Silicon bronze - C65100 | 0.0086 | 0.0028 | 0.0000 | 0.0000 |
| Drum washer | 300 series stainless steel | 0.1003 | 0.0790 | 0.0597 | 0.0775 |
| Top plug weldment | Type 304 stainless steel | 0.2715 | 0.2665 | 0.1636 | 0.1644 |

**Table 2.55. Diametrical damage comparison of TU-2 with analytical predictions**

**(in.)**

| Axial measurement location | 0 to 180° | | | 90 to 270° | | |
|---|---|---|---|---|---|---|
| | Test results | Analytical results with BoroBond | Analytical results with Cat 277-4 | Test results | Analytical results with BoroBond | Analytical results with Cat 277-4 |
| Top false wire | 17.63 | 18.1 | 18 | 19.81 | 19.6 | 19.6 |
| Top rolling hoop | 17.38 | 16.6 | 16.6 | 19.75 | 19.75 | 20.1 |
| CG & top rolling hoop | 17 | 16.5 | 16.5 | 20 | 20 | 20.4 |
| CG rolling hoop | 16 | 16.3 | 16.3 | 20.25 | 20.25 | 20.5 |
| Bottom rolling hoop | 15.5 | 16.1 | 16.1 | 20.13 | 20.13 | 20 |
| Bottom false wire | 18 | 17.6 | 17.6 | 19.25 | 19.38 | 19.4 |

**Table 2.56. Flat contour damage comparison of TU-2 with analytical predictions**

**(in.)**

| Axial measurement location | Flats width @ 0° | | | Flats width @ 180° | | |
|---|---|---|---|---|---|---|
| | Test results | Analytical results with BoroBond | Analytical results with Cat 277-4 | Test results | Analytical results with BoroBond | Analytical results with Cat 277-4 |
| Top false wire | 8 | 9.2 | 9.2 | 6.25 | 0 | 0 |
| Top rolling hoop | 9 | 8.4 | 9.3 | 8.88 | 10.1 | 10.1 |
| CG & top rolling hoop | 10.13 | 8.4 | 8.4 | 9.63 | 8.4 | 9.3 |
| CG rolling hoop | 9.88 | 9.3 | 9.3 | 12 | 9.3 | 9.3 |
| Bottom rolling hoop | 9.88 | 9.3 | 9.3 | 14.88 | 10.1 | 10.1 |
| Bottom false wire | 9.38 | 10.1 | 10.1 | 0 | 0 | 0 |




**Fig. 2.26. Visual comparison of the cumulative damage on the rigid surface side after the four drop tests (from left to right: TU-2, analytical results with BoroBond, analytical results with Cat 277-4).**



**Fig. 2.27. Visual comparison of the cumulative damage on the crush plate side after the three drop tests (from left to right: TU-2, analytical results with BoroBond, analytical results with Cat 277-4).**

**Table 2.57. Cumulative analytical side drop test maximum effective plastic strain results**

| Component | Component material | Effective plastic strain (in./in.) | |
|---|---|---|---|
| | | Model with BoroBond | Model with Cat 277-4 |
| CV body | Type 304L stainless steel | 0.0462 | 0.0525 |
| CV lid | Type 304L stainless steel | 0.0004 | 0.0004 |
| CV closure nut | SA-479 Nitronic 60 | 0.0000 | 0.0005 |
| Angle | Type 304 stainless steel | 0.0816 | 0.0845 |
| Drum | Type 304 stainless steel | 0.2623 | 0.2814 |
| Drum bottom | Type 304 stainless steel | 0.2807 | 0.2827 |
| Liner | Type 304 stainless steel | 0.2005 | 0.2022 |
| Lid | Type 304 stainless steel | 0.6411 | 0.6413 |
| Lid stiffener | Type 304 stainless steel | 0.0217 | 0.0171 |
| Drum studs | Type 304 stainless steel | 0.1753 | 0.2364 |
| Drum hex nut | Silicon bronze - C65100 | 0.0000 | 0.0018 |
| Drum washer | 300 series stainless steel | 0.1034 | 0.0439 |
| Top plug weldment | Type 304 stainless steel | 0.1258 | 0.1286 |

**Table 2.58. Diametrical damage comparison of TU-3 with analytical predictions [diameter (in.)]**

| Axial measurement location | 0 to 180° | | | 90 to 270° | | |
|---|---|---|---|---|---|---|
| | Test results | Analytical results with BoroBond | Analytical results with Cat 277-4 | Test results | Analytical results with BoroBond | Analytical results with Cat 277-4 |
| Top false wire | 19.25 | 19 | 19 | 19.06 | 19 | 19 |
| Top rolling hoop | 18.75 | 18.9 | 18.9 | 20.25 | 20.6 | 20.6 |
| CG & top rolling hoop | 19.25 | 19.4 | 19.4 | 19.75 | 19.9 | 19.8 |
| CG rolling hoop | 19.13 | 19.3 | 19.3 | 19.25 | 19.4 | 19.4 |
| Bottom rolling hoop | 19.13 | 19.3 | 19.3 | 19.75 | 20.4 | 20.4 |
| Bottom false wire | 18 | 18.6 | 18.6 | 19.38 | 19.4 | 19.4 |

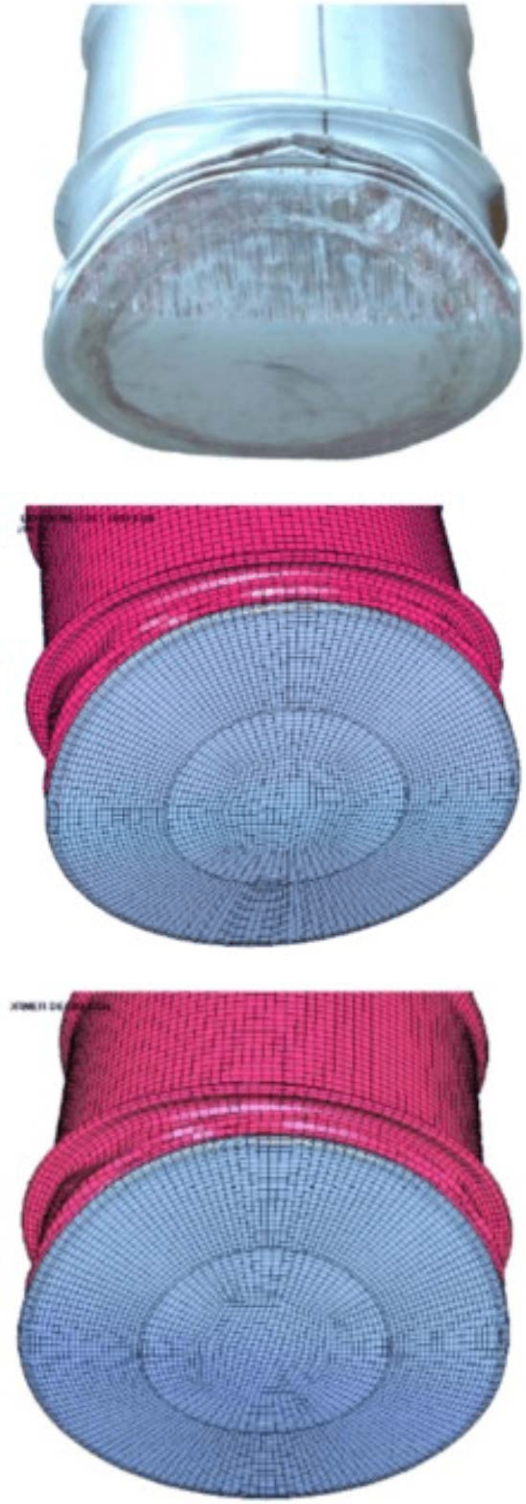


**Fig. 2.28. Visual comparison of the cumulative bottom damage after the three drop tests (from top to bottom: TU-3, analytical results with BoroBond, analytical results with Cat 277-4).**

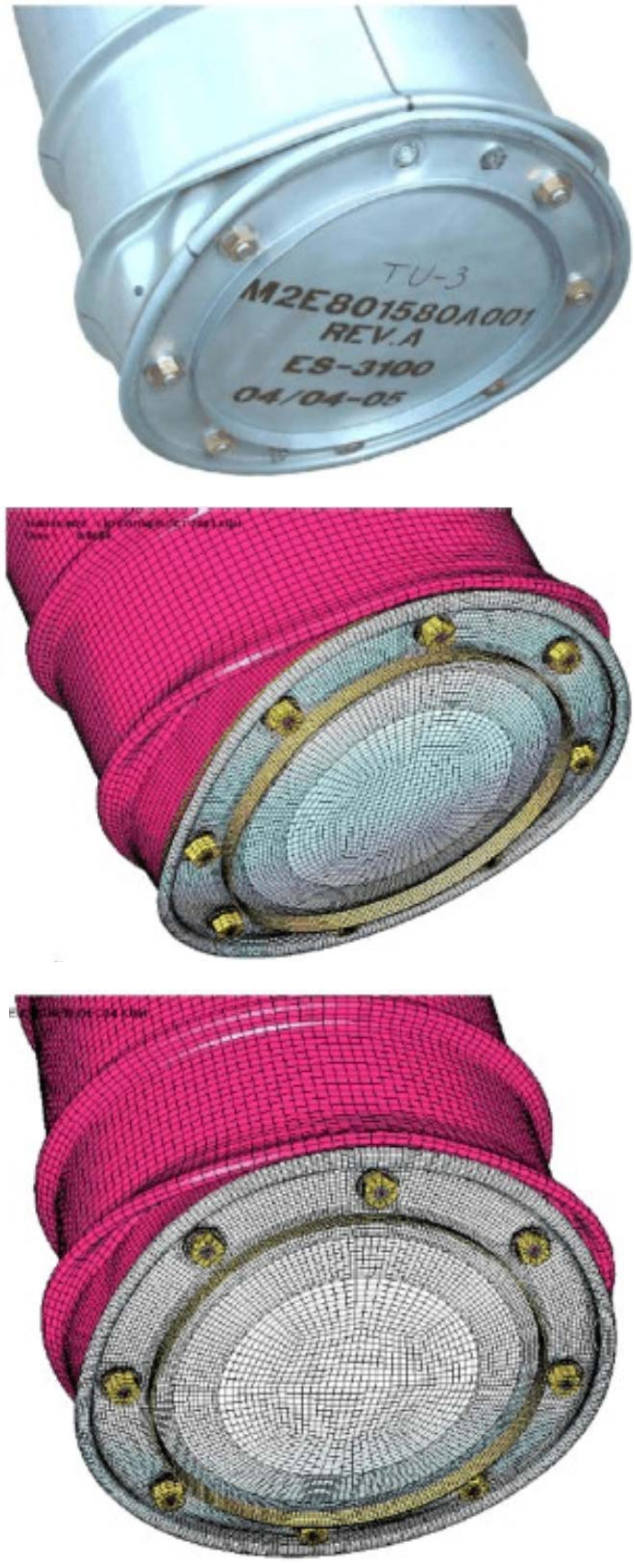



**Fig. 2.29. Visual comparison of the cumulative lid damage after the three drop tests (from top to bottom: TU-3, analytical results with BoroBond, analytical results with Cat 277-4).**

**Table 2.59. Cumulative analytical corner drop test maximum effective plastic strain results**

| Component | Component material | Effective plastic strain (in./in.) | |
|---|---|---|---|
| | | Model with BoroBond | Model with Cat 277-4 |
| CV body | Type 304L stainless steel | 0.0364 | 0.0371 |
| CV lid | Type 304L stainless steel | 0.0024 | 0.0051 |
| CV closure nut | SA-479 Nitronic 60 | 0.0000 | 0.0002 |
| Angle | Type 304 stainless steel | 0.0464 | 0.0462 |
| Drum | Type 304 stainless steel | 0.3787 | 0.3830 |
| Drum bottom | Type 304 stainless steel | 0.0731 | 0.0761 |
| Liner | Type 304 stainless steel | 0.5507 | 0.5254 |
| Lid | Type 304 stainless steel | 0.3579 | 0.3622 |
| Lid stiffener | Type 304 stainless steel | 0.0272 | 0.0272 |
| Drum studs | Type 304 stainless steel | 0.5578 | 0.5598 |
| Drum hex nut | Silicon bronze - C65100 | 0.2258 | 0.2266 |
| Drum washer | 300 series stainless steel | 0.1111 | 0.1528 |
| Top plug weldment | Type 304 stainless steel | 0.1170 | 0.1166 |

**Table 2.60. Diametrical damage comparison of TU-4 with analytical predictions [diameter (in.)]**

| Axial measurement location | 0 to 180° | | | 90 to 270° | | |
|---|---|---|---|---|---|---|
| | Test results | Analytical results with BoroBond | Analytical results with Cat 277-4 | Test results | Analytical results with BoroBond | Analytical results with Cat 277-4 |
| Top false wire | 19.25 | 19.3 | 19.3 | 19.38 | 19.3 | 19.3 |
| Top rolling hoop | 20.00 | 20.2 | 20.1 | 20.13 | 20.2 | 20.1 |
| CG & top rolling hoop | 20.00 | 20.2 | 20.2 | 20.06 | 20.2 | 20.2 |
| CG rolling hoop | 19.44 | 20.1 | 20.1 | 19.5 | 20.1 | 20.1 |
| Bottom rolling hoop | 19.94 | 20.5 | 20.5 | 20 | 20.5 | 20.5 |
| Bottom false wire | 19.25 | 19.4 | 19.4 | 19.25 | 19.4 | 19.4 |



**Fig. 2.30. Visual comparison of the cumulative damage after the three drop tests (from left to right: TU-4, analytical results with BoroBond, analytical results with Cat 277-4).**

**Table 2.61. Cumulative analytical top drop test maximum effective plastic strain results**

| Component | Component material | Effective plastic strain (in./in.) | |
|---|---|---|---|
| | | Model with BoroBond | Model with Cat 277-4 |
| CV body | Type 304L stainless steel | 0.0053 | 0.0083 |
| CV lid | Type 304L stainless steel | 0.0034 | 0.0072 |
| CV closure nut | SA-479 Nitronic 60 | 0.0000 | 0.0011 |
| Angle | Type 304 stainless steel | 0.0304 | 0.0308 |
| Drum | Type 304 stainless steel | 0.1258 | 0.1237 |
| Drum bottom | Type 304 stainless steel | 0.0312 | 0.0267 |
| Liner | Type 304 stainless steel | 0.3585 | 0.3812 |
| Lid | Type 304 stainless steel | 0.1415 | 0.1389 |
| Lid stiffener | Type 304 stainless steel | 0.0098 | 0.0100 |
| Drum studs | Type 304 stainless steel | 0.1541 | 0.1535 |
| Drum hex nuts | Silicon bronze - C65100 | 0.0170 | 0.0173 |
| Drum washer | 300 series stainless steel | 0.0510 | 0.0506 |
| Top plug weldment | Type 304 stainless steel | 0.0944 | 0.0960 |

**Table 2.62. ES-3100 test package weights before and after 10 CFR 71.73(c)(4) HAC testing**

| Test Unit | Pre-test [a] weight [kg (lb)] | Post-test [a] weight [kg (lb)] | Thermal test weight loss [kg (lb)] | BoroBond4 or Cat 277-4 original weight [kg (lb)] | Water weight in BoroBond4 or Cat 277-4 [kg (lb)] | Water loss percent [d] (%) |
|---|---|---|---|---|---|---|
| 1 | 202.3 (446) | 202.3 (446) | 0.0 (0) | 20.7 (45.64) [b] | 4.91 (10.82) [c] | 0.00 |
| 2 | 202.8 (447) | 202.8 (447) | 0.0 (0) | 20.5 (45.19) [b] | 4.86 (10.72) [c] | 0 |
| 3 | 203.7 (449) | 203.2 (448) | 0.45 (1) | 20.5 (45.19) [b] | 4.87 (10.74) [c] | 9.31 |
| 4 | 201.8 (445) | 201.4 (444) | 0.45 (1) | 20.4 (44.97) [b] | 4.84 (10.66) [c] | 9.38 |
| 5 | 157.4 (347) | 156.9 (346) | 0.45 (1) | 20.6 (45.42) [b] | 4.89 (10.77) [c] | 9.29 |
| 8 | 204.6 (451) | 202.8 (447) | 1.81 (4) [e] | 25.40 (56.0) | 8.28 (18.24) | 10.96 |

[a] ORNL/NTRC-013 and ORNL/NTRC-047.
[b] Weight of BoroBond4 and water obtained from casting data (Barton).
[c] This weight is based on TGA measurements and calculation showing that the minimum water percent is 23.71%.
[d] All weight loss attributed to loss of water in BoroBond4 or 277-4.
[e] Half of weight loss attributed to loss of water in 277-4. See ORNL/NTRC-047 Test Form 1 for weight loss in drum assembly.

Following the thermal test, all six containment boundaries were subjected to leak testing of the O-ring cavity as well as the full-body helium leak check. To verify the entire containment boundary, all test units were drilled and tapped for a helium leak check using the procedure documented in the test reports (ORNL/NTRC-013 and ORNL/NTRC-047). The procedure consisted of creating a near vacuum inside the containment vessel and supplying a helium environment around the exterior of the assembly. The maximum recorded helium leak rate for any of these containment vessels was $2.0 \times 10^{-7}$ $cm^3/s$ as documented after 17 min of leak checking. This procedure measures leakage in the opposite direction to leakage from the vessel. It could be postulated that the additional pressure differential (ambient on the exterior and a near vacuum inside) would help to further compress the O-rings during this test. However, since the containment vessel closure nut is screwed down, the additional pressure does not compress the O-ring more than a few ten thousands of an inch based on mismatch between the internal and external threaded joint. Only rotation of the closure nut will alter O-ring compression significantly. Pictures taken of all containment vessel tops following testing showed that the closure nut had rotated a maximum of 0.15 cm (0.060 in.) [Fig. 2.31] from its original radial position obtained during assembly (Fig. 2.32) except for TU-4, which showed no rotation. Based on the pitch of the closure nut, this rotation translates into only 0.0009 cm (0.00035 in.) decompression of the O-rings. This compares to the original nominal compression of 0.064 cm (0.025 in.). According to the *Parker O-Ring Handbook*, the minimum squeeze for all seals, regardless of cross section, should be ~0.018 cm (0.007 in.). Using the nominal compression of 0.064 cm (0.025 in.) and subtracting the decompression from rotation and the minimal pressure differential compression, there is ample O-ring compression. Therefore, the leak test in either direction for this containment vessel arrangement is valid. As required in 10 CFR 71.73(c)(5), the containment vessels were submerged under a 0.9-m (3-ft) head of water following the leakage tests, with no water in-leakage permitted. Following this immersion test, the containment vessels were opened. The lid assembly, with the O-rings in place on the body, are joined together by torquing the closure nut and sealing lid assembly to 162.7 ± 6.8 N·m (120 ± 5 ft-lb). The lowest break-loose torque value of 40.7 N·m (30 ft-lb) was recorded for TU-4. Visual inspection following the testing indicated that neither the vessel bodies, the O-rings, the seal areas, nor the vessel lid assemblies were damaged during the tests. In TU-5, the convenience cans had buckled from the pressure differential caused during the leak testing operation. However, the containment vessel wall showed little or no signs of impact. Therefore, based on the success of these seven test units (including the containment vessel of TU-6) and the analytical drop simulation effort, the structural integrity of the ES-3100 package, with the previously mentioned modifications, meets all the applicable requirements of 10 CFR 71.73 for transport of the proposed contents.



**Fig. 2.31. Containment vessel markings at assembly (swivel hoist ring removed prior to testing).**

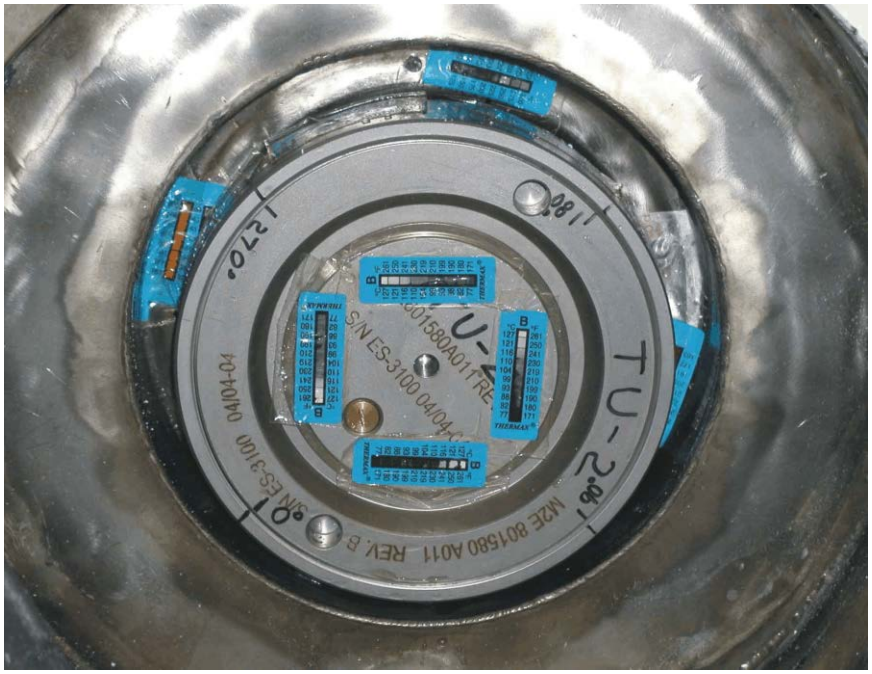



**Fig. 2.32. Containment vessel marking after compliance testing.**

## 2.8 ACCIDENT CONDITIONS FOR AIR TRANSPORT OF PLUTONIUM

The proposed contents to be shipped in the ES-3100 have only trace amounts of transuranic isotopes. Since the contents contain no more than an $A_2$ quantity of plutonium in any isotope or form and will be shipped in accordance with 10 CFR 71.5 per 10 CFR 71.88(a)(3), the requirements in 10 CFR 71.74 are not applicable.

## 2.9 ACCIDENT CONDITIONS FOR FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT

The expanded tests specified in 10 CFR 71.55(f)(1), (2), or (3) for fissile material package designs for air transportation were not conducted. The issue of subcriticality is addressed in Sect. 6 with content mass limits as addressed in Sect. 1.2.2 for air transport.

## 2.10 SPECIAL FORM

The package does not include any special form of radioactive material. Hence, the requirements of 10 CFR 71.75 and 71.77 are not applicable.

## 2.11 FUEL RODS

The contents do not utilize cladding for the containment of radioactive materials. Therefore, this requirement is not applicable.

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# 3. THERMAL EVALUATION

Design analysis, similarity, and full-scale testing (see Sect. 2) have demonstrated that the ES-3100 shipping package is in compliance with the applicable requirements of Title 10 Code of Federal Regulations (CFR) 71 (10 CFR 71) when used to ship highly enriched uranium (HEU) having a maximum gross weight up to 35.2 kg (77.60 lb). The ES-3100 has a nominal gross shipping weight that ranges from 146.88 kg (323.79 lb) to 187.81 kg (414.05 lb) for the empty and maximum weight containment vessel configurations shown in Table 2.8, respectively.

## 3.1 DESCRIPTION OF THERMAL DESIGN

The drum assembly of the shipping package is defined as the structure that maintains the position of and provides the impact and thermal barrier surrounding the containment boundary. Preserving the location of the containment boundary within the packaging prevents reduction of the shielding and subcriticality effectiveness. The nominal weight of the drum assembly is 131.89 kg (290.76 lb).

The ES-3100 package is evaluated for a maximum heat source of 5 W (Sect. 3.1.2); however, no active cooling systems or specific thermal design features are required. A lightweight cast refractory insulation between the inner liner and the drum provides thermal protection of the contents from external heat sources.

Thermal criteria are applied to the package in accordance with 10 CFR 71 for Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC). These requirements specify that each package design provide containment, shielding, and criticality safety at temperatures ranging from −40 to 38°C (−40 to 100°F) with full insolation. Also, in accordance with *Packaging and Transportation of Radioactive Material* [10 CFR 71.43(g)], a package must be designed, constructed, and prepared for transport so in still air at 38°C (100°F) and in the shade no accessible surface of a package would have a temperature exceeding 50°C (122°F) in a nonexclusive use shipment, or 85°C (185°F) in an exclusive use shipment. In addition, each package will experience no significant reduction in effectiveness as the result of being exposed to a thermal radiation environment of 800°C (1475°F) for 30 min with an emissivity coefficient of at least 0.9.

The maximum internal pressures and thermal stresses for both NCT and HAC are discussed and calculated (Sects. 3.3.2, 3.3.3, and 3.4.3) for use in the structural evaluation. The calculated pressures are well below the design pressures of the package components, and the effect of thermal stresses on the package is negligible (Sects. 2.6.1.2 and 2.7.4.2).

Compliance with the NCT thermal requirements is shown by analysis (Sect. 3.3.1). Since the components to be shipped have a maximum decay heat load of 5 W, a thermal analysis was conducted for the ES-3100 package (DAC-PKG-801940-A001). The maximum predicted temperature on the exterior of the package, while stored at 38°C (100°F) in the shade, is 40.22°C (104.39°F) [Table 3.14]. The analysis shows that no accessible surface of the package would have a temperature exceeding 50°C (122°F). Therefore, the requirement of 10 CFR 71.43(g) would be satisfied. If the package is exposed to solar radiation at 38°C (100°F) in still air, the conservatively calculated temperatures at the top of the drum, center of containment vessel lid, and on the containment vessel near the O-ring sealing surfaces are 118.86°C (245.94°F), 91.92°C (197.46°F), and 91.87°C (197.36°F), respectively (Sect. 3.3.1 and Table 3.15). For conservatism, the O-ring sealing surface temperature will be assumed to be 91.87°C (197.36°F). At the low-temperature range and neglecting decay heating, the package components would stabilize at −40°C (−40°F), which is within normal operating limits of the packaging materials (Sect. 2.2).

Six full-scale packages were subjected to the HAC thermal test following the drop, crush and puncture tests (Sects. 2.7.1 through 2.7.3). All of these test packages were exposed to a thermal radiation environment of >800°C (>1475°F) for well over 30 min in a furnace. Other temperature conditions before and during the thermal testing are given in ORNL/NTRC-013 and ORNL/NTRC-047 for the furnace, test packages, and package supports. The maximum temperature recorded during the tests on the external surface of any of the containment vessels was 127.2°C (261°F). This containment vessel maximum temperature reading is the highest value shown in Table 3.4. This temperature was recorded on Test Unit (TU)-4 and TU-5 on the containment vessel sealing lid. The maximum internal temperature adjacent to the O-rings was 116°C (241°F). Temperature adjustments are then added to the containment vessel's maximum recorded temperature to correct for measuring accuracy, internal decay heating, insolation heating during cool down, location of crush plate damage, neutron poison substitution, thermal capacitance difference between mockups and actual contents, and material density variations. Detailed discussion of each temperature adjustment is provided in Sect. 3.4.3. Although TU-5 was tested with a mock-up that represented the lightest proposed content at that time, a new lower weight limit has been established (empty containment vessel). The containment vessel's recorded temperature values were lower on all other test units, which consisted of much heavier mock-up contents. Therefore, a temperature correction is needed for weight differences of the contents shipped and the tested weights.

### 3.1.1 Design Features

The drum assembly for the ES-3100 consists of an internally flanged Type 304L stainless-steel 30-gal modified drum with two Type 304L stainless-steel inner liners, one filled with noncombustible cast refractory insulation and impact limiter and one filled with noncombustible cast neutron poison; a stainless-steel top plug with noncombustible cast refractory insulation, silicone rubber pads, silicon bronze hex-head nuts, and a stainless-steel lid and bottom (Drawing M2E801580A031, Appendix 1.3.7). The drum's diameter (inner diameter of 18.25 in.) and corrugations meet the requirements of Military Standard MS27683. All other dimensions are controlled by Drawing M2E801580A004 (Appendix 1.3.7). Modifications to the drum from MS27683 include the following: (1) the overall height was increased; (2) the drum was fabricated with two false wire open ends; and (3) a 0.27-cm (12-gauge, 0.1046-in.)–thick concave cover was welded to the bottom false wire opening (Drawing M2E801580A005, Appendix 1.3.7). Four 0.795-cm (0.313-in.)–diam equally spaced holes are drilled in the top external sidewall to prevent a pressure buildup between the drum and inner liner. The holes are filled with a plastic plug to provide a moisture barrier for the cast refractory insulation during NCT. The cavity created by the inner liners is a three-tiered volume with a 37.52-cm (14.77-in.) inside diameter 13.26-cm (5.22-in.) deep, a 21.84-cm (8.60-in.) inside diameter 5.59-cm (2.20-in) deep, and an additional 15.85-cm (6.24-in.) inside diameter 78.31-cm (30.83-in.) deep. Drum and inner liner wall thickness is 0.15 cm (16 gauge, 0.0598 in.).

The volume between the drum and mid liner is filled with a lightweight noncombustible cast refractory material called Kaolite 1600 (Kaolite product data sheet). The material is composed of portland cement, water, and vermiculite and has an average density of 358.8 kg/$m^3$ (22.4 lb/$ft^3$). The procedure for manufacturing and documenting the insulation, JS-YMN3-801580-A003 (Appendix 1.3.4), is referenced on Drawings M2E801580A002 and M2E801580A008 (Appendix 1.3.7) for the drum body weldment and top plug weldment, respectively. The insulation has a maximum continuous service temperature limit of 871°C (1600°F) due to the presence of the vermiculite and portland cement.

The volume inside the center liner tube is filled with a noncombustible cast neutron poison (absorber) material called Cat 277-4, which is created by mixing Cat 277-0 material from Shieldwerx (SWX-277-0) and boron carbide ($B_4C$). The material is composed of aluminum, magnesium, calcium boron, carbon, silicon, sulfur, sodium, iron, and water. The final mixture will have an average density of 1762 kg/$m^3$ (110 lb/$ft^3$). The procedure for manufacturing and documenting this material, JS-YMN3-801580-A005 (Appendix 1.3.5), is referenced on Drawing M2E801580A002 (Appendix 1.3.7). This neutron poison material has a maximum continuous service temperature limit of 150.0°C (302°F). At this temperature, the moisture inside the Cat 277-4 material remains an integral part of the composite material, and moisture content loss is negligible.

The top plug is fabricated in accordance with Drawing M2E801580A008 (Appendix 1.3.7), with an overall diameter of 36.50 cm (14.37 in.) and a height of 13.41 cm (5.28 in.). The plug's rim, bottom sheet, and top sheet are fabricated from 0.15-cm (16-gauge, 0.0598-in.)–thick Type 304/304L stainless-steel sheet per ASME SA-240. Four lifting inserts are welded into the top sheet for loading and unloading operations. The internal volume of the top plug assembly is filled with Kaolite 1600 in accordance with JS-YMN3-801580-A003 (Appendix 1.3.4).

Three silicone rubber pads complete the drum assembly. One pad is placed on the bottom of the most inward liner to support the containment vessel during transport. Another pad is placed on the top shelf of the mid liner to support the top plug during transport. The final plug is placed over the top of the containment vessel lid and closure nut assembly. Pads are molded to the shapes as defined on Drawing M2E801580A009 (Appendix 1.3.7) using silicone rubber with a Shore A durometer reading of 22 ± 5.

### 3.1.2 Content's Decay Heat

The maximum decay heat and radioactivity of the contents (Sect. 4) are based on a maximum of 35.2 kg of HEU in the isotopic and mass distribution at fabrication as shown in Table 3.1.

**Table 3.1. Isotopic mass and weight percent for the HEU contents [a]**

| Nuclide | Weight percent | Mass (g) |
|---|---|---|
| $^{232}U$ | 0.000004 | 0.001408 |
| $^{233}U$ | 0.600000 | 211.200000 |
| $^{234}U$ | 2.000000 | 704.000000 |
| $^{235}U$ | 54.819996 | 19,296.638592 |
| $^{236}U$ | 40.000000 | 14,080.000000 |
| $^{238}U$ | 0.000000 | 0.000000 |
| Transuranic | 0.080000 [b] | 28.160000 |
| $^{237}Np$ | 2.500000 | 880.000000 |
| **Total** | **100.000000** | **35,200.000000** |

[a] Weight percent values of individual isotopes are those that generate the largest activity within the allowable ranges presented in Sect. 1.2.2.

[b] The transuranic weight percent of 0.080000 applies to ground transport only. The maximum transuranic weight percent in contents transported by air will be 0.004000.

Using the ORIGEN-S program (NUREG/CR-0200) for determining decay heat values and predicting the isotopic decay patterns from 0 to 70 years from original fabrication, the following decay heat loads are predicted and shown in Table 3.2. Isotopic mass distribution has been calculated in Sect. 4 and shown in Table 2 of Appendix 4.5.1. The maximum decay heat load is rounded up from 3.494 to 5 W, and 5 W is used in subsequent analyses for temperature predictions. Contributions from the transuranics and $^{237}Np$ at the bottom of Table 3.2 remain constant for the time period evaluated. The decay heat per gram value used for the transuranic isotopes was an average of the decay heat values for $^{238}Pu$, $^{239}Pu$, $^{240}Pu$, $^{241}Pu$, $^{242}Pu$ and $^{241}Am$.

### 3.1.3 Summary Tables of Temperatures

#### 3.1.3.1 NCT summary tables

Thermal evaluation of the package design for NCT was performed by analysis (DAC-PKG-801940-A001). The ES-3100 shipping container has been conservatively evaluated empty of all containment vessel internal components for NCT. A summary of the maximum and minimum predicted temperatures for the drum assembly and containment vessel are shown in Table 3.3. A comprehensive discussion of the NCT evaluation is provided in Sect. 3.3.

## Table 3.2. Decay heat for 35.2 kg of HEU content (watts)

| Decay heat (Watts per gram) | Isotope | Decay time | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 years | 5 years | 10 years | 20 years | 30 years | 40 years | 50 years | 60 years | 70 years |
| 1.7920E-02 | Pb-210 | 0.0000E+00 | 2.535964E-12 | 1.955594E-11 | 1.463541E-10 | 4.579875E-10 | 1.015647E-09 | 1.854660E-09 | 3.028017E-09 | 4.529408E-09 |
| 2.6280E+03 | Pb-212 | 0.0000E+00 | 4.773325E-05 | 5.328363E-05 | 4.958338E-05 | 4.477305E-05 | 4.070278E-05 | 3.678051E-05 | 3.330227E-05 | 3.015706E-05 |
| 2.8650E+02 | Bi-210 | 0.0000E+00 | 2.500751E-11 | 1.927998E-10 | 1.433898E-09 | 4.517486E-09 | 1.000300E-08 | 1.831195E-08 | 2.984767E-08 | 4.456984E-08 |
| 2.4500E+05 | Bi-212 | 0.0000E+00 | 4.214730E-04 | 4.698388E-04 | 4.387465E-04 | 3.972902E-04 | 3.592885E-04 | 3.257780E-04 | 2.950312E-04 | 2.670481E-04 |
| 1.4420E+02 | Po-210 | 0.0000E+00 | 3.472645E-10 | 2.680638E-09 | 1.990171E-08 | 6.275130E-08 | 1.391089E-07 | 2.548637E-07 | 4.132651E-07 | 6.193899E-07 |
| 5.1130E+03 | Rn-222 | 0.0000E+00 | 7.235482E-09 | 2.894193E-08 | 1.155517E-07 | 2.599014E-07 | 4.607670E-07 | 7.199484E-07 | 1.033126E-06 | 1.407499E-06 |
| 1.8230E+03 | Ra-223 | 0.0000E+00 | 1.189035E-08 | 4.502854E-08 | 1.639320E-07 | 3.359551E-07 | 5.452674E-07 | 7.844815E-07 | 1.044803E-06 | 1.319195E-06 |
| 5.4700E+03 | Ra-224 | 0.0000E+00 | 8.625971E-04 | 9.627200E-04 | 9.011059E-04 | 8.163866E-04 | 7.378287E-04 | 6.677427E-04 | 6.045882E-04 | 5.475952E-04 |
| 2.8380E+01 | Ra-225 | 0.0000E+00 | 5.994152E-07 | 1.294737E-06 | 2.589474E-06 | 3.884210E-06 | 5.172953E-06 | 6.473684E-06 | 7.732456E-06 | 9.051169E-06 |
| 2.8600E-02 | Ra-226 | 0.0000E+00 | 6.302640E-09 | 2.517029E-08 | 1.006812E-07 | 2.255258E-07 | 4.007110E-07 | 6.262368E-07 | 9.000895E-07 | 1.224283E-06 |
| 1.5200E-02 | Ra-228 | 0.0000E+00 | 3.124058E-15 | 1.048485E-14 | 3.124058E-14 | 5.499198E-14 | 7.959929E-14 | 1.044206E-13 | 1.294558E-13 | 1.544911E-13 |
| 2.0290E+03 | Ac-225 | 0.0000E+00 | 3.428182E-05 | 6.256431E-05 | 1.251286E-04 | 1.876929E-04 | 2.498287E-04 | 3.123930E-04 | 3.745288E-04 | 4.370931E-04 |
| 3.5000E-02 | Ac-227 | 0.0000E+00 | 1.614311E-10 | 6.139787E-10 | 2.222211E-09 | 4.559248E-09 | 7.429885E-09 | 1.067202E-08 | 1.418433E-08 | 1.789927E-08 |
| 1.7460E+04 | Ac-228 | 0.0000E+00 | 4.376020E-13 | 1.470146E-12 | 4.376020E-12 | 7.694912E-12 | 1.116131E-11 | 1.465229E-11 | 1.814328E-11 | 2.165884E-11 |
| 1.1250E+03 | Th-227 | 0.0000E+00 | 1.204834E-08 | 4.580540E-08 | 1.660717E-07 | 3.408269E-07 | 5.535723E-07 | 7.967100E-07 | 1.059385E-06 | 1.339428E-06 |
| 2.6850E+01 | Th-228 | 0.0000E+00 | 8.242674E-04 | 9.187935E-04 | 8.582968E-04 | 7.788949E-04 | 7.032741E-04 | 6.389964E-04 | 5.784997E-04 | 5.217840E-04 |
| 6.0870E-03 | Th-229 | 0.0000E+00 | 3.856882E-05 | 5.502484E-05 | 1.099211E-04 | 1.645603E-04 | 2.198423E-04 | 2.738386E-04 | 3.291206E-04 | 3.844025E-04 |
| 5.8220E-04 | Th-230 | 0.0000E+00 | 5.697049E-06 | 1.135311E-05 | 2.274721E-05 | 3.410032E-05 | 4.549442E-05 | 5.697049E-05 | 6.803670E-05 | 7.951277E-05 |
| 5.7940E+02 | Th-231 | 0.0000E+00 | 4.550499E-05 | 4.550499E-05 | 4.550499E-05 | 4.550499E-05 | 4.550499E-05 | 4.550499E-05 | 4.550499E-05 | 4.550499E-05 |
| 2.6590E-09 | Th-232 | 0.0000E+00 | 5.428104E-12 | 1.089364E-11 | 2.178729E-11 | 3.268093E-11 | 4.342483E-11 | 5.428104E-11 | 6.551160E-11 | 7.636781E-11 |
| 9.5900E+00 | Th-234 | 0.0000E+00 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 |
| 1.4390E-03 | Pa-231 | 0.0000E+00 | 1.343862E-07 | 2.690500E-07 | 5.386554E-07 | 8.079830E-07 | 1.074534E-06 | 1.343862E-06 | 1.613190E-06 | 1.879741E-06 |
| 5.2710E+01 | Pa-233 | 0.0000E+00 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 |
| 7.0800E-01 | U-232 | 9.9686E-04 | 9.470208E-04 | 9.021619E-04 | 8.174285E-04 | 7.396731E-04 | 6.698926E-04 | 6.070902E-04 | 5.492721E-04 | 4.974351E-04 |
| 2.8070E-04 | U-233 | 5.9280E-02 | 5.927847E-02 | 5.927771E-02 | 5.927518E-02 | 5.927266E-02 | 5.927011E-02 | 5.926762E-02 | 5.926507E-02 | 5.926252E-02 |
| 1.7910E-04 | U-234 | 1.2609E-01 | 1.260924E-01 | 1.260907E-01 | 1.260871E-01 | 1.260837E-01 | 1.260801E-01 | 1.260766E-01 | 1.260732E-01 | 1.260697E-01 |
| 6.0000E-08 | U-235 | 1.1578E-03 | 1.157798E-03 | 1.157798E-03 | 1.157798E-03 | 1.157798E-03 | 1.157798E-03 | 1.157798E-03 | 1.157798E-03 | 1.157798E-03 |
| 2.0000E-06 | U-236 | 2.4656E-02 | 2.465563E-02 | 2.465562E-02 | 2.465561E-02 | 2.465561E-02 | 2.465560E-02 | 2.465559E-02 | 2.465559E-02 | 2.465558E-02 |
| 8.5111E-09 | U-238 | 0.0000E+00 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 |
| 1.1580E-01 | transuranic | 3.261285E+00 | 3.261285E+00 | 3.261285E+00 | 3.261285E+00 | 3.261285E+00 | 3.261285E+00 | 3.261285E+00 | 3.261285E+00 | 3.261285E+00 |
| 2.0100E-05 | Np-237 | 1.768800E-02 | 1.768800E-02 | 1.768800E-02 | 1.768800E-02 | 1.768800E-02 | 1.768800E-02 | 1.768800E-02 | 1.768800E-02 | 1.768800E-02 |
| | **Total watts** | **3.491158E+00** | **3.493385E+00** | **3.493638E+00** | **3.493521E+00** | **3.493358E+00** | **3.493217E+00** | **3.493107E+00** | **3.493016E+00** | **3.492946E+00** |

**Table 3.3. Summary of results of evaluation for the ES-3100 under NCT**

| Conditions | Calculated results | Allowable limit | SARP reference |
|---|---|---|---|
| Minimum package temperature, °C (°F) | −40 (−40) | −40 (−40) | Sect. 3.3.1 |
| Maximum drum temperature with insolation, °C (°F) | 118.86 (245.94) [a] | N/A | Sect. 3.3.1 |
| Maximum containment vessel temperature with insolation, °C (°F) | 91.93 (197.48) [a] | 427 (800) [b] | Sect. 3.3.1 |
| Maximum O-ring temperature, °C (°F) | 91.87 (197.36) [a] | 150 (302) [c]<br>204 (400) [d] | Sect. 3.3.1 |

[a] DAC-PKG-801940-A001.
[b] *ASME Boiler and Pressure Code*, Sect. II, Part D, maximum allowable temperature for Sect. III, Div. 1, Subsection NB vessel.
[c] Maximum ethylene propylene diene monomer O-ring seal life up to 150°C (302°F) for 1000 h of continuous service (*Parker O-Ring Handbook*, Fig. 2-28).
[d] Maximum fluorocarbon elastomer O-ring seal life up to 204°C (400°F) for 1000 h of continuous service (*Parker O-Ring Handbook*, Fig. 2-28).

### 3.1.3.2 HAC temperature summary tables

Thermal evaluation of the package design for HAC was performed by a combination of physical testing and analysis. Temperature indicators (patches) were placed on the surface of each containment vessel, inner liner, and mock-up component during thermal testing. The blackout temperatures that occurred during thermal testing are recorded for each test unit; the maximum blackout temperatures are listed in Table 3.4. In order to more accurately predict the final HAC temperatures, the blackout temperatures are increased to account for (1) the temperature interval between blackout dots; (2) the ambient temperature of the package prior to insertion into the furnace; (3) the temperature increase due to the effects of applying solar insolation during post-HAC thermal test cool down; (4) the temperature increase due to the decay heat load of the actual contents being shipped; (5) effects of crushing at different locations along the body of the shipping package; (6) thermal capacitance difference in the proposed contents and hardware used during testing; (7) temperature difference occurring when using Cat 277-4 in place of Borobond4; and (8) temperature difference resulting from variations in Kaolite 1600 and Cat 277-4 material densities. A summary of the maximum and minimum predicted temperatures for the drum assembly and containment vessel is shown in Table 3.5. A comprehensive discussion of the HAC evaluation is provided in Sect. 3.4.

**Table 3.4. Maximum HAC temperatures recorded on the test packages' interior surfaces**

| Temperature patch location [a] | ES-3100 Test Unit | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| | [°C (°F)] | [°C (°F)] | [°C (°F)] | [°C (°F)] | [°C (°F)] |
| Top plug bottom | 149 (300) | 163 (325) | 177 (350) | 177 (350) | 177 (350) |
| Inner liner | | | | | |
| Flange step wall | 135 (275) | 163 (325) | 135 (275) | 135 (275) | 135 (275) |
| BoroBond4 step | 107 (225) | 135 (275) | 107 (225) | 177 (350) [b] | 121 (250) |
| Adjacent to containment vessel body wall high | 99 (210) | 99 (210) | 99 (210) | 99 (210) | 104 (219) |
| Adjacent to containment vessel body wall middle | 99 (210) | 93 (199) | 116 (241) | 93 (199) | 99 (210) |
| Bottom flat portion | 104 (219) | 99 (210) | 99 (210) | 127 (261) | 110 (230) |
| Containment boundary | | | | | |
| Lid (external top) | 116 (241) | 110 (230) | 116 (241) | 127 (261) | 127 (261) |
| Lid (internal) | 104 (219) | 104 (219) | 110 (230) | 110 (230) | 116 (241) |
| Flange (external) | 116 (241) | 110 (230) | 110 (230) | 116 (241) | 121 (250) |
| Flange (internal) | 104 (219) | 99 (210) | 116 (241) [b] | 104 (219) | 116 (241) |
| Body wall mid height | 99 (210) | 88 (190) | 99 (210) | 82 (180) | 93 (199) |
| Bottom end cap (center) | 99 (210) | 99 (210) | 88 (190) | 110 (230) | 99 (210) |
| Mock-up | | | | | |
| Side top | 82 (180) | 77 (171) | 77 (171) | 77 (171) | 99 (210) |
| Side middle | 77 (171) | 77 (171) | 77 (171) | 77 (171) | 93 (199) |
| Side bottom | 77 (171) | 77 (171) | 77 (171) | 77 (171) | 88 (190) |

[a] Refer to figures for exact locations and to Tables 5.3 through 5.7 in ORNL/NTRC-013 for recorded values.
[b] Temperature-indicating patch may have been damaged due to impact with surrounding structure.

**Table 3.5. Summary of results of evaluation under HAC for the ES-3100 shipping arrangement using bounding case parameters**

| Condition | Results | Design limits | SARP reference |
|---|---|---|---|
| Maximum adjusted containment vessel temperature during testing, °C (°F) | 167.22 (332.99) | 426.67 (800) [a] | Sect. 3.4.3 |
| Maximum adjusted O-ring temperature, °C (°F) | 156.19 (313.14) [b] | 150(302) [b]<br>204(400) [c] | Sect. 3.4.3 |

[a] *ASME Boiler and Pressure Code*, Sect. II, Part D, maximum allowable temperature for Sect. III, Div. 1, Subsection NB vessel.
[b] Maximum ethylene propylene diene monomer O-ring seal life at 156.19°C (313.14°F) is several hundred hours (*Parker O-Ring Handbook*, Fig. 2-24). Limit shown is for 1000 h of continuous service at a temperature up to 150°C (302°F).
[c] Limit shown is for 1000 h of continuous service at a temperature up to 204°C (400°F) for fluorocarbon elastomer O-ring material (*Parker O-Ring Handbook*, Fig. 2-24).

### 3.1.4 Summary Tables of Maximum Pressures

#### 3.1.4.1 Maximum NCT pressures

Table 3.6 summarizes the results from Appendix 3.5.1 in which the pressure of the containment vessel when subjected to the tests and conditions of NCT per 10 CFR 71.71 has been determined for the most restrictive containment vessel arrangements (CVAs) shipped in the ES-3100. The most restrictive CVAs are those in which the void volume inside the containment vessel is minimized based on content volumes and those CVAs that carry the largest mass of items that offgas at the predicted temperatures during NCT. Several convenience container heights are proposed for shipment (Fig. 1.4). Shipping configurations will use these containers in any configuration as long as it does not exceed the HEU weight limit and form and does not exceed the height constraint of the containment vessel. However, in order to determine the worst-case shipping configuration, the arrangements that minimize the void volume inside the containment vessel are analyzed as follows:

1. one shipment will contain six cans with external dimensions of 10.8-cm (4.25-in.) diam by 12.38-cm (4.875-in.)–high cans;

2. one shipment will contain five cans with external dimensions of 10.8-cm (4.25-in.) diam by 12.38-cm (4.875-in.)–high cans and three can spacers;

3. one shipment will contain three cans with external dimensions of 10.8-cm (4.25-in.) diam by 22.23-cm (8.75-in.) high and two can spacers;

4. one shipment will contain three cans with external dimensions of 10.8-cm (4.25-in.) diam by 25.4 cm (10 in.) high;

5. one shipment will contain six nickel cans with external dimensions of 7.62-cm (3.00-in.) diam by 12.07-cm (4.75-in.) high;

6. one shipment will contain three polyethylene bottles with external dimensions of 12.54-cm (4.94-in.) diam by 22.1-cm (8.7-in.) high;

7. one shipment will contain three Teflon bottles with external dimensions of 11.91-cm (4.69-in.) diam by 23.88-cm (9.4-in.) high;

8. one shipment will contain a brazed assembly of two cans with final external dimensions of 10.8-cm (4.25-in.) diam by 44.46-cm (17.50-in.) high. An empty can with external dimensions of 10.8-cm (4.25-in.) diam by 22.23-cm (8.75-in.) high will be placed on top or bottom of the 44.46-cm (17.50-in.)-high can;

9. one shipment will contain fuel rods, or tubes, or plates greater than 43.18 cm (17.00 in.) in length. These items are bundled together and protected on both ends with an open-ended can with external dimensions of ≤12.7-cm (5.0-in.) diam by ≤ 22.23-cm (8.75-in.) high. Total assembly height will be ≤77.47 cm (30.5 in.). If space is available inside the containment vessel, stainless-steel metal scrubbers will be added on the bottom and top of this assembly or an empty can will be placed on top or bottom of this partially canned assembly;

10. one shipment will contain three cans brazed together with external dimensions of 4.25-in. diam by ~30-in. high; and

11. one shipment will contain closed cans with diameters >4.25 in. In this situation, the void volume inside the loaded containment vessel must be ≥55 $in.^3$

**Table 3.6. Total pressure inside the containment vessel at 91.93°C (197.48°F) [a]**

| CVA | $n_a$ [b] (lb-mol) | $n_v$ [b] (lb-mol) | $n_{po}$ [b] (lb-mol) | $n_{bo}$ [b] (lb-mol) | $n_{tf}$ [b] (lb-mol) | $n_{H2}$ [b] (lb-mol) | $n_{O2}$ [b] (lb-mol) | $n_T$ [b] (lb-mol) | $P_T$ (psia) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2.1527E-05 | 6.6047E-04 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 3.6862E-05 | 1.8431E-05 | 7.3729E-04 | 19.457 |
| 7 | 4.7285E-04 | 2.8668E-04[C] | 0.0000E+00 | 0.0000E+00 | 2.2296E-05 | 2.5558E-05 | 1.2779E-05 | 8.2016E-04 | 31.218 |
| 11 | 2.5278E-06 | 7.7556E-05 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 4.3285E-06 | 2.1643E-06 | 8.6577E-05 | 19.457 |

[a] This assumes that the internal convenience cans, polyethylene or Teflon FEP bottles, and Cat 277-4 spacer cans are not sealed.

[b] $n_a$—molar quantity of dry air in the gas mixture;
$n_v$—molar quantity of water vapor in the gas mixture;
$n_{po}$—molar quantity of gas due to offgassing of the silicone rubber pads;
$n_{bo}$—molar quantity of gas due to offgassing of the polyethylene bags, bottles, and lifting sling;
$n_{tf}$—molar quantity of gas due to offgassing of the Teflon bottles;
$n_{H2}$—molar quantity of hydrogen gas due to radiolysis of water;
$n_{O2}$—molar quantity of oxygen gas due to radiolysis of water; and
$n_T$—total molar quantity in the gas mixture.

[c] This value is the molar quantity of water vapor generated from the efflorescence of UNX crystals.

These arrangements are shown in Fig. 1.4. To determine the ES-3100's maximum normal operating pressure, the following assumptions have been used in the calculations:

1. the HEU contents are loaded into convenience cans, and convenience cans are placed inside the containment vessel at standard temperature ($T_{amb}$) and pressure ($P_t$) [25°C (77°F) and 101.35 kPa (14.7 psia)] with air at a maximum relative humidity of 100% for all configurations except for CVA 7; CVA 7 assumes the air is 100% dry;

2. the convenience cans and bottles are assumed to not be sealed to maximize the void volume inside the containment vessel;

3. convenience can and bottle geometry does not change during pressure increase inside containment vessel;

4. if metal convenience cans are used, the total amount of polyethylene bagging and lifting slings is limited to 500 g per containment vessel shipping arrangement;

5. the mass of offgassing material (polyethylene bagging or bottles, Teflon bottles, silicone pads, lifting slings) is assumed to be 1490 g for the offgassing evaluation of CVA 7;

6. CVA 11 uses metal cans and, therefore, is limited to 500 g of polyethylene bagging and lifting slings.

The offgassing material limits identified in assumptions 4 and 5 have been established based on the needs of shippers. All configurations are limited to 500 g of polyethylene in the form of bags, slings, and/or bottles. When the requirement to ship material in Teflon bottles arose, the upper limit of 1490 g of offgassing material was established. This limit is a combination of three Teflon bottles (330 g per bottle) and the original 500-g allowance for polyethylene material. These offgassing material limits have been used in calculations pertaining to containment vessel pressure, radioactive material leakage criteria, and criticality control. Therefore, portions of the safety basis for this shipping package have been based on these material limits.

NUREG-1609, Sect. 4.5.2.3, requires the applicant to demonstrate that any combustible gases generated in the package during a period of one year do not exceed 5% (by volume) of the free gas volume in any confined region of the package. No credit should be taken for getters, catalysts, or other recombination devices. The analysis conducted in Appendix 3.5.4 evaluates the different packaging arrangements for the generation of hydrogen gas due to the radiolysis of water vapor, free water, interstitial water, polyurethane bags, and polyurethane or Teflon bottles. By limiting the mass and the material composition as shown in Appendix 3.5.4, the combustible gas concentration limit stated in NUREG-1609 is not exceeded. These limits are further discussed and shown in Tables 1.3 and 1.3a. Getters, catalysts, or other recombination devices are not employed in any of the containment vessel packaging arrangements. The analysis conducted in Appendix 3.5.1 predicts the maximum normal operating pressure inside the containment vessel for the various packaging arrangements and masses discussed previously. This appendix also includes the hydrogen gas generation predicted by Appendix 3.5.4.

The uranyl nitrate crystals (UNX) in any hydrated state are very efflorescent and will lose water molecules at the temperature shown in Table 3.3 [91.93°C (197.48°F)]. As shown in Table 3.6, the containment vessel pressure is calculated to be 215.24 kPa (31.218 psia) with the contribution from UNX crystal efflorescence. This calculation is shown in greater detail in Appendix 3.5.1.

### 3.1.4.2 Maximum HAC pressures

Table 3.7 summarizes the results from Appendix 3.5.2 in which the pressure of the containment vessel when subjected to the tests and conditions of HAC per 10 CFR 71.73 has been determined for the most restrictive CVAs shipped in the ES-3100. The shipping configurations discussed in Sect. 3.1.4.1 are evaluated for HAC. To determine the maximum pressure generated inside the ES-3100's containment vessel due to HAC conditions, the following assumptions have been used in the calculations:

1. the initial pressure inside the containment vessel is the maximum normal operating pressure shown in Table 3.6 for each CVA at standard temperature [25°C (77°F)];

2. the convenience cans and bottles are assumed to not be sealed in order to maximize the void volume inside the containment vessel;

3. convenience can and bottle geometry does not change during pressure increase inside containment vessel or because of damage from compliance testing;

4. if metal convenience cans are used, the total amount of polyethylene bagging and lifting slings is limited to 500 g per containment vessel shipping arrangement;

5. the mass of offgassing material (polyethylene bagging or bottles, Teflon bottles, silicone pads, lifting slings) is assumed to be 1490 g for the offgassing evaluation of CVA 7;

6. CVAs that utilize closed convenience cans with a diameter greater than 10.8 cm (4.25 in.) will have a minimum void volume of $\geq$55 $in.^3$ for gas evolution and expansion;

7. hydrogen and oxygen molar quantities calculated in Appendix 3.5.1 are conservatively added to the gas mixture for HAC; and

8. the contribution in pressure generated by the efflorescence of UNX crystals is incorporated into the results for CVA 7.

**Table 3.7. Total pressure inside the containment vessel at 140.36°C (284.64°F) [a] with efflorescence**

| CVA | $n_{MNOP}$ [b] (lb-mol) | $n_{po}$ [b] (lb-mol) | $n_{bo}$ [b] (lb-mol) | $n_{tf}$ [b] (lb-mol) | $n_{r-H2}$ [b] (lb-mol) | $n_{r-O2}$ [b] (lb-mol) | $n_{CE-WV}$ [b,c] (lb-mol) | $n_T$ [b] (lb-mol) | $P_T$ (psia) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 9.0270E-04 | 1.3458E-05 | 3.1529E-04 | 0.0000E+00 | 3.6862E-05 | 1.8431E-05 | 0.0000E+00 | 1.2867E-03 | 38.459 |
| 7 | 1.0042E-03 | 0.0000E+00 | 3.1529E-04 | 2.2296E-05 | 2.5558E-05 | 1.2779E-05 | 1.2286E-03 | 2.6087E-03 | 112.458 |
| 11 | 1.0600E-04 | 1.3485E-05 | 3.1529E-04 | 0.0000E+00 | 4.3285E-06 | 2.1643E-06 | 0.0000E+00 | 4.4127E-04 | 112.318 |

[a] This assumes that the internal convenience cans, polyethylene or Teflon FEP bottles, and Cat 277-4 spacer cans are not sealed.

[b] $n_{MNOP}$—molar quantity of the gas mixture at maximum normal operating pressure at standard temperature [25°C (77°F)];
$n_{po}$—molar quantity of gas due to offgassing of the silicone rubber pads;
$n_{bo}$—molar quantity of gas due to offgassing of the polyethylene bags, bottles, and lifting sling;
$n_{tf}$—molar quantity of gas due to offgassing of the Teflon bottles;
$n_{r-H2}$—molar quantity of hydrogen gas due to radiolysis of water;
$n_{r-O2}$—molar quantity of oxygen gas due to radiolysis of water;
$n_{CE-WV}$—molar quantity of water vapor due to efflorescence of UNX crystals; and
$n_T$—total molar quantity in the gas mixture.

[c] Efflorescence of UNX crystals as water vapor.

The offgassing material limits identified in assumptions 4 and 5 have been established based on the needs of shippers. All configurations are limited to 500 g of polyethylene in the form of bags, slings, and/or bottles. When the requirement to ship material in Teflon bottles arose, the upper limit of 1490 g of offgassing material was established. This limit is a combination of three Teflon bottles (330 g per bottle) and the original 500 g allowance for polyethylene material. These offgassing material limits have been used in calculations pertaining to containment vessel pressure, radioactive material leakage criteria, and criticality control. Therefore, portions of the safety basis for this shipping package have been based on these material limits.

## 3.2 MATERIAL PROPERTIES AND COMPONENT SPECIFICATIONS

### 3.2.1 Material Properties

Thermal properties at various temperatures for the stainless steel used in the fabrication of the drum, noncombustible cast refractory (Kaolite 1600), noncombustible neutron poison [BoroBond 4 (initial design) or Cat 277-4 (final design)], silicone rubber pads, and air are listed in Table 3.8. Properties used to evaluate thermal stresses due to differences in coefficient of thermal expansion are listed in Table 3.9.

### 3.2.2 Component Specifications

Component specifications are listed in Tables 3.10 and 3.11.

**Table 3.8. Thermal properties of the materials used in the thermal analysis**

| Material | Temperature (°F) | Thermal conductivity (Btu/h-in.-°F) | Density ($lb_m/in.^3$) | Specific heat ($Btu/lb_m$-°F) | Emissivity |
|---|---|---|---|---|---|
| Stainless steel | −279.67 | 0.443 [a] | 0.285 [a] | 0.065 [a] | 0.22 [a] |
| | −99.67 | 0.607 | – | 0.096 | – |
| | 260.33 | 0.799 | – | 0.123 | – |
| | 620.33 | 0.953 | – | 0.133 | – |
| | 980.33 | 1.088 | – | 0.139 | – |
| | 1340.33 | 1.223 | – | 0.146 | – |
| | 1700.33 | 1.348 | – | 0.153 | – |
| | 2240.33 | 1.526 | – | 0.163 | – |
| Kaolite 1600 | 68 | 0.0093 [b] | 0.011 [c] | 0.2 [d] | – |
| | 212 | 0.0091 | – | – | – |
| | 392 | 0.0081 | – | – | – |
| | 572 | 0.0072 | – | – | – |
| | 1112 | 0.0082 | – | – | – |
| Neutron poison (Cat 277-4) | −31 | 0.0457 [e] | 0.0579 [f] | 0.125 [e] | – |
| | 73.4 | 0.0485 | – | 0.186 | – |
| | 140 | 0.04 | – | 0.239 | – |
| | 212 | 0.0295 | – | 0.242 | – |
| | 302 | 0.0305 | – | 0.291 | – |
| Neutron poison (BoroBond4) | 25 | 0.0450 [g] | 0.0683 [g] | 0.2160 [g] | – |
| | 77 | 0.0576 | – | – | – |
| | 100 | 0.0632 | – | – | – |
| | 104 | 0.0642 | – | – | – |
| Silicone rubber | – | 0.0161 [h] | 0.047 [h] | 0.300 [h] | 1.0 [i] |
| Air | −9.67 | $1.074 \times 10^{-3}$ [a] | $4.064 \times 10^{-5}$ [a, j] | 0.240 [a] | – |
| | 80.33 | $1.266 \times 10^{-3}$ | – | 0.241 | – |
| | 170.33 | $1.445 \times 10^{-3}$ | – | 0.241 | – |
| | 260.33 | $1.628 \times 10^{-3}$ | – | 0.242 | – |
| | 350.33 | $1.796 \times 10^{-3}$ | – | 0.244 | – |
| | 440.33 | $1.960 \times 10^{-3}$ | – | 0.246 | – |
| | 530.33 | $2.114 \times 10^{-3}$ | – | 0.248 | – |
| | 620.33 | $2.258 \times 10^{-3}$ | – | 0.251 | – |
| | 710.33 | $2.393 \times 10^{-3}$ | – | 0.254 | – |
| | 800.33 | $2.523 \times 10^{-3}$ | – | 0.257 | – |
| | 890.33 | $2.644 \times 10^{-3}$ | – | 0.260 | – |
| | 980.33 | $2.759 \times 10^{-3}$ | – | 0.263 | – |
| | 1070.33 | $2.870 \times 10^{-3}$ | – | 0.265 | – |
| | 1160.33 | $2.985 \times 10^{-3}$ | – | 0.268 | – |

**Table 3.8. Thermal properties of the materials used in the thermal analysis**

| Material | Temperature (°F) | Thermal conductivity (Btu/h-in.-°F) | Density ($lb_m/in.^3$) | Specific heat ($Btu/lb_m$-°F) | Emissivity |
|---|---|---|---|---|---|
| | 1250.33 | $3.096 \times 10^{-3}$ | – | 0.270 | – |
| | 1340.33 | $3.212 \times 10^{-3}$ | – | 0.273 | – |
| | 1520.33 | $3.443 \times 10^{-3}$ | – | 0.277 | – |

[a] Incropera and DeWitt.
[b] ORNL/TM-2003/49.
[c] Based on a baked density of 19.4 lbm/ft$^3$ (0.011 lbm/in.$^3$). Specification JS-YMN3-801580-A003 (Appendix 1.3.4) requires a baked density of 22.4 ± 3 lbm/ft$^3$. Using a lower value for the Kaolite density results in higher temperatures on the containment vessel because the heat capacity of the Kaolite is minimized—allowing more heat to flow to the containment vessel; therefore, the thermal analyses are performed using a low-end density of 19.4 lbm/ft$^3$. The HAC analyses also consider a high-end density of 30 lbm/ft$^3$.
[d] Breuer, fax communication to J. C. Anderson.
[e] ORNL/TM-2004/290. Specific heat values are presented in MJ/m$^3$-K and converted to mass-based units using a density of 105 lbm/ft$^3$.
[f] Based on a cured density of 100 lbm/ft$^3$ (0.0579 lbm/in.$^3$). Y/DW-1987, presents a range of measured densities between ~100 and 110 lbm/ft$^3$ for Cat 277-4. Therefore, in order to minimize the heat capacity of the material and allow more heat to be transferred to the containment vessel, the lower-end value is used. The HAC analyses also consider a high-end density of 110 lbm/ft$^3$.
[g] Hall, e-mail communication with presentation attachment to G. A. Byington.
[h] Therm 1.2.
[i] Conservatively modeled as 1.0.
[j] Constant density evaluated at 100°F.

**Table 3.9. Mechanical properties of the materials used in the static stress analyses**

| Material | Temperature (°F) | Modulus of elasticity (psi) | Poisson's ratio | Density ($lb_m/in.^3$) | Coefficient of thermal expansion (in./in./°F) |
|---|---|---|---|---|---|
| Stainless steel | −40 | $28.6 \times 10^6$ [a] | 0.29 [b] | 0.285 [d] | $8.2 \times 10^{-6}$ [e] |
| | 100 | $28.14 \times 10^6$ | — | — | $8.6 \times 10^{-6}$ |
| | 200 | $27.6 \times 10^6$ | — | — | $8.9 \times 10^{-6}$ |
| | 300 | $27.0 \times 10^6$ | — | — | $9.2 \times 10^{-6}$ |
| Kaolite | — | 29,210 [c] | 0.01 [c] | 0.013 [f] | $5.04 \times 10^{-6}$ [g] |
| Neutron absorber (Cat 277-4) | −40 | $1.991 \times 10^6$ [h] | 0.33 [h] | 0.0608 [h] | $7.056 \times 10^{-6}$ [i] |
| | −4 | — | — | — | $7.222 \times 10^{-6}$ |
| | 32 | — | — | — | $7.222 \times 10^{-6}$ |
| | 70 | $0.984 \times 10^6$ | 0.28 | — | — |
| | 100 | $0.403 \times 10^6$ | 0.25 | — | — |
| | 104 | — | — | — | $7.000 \times 10^{-6}$ |
| | 140 | — | — | — | $6.444 \times 10^{-6}$ |
| | 176 | — | — | — | $5.778 \times 10^{-6}$ |
| | 212 | — | — | — | $5.389 \times 10^{-6}$ |
| | 248 | — | — | — | $5.056 \times 10^{-6}$ |
| | 284 | — | — | — | $4.889 \times 10^{-6}$ |
| | 302 | — | — | — | $4.833 \times 10^{-6}$ |

[a] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Subpart 2, Tables TE-1, B column, and TM-1.
[b] STRAIN 2.0.
[c] DAC-EA-801699-A001. (The Poisson's ratio of Kaolite is assumed to be a small value of 0.01.)
[d] Incropera and DeWitt.
[e] MIL-HDBK-5H.
[f] Specification JS-YMN3-801580-A003 (Appendix 1.3.4) requires a baked density of 22.4 ± 3 $lbm/ft^3$.
[g] E-mail communication, Ken Moody (Thermal Ceramics, Inc.) to Paul Bales (BWXT Y-12), December 9, 2004.
[h] Y/DW-1987.
[i] ORNL/TM-2004/290. Coefficient of thermal expansion at each temperature taken as the maximum of values for Runs 2, 3, and 5.

**Table 3.10. ES-3100 packaging material specifications**

| Component | Specifications |
|---|---|
| | **Drum assembly** |
| Drum washers | 1.375 OD × 0.812 ID × 0.25 in. thick, 300 Series stainless steel |
| Drum threaded weld studs | 5/8-11 × 7/8 Lg, ARC FT, Type 304 or 304L stainless-steel studs |
| Drum hex nuts | $\frac{5}{8}$-11 UNC-2B, silicon bronze C65100 |
| Drum lid weldment | Modified 30-gal, 16-gauge (MS27683) lid, Type 304 or 304L stainless steel; and an 11-gauge-thick sheet, Type 304 or 304L stainless steel, ASME SA-240 |
| Drum weldment | Modified 30-gal, 16-gauge (MS27683), Type 304 or 304L stainless steel, ASME SA-240, manufactured per Drawing M2E801580A004 (Appendix 1.3.7) |
| Drum plugs | Nylon plastic plug, Micro Plastic, Inc. |
| | **Impact limiter, insulation enclosure, neutron absorber, and drum packing material** |
| Insulation and impact limiter (not removable) | Lightweight cast refractory insulation, Kaolite 1600, 358.8 ±48.1 kg/m$^3$ (22.4 ±3 lb/ft$^3$) density, cast in stainless-steel shells in the drum and top plug |
| Neutron absorber | Cat 277-4, 1681.9 + 240.3/−80.1 kg/m$^3$ (105 + 15/−5 lb/ft$^3$) density |
| Top plug (removable) | Type 304 or 304L stainless steel, ASME SA-240 (body), ASME SA-479 (lifting inserts) |
| Inner liners | Type 304 or 304L stainless steel, ASME SA-240 (body), ASME SA-479 (modified angle) |
| Silicone pads | Silicone rubber, 22 ±5 Shore A, color black/gray |
| Aluminum foil duct tape | McMaster Carr Part # 7616A21, temperature range −40 to 121°C (−40 to 250°F) |
| | **Containment vessel** |
| Containment vessel plug | Part # 04-2126, Modified VCO threaded plug with O-ring, brass |
| Containment vessel hoist ring | 3052T56, Swivel hoist ring, alloy steel (not used for shipment) |
| Containment vessel | Method 1: Type TP304L stainless steel ASME SA-312 (seamless pipe body); Type F304L, stainless steel, ASME SA-182 (flange and end cap); Type 304, stainless steel, ASME SA-479 (sealing lid), Nitronic 60 stainless steel per ASME SA-479, UNS-S21800 (closure nut)<br>Method 2: Type F304L stainless-steel ASME SA-182 (body, flange, and end cap); Type 304, stainless steel, ASME SA-479 (sealing lid), Nitronic 60 stainless steel per ASME SA-479, UNS-S21800 (closure nut)<br>All components per *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Table 2A |
| Containment vessel O-rings | Elastomer, ethylene propylene diene monomer, Specification M3BA712A14B13F17 in ASTM D 2000 per SPC-M801580-0002 (Appendix 1.3.10); or fluorocarbon elastomer (Parker Compound VM835-75), SAE AMS-R-83485 per SPC-M801580-0001 (Appendix 1.3.9) |
| Containment vessel lid assembly retaining ring | Smalley Steel Ring Co., Part #WSM-400-S02, Type 302 stainless steel |
| Containment vessel O-ring lubricant | Clear dimethyl siloxane polymer |

**Table 3.10. ES-3100 packaging material specifications**

| Component | Specifications |
|---|---|
| Containment vessel closure nut lubricant | Krytox #240AC |
| Containment vessel body dowel pins | 0.2501/0.2503-in. OD × 0.50-in. long, 18-8 stainless steel |
| | **Containment vessel packing material** |
| Convenience cans | Stainless steel, aluminum, or tinned carbon steel with stainless-steel can handles and nylon-coated stainless-steel wire; nickel-alloy (200 series, passivated) in nylon mesh bag |
| Convenience bottles | Polyethylene, glass, or Teflon FEP |
| Silicone rubber pads | Silicone rubber, 22 ±5 Shore A, color black/gray |
| Can spacers | Stainless-steel can filled with Cat 277-4 |
| Bagging | Polyethylene |
| Metal scouring scrubbers | Stainless steel, McMaster Carr Part #7361T13 |

**Table 3.11. Component allowable service temperature and pressure**

| Component | Allowable service temperature range [°C (°F)] | Allowable pressure range [kPa (psia)] |
|---|---|---|
| **Drum assembly** | | |
| Stainless-steel drum and lid | −40 to 871 (−40 to 1600) [a] | 48.3 (7) |
| Silicon bronze nuts | −40 to 871 (−40 to 1600) [a] | N/A |
| Stainless-steel washers | −40 to 871 (−40 to 1600) [a] | N/A |
| Stainless-steel mid liner | −40 to 871 (−40 to 1600) [a] | N/A |
| Stainless-steel inner liner | −40 to 871 (−40 to 1600) [b] | N/A |
| Stainless-steel top plug weldment | −40 to 871 (−40 to 1600) [a] | N/A |
| Kaolite 1600 | −40 to 871 (−40 to 1600) [a] | N/A |
| Cat 277-4 | −40 to 150 (−40 to 302) [c] | N/A |
| Silicone rubber pads | −40 to 232 (−40 to 450) | N/A |
| **Containment vessel** | | |
| Stainless-steel body and sealing lid | −40 to 427 (−40 to 800) [d] | 149.62 (21.7) external<br>699.82 (101.5) internal |
| Nitronic 60 closure nut | −40 to 427 (−40 to 800) [d] | 149.62 (21.7) external<br>699.82 (101.5) internal |
| Stainless-steel retaining ring | −40 to 427 (−40 to 800) [d] | N/A |
| Dowel pins | −40 to 427 (−40 to 800) [d] | N/A |
| Brass VCO plug (with O-ring) | −40 to 204 (−40 to 400) [e] | |
| Fluorocarbon elastomer O-rings | −40 to 204 (−40 to 400) [e] | $5.52 \times 10^3$ (800) with no backing rings [e] |
| Ethylene propylene diene monomer O-rings | −40 to 150 (−40 to 302) [e] | $5.52 \times 10^3$ (800) with no backing rings [e] |
| Containment vessel silicone pads | −40 to 232 (−40 to 450) | N/A |

[a] This limit is established by the proximity of the Kaolite 1600 material.
[b] This limit is established based on the fact that the inner liner material is identical to the drum material.
[c] This limit is established based on criticality limits of moisture loss.
[d] This limit is established by the *ASME Boiler and Pressure Vessel Code.*
[e] This limit is provided by the *Parker O-Ring Handbook* for each material's continuous service limit.

## 3.3 THERMAL EVALUATION UNDER NORMAL CONDITIONS OF TRANSPORT

Thermal evaluation of the package design for NCT was performed by analysis and documented in DAC-PKG-801699-A001 and DAC-PKG-801940-A001.

DAC-PKG-801699-A001 uses a two-dimensional axisymmetric finite element model of the ES-3100 shipping container constructed using MSC.Patran and imported as an orphaned mesh into ABAQUS/CAE for application of boundary conditions, interactions, and loads. MSC.Patran and ABAQUS/CAE have been benchmarked against physical test data for a Y-12 packaging application and shown to provide accurate results (DAC-PKG-801805-A003). The model was constructed of DCAX4 (four-node linear axisymmetric heat transfer quadrilateral) and DCAX3 (3-node linear axisymmetric heat transfer triangular) elements for evaluation for NCT and HAC. The actual contents of the ES-3100 shipping container were not specifically modeled—instead, the content source heat load (if desired) was modeled

by applying a uniform heat flux to the inner surfaces of the containment vessel. This was a conservative approach in that package temperatures will not be reduced in a transient analysis by the heat capacity of the contents. Thermal properties of the materials used in the analysis are presented in Table 3.8. Prior to the change of neutron absorber from BoroBond4 to Cat 277-4, parameters, such as Kaolite 1600 density, BoroBond4 thermal conductivity, and decay heat loads, were varied to encompass the range of potential variations in material properties. The available thermal conductivity information on BoroBond4 was limited to moderate temperatures in the range of −3.89°C (25°F) to 40°C (104°F) [Hall 2004]. Using the available thermal conductivity data for BoroBond4, thermal analyses for NCT and HAC were performed and are documented in DAC-PKG-801699-A001. Nodal locations for temperatures presented are shown in Fig. 3.1.

Based on the results reported in DAC-PKG-801699-A001 and shown in Tables 3.12 and 3.13, it was determined that the higher temperatures occurred when the lowest density of the Kaolite 1600 was used. Therefore, a subsequent analysis using the proposed Cat 277-4 neutron absorber during NCT with a Kaolite 1600 density of 19.4 $lb/ft^3$ was conducted and documented in DAC-PKG-801940-A001. A two-dimensional axisymmetric finite element model of the ES-3100 shipping container was constructed using ANSYS software for application of boundary conditions, interactions, and loads. A schematic of the finite element model is presented in Fig. 3.2 with details of the upper and lower portions of the model shown in Figs. 3.3 and 3.4, respectively. The model consists of five materials: stainless steel (drum, liners, and containment vessel), Kaolite, neutron absorber, silicone rubber, and air in the gaps between the drum liner and containment vessel and between the drum liner and top plug. Degree-of-freedom “ties” are made at the interfaces of the different material regions in order to allow the heat to flow through the model. The actual contents of the ES-3100 shipping container are not specifically modeled—instead, the content source heat load (if desired) is modeled by applying a uniform heat flux to the inner surfaces of the containment vessel. This is a conservative approach in that package temperatures will not be reduced in a transient analysis by the heat capacity of the contents. The results for the steady state condition at 38°C (100°F) in the shade, and the transient condition of applying solar insolation are shown in Tables 3.14 and 3.15 for the proposed configuration (package with Cat 277-4 neutron absorber).

### 3.3.1 Heat and Cold

The ambient temperature requirement for NCT is 38°C (100°F). Since the components to be shipped have an assumed decay heat load of 5 W, a thermal analysis was conducted for the ES-3100 package with and without full solar insolation. The maximum predicted temperature, while stored at 38°C (100°F) in the shade, for the external drum assembly and the containment vessel is 40.22°C (104.39°F) and 46.45°C (115.61°F), respectively. The analysis shows that no accessible surface of the package would have a temperature exceeding 50°C (122°F). Therefore, the requirement of 10 CFR 71.43(g) would be satisfied for either transportation mode (exclusive use or nonexclusive use).

If the package is exposed to solar radiation at 38°C (100°F) in still air, the conservatively calculated temperatures at the top of the drum, on the top surface of the containment vessel, and on the containment vessel near the O-ring sealing surfaces, are 118.86°C (245.94°F), 91.92°C (197.46°F), and 91.87°C (197.36°F), respectively, for the ES-3100 (Table 3.15). These temperatures are within the service limits of all packaging components, including the O-rings. The normal service temperature range of the O-rings used in the containment boundary is −40 to 150°C (−40 to 302°F) for the ethylene propylene diene monomer (EPDM) O-rings and −40 to 204°C (−40 to 400°F) for the fluorocarbon elastomer O-rings [Table 3.11], in accordance with *Parker O-Ring Handbook.* Thus, the seal will not be affected by this maximum normal operating temperature.

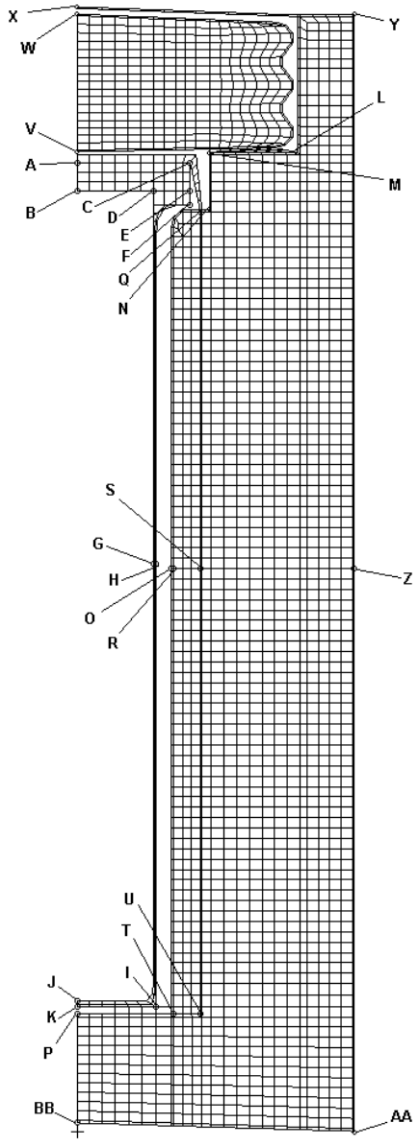



**Fig. 3.1. MSC.Patran axisymmetric finite element model of the ES-3100 shipping container with BoroBond 4—nodal locations of interest (elements representing air not shown for clarity).**

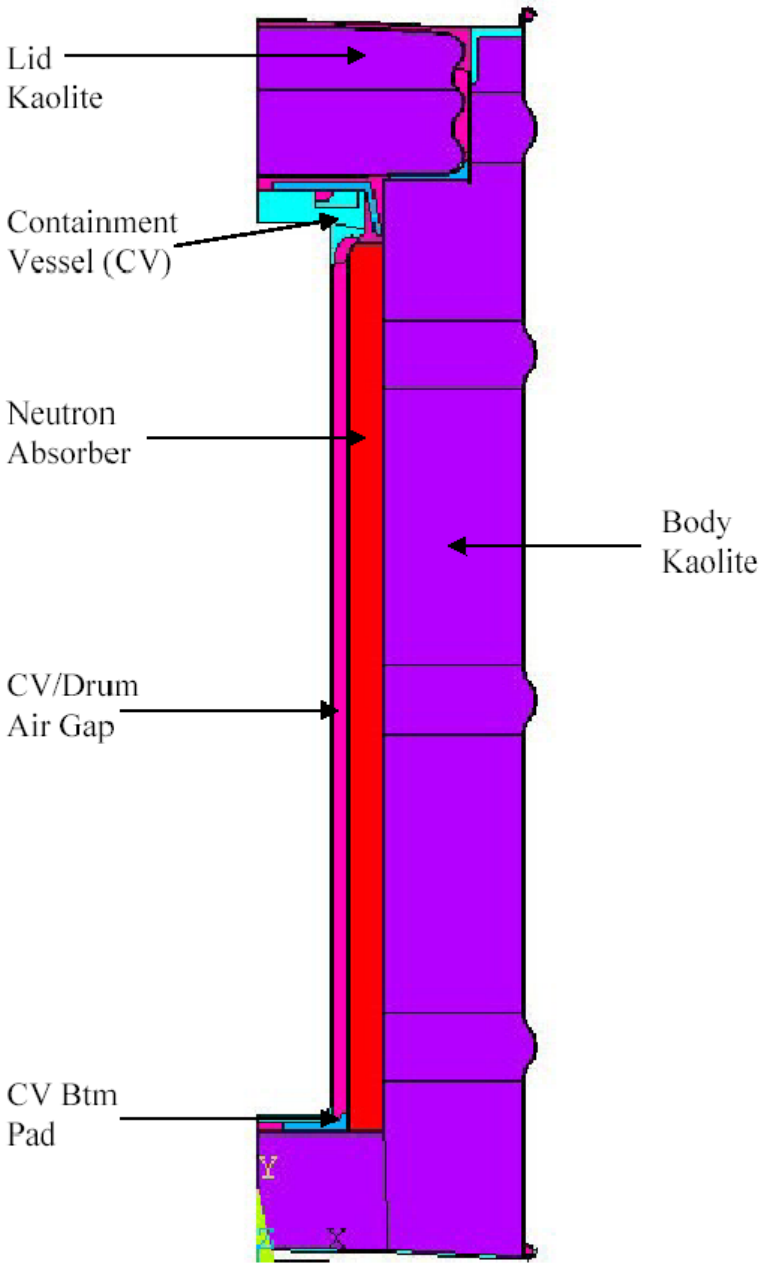



**Fig. 3.2. ANSYS axisymmetric finite element model of the ES-3100 shipping container with Cat 277-4.**

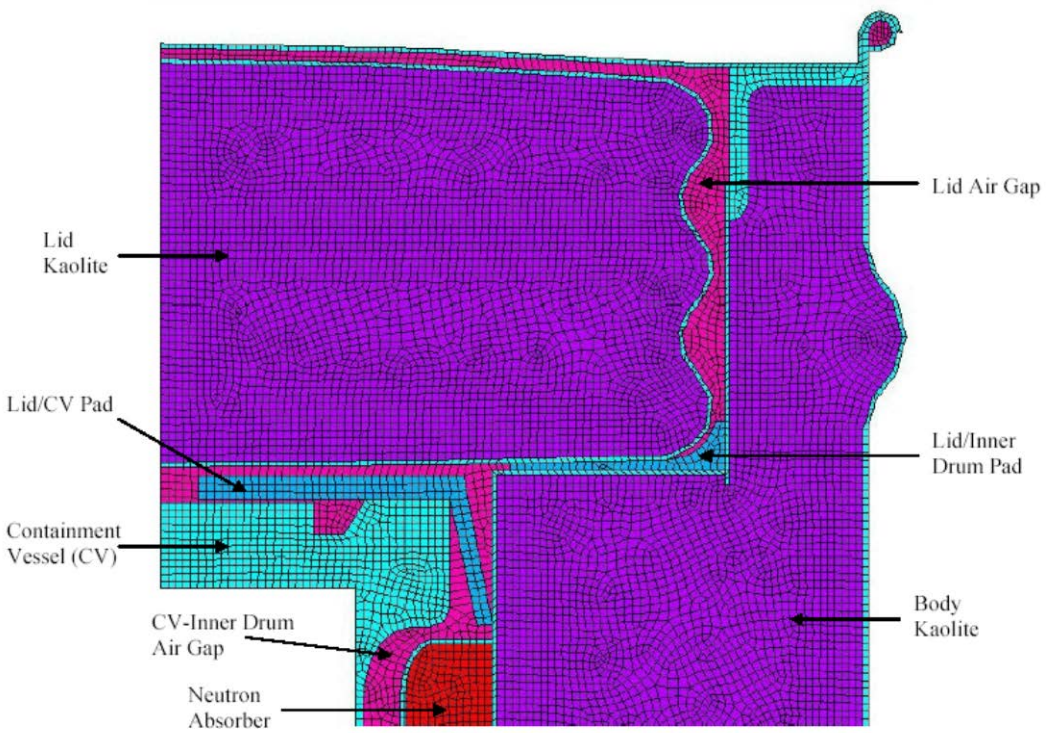



**Fig. 3.3. ANSYS axisymmetric finite element model of the ES-3100 shipping container with Cat 277-4 (upper portion detail).**

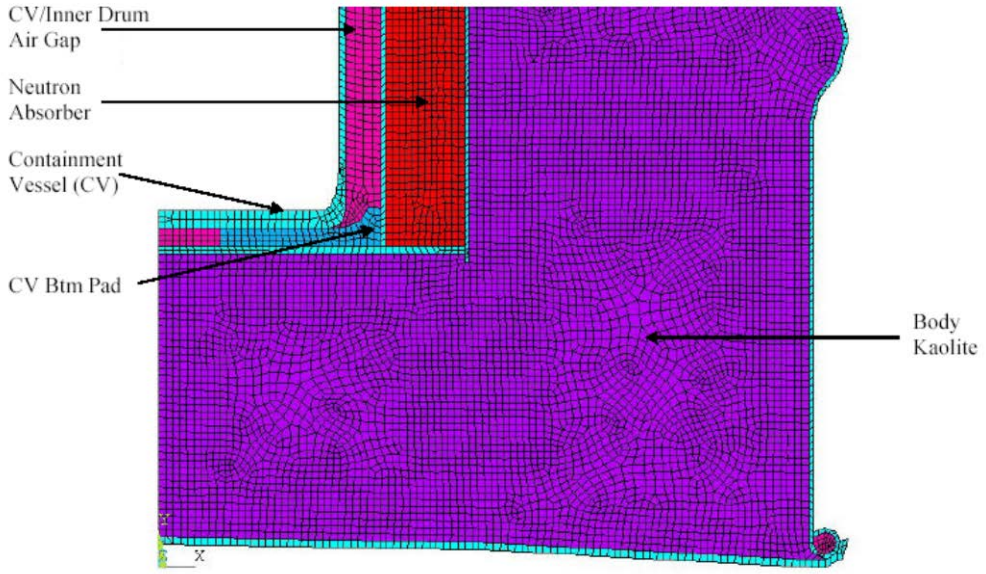



**Fig. 3.4. ANSYS axisymmetric finite element model of the ES-3100 shipping container with Cat 277-4 (lower portion detail).**

**Table 3.12. Maximum "quasi steady-state" temperatures during NCT for the ES-3100 shipping container with various content heat loads—Kaolite density of 19.4 lb/ft$^3$ and BoroBond4**

| Node [a] | Location | Maximum "quasi steady-state" temperature, °C (°F) [c] | | | |
|---|---|---|---|---|---|
| | | 0 W | 0.4 W | 20 W | 30 W |
| A | CV [d] lid, top, center | 88.30 (190.95) | 88.62 (191.52) | 103.84 (218.91) | 111.35 (232.42) |
| B | CV lid, bottom, center | 88.28 (190.90) | 88.60 (191.48) | 103.90 (219.03) | 111.45 (232.62) |
| C | CV lid, top, outer | 88.32 (190.97) | 88.63 (191.54) | 103.61 (218.50) | 111.00 (231.80) |
| D | CV flange at interface, inner [b] | 88.24 (190.83) | 88.56 (191.41) | 103.87 (218.96) | 111.42 (232.55) |
| E | CV flange at interface, outer [b] | 88.25 (190.84) | 88.56 (191.41) | 103.77 (218.78) | 111.27 (232.28) |
| F | CV flange, bottom, outer | 88.24 (190.82) | 88.55 (191.39) | 103.75 (218.75) | 111.25 (232.24) |
| G | CV shell, mid-height, inner | 83.04 (181.47) | 83.61 (182.50) | 110.50 (230.89) | 123.46 (254.23) |
| H | CV shell, mid-height, outer | 83.04 (181.47) | 83.61 (182.50) | 110.49 (230.88) | 123.45 (254.21) |
| I | CV bottom, outer | 83.36 (182.04) | 83.75 (182.74) | 102.58 (216.64) | 111.99 (233.59) |
| J | CV bottom, center, inner | 88.37 (182.07) | 83.76 (182.77) | 102.70 (216.86) | 112.17 (233.91) |
| K | CV bottom, center, outer | 88.37 (181.07) | 83.76 (182.77) | 102.69 (216.84) | 112.15 (233.87) |
| L | Drum liner, plug cavity, outer | 98.72 (209.70) | 98.80 (209.85) | 102.63 (216.73) | 104.58 (220.24) |
| M | Drum liner, plug cavity, inner | 94.43 (201.97) | 94.58 (202.24) | 101.92 (215.46) | 105.65 (222.16) |
| N | Drum liner, CV flange cavity, outer | 89.43 (192.97) | 89.63 (193.34) | 99.83 (211.70) | 105.01 (221.02) |
| O | Drum liner, CV cavity, mid-height, inner | 83.12 (181.62) | 83.43 (182.18) | 98.63 (209.54) | 106.40 (223.52) |
| P | Drum liner, CV cavity, bottom, inner | 83.62 (182.52) | 83.96 (183.13) | 100.36 (212.65) | 108.60 (227.48) |
| Q | Borobond4, top, outer | 88.82 (191.88) | 89.04 (192.27) | 99.65 (211.38) | 105.04 (221.07) |
| R | Borobond4, mid-height, inner | 83.12 (181.62) | 83.43 (182.18) | 98.63 (209.53) | 106.39 (223.51) |
| S | Borobond4, mid-height, outer | 83.03 (181.46) | 83.33 (182.00) | 97.91 (208.23) | 105.36 (221.65) |
| T | Borobond4, bottom, inner | 83.55 (182.39) | 83.85 (182.93) | 98.58 (209.45) | 106.03 (222.86) |
| U | Borobond4, bottom, outer | 83.51 (182.31) | 83.80 (182.83) | 97.82 (208.07) | 104.90 (238.82) |
| V | Drum plug liner, bottom, center | 112.01 (233.62) | 112.05 (233.69) | 113.95 (237.11) | 114.90 (238.82) |
| W | Drum plug liner, top, center | 92.09 (197.77) | 92.31 (198.16) | 102.93 (217.27) | 108.26 (226.87) |
| X | Drum lid, top, center | 118.01 (244.42) | 118.03 (244.45) | 118.77 (245.79) | 119.15 (246.47) |
| Y | Drum lid, top, outer | 107.33 (225.19) | 107.34 (225.22) | 108.22 (226.80) | 108.67 (227.60) |
| Z | Drum, mid-height, outer | 92.27 (198.08) | 92.30 (198.14) | 93.81 (200.86) | 94.58 (202.24) |
| AA | Drum bottom, outer | 91.70 (197.06) | 91.74 (197.13) | 93.61 (200.49) | 94.54 (202.18) |
| BB | Drum bottom, center | 88.82 (191.88) | 88.93 (192.07) | 93.84 (200.91) | 96.30 (205.35) |

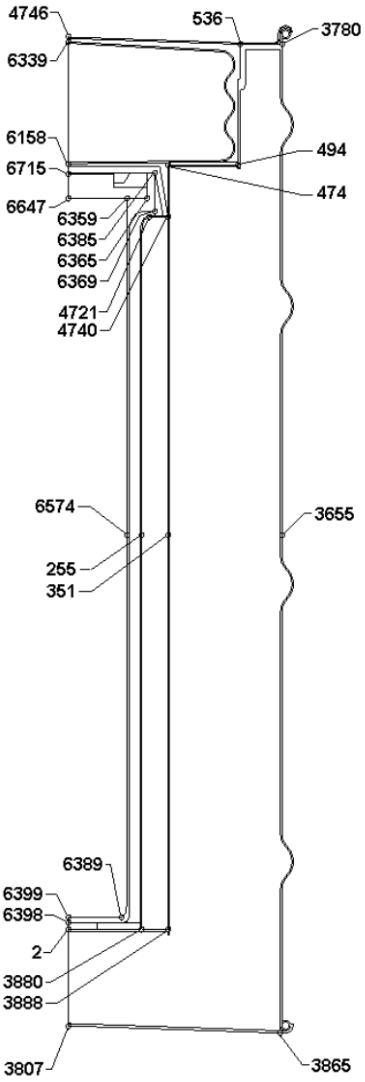
[a] See Fig. 3.1.
[b] Approximate location of the CV O-ring.
[c] Temperatures calculated in DAC-PKG-801699-A001.
[d] CV—containment vessel.

**Table 3.13. Maximum "quasi steady-state" temperatures during NCT for the ES-3100 shipping container with various content heat loads—Kaolite density of 30 lb/ft$^3$ and BoroBond4**

| Node [a] | Location | Maximum "quasi steady-state" temperature, °C (°F) [c] | | | |
|---|---|---|---|---|---|
| | | 0 W | 0.4 W | 20 W | 30 W |
| A | CV [d] lid, top, center | 86.56 (187.81) | 86.88 (188.38) | 102.98 (215.74) | 109.59 (229.26) |
| B | CV lid, bottom, center | 86.56 (187.80) | 86.88 (188.38) | 102.16 (215.90) | 109.71 (229.47) |
| C | CV lid, top, outer | 86.54 (187.78) | 86.86 (188.34) | 101.89 (215.41) | 109.31 (228.75) |
| D | CV flange at interface, inner [b] | 86.47 (187.64) | 86.79 (188.21) | 102.09 (215.77) | 109.67 (229.40) |
| E | CV flange at interface, outer [b] | 86.44 (187.59) | 86.76 (188.16) | 102.00 (215.61) | 109.53 (229.15) |
| F | CV flange, bottom, outer | 86.42 (187.56) | 86.74 (188.13) | 101.99 (215.58) | 109.51 (229.12) |
| G | CV shell, mid-height, inner | 81.52 (178.74) | 82.09 (179.76) | 109.01 (228.21) | 121.98 (251.57) |
| H | CV shell, mid-height, outer | 81.52 (178.74) | 82.09 (179.76) | 109.00 (228.19) | 121.97 (251.55) |
| I | CV bottom, outer | 81.32 (178.37) | 81.71 (179.08) | 100.57 (213.02) | 109.99 (229.99) |
| J | CV bottom, center, inner | 81.37 (178.47) | 81.77 (179.18) | 100.73 (213.31) | 110.21 (230.38) |
| K | CV bottom, center, outer | 81.37 (178.47) | 81.77 (179.18) | 100.72 (213.29) | 110.19 (230.34) |
| L | Drum liner, plug cavity, outer | 97.74 (207.93) | 97.82 (208.07) | 101.65 (214.96) | 103.59 (218.47) |
| M | Drum liner, plug cavity, inner | 92.91 (199.23) | 93.06 (199.50) | 100.40 (212.72) | 104.13 (219.43) |
| N | Drum liner, CV flange cavity, outer | 87.69 (189.84) | 87.90 (190.21) | 98.09 (208.57) | 103.27 (217.43) |
| O | Drum liner, CV cavity, mid-height, inner | 81.30 (178.35) | 81.61 (178.90) | 96.82 (206.27) | 104.13 (219.43) |
| P | Drum liner, CV cavity, bottom, inner | 81.52 (178.74) | 81.86 (179.35) | 98.30 (208.94) | 106.56 (223.80) |
| Q | Borobond4, top, outer | 87.36 (189.25) | 87.58 (189.64) | 98.19 (208.74) | 103.57 (218.43) |
| R | Borobond4, mid-height, inner | 81.30 (178.35) | 81.61 (178.90) | 98.81 (206.26) | 104.58 (220.24) |
| S | Borobond4, mid-height, outer | 81.37 (178.46) | 81.66 (178.99) | 96.24 (205.23) | 103.69 (218.64) |
| T | Borobond4, bottom, inner | 81.67 (179.01) | 81.98 (179.56) | 96.73 (206.12) | 104.19 (219.55) |
| U | Borobond4, bottom, outer | 81.78 (179.21) | 82.07 (179.72) | 96.11 (205.00) | 103.23 (217.81) |
| V | Drum plug liner, bottom, center | 111.30 (232.35) | 111.34 (232.42) | 113.25 (235.85) | 114.21 (237.57) |
| W | Drum plug liner, top, center | 90.70 (195.26) | 90.92 (195.66) | 101.53 (214.76) | 106.87 (224.36) |
| X | Drum lid, top, center | 117.74 (243.93) | 117.75 (243.96) | 118.50 (245.30) | 118.88 (245.98) |
| Y | Drum lid, top, outer | 107.04 (224.68) | 107.06 (224.71) | 107.94 (226.29) | 108.39 (227.10) |
| Z | Drum, mid-height, outer | 91.86 (197.36) | 91.90 (197.41) | 93.42 (200.15) | 94.18 (201.53) |
| AA | Drum bottom, outer | 91.00 (195.79) | 91.04 (195.86) | 92.92 (199.26) | 93.87 (200.96) |
| BB | Drum bottom, center | 87.21 (188.97) | 87.31 (189.15) | 92.26 (198.07) | 94.74 (202.54) |

[a] See Fig. 3.1.
[b] Approximate location of the CV O-ring.
[c] Temperatures calculated in DAC-PKG-801699-A001.
[d] CV—containment vessel.

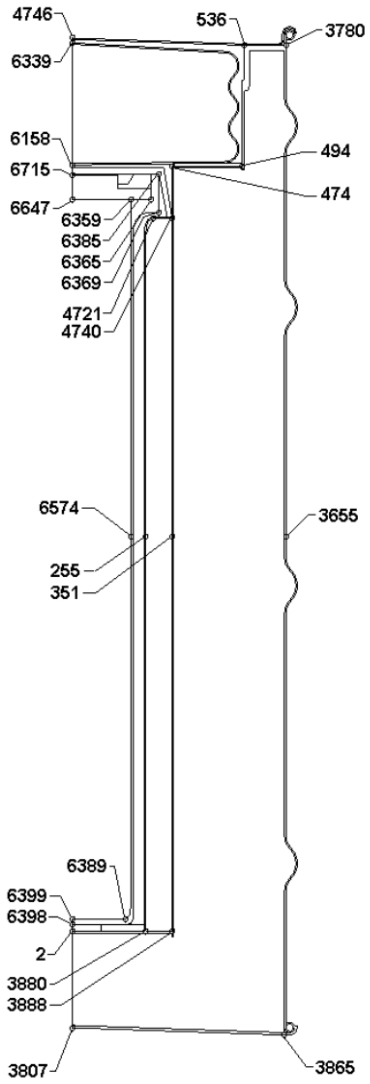
**Table 3.14. ES-3100 shipping container maximum steady-state temperatures with Cat 277-4 (no insolation)—Kaolite density of 19.4 lb/ft$^3$**

| Node map [a] | Node coordinates (in.) | | | Maximum temperature [d] (°F) | Maximum temperature [e] (°F) |
|---|---|---|---|---|---|
| | No. | r | z | 5 W | 5 W |
|  | 2 | 0.000 | 4.505 | 109.69 | 140.43 |
| | 255 | 3.180 | 21.528 | 108.66 | 139.54 |
| | 351 | 4.300 | 21.528 | 108.16 | 139.00 |
| | 474 | 4.300 | 37.535 | 104.93 | 135.75 |
| | 494 | 7.325 | 37.525 | 103.23 | 134.06 |
| | 536 | 7.385 | 42.755 | 101.81 | 132.66 |
| | 3655[c] | 9.185 | 21.528 | 102.77 | 133.57 |
| | 3780[c] | 9.185 | 42.755 | 101.71 | 132.57 |
| | 3807[c] | 0.000 | 0.320 | 104.39 | 135.15 |
| | 3865[c] | 9.185 | 0.008 | 102.96 | 133.76 |
| | 3880 | 3.178 | 4.505 | 108.46 | 139.26 |
| | 3888 | 4.300 | 4.505 | 107.99 | 138.80 |
| | 4721 | 3.500 | 35.275 | 106.60 | 137.42 |
| | 4740 | 4.300 | 35.275 | 106.30 | 137.11 |
| | 4746[c] | 0.000 | 43.065 | 101.82 | 132.68 |
| | 6158 | 0.000 | 37.579 | 106.27 | 137.05 |
| | 6339 | 0.000 | 42.859 | 102.28 | 133.10 |
| | 6359[b] | 2.530 | 36.075 | 109.38 | 140.00 |
| | 6365[b] | 3.425 | 36.075 | 109.35 | 139.96 |
| | 6369 | 3.750 | 35.525 | 109.33 | 139.95 |
| | 6385 | 3.750 | 37.175 | 109.21 | 139.83 |
| | 6389 | 2.310 | 5.025 | 111.12 | 141.81 |
| | 6398 | 0.000 | 4.775 | 110.94 | 141.65 |
| | 6399 | 0.000 | 5.025 | 110.94 | 141.65 |
| | 6574 | 2.530 | 21.528 | 115.61 | 145.99 |
| | 6647 | 0.000 | 36.075 | 109.39 | 140.01 |
| | 6715 | 0.000 | 37.135 | 109.36 | 139.97 |



[a] See Fig. 7 in DAC-PKG-801940-A001 for details of node locations.
[b] Approximate location of the containment vessel O-ring.
[c] These nodes are at the accessible surfaces of the package (i.e., the drum, drum lid, and drum bottom plate).
[d] Temperatures calculated in DAC-PKG-801940-A001 at 100°F (38°C) ambient temperature for ground transport.
[e] Temperatures calculated in DAC-PKG-801940-A001 at 131°F (55°C) ambient temperature for air transport. The maximum containment vessel temperature reported in DAC-PKG-801940-A001 is 146.11°F. This maximum temperature occurs at a node not reported in this table.

**Table 3.15. ES-3100 shipping container maximum "quasi steady-state" temperatures during NCT with various content heat loads and Cat 277-4 (100°F ambient temperature, with insolation)**

| Node map [a] | Node coordinates (in.) | | | Maximum "quasi steady-state" temperature [c] (°F) | |
|---|---|---|---|---|---|
| | No. | r | z | 0 W | 5 W |
|  | 2 | 0.000 | 4.505 | 180.74 | 188.26 |
| | 255 | 3.000 | 21.528 | 179.61 | 186.51 |
| | 351 | 4.300 | 21.528 | 179.75 | 186.00 |
| | 474 | 4.300 | 37.535 | 202.74 | 206.02 |
| | 494 | 7.325 | 37.525 | 211.30 | 212.96 |
| | 536 | 7.385 | 42.755 | 231.73 | 232.10 |
| | 3655 | 9.185 | 21.528 | 198.09 | 198.77 |
| | 3780 | 9.185 | 42.755 | 230.35 | 230.64 |
| | 3807 | 0.000 | 0.320 | 191.04 | 193.29 |
| | 3865 | 9.185 | 0.008 | 196.66 | 197.53 |
| | 3880 | 3.178 | 4.505 | 180.91 | 187.34 |
| | 3888 | 4.300 | 4.505 | 181.17 | 187.14 |
| | 4721 | 3.500 | 35.275 | 191.41 | 196.32 |
| | 4740 | 4.300 | 35.275 | 192.73 | 197.32 |
| | 4746 | 0.000 | 43.065 | 245.60 | 245.94 |
| | 6158 | 0.000 | 37.579 | 200.32 | 204.85 |
| | 6339 | 0.000 | 42.859 | 238.12 | 238.81 |
| | 6359 [b] | 2.530 | 36.075 | 190.13 | 197.36 |
| | 6365 [b] | 3.425 | 36.075 | 190.13 | 197.32 |
| | 6369 | 3.750 | 35.525 | 190.11 | 197.29 |
| | 6385 | 3.750 | 37.175 | 190.23 | 197.29 |
| | 6389 | 2.310 | 5.025 | 180.25 | 189.10 |
| | 6398 | 0.000 | 4.775 | 180.33 | 189.03 |
| | 6399 | 0.000 | 5.025 | 180.33 | 189.04 |
| | 6574 | 2.530 | 21.528 | 179.74 | 192.42 |
| | 6647 | 0.000 | 36.075 | 190.24 | 197.48 |
| | 6715 | 0.000 | 37.135 | 190.26 | 197.46 |

[a] See Fig. 7 in DAC-PKG-801940-A001 for details of node locations.
[b] Approximate location of the containment vessel O-ring.
[c] Temperatures calculated in DAC-PKG-801940-A001.

Using the temperatures calculated for the conditions of 10 CFR 71.71(c)(1), Appendix 3.5.1 predicts that the maximum normal operating pressure inside the containment vessel will be 215.24 kPa (31.218 psia). For conservatism and for use in Sects. 2 and 4 during NCT, the maximum gas temperature and the maximum normal operating pressure in the containment vessel are rounded up to 93.33°C (200.0°F), and 215.46 kPa (31.25 psia), respectively. The design absolute pressure of the containment vessel is 801.17 kPa (116.2 psia), and the hydrostatic test pressure is 1135.57 kPa (164.7 psia). Thus, increasing the internal pressure of the containment vessel to a maximum of 215.46 kPa (31.25 psia) during NCT would have no detrimental effect. Stresses generated in the containment vessel at this pressure are insignificant compared to the materials of construction allowable stress. Table 2.20 provides a summary of the pressures and temperatures for NCT. As discussed in Sect. 2.6.1.4, the containment vessel and vessel closure nut stresses for these pressure conditions are below the allowable stress values.

Prior to testing the ES-2M design (a similarly constructed shipping package), each test unit was radiographed to determine the integrity of the Kaolite 1600 impact and insulation material. Following casting of the material inside the drum, some three-dimensional curving cracks were seen in some packages near the top thinner sections from the bottom of the liner to the bottom drum edge. After vibration testing, radiography of the ES-2M TU-4 showed that the lower half of the impact limiter was broken into small pieces (GAB1296-2). To evaluate these findings, TU-4 was reassembled and subjected to HAC sequential testing (GAB1296-2). After vibration and impact testing, many three-dimensional curving cracks were seen around the impact areas, and the inner liner was also visibly deformed. Nevertheless, temperatures at the containment boundary were similar to other packages not subjected to vibration testing prior to HAC testing. No inleakage of water was recorded following immersion. Also, TU-4 of the ES-3100 shipping package was subjected to the full NCT test battery including vibration.

Following these tests, the containment vessel of the ES-2M TU-4 was removed, and a full body helium leak check was performed. The test unit passed the leak-tight criteria in accordance with ANSI N14.5-1997. The containment vessel was then reassembled into the previously tested drum assembly and subjected to the complete HAC testing. Based on the success of this unit and the similar design of the ES-2M, it can be concluded that vibration normally incident to transport does not reduce the effectiveness of the ES-3100 packaging during HAC testing. The ES-3100 has been tested to determine the effectiveness of the package following a sequential NCT 1.2-m (4-ft) drop test and HAC test battery. Throughout all of the vibration and structural testing, the effectiveness of the Kaolite 1600 material as an impact limiter and thermal insulation was not substantially reduced.

Also, in accordance with 10 CFR 71.71(c)(2), the containment vessel pressure must be calculated at −40°C (−40°F). Given the initial conditions of temperature, relative humidity, no silicone rubber or polyethylene bag offgassing, the pressure is calculated as follows:

$$P_1 \text{ @ } 25°C = P_a + P_v + P_{fo},$$

where

$P_a$ = 98.15 kPa (14.236 psia), (Appendix 3.5.1)
$P_v$ = 3.20 kPa (0.464 psia), (Appendix 3.5.1)
$P_{fo}$ = 0. (no offgassing, Appendix 3.5.1)

At −40°C (−40°F), the partial pressure of the water vapor is conservatively assumed to be zero. Therefore, the final pressure of the mixture at −40°C (−40°F) is calculated according to the ideal gas law based solely on the partial pressure of the air.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2},$$

where

$P_1$ = 98.15 kPa (14.236 psia),
$T_1$ = 25°C (298.15 K),
$T_2$ = −40°C (233.15 K),
$V_1$ = $V_2$, and

rearranging and solving for $P_2$,

$P_2$ = $P_1 (T_2 / T_1)$,
= (98.15)(233.15 / 298.15),
= 76.76 kPa (11.13 psia).

The cold condition for NCT specified in 10 CFR 71.71 is an ambient temperature in still air and shade of −40°C (−40°F). The 35.2 kg (77.60 lb) of HEU contents in the ES-3100 package generates a maximum bounding decay heat load of 5 W. However, in accordance with Nuclear Regulatory Commission (NRC) Regulatory Guide 7.8, the thermal effects of this internal heat source are neglected during evaluation of the package performance at −40°C (−40°F). When exposed to this condition, the package component temperatures will stabilize over time at a temperature approaching −40°C (−40°F). The package has been examined for use at −40°C (−40°F) (Sect. 2.6.2). No detrimental effects on the package structure or sealing capability result from this minimum temperature requirement. The normal service temperature range of the O-rings used in the containment boundary is −40 to 150°C (−40 to 302°F) for the EPDM O-rings and −40 to 204°C (−40 to 400°F) for the fluorocarbon elastomer O-rings [Table 3.11], in accordance with the *Parker O-Ring Handbook*; thus, the seal will not be affected by this minimum package temperature in accordance with 10 CFR 71.71(c)(2). Leak testing conducted on TU-2 and TU-8 to the leak tight criteria stipulated by ANSI N14.5-1997 following compliance testing provides justification of the above statements.

Summarizing 10 CFR 71.43(f), the tests and conditions of NCT shall not substantially reduce the effectiveness of the packaging to withstand HAC sequential testing. The effectiveness of the ES-3100 to withstand HAC sequential testing is not diminished through application of the tests and conditions stipulated in 10 CFR 71.71. The justification for this statement is provided by physical testing of both the ES-2M and ES-3100 test packages. Due to the similarities in design, fabrication, and material used in construction of both the ES-2M and the ES-3100 package, the Kaolite 1600 physical characteristics will hold true for both designs. The integrity of the Kaolite 1600 is not significantly affected by the NCT vibration and 1.2-m (4-ft) drop tests.

### 3.3.2 Maximum Normal Operating Pressure

The stainless-steel drum and cast refractory system will not pressurize as a result of temperature increases because of four ventilation holes (0.795 cm [0.313 in.] in diameter) drilled in the drum side wall 3.81 cm (1.5 in.) from the flanged top and equally spaced around the drum. The holes are filled with nylon plugs, but they are not hermetically sealed. The inner liner encapsulating the noncombustible neutron poison (Cat 277-4) will not pressurize as a result of temperature increases because of three ventilation holes (0.635 cm [0.25 in.] in diameter) and a slot (1.63 cm [0.64 in.] in width and 4.17 cm [1.64 in.] in

length) drilled into this inner liner. These features are covered during transport with aluminum tape to prevent contamination of the neutron poison. This tape does not represent a hermetic seal.

The maximum normal operating pressure is defined in 10 CFR 71.4 as the maximum gauge pressure that would develop in the containment system in a period of one year under the heat conditions specified in 10 CFR 71.71(c)(1). The internal pressure developed under these conditions in the ES-3100 containment vessel is calculated in Appendix 3.5.1 for the most restrictive containment vessel configurations. For conservatism, the decay heat of 5 W was used for the maximum internal heat load in evaluating the package for NCT. The maximum calculated adjusted internal absolute pressure in the containment vessel with solar insolation and the bounding case parameters is 215.46 kPa (31.25 psia). This pressure incorporates offgassing of the silicone rubber pads, polyethylene bottles, Teflon bottles, and polyethylene bagging and hydrogen gas generation from the radiolysis of water and/or other packing materials. The initial environment inside the containment vessel when assembled is at ambient temperature and pressure with 100% relative humidity. The heat-transfer capability of the packaging is not degraded due to gap creation caused by differences in the fabrication material's coefficient of thermal expansion. Modeling assumed nominal gaps and position based on the engineering drawings of Appendix 1.3.7.

### 3.3.3 Maximum Thermal Stresses

The temperature of the package under NCT will vary from a low of −40°C (−40°F) throughout the package to a maximum of 118.86 and 91.93°C (245.94 and 197.48°F) on the surface of the drum and the containment vessel, respectively (Sect. 3.3.1). The slow temperature increase or decrease experienced in normal conditions between these limits will result in an essentially uniform temperature change throughout the package. All materials of construction are within this operating temperature range (Table 3.11). Thermal stresses due to differences in thermal expansion are insignificant, as discussed in Sects. 2.6.1.2 and 2.6.2.

Most of the components of the packaging are completely unrestrained. Therefore, any thermal stresses in the packaging components as the temperature varies between the extremes listed above will have no effect on the ability of the packaging to maintain containment, shielding integrity, and nuclear subcriticality. The maximum stresses due to pressure under NCT for the containment vessel are given in Tables 2.21 and 2.22. These values are significantly below the allowable stresses for the packaging components. The Kaolite 1600 insulation and Cat 277-4 materials are poured and cast in place during the fabrication of the drum weldment (Drawing M2E801580A002, Appendix 1.3.7). This situation produces a zero gap between the these materials and the bounding drum and inner liners. Due to differences in coefficients of thermal expansion, some radial and axial interference is expected due to thermal growth or contraction of the inner liners. These radial and axial interferences and induced stresses are calculated in DAC-PKG-801940-A002. The results show that the stresses induced are minimal and do not reduce the effectiveness of the drum assembly. Further discussion of these stresses is provided in Sects. 2.6.1.2 and 2.6.2.

The containment vessel, which is Type 304L austenitic (iron-nickel-chromium) stainless steel, is designed and fabricated in accordance with Sects. III SubSect. NB and IX of the *ASME Boiler and Pressure Vessel Code*. The two sealing surfaces of each containment boundary are joined together by torquing the closure nut inside the containment vessel body to 162.7 ±6.8 N·m (120 ±5 lbf-ft). The O-ring material is either EPDM or fluorocarbon elastomer.

The design temperature range of the containment vessel is −29 to 176.7°C (−20 to 350°F) (DAC-M900000-0003). However, the package has been evaluated to −40°C (−40°F) (Sect. 2.6.2). The thermal properties of the stainless-steel container body, lid, and closure nut are not critical at these temperatures. The O-ring seal is important for the containment properties of the containment vessel. The normal service temperature range for the EPDM O-ring is −40 to 150°C (−40 to 302°F) and −40 to 204°C (−40 to 400°F) for the fluorocarbon elastomer O-rings [Table 3.11] for 1000 h of continuous service.

## 3.4 THERMAL EVALUATION UNDER HYPOTHETICAL ACCIDENT CONDITIONS

### 3.4.1 Initial Conditions

Six full-scale packages were tested in the sequence shown in Table 2.19. Each ES-3100 test package was subjected to the 1.2-m (4-ft) drop test in accordance with 10 CFR 71.71(c)(5) prior to the sequential HAC tests in accordance with 10 CFR 71.73 (free drop, crush, puncture, thermal, and immersion tests). One of these units (TU-4) had previously completed the tests and conditions stipulated in 10 CFR 71.71(c)(5) through (c)(10), excluding (c)(8). Two different mock-up configurations were used to represent the minimum and maximum proposed shipping weight and to simulate various center of gravity locations. The structural and thermal interface between the mock-up component and the containment vessel was designed to match that of the actual hardware proposed for transport. Based on LS-DYNA drop simulations (DAC-EA-801699-A001 and DAC-EA-801699-A002) the six test units with their associated test weights represent the worst drop orientations for the ES-3100 package. TU-5 used a near replicate of the lightest weight contents for its mock-up component. TU-8 was tested much later than the original five units. It was equipped with a containment vessel using Viton GLT-S O-rings instead of the EPDM O-rings and Cat 277-4 material instead of the BoroBond for the neutron poison. TU-8 was a true production unit using the flow forming fabrication method for the containment vessel. However, the drum assembly (also a production unit) was rejected based on prompt gamma-ray neutron activation analysis (PGNAA) readings and became available for further compliance testing. TU-8 also was equipped with a top plug that was ~3 lb heavier than allowed by Sect. 8.2.3.2. This failed PGNAA reading and heavy top plug issues have no significant effect on the temperature and structural response of the package when subjected to the compliance tests in accordance with 10 CFR 71.71(c)(7) and 71.73(c)(1) through (c)(5). NCT free-drop, 9-m (30-ft) free drop, 9-m (30-ft) crush and puncture tests were made as specified in 10 CFR 71.71(c)(1), and 73(c)(1) through (c)(3) on all six full-scale test packages prior to thermal testing. The results of this testing are discussed in Sects. 2.7.1, 2.7.2, and 2.7.3. The 1.2-m (4-ft), 9-m (30-ft) drop and crush test orientations were as follows: two tests with the long axis of drum at an oblique angle of 12° to impact surface; a center of gravity over the corner of the drum lid; a drop with the long axis of drum parallel with the impact surface; and a vertical drop on to the drum's lid. The subsequent 40-in. puncture drops were made at various orientations as shown in Table 2.19.

Prior to the thermal test, each test unit was preheated to the maximum temperature extreme in accordance with 10 CFR 71.73(b). Since the containment vessels were initially assembled at ~101.35 kPa (14.7 psia) at 25°C (77°F), the initial internal containment vessel pressure was ~105.70 kPa (15.33 psia) at 38°C (100°F) using the ideal gas law. In accordance with 10 CFR 71.73(b)(1), the internal pressure should be that calculated for the maximum normal operating pressure or the adjusted calculated value of 215.46 kPa (31.25 psia). This slight pressure differential has little or no effect on the thermal test results. The maximum decay heat load of the contents is calculated to be 5 W based on 35.2 kg of HEU. Analysis of the ES-3100 package after thermal HAC tests both with and without the decay heat load has been performed. The maximum projected temperature increase during HAC due to a 5 W heat source without insolation and assuming densities for Kaolite and neutron absorber that result in the largest temperature difference, as calculated in DAC-PKG-801940-A001, would be ~4.56°C (8.20°F) at the

containment vessel's top (node 6715), ~4.56°C (8.21°F) at the containment vessel's O-ring (node 6359), ~7.49°C (13.48°F) at the containment vessel's mid body (node 6574), and ~5.28°C (9.50°F) at the containment vessel bottom (node 6399). These temperature differentials are representative for both the Kaolite 1600 densities evaluated.

### 3.4.2 Fire Test Conditions

Full-scale testing in accordance with 10 CFR 71.73 for HAC was conducted on prototypical packages. Therefore, no analyses were conducted to show compliance with the HAC thermal test. However, analyses were conducted and are discussed in Sect. 3.4.3 to determine the thermal impacts of an internal heat source, application of insolation during cool down, location of crush plate impact on test unit, and thermal capacitance differences between test hardware and proposed shipping hardware.

Full-scale testing of six ES-3100 test units was conducted in accordance with 10 CFR 71.73(c)(4) for HAC. A single full-scale ES-3100 test unit (TU-4) was assembled and subjected to both NCT and to the sequential tests specified in 10 CFR 71.73(c). The furnace used for thermal testing was the No. 3 Furnace at Timken Steel Company in Latrobe, Penn., which is a gas-fired furnace. Oxygen content in stack gases from the furnace were not monitored because it was not anticipated that any of the package's materials of construction were combustible. There was some burning of the silicone pads which are placed between the inner liners and the top plugs of the packages. However, it should be noted that this furnace employs "pulsed" fire burners. This type of burner is unique in that the natural gas flow rate is varied based on furnace controller demands, but the flow of air through the burners is constant, even when no gas is flowing, thereby ensuring a very rich furnace atmosphere capable of supporting any combustion of package materials of construction.

The most significant change to the definition of the HAC thermal test in the current 10 CFR 71 is the requirement for calculation purposes to base convective heat input on "that value which may be demonstrated to exist if the package was exposed to the fire specified." This is not especially significant for this package because it was tested in the gas-fired furnace with burners placed in an attitude which produced a strong convective swirl. Careful examination of the thermal test data indicates that the total heat imparted to the packages was significantly greater than the required total heat specified in 10 CFR 71.73(c)(4). Compliance with ASTM E 2230, *Standard Practice for Thermal Qualification of Type B Packages for Radioactive Material*, was accomplished by the method described in Sect. 7.3 of this standard. This standard is in general agreement with Paragraph 2.2.1 ("Steady-state Method of Compliance") of SG 140.1 entitled *Combination Test/Analysis Method Used to Demonstrate Compliance to DOE Type B Packaging Thermal Test Requirements (30 Minute Fire Test).*

Prior to the beginning of the thermal test, the furnace was characterized for temperature and heat recovery times. The support stand was welded to a large steel plate which had been placed on the floor of the furnace prior to heating. This steel plate acted as the radiating surface at the bottom of the furnace, as well as providing the ability to hold the test stand rigidly in place. Before heating the furnace, workers practiced loading and unloading test packages from the cold furnace to ensure that the furnace door would not remain open >90 s during each loading. In fact, the maximum time the door was open during any loading was 64 s. As discussed in *Test Report of the ES-3100 Package* (ORNL/NTRC-013) and *Test Report for Certification Testing of the ES-3100 Shipping Package with Flow Formed CV and Viton O-rings* (ORNL/NTRC-047), six thermocouples were affixed to the drum assembly's exterior surface. Metal retainer clips were welded to the exterior surface to hold the thermocouples in place. The thermocouple tips were inserted underneath the metal clips, and the wire was wrapped around the metal clip. To eliminate any radiant heat exchange between the thermocouples and the furnace walls, the tips and metal clips were covered with a ceramic coating. Three thermocouples were mounted on each of the walls of the furnace, as well as on the furnace floor, on the furnace door, and three thermocouples were mounted on the test stand.

A minimum of 24 h prior to the beginning of all testing, the furnace was turned on with a set-point temperature of 871°C (1600°F). Following each test, the furnace set point was adjusted to 871°C (1600°F) for at least 45 min prior to the beginning of the next test. The furnace control data recorder ran continuously for the entire duration of the preheat cycle test. TU-1 through TU-5 and TU-8 were preheated to >38°C (100°F) by placing the packages in an environmental chamber, which was heated by a torpedo-type kerosene space heater controlled by a mechanical bulb thermostat with a control range of 38 to 93°C (100 to 200°F). The environmental chambers were similar: a welded steel frame with fiberglass insulation panels. Figure 3.5 shows the chamber used for TU-1 through TU-5, which was heated from the bottom with four floor register vents located around the perimeter and a 20.32-cm (8-in.)–diam manual dampened center venting stove pipe. For a visual description of the setup used for TU-8, see Fig. 5.26 in ORNL/NTRC-047.

The set point temperature of the environmental chamber was monitored and adjusted for the duration of the preheat cycle. Initially, the thermostat was set to 66°C (150°F) for ~23 h. The thermostat set point was then reduced to 43°C (110°F) for the remainder of the preheat cycle (24 h). All packages were preheated for at least 47 h. No test package was loaded into the furnace until 15 of the 18 thermocouples monitoring the furnace had a reading of 800°C (1475°F) or higher. All packages were placed in the preheated furnace on the support stand with the long axis positioned horizontally, and the package lid facing toward a furnace side wall (Fig. 3.6). These packages were exposed to the radiation environment for a minimum of 30 min after all functioning furnace thermocouples and at least four of the six test package exterior surface thermocouples reached a temperature of 800°C (1475°F). During the testing of each package, the thermocouple temperature data recorder was set to record every 15 s.

After each test, the furnace was allowed to reheat for a minimum of 45 min after obtaining the set point temperature before testing the next unit. The furnace control temperature data recorder ran continuously for the duration of the preheat. No test package was loaded into the furnace until all functioning thermocouples on the furnace walls and support stand had again reached a temperature of 800°C (1475°F) or higher.

All units were tested in a horizontal attitude with the top end of the package facing to the right side wall of the furnace and the 0° mark on the drum facing the floor of the furnace. The data from each of the thermal tests, as shown in the test report, show that at least four of the six external drum thermocouples reached temperatures well in excess of 800°C (1475°F) and remained above 800°C (1475°F) during the 30-min thermal testing. Similarly, all other surfaces of the furnace, including the support stand, exceeded 800°C (1475°F) during the timed portion of the thermal test. For the test specified in the regulations, regardless of the amount of heat input by convection, radiation, or conduction, the maximum temperature the skin of the package could reach would be 800°C (1475°F). That is, the source of the heat in the regulatory specified test is at 800°C (1475°F). Heat can only be transferred from a hotter source to a colder source. Thus, regardless of the mode of heat transfer, the greatest temperature a specimen exposed to the 10 CFR 71.73(c)(4) thermal test can attain is 800°C (1475°F). Therefore, the fact that these test packages attained temperatures well in excess of 800°C (1475°F) is an excellent indication that the thermal tests performed not only met the requirements of 10 CFR 71.73(c)(4) but actually exceeded them markedly. The results of these tests are provided in the test reports (ORNL/NTRC-013 and ORNL/NTRC-047).

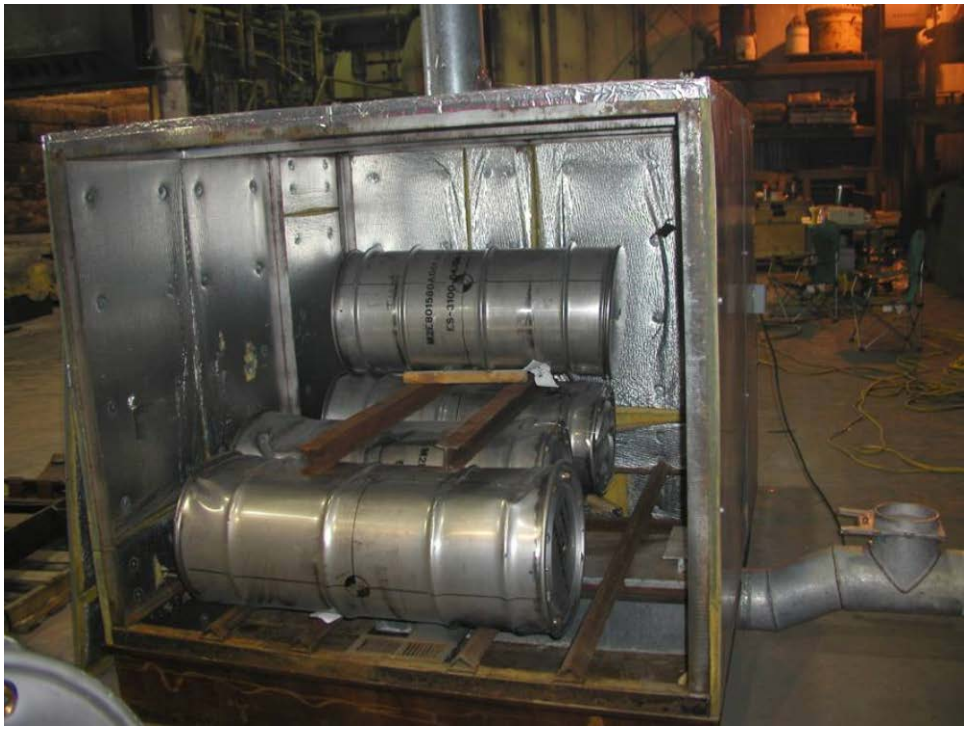


**Fig. 3.5. TU-1 through TU-5 preheat arrangement.**



**Fig. 3.6. Test unit insertion into furnace.**

Each test package was removed from the furnace and placed in an area where it was not exposed to artificial cooling (Figs. 3.7 and 3.8). As the furnace door was opened for each test unit, flaming or smoking was visible at the tamper-indicating device (TID) holes in the drum/lid interface. Flaming continued on some of the packages for a short duration; the longest flame duration was 22 min after removal from the furnace. Smoke was also visible from each of the packages and continued after flames were no longer visible. The packages continued to smoke between 12 and 60 min after removal from the furnace. All the packages were allowed to cool naturally to room temperature. The post-thermal testing weights of each unit are summarized in Table 3.16. The drums were disassembled, and the damage was photographed. Each package was visually inspected, and the condition of the package and any observations were recorded.

### 3.4.3 Maximum Temperatures and Pressure

The six test units previously subjected to both NCT and HAC drop testing were thermally tested in accordance with 10 CFR 71.73(c)(4). To determine the maximum temperatures reached during thermal testing, temperature-indicating patches were placed at various locations throughout the test package at assembly. The temperature range for each patch used is identified in Table 3.17. When the temperature of an indicator was reached, the color would change to black (i.e., blackout temperature). The range of possible blackout temperatures of the patches was from 51.67 to 260°C (125 to 500°F). For TU-1 through TU-5, Table 3.17 defines the number and location of the temperature-indicating patches. Because the configuration (except fluorocarbon elastomer O-rings and Cat 277-4 neutron poison differences) and drop orientation of TU-8 had previously been thermally tested (TU-3), no temperature-indicating patches were used internally in TU-8. The use of fluorocarbon elastomer O-rings in this unit would have no effect on the temperature of the package. A temperature adjustment was evaluated to compensate for conducting the HAC compliance tests with BoroBond4 and substituting Cat 277-4 for the production shipping containers. This adjustment was determined by using an undamaged package and subjecting it to a thermal environment representative of that required by 10 CFR 71.73(c)(4). Based on the analytical results shown in DAC-PKG-801699-A001 and DAC-PKG-801940-A001, the containment vessel in a package using Cat 277-4 would be from 2.5 to 8°F cooler than a package with BoroBond4. Therefore, the results from TU-3 are used without further adjustment for the above configuration changes in TU-8.

Since the structural and thermal interface between the various mock-ups and containment vessels is the same as the actual hardware, the use of steel mock-ups to simulate the contents is not expected to affect the results of the thermal test significantly. The total maximum weight of the test packages ranged from 157.4 kg (347 lb) to 203.7 kg (449 lb). The ES-3100 package has a nominal gross shipping weight that ranges from 146.88 kg (323.79 lb) to 187.81 kg (414.05 lb) for the minimum and maximum weight containment vessel configurations shown in Table 2.8, respectively. However, the effect on temperature is evaluated in the following paragraphs due to thermal capacitance differences between the mock-up and the actual contents.



**Fig. 3.7. Test unit removal from furnace.**




**Fig. 3.8. Test unit cool down and monitoring arrangement.**

**Table 3.16. ES-3100 test package weights before and after 10 CFR 71.73(c)(4) HAC testing**

| Test Unit | Pre-test [a] weight [kg (lb)] | Post-test [a] weight [kg (lb)] | Thermal test weight loss [kg (lb)] | BoroBond4 or Cat 277-4 original weight [kg (lb)] | Water weight in BoroBond4 or Cat 277-4 [kg (lb)] | Water loss percent d (%) |
|---|---|---|---|---|---|---|
| 1 | 202.3 (446) | 202.3 (446) | 0.0 (0) | 20.7 (45.64) [b] | 4.91 (10.82) [c] | 0.00 |
| 2 | 202.8 (447) | 202.8 (447) | 0.0 (0) | 20.5 (45.19) [b] | 4.86 (10.72) [c] | 0 |
| 3 | 203.7 (449) | 203.2 (448) | 0.45 (1) | 20.5 (45.19) [b] | 4.87 (10.74) [c] | 9.31 |
| 4 | 201.8 (445) | 201.4 (444) | 0.45 (1) | 20.4 (44.97) [b] | 4.84 (10.66) [c] | 9.38 |
| 5 | 157.4 (347) | 156.9 (346) | 0.45 (1) | 20.6 (45.42) [b] | 4.89 (10.77) [c] | 9.29 |
| 8 | 204.6 (451) | 202.8 (447) | 1.81 (4) [e] | 25.40 (56.0) | 8.28 (18.24) | 10.96 |

[a] ORNL/NTRC-013 and ORNL/NTRC-047.
[b] Weight of BoroBond4 and water obtained from casting data (Barton).
[c] This weight is based on thermogravimetric analysis measurements and calculation showing that the minimum water percent is 23.71%.
[d] All weight loss attributed to loss of water in BoroBond4 or Cat 277-4.
[e] Half of weight loss attributed to loss of water in Cat 277-4. See ORNL/NTRC-047 Test Form 1 for weight loss in drum assembly.

**Table 3.17. Thermax temperature-indicating patches for test units**

| Patch location | Internal surface | External surface | Temperature range [°C (°F)] | Test report figure [a] |
|---|---|---|---|---|
| Inner liner of drum assembly | | 17 (Full Range) | 52–260 (125–500) | 5.30 |
| Top plug weldment | | 4 (Full Range) | 52–260 (125–500) | 5.31 |
| Containment vessel body flange | 8 (4B & 4C) | 8 (4B & 4C) | "B" 77–127 (171–261)<br>"C" 132–182 (270–360) | 5.28 |
| Containment vessel body (end cap and cylinder) | | 5 (B) | "B" 77–127 (171–261) | 5.28 |
| Containment vessel sealing lid | 4 (B) | 4 (B) | "B" 77–127 (171–261) | 5.29 |
| Test mock-up components | | 6 (B) | "B" 77–127 (171–261) | 5.26 & 5.27 |

[a] ORNL/NTRC-013.

In order to predict the maximum temperature for the packaging components during HAC, transient thermal analyses were performed on the finite element model of the ES-3100 shipping container (undamaged configuration) to simulate HAC as prescribed by 10 CFR 71.73(c)(4) [DAC-PKG-801940-A001]. A 30-min fire of 800°C (1475°F) was simulated by applying natural convection and radiant exchange boundary conditions to all external surfaces of the drum (assuming the drum is in a horizontal orientation) with various content heat loads up to 30 W. There are no heat flux boundary conditions simulating insolation applied to the model before and during the 30-minute fire. The initial temperature distribution within the package having content heat loads as previously stated is obtained from their respective steady-state analyses (Table 3.14). The initial temperature distribution within the package having no content heat load (0 W) is assumed to be at a uniform temperature equal to the ambient temperature of 38°C (100°F). The content heat load is simulated by applying a uniform heat flux to the internal surfaces of the elements representing the containment vessel.

Following the 30-min fire transient analyses, 48-h cool-down transient thermal analyses are performed using the temperature distribution at the end of the fire as the initial temperature distribution. During post-fire cool-down, natural convection and radiant exchange boundary conditions are applied to all external surfaces of the drum (assuming the drum is in a horizontal orientation). Additionally, cases are analyzed in which insolation is included during the post-fire cool-down. For the cases in which insolation is applied to the model during cool-down, insolation is applied during the first 12-h period following the 30-min fire, and then alternated (off, then on) as was done for NCT.

Based on the previous analysis of the ES-3100 package using BoroBond4 (DAC-PKG-801699-A001), it was noted that using the low-end density of Kaolite 1600 results in higher containment vessel temperatures than using the high-end density of Kaolite 1600. For this reason, the NCT and HAC thermal analyses were run using a density of 19.4 lb/ft$^3$. Similarly, the low-end density of the Cat 277-4 material (100 lb/ft$^3$) was also used in these analyses. However, while using these low-end densities will result in higher temperatures to the containment vessel, using the high-end densities for these two materials will result in higher temperature differences from the baseline case. Thus, HAC runs are also made for various content heat loads up to 30 W using a Kaolite 1600 density of 30 lb/ft$^3$ and a Cat 277-4 density of 110 lb/ft$^3$.

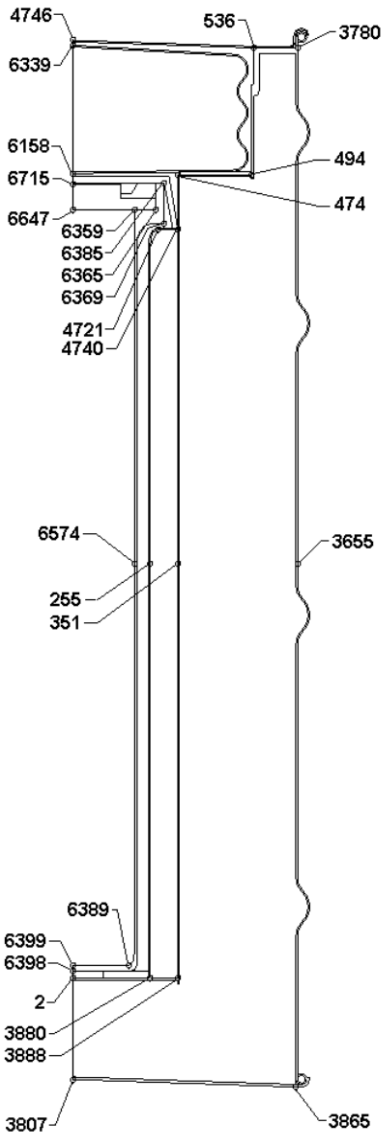
The maximum temperatures calculated for the ES-3100 shipping container for HAC are summarized in Table 3.18 for the analyses using a Kaolite 1600 density of 19.4 lb/ft$^3$ and a Cat 277-4 density of 100 lb/ft$^3$. The maximum temperatures calculated for the ES-3100 shipping container for HAC are summarized in Table 3.19 for the analyses using a Kaolite 1600 density of 30 lb/ft$^3$ and a Cat 277-4 density of 110 lb/ft$^3$. The thermal analyses that use the low-end density values for Kaolite 1600 and Cat 277-4 achieve the higher package temperatures (see Table 3.18).

As previously stated, temperature indicators (patches) were placed on the surface of each containment vessel, inner liner, and mock-up component in TU-1 through TU-5. The blackout temperatures that occurred during thermal testing are recorded for each test unit; the maximum blackout temperatures are listed in Table 3.4. A maximum blackout temperature of 116°C (241°F) was recorded in the vicinity of the O-rings on the containment vessel of TU-5. As discussed below, this temperature will be conservatively adjusted to correlate the test conditions to shipping conditions with decay heat and solar insolation. The blackout temperatures are increased to account for (1) the temperature interval between blackout dots; (2) the ambient temperature of the package prior to insertion into the furnace; (3) the temperature increase due to the effects of applying solar insolation during post-HAC thermal test cool down; (4) the temperature increase due to the decay heat load of the actual contents being shipped; (5) effects of crushing at different locations along the body of the shipping package; (6) thermal capacitance difference in the proposed contents and hardware used during testing; (7) temperature difference occurring when using Borobond4 and Cat 277-4; and (8) temperature difference resulting from variations in Kaolite 1600 and Cat 277-4 material densities.

The initial adjustment for the blackout readings is an increase of 6.11°C (11.0°F) from the patch that blacked out. The highest blackout reading indicates that the actual temperature is somewhere between the highest temperature indicated and the next higher temperature.

The second adjustment compensates for thermal testing at package soak temperatures less than the maximum temperature of 38°C (100°F). In the case of the ES-3100 package, each test unit was thermally soaked to >38°C (100°F) prior to insertion into the furnace. Therefore, there is no temperature adjustment required.

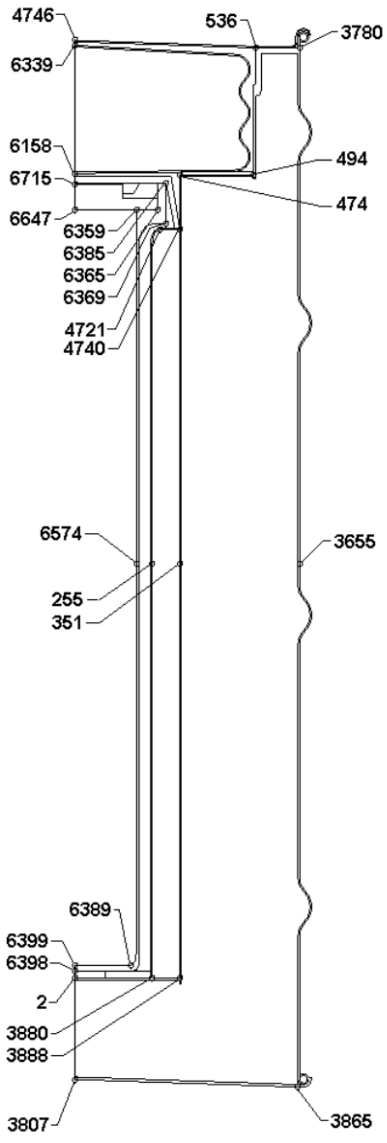
**Table 3.18. ES-3100 package HAC maximum temperatures (Kaolite 1600 density of 19.4 lb/ft$^3$ and Cat 277-4 density of 100 lb/ft$^3$)**

| Node map | Node coordinates (in.) | | | HAC maximum temperature [c] (°F) | | | |
|---|---|---|---|---|---|---|---|
| | | | | 0 W | | 5 W | |
| | No. | r | z | Insolation during cool-down? | | Insolation during cool-down? | |
| | | | | No b | Yes | No | Yes |
|  | 2 | 0.000 | 4.505 | 218.57 | 227.34 | 226.83 | 235.47 |
| | 255 | 3.180 | 21.528 | 192.62 | 212.35 | 200.41 | 219.88 |
| | 351 | 4.300 | 21.528 | 193.97 | 211.78 | 201.16 | 218.55 |
| | 474 | 4.300 | 37.535 | 387.76 | 392.12 | 391.72 | 396.07 |
| | 494 | 7.325 | 37.525 | 636.45 | 637.51 | 638.80 | 639.87 |
| | 536 | 7.385 | 42.755 | 1401.24 | 1401.24 | 1401.38 | 1401.38 |
| | 3655 | 9.185 | 21.528 | 1458.92 | 1458.92 | 1458.98 | 1458.98 |
| | 3780 | 9.185 | 42.755 | 1455.20 | 1455.20 | 1455.24 | 1455.24 |
| | 3807 | 0.000 | 0.320 | 1456.37 | 1456.37 | 1456.46 | 1456.46 |
| | 3865 | 9.185 | 0.008 | 1472.23 | 1472.23 | 1472.24 | 1472.24 |
| | 3880 | 3.178 | 4.505 | 224.21 | 231.73 | 231.44 | 238.83 |
| | 3888 | 4.300 | 4.505 | 229.89 | 236.49 | 236.61 | 243.09 |
| | 4721 | 3.500 | 35.275 | 241.99 | 249.86 | 247.64 | 255.45 |
| | 4740 | 4.300 | 35.275 | 255.69 | 262.15 | 260.99 | 267.39 |
| | 4746 | 0.000 | 43.065 | 1452.75 | 1452.75 | 1452.80 | 1452.80 |
| | 6158 | 0.000 | 37.579 | 298.55 | 302.57 | 303.83 | 307.84 |
| | 6339 | 0.000 | 42.859 | 1357.12 | 1357.12 | 1357.44 | 1357.44 |
| | 6359 [a] | 2.530 | 36.075 | 221.32 | 235.09 | 229.53 | 243.04 |
| | 6365 [a] | 3.425 | 36.075 | 221.34 | 235.11 | 229.52 | 243.03 |
| | 6369 | 3.750 | 35.525 | 221.34 | 235.11 | 229.50 | 243.01 |
| | 6385 | 3.750 | 37.175 | 221.74 | 235.39 | 229.78 | 243.17 |
| | 6389 | 2.310 | 5.025 | 213.26 | 223.89 | 222.83 | 233.30 |
| | 6398 | 0.000 | 4.775 | 213.95 | 224.48 | 223.37 | 233.75 |
| | 6399 | 0.000 | 5.025 | 213.95 | 224.48 | 223.38 | 233.75 |
| | 6574 | 2.530 | 21.528 | 193.20 | 214.09 | 206.59 | 226.95 |
| | 6647 | 0.000 | 36.075 | 221.45 | 235.19 | 229.69 | 243.16 |
| | 6715 | 0.000 | 37.135 | 221.54 | 235.24 | 229.74 | 243.18 |



[a] Approximate location of the containment vessel O-ring.
[b] Baseline case for ΔT comparisons.
[c] Temperatures calculated in DAC-PKG-801940-A001.

**Table 3.19. ES-3100 shipping container HAC maximum temperatures (Kaolite 1600 density of 30 lb/ft$^3$ and Cat 277-4 density of 110 lb/ft$^3$)**

| Node map | Node coordinates (in.) | | | HAC maximum temperature [c] (°F) | | | |
|---|---|---|---|---|---|---|---|
| | | | | 0 W | | 5 W | |
| | No. | r | z | Insolation during cool-down? | | Insolation during cool-down? | |
| | | | | No [b] | Yes | No | Yes |
|  | 2 | 0.000 | 4.505 | 208.90 | 219.11 | 217.23 | 227.23 |
| | 255 | 3.180 | 21.528 | 186.18 | 208.50 | 194.00 | 216.04 |
| | 351 | 4.300 | 21.528 | 186.78 | 208.11 | 193.94 | 214.89 |
| | 474 | 4.300 | 37.535 | 359.09 | 362.05 | 363.14 | 366.11 |
| | 494 | 7.325 | 37.525 | 594.36 | 596.62 | 596.71 | 598.97 |
| | 536 | 7.385 | 42.755 | 1395.15 | 1395.15 | 1395.29 | 1395.29 |
| | 3655 | 9.185 | 21.528 | 1456.25 | 1456.25 | 1456.31 | 1456.31 |
| | 3780 | 9.185 | 42.755 | 1453.48 | 1453.48 | 1453.52 | 1453.52 |
| | 3807 | 0.000 | 0.320 | 1453.70 | 1453.70 | 1453.80 | 1453.80 |
| | 3865 | 9.185 | 0.008 | 1471.38 | 1471.38 | 1471.39 | 1471.39 |
| | 3880 | 3.178 | 4.505 | 213.14 | 222.36 | 220.46 | 229.47 |
| | 3888 | 4.300 | 4.505 | 217.29 | 225.83 | 224.12 | 232.52 |
| | 4721 | 3.500 | 35.275 | 230.23 | 239.26 | 235.98 | 244.93 |
| | 4740 | 4.300 | 35.275 | 241.51 | 248.75 | 246.91 | 254.07 |
| | 4746 | 0.000 | 43.065 | 1449.69 | 1449.69 | 1449.76 | 1449.76 |
| | 6158 | 0.000 | 37.579 | 278.41 | 284.11 | 283.73 | 289.44 |
| | 6339 | 0.000 | 42.859 | 1339.69 | 1339.69 | 1340.05 | 1340.05 |
| | 6359 [a] | 2.530 | 36.075 | 215.59 | 229.94 | 223.79 | 237.89 |
| | 6365 [a] | 3.425 | 36.075 | 215.59 | 229.95 | 223.75 | 237.87 |
| | 6369 | 3.750 | 35.525 | 215.57 | 229.95 | 223.72 | 237.85 |
| | 6385 | 3.750 | 37.175 | 215.89 | 230.22 | 223.91 | 238.01 |
| | 6389 | 2.310 | 5.025 | 204.68 | 216.74 | 214.33 | 226.16 |
| | 6398 | 0.000 | 4.775 | 205.27 | 217.13 | 214.76 | 226.40 |
| | 6399 | 0.000 | 5.025 | 205.27 | 217.13 | 214.77 | 226.40 |
| | 6574 | 2.530 | 21.528 | 187.66 | 209.82 | 201.14 | 222.75 |
| | 6647 | 0.000 | 36.075 | 215.81 | 230.06 | 224.03 | 238.04 |
| | 6715 | 0.000 | 37.135 | 215.88 | 230.12 | 224.07 | 238.06 |



[a] Approximate location of the containment vessel O-ring.
[b] Baseline case for ΔT comparisons.
[c] Temperatures calculated in DAC-PKG-801940-A001.

The third adjustment is a temperature increase to represent the effect of insolation heat flux on the package immediately following the conclusion of the thermal HAC test. Analyses of the ES-3100 package after thermal HAC tests both with and without insolation have been performed (DAC-PKG-801940-A001). Results from these analyses indicate an increase of ~7.47°C (13.44°F) at the containment vessel top (node 6715), ~7.51°C (13.51°F) at the containment vessel O-ring (node 6359), ~11.31°C (20.36°F) at the containment vessel mid body (node 6574), and ~5.76°C (10.37°F) at the containment vessel bottom (node 6399), as a result of applying insolation following HAC thermal testing. These increases are extracted from Tables 3.18 and 3.19. The most pronounced effect of applying the insolation heat flux was that it increased the time required to cool the package to NCT type conditions. Nevertheless, the influence of insolation is included in the adjustments to the blackout temperatures.

The fourth temperature adjustment considered is the temperature increase due to the decay heat load of the actual contents being shipped. A maximum decay heat load of 5 W is calculated as the bounding case for 35.2 kg of HEU. HAC analysis of the ES-3100 package both with and without the decay heat load has been performed, with the results shown in Tables 3.18 and 3.19. The maximum projected temperature increase during HAC due to a 5 W heat source, as calculated in DAC-PKG-801940-A001, would be ~4.56°C (8.20°F) at the containment vessel top (node 6715), ~4.56°C (8.21°F) at the containment vessel O-ring (node 6359), ~7.49°C (13.48°F) at the containment vessel mid body (node 6574), and ~5.28°C (9.50°F) at the containment vessel bottom (node 6399).

The fifth temperature adjustment considered is the temperature increase to the containment vessel based on the location of impact from the 500 kg (1100 lb) crush plate. Based on the differences in location of the crush plate between TU-1 and TU-2, crushing the shipping package with the center of gravity of the plate directly above the containment vessel flange increases the containment vessel temperature on average ~6.11°C (11°F).

The sixth adjustment compensates for the shipment of very small quantities of HEU, rather than the steel mock-ups, and removes the requirement for a minimum content weight. The higher content weight was used for testing to cover the possibility of shipping larger components without retesting. The larger content weight gave conservative structural deformation test results to the drum assembly than would the actual shipping weight. One effect, however, of using the larger test mass could be to reduce the containment vessel's temperature rise during the thermal test because the mock-up acts like a heat sink. In order to evaluate this temperature adjustment, a mock-up of the originally lightest proposed shipment was used in TU-5. The structural and thermal interface between the mock-up components and the containment vessel was designed to match that of the actual shipping hardware, thereby providing the same conductive heat path for thermal testing. As shown by the test results, both the containment vessel and mock-up components of TU-5 recorded higher temperatures than the other test units. This supports the theory that the heavier mock-ups act as heat sinks for the containment vessel. Since the earlier compliance testing, even lower amounts of material are proposed for shipment in the ES-3100. In order to quantify the magnitude of this adjustment, a heat transfer balance is conducted below. This method represents a conservative approach to estimating the adjustment and is not intended to reflect the actual temperature difference. Since the blackouts were recorded on the surface of the mock-up component, adjusted temperatures of 64°C (219°F), 99°C (210°F), and 93°C (199°F) for the top can, middle can, and bottom can are assumed for the following heat transfer equations. The amount of heat absorbed by the mock-up components during the thermal test of TU-5 is calculated as follows:

$$Q = C_{pi} \times (T_{maxi} - T_{mini}) \times W_{Mi}$$

The mockup components for TU-5 consisted of three 10-in.–high steel cans. Two of the upper cans were empty. The bottom can contained 5.9 lb of steel grit. Each individual can weighed ~0.70 lb. Two temperature-indicating patches were placed around the external mid height diameter of each can ~180°

apart. The blackout readings on the top, mid, and bottom cans were 99°C (210°F), 93°C (199°F), and 88°C (190°F), respectively. Each of these readings is increased by either 5 or 6°C (9 or 11°F) due to the accuracy of the patches. Therefore, the top can, middle can, and bottom can and steel grit reached an adjusted temperature of 104°C (219°F), 99°C (210°F), and 93°C (199°F), respectively. Therefore, the mockup contents absorbed ~ $9.476 \times 10^4$ J as calculated below:

$$\begin{aligned} Q_A &= \sum C_{pi} \times (T_{maxi} - T_{mini}) \times W_{Mi}, \\ &= 460.5 \times (104 - 37.78) \times (0.318) + 460.5 \times (99 - 37.78) \times (0.318) + 460.5 \\ &\quad \times (93 - 37.78) \times (2.99), \\ &= 94760.2 \text{ J}, \end{aligned}$$

where

$Q_A$ = absorbed heat by mockup contents,

$C_{pi}$ = specific heat of the steel cans and grit,
= 460.5 J/kg-°C (0.11 Btu/lb-°F),

$T_{maxi}$ = recorded mock-up can temperatures,
= 104°C (219°F), (top can)
= 99°C (210°F), (middle can)
= 93°C (199°F), (bottom can and steel grit)

$T_{mini}$ = temperature of preheated test units,
= 37.78°C (100°F),

$W_{MI}$ = mock-up component weights for TU-5,
= 0.318 kg (0.70 lb), (top can)
= 0.318 kg (0.70 lb), (middle can)
= 2.99 kg (6.60 lb). (bottom can and steel grit)

The sixth temperature adjustment caused by adding this $9.476 \times 10^4$ J (89.81Btu) of heat from the mockup contents into the containment vessel can then be calculated by using the following equation:

$$\begin{aligned} dT &= Q_A / (C_{pcv} \times W_{cv}), \\ &= 9.476 \times 10^4 \text{ J} / (502.36 \text{ J/kg-°C} \times 14.97 \text{ kg}), \\ &= 12.60°\text{C} (22.68°\text{F}), \end{aligned}$$

where

$C_{pcv}$ = specific heat of the stainless steel containment vessel,
= 502.36 J/kg-°C,

$W_{cv}$ = mass of the empty stainless steel containment vessel,
= 14.97 kg.

The sixth temperature adjustment is 12.60°C (22.68°F).

The seventh temperature adjustment compensates for conducting the HAC compliance tests with BoroBond4 and substituting Cat 277-4 for the production shipping containers. This adjustment is determined by using an undamaged package and subjecting it to a thermal environment representative of that required by 10 CFR 71.73(c)(4). Based on the analytical results shown in DAC-PKG-801699-A001 and DAC-PKG-801940-A001, the containment vessel in a package using Cat 277-4 would be from 2.5°F to 8°F cooler than a package with BoroBond4. Conservatively, the temperatures will not be adjusted due to the neutron poison change.

The eighth and final temperature adjustment compensates for material density variation in the Kaolite 1600 and Cat 277-4 material during HAC compliance tests. Again, this temperature adjustment was predicted for an undamaged package using the finite element method. Based on the analytical results shown in DAC-PKG-801940-A001 (Tables 3.18 and 3.19), the containment vessel temperature was predicted to be ~3.15°C (5.67°F) higher at the containment vessel top (node 6715), ~3.19°C (5.74°F) higher at the containment vessel O-ring (node 6359), ~3.08°C (5.54°F) higher at the containment vessel mid body (node 6574), and ~4.82°C (8.68°F) at the containment vessel's bottom (node 6399) when the lower density values for Kaolite 1600 and the neutron poison were used. Since actual compliance testing was conducted with these densities on the high side, the above adjustments must be added to the containment vessel temperatures.

Table 3.20 summarizes the numerous temperature adjustments needed for the containment vessel.

**Table 3.20. Predicted temperature adjustments (°F) for containment vessel due to HAC**

| Node [a] | Analytical temperature adjustments | | | | | | | | Total temp adjustment |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | |
| 6715 | 11.00 | 0.00 | 13.44 | 8.20 | 11.00 | 22.68 | 0.00 | 5.67 | 71.99 |
| 6359 | 11.00 | 0.00 | 13.51 | 8.21 | 11.00 | 22.68 | 0.00 | 5.74 | 72.14 |
| 6574 | 11.00 | 0.00 | 20.36 | 13.48 | 11.00 | 22.68 | 0.00 | 5.54 | 84.06 |
| 6399 | 11.00 | 0.00 | 10.37 | 9.50 | 11.00 | 22.68 | 0.00 | 8.68 | 73.23 |

[a] See Fig. 7 in DAC-PKG-801940-A001 for details of node locations.

Table 3.21 shows the results of adding the eight temperature adjustments previously discussed to the black-out temperatures for the containment vessel with the 3.6-kg (8-lb) mock-up (TU-5). These adjusted temperatures would not adversely affect the stainless-steel components of the containment vessel. EPDM O-rings are rated for reliable service for a continuous 1000 h at −40 to 150°C (−40 to 302°F); fluorocarbon elastomer O-rings are rated for reliable service for a continuous 1000 h at −40 to 204°C (−40 to 400°F) [Table 3.11]. As shown in Fig. 2-24 of the *Parker O-Ring Handbook*, these O-ring materials can survive at the predicted temperature shown in Table 3.21 (313.14°F) for several hundred hours. Because the predicted temperature is only ~6.1°C (11°F) above the continuous service temperature of 150°C (302°F) for the EPDM O-ring and less than the continuous service temperature of 204°C (400°F) for the fluorocarbon elastomer O-ring, the thermally tested packages with insolation would cool to acceptable limits within 24 h. Therefore, these adjusted temperatures would not adversely affect the containment vessel O-rings.

**Table 3.21. Predicted temperatures of the containment vessel due to HAC**

| Node [a] | Analytical temperature adjustments (°F) | Maximum blackout temperature on TU-5 (°F) | Final predicted temperature (°F) |
|---|---|---|---|
| 6715 | 71.99 | 261 | 332.99 |
| 6359 | 72.14 | 241 | 313.14 |
| 6574 | 84.06 | 199 | 283.06 |
| 6399 | 73.23 | 210 | 283.23 |

[a] See Fig. 7 in DAC-PKG-801940-A001 for node locations.

To determine the maximum pressure inside the containment vessel as a result of thermal testing, the average adjusted gas temperature must be calculated based on the above results. The approach used is to divide the containment vessel volume into three distinct equal regions and then average the three together. The first volume is represented by the gas adjacent to the containment vessel lid and flange region and the top convenience can. Based on the temperature recorded near the O-rings [116.11°C (241°F)] and the temperature recorded on the external surface of the convenience can [98.89°C (210°F)], the average temperature of the gas in this region is 107.50°C (225.50°F). Using the temperature adjustment of 40.08°C (72.14°F) for this region, the adjusted average temperature in the first region is 147.58°C (297.64°F). The second volume is represented by the gas adjacent to the second convenience can from the top. Based on the temperature recorded on the containment vessel wall and convenience can [92.78°C (199°F)], the average temperature of gas in this region is 92.78°C (199°F). Using the temperature adjustment of 46.70°C (84.06°F) for this region, the adjusted average temperature in the second region is 139.48°C (283.06°F). The third and final volume is represented by the gas adjacent to the bottom convenience can. Again based on the convenience can temperature [87.78°C (190°F)] and the containment vessel end cap temperature [98.89°C (210°F)], the average temperature of gas in this region is 93.33°C (200°F). Using the temperature adjustment of 40.68°C (73.23°F) for this region, the adjusted average temperature in the third region is 134.02°C (273.23°F). Averaging these three temperatures, an average adjusted gas temperature of 140.36°C (284.64°F) is determined for the containment vessel.

As shown in Appendix 3.5.2, the maximum adjusted average gas temperature and pressure in the containment vessel during accident conditions was calculated to be 140.36°C (284.64°F), and 775.37 kPa (112.458 psia), respectively. For conservatism and for use in Sects. 2 and 4, the maximum adjusted average gas temperature and pressure in the containment vessel during accident conditions are rounded up to 140.56°C (285.0°F) and 775.66 kPa (112.50 psia), respectively.

The maximum adjusted temperature on the surface of the containment vessel, adjacent to the O-rings, was 156.19°C (313.14°F). This is well within the design range for the packaging. The full body helium leak test on all test units following thermal testing meets the “leaktight” criteria in accordance with ANSI N14.5-1997. Visual inspection following testing and unloading indicated that no distortion or damage occurred in the containment vessel wall, sealing lid, closure nut, O-rings, or sealing surfaces. No water was visible inside the containment vessel following the 0.9-m (3-ft) water immersion test or the 15-m (50-ft) water immersion test on TU-6.

The ES-3100 package satisfies the requirements of 10 CFR 71.73 for transport of the 35.2-kg (77.60-lb) arrangements shown in Table 2.8. Section 2.7 has additional details to support this conclusion.

### 3.4.4 Maximum Thermal Stresses

The maximum adjusted HAC temperature of the ES-3100 containment vessel was based upon the thermal testing results in the vicinity of the O-rings. The maximum temperature recorded in the vicinity of the ES-3100 O-rings (241°F) is shown in Table 3.4. As shown in Sect. 3.4.3, the maximum temperature for the containment vessel at the O-ring location was adjusted for the ES-3100 package to 156.19°C (313.14°F). Hence, no damage would be expected to the O-rings during HAC.

The test packages were all preheated to >38°C (100°F) prior to being placed in the furnace, which was heated to >800°C (1475°F). As noted in the test report (ORNL/NTRC-013), the temperatures recorded on the containment vessels of TU-1 through TU-5 were fairly uniform, both vertically and circumferentially. The maximum temperature variation on the containment vessels was ~50°F (from the test temperatures reported in Table 3.4). No damage would be expected on the containment vessel from thermal stresses resulting from a temperature differential of this magnitude. This conclusion is based on the guidelines given in *ASME Boiler and Pressure Vessel Code*, Sect. III. Thermal stress is defined as a self-balancing stress produced by a nonuniform distribution of temperature (*ASME Boiler and Pressure Vessel Code*, Sect. III, NB-3213.13). This paragraph further states that there are two types of thermal stresses: general thermal stress and local thermal stress. An example of a general stress is that produced by an axial temperature distribution in a cylindrical shell (NB-3213.9). This general stress is further classified (NB-3213.9) as a secondary stress (that is, a normal stress or a shear stress developed by the constraint of adjacent materials or by self-constraint of the structure). NB-3213.9 further states that the basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions that cause the stress to occur, and failure from a single application would not be expected. An example of a local thermal stress is a small hot spot in the wall of a pressure vessel (NB-3213.13). Local thermal stress is associated with almost complete suppression of the differential expansion and thus produces no significant distortion. Such stresses are considered only from a fatigue standpoint. Fatigue will not result from a one-time cyclic event such as an accidental fire.

Following the thermal test, the volume between the O-rings on the six containment vessels (Sect. 2.7.4) was then leak tested and met the air leak-rate criterion of $10^{-4}$ ref-$cm^3$/s. Following the O-ring leak check, the six containment vessels were drilled and tapped for full body helium leak testing. All six containment vessels passed the leak rate criteria for leaktightness per ANSI N14.5-1997. The containment vessels were then submerged under a pressure equivalent to 0.9 m (3 ft) of water for 8 h, with no leakage noted (Sect. 2.7.5). Visual inspection following testing and disassembly also indicated that no distortion or damage occurred in the containment vessel wall, sealing lid, closure nut, O-rings, or sealing surfaces. These tests and observations demonstrate that thermal stresses produced during testing did not affect the containment capability of the containment vessel.

### 3.4.5 Accident Conditions for Fissile Material Packages for Air Transport

The expanded fire test conditions specified in 10 CFR 71.55(f)(1)(iv) for fissile material package designs for air transportation was not conducted. The issue of subcriticality is addressed in Sect. 6 with content mass limits as addressed in Sect. 1 for air transport.

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## 3.5 APPENDICES

3.5.1 Containment Vessel Pressure due to Normal Conditions of Transport for the Proposed Contents

3.5.2 Containment Vessel Pressure due to Hypothetical Accident Conditions for the Proposed Contents

3.5.3 Silicone Rubber Thermal Properties from Therm 1.2 Database

3.5.4 Estimates of Hydrogen Buildup in the ES-3100 Package Containing Highly Enriched Uranium

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## Appendix 3.5.1

## Containment Vessel Pressure due to Normal Conditions of Transport for the Proposed Contents

The following calculations determine the pressure of the containment vessel when subjected to the tests and conditions of Normal Condition of Transport per 10 CFR 71.71 for the most restrictive convenience can arrangements shipped in the ES-3100. The following packaging arrangements are evaluated for shipment:

1. one shipment will contain six cans with external dimensions of 4.25-in. diam by 4.875-in. high;

2. one shipment will contain five cans with external dimensions of 4.25-in. diam by 4.875-in. high and three can spacers, top can will be empty;

3. one shipment will contain three cans with external dimension of 4.25-in. diam by 8.75-in. high and two can spacers;

4. one shipment will contain three cans with external dimension of 4.25-in. diam by 10-in. high;

5. one shipment will contain six cans with external dimension of 3.00-in. diam by 4.75-in. high;

6. one shipment will contain three polyethylene bottles with external dimensions of 4.94-in. diam by 8.7-in. high;

7. one shipment will contain three Teflon FEP bottles with external dimensions of 4.69-in. diam by 9.4-in. high;

8. one shipment will contain a brazed assembly of two cans with final external dimensions of 4.25-in. diam by 17.50-in. high. An empty can with external dimensions of 4.25-in. diam by 8.75-in. high will be placed on top or bottom of the 17.50-in.–high can;

9. one shipment will contain fuel rods, or tubes, or plates greater than 17.00 in. in length. These items are bundled together and protected on both ends with an open-ended can with external dimensions of ≤5.0-in. diam by ≤ 8.75-in. high. Total assembly height will be ≤30.5 in. If space is available inside the containment vessel, stainless-steel metal scrubbers will be added on the bottom and top of this assembly or an empty convenience can will be placed on the top or bottom of the assembly;

10. one shipment will contain three cans brazed together with external dimensions of 4.25-in. diam by ~30-in. high; and

11. one shipment will contain closed cans with diameters >4.25 in. In this situation, the void volume inside the loaded containment vessel must be ≥55 $in.^3$ in order to not exceed the previously high pressure prediction for containment vessel arrangement (CVA) 7.

To determine this pressure, the following assumptions have been made:

1. The highly enriched uranium (HEU) contents are loaded into convenience cans which are placed inside the ES-3100 containment vessel at standard temperature ($T_{amb}$) and pressure ($P_t$) [25°C (77°F) and 101.35 kPa (14.7 psia)] with air at a maximum relative humidity of 100% for all configurations except for CVA 7. CVA 7 assumes the air is 100% dry.

2. The convenience cans are assumed to not be sealed.

3. Convenience can and bottle geometry does not change during pressure increase inside containment vessel.

4. If metal convenience cans are used, the total amount of polyethylene bagging and lifting slings is limited to 500 g per containment vessel shipping arrangement.

5. The mass of offgassing material (polyethylene bagging or bottles, Teflon bottles, silicone pads, lifting slings) is assumed to be 1490 g for the offgassing evaluation of CVA 7.

6. CVA 11 uses metal cans and, therefore, is limited to 500 g of polyethylene bagging and lifting slings.

The offgassing material limits identified in assumptions 4 and 5 have been established based on the needs of shippers. All configurations are limited to 500 g of polyethylene in the form of bags, slings, and/or bottles. When the requirement to ship material in Teflon bottles arose, the upper limit of 1490 g of offgassing material was established. This limit is a combination of three Teflon bottles (330 g per bottle) and the original 500 g allowance for polyethylene material. These offgassing material limits have been used in calculations pertaining to containment vessel pressure, radioactive material leakage criteria, and criticality control. Therefore, portions of the safety basis for this shipping package have been based on these material limits.

Applying Dalton's law concerning a mixture of gases, the properties of each component are considered as though each component exists separately at the volume and temperature of the mixture. Therefore, the molar quantities of each constituent inside the containment vessel (i.e., dry air, water vapor, polyethylene bagging, and silicone rubber) must be calculated individually.

To calculate these molar properties, the void volume of the containment vessel must be determined. The volume inside an empty ES-3100 containment vessel was determined from ALGOR finite element software to be 637.18 $in.^3$ (10,441.51 $cm^3$).

**I. Molar quantity determination for dry air and water vapor**

According to *Fundamentals of Classical Thermodynamics* (Van Wylen),

> "Relative humidity (Φ) is defined as the ratio of the mole fraction in the mixture to the mole fraction of vapor in a saturated mixture at the same temperature and total pressure."

Since the vapor is considered an ideal gas, the definition reduces to the ratio of the partial pressure of the vapor ($P_v$) as it exists in the mixture to the saturation pressure of the vapor ($P_g$) at the same temperature.

Therefore,

$$\Phi = P_v / P_g .$$

From the above equation and interpolating the values given in Table A.1.1 of *Fundamentals of Classical Thermodynamics* (Van Wylen), the partial pressure of the water vapor at saturation is:

$$\begin{aligned} P_v &= 1.0\ (0.464)\ \text{psia}, \\ &= 0.464\ \text{psia}. \end{aligned}$$

The partial pressure of the dry air ($P_a$) in the volume:

$$\begin{aligned} P_a &= P_t - P_v , \\ &= 14.7 - 0.464, \\ &= 14.236\ \text{psia}. \end{aligned}$$

From the ideal gas law, the number of water vapor moles and dry air moles in the void volume ($V_V$) for each CVA is calculated as follows:

$$n_v = \frac{P_v \times V_v}{R_u \times T_{amb} \times 12} , \quad n_a = \frac{P_a \times V_v}{R_u \times T_{amb} \times 12} .$$

To determine the number of moles, the void volume of the air mixture must be determined. The void volume ($V_V$) in the containment vessel for each CVA is calculated as follows:

$$V_V = V_{ECV} - V_{SP} - V_{PB} - V_{SCC} - V_{CS} - V_{CH} ,$$

where

$V_{ECV}$ = volume inside an empty containment vessel,
$V_{SP}$ = silicone pad volume,
$V_{PB}$ = polyethylene bagging or lifting sling volume,
$V_{SCC}$ = structural volume of the convenience cans or bottles,
$V_{CS}$ = external volume of the can spacers,
$V_{CH}$ = external volume of the convenience can handles.

A summary for each CVA is shown in Table 1.

The bounding case for oxide material contained in 4.25-in–diam cans based on the volumes listed in Table 1 is CVA 1 at 588.46 in.$^3$ CVA 1's void volume is the lowest of the volumes shown in Table 1 for configurations that are used to transport the materials in the form of oxide. CVA 2 and CVA 3 have smaller volumes primarily due to the use of can spacers. Can spacers are not required when transporting oxides. To determine the minimum volume for this configuration, the mass limit of 15.13 kg of oxides is used in conjunction with the lowest density oxide of 7.3 kg/L ($UO_3$). The resulting volume is 15.13 kg / 7.3 kg/L × 1 ft$^3$ / 28.32 L × 1728 in.$^3$ / ft$^3$ = 126.464 in.$^3$ Therefore, the bounding volume for CVA 1 is 588.46 in.$^3$ − 126.464 in.$^3$ = 462.00 in.$^3$

**Table 1. Containment vessel void volume for each CVA**

| | CVA | $V_{ECV}$ (in.$^3$) | $V_{SP}$ [a] (in.$^3$) | $V_{PB}$ (in.$^3$) | $V_{SCC}$ (in.$^3$) | $V_{CS}$ (in.$^3$) | $V_{CH}$ (in.$^3$) | $V_V$ (in.$^3$) |
|---|---|---|---|---|---|---|---|---|
| 1 | Six 4.875-in.–high cans<br>Seven silicone pads<br>Six can handles | 637.18 | 9.35 | 30.51 | 7.84 | 0.00 | 1.02 | 588.46 |
| 2 | Five 4.875-high cans<br>Nine silicone pads<br>Three Cat 277-4 spacers<br>Eight can handles | 637.18 | 12.03 | 30.51 | 6.47 | 60.60 | 1.36 | 526.21 |
| 3 | Three 8.75-in.–high cans<br>Two Cat 277-4 spacers<br>Six silicone pads<br>Five can handles | 637.18 | 8.02 | 30.51 | 5.14 | 40.40 | 0.85 | 552.26 |
| 4 | Three 10-in.–high cans<br>Four silicone pads<br>Three can handles | 637.18 | 5.35 | 30.51 | 5.56 | 0.00 | 0.51 | 595.26 |
| 5 | Six 4.75-in.–high nickel cans | 637.18 | 0.00 | 30.51 | 12.64 | 0.00 | 1.02 | 593.01 |
| 6 | Three 4.94-in.–OD polyethylene bottles | 637.18 | 0.00 | 9.46 | 21.05 | 0.00 | 0.00 | 606.67 |
| 7 | Three 4.69-in.–OD Teflon FEP bottles | 637.18 | 0.00 | 30.51 | 27.95 | 0.00 | 0.00 | 578.72 |
| 8 | One 17.5-in.–high can loaded<br>One 8.75-in.–high can empty<br>Three silicone pads<br>Two can handles | This configuration is bounded by CVA 3 | | | | | | |
| 9 | Two open-ended cans<br>One empty convenience can<br>with height ≤ 8.75-in.<br>Three silicone pads<br>Two can handles | This configuration is bounded by CVA 4 b | | | | | | |
| 10 | Three 10-in. cans brazed together<br>Two silicone pads<br>One can handle | This configuration is bounded by CVA 4 | | | | | | |
| 11 | Closed convenience cans with diameters greater or equal to 4.25-in.<br>Seven silicone pads | | | | | | | 54.25 (min.) |

[a] This assumes that the internal convenience cans, polyethylene or Teflon FEP bottles, and Cat 277-4 spacer cans are not sealed.

[b] Although CVA 9 may slightly exceed the height of the combined three 25.4 cm (10 in.) can height (CVA 4), the open-ended cans and contents produce a larger void volume and thereby lower overall pressure inside the containment vessel.

Only CVA 7 can accommodate the uranyl nitrate crystals (UNX) held in the Teflon bottles. CVA 7 is limited to 9.17 kg of the uranyl nitrate hexahydrate crystals and 11.9 kg of uranyl nitrate trihydrate crystals (see Appendix 3.5.4). For the bounding pressure calculation, the smallest resulting free volume in CVA 7 is then 578.72 − 11.9 kg / 2.81 kg/L × 1 ft$^3$ / 28.32 L × 1728 in.$^3$ / ft$^3$ = 578.72 in.$^3$ − 258.4 in.$^3$ = 320.32 in.$^3$

The bounding case for all materials contained in cans with a diameter >4.25 in. is determined by not exceeding the maximum predicted HAC pressure previously determined for CVAs 1 and 7. A minimum void volume of 54.25 in.$^3$ in the containment vessel has been calculated. This value is conservatively rounded up to 55 in.$^3$

Using the above molar equations and bounding volumes, the number of moles for water vapor and dry air in the vessel for CVAs 1, 7, and 11 are summarized in Table 2.

**Table 2. Water vapor and dry air molar summary for each CVA**

| CVA | $P_a$ (psia) | $P_v$ (psia) | $V_V$ (in.$^3$) | $R_u$ (ft-lb/lb-mol·R) | $T_{amb}$ (R) | $n_v$ (lb-mol) | $n_a$ (lb-mol) |
|---|---|---|---|---|---|---|---|
| 1 | 14.236 | 0.464 | 462.00 | 1545.32 | 537 | 2.1527E-05 | 6.6047E-04 |
| 7 | 14.700 [a] | 0.000 [a] | 320.32 | 1545.32 | 537 | 0.0000E+00 | 4.7285E-04 |
| 11 | 14.236 | 0.464 | 54.25 | 1545.32 | 537 | 2.5278E-06 | 7.7556E-05 |

[a] This represents a worst case set of conditions due to the later addition of water vapor from efflorescence of the UNX crystals.

## II. Molar quantity determination due to offgassing for each containment vessel arrangement

The maximum temperature calculated for the containment vessel is 91.93°C (197.48°F). This temperature is assumed to be constant throughout the containment vessel and contents. Therefore, the polyethylene bags, polyethylene bottles, Teflon FEP bottles, and silicone rubber can pads are assumed to be at this temperature.

Using the above calculated results and the specific gas generation of polyethylene bags and silicone rubber pad measurements at temperatures up to 170°C (338°F) conducted by the Y-12 Development Division, the amount of gas ($V_{bo}$ and $V_{po}$) generated due to offgassing of the polyethylene bags and bottles, and silicone rubber can pads at any temperature is estimated by first determining the offgassing volume per unit mass at temperature and multiplying that by the total mass of the bags and can supports inside the containment vessel. Based on testing at a temperature of 93.33°C (200°F), no recordable offgassing occurred in the polyethylene bags and bottles, or silicone rubber pad material as documented in Y/DZ-2585. The data showed that the Teflon FEP material offgassing volume per unit mass ($V_{tf}$) was conservatively assumed to be 0.25 cm$^3$/g@STP (Y/DZ-2720). These values are used to determine the offgassing volumes as shown below:

$V_{po} = W_p \times 0.0 / 16.387$ (in.$^3$) (offgassing volume of silicone rubber pads)

$V_{bo} = W_b \times 0.0 / 16.387$ (in.$^3$) (offgassing volume of polyethylene bags and bottles or lifting sling)

$V_{tf} = W_{tf} \times 0.25 / 16.387$ (in.$^3$) (offgassing volume of Teflon bottles)

From the ideal gas law, the number of gas moles in the volume at standard temperature and pressure is as follows:

$$n_{io} = \frac{P_v \times V_i}{R_u \times T_{amb} \times 12}.$$

A summary of the results obtained using the above equations for the bounding CVA is presented in Tables 3, 4, and 5.

**Table 3. Molar quantity of gas generated due to the silicone rubber pad offgassing [a]**

| CVA | $W_p$ (g) | $V_{po}$ ($in.^3$) | $P_V$ (psia) | $R_u$ (ft-lb/lb-mol·R) | $T_{amb}$ (R) | $n_{po}$ (lb-mol) |
|---|---|---|---|---|---|---|
| 1 | 186.74 | 0.00 | 14.7 | 1545.32 | 537 | 0.0000E+00 |
| 7 | 0.00 | 0.00 | 14.7 | 1545.32 | 537 | 0.0000E+00 |
| 11 | 186.74 | 0.00 | 14.7 | 1545.32 | 537 | 0.0000E+00 |

[a] Silicone rubber pad weight determined from Table 2.8.

**Table 4. Molar quantity of gas generated due to the polyethylene bag, sling and bottle offgassing**

| CVA | $W_b$ (g) | $V_{bo}$ ($in.^3$) | $P_V$ (psia) | $R_u$ (ft-lb/lb-mol·R) | $T_{amb}$ (R) | $n_{bo}$ (lb-mol) |
|---|---|---|---|---|---|---|
| 1 | 500.00 | 0.00 | 14.7 | 1545.32 | 537 | 0.0000E+00 |
| 7 | 500.00 | 0.00 | 14.7 | 1545.32 | 537 | 0.0000E+00 |
| 11 | 500.00 | 0.00 | 14.7 | 1545.32 | 537 | 0.0000E+00 |

**Table 5. Molar quantity of gas generated due to the Teflon bottle offgassing**

| CVA | $W_{tf}$ (g) | $V_{tf}$ ($in.^3$) | $P_V$ (psia) | $R_u$ (ft-lb/lb-mol·R) | $T_{amb}$ (R) | $n_{tf}$ (lb-mol) |
|---|---|---|---|---|---|---|
| 7 | 990.00 | 15.10 | 14.7 | 1545.32 | 537 | 2.2296E-05 |

## III. Gas generation due to radiolysis of water

Buildup of hydrogen gas ($H_2$) and oxygen gas ($O_2$) in the ES-3100 containment vessel due to radiolysis is incorporated into the pressure calculation by assuming that 5 mol % of the free volume is hydrogen gas. Since each mole of H2 generated is accompanied by 0.5 mol of $O_2$, the concentration of $H_2$ will reach 5 mol % when volume of $H_2$ is 0.05405 times the initial void volume (see Sect. 3.5.4.8 of Appendix 3.5.4). Using the ideal gas law, the number of gas moles of hydrogen in the volume at standard temperature and pressure is:

$$n_r = \frac{P_v \times V_r}{R_u \times T_{amb} \times 12},$$

where

$n_r$ = individual molar quantity for hydrogen and oxygen gas;
$V_r$ = volume of gas assumed generated by radiolysis.

A summary of the results for hydrogen and oxygen generation due to radiolysis using the above equation is presented in Table 6.

**Table 6. Molar quantity of oxygen and hydrogen gas generation due to radiolysis**

| CVA | $V_v$ (in.$^3$) | $V_h$ (in.$^3$) | $P_v$ (psia) | $R_u$ (ft-lb/lb-mol·R) | $T_{amb}$ (R) | $n_{r-H2}$ (lb-mol) | $n_{r-O2}$ (lb-mol) |
|---|---|---|---|---|---|---|---|
| 1 | 462.00 | 24.97 | 14.7 | 1545.32 | 537.0 | 3.6861E-05 | 1.8430E-05 |
| 7 | 320.32 | 17.31 | 14.7 | 1545.32 | 537.0 | 2.5558E-05 | 1.2779E-05 |
| 11 | 54.25 | 2.93 | 14.7 | 1545.32 | 537.0 | 4.3285E-06 | 2.1643E-06 |

## IV. Molar quantity of gas generated due to the efflorescence nature of the uranyl nitrate crystals

The UNX crystals in any hydrated state will decompose and lose water molecules at the temperature shown in Table 3.3 [197.48°F (91.93°C)]. The partial pressure of water vapor in this mixture is conservatively estimated to be the saturated vapor pressure ($P_{sv}$) of water at 197.48°F or 10.9117 psia. Using the ideal gas law, the molar quantity of water vapor (nv) in this volume at the maximum containment vessel temperature and the saturated vapor pressure is:

$$n_v = \frac{P_{sv} \times V_v}{R_u \times T_{cv} \times 12},$$

= (10.9117 × 320.32) / (1545.32 × 12 × 657.48),
= $2.8668 \times 10^{-4}$ lb-mol,

where

$n_v$ = molar quantity for water vapor;
$V_v$ = void volume of containment vessel;
$T_{cv}$ = maximum temperature of containment vessel; and
$P_{sv}$ = interpolated saturated vapor pressure of water at temperature from *Fundamental of Classical Thermodynamic* (Van Wylen), Table A.1.1, p. 650.

## V. Total pressure due to offgassing and NCT temperatures inside the containment vessel

The total pressure of the mixture at 91.93°C (197.48°F), $P_T$, for the bounding CVA is the sum of each of the previously calculated molar quantities. Table 7 summarizes the molar constituents and total pressure of each bounding CVA. The following equation is used to calculated the final containment vessel pressure:

$P_{91.93°C}$ = ( $\sum n_i \times R \times T \times 12$ ) / $V_{GMV}$ ,

where

$n_i$ = individual molar quantity for each gas,

T = average gas temperature,
= 91.93°C (197.48°F),

$V_{GMV}$ = $V_v$ = gas mixture volume.

**Table 7. Total pressure inside the containment vessel at 91.93°C (197.48°F) [a]**

| CVA | $n_a$ [b] (lb-mol) | $n_v$ [b] (lb-mol) | $n_{po}$ [b] (lb-mol) | $n_{bo}$ [b] (lb-mol) | $n_{tf}$ [b] (lb-mol) | $n_{H2}$ [b] (lb-mol) | $n_{O2}$ [b] (lb-mol) | $n_T$ [b] (lb-mol) | $P_T$ (psia) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 6.6047E-04 | 2.1527E-05 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 3.6862E-05 | 1.8431E-05 | 7.3729E-04 | 19.457 |
| 7 | 4.7285E-04 | 2.8668E-04 [c] | 0.0000E+00 | 0.0000E+00 | 2.2296E-05 | 2.5558E-05 | 1.2779E-05 | 8.2016E-04 | 31.218 |
| 11 | 7.7556E-05 | 2.5278E-06 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 4.3285E-06 | 2.1643E-06 | 8.6577E-05 | 19.457 |

[a] This assumes that the internal convenience cans, polyethylene or Teflon FEP bottles, and Cat 277-4 spacer cans are not sealed.

[b] $n_a$—molar quantity of dry air in the gas mixture;
$n_v$—molar quantity of water vapor in the gas mixture;
$n_{po}$—molar quantity of gas due to offgassing of the silicone rubber pads;
$n_{bo}$—molar quantity of gas due to offgassing of the polyethylene bags, bottles, and lifting sling;
$n_{tf}$—molar quantity of gas due to offgassing of the Teflon bottles;
$n_{H2}$—molar quantity of hydrogen gas due to radiolysis of water;
$n_{O2}$—molar quantity of oxygen gas due to radiolysis of water; and
$n_T$—total molar quantity in the gas mixture.

[c] This value is the molar quantity of water vapor generated from the efflorescence of UNX crystals.

## VI. Total pressure at −40°C (−40°F)

At −40°C (−40°F), the partial pressure of the water vapor is conservatively assumed to be zero. Therefore, the final pressure of the mixture at −40°C (−40°F) is calculated according to the ideal gas law based solely on the partial pressure of the air.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2},$$

where

$P_1$ = 14.236 psi,
$T_1$ = 77°F = 536.67 R,
$T_2$ = −40°F = 419.67 R,
$V_1$ = $V_2$.

Rearranging and solving for $P_2$,

$P_2$ = $P_1 (T_2 / T_1)$,
= (14.236)(419.67 / 536.67),
= 11.13 psia.

## VII. Maximum containment vessel pressure differential in accordance with air transport guidance

The methodology used to determine the maximum pressure differential for air transport in accordance with TS-R-1, Paragraph 618 incorporates the following assumptions.

1. The three containment vessel arrangements previously discussed in this appendix will be evaluated.

2. Evaluation will be conducted at the maximum containment vessel temperature shown in Table 3.14 for air transport.

3. Maximum containment vessel temperature was determined using an ambient temperature of 55°C, self-heating of the package contents, and no insolation.

4. Maximum pressure differential is the maximum normal operating pressure (MNOP) plus 95 kPa.

A value of 146.11°F was determined and documented in DAC-PKG-801940-A001 and is used as an average temperature of the containment vessel. The molar quantity results shown in Table 8 will be evaluated at this temperature as shown in Table 9. The molar values shown in Table 8 for CVA 7 are very conservative because the water vapor molar quantity includes water vapor generated from the efflorescence of UNX crystals. UNX crystals will not be transported by air.

**Table 8. Total molar quantities inside the containment vessel [a]**

| CVA | $n_a$ [b] (lb-mol) | $n_v$ [b] (lb-mol) | $n_{po}$ [b] (lb-mol) | $n_{bo}$ [b] (lb-mol) | $n_{tf}$ [b] (lb-mol) | $n_{H2}$ [b] (lb-mol) | $n_{O2}$ [b] (lb-mol) | $n_T$ [b] (lb-mol) |
|---|---|---|---|---|---|---|---|---|
| 1 | 6.6047E-04 | 2.1527E-05 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 3.6862E-05 | 1.8431E-05 | 7.3729E-04 |
| 7 | 4.7285E-04 | 2.8668E-04 [c] | 0.0000E+00 | 0.0000E+00 | 2.2296E-05 | 2.5558E-05 | 1.2779E-05 | 8.2016E-04 |
| 11 | 7.7556E-05 | 2.5278E-06 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 4.3285E-06 | 2.1643E-06 | 8.6577E-05 |

[a] This assumes that the internal convenience cans, polyethylene or Teflon FEP bottles, and Cat 277-4 spacer cans are not sealed.

[b] $n_a$—molar quantity of dry air in the gas mixture;
$n_v$—molar quantity of water vapor in the gas mixture;
$n_{po}$—molar quantity of gas due to offgassing of the silicone rubber pads;
$n_{bo}$—molar quantity of gas due to offgassing of the polyethylene bags, bottles, and lifting sling;
$n_{tf}$—molar quantity of gas due to offgassing of the Teflon bottles;
$n_{H2}$—molar quantity of hydrogen gas due to radiolysis of water;
$n_{O2}$—molar quantity of oxygen gas due to radiolysis of water; and
$n_T$—total molar quantity in the gas mixture.

[c] This value is the molar quantity of water vapor generated from the efflorescence of UNX crystals.

Therefore, the maximum differential pressure ($P_{DIFF}$) generated under air transport conditions is the maximum pressure calculated in Table 9 plus 95 kPa (13.78 psi). This pressure differential will be used in Table 2.21a to evaluate the containment vessel structural integrity for air transport.

**Table 9. Containment vessel MNOP at 63.39°C (146.11°F)**

| CVA | $n_T$ (lb-mol) | $P_{MNOP}$ (psia) | $P_{DIFF}$ (psig) |
|---|---|---|---|
| 1 | 7.3729E-04 | 17.937 | 31.717 |
| 7 | 8.2016E-04 | 28.778 | 42.558 |
| 11 | 8.6577E-05 | 17.937 | 31.717 |

## Appendix 3.5.2

## Containment Vessel Pressure due to Hypothetical Accident Conditions for the Proposed Contents

The following calculations determine the pressure of the containment vessel when subjected to the tests and conditions of Hypothetical Accident Conditions per 10 CFR 71.73 for the most restrictive convenience can arrangements shipped in the ES-3100 package. The following packaging arrangements are evaluated for shipment:

1. one shipment will contain six cans with external dimensions of 4.25-in. diam by 4.875-in. high;
2. one shipment will contain five cans with external dimensions of 4.25-in. diam by 4.875-in. high and three can spacers, the top can is empty;
3. one shipment will contain three cans with external dimensions of 4.25-in. diam by 8.75-in. high and two can spacers;
4. one shipment will contain three cans with external dimensions of 4.25-in. diam by 10-in. high;
5. one shipment will contain six nickel cans with external dimensions of 3.00-in. diam by 4.75-in. high;
6. one shipment will contain three polyethylene bottles with external dimensions of 4.94-in. diam by 8.7-in. high;
7. one shipment will contain three Teflon FEP bottles with external dimensions of 4.69-in. diam by 9.4-in. high;
8. one shipment will contain a brazed assembly of two cans with final external dimensions of 4.25-in. diam by 17.50-in. high. An empty can with external dimensions of 4.25-in. diam by 8.75-in. high will be placed on top or bottom of the 17.50-in.–high can;
9. one shipment will contain fuel rods, or tubes, or plates greater than 17.00 in. in length. These items are bundled together and protected on both ends with an open-ended can with external dimensions of ≤5.0-in. diam by ≤ 8.75-in. high. Total assembly height will be ≤30.5 in. If space is available inside the containment vessel, stainless-steel metal scrubbers will be added on the bottom and top of this assembly or an empty convenience can will be placed on the top or bottom of the assembly;
10. one shipment will contain three cans brazed together with external dimensions of 4.25-in. diam by ~30-in. high; and
11. one shipment will contain closed cans with diameters >4.25 in. In this situation, the void volume inside the loaded containment vessel must be ≥55 $in.^3$ in order to not exceed the previously high pressure prediction for containment vessel arrangement (CVA) 7.

To determine this pressure, the following assumptions have been made.

1. The highly enriched uranium (HEU) contents are loaded into convenience cans and placed inside the ES-3100 containment vessel at standard temperature [25°C (77°F)] and at the maximum normal operating pressure (see Table 7 of Appendix 3.5.1).

2. The convenience cans are assumed to not be sealed.

3. Convenience can and bottle geometry does not change during pressure increase inside containment vessel.

4. If metal convenience cans are used, the total amount of polyethylene bagging and lifting slings is limited to 500 g per containment vessel shipping arrangement.

5. The mass of offgassing material (polyethylene bagging or bottles, Teflon bottles, silicone pads, lifting slings) is assumed to be 1490 g for the offgassing evaluation of CVA 7.

6. Hydrogen and oxygen molar quantities calculated in Appendix 3.5.1 are conservatively added to the gas mixture for HAC.

7. The contribution in pressure generated by the efflorescence of uranyl nitrate crystals (UNX) is incorporated into the results for CVA 7.

8. CVA 11 uses metal cans and, therefore, is limited to 500 g of polyethylene bagging and lifting slings.

The offgassing material limits identified in assumptions 4 and 5 have been established based on the needs of shippers. All configurations are limited to 500 g of polyethylene in the form of bags, slings, and/or bottles. When the requirements to ship material in Teflon bottles arose, the upper limit of 1490 g of offgassing material was established. This limit is a combination of three Teflon bottles (990 g) and the original 500 g allowance for polyethylene material. These offgassing material limits have been used in calculations pertaining to containment vessel pressure, radioactive material leakage criteria, and criticality control. Therefore, portions of the safety basis for this shipping package have been based on these material limits.

Applying Dalton's law concerning a mixture of gases, the properties of each component are considered as though each component exists separately at the volume and temperature of the mixture. Therefore, the molar quantities of each constituent inside the containment vessel (i.e., dry air, water vapor, polyethylene bagging and bottles, silicone rubber pads, and Teflon bottles) must be calculated individually.

To calculate these molar properties, the void volume of the containment vessel must be determined. The volume inside an empty ES-3100 containment vessel was determined from ALGOR finite element software to be 637.18 $in.^3$ (10,441.51 $cm^3$).

**I. Molar quantity determination based on MNOP**

To use the maximum normal operating pressure at standard temperature, the number of lb-mol of gas needs to be increased using the following equation:

$$n_{MNOP} = \frac{P_T \times V_v}{R_u \times T_{amb} \times 12} \ (molar\ equation)\ .$$

**Table 1. Total pressure inside the containment vessel at 91.93°C (197.48°F) [a]**

| CVA | $n_a$ [b] (lb-mol) | $n_v$ [b] (lb-mol) | $n_{po}$ [b] (lb-mol) | $n_{bo}$ [b] (lb-mol) | $n_{tf}$ [b] (lb-mol) | $n_{H2}$ [b] (lb-mol) | $n_{O2}$ [b] (lb-mol) | $n_T$ [b] (lb-mol) | $P_T$ (psia) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 6.6047E-04 | 2.1527E-05 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 3.6862E-05 | 1.8431E-05 | 7.3729E-04 | 19.457 |
| 7 | 4.7285E-04 [c] | 2.8668E-04 [c] | 0.0000E+00 | 0.0000E+00 | 2.2296E-05 | 2.5558E-05 | 1.2779E-05 | 8.2016E-04 | 31.218 |
| 11 | 7.7556E-05 | 2.5278E-06 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 4.3285E-06 | 2.1643E-06 | 8.6577E-05 | 19.457 |

[a] This assumes that the internal convenience cans, polyethylene or Teflon FEP bottles, and Cat 277-4 spacer cans are not sealed.

[b] $n_a$—molar quantity of dry air in the gas mixture;
$n_v$—molar quantity of water vapor in the gas mixture;
$n_{po}$—molar quantity of gas due to offgassing of the silicone rubber pads;
$n_{bo}$—molar quantity of gas due to offgassing of the polyethylene bags, bottles, and lifting sling;
$n_{tf}$—molar quantity of gas due to offgassing of the Teflon bottles;
$n_{H2}$—molar quantity of hydrogen gas due to radiolysis of water;
$n_{O2}$—molar quantity of oxygen gas due to radiolysis of water; and
$n_T$—total molar quantity in the gas mixture.

[c] For CVA 7, using 100% dry air at containment vessel closure and the saturated vapor pressure at temperature for the water vapor constituent, the highest pressure is generated.

Using $P_T$ from Table 1 and the molar equation, the total number of moles is summarized in Table 2.

**Table 2. Molar summary at MNOP and 25°C (77°F)**

| CVA | $P_T$ (psia) | $V_V$ ($in.^3$) | $R_u$ (ft-lb/lb-mol·R) | $T_{amb}$ (R) | $n_{MNOP}$ (lb-mol) |
|---|---|---|---|---|---|
| 1 | 19.457 | 462.00 | 1545.32 | 537 | 9.0270E-04 |
| 7 | 31.218 | 320.32 | 1545.32 | 537 | 1.0042E-03 |
| 11 | 19.457 | 54.25 | 1545.32 | 537 | 1.0600E-04 |

## II. Molar quantity determination due to offgassing for each containment vessel arrangement

To determine the maximum pressure inside the containment vessel as a result of thermal testing, the average adjusted gas temperature must be calculated based on the above results. The approach used is to divide the containment vessel volume into three distinct equal regions and then average the three together. The first volume is represented by the gas adjacent to the containment vessel lid and flange region and the top convenience can. Based on the temperature recorded near the O-rings [116.11°C (241°F)] and the temperature recorded on the external surface of the convenience can [98.89°C (210°F)], the average temperature of the gas in this region is 107.50°C (225.50°F). Using the temperature adjustment of 40.08°C (72.14°F) for this region (Sect. 3.4.3), the adjusted average temperature in the first region is 147.58°C (297.64°F). The second volume is represented by the gas adjacent to the second convenience can from the top. Based on the temperature recorded on the containment vessel wall and convenience can [92.78°C (199°F)], the average temperature of gas in this region is 92.78°C (199°F). Using the temperature adjustment of 46.70°C (84.06°F) for this region (Sect. 3.4.3), the adjusted average temperature in the second region is 139.48°C (283.06°F). The third and final volume is represented by the gas adjacent to the bottom convenience can. Again based on the convenience can temperature [87.78°C (190°F)] and the containment vessel end cap temperature [98.89°C (210°F)], the average temperature of gas in this region is 93.33°C (200°F). Using the temperature adjustment of 40.68°C (73.23°F) for this region (Sect. 3.4.3), the adjusted average temperature in the third region is 134.02°C

(273.23°F). Averaging these three temperatures, an average adjusted gas temperature of 140.36°C (284.64°F) is determined for the containment vessel.

Using the above calculated results and the specific gas generation of polyethylene bags and silicone rubber pads measurements at temperatures up to 170°C (338°F) conducted by the Y-12 Development Division (Y/DZ-2585), the amount of gas generated due to offgassing of the silicone rubber can pads, the polyethylene bags and bottles, and the Teflon FEP bottles at 140.36°C (284.64°F), ($V_{po}$, $V_{bo}$, and $V_{tf}$) is estimated by first determining the offgassing volume per unit mass at temperature and multiplying that by the total mass of the bags, bottles, slings, and silicone rubber can supports inside the containment vessel. Based on testing at an approximate temperature of 141.11°C (286.00°F), values of ~7.0 and ~0.8 $cm^3/g$ @STP for the polyethylene bagging and bottles, and silicone rubber pads, respectively, were taken from the curves for the offgassing volume per unit mass as documented in Y/DZ-2585. The data showed that the Teflon FEP material offgassing volume per unit mass ($V_{tf}$) was conservatively assumed to be 0.25 $cm^3/g$@STP (Y/DZ-2720). These values are used to determine the offgassing volume as shown below:

$V_{po} = W_p \times 0.8 / 16.387\ (in.^3)$ (offgassing volume of silicone rubber pads)

$V_{bo} = W_b \times 7.0 / 16.387\ (in.^3)$ (offgassing volume of polyethylene bags, bottles, and lifting sling)

$V_{tf} = W_{tf} \times 0.25 / 16.387\ (in.^3)$ (offgassing bottles of Teflon FEP bottles)

From the ideal gas law, the number of gas moles in the volume is as follows:

$$n_i = \frac{P_v \times V_i}{R_u \times T_{amb} \times 12}.$$

A summary of the results obtained using the above equations for CVAs 1, 7, and 11 is presented in Tables 3, 4, and 5.

**Table 3. Molar quantity of gas generated due to the silicone rubber pad offgassing [a]**

| CVA | $W_p$ (g) | $V_{po}$ ($in.^3$) | $P_V$ (psia) | $R_u$ (ft-lb/lb-mol·R) | $T_{amb}$ (R) | $n_{po}$ (lb-mol) |
|---|---|---|---|---|---|---|
| 1 | 186.74 | 9.12 | 14.7 | 1545.32 | 537 | 1.3458E-05 |
| 7 | 0.00 | 0.00 | 14.7 | 1545.32 | 537 | 0.0000E+00 |
| 11 | 186.74 | 9.12 | 14.7 | 1545.32 | 537 | 1.3458E-05 |

[a] Silicone rubber pad weight determined from Table 2.8.

**Table 4. Molar quantity of gas generated due to polyethylene bag, sling, and bottle offgassing**

| CVA | $W_b$ (g) | $V_{bo}$ (in.$^3$) | $P_V$ (psia) | $R_u$ (ft-lb/lb-mol·R) | $T_{amb}$ (R) | $n_{bo}$ (lb-mol) |
|---|---|---|---|---|---|---|
| 1 | 500.00 | 213.58 | 14.7 | 1545.32 | 537 | 3.1529E-04 |
| 7 | 500.00 | 213.58 | 14.7 | 1545.32 | 537 | 3.1529E-04 |
| 11 | 500.00 | 213.58 | 14.7 | 1545.32 | 537 | 3.1529E-04 |

**Table 5. Molar quantity of gas generated due to the Teflon FEP bottle offgassing**

| CVA | $W_{tf}$ (g) | $V_{tf}$ (in.$^3$) | $P_V$ (psia) | $R_u$ (ft-lb/lb-mol·R) | $T_{amb}$ (R) | $n_{tf}$ (lb-mol) |
|---|---|---|---|---|---|---|
| 7 | 990.00 | 15.10 | 14.7 | 1545.32 | 537 | 2.2296E-05 |

## III. Gas generation due to radiolysis of water

Buildup of hydrogen gas ($H_2$) and oxygen gas ($O_2$) in the ES-3100 containment vessel due to radiolysis is incorporated into the pressure calculation by assuming that 5 mol % of the free volume is hydrogen gas. Since each mole of H2 generated is accompanied by 0.5 mol of $O_2$, the concentration of $H_2$ will reach 5 mol % when volume of $H_2$ is 0.05405 times the initial void volume (see Sect. 3.5.4.8 of Appendix 3.5.4). Using the ideal gas law, the number of gas moles of hydrogen in the volume at standard temperature and pressure is:

$$n_r = \frac{P_v \times V_r}{R_u \times T_{amb} \times 12},$$

where

$n_r$ = individual molar quantity for hydrogen and oxygen gas,
$V_r$ = volume of gas assumed generated by radiolysis.

A summary of the results for hydrogen and oxygen generation due to radiolysis using the above equation is presented in Table 6.

**Table 6. Molar quantity of oxygen and hydrogen gas generation due to radiolysis**

| CVA | $V_v$ (in.$^3$) | $V_h$ (in.$^3$) | $P_v$ (psia) | $R_u$ (ft-lb/lb-mol·R) | $T_{amb}$ (R) | $n_{r-H2}$ (lb-mol) | $n_{r-O2}$ (lb-mol) |
|---|---|---|---|---|---|---|---|
| 1 | 462.00 | 24.97 | 14.7 | 1545.32 | 537.0 | 3.6861E-05 | 1.8430E-05 |
| 7 | 320.32 | 17.31 | 14.7 | 1545.32 | 537.0 | 2.5558E-05 | 1.2779E-05 |
| 11 | 54.25 | 2.93 | 14.7 | 1545.32 | 537.0 | 4.3285E-06 | 2.1643E-06 |

## IV. Molar quantity of gas generated due to the efflorescence nature of the uranyl nitrate crystals

The UNX crystals in any hydrated state will decompose and lose water molecules at the average gas temperature shown in Sect. 3.4.3 [140.36°F (284.64°C)]. The partial pressure of water vapor in this mixture is conservatively estimated to be the saturated vapor pressure ($P_{sv}$) of water at 284.64°F or 52.964 psia. Using the ideal gas law, the molar quantity of water vapor ($n_v$) in this volume at the maximum containment vessel temperature and the saturated vapor pressure is:

$$\begin{aligned} n_v &= (P_{sv} \times V_v) / (R_u \times T_{cv} \times 12); \\ &= (52.964)(320.32) / (1545.32 \times 12 \times 744.64); \\ &= 1.2286 \times 10^{-3} \text{ lb-mol}; \end{aligned}$$

where

$n_v$ = individual molar quantity for water vapor;
$V_v$ = void volume of containment vessel;
$T_{cv}$ = average gas temperature inside the containment vessel; and
$P_{sv}$ = interpolated saturated vapor pressure of water at temperature from *Fundamental of Classical Thermodynamic* (Van Wylen), Table A.1.1, p. 650.

## V. Total pressure due to offgassing and HAC temperatures inside the containment vessel with efflorescence of uranyl nitrate crystals

The total pressure of the mixture at 140.36°C (284.64°F), $P_T$, for each CVA is the sum of each of the previously calculated molar quantities. Table 7 summarizes the molar constituents and total pressure of each CVA. The following equation is used to calculate the final containment vessel pressure:

$$P_{140.36°C} = ( \sum n_i \times R \times T \times 12 ) / V_{GMV},$$

where

$n_i$ = individual molar quantity for each gas,

$T$ = average gas temperature,
= 140.36°C (284.64°F),

$V_{GMV}$ = $V_v$,
= gas mixture volume.

**Table 7. Total pressure inside the containment vessel at 140.36°C (284.64°F) with efflorescence [a]**

| CVA | $n_{MNOP}$ [b] (lb-mol) | $n_{po}$ [b] (lb-mol) | $n_{bo}$ [b] (lb-mol) | $n_{tf}$ [b] (lb-mol) | $n_{r-H2}$ [b] (lb-mol) | $n_{r-O2}$ [b] (lb-mol) | $n_{CE-WV}$ [b, c] (lb-mol) | $n_T$ [b] (lb-mol) | $P_T$ (psia) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 9.0270E-04 | 1.3458E-05 | 3.1529E-04 | 0.0000E+00 | 3.6862E-05 | 1.8431E-05 | 0.0000E+00 | 1.2867E-03 | 38.459 |
| 7 | 1.0042E-03 | 0.0000E+00 | 3.1529E-04 | 2.2296E-05 | 2.5558E-05 | 1.2779E-05 | 1.2286E-03 | 2.6087E-03 | 112.458 |
| 11 | 1.0600E-04 | 1.3485E-05 | 3.1529E-04 | 0.0000E+00 | 4.3285E-06 | 2.1643E-06 | 0.0000E+00 | 4.4127E-04 | 112.318 |

[a] This assumes that the internal convenience cans, polyethylene or Teflon FEP bottles, and Cat 277-4 spacer cans are not sealed.

[b] $n_{MNOP}$—molar quantity of the gas mixture at maximum normal operating pressure at standard temperature [25°C (77°F)];
$n_{po}$—molar quantity of gas due to offgassing of the silicone rubber pads;
$n_{bo}$—molar quantity of gas due to offgassing of the polyethylene bags, bottles, and lifting sling;
$n_{tf}$—molar quantity of gas due to offgassing of the Teflon bottles;
$n_{r-H2}$—molar quantity of hydrogen gas due to radiolysis of water;
$n_{r-O2}$—molar quantity of oxygen gas due to radiolysis of water;
$n_{CE-WV}$—molar quantity of water vapor due to efflorescence of UNX crystals; and
$n_T$—total molar quantity in the gas mixture.

[c] Efflorescence of UNX crystals as water vapor.

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## Appendix 3.5.3

### Silicone Rubber Thermal Properties from Therm 1.2 Database

The thermal properties for silicone rubber used in the thermal analyses of the ES-3100 shipping container were obtained from the Therm 1.2 Thermal Properties Database by R. A. Bailey. Since Therm 1.2 is not a publicly available program, screen captures from Therm 1.2 of the data for silicone rubber are presented in Figs. 1 and 2 in English and SI units, respectively.

```
                  silicone rubber, medium k (see ref 5)
         ------------------------------------------------------------
         Density                              .04696548   lb/in**3
         Specific Heat                        .3          Btu/lb°F
         Conductivity                         .01612725   Btu/hr in°F
         Maximum Material Temp             545.0          °F
         silicone rubber, medium k (see ref 5)
         ------------------------------------------------------------
References:
    fleming p           private collection of plastics data           1968
                        materials engr  matl selector issue           1967
                        metals handbook  8th ed                       1961
    moyer j             private collection of thermal data            1968
Material properties quality
    Density                 -  Good data, or no way of estimating quality.
    Specific Heat           -  Poor or conflicting data.  Used best or average.
    Conductivity            -  Poor or conflicting data.  Used best or average.
    Transition Temperature  -  Good data, or no way of estimating quality.
    Latent Heat             -  No data.  Made no estimate.
    Specific Heat Tables    -  No data.  Made no estimate.
    Conductivity Tables     -  No data.  Made no estimate.
```

**Fig. 1. Silicone rubber thermal properties from Therm 1.2 (English units).**

```
         silicone rubber, medium k (see ref 5)
         ------------------------------------------------------------
         Density                          1300.0          kg/m**3
         Specific Heat                    1255.2          J/kg°K
         Conductivity                         .33472      J/sec m°K
         Maximum Material Temp             558.15         °K
         silicone rubber, medium k (see ref 5)
         ------------------------------------------------------------
References:
    fleming p           private collection of plastics data           1968
                        materials engr  matl selector issue           1967
                      metals handbook  8th ed                    1961
    moyer j           private collection of thermal data          1968
Material properties quality
    Density                -  Good data, or no way of estimating quality.
    Specific Heat          -  Poor or conflicting data.  Used best or average.
    Conductivity           -  Poor or conflicting data.  Used best or average.
    Transition Temperature -  Good data, or no way of estimating quality.
    Latent Heat            -  No data.  Made no estimate.
    Specific Heat Tables   -  No data.  Made no estimate.
    Conductivity Tables    -  No data.  Made no estimate.
```

**Fig. 2. Silicone rubber thermal properties from Therm 1.2 (SI units).**

## Appendix 3.5.4

## Estimates of Hydrogen Buildup in the ES-3100 Package Containing Highly Enriched Uranium

### 3.5.4.0 Summary

Table 3.5.4.1 below indicates that the ES-3100 package with Containment Vessel Arrangement 1 (CVA 1, see Appendix 3.5.1) and a 15.13-kg load of uranium oxide with 3 wt % water, will generate 5 mol % of hydrogen in the void space of the containment vessel in ~1.5 years (18 months). With CVA 7, a load of 4.75 kg of uranyl nitrate hexahydrate crystals [UO2(NO3)2·XH2O, X = 6, 21.6 wt % water] or a load of 6.70 kg of uranyl nitrate trihydrate crystals (X=3, 12.1 wt % water) will generate 5 mol % of hydrogen in ~1.2 years (15 months). With CVA 7, a load of 9.17 kg of hexahydrate crystals will generate 5 mol % in ~0.46 years (5.6 months) while a load of 11.90 kg of trihydrate crystals will generate 5 mol % in ~0.49 years (5.8 months).

**Table 3.5.4.1 Summary of load weights and shipment durations**

| Weight (kg) | Water | | Time to 5 mol % hydrogen (y/month) |
|---|---|---|---|
| | X | wt % | |
| **Oxides [CVA 1] [a]** | | | |
| 15.13 | $UO_2$ | 3.0 | 1.51/18.2 |
| 15.13 | $U_3O_8$ | 3.0 | 1.51/18.1 |
| 15.13 | $UO_3$ | 3.0 | 1.49/17.9 |
| **$UO_2(NO_3)_2 \cdot XH_2O$ [CVA 7] [b]** | | | |
| 4.75 | 6 | 21.64 | 1.20/14.4 |
| 6.70 | 3 | 12.13 | 1.22/14.6 |
| 9.17 | 6 | 21.64 | 0.464/5.6 |
| 11.90 | 3 | 12.13 | 0.486/5.8 |

[a] CVA 1 consists of six steel cans (see Sect. 3.1.4.1).
[b] CVA 7 consists of three Teflon bottles (see Sect. 3.1.4.1).

### 3.5.4.1 Introduction

There is a concern that hydrogen gas ($H_2$) could build up to dangerous levels in the ES-3100 package. Consequently, it is necessary to estimate the combination of shipping weight and transit time that limits the $H_2$ concentration in the package to 5 mol % (established as a limit for the purposes of this analysis). The $H_2$ can be generated by radiolysis and/or chemical reaction involving any material containing hydrogen. Of the anticipated materials to be shipped, the only chemical reaction would be metal reacting with water (or water vapor) to form $H_2$ and a metal oxide. It will be shown that radiolysis of water is the major source of $H_2$ for uranium oxides and uranyl nitrate crystals.

The materials that may be shipped in the ES-3100 include highly enriched uranium (HEU) in the form of uranium oxide ($UO_3$, $U_3O_8$, and $UO_2$) and uranyl nitrate crystals [UNX or $UO_2(NO_3)_2 \cdot XH_2O$]. The water associated with oxides ranges from 0 to 3 wt % (Sect. 1.2.2). The water in UNX ranges from X = 0 to X = 6 (0 to 21.6 wt %). The molecular weights of uranyl nitrate [$UO_2(NO_3)_2$] and $H_2O$ are 391 and 18 g/mol, respectively, so the fraction of water in UN6 is $6 \times 18 / (391 + 6 \times 18) = 0.216$. There is no liquid water (sorbed or interstitial) associated with any of the other contents. However, the air in the void

spaces of the package contains water vapor (humidity). It will be shown that the maximum amount of $H_2$ from humidity is below 5 mol %.

### 3.5.4.2 Initial hydrogen in convenience containers

It was suggested that convenience containers stored for a long period of time could accumulate significant amounts of $H_2$ in the containers before being placed in the ES-3100. The convenience containers are Teflon bottles for UNX, and cans or polyethylene bottles for other materials. An estimate of the accumulated $H_2$ is given in this section.

The ES-3100 has several containment vessel arrangements (CVAs, see Appendix 3.5.1, Table 1) for the convenience containers. CVA 7 consists of three Teflon bottles and is the only arrangement for UNX. CVAs 5 (nickel alloy cans) and 6 (polyethylene bottles) can only be used for oxides while the remaining CVAs (steel cans) may be used for oxides or metal. The bounding arrangement for oxides is CVA 1 (6 steel cans) because it has the smallest free volume (588.45 $in.^3$, see Appendix 3.5.1, Table 1).

The $H_2$ generated in a container can leak out through tiny spaces in imperfect lids and by permeation or diffusion through the walls of the container. The largest leaks are through the lids but these are difficult to characterize. Consequently, this calculation conservatively considers only permeation and diffusion through the cylindrical surfaces. Because permeation is usually a faster mechanism than diffusion and is more likely with plastics, the permeation model was used for the Teflon bottles. Since metals are not very permeable, the diffusion model was used for the cans.

The rate of gas loss through permeation is based on an equation in *Perry's Chemical Engineers' Handbook* (p. 6-39, Eq. 6-170). The resulting expression is

$$d(n_P) / dt = -P_T \times \Delta P \times A_T / \tau_T \times \rho_G \times (1 + \Delta P / P_0),$$

where

$n_P$ = the amount of gas in the three Teflon bottles, mol;
$t$ = time, y;
$P_T$ = the permeability of $H_2$ through Teflon, $cm^2/y \cdot Pa$;
$\Delta P$ = the pressure increase over the initial value, Pa;
$A_T$ = the cylindrical area of three Teflon bottles (each is 4.69-in. diam × 9.4-in. tall) 2682.8 $cm^2$ (Y/HDPO/03-43);
$\tau_T$ = the thickness of each bottle, 0.13 cm (Y/HDPO/03-43);
$\rho_G$ = the molar density of an ideal gas at 25°C and 1 atm, $4.087 \times 10^{-5}$ $mol/cm^3$;
$P_0$ = the initial pressure in the bottles, 101,325 Pa (1 atm); and
$1 + \Delta P / P_0$ corrects the gas density for the pressure increase.

The permeability of $H_2$ through Teflon at 25°C is $3.12 \times 10^{-5}$ $cm^2/y \cdot Pa$ (equivalent to $9.89 \times 10^{-8}$ $cm^2/s \cdot Bar$ (*Parker O-Ring Handbook*, Table 3-24, p.3-30).

At steady state, the permeation rate is balanced by the gas generation rate.

$$1.5 \times d(n_{H2}) / dt = P_T \times \Delta P \times A_T / \tau_T \times \rho_G \times (1 + \Delta P / P_0),$$

$$\rightarrow \Delta P \times (1 + \Delta P / P_0) = [1.5 \times d(n_{H2}) / dt] / [P_T \times A_T / \tau_T \times \rho_G],$$

where

$d(n_{H2}) / dt$ = the $H_2$ generation rate, 0.01379 mol/y for 4750 g of $UO_2(NO_3)_2 \cdot 6H_2O$ (see Sect. 3.5.4.7);
1.5 = a factor to account for the oxygen released with the hydrogen.

As an example for 4750 g of $UO_2(NO_3)_2 \cdot 6H_2O$, the above expression for $\Delta P$ with the above parameters is $\Delta P = \{[1.5 \times 0.01379 \text{ mol/y}] / [3.12 \times 10^{-5} \text{ cm}^2/\text{y} \cdot \text{Pa} \times (2682.8 \text{ cm}^2 / 0.13 \text{ cm}) \times 4.087 \times 10^{-5} \text{ mol/cm}^3]\} / (1 + \Delta P / 101{,}325 \text{ Pa})$. $\Delta P = 779.5$ Pa satisfies the above expression.

The steady-state mole fraction and $H_2$ amount are

$$f_{H2B} = (2 / 3) \times \Delta P / (P_0 + \Delta P),$$
$$n_{H2B} = f_{H2B} \times V_B \times \rho_G \times (1 + \Delta P / P_0) = V_B \times \rho_G \times (2 / 3) \times \Delta P / P_0,$$
$$V_B = 6840 - Wt_{UNX} / \rho_{UN6},$$

where

$f_{H2B}$ = the mole fraction of $H_2$ in the bottles;
$n_{H2B}$ = the amount of $H_2$ in the three bottles, mol;
2 / 3 = a factor to account for the fact that 1 / 3 of the pressure increase is due to oxygen;
$V_B$ = the free volume of the 3 bottles, $\text{cm}^3$ [5149.6 $\text{cm}^3$ for 4750 g of $UO_2(NO_3)_2 \cdot 6H_2O$];
6840 = the empty void volume of three Teflon bottles, 6840 $\text{cm}^3$ (Y/HDPO/03-43);
$Wt_{UNX}$ = the total weight of UNX in the containers, g;
$\rho_{UN6}$ = the theoretical density of UN6 and, lacking data for other UNX hydrates, is also applied to all the hydrates, 2.81 $\text{g/cm}^3$ (CRC Handbook, p. 4-94).

For the example of 4750 g of $UO_2(NO_3)_2 \cdot 6H_2O$, the above equation becomes

$$n_{H2B} = 5149.6 \text{ cm}^3 \times 4.087 \times 10^{-5} \text{ mol/cm}^3 \times (2 / 3) \times 779.5 \text{ Pa} / 101{,}325 \text{ Pa},$$
$$= 0.001079 \text{ mol.}$$

The rate of $H_2$ loss through diffusion is based on an equation in *Perry's Chemical Engineers' Handbook* (p. 5-47, Eq. 5-189). The resulting expression is

$$d(n_{H2C}) / dt = -D \times \Delta C \times A_D / \tau_D,$$

where

$n_{H2C}$ = the amount of $H_2$ in the 6 cans, mol;
$d(n_{H2C}) / dt$ = the rate of $H_2$ lost through diffusion from the 6 cans, mol/y;
D = the diffusivity, $\text{cm}^2/\text{y}$;
$\Delta C$ = the $H_2$ concentration increase over the initial value, $\text{mol/cm}^3$;
$A_D$ = the cylindrical area of six steel cans, (each is 4.25-in. diam × 4.88-in. tall, see Sect. 1, Fig. 1.4), 2522.2 $\text{cm}^2$;
$\tau_D$ = the thickness of the can (assumed to be 0.012 in.), 0.0305 cm.

At steady state, the diffusion rate is balanced by the $H_2$ generation rate.

$$d(n_{H2}) / dt = D \times \Delta C \times A_D / \tau_D \rightarrow \Delta C$$
$$= [d(n_{H2}) / dt] / [D \times A_D / \tau_D]$$

The steady-state $H_2$ amount and mole fraction are

$$n_{H2C} = V_C \times \Delta C,$$
$$f_{H2C} = (V_C \times \Delta C) / (V_C \times \rho_G) = \Delta C / \rho_G,$$
$$V_C = V_0 - Wt_{OX} / \rho_{OX},$$

where

$f_{H2C}$ = the mole fraction of $H_2$ in the cans;
$V_C$ = the free volume in 6 cans, $cm^3$ (5001.3 $cm^3$ for 15,130 g of $U_3O_8$);
$V_0$ = the free volume of the 6 empty cans, 6806.8 $cm^3$;
$Wt_{OX}$ = the total weight of uranium oxides in the containers, g;
$\rho_{OX}$ = the theoretical density of uranium oxides, 7.3 $g/cm^3$ for $UO_3$, 8.38 for $U_3O_8$, and 10.97 for $UO_2$ (CRC Handbook, p. 4-94).

$H_2$ diffusion is discussed at http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/03_babu_transfer.pdf, p. 42 (Sudarsanam 2005). There is a wide range of values for diffusivity at room temperatures and a suggested value of ~$5 \times 10^{-7}$ $cm^2/s$ (15.8 $cm^2/y$) is probably a low number for plain steel without welds or rough surfaces. This is the value used for calculating the diffusion loss rate of $H_2$ from the cans.

For 15,130 g of $U_3O_8$, the value of $d(n_{H2}) / dt$ is 0.01185 mol/y (see Sect. 3.5.4.7). $\Delta C$ = 0.01185 mol/y / [15.8 $cm^2/y$ × 2522.2 $cm^2$ / 0.0305 cm] = 9.078E-09 $mol/cm^3$. The amount of $H_2$ in the 6 cans is $n_{H2C}$ = 5001.3 $cm^3$ × 9.078E-09 $mol/cm^3$ = 4.540E-05 mol.

The above analysis assumed the material to be shipped is distributed equally to the maximum number of convenience containers for the specified CVAs (3 bottles for CVA 7 and 6 cans for CVA 1). If the material can be packed into fewer convenience containers, the amount of initial $H_2$ would be less. The expressions for C and $n_{H2C}$ indicate that $n_{H2C}$ is proportional to $V_C / A_D = (V_0 - Wt_{OX} / \rho_{OX}) / A_D$. If the empty volume and surface area of a single can is v and a, respectively, the above proportionality becomes $(Nc \times v - Wt_{OX} / \rho_{OX}) / (Nc \times a) = v / a - Wt_{OX} / (Nc \times a \times \rho_{OX})$ where Nc is the number of cans (1 to 6). As Nc increases, $Wt_{OX} / (Nc \times a \times \rho_{OX})$ decreases so that less is subtracted from v / a. The result is increasing $n_{H2C}$.

### 3.5.4.3 Hydrogen generation by chemical reaction with water

Metals can combine with the oxygen in water to release $H_2$. The only source of water for metals is the humidity of the air in the void spaces of the package. The air is assumed to be at 25°C, 1 atm (101.325 kPa) and 100% relative humidity. The vapor pressure of water at 25°C is 3.1690 kPa (CRC Handbook, p. 6-8), so the initial concentration of water vapor is 3.1690 / 101.325 = 0.031 mol fraction. Since 1 mol of water vapor produces 1 mol of $H_2$ and the oxygen is bound up as solid metal oxides, this reaction does not change the total gas pressure. Therefore, if all the water vapor reacts with the metal, the maximum concentration of $H_2$ is also 0.031 mol fraction, which is below the 5 mol % limit.

### 3.5.4.4 Radiation energy calculations

The radiation energy that drives radiolysis can be estimated from the decay rate and maximum decay energy of each radionuclide that makes up the HEU compounds (oxides and crystals). The bounding information to calculate these terms and the results are given in Table 3.5.4.2. It should be noted that the transuranic concentration can be much higher for HEU metal.

**Table 3.5.4.2. Radiation energy calculations**

| Nuclide | $Wt\%_n$ [a] | $MW_n$ [b] (g/mol) | $T_{Hn}$ [b] (y) | $\alpha_{Mn}$ [b] (MeV) | $D_{Rn}$ [c] [atms/(g y)] | Nuclide contr [c] [MeV/(gU y)] |
|---|---|---|---|---|---|---|
| $^{232}U$ | 4.00E-06 | 232.0371 | 6.89E+01 | 5.414 | 2.61E+19 | 5.65E+12 |
| $^{233}U$ | 6.00E-01 | 233.0396 | 1.59E+05 | 4.909 | 1.13E+16 | 3.32E+14 |
| $^{234}U$ | 2.00E+00 | 234.0409 | 2.45E+05 | 4.856 | 7.28E+15 | 7.07E+14 |
| $^{235}U$ | 5.49E+01 | 235.0439 | 7.04E+08 | 4.679 | 2.52E+12 | 6.48E+12 |
| $^{236}U$ | 4.00E+01 | 236.0456 | 2.34E+07 | 4.569 | 7.56E+13 | 1.38E+14 |
| $^{238}U$ | 0.00E+00 | 238.0508 | 4.46E+09 | 4.185 | 3.93E+11 | 0.00E+00 |
| Transur | 4.00E-03 | | | 5.476 [d] | 4.73E+17 | 1.04E+14 |
| $^{237}Np$ | 2.50E+00 | 237.0482 | 2.14E+06 | 4.957 | 8.23E+14 | 1.02E+14 |
| Total | 1.00E+02 | | | | | 1.395E+15 |

[a] Wt % from Appendix 4.5.1 (Table 1). Maximum transuranic for compounds is 40 μg/gU and 0.60 MBq/gU activity.
[b] MW is molecular weight; $T_H$ is half life; and α is the maximum energy emitted (*CRC Handbook of Chemistry and Physics*, pp. 11-140 and 11-141).
[c] $D_R$ is decay rate, and Nuclide Contr is the contribution of each nuclide to the total rate of decay energy.
[d] Transuranic α assumed to be equal to $^{246}Cm$.

The decay rate per gram of the $n^{th}$ radionuclide is

$$D_{Rn} = [\ln(2) / T_{Hn}] \times A_N / MW_n;$$
$$= \text{the decay rate of the } n^{th} \text{ radionuclide, atoms/y;}$$

$T_{Hn}$ = half life of the $n^{th}$ radionuclide, y;
$A_N$ = Avogadro's number, $6.022 \times 10^{23}$ molecules/mol;
$MW_n$ = the molecular (atomic) weight of the $n^{th}$ radionuclide, g/mol.

All the radionuclides in Table 3.5.4.2 are primarily α emitters, and the total rate of radiation dose is given as

$$D_E = \sum_{n=1}^{N} \frac{Wt\%_n \times D_{Rn} \times \alpha_{Mn}}{100},$$

where

$D_E$ = the total rate of decay energy per gram of uranium, Mev/(gU y);
$Wt\%_n$ = the weight percent of the $n^{th}$ radionuclide in the uranium;
$\alpha_{Mn}$ = the α energy emitted in the decay of the $n^{th}$ radionuclide, MeV; and
N = the total number of radionuclides.

The above calculation of $D_E$ for HEU is $1.395 \times 10^{15}$ MeV/(gU y).

### 3.5.4.5 Hydrogen generation by radiolysis of polyethylene

Almost all the radiation energy from HEU is due to alpha particles with energies of 4–5 MeV (Table 3.5.4.2). These particles are not very penetrating and will only deposit their energy into materials that are in intimate contact with the uranium atoms (i.e., the water of hydration in uranyl nitrate crystals and the water associated with the oxides). The polyethylene is in the form of bottles and bags that

surround the uranium and the only alpha particles that reach the polyethylene come from the outer range of alpha particle penetration within the HEU.

Equations 1.9 and 1.10 on p. 9 in *Handbook of Radioactivity Analysis* approximate the range of alpha particle penetration in air, and other materials for α energy in the range of 4 to 7 MeV. These are combined to give the following expression for calculating the range in HEU (metal, oxide, or crystals).

$$R = 9.6 \times 10^{-7} \times \alpha_{MA}^{3/2} \times (MW_A)^{½} / \rho,$$

where

$R$ = the range of alpha particle penetration in the HEU, m;
$\alpha_{MA}$ = the average α energy emitted by the HEU, ~4.9 MeV (Table 3.5.4.2);
$MW_A$ = the average molecular weight of the HEU, ~235.5 g/mol (Table 3.5.4.2); and
$\rho$ = the density of the HEU, g/cm$^3$.

The range increases with decreasing ρ, and the smallest value for ρ is ~1.5 g/cm$^3$. {The smallest approximate bulk density of HEU oxide, *Cost-Effectiveness of Utilizing Surplus Depleted Uranium (DU)*, [WM-4009]}. The resulting range is $1.07 \times 10^{-4}$ m.

The radius of a polyethylene bottle is 0.0627 m [4.94-in. diam (Table 2.10), configuration designated as CVA 6]. If the HEU oxide fills the bottle, the alpha particles generated in the outer range come from the HEU between 0.0627 and $(0.0627 - 1.07 \times 10^{-4}$ m). For an infinite cylinder, the fraction of the total radiation within this range is $[(0.0627)^2 - (0.0627 - 1.07 \times 10^{-4})^2] / (0.0627)^2 = 0.00339$. Half of this radiation would be directed toward the center of the cylinder, and much of the outward-directed portion would be absorbed passing through the HEU. Consequently, the radiation absorbed by the polyethylene would be much less than 1% of that absorbed by the water, and the $H_2$ generated in the polyethylene would be correspondingly less than that generated in the water.

### 3.5.4.6 Hydrogen generation by radiolysis of water

Assuming an infinite amount of water is available, the radiolytic hydrogen generation rate is given by the following expression (based on NUREG/CR-6673, p. 31, Eq. 4.7):

$$d(n_{H2}) / dt = (D_H / 100) \times [G(H_2) / A_N],$$

where

$n_{H2}$ = the amount of hydrogen generated, mol;
$t$ = time, y;
$D_H$ = the decay energy absorbed by the water, eV/y; and
$G(H_2)$ = a radiolytic hydrogen generation factor for alpha radiation in water, molecules $H_2$/100 eV absorbed by water.

### 3.5.4.7 Radiolytic hydrogen generation factors for alpha radiation in water

A bounding value for $G(H_2)$ with alpha radiation is 1.6 molecules $H_2$/100 eV absorbed by water (NUREG/CR-6673, p. 12, Table 3.1). However, 2003 experimental data from Oak Ridge National Laboratory suggest lower $G(H_2)$ values [*Alpha Radiolysis of Sorbed Water on Uranium Oxides and Uranium Oxyfluorides* (ORNL/TM-2003/172) and *Water Sorption and Radiolysis Studies for Neptunium Oxides* (ORNL/TM-2003/194)]. Table 3.5.4.3 lists the $G(H_2)$ values derived from these experiments. The largest of the ORNL values (1.02) is used for the hydrogen generation calculations.

**Table 3.5.4.3. $G(H_2)$ values derived from alpha radiolysis experiments**

| Sample description | $e^-(H_2O)$ | $e^-$(rem) | $f_{H2O}$ | Gf | molecules/100 eV | | |
|---|---|---|---|---|---|---|---|
| | | | | | G'(gas) [a] | G'($H_2$) | G($H_2$) |
| **Icenhour and Toth, ORNL/TM-2003/172, 2003** | | | | | | | |
| Fig. 3.3. Samp A-2-2, $UO_3$, 10% $H_2O$, 350°C | 0.0556 | 0.3689 | 0.1000 | 0.1309 | 0.1507 | 0.1005 | 0.77 |
| Fig. 3.5. Samp A-4-1 $U_3O_8$, 2% $H_2O$, 650°C | 0.0111 | 0.4000 | 0.0200 | 0.0270 | 0.0113 | 0.0075 | 0.28 |
| **Icenhour et al., ORNL/TM-2003/194, 2004** | | | | | | | |
| Fig. 4.12. Samp Al 3, $NpO_2$, 8% $H_2O$, 650°C | 0.0444 | 0.3728 | 0.0800 | 0.1065 | 0.1100 | 0.0733 | 0.69 |
| Fig. 4.11. Samp Al 2, $NpO_2$, 1% $H_2O$, 650°C | 0.0056 | 0.4012 | 0.0100 | 0.0137 | 0.0210 | 0.0140 | 1.02 |
| Fig. 4.13. Samp Al 4, $NpO_2$, 1% $H_2O$, 800°C | 0.0056 | 0.4012 | 0.0100 | 0.0137 | 0.0060 | 0.0040 | 0.29 |
| Fig. 4.14. Samp Al 5, $NpO_2$, 0.5% $H_2O$, 650°C | 0.0028 | 0.4032 | 0.0050 | 0.0068 | 0.0043 | 0.0029 | 0.42 |

[a] G'(gas) for ORNL/TM-2003/172 is based on a measured slope in Fig. 3.3 or 3.5. For ORNL/TM-2003/194, the values are listed on Figs. 4.11–4.14.

The G'(gas) value is the initial slope of the gas yield (mmol/g material) versus the decay energy (MGy) converted to units of molecules of gas per 100 eV. G'(gas) for ORNL/TM-2003/172 is based on a measured slope in Fig. 3.3 or 3.5 while the values for ORNL/TM-2003/194 are listed on Figs. 4.11 through 4.14. Figure 3.5.4.1 is from ORNL/TM-2003/172 (p. 9, Fig. 3.5) with lines added to outline the initial slope and facilitate reading values. From Fig. 3.5.4.1, the gas yield difference along the slope is $0.023 - (-0.0005) = 0.0235$ millimol/g or $0.0235 \times A_N / 1000 = 1.42 \times 10^{19}$ molecules/g. The decay energy difference along the slope is 20.0 MGy or $20.0 \times 6.24 \times 10^{21} = 1.25 \times 10^{23}$ eV ($6.24 \times 10^{21}$ eV/g = 1 MGy). Therefore, G'(gas) is $1.42 \times 10^{19} / 1.25 \times 10^{23}) \times 100 = 0.0113$ molecules gas/100 eV. It is assumed the gas is due to the decomposition of $H_2O$ and has a molar composition of 2/3 $H_2$ and 1/3 oxygen ($O_2$). The derived G'($H_2$) is 2/3 of the G'(gas) value or 0.00756 molecules $H_2$/100 eV decay energy.

The radiation calculated in Table 3.5.4.2 is the decay energy rather than the energy absorbed by the water associated with the material. The energy absorbed by the associated water, $D_H$, is approximately equal to the decay energy, $D_E$, multiplied by the fraction of electrons associated with the water or

$$Gf = e^-(H_2O) / e^-(mat),$$

where

$$e^-(mat) = \sum_{i=1}^{I} e^-(mat_i);$$

Gf = the fraction of electrons associated with the water;
$e^-(H_2O)$ = the number of electrons associated with the water, electrons/molecule;
$e^-$(mat) = the total number of electrons associated with the molecular species; electrons/molecule;
$e^-(mat_i)$ = the contribution of the $i^{th}$ molecular species to $e^-$(mat); and
I = the total number of molecular species.

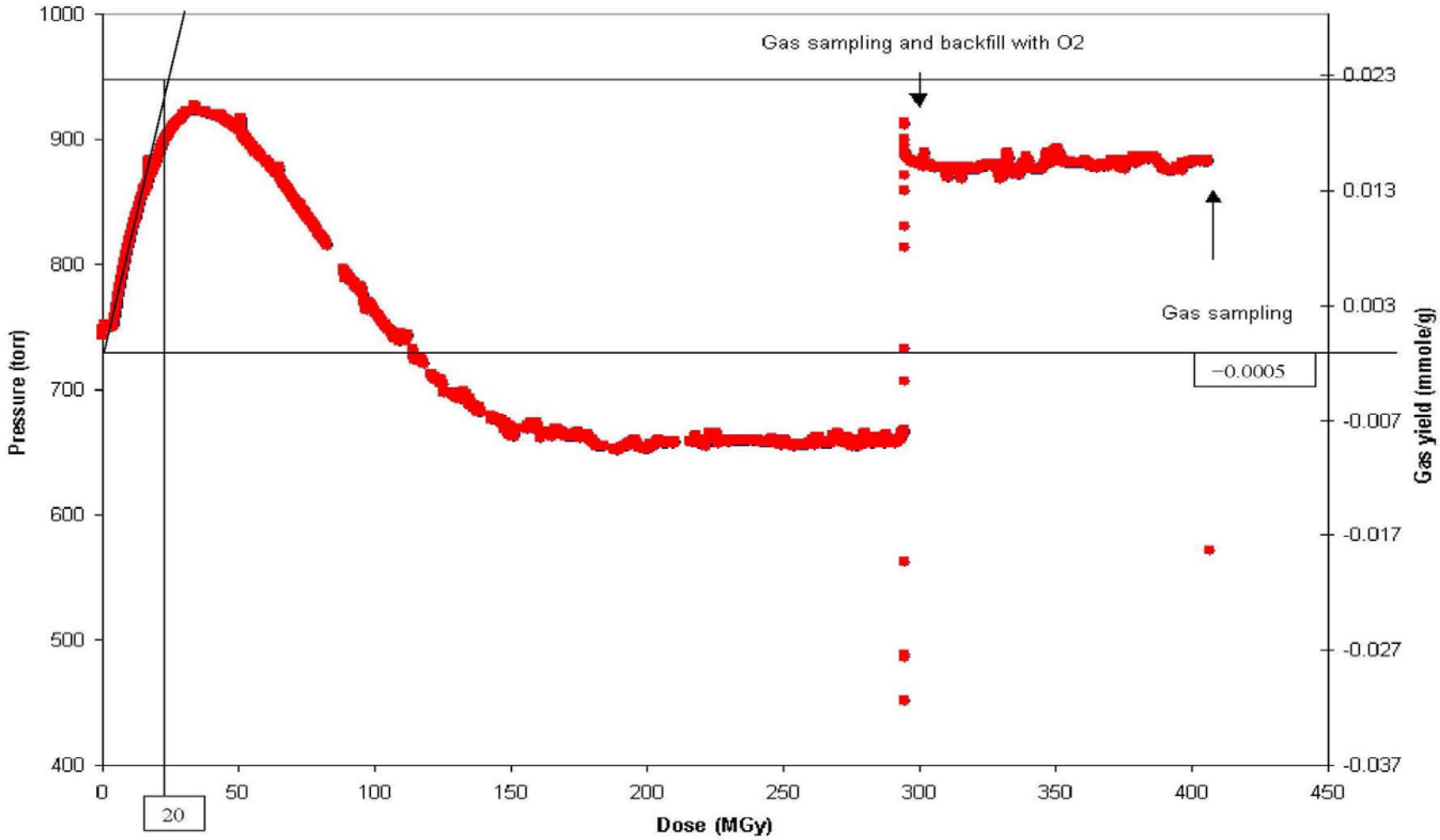



**Fig. 3.5.4.1. Pressure and gas yield as a function of dose.**

**Note:** Based on Fig. 3.5 in *Alpha Radiolysis of Sorbed Water on Uranium Oxides and Uranium Oxyfluorides* (ORNL/TM-2003/172), Sample A-4-1 (5.64 g $U_3O_8$ with 2 wt % $H_2O$, spiked with 0.0249 g $^{244}Cm$).

The energy absorbed by the water is

$$D_H = Gf \times D_E,$$

and

$$G'(H_2) = Gf \times G(H_2) \rightarrow G(H_2) = G'(H_2) / Gf.$$

Two methods to calculate Gf are reported in *Calculation of Hydrogen Generation Rates for Storage of Post-KIS Oxide in 9975 Shipping Containers* (Calculation No. N-CLC-K-00219, p. 9 and 10). In the more rigorous of the two methods, Gf is estimated from the material stoichiometry and molecular weights. Using this more rigorous method, $e^-(mat_i)$ is calculated as

$$e^-(mat_i) = f_i \times \sum_{i=1}^{J} \frac{n_{i,j} \times Z_{i,j}}{MW_i},$$

where

$f_i$ = the weight fraction of the $i^{th}$ molecular species,
$MW_i$ = the molecular weight of the $i^{th}$ species,
$n_{i,j}$ = the number of moles of the $j^{th}$ element in the $i^{th}$ species,
$J$ = the total number of elements in the $i^{th}$ species, and
$Z_{i,j}$ = the atomic number of the $j^{th}$ element in the $i^{th}$ species.

According to the preceding equation, the expression for the number of electrons associated with the water is

$$e^-(H_2O) = f_{H2O} \times 10 / (16 + 2) = f_{H2O} \times 0.5556.$$

A mixture of water and $U_3O_8$ (assuming all the uranium is $^{235}U$) is

$$e^-(mat) = f_{H2O} \times 0.5556 + f_{U3O8} \times (3 \times 92 + 8 \times 8) / (3 \times 235 + 8 \times 16) = f_{H2O} \times 0.5556 + f_{U3O8} \times 0.4082$$

where

$f_{H2O}$ = the weight fraction of water and

$f_{U3O8}$ = the weight fraction of $U_3O_8$
= $1 - f_{H2O}$ if no other material is present.

A $G'(H_2)$ value of 0.00756 molecules $H_2$/100 eV decay energy is derived from the experiment by Icenhour and Toth with a $U_3O_8$ sample (5.64 g) containing 2% water and spiked with 0.0249 g $^{244}Cm$ (ORNL/TM-2003/172, p. 7, Table 3.1). The mass of $^{244}Cm$ can be neglected, so the calculation of $G(H_2)$ for this sample is $e^-(H_2O) = 0.02 \times 0.5556 = 0.0111$; $e^-(mat) = 0.0111 + 0.98 \times 0.4082 = 0.4111$; $Gf = 0.0111 / 0.4111 = 0.0270$; and $G(H_2) = 0.00756 / 0.0270 = 0.280$ molecules $H_2$/100 eV absorbed by the water. Since the largest of the ORNL values (1.02) is used for the hydrogen generation calculations, the $G'(H_2)$ value for any other water content is the corresponding value of $Gf \times 1.02$.

To calculate Gf for $UO_2(NO_3)_2 \cdot XH_2O$, the two components are $UO_2(NO_3)_2$ and $H_2O$, where $f_{H2O}$ is

$$f_{H2O} = X \times (2 + 16) / [235 + 2 \times 16 + 2 \times (14 + 3 \times 16) + X \times (2 + 16)],$$
$$= 1 / [1 + 391 / (X \times 18)],$$

$$e^-(mat) = f_{H2O} \times 0.5556 + f_{UN2O8} \times (92 + 8 \times 8 + 2 \times 7) / (391),$$
$$= f_{H2O} \times 0.5556 + f_{UN2O8} \times 0.4348,$$

$f_{UN2O8}$ = the weight fraction of $UO_2(NO_3)_2 = 1 - f_{H2O}$.

The following example calculations are for $U_3O_8$ with 3% $H_2O$ and $UO_2(NO_3)_2 \cdot XH_2O$ with X = 6 ($f_{H2O}$ = 0.2164, Sect. 3.5.4.1). The $e^-(H_2O)$ and $e^-(mat)$ values for the $U_3O_8$ are 0.0300 × 0.5556 = 0.0167 and 0.0167 + 0.9700 × 0.4082 = 0.4126, respectively. The resulting Gf and G'($H_2$) values for the $U_3O_8$ are 0.0167 / 0.4126 = 0.0404 and 0.0404 × 1.02 = 0.0412, respectively. The corresponding values for $UO_2(NO_3)_2 \cdot 6H_2O$ are $e^-(H_2O)$ = 0.2164 × 0.5556 = 0.1202, $e^-(mat)$ = 0.1202 + 0.7836 × 0.4348 = 0.4609, Gf = 0.1202 / 0.4609 = 0.2608, and G'($H_2$) = 0.2608 × 1.02 = 0.2661.

The equation for the $H_2$ generation rate ($d(n_{H2})/dt$, mol $H_2$/y) is given in Sect. 3.5.4.6. The emitted radiation rate is $1.395 \times 10^{21}$ eV/[GU Y] (1.395E+15 MeV/[gU y], Table 3.5.4.2). The uranium content of $U_3O_8$ with 3% $H_2O$ is (1 − 0.0300) × 3 × 235 / (3 × 235 + 8 × 16) = 0.8209 gU/g and $UO_2(NO_3)_2 \cdot 6H_2O$ is 235 / (235 + 2 × 16 + 2 × [14 + 3 × 16] + 6 × (2 + 16) = 0.4709 gU/g. For 15,130 g of $U_3O_8$ with 3% $H_2O$, $d(n_{H2}) / dt = 15{,}130 \times 0.8209 \times 1.39 \times 10^{21} \times 0.0412 / (100 \times 6.022 \times 10^{23}) = 0.01185$ mol $H_2$/y. For 4750 g of $UO_2(NO_3)_2 \cdot 6H_2O$, $d(n_{H2}) / dt = 4750 \times 0.4709 \times 1.39 \times 10^{21} \times 0.2661 / (100 \times 6.022 \times 10^{23})$ = 0.0137 mol $H_2$/y.

### 3.5.4.8 Time to reach 5 mol %

The time at which the $H_2$ concentration in the void space of the package reaches 5 mol % depends on the $H_2$ generation rate and the initial amount of gas in the void space. This void space includes the internal void space within the convenience containers and the void space in the containment vessel outside the convenience containers. It is assumed that the convenience containers are open to the containment vessel and all the gases initially present, and subsequently generated, are mixed in this void space.

The initial amount of gas in the void space is given by

$$n_I = V_{VT} \times \rho_G,$$
$$V_{VT} = V_{BT} - Wt / \rho,$$

where

$n_I$ = the initial amount of gas in the containment vessel void space, mol;
$V_{VT}$ = the void volume of the loaded containment vessel, $cm^3$;
$V_{BT}$ = the void volume of the containment vessel with empty convenience containers, 9,643.0 $cm^3$ (588.45 $in.^3$) and 9,483.5 $cm^3$ (578.72 $in.^3$) for CVA 1 and CVA 7, respectively (Appendix 3.5.1, Table 1);
Wt = the total load weight ($Wt_{UNX}$ or $Wt_{OX}$), g;
$\rho$ = the density of the load material ($\rho_{UNX}$ or $\rho_{OX}$).

Since each mole of $H_2$ generated is accompanied by 0.5 mol of $O_2$, the concentration of $H_2$ will reach 5 mol % when

$$(n_{H2GN} + n_{H2I}) / (1.5 \times n_{H2GN} + n_I) = 0.05 \text{ or } n_{H2GN} = 0.05405 \times n_I - 1.08108 \times n_{H2I},$$

where

$n_{H2GN}$ = the amount of $H_2$ generated after the containment vessel is loaded, mol,
$n_{H2I}$ = the initial amount of $H_2$ in the convenience containers when the containment vessel is loaded (= $n_{H2B}$ or $n_{H2C}$), mol.

As an example, 15,130 g of $U_3O_8$ ($\rho$ is 8.38 g/cm$^3$) in a CVA 1 configuration will result in a loaded void volume ($V_{VT}$) of 9643.0 − 15130 / 8.38 = 7837.5 cm$^3$. The initial amount of gas ($n_I$) is 7837.5 cm$^3$ × 4.087 × 10$^{-5}$ mol/cm$^3$ = 0.32035 mol. The initial amount of $H_2$ in the convenience containers ($n_{H2I}$) is 4.5402E-05 mol (Sect. 3.5.4.2) so $n_{H2GN}$ = 0.05405 × 0.32035 − 1.08108 × 4.54E-05 = 0.017267 mol.

### 3.5.4.9 Hydrogen buildup

The buildup of $H_2$ in the containment vessel can be expressed as

$$\frac{d(n_{H2GN})}{dt} = \frac{d(n_{H2})}{dt} - L_{MH2},$$

where

$L_{MH2}$ = the permeation loss rate of $H_2$ through the main O-ring of the containment vessel, mol /y.

*Parker O-Ring Handbook* (Sect. 3.12.1, p. 3-21) gives the following expression for the permeation loss of $H_2$ through an O-ring:

$L_{VH2}$ = $0.7 \times F \times D \times P \times Q \times (1 - S)^2$;
= the permeation loss rate of $H_2$ through the O-ring, Std cm$^3$ $H_2$/s;

F = the permeability of hydrogen through the O-ring material (ethylene propylene, Table 3.10) at 38°C, 28.9E-08 Std cm$^3$ $H_2$/(cm s bar) [*Parker O-Ring Handbook*, Table 3-24, p. 3-29];
D = the inside diameter of the O-ring, 5.359 in. (Drawing M2E801580A013, Appendix 1.3.7);
P = the pressure differential across the seal, psi;
S = the fraction of the O-ring cross-section reduced by squeezing the ring in the gland, 0.15 to 0.21 (Sect. 4.1.1), 0.21 conservatively selected;
Q = a factor depending on S (ring is lubricated, Table 3.10), 0.72 (*Parker O-Ring Handbook*, Fig. 3-11, p. 3-21);
$L_{MH2}$ = $L_{VH2}$ multiplied by (3600 s/h × 24 h/d × 365.25 d/y) and divided by 22,414 Std cm$^3$/mol.

The pressure increase in the containment vessel is given by

$P = 1.5 \times n_{H2GN} / n_I \times P_i$,
$P_i$ = the initial pressure of the gas in the containment vessel, 14.7 psia.

If the initial pressure is equal to the ambient pressure (the usual situation), the pressure differential across the seal is equal to P.

If all of the above terms are combined, the expression for $d(n_{H2GN}) / dt$ becomes

$$\frac{d(n_{H2GN})}{dt} = \frac{d(n_{H2})}{dt} - \frac{k \times n_{H2GN}}{n_I},$$

$$\begin{aligned} k &= 0.7 \times F \times D \times 1.5 \times P_i \times Q \times (1 - S)^2 \times (3600 \times 24 \times 365.25) / 22414, \\ &= 0.01512 \text{ mol/y}. \end{aligned}$$

The solution to the above differential equation is

$$n_{H2GN} = [d(n_{H2}) / dt] \times n_I / k \times [1.0 - \exp(-k \times t / n_I)],$$

and the time when $n_{H2GN}$ reaches $0.05405 \times n_I - 1.08108 \times n_{H2I}$ is

$$t = -\text{Ln}(1.0 - [0.05405 \times n_I - 1.08108 \times n_{H2I}] \times k / [d(n_{H2}) / dt \times n_I]) \times n_I / k.$$

As an example, the time for the 15,130 g of $U_3O_8$ is $-\text{Ln}(1.0 - 0.017267 \text{ mol} \times 0.01512 \text{ mol/y} / [0.01185 \text{ mol/y} \times 0.32035 \text{ mol}]) \times 0.32035 \text{ mol} / 0.01512 \text{ mol/y} = 1.51$ y.

As shown in Table 3.5.4.2, the bounding value of the decay energy ($D_E$) is $1.39 \times 10^{15}$ MeV/(gU y). The energy per gram of material is the product of $D_E \times$ the fraction of uranium in the material. The fraction of uranium in $UO_2$ with $f_{H2O} = 0.03$ (3% water) is $(1 - 0.03) \times 235 / (235 + 2 \times 16) = 0.85375$ gU/g material. Similarly, the fractions in $U_3O_8$ and $UO_3$ are 0.82095 and 0.80548, respectively. The corresponding fraction in crystals is $235 / [235 + 2 \times 16 + 2 \times (14 + 3 \times 16) + X \times (2 + 16)] = 0.47094$ gU/g material for X = 6 [$UO_2(NO_3)_2 \cdot 6H_2O$] and 0.52809 for X = 3 [$UO_2(NO_3)_2 \cdot 3H_2O$]. The decay energies are $1.19 \times 10^{15}$ MeV/y g material for $UO_2$ with 3% $H_2O$, $1.15 \times 10^{15}$ for $U_3O_8$, $1.12 \times 10^{15}$ for $UO_3$, $6.57 \times 10^{14}$ for $UO_2(NO_3)_2 \cdot 6H_2O$, and $7.37 \times 10^{14}$ for $UO_2(NO_3)_2 \cdot 3H_2O$.

Table 3.5.4.4 summarizes the calculations for the time to reach 5 mol % $H_2$ in the void space of the containment vessel, as a function of the total weight of the material in the containers (Wt). The total amount of $H_2$ in the void space is the sum of the initial $H_2$ plus the added $H_2$ while the total gas in the void space is the sum of the initial gas plus 1.5 times the added $H_2$. The 1.5 factor accounts for the $O_2$ generated with the $H_2$. For 15.13 kg of $U_3O_8$ with 3% $H_2O$, the time to reach 5 mol % $H_2$ in the void space is 1.5 years or 18.2 months. At that time, the total amount of $H_2$ in the void space is 0.00005 + 0.01820 = 0.01825 mol while the total gas in the void space is 0.33777 + 1.5 × 0.01820 = 0.36507 mol.

**Table 3.5.4.4. Summary of calculation results**

| Weight (kg) | Density ($g/cm^3$) | Void volume ($cm^3$) | Gas amounts (mol) | | | Water content | | Material uranium content (gU/g) | Annual radiation rate [a] | Gf | G'($H_2$) [b] | $n_{H2}$ rate (mol/y) | Time to 5 % (y/mo) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial total | Initial $H_2$ | Added $H_2$ | X | (wt %) | | | | | | |
| **U Oxides ($UO_2$) [CVA 1]** | | | | | | | | | | | | | |
| 15.13 | 10.97 | 8263.8 | 0.33777 | 0.00005 | 0.018202 | | 3.0 | 0.85375 | 1.19E+15 | 0.04075 | 0.04156 | 0.01243 | 1.5/18.2 |
| **U Oxides ($U_3O_8$) [CVA 1]** | | | | | | | | | | | | | |
| 15.13 | 8.38 | 7837.5 | 0.32035 | 0.00005 | 0.017267 | | 3.0 | 0.82095 | 1.15E+15 | 0.04040 | 0.04120 | 0.01185 | 1.5/18.1 |
| **U Oxides ($UO_3$) [CVA 1]** | | | | | | | | | | | | | |
| 15.13 | 7.30 | 7570.4 | 0.30943 | 0.00004 | 0.016681 | | 3.0 | 0.80548 | 1.12E+15 | 0.04023 | 0.04104 | 0.01158 | 1.5/17.9 |
| **$UO_2(NO_3)_2 \cdot XH_2O$ [CVA 7]** | | | | | | | | | | | | | |
| 4.75 | 2.81 | 7793.1 | 0.31853 | 0.00108 | 0.016051 | 6.00 | 21.64 | 0.47094 | 6.57E+14 | 0.26087 | 0.26609 | 0.01379 | 1.2/14.4 |
| 6.70 | 2.81 | 7099.2 | 0.29017 | 0.00085 | 0.014766 | 3.00 | 12.13 | 0.52809 | 7.37E+14 | 0.15000 | 0.15300 | 0.01254 | 1.2/14.6 |
| 9.17 | 2.81 | 6220.2 | 0.25424 | 0.00144 | 0.012189 | 6.00 | 21.64 | 0.47094 | 6.57E+14 | 0.26087 | 0.26609 | 0.02661 | 0.46/5.6 |
| 11.90 | 2.81 | 5248.6 | 0.21453 | 0.00088 | 0.010647 | 3.00 | 12.13 | 0.52809 | 7.37E+14 | 0.15000 | 0.15300 | 0.02227 | 0.49/5.8 |

[a] Units are MeV/(g y).
[b] Units are molecules $H_2$/100 eV.

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# 4. CONTAINMENT

Design analysis, full-scale testing, and similarity of the ES-3100 prototypes have been used to demonstrate that the ES-3100 package with highly enriched uranium (HEU) is in compliance with the applicable containment requirements of Title 10 Code of Federal Regulations, Part 71 (10 CFR 71). The containment requirements of 10 CFR 71.51 are shown in Table 4.1. A bounding load case has been established for the ES-3100 package, and it assumes that the maximum HEU content is 35.2 kg (Sect. 1.2.2.6) with a decay heat load of 5 W (Sect. 3.1.2). This decay heat load and the volumes established for the convenience cans, polyethylene bagging, spacers, silicone rubber pads, and the containment vessel void volume are discussed in Sect. 3.1.2 and Appendix 3.5.1. Sections 2 and 3 of this safety analysis report for packaging (SARP) also examine the effects of the lightest weight HEU content [2.77 kg (6.11 lb)]. Section 3.4.3 also examines the conservative effects of shipping no contents inside the containment vessel but including the maximum decay heat load for the proposed contents. The evaluations in Sects. 2, 3, and 4 have demonstrated that the ES-3100 shipping package with HEU content weight ranging from 0 kg (0 lb) to 35.2 kg (77.60 lb) meets the containment requirements specified in 10 CFR 71 for all conditions of transport. A summary of the containment boundary design and fabrication acceptance basis is given in Table 4.2. No credit is taken for the various convenience cans' ability to protect the HEU contents from being released.

**Table 4.1. Containment requirements of transport for Type B packages [a]**

| Condition | Allowable release rate |
|---|---|
| Normal Conditions of Transport (NCT) | $R_N = 10^{-6}$ $A_2$ per hour = $2.78 \times 10^{-10}$ $A_2$ per second |
| Hypothetical Accident Conditions (HAC) | $R_A = A_2$ in 1 week = $1.65 \times 10^{-6}$ $A_2$ per second<br>For $^{85}Kr$, a value of 10 $A_2$ in 1 week is used |

[a] From ANSI N14.5-1997, Sects. 5.4.1 and 5.4.2, and 10 CFR 71.51(a)(1) and (a)(2).

**Table 4.2. Summary of the containment vessel design and fabrication acceptance basis**

| | |
|---|---|
| Weight (empty, nominal) | 15.10 kg (33.29 lb) |
| Temperature at loading (air fill, average) | 25°C (77°F) |
| Pressure at loading (air fill, average) | 101.35 kPa (14.70 psia) |
| Hydrostatic pressure test | 1034 ± 34 kPa (150 ± 5) gauge |
| Leakage rate testing [a] | |
| Acceptance leakage rate test, air (or equivalent) | |
| Containment boundary [b] | $L_T \leq 1 \times 10^{-7}$ ref-cm$^3$/s |
| Fabrication verification of O-ring seal [c] | $L_T \leq 1 \times 10^{-4}$ ref-cm$^3$/s |
| Preshipment, air [d] | $L_T \leq L_R$ or no detected leakage when tested to a sensitivity of $1 \times 10^{-3}$ ref-cm$^3$/s |

[a] $L_T$ is the maximum allowable test leakage rate for a set of testing conditions.
[b] Acceptance leakage testing of the containment boundary includes fabrication, periodic (within 12 months of use), and maintenance testing. According to Subclause 2.1 of ANSI N14.5-1997, *leaktight* is defined as an air leakage rate of $1 \times 10^{-7}$ ref-cm$^3$/s; under the same conditions, this air leakage rate is ~ equal to a helium leakage rate of $2 \times 10^{-7}$ cm$^3$/s.
[c] Performed at initial fabrication on the fully assembled containment vessel with both O-rings installed to demonstrate the functionality of the leak-test port and sealing capability of the outer O-ring (Appendix 1.3.3).
[d] $L_R$ as defined in ANSI N14.5-1997, Subclause 6.2, is the more restrictive reference air leakage rate based on the allowable leakage rate for both NCT and HAC.

The analysis documented in Appendix 4.5.1 was conducted to establish the upper limit for the total activity and the maximum number of $A_2$s proposed for transport in the ES-3100 package. The maximum activity [$7.2554 \times 10^{-1}$ TBq (19.6092 Ci)] of the contents occurs 10 years after initial fabrication. When the maximum activity-to-$A_2$ value ($4.7528 \times 10^{3}$) is reached at ~70 years from material fabrication, the corresponding activity is $7.2456 \times 10^{-1}$ TBq (19.5827 Ci). These values have been determined using a maximum of 35.2 kg of HEU with isotopic weight percents as shown in Table 4.3. By applying the maximum weight percents of isotopes $^{233}$U, $^{234}$U, $^{236}$U and by incorporating the traces of $^{232}$U and the transuranic isotopes, the maximum activity, minimum $A_2$ value, and the minimum leakage requirements were determined for the proposed contents and are summarized in Tables 4.4, 4.5, and 4.6. The mass and isotopic concentrations used for the proposed content do not take into consideration limits based on shielding and subcriticality.

**Table 4.3. Isotopic mass and weight percent for the HEU contents [a]**

| Nuclide | Weight percent | Mass (g) |
|---|---|---|
| U-232 | 0.000004 | 0.001408 |
| U-233 | 0.600000 | 211.200000 |
| U-234 | 2.000000 | 704.000000 |
| U-235 | 54.819996 | 19,296.638592 |
| U-236 | 40.000000 | 14,080.000000 |
| U-238 | 0.000000 | 0.000000 |
| Transuranic | 0.080000 [b] | 28.160000 |
| Np-237 | 2.500000 | 880.000000 |
| **Total** | **100.000000** | **35,200.000000** |

[a] Weight percent values of individual isotopes are those that generate the largest activity within the allowable ranges presented in Sect. 1.2.2.

[b] The transuranic weight percent of 0.080000 applies to ground transport only. The maximum transuranic weight percent in contents transported by air will be 0.004000.

**Table 4.4. Activity, $A_2$ value, and number of $A_2$ proposed for transport**

| Year | Fast absorption | | | Medium absorption | | | Slow absorption | | |
|---|---|---|---|---|---|---|---|---|---|
| | Activity (TBq) | $A_2$ (TBq) | Act / $A_2$ | Activity (TBq) | $A_2$ (TBq) | Act / $A_2$ | Activity (TBq) | $A_2$ (TBq) | Act / $A_2$ |
| 0 | 7.197E-01 | 1.5289E-04 | 4.707E+03 | 7.1974E-01 | 1.5253E-04 | 4.7185E+03 | 7.1974E-01 | 1.5148E-04 | 4.751E+03 |
| 5 | 7.251E-01 | 1.5399E-04 | 4.709E+03 | 7.2507E-01 | 1.5363E-04 | 4.7197E+03 | 7.2507E-01 | 1.5257E-04 | 4.752E+03 |
| 10 | 7.255E-01 | 1.5408E-04 | 4.709E+03 | 7.2554E-01 | 1.5372E-04 | 4.7199E+03 | 7.2554E-01 | 1.5267E-04 | 4.752E+03 |
| 20 | 7.254E-01 | 1.5404E-04 | 4.709E+03 | 7.2538E-01 | 1.5368E-04 | 4.7200E+03 | 7.2538E-01 | 1.5263E-04 | 4.752E+03 |
| 30 | 7.251E-01 | 1.5399E-04 | 4.709E+03 | 7.2514E-01 | 1.5363E-04 | 4.7200E+03 | 7.2514E-01 | 1.5258E-04 | 4.752E+03 |
| 40 | 7.249E-01 | 1.5394E-04 | 4.709E+03 | 7.2494E-01 | 1.5358E-04 | 4.7201E+03 | 7.2494E-01 | 1.5254E-04 | 4.753E+03 |
| 50 | 7.248E-01 | 1.5390E-04 | 4.709E+03 | 7.2478E-01 | 1.5355E-04 | 4.7202E+03 | 7.2478E-01 | 1.5250E-04 | 4.753E+03 |
| 60 | 7.247E-01 | 1.5387E-04 | 4.709E+03 | 7.2465E-01 | 1.5352E-04 | 4.7203E+03 | 7.2465E-01 | 1.5247E-04 | 4.753E+03 |
| 70 | 7.246E-01 | 1.5385E-04 | 4.710E+03 | 7.2456E-01 | 1.5349E-04 | 4.7206E+03 | 7.246E-01 | 1.5245E-04 | 4.7528E+03 |

**Table 4.5. Regulatory leakage criteria for NCT [a]**

| Verification activity | Fast absorption | | Medium absorption | | Slow absorption | |
|---|---|---|---|---|---|---|
| | $L_{RN - air}$ (ref-cm$^3$/s) | $L_{RN - He}$ (cm$^3$/s) | $L_{RN - air}$ (ref-cm$^3$/s) | $L_{RN - He}$ (cm$^3$/s) | $L_{RN - air}$ (ref-cm$^3$/s) | $L_{RN - He}$ (cm$^3$/s) |
| Design | 1.3916E-04 | 1.7141E-04 | 1.3884E-04 | 1.7104E-04 | 1.3792E-04 | 1.6996E-04 |

[a] The procedure used to calculate the above criteria is shown in Appendix 4.5.2. This data has been extracted from Table 1 in Appendix 4.5.2.

**Table 4.6. Containment vessel verification tests criteria for NCT**

| Test type | Test values | Leakage test procedure |
|---|---|---|
| **Design and compliance leakage testing** | | |
| Design verification of O-ring seal (air) | $L_T \leq 1.0 \times 10^{-4}$ ref-cm$^3$/s | See ORNL/NTRC-013 and ORNL/NTRC-047 |
| Design verification of containment vessel boundary (helium) | $L_T \leq 2.0 \times 10^{-7}$ cm$^3$/s | See ORNL/NTRC-013 and ORNL/NTRC-047 |
| **Verification leakage testing** | | |
| Fabrication, periodic, and maintenance (helium) | $L_T \leq 2.0 \times 10^{-7}$ cm$^3$/s | Y51-01-B2-R-140 (Appendix 8.3.1) or equivalent |
| Fabrication verification of O-ring seal (air) | $L_T \leq 1.0 \times 10^{-4}$ ref-cm$^3$/s | Tested at initial fabrication in accordance with the supplier's approved procedure as required by Appendix 1.3.3 |
| Preshipment (air) | $L_T \leq L_R$ or no detected leakage when tested to a sensitivity of $1 \times 10^{-3}$ ref-cm$^3$/s | Y51-01-B2-R-074 (Appendix 7.5.2) or equivalent |

The initial composition of the content contains several isotopes of uranium (Sect. 1.2.2). As a result of radioactive decay, the ingrowth of uranium daughter products occurs, and these concentrations of daughter products will vary with time. The uranium isotopes and daughter products are considered a mixture of radionuclides, and the method for determining the mixture's $A_2$ value in Section IV, Appendix A, 10 CFR 71 is applied. The $A_2$ value for the most conservative set of contents defined in Sect. 1.2.2 has been calculated in Appendix 4.5.1. Since the HEU can be in the form of oxides ($U_3O_8$-Al, $UO_2$-Mg, $UO_2$-$ZrO_2$, $UO_2$, $UO_3$, and $U_3O_8$), uranyl nitrate crystals (UNX), metal or alloy, research reactor fuel elements and components, or compounds, the calculation of the mixture's $A_2$ used the various uranium isotopic $A_2$ values for fast, medium, and slow lung absorption criteria shown in Table A-1 of Appendix A of 10 CFR 71.

The mass and material compositions analyzed in this section of the SARP are not limited by the combustible gas requirements stated in NUREG-1609, Sect. 4.5.2.3, which requires the applicant to demonstrate that any combustible gases generated in the package during a period of one year do not exceed 5% (by volume) of the free gas volume in any confined region of the package. No credit should

be taken for getters, catalysts, or other recombination devices. The analysis conducted in Appendix 3.5.4 evaluates the different packaging arrangements for the generation of hydrogen gas due to the radiolysis of water vapor, free water, interstitial water, polyurethane bags, and polyurethane or Teflon bottles. By limiting the mass and the material distribution as shown in Appendix 3.5.4, the combustible gas concentration limit stated in NUREG-1609 is not exceeded. These limits are further shown in Tables 1.3 and 1.3a. Getters, catalysts, or other recombination devices are not employed in any of the containment vessel packaging arrangements. The analysis conducted in Appendix 3.5.1 predicts the maximum normal operating pressure inside the containment vessel for the various packaging arrangements and masses discussed previously. This appendix also includes the hydrogen gas generation predicted by Appendix 3.5.4.

## 4.1 DESCRIPTION OF THE CONTAINMENT SYSTEM

As shown in Table 4.4, the number of $A_2$s proposed for shipping exceeds 3000. In accordance with NUREG 1609, the containment vessel is a Category I vessel. Therefore, the containment vessel is designed (using nominal dimensions for each component), fabricated, and inspected in accordance with the American Society of Mechanical Engineers (ASME) *Boiler and Pressure Vessel Code*, Sect. III, Div. 1, Subsection NB and Sect. IX.

### 4.1.1 Containment Boundary

The containment boundary consists of the vessel's body, lid assembly, and inner O-ring (Sect. 1.2.1.5, Fig. 1.3). Only the inner O-ring is considered part of the boundary. The outer O-ring is provided to allow a post-assembly verification leak check. Two methods of fabrication may be used to fabricate the containment vessel body as shown on Drawing M2E801580A012 (Appendix 1.3.7). The first method uses a standard 5-in., schedule 40 stainless-steel pipe per ASME SA-312 Type TP304L, a machined flat-head bottom forging per ASME SA-182 Type F304L, and a machined top flange forging per ASME SA-182 Type F304L. The nominal outside diameter of the 5-in. schedule 40 pipe is machined to match the nominal wall thickness of 0.254 cm (0.100 in.). Each of these pieces is joined with full-penetration circumferential weld as shown on sheet 2 of Drawing M2E801580A012 (Appendix 1.3.7). The weld filler material conforms to Sect. II, Part C, of the *ASME Boiler and Pressure Vessel Code*. All full-penetration welds are dye penetrant and radiographically inspected in accordance with Sect. III, Div. 1, Subsection NB-5000, of the *ASME Boiler and Pressure Vessel Code*. The top flange is machined to match the schedule 40 stainless-steel 5-in. pipe, to provide two concentric half-dovetailed O-ring grooves in the flat face, to provide locations for two 18-8 stainless-steel dowel pins, and to provide the threaded portion for closure using the lid assembly. The second method of fabrication uses flow forming to create the complete body (flat bottom, cylindrical body, and flange) from a single forged billet or bar with final material properties in accordance with ASME SA-182 Type F304L. Final machining of the top flange area is identical to that of the welded forging method. The lid assembly, which completes the containment boundary structure, consists of a sealing lid, closure nut, and external retaining ring (Drawing M2E801580A014, Appendix 1.3.7). The containment vessel sealing lid (Drawing M2E801580A015, Appendix 1.3.7) is machined from Type 304 stainless-steel bar with final material properties in accordance with ASME SA-479. The containment vessel closure nut is machined from a Nitronic 60 stainless-steel bar with material properties in accordance with ASME SA-479. These two components are held together using an external retaining ring made from Type 302 stainless steel. A

weld is used to seal around a plug that is inserted inside the hole used for machining the pathway for leak testing between the O-rings. Since this plug and weld are outside the containment boundary, the weld is not important to safety. However, it is important to operation because its sealing capability is needed to properly conduct the preshipment leak test. This weld is addressed in Paragraph 3.4 of the containment vessel equipment specification (JS-YMN3-801580-A001, Appendix 1.3.3). In this specification, the weld is inspected visually and using dye penetrant. The requirements of NB-5110 and NB-5350 of the *ASME Boiler and Pressure Vessel Code* also apply. The sealing lid is further machined to accept a ⅜-in.-16 swivel hoist ring bolt, to provide a leak-check port between the elastomeric O-rings, and notched along the perimeter to engage two dowel pins. The lid assembly, with the O-rings in place on the body, are joined together by torquing the closure nut and sealing lid assembly to 162.7 ± 6.78 N·m (120 ± 5 ft-lb). The sealing lid portion of the assembly is restrained from rotating during this torquing operation by the two dowel pins installed in the body flange. This torquing of the closure nut represents the positive fastening device used to satisfy the requirements of 10 CFR 71.43(c). The effectiveness of this closure system has been demonstrated by the NCT and HAC tests, which show that the complete containment system, including welds and O-ring seals, meet the leaktight criterion as defined in ANSI N14.5-1997 after the conclusion of the test series documented in ORNL/NTRC-013 and ORNL/NTRC-047.

10 CFR 71.73(c) requires that the package containment vessel be immersed in 15 m (50 ft) of water, which is equivalent to an external pressure differential of 150 kPa (21.7 psi). The design analyses (DAC-M900000-0003) show that this vessel is conservatively rated for the 150-kPa (21.7-psi) external pressure differential requirement, as well as for an internal pressure differential of 699.82 kPa (101.5 psig). A summary of the containment boundary design and acceptance basis is given in Table 4.2.

The ES-3100 package has no connections, fittings, valves, tapped holes, or other devices that penetrate the containment boundary; therefore, the package does not allow continuous venting during transport. The leak test port on the containment vessel lid accesses the annulus between the two O-rings. Since the outer O-ring is not considered to be part of the containment boundary, this leak test port does not penetrate the containment boundary. Therefore, the requirements of 10 CFR 71.43(e) and (h) are not applicable.

The containment vessel O-rings (Drawings M2E801580A013 and M-801580-0013, Appendix 1.3.7) are manufactured from either ethylene propylene diene monomer (EPDM) in accordance with Equipment Specification SPC-M801580-0002 (Appendix 1.3.10) or a fluorocarbon elastomer (Viton) in accordance with Equipment Specification SPC-M801580-0001 (Appendix 1.3.9).

The EPDM O-rings are rated for continuous service as a static face seal in the temperature range of −40 to 150°C (−40 to 302°F) [*Parker O-Ring Handbook*, Fig. 2-24]. Tests conducted by Los Alamos National Laboratory (LANL) on a similar compound used as a static face seal, are documented in *SAFKEG 2863B Tests for Verification of O-ring Performance* (TR 96/12/20). The material compound for the LANL tests was certified to ASTM D 2000 as M3BA610A14B13F17. The ES-3100 package O-rings are also certified to ASTM D 2000 as M3BA712A14B13F17. The class of material in the LANL test is identical except that the durometer and tensile strengths are somewhat less than those of the ES-3100 package. Each material was tested in accordance with ASTM D 2137 for brittleness at −40°C (−40°F) without failure. The leak test fixture, as reported in TR 96/12/20, provided a maximum compression of 25.7% in a static face seal configuration. The compression range provided by the flange and lid design

of the ES-3100 package is 14.8 to 20.8% or 0.051 to 0.076 cm (0.020 to 0.030 in.) compression due to the half-dovetail design. Furthermore, *Parker O-Ring Handbook* states that the minimum squeeze for all seals, regardless of cross-section, should be ~0.018 cm (0.007 in.). Since the minimum compression is 0.051 cm (0.020 in.) and the flange and lid with the closure nut have nearly identical coefficient of thermal expansion, the sealing performance at −40°C (−40°F) should not be degraded. Therefore, the performance of the ES-3100 O-rings should be representative of those documented in TR 96/12/20. These tests demonstrated that the O-rings were leaktight over the temperature range of −40 to 205°C (−40 to 401°F), which is greater than the operating temperature range of −40 to 156.19°C (−40 to 313.14°F) of the ES-3100 containment vessel (Table 3.5). In addition to component testing, an ES-3100 full-scale test unit [Test Unit (TU)-2] was chilled to ≤ −40°C and later subjected to an NCT drop test and the entire HAC test battery. The containment vessel was leak tested and achieved "leaktight" status. Therefore, the continuous service temperature rating of the EPDM O-ring has been verified by testing.

The fluorocarbon elastomer O-rings are rated for continuous service as a static face seal in the temperature range of −40 to 204°C (−40 to 400°F) [*Parker O-Ring Handbook*, Fig. 2-24]. Laboratory tests have been ongoing at the Savannah River National Laboratory (SRNL) since 2003 studying the performance of Viton GLT O-rings in the K-Area Materials Storage facility at the Savannah River Site. Data from these tests indicate that negligible degradation to the Viton GLT O-rings occurs at temperatures of 200°F or less, for a period of 5 years (SRNL-MST-2008-00127). No impact on the ability of the seal on the 9975 primary containment vessel (PCV) is expected. A −40°F cold test was performed on a prototype PCV (9965) at minimum internal pressure. The PCV was helium leak-rate tested per Nuclear Regulatory Commission (NRC) Regulatory Guide 7.4 and the bell jar method in ANSI N14.5-1997. The PCV was fitted with two Viton GLT O-rings and cooled to −40°F. The bell jar was evacuated and the PCV was pressurized to 15 psig helium internal pressure. The test showed that the PCV remained leaktight to a sensitivity $<1 \times 10^{-7}$ ref-cm$^3$/s for 10 min. Repeating the above test confirmed the results (SRL-PTG-90-0047). O-rings made from Viton GLT-S are acceptable replacements for Viton GLT O-rings as there is no technical basis to suspect their thermal resistance and long-term aging behavior will be significantly different (SRNL-EES-2006-00056). The design of the 9975 PCV and the 9977 6-in. containment vessel is essentially the same, with the 6-in. containment vessel being a scaled up version of the PCV (a 5-in. diam containment vessel). Secondary effects due to long-term storage or use, such as compression set, thermal set, etc., are also captured under the surveillance program results. O-rings are captured inside the containment vessel of the ES-3100 in a static face seal (axial) method. The half-dovetail O-ring grove design provides ~18% compression when metal-to-metal contact of the body and lid is achieved at closure (*Parker O-Ring Handbook*, Design Chart 4-5). The conical (radial) sealing surfaces for the 9965, 9975, and 9977 containment vessels are like an industrial static seal providing ~16 to 23% compression of the O-ring (SRNS-TR-2009-00259). Because the O-ring compressions are similar between designs and the O-ring compounds and size are comparable, the SRNL surveillance program data should be applicable for Viton GLT-S O-ring use in the ES-3100 containment vessel. In addition to component testing, an ES-3100 full-scale test unit (TU-8) was chilled to ≤ −40°C and later subjected to an NCT drop test and the entire HAC test battery (ORNL/NTRC-047). The containment vessel was leak tested and achieved leaktight status (ORNL/NTRC-047). Therefore, the continuous service temperature rating of the fluorocarbon elastomer O-rings in the ES-3100 containment vessel has been verified by similarity and actual compliance testing.

### 4.1.2 Special Requirements for Plutonium

The HEU contents have only trace amounts of the transuranic isotopes. Therefore, the requirements in 10 CFR 71.63 and 71.74 are not applicable.

## 4.2 CONTAINMENT UNDER NORMAL CONDITIONS OF TRANSPORT

Title 10 CFR 71.51(a)(1) specifies that there shall be no loss or dispersal of radioactive contents as demonstrated to a sensitivity of $10^{-6}$ $A_2$ per hour, no significant increase in external radiation levels, and no substantial reduction in the effectiveness of the packaging. The initial composition of the HEU contains several isotopes of uranium and transuranic contributors (Table 4.3). As a result of radioactive decay, uranium, transuranics, and daughter product isotopes are present in the HEU contents at varying concentrations depending on the length of decay time. The HEU, with its isotopes and daughter isotopes and contributions from unknown transuranic isotopes, qualifies as a mixture for $A_2$ determination (Appendix A of 10 CFR 71). The $A_2$ value and the maximum content activity-to-$A_2$ value ratio for this mixture have been calculated for several different decay times (Table 4.4). As calculated in Appendix 4.5.1, the $A_2$ value [$1.5245 \times 10^{-4}$ TBq ($4.1203 \times 10^{-3}$ Ci)] and the maximum content activity-to-$A_2$ ratio ($4.7528 \times 10^{3}$) used to qualify this package occurs at ~70 years of decay. As previously stated, these values have been determined using a bounding case maximum of 35.2 kg of HEU with isotopic weight percent values as shown in Table 4.3. The specified composition is a very conservative upper bound achieved by using the maximum weight percent values for the higher specific activity isotopes ($^{232}$U, $^{233}$U, $^{234}$U, and $^{236}$U), including contributions from other transuranics and $^{237}$Np.

The maximum activity, minimum $A_2$, and minimum leakage requirements were determined for this worst case scenario and are presented in Tables 4.4 and 4.5. These masses and isotopic concentrations were used for the proposed contents without regard to limits established based on shielding and subcriticality considerations. The actual mass limits affirmed for this shipping package are established in Sect. 1 (Tables 1.3, 1.3a, and 1.3b). The analyses conducted in Appendix 4.5.2 assume that the total mass of uranium for each component is available for release as an aerosol (worst case). From experimental tests, the maximum aerosol density containing uranium particulate was reported in "Leakage of Radioactive Powders from Containers" (Curren and Bond) to be $9.0 \times 10^{-6}$ g/cm$^3$. This aerosol density is used to calculate the total activity concentration in ANSI N14.5-1997, Sect. B.15, Examples 13, 27, and 29.

The containment criteria for the ES-3100 package will be leaktight (defined in paragraph 2.1 of ANSI N14.5-1997 as having a leakage rate $\leq 1 \times 10^{-7}$ ref-cm$^3$/s) during the prototype tests. This leaktight criterion satisfies the design verification requirement stipulated in paragraph 7.2.4 of ANSI N14.5-1997. The requirements of ANSI N14.5-1997 are used for all stages of containment verification for the ES-3100 (i.e., design, fabrication, maintenance, periodic and preshipment).

The design, fabrication, maintenance, and periodic leakage rate limit is $1 \times 10^{-7}$ ref-cm$^3$/s air (or equivalent). Preshipment leakage rate testing, which demonstrates correct assembly of the containment vessel, shall be performed to the acceptance criterion of either (1) a leakage rate of not more than the reference air leakage rate, $L_R$, or (2) no detected leakage when tested to a sensitivity of at least $10^{-3}$ ref-cm$^3$/s (ANSI N14.5-1997, Subclause 7.6.4). The preshipment, fabrication, maintenance and

periodic leakage rate tests are required to be conducted on each containment vessel in accordance with ANSI N14.5-1997 and are specified in Chapters 7 and 8. These leakage rates are not dependent on filters or mechanical cooling.

The complete design verification testing of the ES-3100 package for NCT was conducted on test unit TU-4. Since the containment vessel was assembled at ambient conditions, the pressure was nominally 101.35 kPa (14.70 psia) at 25°C (77°F). In accordance with 10 CFR 71.71(b), the initial pressure inside each containment vessel should be the maximum normal operating pressure (MNOP). As calculated in Appendix 3.5.1 and rounded up, the bounding case MNOP is 114.11 kPa (16.55 psia). The stresses at the MNOP are insignificant compared to the allowable stresses (Tables 2.21 and 2.21a). O-ring grooves are designed and fabricated in accordance with guidance from the *Parker O-Ring Handbook*. In accordance with Fig. 3-2 of the *Parker O-Ring Handbook*, the durometer of the O-ring, and the tolerance gap from the production drawings, the O-ring should be able to withstand ~800 psig before anti-extrusion devices are required. Therefore, conducting a compliance test with the MNOP in the containment vessel will have little, if any, effect on the results.

Following the design verification testing of paragraphs 10 CFR 71.71(c)(5) through 71.71(c)(10) excluding 71.71(c)(8), TU-4 was subjected to the sequential testing of paragraphs 10 CFR 71.73(c)(1) through (c)(4). Upon removal of the containment vessel from the drum assembly, the cavity between the O-rings was leak checked. This unit recorded a leak rate between the O-rings of $2.4773 \times 10^{-5}$ ref-cm$^3$/s.

Following the O-ring leak test, the entire containment boundary of TU-4 was helium leak tested to a value $\leq 2 \times 10^{-7}$ cm$^3$/s, thereby verifying a leak-tight boundary. The leak-test procedure followed to verify this criterion is documented in the ES-3100 test report (ORNL/NTRC-013). The maximum recorded helium leakage rate for this containment vessel was $2.0 \times 10^{-7}$ cm$^3$/s after 20 min of testing. Visual inspection following the testing indicated that neither the vessel body, the O-rings, the seal areas, nor the vessel lid assembly were damaged during the tests. Pictures taken of the containment vessel top following testing showed that the closure nut had rotated a maximum of 0.15 cm (0.060 in.) from its original radial position obtained during assembly. Based on the pitch of the closure nut, this rotation translates into only 0.0013 cm (0.0005 in.) decompression of the O-rings. This compares to the original nominal compression of 0.064 cm (0.025 in.). Therefore, O-ring compression was maintained during compliance testing. Based on these results, the ES-3100 package meets and exceeds the containment criteria specified in 10 CFR 71.51 for NCT when used to ship the contents described in the introductory section of this chapter.

Following fabrication, the containment vessel undergoes hydrostatic pressure testing to 1034 kPa (150 psi) gauge. The hydrostatic test is conducted before the final leakage test. Following the hydrostatic pressure test, and prior to conducting the leakage test, the containment vessel and O-ring cavity must be thoroughly dried. Each vessel is then leak tested with helium to $2 \times 10^{-7}$ cm$^3$/s. In accordance with *ASME Boiler and Pressure Vessel Code*, Sect. V, Subsection A, Article 10, Appendix IX, "Helium Mass Spectrometer Test—Hood Technique," a system response time must be established to determine the helium leak testing duration. The fabricators of this package used the *ASME Boiler and Pressure Vessel Code* approach and determined that the system response time for their setup of this containment vessel was ~15 s. To ensure that the leak detector steady-state (equilibrium) response is reached, the helium leak test duration was established at 2 min (8 × system response time). This test

ensures the containment vessel's integrity (walls, welds, inner O-ring seal) as delivered for use in accordance with paragraph 6.3.2 of ANSI N14.5-1997.

Following placement of the HEU content inside the containment vessel and joining the body and lid assembly, the volume between the containment vessel's O-ring seals is typically evacuated and leak checked using the pressure rise air leak test prescribed in Sect. 7.1.2.1. The acceptance criterion for preshipment leakage rate testing shall be either (1) a leakage rate of not more than the reference air leakage rate, $L_R$, or (2) no detected leakage rate when tested to a sensitivity of at least $10^{-3}$ ref-cm$^3$/s. This ensures that each containment vessel has been properly assembled in accordance with paragraph 7.6.4 of ANSI N14.5-1997.

The design verification tests were conducted following compliance tests in accordance with 10 CFR 71.71 and 71.73. The effectiveness of this closure system has been demonstrated by the NCT and HAC tests, which show that the complete containment system, including welds and O-ring seals, meet the leaktight criterion as defined in ANSI N14.5-1997 after the conclusion of the test series documented in ORNL/NTRC-013 and ORNL/NTRC-047.

## 4.3 CONTAINMENT UNDER HYPOTHETICAL ACCIDENT CONDITIONS

**Requirements.** A Type B package, in addition to satisfying the requirements of paragraphs 10 CFR 71.41 through 71.47, must be designed, constructed, and prepared for shipment so under the tests specified in Sect. 71.73 ("Hypothetical Accident Conditions"), there would be no escape of $^{85}$Kr exceeding 10 $A_2$ in one week, no escape of other radioactive material exceeding a total amount $A_2$ in one week, and no external radiation dose rate exceeding 10 mSv/h (1 rem/h) at 1 m (40 in.) from the external surface of the package.

**Analysis.** Calculations have been conducted in Appendix 4.5.2 to determine the regulatory leakage criteria to satisfy the above requirements. The results are shown in Table 4.7. These analyses assume that the total mass of uranium for each component is available for release as an aerosol (worst case). From experimental tests, the maximum aerosol density containing uranium particulate was reported by Curren and Bond to be $9.0 \times 10^{-6}$ g/cm$^3$. This aerosol density is used to calculate the total activity concentration in ANSI N14.5-1997, Sect. B.15, Examples 13, 27, and 29. Design leakage rate verification testing of the containment boundary (Table 4.8) was conducted on TU-1 through TU-6 and TU-8 and documented in the test reports (ORNL/NTRC-013 and ORNL/NTRC-047). Since each containment vessel was assembled at ambient conditions, the pressure was nominally 101.35 kPa (14.70 psi) at 25°C (77°F). In accordance with 10 CFR 71.73(b), for these tests, the initial pressure inside each containment vessel should be the maximum normal operating pressure. As shown in Tables 2.21 and 2.21a, the stresses at the maximum normal operating pressure are insignificant compared to the allowable stresses. Therefore, conducting compliance testing with nominal pressure in the containment vessel would have little, if any, effect on the results. During the structural and thermal tests conducted on the ES-3100 for HAC, the drum experienced plastic deformation, and the insulation and impact limiter material experienced some deterioration, as anticipated (Sect. 2.7). The containment vessels did not exhibit any signs of damage and passed post-test leak tests and the subsequent 10 CFR 71.73(c)(5)–specified 0.9-m (3-ft) water immersion tests except for TU-6. TU-6 was subjected to the test specified in 10 CFR 71.73(c)(6). After completion of this test, the containment vessel was removed and the lid was drilled and tapped for a helium leak-check port. The entire containment

boundary was then helium leak checked and passed the leaktight criteria. Also, no visible water was seen inside the inner O-ring groove of TU-6 and no water was observed inside any of the other test units.

To verify the entire containment boundary to the leaktight criteria, the containment vessels of TU-1 through TU-5 and TU-8 were helium leak tested using the procedure shown in the test reports (ORNL/NTRC-013 and ORNL/NTRC-047). These test units had previously been subjected to the drop test stipulated in 10 CFR 71.71 (c)(6) and the sequential tests stipulated in 10 CFR 71.73 except for TU-4, which had been first subjected to the testing in accordance with 10 CFR 71.71. The maximum recorded helium leak rate for any of these containment vessels was $2.0 \times 10^{-7}$ $cm^3/s$ after 17 min of testing on TU-8 as documented in Sect. 6.2.2 of ORNL/NTRC-047. As previously discussed, this test unit used Viton GLT-S O-rings (VM835-75). TU-2 and TU-5 displayed some unusual pulsing action during leak testing. The root cause of these oscillatory leak rates has not been determined. However, it is postulated that the seal around the machined port in the lid that is used for helium leak checking the test units was the cause of this unusual pattern. In accordance with the *ASME Boiler and Pressure Vessel Code*, Sect. V, Subsection A, Article 10, Appendix IX, "Helium Mass Spectrometer Test – Hood Technique," a system response time must be established to determine the helium leak testing duration. The fabricators of this package used this *ASME Boiler and Pressure Vessel Code* approach and determined that the system response time for their leak test setup with this containment vessel was ~15 s. To ensure that the leak detector steady-state (equilibrium) response is reached, the helium leak test duration was established at 2 min (8 × system response time). Since the helium leakage rates observed at NTRC (ORNL/NTRC-013 and ORNL/NTRC-047), using a configuration similar to the fabricator's test arrangement, remained below the ANSI N14.5-1997 leak tight value for ~10 min, it was determined that the test duration was adequate and the units were leaktight. The peak amplitude changed after adding helium in a manner expected for diffusion through the O-rings rather than a rise immediately following the addition of helium that would indicate a leak to the outside of the containment vessel. This is further discussed and graphically presented in Sect. 5.2.2 of ORNL/NTRC-013 and Sect. 6.2.2 of ORNL/NTRC-047. These measured leakage rates verify that the containment vessels are leaktight in accordance with ANSI N14.5-1997. Therefore, the containment boundary of the ES-3100 package was maintained during the HAC testing.

**Table 4.7. Regulatory leakage criteria for HAC [a]**

| Verification activity | Fast absorption | | Medium absorption | | Slow absorption | |
|---|---|---|---|---|---|---|
| | $L_{RA\text{ - air}}$ (ref-$cm^3/s$) | $L_{RA\text{ - He}}$ ($cm^3/s$) | $L_{RA\text{ - air}}$ (ref-$cm^3/s$) | $L_{RA\text{ - He}}$ ($cm^3/s$) | $L_{RA\text{ - air}}$ (ref-$cm^3/s$) | $L_{RA\text{ - He}}$ ($cm^3/s$) |
| Design | 2.3879E-01 | 2.3551E-01 | 2.3824E-01 | 2.3497E-01 | 2.3663E-01 | 2.3341E-01 |

[a] The procedure used to calculate the above criteria is shown in Appendix 4.5.2.

**Table 4.8. Containment vessel design verification tests for HAC**

| Test type | Test values | Leakage test procedure |
|---|---|---|
| **Design and compliance leakage testing** | | |
| Design verification of O-ring seal (air) | $L_T \leq 1.0 \times 10^{-4}$ ref-cm$^3$/s | See ORNL/NTRC-013 and ORNL/NTRC-047 |
| Design verification of containment vessel boundary (helium) | $L_T \leq 2.0 \times 10^{-7}$ cm$^3$/s | See ORNL/NTRC-013 and ORNL/NTRC-047 |

The 35.2 kg of HEU content is unirradiated; therefore, only very small quantities of fission gas products will be produced from spontaneous fission and subcritical neutron induced fission. Fission gas products are produced in such small quantities that they have no measurable effect on the releasable content source term or containment vessel pressurization. Fission gas products will not be considered further in this SARP.

## 4.4 LEAKAGE RATE TESTS FOR TYPE B PACKAGES

The maximum allowable release of radioactive material allowed by 10 CFR 71.51(a)(2) under HAC is $A_2$ in one week. Title 10 CFR 71.51(a)(2) also specifies that there be no escape of $^{85}$Kr exceeding 10 $A_2$ in one week. ANSI N14.5-1997 specifies the leakage test methods and leakage rates that are accepted in NRC Regulatory Guide 7.4 as demonstrating that a package meets the 10 CFR 71.51(a)(2) requirements for containment. The containment criteria for the ES-3100 package will be leaktight, defined in ANSI N14.5 paragraph 2.1 as having a leakage rate $\leq 1 \times 10^{-7}$ ref-cm$^3$/s, during the prototype tests. This leaktight criterion satisfies the design verification requirement stipulated in paragraph 7.2.4 of ANSI N14.5-1997. The requirements of ANSI N14.5-1997 are used for all stages of containment verification for the ES-3100 (i.e., design, fabrication, maintenance, periodic and preshipment). The design, fabrication, maintenance, and periodic leakage rate limit is $1 \times 10^{-7}$ ref-cm$^3$/s air (or equivalent). Preshipment leakage rate testing, which demonstrates correct assembly of the containment vessel, shall be performed to the acceptance criterion of either (1) a leakage rate of not more than the reference air leakage rate, $L_R$, or (2) no detected leakage when tested to a sensitivity of at least $10^{-3}$ ref-cm$^3$/s (ANSI N14.5-1997, Subclause 7.6.4). The preshipment, fabrication, maintenance, and periodic leakage rate tests are required to be conducted on each containment vessel in accordance with ANSI N14.5-1997 and are specified in Chapters 7 and 8. These leakage rates are not dependent on filters or mechanical cooling.

The requirements of ANSI N14.5-1997 are used for all stages of containment verification for the ES-3100; the design (HAC test) leakage rate limit is $1 \times 10^{-7}$ ref-cm$^3$/s (which is defined as leaktight in ANSI N14.5-1997). The packaging has been shown to maintain containment before and after prototype testing by leakage tests performed for containment verification to the requirements of ANSI N14.5-1997. TU-4's containment vessel was subjected to both the NCT and HAC tests. TU-1 through TU-5 and TU-8 were subjected to the free drop stipulated in 10 CFR 71.71(c)(7) and to the sequential HAC test stipulated in 10 CFR 71.73. Following these tests, each containment vessel was helium leak tested in accordance with the test plan. Again, the test results verified that the containment vessels were leaktight. Thus, there

could be no release of radioactive materials from the containment vessels. These leakage rates are not dependent on filters or mechanical cooling. These measured leakage rates verify that the containment vessels are leaktight in accordance with ANSI N14.5-1997.

Therefore, the ES-3100 package meets the containment criteria as specified in 10 CFR 71.73 for HAC when shipping the proposed 35.2 kg of HEU in the containment vessel.

## 4.5 APPENDICES

4.5.1 Determination of $A_2$ for the ES-3100 Package with HEU Contents

4.5.2 Calculation of the ES-3100 Containment Vessel's Regulatory Reference Air Leakage Rates

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## Appendix 4.5.1

## Determination of $A_2$ for the ES-3100 Package with HEU Contents

### Introduction

The containment criteria for radioactive, fissile material packages are given in 10 CFR 71.51(a)(1) for Normal Conditions of Transport (NCT) [$\leq 10^{-6}$ $A_2$/h] and in 71.51(a)(2) for Hypothetical Accident Conditions (HAC) [$\leq A_2$ in a week]. The $A_2$ value for this mixture of radioisotopes must be determined to establish the content containment criteria and to determine the maximum release quantity that is allowed by the regulations. These values for a mixture of isotopes are determined by the methodology given in 10 CFR 71, Appendix A, "Determination of $A_1$ and $A_2$," Sect. IV. The results of these analyses are used to demonstrate compliance of the ES-3100 package with the containment requirements of 10 CFR 71.

### Scope

The $A_2$ value of the highly enriched uranium (HEU) content to be shipped is evaluated based on the mass and weight percents of HEU shown in Table 1 and defined in Sect. 1.2.2. The weight percents shown in Table 1 are the ones that generate the largest activity within the allowable ranges presented in Sect. 1.2.2. Incorporating the new 10 CFR 71 $A_2$ values for the uranium isotopes, three different categories have been established based on the absorption rate of the uranium isotopes. The fast lung absorption, medium lung absorption, and slow lung absorption categories are addressed in subsequent sections. By applying the maximum weight percents of isotopes $^{232}$U, $^{233}$U, $^{234}$U, $^{236}$U and by incorporating the traces of $^{237}$Np and the transuranic isotopes, the maximum activity, minimum $A_2$ value, and the minimum leakage requirements were determined for each category of absorption for the HEU contents. The mass and isotopic concentrations used for the proposed content do not take into consideration limits based on shielding and subcriticality.

**Table 1. Isotopic mass and weight percent for the HEU contents [a]**

| Nuclide | Weight percent | Mass (g) |
|---|---|---|
| U-232 | 0.000004 | 0.001408 |
| U-233 | 0.600000 | 211.200000 |
| U-234 | 2.000000 | 704.000000 |
| U-235 | 54.819996 | 19,296.638592 |
| U-236 | 40.000000 | 14,080.000000 |
| U-238 | 0.000000 | 0.000000 |
| Transuranic | 0.080000 [b] | 28.160000 |
| Np-237 | 2.500000 | 880.000000 |
| **Total** | **100.000000** | **35,200.000000** |

[a] Weight percents values of individual isotopes are those that generate the largest activity within the allowable ranges presented in Sect. 1.2.2.

[b] The transuranic weight percent of 0.080000 applies to ground transport only. The maximum transuranic weight percent in contents transported by air will be 0.004000.

According to 10 CFR 71, Appendix A, parent and daughter nuclides are considered to be a mixture of different nuclides than those of the parent nuclide. The radioactive decay of uranium [refer to the decay chains presented by Dr. David C. Kocher, *Radioactive Decay Data Tables* (DOE/TIC-11026)] creates isotopes that will accumulate enough activity to exceed their respective criteria for limited quantities (49 CFR 173.425, Table 4, "Activity Limits for Limited Quantities, Instruments, and Articles") and for Type A quantities of radionuclides (10 CFR 71, Table A-1, "$A_1$ and $A_2$ Values for Radionuclides"). Furthermore, the $A_2$ value for the mixture will change over time as a result of radioactive decay. The analysis below shows that the $A_2$ value for this mixture reaches a minimum at initial fabrication, increases to the $10^{th}$ year, and declines through the $70^{th}$ year.

**Analysis**

**Mass Tables.** The mass and weight fractions for HEU isotopes used in the containment calculations are presented in Table 1. For conservatism, a small quantity of $^{232}U$ is assumed in this material at fabrication.

**ORIGEN-S Results.** The source terms of the isotopes in the mixtures were evaluated using the ORIGEN-S computer program (NUREG/CR-0200). The mass values for the parent and daughter products are presented in Table 2 for the time interval of 0–70 years. Contributions from the transuranics and $^{237}Np$ are held constant at each time interval during the 70-year evaluation.

The $A_2$ value of each mixture was calculated using the procedure shown in Tables 3, 4, and 5 for the above time intervals. The $70^{th}$ year of decay represents the smallest value of $A_2$ and the maximum activity-to-$A_2$ value ratio (the smallest maximum allowable leakage rate within the time interval examined). A summary of the content activity and the $A_2$ value of the various configurations for the above time interval is given in Table 6.

From Sect. 1.2.2, the activity and mass concentrations for the transuranics are $1.2 \times 10^{7}$ Bq/gU and 800 µg/gU (ground transport only), respectively. Using a maximum uranium mass of 35.2 kg, the mass of transuranics is calculated to be 28.160 g and the activity is calculated to be $4.2240 \times 10^{-1}$ TBq. Dividing this activity by the mass results in a specific activity of $1.5 \times 10^{-2}$ TBq/g. In accordance with 10 CFR 71, Appendix A, Table A-3 for "contents with no relevant data," an $A_2$ value of $9.0 \times 10^{-5}$ TBq is obtained.

Section 1.2.2 gives a maximum concentration for Np-237 of 0.025 g/gU. Using a maximum uranium mass of 35.2 kg, the mass of Np-237 is calculated to be 880 g. This value is used in Tables 3, 4, and 5 for the Np-237 contents.

**Results**

The containment criteria analysis indicates that the HEU contents must be shipped in a Type B material package since their activities are greater than the $A_2$ value. The smallest $A_2$ value of $1.5245 \times 10^{-4}$ TBq ($4.1203 \times 10^{-3}$ Ci) in conjunction with the maximum activity-to-$A_2$ value ratio of 4,752.8 occurs after ~70 years of decay for the assumed maximum 35.2 kg of HEU.

**Table 2. Mass values of parent and daughter products for 35.2 kg of HEU**

| Isotope | 0 years | 5 years | 10 years | 20 years | 30 years | 40 years | 50 years | 60 years | 70 years |
|---|---|---|---|---|---|---|---|---|---|
| Pb-210 | 0.0000E+00 | 1.4150E-10 | 1.0912E-09 | 8.1664E-09 | 2.5555E-08 | 5.6672E-08 | 1.0349E-07 | 1.6896E-07 | 2.5274E-07 |
| Pb-212 | 0.0000E+00 | 1.8163E-08 | 2.0275E-08 | 1.8867E-08 | 1.7037E-08 | 1.5488E-08 | 1.3996E-08 | 1.2672E-08 | 1.1475E-08 |
| Bi-210 | 0.0000E+00 | 8.7296E-14 | 6.7302E-13 | 5.0054E-12 | 1.5770E-11 | 3.4918E-11 | 6.3923E-11 | 1.0419E-10 | 1.5558E-10 |
| Bi-212 | 0.0000E+00 | 1.7178E-09 | 1.9149E-09 | 1.7882E-09 | 1.6192E-09 | 1.4643E-09 | 1.3277E-09 | 1.2024E-09 | 1.0884E-09 |
| Po-210 | 0.0000E+00 | 2.4077E-12 | 1.8586E-11 | 1.3798E-10 | 4.3507E-10 | 9.6448E-10 | 1.7670E-09 | 2.8653E-09 | 4.2944E-09 |
| Rn-222 | 0.0000E+00 | 1.4150E-12 | 5.6602E-12 | 2.2598E-11 | 5.0829E-11 | 9.0112E-11 | 1.4080E-10 | 2.0205E-10 | 2.7526E-10 |
| Ra-223 | 0.0000E+00 | 6.5223E-12 | 2.4700E-11 | 8.9922E-11 | 1.8428E-10 | 2.9910E-10 | 4.3032E-10 | 5.7311E-10 | 7.2362E-10 |
| Ra-224 | 0.0000E+00 | 1.5770E-07 | 1.7600E-07 | 1.6474E-07 | 1.4925E-07 | 1.3489E-07 | 1.2207E-07 | 1.1053E-07 | 1.0011E-07 |
| Ra-225 | 0.0000E+00 | 2.1120E-08 | 4.5619E-08 | 9.1238E-08 | 1.3686E-07 | 1.8227E-07 | 2.2810E-07 | 2.7245E-07 | 3.1891E-07 |
| Ra-226 | 0.0000E+00 | 2.2035E-07 | 8.8000E-07 | 3.5200E-06 | 7.8848E-06 | 1.4010E-05 | 2.1894E-05 | 3.1469E-05 | 4.2803E-05 |
| Ra-228 | 0.0000E+00 | 2.0557E-13 | 6.8992E-13 | 2.0557E-12 | 3.6186E-12 | 5.2378E-12 | 6.8710E-12 | 8.5184E-12 | 1.0166E-11 |
| Ac-225 | 0.0000E+00 | 1.6896E-08 | 3.0835E-08 | 6.1670E-08 | 9.2506E-08 | 1.2313E-07 | 1.5396E-07 | 1.8459E-07 | 2.1542E-07 |
| Ac-227 | 0.0000E+00 | 4.6119E-09 | 1.7541E-08 | 6.3486E-08 | 1.3025E-07 | 2.1226E-07 | 3.0489E-07 | 4.0523E-07 | 5.1136E-07 |
| Ac-228 | 0.0000E+00 | 2.5062E-17 | 8.4198E-17 | 2.5062E-16 | 4.4070E-16 | 6.3923E-16 | 8.3917E-16 | 1.0391E-15 | 1.2404E-15 |
| Th-227 | 0.0000E+00 | 1.0710E-11 | 4.0716E-11 | 1.4762E-10 | 3.0296E-10 | 4.9206E-10 | 7.0819E-10 | 9.4168E-10 | 1.1906E-09 |
| Th-228 | 0.0000E+00 | 3.0694E-05 | 3.4214E-05 | 3.1962E-05 | 2.9005E-05 | 2.6189E-05 | 2.3795E-05 | 2.1542E-05 | 1.9430E-05 |
| Th-229 | 0.0000E+00 | 6.3360E-03 | 9.0394E-03 | 1.8058E-02 | 2.7034E-02 | 3.6115E-02 | 4.4986E-02 | 5.4067E-02 | 6.3149E-02 |
| Th-230 | 0.0000E+00 | 9.7856E-03 | 1.9501E-02 | 3.9072E-02 | 5.8573E-02 | 7.8144E-02 | 9.7856E-02 | 1.1686E-01 | 1.3658E-01 |
| Th-231 | 0.0000E+00 | 7.8537E-08 | 7.8537E-08 | 7.8537E-08 | 7.8537E-08 | 7.8537E-08 | 7.8537E-08 | 7.8537E-08 | 7.8537E-08 |
| Th-232 | 0.0000E+00 | 2.0416E-03 | 4.0973E-03 | 8.1946E-03 | 1.2292E-02 | 1.6333E-02 | 2.0416E-02 | 2.4640E-02 | 2.8723E-02 |
| Th-234 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 |
| Pa-231 | 0.0000E+00 | 9.3396E-05 | 1.8698E-04 | 3.7435E-04 | 5.6153E-04 | 7.4678E-04 | 9.3396E-04 | 1.1211E-03 | 1.3064E-03 |
| Pa-233 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 |
| U-232 | 1.4080E-03 | 1.3376E-03 | 1.2742E-03 | 1.1546E-03 | 1.0447E-03 | 9.4618E-04 | 8.5747E-04 | 7.7581E-04 | 7.0259E-04 |
| U-233 | 2.1120E+02 | 2.1119E+02 | 2.1119E+02 | 2.1118E+02 | 2.1117E+02 | 2.1116E+02 | 2.1116E+02 | 2.1115E+02 | 2.1114E+02 |
| U-234 | 7.0400E+02 | 7.0399E+02 | 7.0398E+02 | 7.0396E+02 | 7.0394E+02 | 7.0392E+02 | 7.0390E+02 | 7.0388E+02 | 7.0386E+02 |
| U-235 | 1.9297E+04 | 1.9297E+04 | 1.9297E+04 | 1.9297E+04 | 1.9297E+04 | 1.9297E+04 | 1.9297E+04 | 1.9297E+04 | 1.9297E+04 |
| U-236 | 1.4080E+04 | 1.4080E+04 | 1.4080E+04 | 1.4080E+04 | 1.4080E+04 | 1.4080E+04 | 1.4080E+04 | 1.4080E+04 | 1.4080E+04 |
| U-238 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 |
| Trans. | 2.8160E+01 | 2.8160E+01 | 2.8160E+01 | 2.8160E+01 | 2.8160E+01 | 2.8160E+01 | 2.8160E+01 | 2.8160E+01 | 2.8160E+01 |
| Np-237 | 8.8000E+02 | 8.8000E+02 | 8.8000E+02 | 8.8000E+02 | 8.8000E+02 | 8.8000E+02 | 8.8000E+02 | 8.8000E+02 | 8.8000E+02 |
| **Total** | **3.5200E+04** | **3.5200E+04** | **3.5200E+04** | **3.5200E+04** | **3.5200E+04** | **3.5200E+04** | **3.5200E+04** | **3.5200E+04** | **3.5200E+04** |

**Table 3. $A_2$ value calculation for 35.2 kg HEU for fast absorption uranium at 70 years**

| Isotope | Mass at 70 years (g) | Specific activity (TBq/g) | Activity (TBq) | $A_2$ (TBq) | f(i) (TBq/TBq) | f(i) / $A_2$ (1/TBq) |
|---|---|---|---|---|---|---|
| Pb-210 | 2.5274E-07 | 2.8000E+00 | 7.0767E-07 | 5.0000E-02 | 9.7669E-07 | 1.9534E-05 |
| Pb-212 | 1.1475E-08 | 5.1000E+04 | 5.8523E-04 | 2.0000E-01 | 8.0770E-04 | 4.0385E-03 |
| Bi-210 | 1.5558E-10 | 4.6000E+03 | 7.1567E-07 | 6.0000E-01 | 9.8773E-07 | 1.6462E-06 |
| Bi-212 | 1.0884E-09 | 5.4000E+05 | 5.8774E-04 | 6.0000E-01 | 8.1116E-04 | 1.3519E-03 |
| Po-210 | 4.2944E-09 | 1.7000E+02 | 7.3005E-07 | 2.0000E-02 | 1.0076E-06 | 5.0379E-05 |
| Rn-222 | 2.7526E-10 | 5.7000E+03 | 1.5690E-06 | 4.0000E-03 | 2.1654E-06 | 5.4136E-04 |
| Ra-223 | 7.2362E-10 | 1.9000E+03 | 1.3749E-06 | 7.0000E-03 | 1.8975E-06 | 2.7108E-04 |
| Ra-224 | 1.0011E-07 | 5.9000E+03 | 5.9065E-04 | 2.0000E-02 | 8.1518E-04 | 4.0759E-02 |
| Ra-225 | 3.1891E-07 | 1.5000E+03 | 4.7837E-04 | 4.0000E-03 | 6.6022E-04 | 1.6505E-01 |
| Ra-226 | 4.2803E-05 | 3.7000E-02 | 1.5837E-06 | 3.0000E-03 | 2.1858E-06 | 7.2859E-04 |
| Ra-228 | 1.0166E-11 | 1.0000E+01 | 1.0166E-10 | 2.0000E-02 | 1.4031E-10 | 7.0153E-09 |
| Ac-225 | 2.1542E-07 | 2.1000E+03 | 4.5238E-04 | 6.0000E-03 | 6.2435E-04 | 1.0406E-01 |
| Ac-227 | 5.1136E-07 | 2.7000E+00 | 1.3807E-06 | 9.0000E-05 | 1.9055E-06 | 2.1173E-02 |
| Ac-228 | 1.2404E-15 | 8.4000E+04 | 1.0419E-10 | 5.0000E-01 | 1.4380E-10 | 2.8761E-10 |
| Th-227 | 1.1906E-09 | 1.1000E+03 | 1.3097E-06 | 5.0000E-03 | 1.8075E-06 | 3.6151E-04 |
| Th-228 | 1.9430E-05 | 3.0000E+01 | 5.8290E-04 | 1.0000E-03 | 8.0449E-04 | 8.0449E-01 |
| Th-229 | 6.3149E-02 | 7.9000E-03 | 4.9888E-04 | 5.0000E-04 | 6.8852E-04 | 1.3771E+00 |
| Th-230 | 1.3658E-01 | 7.6000E-04 | 1.0380E-04 | 1.0000E-03 | 1.4326E-04 | 1.4326E-01 |
| Th-231 | 7.8537E-08 | 2.0000E+04 | 1.5707E-03 | 2.0000E-02 | 2.1679E-03 | 1.0839E-01 |
| Th-232 | 2.8723E-02 | 4.0000E-09 | 1.1489E-10 | UNLIMITED | 1.5857E-10 | -- |
| Pa-231 | 1.3064E-03 | 1.7000E-03 | 2.2209E-06 | 4.0000E-04 | 3.0651E-06 | 7.6628E-03 |
| U-232 | 7.0259E-04 | 8.3000E-01 | 5.8315E-04 | 1.0000E-02 | 8.0483E-04 | 8.0483E-02 |
| U-233 | 2.1114E+02 | 3.6000E-04 | 7.6010E-02 | 9.0000E-02 | 1.0491E-01 | 1.1656E+00 |
| U-234 | 7.0386E+02 | 2.3000E-04 | 1.6189E-01 | 9.0000E-02 | 2.2343E-01 | 2.4825E+00 |
| U-235 | 1.9297E+04 | 8.0000E-08 | 1.5438E-03 | UNLIMITED | 2.1306E-03 | -- |
| U-236 | 1.4080E+04 | 2.4000E-06 | 3.3792E-02 | UNLIMITED | 4.6638E-02 | -- |
| Transuranic | 2.8160E+01 | 1.5000E-02 | 4.2240E-01 | 9.0000E-05 | 5.8298E-01 | 6.4775E+03 |
| Np-237 | 8.8000E+02 | 2.6000E-05 | 2.2880E-02 | 2.0000E-03 | 3.1578E-02 | 1.5789E+01 |
| **Total Mass =** | **3.5200E+04** | **$\sum$ Act. =** | **7.2456E-01** | | **$\sum$ f(i) / $A_2$ =** | **6.4998E+03** |

$$A_2 \text{ (mixture)} = \frac{1}{\sum f(i)/A_2} = \frac{1}{6.4998 \times 10^3 \text{ (1/TBq)}} = 1.5385 \times 10^{-4} \text{ TBq}$$

**Table 4. $A_2$ value calculation for 35.2 kg HEU for medium absorption uranium at 70 years**

| Isotope | Mass at 70 years (g) | Specific activity (TBq/g) | Activity (TBq) | $A_2$ (TBq) | f(i) (TBq/TBq) | f(i) / $A_2$ (1/TBq) |
|---|---|---|---|---|---|---|
| Pb-210 | 2.5274E-07 | 2.8000E+00 | 7.0767E-07 | 5.0000E-02 | 9.7669E-07 | 1.9534E-05 |
| Pb-212 | 1.1475E-08 | 5.1000E+04 | 5.8523E-04 | 2.0000E-01 | 8.0770E-04 | 4.0385E-03 |
| Bi-210 | 1.5558E-10 | 4.6000E+03 | 7.1569E-07 | 6.0000E-01 | 9.8775E-07 | 1.6463E-06 |
| Bi-212 | 1.0884E-09 | 5.4000E+05 | 5.8773E-04 | 6.0000E-01 | 8.1115E-04 | 1.3519E-03 |
| Po-210 | 4.2944E-09 | 1.7000E+02 | 7.3005E-07 | 2.0000E-02 | 1.0076E-06 | 5.0379E-05 |
| Rn-222 | 2.7526E-10 | 5.7000E+03 | 1.5690E-06 | 4.0000E-03 | 2.1655E-06 | 5.4137E-04 |
| Ra-223 | 7.2362E-10 | 1.9000E+03 | 1.3749E-06 | 7.0000E-03 | 1.8975E-06 | 2.7108E-04 |
| Ra-224 | 1.0011E-07 | 5.9000E+03 | 5.9064E-04 | 2.0000E-02 | 8.1517E-04 | 4.0759E-02 |
| Ra-225 | 3.1891E-07 | 1.5000E+03 | 4.7837E-04 | 4.0000E-03 | 6.6022E-04 | 1.6505E-01 |
| Ra-226 | 4.2803E-05 | 3.7000E-02 | 1.5837E-06 | 3.0000E-03 | 2.1858E-06 | 7.2859E-04 |
| Ra-228 | 1.0166E-11 | 1.0000E+01 | 1.0166E-10 | 2.0000E-02 | 1.4030E-10 | 7.0151E-09 |
| Ac-225 | 2.1542E-07 | 2.1000E+03 | 4.5239E-04 | 6.0000E-03 | 6.2437E-04 | 1.0406E-01 |
| Ac-227 | 5.1136E-07 | 2.7000E+00 | 1.3807E-06 | 9.0000E-05 | 1.9055E-06 | 2.1173E-02 |
| Ac-228 | 1.2404E-15 | 8.4000E+04 | 1.0420E-10 | 5.0000E-01 | 1.4381E-10 | 2.8762E-10 |
| Th-227 | 1.1906E-09 | 1.1000E+03 | 1.3097E-06 | 5.0000E-03 | 1.8075E-06 | 3.6151E-04 |
| Th-228 | 1.9430E-05 | 3.0000E+01 | 5.8291E-04 | 1.0000E-03 | 8.0451E-04 | 8.0451E-01 |
| Th-229 | 6.3149E-02 | 7.9000E-03 | 4.9888E-04 | 5.0000E-04 | 6.8852E-04 | 1.3770E+00 |
| Th-230 | 1.3658E-01 | 7.6000E-04 | 1.0380E-04 | 1.0000E-03 | 1.4326E-04 | 1.4326E-01 |
| Th-231 | 7.8537E-08 | 2.0000E+04 | 1.5707E-03 | 2.0000E-02 | 2.1679E-03 | 1.0839E-01 |
| Th-232 | 2.8723E-02 | 4.0000E-09 | 1.1489E-10 | UNLIMITED | 1.5857E-10 | -- |
| Pa-231 | 1.3064E-03 | 1.7000E-03 | 2.2209E-06 | 4.0000E-04 | 3.0651E-06 | 7.6628E-03 |
| U-232 | 7.0259E-04 | 8.3000E-01 | 5.8315E-04 | 7.0000E-03 | 8.0484E-04 | 1.1498E-01 |
| U-233 | 2.1114E+02 | 3.6000E-04 | 7.6009E-02 | 2.0000E-02 | 1.0490E-01 | 5.2452E+00 |
| U-234 | 7.0386E+02 | 2.3000E-04 | 1.6189E-01 | 2.0000E-02 | 2.2343E-01 | 1.1172E+01 |
| U-235 | 1.9297E+04 | 8.0000E-08 | 1.5437E-03 | UNLIMITED | 2.1306E-03 | -- |
| U-236 | 1.4080E+04 | 2.4000E-06 | 3.3792E-02 | 2.0000E-02 | 4.6638E-02 | 2.3319E+00 |
| Transuranic | 2.8160E+01 | 1.5000E-02 | 4.2240E-01 | 9.0000E-05 | 5.8298E-01 | 6.4775E+03 |
| Np-237 | 8.8000E+02 | 2.6000E-05 | 2.2880E-02 | 2.0000E-03 | 3.1578E-02 | 1.5789E+01 |
| **Total Mass =** | **3.5200E+04** | **∑ Act. =** | **7.2456E-01** | | **∑ f(i) / A2 =** | **6.5149E+03** |

$$A_2 \text{ (mixture)} = \frac{1}{\sum f(i)/A_2} = \frac{1}{6.5149 \times 10^3 \text{ (1/TBq)}} = 1.5349 \times 10^{-4} \text{ TBq}$$

**Table 5. $A_2$ value calculation for 35.2 kg HEU for slow absorption uranium at 70 years**

| Isotope | Mass at 70 years (g) | Specific activity (TBq/g) | Activity (TBq) | $A_2$ (TBq) | f(i) (TBq/TBq) | f(i) / $A_2$ (1/TBq) |
|---|---|---|---|---|---|---|
| Pb-210 | 2.5274E-07 | 2.8000E+00 | 7.0766E-07 | 5.0000E-02 | 9.7668E-07 | 1.9534E-05 |
| Pb-212 | 1.1475E-08 | 5.1000E+04 | 5.8524E-04 | 2.0000E-01 | 8.0771E-04 | 4.0386E-03 |
| Bi-210 | 1.5558E-10 | 4.6000E+03 | 7.1569E-07 | 6.0000E-01 | 9.8775E-07 | 1.6463E-06 |
| Bi-212 | 1.0884E-09 | 5.4000E+05 | 5.8773E-04 | 6.0000E-01 | 8.1115E-04 | 1.3519E-03 |
| Po-210 | 4.2944E-09 | 1.7000E+02 | 7.3005E-07 | 2.0000E-02 | 1.0076E-06 | 5.0379E-05 |
| Rn-222 | 2.7526E-10 | 5.7000E+03 | 1.5690E-06 | 4.0000E-03 | 2.1655E-06 | 5.4137E-04 |
| Ra-223 | 7.2362E-10 | 1.9000E+03 | 1.3749E-06 | 7.0000E-03 | 1.8975E-06 | 2.7108E-04 |
| Ra-224 | 1.0011E-07 | 5.9000E+03 | 5.9064E-04 | 2.0000E-02 | 8.1517E-04 | 4.0759E-02 |
| Ra-225 | 3.1891E-07 | 1.5000E+03 | 4.7837E-04 | 4.0000E-03 | 6.6022E-04 | 1.6505E-01 |
| Ra-226 | 4.2803E-05 | 3.7000E-02 | 1.5837E-06 | 3.0000E-03 | 2.1858E-06 | 7.2859E-04 |
| Ra-228 | 1.0166E-11 | 1.0000E+01 | 1.0166E-10 | 2.0000E-02 | 1.4030E-10 | 7.0151E-09 |
| Ac-225 | 2.1542E-07 | 2.1000E+03 | 4.5239E-04 | 6.0000E-03 | 6.2437E-04 | 1.0406E-01 |
| Ac-227 | 5.1136E-07 | 2.7000E+00 | 1.3807E-06 | 9.0000E-05 | 1.9055E-06 | 2.1173E-02 |
| Ac-228 | 1.2404E-15 | 8.4000E+04 | 1.0420E-10 | 5.0000E-01 | 1.4381E-10 | 2.8762E-10 |
| Th-227 | 1.1906E-09 | 1.1000E+03 | 1.3097E-06 | 5.0000E-03 | 1.8075E-06 | 3.6151E-04 |
| Th-228 | 1.9430E-05 | 3.0000E+01 | 5.8291E-04 | 1.0000E-03 | 8.0451E-04 | 8.0451E-01 |
| Th-229 | 6.3149E-02 | 7.9000E-03 | 4.9888E-04 | 5.0000E-04 | 6.8852E-04 | 1.3770E+00 |
| Th-230 | 1.3658E-01 | 7.6000E-04 | 1.0380E-04 | 1.0000E-03 | 1.4326E-04 | 1.4326E-01 |
| Th-231 | 7.8537E-08 | 2.0000E+04 | 1.5707E-03 | 2.0000E-02 | 2.1679E-03 | 1.0839E-01 |
| Th-232 | 2.8723E-02 | 4.0000E-09 | 1.1489E-10 | UNLIMITED | 1.5857E-10 | -- |
| Pa-231 | 1.3064E-03 | 1.7000E-03 | 2.2209E-06 | 4.0000E-04 | 3.0651E-06 | 7.6628E-03 |
| U-232 | 7.0259E-04 | 8.3000E-01 | 5.8315E-04 | 1.0000E-03 | 8.0484E-04 | 8.0484E-01 |
| U-233 | 2.1114E+02 | 3.6000E-04 | 7.6009E-02 | 6.0000E-03 | 1.0490E-01 | 1.7484E+01 |
| U-234 | 7.0386E+02 | 2.3000E-04 | 1.6189E-01 | 6.0000E-03 | 2.2343E-01 | 3.7238E+01 |
| U-235 | 1.9297E+04 | 8.0000E-08 | 1.5437E-03 | UNLIMITED | 2.1306E-03 | -- |
| U-236 | 1.4080E+04 | 2.4000E-06 | 3.3792E-02 | 6.0000E-03 | 4.6638E-02 | 7.7730E+00 |
| Transuranic | 2.8160E+01 | 1.5000E-02 | 4.2240E-01 | 9.0000E-05 | 5.8298E-01 | 6.4775E+03 |
| Np-237 | 8.8000E+02 | 2.6000E-05 | 2.2880E-02 | 2.0000E-03 | 3.1578E-02 | 1.5789E+01 |
| **Total Mass =** | **3.5200E+04** | **∑ Act. =** | **7.2456E-01** | | **∑ f(i) / $A_2$ =** | **6.5594E+03** |

$$A_2 \text{ (mixture)} = \frac{1}{\sum f(i)/A_2} = \frac{1}{6.5594 \times 10^3 \text{ (1/TBq)}} = 1.5245 \times 10^{-4} \text{ TBq}$$

**Table 6. Activity, $A_2$ value, and activity-to-$A_2$ ratio for the enriched uranium contents**

| Year | Activity (TBq) | $A_2$-Mixture (TBq) | | | Activity/$A_2$ | | |
|---|---|---|---|---|---|---|---|
| | | Fast | Medium | Slow | Fast | Medium | Slow |
| 0 | 7.1974E-01 | 1.5289E-04 | 1.5253E-04 | 1.5148E-04 | 4707.57 | 4718.68 | 4751.39 |
| 5 | 7.2507E-01 | 1.5399E-04 | 1.5363E-04 | 1.5257E-04 | 4708.55 | 4719.59 | 4752.38 |
| 10 | 7.2554E-01 | 1.5408E-04 | 1.5372E-04 | 1.5267E-04 | 4708.85 | 4719.88 | 4752.34 |
| 20 | 7.2538E-01 | 1.5404E-04 | 1.5368E-04 | 1.5263E-04 | 4709.04 | 4720.07 | 4752.54 |
| 30 | 7.2514E-01 | 1.5399E-04 | 1.5363E-04 | 1.5258E-04 | 4709.01 | 4720.04 | 4752.52 |
| 40 | 7.2494E-01 | 1.5394E-04 | 1.5358E-04 | 1.5254E-04 | 4709.24 | 4720.28 | 4752.46 |
| 50 | 7.2478E-01 | 1.5390E-04 | 1.5355E-04 | 1.5250E-04 | 4709.42 | 4720.16 | 4752.66 |
| 60 | 7.2465E-01 | 1.5387E-04 | 1.5352E-04 | 1.5247E-04 | 4709.50 | 4720.23 | 4752.74 |
| 70 | 7.2456E-01 [a] | 1.5385E-04 | 1.5349E-04 | 1.5245E-04 [a] | 4709.52 | 4720.57 | 4752.77 [a] |

[a] The $A_2$, total activity, and activity-to-$A_2$ ratio values used in Appendix 4.5.2.

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## Appendix 4.5.2

## Calculation of the ES-3100 Containment Vessel's Regulatory Reference Air Leakage Rates

### Introduction

The ES-3100 leak-testing requirements of the containment boundary are based on the smallest maximum allowable leakage rate generated from the maximum uranium content defined in Table 4.3. Section 5 of ANSI N14.5-1997 defines the maximum allowable leakage rate based on the maximum allowable release rate. These leakage rates, $L_N$ and $L_A$, are the maximum allowable O-ring seal leakage rates for Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC). The worst-case maximum allowable leakage rates are used to calculate an equivalent leakage hole diameter following ANSI N14.5-1997, Appendix B, for each condition of transport. This leakage hole diameter is used to calculate a reference air and a helium leakage rate for leak testing. A bounding mass for the highly enriched uranium (HEU) content of 35.2 kg is used in this calculation to certify the ES-3100 package for shipment. The maximum allowable leakage rates are calculated using this maximum content mass in a much more dispersive form (oxide powder) at the highest calculated pressures and temperatures. This appendix shows the procedure used to calculate the leak criteria for the uranium constituents in the "slow lung absorption" group. Table 1 shows the results of using this procedure for fast, medium, and slow absorption uranium constituents as a function of decay time.

### HEU Content

Calculate $R_N$ and $R_A$: (Table 4.1)

The maximum allowable release rate is based on using $A_2$.

$A_2 = 1.5245 \times 10^{-4}$ TBq, ($4.1203 \times 10^{-3}$ Ci). [Table 6 (Appendix 4.5.1)]

The containment requirements for NCT and HAC are:

$R_N = A_2 \times 10^{-6}$ TBq/h,
$= A_2 \times 2.78 \times 10^{-10}$ TBq/s, [ANSI N14.5-1997 (Eq. 1)]
$= 1.5245 \times 10^{-4} \times 2.78 \times 10^{-10}$ TBq/s,
$= 4.2382 \times 10^{-14}$ TBq/s, ($1.1455 \times 10^{-12}$ Ci/s).

$R_A = A_2$ (TBq/week),
$= A_2 \times 1.65 \times 10^{-6}$ (TBq/s), [ANSI N14.5-1997 (Eq. 2)]
$= 1.5245 \times 10^{-4} \times 1.65 \times 10^{-6}$ TBq/s,
$= 2.5155 \times 10^{-10}$ TBq/s, ($6.7986 \times 10^{-9}$ Ci/s). (or limited to 10 $A_2$/week of $^{85}$Kr)

Following ANSI N14.5-1997, the medium aerosol activity must be calculated to determine the leakage rates.

m = total nuclide mass in the package available for release (g),
TotA = total activity in the package available for release (TBq),
TSA = total specific activity in the package available for release (TBq/g).

**Table 1. Regulatory leakage criteria for 35.2 kg of HEU**

| Years from fabrication | | NCT | | HAC | |
|---|---|---|---|---|---|
| | | $L_{RN - air}$ (ref-cm$^3$/s) | $L_{RN - He}$ (cm$^3$/s) | $L_{RA - air}$ (ref-cm$^3$/s) | $L_{RA - He}$ (cm$^3$/s) |
| Fast absorption | 0 | 1.3922E-04 | 1.7148E-04 | 2.3889E-01 | 2.3560E-01 |
| | 5 | 1.3918E-04 | 1.7144E-04 | 2.3883E-01 | 2.3555E-01 |
| | 10 | 1.3918E-04 | 1.7143E-04 | 2.3882E-01 | 2.3554E-01 |
| | 20 | 1.3918E-04 | 1.7143E-04 | 2.3881E-01 | 2.3553E-01 |
| | 30 | 1.3917E-04 | 1.7143E-04 | 2.3881E-01 | 2.3553E-01 |
| | 40 | 1.3917E-04 | 1.7143E-04 | 2.3880E-01 | 2.3552E-01 |
| | 50 | 1.3917E-04 | 1.7142E-04 | 2.3880E-01 | 2.3552E-01 |
| | 60 | 1.3916E-04 | 1.7142E-04 | 2.3879E-01 | 2.3551E-01 |
| | 70 | 1.3916E-04 | 1.7141E-04 | 2.3879E-01 | 2.3551E-01 |
| Medium absorption | 0 | 1.3890E-04 | 1.7111E-04 | 2.3833E-01 | 2.3507E-01 |
| | 5 | 1.3887E-04 | 1.7107E-04 | 2.3827E-01 | 2.3501E-01 |
| | 10 | 1.3886E-04 | 1.7106E-04 | 2.3827E-01 | 2.3500E-01 |
| | 20 | 1.3886E-04 | 1.7106E-04 | 2.3826E-01 | 2.3499E-01 |
| | 30 | 1.3886E-04 | 1.7106E-04 | 2.3826E-01 | 2.3499E-01 |
| | 40 | 1.3885E-04 | 1.7105E-04 | 2.3825E-01 | 2.3499E-01 |
| | 50 | 1.3885E-04 | 1.7105E-04 | 2.3825E-01 | 2.3498E-01 |
| | 60 | 1.3885E-04 | 1.7105E-04 | 2.3824E-01 | 2.3498E-01 |
| | 70 | 1.3884E-04 | 1.7104E-04 | 2.3824E-01 | 2.3497E-01 |
| Slow absorption | 0 | 1.3796E-04 | 1.7001E-04 | 2.3670E-01 | 2.3348E-01 |
| | 5 | 1.3793E-04 | 1.6997E-04 | 2.3665E-01 | 2.3342E-01 |
| | 10 | 1.3792E-04 | 1.6997E-04 | 2.3664E-01 | 2.3342E-01 |
| | 20 | 1.3792E-04 | 1.6997E-04 | 2.3664E-01 | 2.3342E-01 |
| | 30 | 1.3792E-04 | 1.6997E-04 | 2.3664E-01 | 2.3342E-01 |
| | 40 | 1.3792E-04 | 1.6997E-04 | 2.3664E-01 | 2.3342E-01 |
| | 50 | 1.3792E-04 | 1.6997E-04 | 2.3664E-01 | 2.3341E-01 |
| | 60 | 1.3792E-04 | 1.6997E-04 | 2.3663E-01 | 2.3341E-01 |
| | 70 | 1.3792E-04 | 1.6996E-04 | 2.3663E-01 | 2.3341E-01 |

For HEU content:

TSA = TotA / m,

= $7.2456 \times 10^{-1}$ (TBq) / 35,200 (g), [Table 6 (Appendix 4.5.1)]

= $2.0584 \times 10^{-5}$ TBq/g,

$\rho P$ = $9 \times 10^{-6}$ g/cm$^3$. (The maximum density of powder aerosols in the fill gas)

For any packaging arrangement:

$C_N$ = activity per unit volume of medium that could escape from the containment system (TBq/cm$^3$),
= TSA × $\rho_P$,
= $2.0584 \times 10^{-5}$ (TBq/g) × $9 \times 10^{-6}$ (g/cm$^3$),
= $1.8526 \times 10^{-10}$ TBq/cm$^3$.

Using Curren's maximum aerosol density, $C_A = C_N$:

$C_A$ = activity per unit volume of exiting gas (TBq/cm$^3$), (HAC)
= $1.8526 \times 10^{-10}$ TBq/cm$^3$.

Section 6.1 of ANSI N14.5-1997 calculates $L_N$ with (Eq. 3) and $L_A$ with (Eq. 4). $L_N$ and $L_A$ are the maximum allowable leakage rates for the containment vessel fill gas aerosol during NCT and HAC, respectively.

$L_N$ = maximum allowable leakage rate for the medium for NCT (TBq/cm$^3$),
= $R_N / C_N$, [ANSI N14.5-1997 (Eq. 3)]
= $4.2382 \times 10^{-14}$ (TBq/s) / $1.8526 \times 10^{-10}$ (TBq/cm$^3$),
= $2.2878 \times 10^{-4}$ cm$^3$/s,

$L_A$ = maximum allowable leakage rate for the medium for HAC (TBq/cm$^3$),
= $R_A / C_A$,
= $2.5155 \times 10^{-10}$ (TBq/s) / $1.8526 \times 10^{-10}$ (TBq/cm$^3$),
= 1.3578 cm$^3$/s.

$L_N$ and $L_A$ correspond to the upstream volumetric leakage rate ($L_u$) at the upstream pressure ($P_u$) in the ANSI N14.5-1997 formulas for use later in this appendix. The reference air leakage rates $L_{R,N}$ and $L_{R,A}$ for NCT and HAC, based on the $L_N$ and $L_A$, are then calculated using the maximum temperatures and pressure combinations from Table 7 in Appendix 3.5.4 (NCT) and from Table 7 in Appendix 3.5.5 (HAC) as the basis. For conservatism, the latter values have been rounded up to compensate for numerical tolerance issues. Therefore, the following analyses will use a pressure of 31.25 psia at a temperature of 200°F for the NCT evaluation and a pressure of 112.50 psia at a temperature of 285.00°F for the HAC evaluation.

**Determination of the Leakage Test Procedure Requirements for the HEU Content**

This calculation will examine the most conservative effects of a fully loaded containment vessel with an HEU mass of 35.2 kg. The smallest allowable leakage values are shown in Tables 4.5 and 4.7. The $A_2$ value and the maximum content activity-to-$A_2$ value ratio for this mixture were calculated for several different decay times (Table 6, Appendix 4.5.1). As calculated in Appendix 4.5.1, the $A_2$ value and the maximum content activity-to-$A_2$ ratio used to qualify this package occur at ~70 years of decay and are $1.5245 \times 10^{-4}$ TBq ($4.1203 \times 10^{-3}$ Ci) and 4,752.8 respectively. These values are used to determine the leakage test procedural requirements when packaging any convenience cans/contents arrangements in the ES-3100 package. The convenience cans/contents are sealed inside the containment vessel in an environmentally controlled area.

The following analysis determines the maximum allowable O-ring seal air reference leakage rate for both NCT and HAC. The ANSI N14.5-1997 recommended method using a straight circular tube to model the leakage path is applied. Using this "standard" leakage hole model permits the calculation of equivalent reference leakage rates from which leak-test requirements can be established. Viscosity data for air and helium used in the following analyses were obtained from curve fitting routines at specific temperatures based on viscosity data for air (*CRC Handbook of Chemistry and Physics*) and helium (NBS Technical Note 631).

$L_N$ and $L_A$ correspond to the upstream volumetric leakage rate ($L_u$) at the upstream pressure ($P_u$).

$$L_N = 2.2878 \times 10^{-4} \text{ cm}^3/\text{s},$$
$$L_A = 1.3578 \text{ cm}^3/\text{s}.$$

Find the maximum pressure and temperature in the containment vessel:

Converting the temperature to degrees Kelvin:

$$T = 273.15 + T\ (°C),$$
$$= 273.15 + 5 / 9\ (°F - 32)\ (K),$$

$$T_N = 273.15 + 5 / 9\ (200.00°F - 32)\ (K), \quad (T = 200.00°F)$$
$$= 366.48 \text{ K}, \quad (NCT)$$

$$T_A = 273.15 + 5 / 9\ (285.00°F - 32)\ (K), \quad (T = 285.00°F)$$
$$= 413.71 \text{ K}. \quad (HAC)$$

Converting the pressures from psia to atmospheres:

$$P_N = P\ (psia) / 14.696\ (psia/atm), \quad (where\ P\ is\ the\ pressure\ in\ Sect.\ 3.3.2)$$
$$= 31.250\ (psia) / 14.696\ (psia/atm), \quad (rounded\ up\ for\ NCT)$$
$$= 2.1264 \text{ atm},$$

$$P_A = P\ (psia) / 14.696\ (psia/atm), \quad (where\ P\ is\ the\ pressure\ in\ Sect.\ 3.4.3)$$
$$= 112.50\ (psia) / 14.696\ (psia/atm), \quad (rounded\ up\ for\ HAC)$$
$$= 7.6551 \text{ atm}.$$

**NCT Leakage Hole Diameter for the HEU Content**

The following calculations determine the leakage hole diameter that generates the maximum allowable leakage rate during NCT. To keep these calculations conservative, the maximum values for temperature and pressure were used as steady-state conditions for NCT.

Input data for NCT with air fill gas:

$L_N = 2.2878 \times 10^{-4} \text{ cm}^3/\text{s}$, (Maximum upstream leakage)
$P_u = 2.1264$ atm, (Upstream pressure = 31.25 psia)
$P_d = 0.2382$ atm, [Downstream pressure = 3.5 psia, per 10 CFR 71.71(3)]
$a = 0.3531$ cm, (Leak path length, 0.139-in. O-ring section diameter)
$T = 366.48$ K, (Fill gas temperature = 200.00°F)

$\mu$ = 0.02165 cP, (Viscosity at temperature)
M = 29 g/g-mol. (Molecular weight of fill gas)

The average pressure is:

$P_a = (P_u + P_d) / 2,$
$= (2.1264 + 0.2382) / 2,$
$= 1.1823$ atm. (Average pressure during NCT)

According to ANSI N14.5-1997, the flow leakage hole diameter is unknown. Therefore, the mass-like leakage flow rate must be calculated to calculate the average leakage flow rate.

Q is the mass-like leakage for flow using the upstream leakage, $L_u$, and pressure, $P_u$:

$Q = P_u L_u,$ (Eq. B1)
$L_u = L_N,$ (NCT leakage)

$Q = (2.1264)(\text{atm})\ (2.2878 \times 10^{-4})(\text{cm}^3/\text{s}),$
$= 4.8647 \times 10^{-4}$ atm-cm$^3$/s, (NCT mass-like leakage rate)

$Q = P_a L_a,$ (Eq. B1)

$L_a = Q / P_a,$
$= 4.8647 \times 10^{-4}$ (atm-cm$^3$/s) / (1.1823) (atm),
$= 4.1147 \times 10^{-4}$ cm$^3$/s. (NCT average leakage rate)

Solve equations B2–B4 from ANSI N14.5-1997:

$L_a = (F_c + F_m)(P_u - P_d)$ cm$^3$/s, (Eq. B2)
$= (F_c + F_m)(2.1264 - 0.2382),$
$= (1.8882)(F_c + F_m)$ cm$^3$/s,

$F_c = (2.49 \times 10^6)\ D^4 / (a\ \mu)$ (cm$^3$/atm-s), (Eq. B3)
$= (2.49 \times 10^6)\ D^4 / [(0.3531)(0.02165)],$
$= (3.2573 \times 10^8)\ D^4$ cm$^3$/atm-s,

$F_m = (3.81 \times 10^3)\ D^3\ (T / M)^{.5} / (a\ P_a)$ (cm$^3$/atm-s), (Eq. B4)
$= (3.81 \times 10^3)\ D^3\ (366.48 / 29)^{.5} / [(0.3531)(1.1823)],$
$= (3.2447 \times 10^4)\ D^3$ cm$^3$/atm-s.

From the mass-like leakage calculation:

$L_a = 4.1147 \times 10^{-4}$ cm$^3$/s. (NCT average leakage rate)

Find the leakage hole diameter that sets:

$L_2 = L_a.$

Using the equations:

$L_2 = (1.8883)\ (F_c + F_m)\ cm^3/s,$
$F_c = (3.2573 \times 10^8)\ D^4\ cm^3/atm\text{-}s,$
$F_m = (3.2447 \times 10^4)\ D^3\ cm^3/atm\text{-}s.$

To get a better guess on a new D, use:

$$D = D_2\ (L_a / L_2)^{0.252}.$$

Now a guess must be made for $D_2$ to solve Eq. B2 for NCT:

$D_2$ = 0.001 cm, and solve for $L_a = 4.1147 \times 10^{-4}$ $cm^3/s$. (NCT average leakage rate)

| Diameter | $F_c$ | $F_m$ | $L_2$ | $L_a / L_2$ |
|---|---|---|---|---|
| 1.0000E-03 | 3.2573E-04 | 3.2447E-05 | 6.7635E-04 | 6.0837E-01 |
| 8.8229E-04 | 1.9738E-04 | 2.2285E-05 | 4.1479E-04 | 9.9199E-01 |
| 8.8050E-04 | 1.9579E-04 | 2.2150E-05 | 4.1153E-04 | 9.9986E-01 |
| 8.8047E-04 | 1.9576E-04 | 2.2147E-05 | 4.1147E-04 | 1.0000E+00 |
| 8.8047E-04 | 1.9576E-04 | 2.2147E-05 | 4.1147E-04 | 1.0000E+00 |

The NCT leakage hole diameter for the HEU oxide content:

D = 8.8047 × 10−4 cm. (NCT diameter)

**NCT Reference Air Leakage Rate for HEU Content**

The leakage hole diameter found for the maximum allowable leakage rate for NCT will be used to determine the reference air leakage rate. O-ring seal leakage testing must ensure that no leakage is greater than the leakage generated by the hole diameter D = 8.8047 × 10−4 cm. Therefore, the NCT reference leakage flow rate ($L_{R,N}$) must be calculated to determine the allowable test leakage rate.

Input data for NCT reference air leakage rate:

D = $8.8047 \times 10^{-4}$ cm, (From NCT)
a = 0.3531 cm, (Leak path length, 0.139-in. O-ring section diameter)
$P_u$ = 1.0 atm, (Upstream pressure)
$P_d$ = 0.01 atm, (Downstream pressure)
T = 298 K, (Fill gas temperature, 77°F)
M = 29 g/g-mol, (Molecular weight of air)
μ = 0.0185 cP, (Viscosity of air at reference temperature)

Calculate $P_a$:

$P_a = (P_u + P_d) / 2,$
$= (1.0 + 0.01) /2,$
$= 0.505$ atm, (NCT average pressure)

$$F_c = (2.49 \times 10^6)\, D^4 / (a\,\mu)\ (cm^3/atm\text{-}s), \qquad \text{(Eq. B3)}$$
$$= (2.49 \times 10^6)\, (8.8047 \times 10^{-4})^4 / [(0.3531)\ (0.0185)],$$
$$= (3.8122 \times 10^8)\, (8.8047 \times 10^{-4})^4,$$
$$= 2.2911 \times 10^{-4}\ cm^3/atm\text{-}s,$$

$$F_m = (3.81 \times 10^3)\, D^3\, (T / M)^{.5} / (a\, P_a)\ (cm^3/atm\text{-}s), \qquad \text{(Eq. B4)}$$
$$= (3.81 \times 10^3)\, (8.8047 \times 10^{-4})^3\, (298 / 29)^{.5} / [(0.3531)\ (0.505)],$$
$$= (6.8501 \times 10^4)\, 8.8047 \times 10^{-4})^3,$$
$$= 4.6756 \times 10^{-5}\ cm^3/atm\text{-}s,$$

$$L_u = (F_c + F_m)\, (P_u - P_d)\, (P_a / P_u)\ (cm^3/s), \qquad \text{(Eq. B5)}$$
$$= (2.2911 \times 10^{-4} + 4.6756 \times 10^{-5})(cm^3/atm\text{-}s)\ (1.0 - 0.01)(atm)\ (0.505 / 1.0),$$
$$= (2.7587 \times 10^{-4})(cm^3/atm\text{-}s)\ (0.49995)(atm),$$
$$= 1.3792 \times 10^{-4}\ cm^3/s.$$

The reference air leakage rate as defined in ANSI N14.5-1997, Sect. B.3, is the upstream leakage in air.

$$L_{RN,Air} = 1.3792 \times 10^{-4}\ ref\text{-}cm^3/s. \qquad \text{(For HEU oxide content)}$$

The same equations can be used to calculate an allowable leakage rate using helium for leak testing.

$$M = 4\ g/g\text{-}mol, \qquad \text{(Molecular weight of helium)}$$
$$\mu = 0.0198\ cP, \qquad \text{(Viscosity of helium at temperature)}$$

$$F_c = (2.49 \times 10^6)\, D^4 / (a\,\mu)\ (cm^3/atm\text{-}s), \qquad \text{(Eq. B3)}$$
$$= (2.49 \times 10^6)\, (8.8047 \times 10^{-4})^4 / [(0.3531)\ (0.0198)],$$
$$= (3.5619 \times 10^8)\, (8.8047 \times 10^{-4})^4,$$
$$= 2.1407 \times 10^{-4}\ cm^3/atm\text{-}s,$$

$$F_m = (3.81 \times 10^3)\, D^3\, (T / M)^{.5} / (a\, P_a)\ (cm^3/atm\text{-}s), \qquad \text{(Eq. B4)}$$
$$= (3.81 \times 10^3)\, (8.8047 \times 10^{-4})^3\, (298 / 4)^{.5} / [(0.3531)\ (0.505)],$$
$$= (1.8444 \times 10^5)\, (8.8047 \times 10^{-4})^3,$$
$$= 1.2590 \times 10^{-4}\ cm^3/atm\text{-}s,$$

$$L_u = (F_c + F_m)\, (P_u - P_d)\, (P_a / P_u)\ (cm^3/s), \qquad \text{(Eq. B5)}$$
$$= (2.1407 \times 10^{-4} + 1.2590 \times 10^{-4})(cm^3/atm\text{-}s)\ (1.0 - 0.01)(atm)\ (0.505 / 1.0),$$
$$= (3.3997 \times 10^{-4})(cm^3/atm\text{-}s)\ (0.49995)(atm),$$
$$= 1.6996 \times 10^{-4}\ cm^3/s.$$

The allowable leakage rate using helium for leak testing is:

$$L_{RN,\,He} = 1.6996 \times 10^{-4}\ cm^3/s. \qquad \text{(NCT helium test value)}$$

**HAC Leakage Hole Diameter for HEU Content**

The calculation of a maximum allowable leakage rate hole diameter is based on the temperature and pressure of the fill gas aerosol for HAC, assuming the content is in an oxide powder form. Keeping

this calculation conservative, the maximum values for temperature and pressure were used as steady-state conditions for a week. The maximum values were generated during the 30-min burn test for HAC.

Input data for HAC:

$L_A = 1.3578\ cm^3/s$, (Maximum exit leakage)
$P_u = 7.6551$ atm, (Upstream pressure = 112.50 psia)
$P_d = 1.0$ atm, (Downstream pressure)
$T = 413.71$ K, (Fill gas temperature = 285.00°F)
$\mu = 0.02367$ cP, (Viscosity of air at temperature)
$M = 29$ g/g-mol, (Molecular weight of air)
$a = 0.3531$ cm, (Leak path length, 0.139-in. O-ring section diameter)

$P_a = (P_u + P_d) / 2,$
$= (7.6551 + 1.0) / 2,$ (HAC average pressure)
$= 4.3276$ atm.

Q is the mass-like leakage for flow using the upstream leakage, $L_u$, and pressure, $P_u$:

$Q = P_u L_u,$ (Eq. B1)
$L_u = L_A.$ (HAC leakage)

$Q = (7.6551)(atm)\ (1.3578)(cm^3/s),$
$= 10.3944\ atm\text{-}cm^3/s,$ (HAC mass-like leakage rate)

$Q = P_a L_a,$ (Eq. B1)

$L_a = Q / P_a,$
$= 10.3944\ (atm\text{-}cm^3/s) / (4.3276)\ (atm),$
$= 2.4019\ cm^3/s.$ (HAC average leakage rate)

Solve equations B2–B4 from ANSI N14.5-1997:

$L_a = (F_c + F_m)\ (P_u - P_d)\ (cm^3/s),$ (Eq. B2)
$= (F_c + F_m)\ (7.6551 - 1.0),$
$= 6.6551\ (F_c + F_m)\ cm^3/s,$

$F_c = (2.49 \times 10^6)\ D^4 / (a\ \mu)\ (cm^3/atm\text{-}s),$ (Eq. B3)
$= (2.49 \times 10^6)\ D^4 / [(0.3531)\ (0.02367)],$
$= (2.9796 \times 10^8)\ D^4\ cm^3/atm\text{-}s,$

$F_m = (3.81 \times 10^3)\ D^3\ (T / M)^{.5} / (a\ P_a)\ (cm^3/atm\text{-}s),$ (Eq. B4)
$= (3.81 \times 10^3)\ D^3\ (413.71 / 29)^{.5} / [(0.3531)\ (4.3276)],$
$= (9.4184 \times 10^3)\ D^3\ cm^3/atm\text{-}s.$

From the mass-like leakage calculation:

$L_a = 2.4019\ cm^3/s.$ (HAC average leakage rate)

Find the leakage hole diameter that sets:

$$L_2 = L_a.$$

Using the equations:

$$L_2 = 6.6551\ (F_c + F_m)\ cm^3/s,$$
$$F_c = (2.9796 \times 10^8)\ D^4\ cm^3/atm\text{-}s,$$
$$F_m = (9.4184 \times 10^3)\ D^3\ cm^3/atm\text{-}s.$$

To get a better guess on a new D, use:

$$D = D_2\ (L_a / L_2)^{0.252}.$$

Now a guess must be made for $D_2$ to solve Eq. B2 for HAC:

$D_2$ = 0.01 (cm), and solve for $L_a$ = 2.4019 ($cm^3/s$). (HAC average leakage rate)

| Diameter | $F_c$ | $F_m$ | $L_2$ | $L_a / L_2$ |
|---|---|---|---|---|
| 1.0000E-02 | 2.9796E+00 | 9.4184E-03 | 1.9892E+01 | 1.2075E-01 |
| 5.8699E-03 | 3.5374E-01 | 1.9049E-03 | 2.3668E+00 | 1.0148E+00 |
| 5.8917E-03 | 3.5902E-01 | 1.9262E-03 | 2.4021E+00 | 9.9990E-01 |
| 5.8916E-03 | 3.5898E-01 | 1.9260E-03 | 2.4019E+00 | 1.0000E+00 |

The HAC leakage hole diameter for the HEU oxide content is:

$$D = 5.8916 \times 10^{-3}\ cm.$$ (HAC diameter)

**HAC Reference Air Leakage Rate for HEU Content**

The leakage hole diameter found for the maximum allowable leakage rate for HAC will be used to determine the reference air leakage rate. O-ring seal leakage testing must assure that no leakage is greater than the leakage generated by the hole diameter $D = 5.8916 \times 10^{-3}$ cm. Therefore, the HAC reference air leakage rate ($L_{R, A}$) must be calculated to determine the acceptable test leakage rate for post-HAC leakage testing.

Input data for HAC reference air leakage rate:

$D = 5.8916 \times 10^{-3}$ cm, (From the HAC of transport)
$a = 0.3531$ cm, (Leak path length, 0.139-in. O-ring section diameter)
$P_u = 1.0$ atm, (Upstream pressure)
$P_d = 0.01$ atm, (Downstream pressure)
$T = 298$ K, (Fill gas temperature, 77°F)
$M = 29$ g/g-mol, (Molecular weight of air)
$\mu = 0.0185$ cP. (Viscosity at temperature)

Calculate $P_a$:

$P_a = (P_u + P_d) / 2,$
$= 0.505$ atm, (HAC average pressure)

$F_c = (2.49 \times 10^6) D^4 / (a \mu)$ (cm$^3$/atm-s), (Eq. B3)
$= (2.49 \times 10^6) (5.8916 \times 10^{-3})^4 / [(0.3531) (0.0185)],$
$= (3.8122 \times 10^8) (5.8916 \times 10^{-3})^4,$
$= 4.5930 \times 10^{-1}$ cm$^3$/atm-s,

$F_m = (3.81 \times 10^3) D^3 (T / M)^{.5} / (a P_a)$ (cm$^3$/atm-s), (Eq. B4)
$= (3.81 \times 10^3) (5.8916 \times 10^{-3})^3 (298 / 29)^{.5} / [(0.3531) (0.505)],$
$= (6.8501 \times 10^4) (5.8916 \times 10^{-3})^3,$
$= 1.4008 \times 10^{-2}$ cm$^3$/atm-s,

$L_u = (F_c + F_m) (P_u - P_d) (P_a / P_u)$ (cm$^3$/s), (Eq. B5)
$= (4.5930 \times 10^{-1} + 1.4008 \times 10^{-2})$(cm$^3$/atm-s) $(1.0 - 0.01)$(atm) $(0.505 / 1.0),$
$= (4.7331 \times 10^{-1})$(cm$^3$/atm-s) $(0.49995)$(atm),
$= 2.3663 \times 10^{-1}$ cm$^3$/s.

The HAC reference air leakage rate as defined in ANSI N14.5-1997, Sect. B.3, is the upstream leakage in air.

$L_{RA,Air} = 2.3663 \times 10^{-1}$ ref-cm$^3$/s. (for HEU oxide content)

The same equations can be used to calculate an allowable leakage rate using helium for leak testing.

$M = 4$ g/g-mol, (Molecular weight of helium)
$\mu = 0.0198$ cP, (Viscosity of helium at temperature)

$F_c = (2.49 \times 10^6) D^4 / (a \mu)$ (cm$^3$/atm-s), (Eq. B3)
$= (2.49 \times 10^6) (5.8916 \times 10^{-3}$ cm$)^4 / [(0.3531) (0.0198)],$
$= (3.5619 \times 10^8) (5.8916 \times 10^{-3}$ cm$)^4,$
$= 4.2915 \times 10^{-1}$ cm$^3$/atm-s,

$F_m = (3.81 \times 10^3) D^3 (T / M)^{0.5} / (a P_a)$ (cm$^3$/atm-s), (Eq. B4)
$= (3.81 \times 10^3) (5.8916 \times 10^{-3}$ cm$)^3 (298 / 4)^{.5} / [(0.3531) (0.505)],$
$= (1.8444 \times 10^5) (5.8916 \times 10^{-3}$ cm$)^3,$
$= 3.7718 \times 10^{-2}$ cm$^3$/atm-s,

$L_u = (F_c + F_m) (P_u - P_d) (P_a / P_u)$ (cm$^3$/s), (Eq. B5)
$= (4.2915 \times 10^{-1} + 3.7718 \times 10^{-2})$(cm$^3$/atm-s) $(1.0 - 0.01)$(atm) $(0.505 / 1.0),$
$= (4.6686 \times 10^{-1})$(cm$^3$/atm-s) $(0.49995)$(atm),
$= 2.3341 \times 10^{-1}$ cm$^3$/s.

The allowable leakage rate using helium for leak testing for HAC is:

$L_{RA, He} = 2.3341 \times 10^{-1}$ cm$^3$/s. (HAC helium test value)

**Determination of the Leakage Test Procedure Requirements for the HEU Content Transported by Air**

The International Atomic Energy Agency (IAEA) TS-R-1, Paragraph 619, states: "Packages containing radioactive material, to be transported by air, shall be capable of withstanding, without leakage, an internal pressure that produces a pressure differential of not less than the maximum normal operating pressure plus 95 kPa." As shown in Table 2.20, the maximum normal operating pressure (MNOP) was predicted to be 31.25 psia. As shown in Appendix 3.5.1, Table 9, the MNOP determined for air transport is 28.778 psia and is bounded by the value determined for ground transportation. Therefore, the MNOP of 31.25 psia is used in the following analysis. To provide the necessary pressure differential, the following calculations will use an upstream pressure of 45.03 psia and a downstream pressure of 0 psia. Also, the following calculations will examine the most conservative effects of a fully loaded containment vessel with an HEU mass of 35.2 kg. The smallest allowable leakage values are shown in Tables 4.5 and 4.7. The $A_2$ value and the maximum content activity-to-$A_2$ value ratio for this mixture were calculated for several different decay times (Table 6, Appendix 4.5.1). As calculated in Appendix 4.5.1, the $A_2$ value and the maximum content activity-to-$A_2$ ratio used to qualify this package occur at ~70 years of decay and are $1.5245 \times 10^{-4}$ TBq ($4.1203 \times 10^{-3}$ Ci) and 4,752.8, respectively. These values are used to determine the leakage test procedural requirements when packaging any convenience cans/contents arrangements in the ES-3100 package. The convenience cans/contents are sealed inside the containment vessel in an environmentally controlled area.

The following analysis determines the maximum allowable O-ring seal air reference leakage rate for NCT during air transport. The ANSI N14.5-1997 recommended method using a straight circular tube to model the leakage path is applied. Using this "standard" leakage hole model permits the calculation of equivalent reference leakage rates from which leak-test requirements can be established. Viscosity data for air and helium used in the following analyses were obtained from curve fitting routines at specific temperatures based on viscosity data for air (*CRC Handbook of Chemistry and Physics*) and helium (NBS Technical Note 631). To also comply with 49 CFR 173.410(i)(2), the range of temperature evaluated will be from −40 to 55°C (ambient temperature). According to TS-G-1.1, Paragraph 619.3, the evaluation at an ambient temperature of 55°C does not consider insolation; however, self-heating of the package is taken into account. An analysis has been conducted, and results for these conditions are shown in Table 3.14. The maximum temperature predicted for the containment vessel was 63.39°C (146.11°F). This temperature will be used in the following analysis as the maximum gas temperature ($T_{NL}$).

$L_N$ and $L_A$ correspond to the upstream volumetric leakage rate ($L_u$) at the upstream pressure ($P_u$).

$$L_N = 2.2878 \times 10^{-4} \text{ cm}^3/\text{s},$$
$$L_A = 1.3578 \text{ cm}^3/\text{s}.$$

Find the maximum pressure and a temperature in the containment vessel from -40 to 55°C:

Converting the temperature to Kelvin:

$$T = 273.15 + T\ (°C),$$
$$= 273.15 + 5 / 9\ (°F - 32)\ (K),$$

$T_{NL}$ = 273.15 + 5 / 9 (−40°F − 32) (K), [T = −40°F (−40°C)]
= 233.15 K, (NCT low limit)

$T_{NH}$ = 273.15 + 5 / 9 (146.11°F − 32) (K), [T = 146.11°F (63.39°C)]
= 336.54 K, (NCT high limit)

Converting the pressures from psia to atmospheres:

$P_N$ = P (psia) / 14.696 (psia/atm), [where P is the pressure in Sect. 3.3.2 plus 13.78 psia (95 kPa)]
= 45.03 (psia) / 14.696 (psia/atm), (rounded up for NCT)
= 3.0641 atm,

**NCT Leakage Hole Diameter for the HEU Content during Air Transport at the Lower Temperature Limit of TS-G-1.1**

The following calculations determine the leakage hole diameter that generates the maximum allowable leakage rate during NCT. To keep these calculations conservative, the maximum values for temperature and pressure were used as steady-state conditions for NCT as dictated for air transport.

Input data for NCT at the lower temperature limit with air fill gas:

$L_N$ = $2.2878 \times 10^{-4}$ $cm^3/s$, (Maximum upstream leakage)
$P_u$ = 3.0641 atm, (Upstream pressure = 45.03 psia)
$P_d$ = 0 atm, [Downstream pressure = 0 psia, per 10 CFR 71.71(3)]
a = 0.3531 cm, (Leak path length, 0.139-in. O-ring section diameter)
T = 233.15 K, (Fill gas temperature = −40°F)
μ = 0.01518 cP, (Viscosity at temperature)
M = 29 g/g-mol. (Molecular weight of fill gas)

The average pressure is:

$P_a$ = $(P_u + P_d) / 2$,
= (3.0641 + 0) / 2,
= 1.5320 atm. (Average pressure during NCT)

According to ANSI N14.5-1997, the flow leakage hole diameter is unknown. Therefore, the mass-like leakage flow rate must be calculated to calculate the average leakage flow rate.

Q is the mass-like leakage for flow using the upstream leakage, $L_u$, and pressure, $P_u$:

Q = $P_u L_u$, (Eq. B1)
$L_u$ = $L_N$, (NCT leakage)

Q = (3.0641)(atm) $(2.2878 \times 10^{-4})(cm^3/s)$,
= $7.0100 \times 10^{-4}$ atm-$cm^3/s$, (NCT mass-like leakage rate)

Q = $P_a L_a$, (Eq. B1)

$$L_a = Q / P_a,$$
$$= 7.0099 \times 10^{-4} \text{ (atm-cm}^3\text{/s) / (1.5320) (atm)},$$
$$= 4.5755 \times 10^{-4} \text{ cm}^3\text{/s.} \quad \text{(NCT average leakage rate)}$$

Solve equations B2–B4 from ANSI N14.5-1997:

$$L_a = (F_c + F_m) (P_u - P_d) \text{ cm}^3\text{/s,} \quad \text{(Eq. B2)}$$
$$= (F_c + F_m) (3.0641 - 0.0000),$$
$$= (3.0641) (F_c + F_m) \text{ cm}^3\text{/s,}$$

$$F_c = (2.49 \times 10^6) D^4 / (a \mu) \text{ (cm}^3\text{/atm-s),} \quad \text{(Eq. B3)}$$
$$= (2.49 \times 10^6) D^4 / [(0.3531) (0.01518)],$$
$$= (4.6459 \times 10^8) D^4 \text{ cm}^3\text{/atm-s,}$$

$$F_m = (3.81 \times 10^3) D^3 (T / M)^{.5} / (a P_a) \text{ (cm}^3\text{/atm-s),} \quad \text{(Eq. B4)}$$
$$= (3.81 \times 10^3) D^3 (233.15 / 29)^{.5} / [(0.3531) (1.5320)],$$
$$= (1.9972 \times 10^4) D^3 \text{ cm}^3\text{/atm-s.}$$

From the mass-like leakage calculation:

$$L_a = 4.5755 \times 10^{-4} \text{ cm}^3\text{/s.} \quad \text{(NCT average leakage rate)}$$

Find the leakage hole diameter that sets:

$$L_2 = L_a.$$

Using the equations:

$$L_2 = (3.0641) (F_c + F_m) \text{ cm}^3\text{/s,}$$
$$F_c = (4.6469 \times 10^8) D^4 \text{ cm}^3\text{/atm-s,}$$
$$F_m = (1.9972 \times 10^4) D^3 \text{ cm}^3\text{/atm-s.}$$

To get a better guess on a new D, use:

$$D = D_2 (L_a / L_2)^{0.252}.$$

Now a guess must be made for $D_2$ to solve Eq. B2 for NCT:

$$D_2 = 0.001 \text{ cm, and solve for } L_a = 4.5755 \times 10^{-4} \text{ cm}^3\text{/s.} \quad \text{(NCT average leakage rate)}$$

| **Diameter** | **$F_c$** | **$F_m$** | **$L_2$** | **$L_a / L_2$** |
|---|---|---|---|---|
| 1.0000E-03 | 4.6459E-04 | 1.9972E-05 | 1.4847E-03 | 3.0817E-01 |
| 7.4332E-04 | 1.4183E-04 | 8.2025E-06 | 4.5971E-04 | 9.9530E-01 |
| 7.4243E-04 | 1.4116E-04 | 8.1733E-06 | 4.5756E-04 | 9.9997E-01 |
| 7.4243E-04 | 1.4115E-04 | 8.1731E-06 | 4.5755E-04 | 1.0000E+00 |

The NCT leakage hole diameter for the HEU oxide content:

$D = 7.4243 \times 10^{-4}$ cm. (NCT diameter)

**NCT Reference Air Leakage Rate for HEU Content Transported by Air**

The leakage hole diameter found for the maximum allowable leakage rate for NCT will be used to determine the reference air leakage rate. O-ring seal leakage testing must ensure that no leakage is greater than the leakage generated by the hole diameter $D = 7.4243 \times 10^{-4}$ cm. Therefore, the NCT reference leakage flow rate ($L_{R, N}$) must be calculated to determine the allowable test leakage rate.

Input data for NCT reference air leakage rate:

$D = 7.4243 \times 10^{-4}$ cm, (From NCT)
$a = 0.3531$ cm, (Leak path length, 0.139-in. O-ring section diameter)
$P_u = 1.0$ atm, (Upstream pressure)
$P_d = 0.01$ atm, (Downstream pressure)
$T = 298$ K, (Fill gas temperature, 77°F)
$M = 29$ g/g-mol, (Molecular weight of air)
$\mu = 0.0185$ cP, (Viscosity of air at reference temperature)

Calculate $P_a$:

$P_a = (P_u + P_d) / 2,$
$= (1.0 + 0.01) /2,$
$= 0.505$ atm, (NCT average pressure)

$F_c = (2.49 \times 10^6) D^4 / (a \mu)$ (cm$^3$/atm-s), (Eq. B3)
$= (2.49 \times 10^6) (7.4243 \times 10^{-4})^4 / [(0.3531) (0.0185)],$
$= (3.8122 \times 10^8) (7.4243 \times 10^{-4})^4,$
$= 1.1583 \times 10^{-4}$ cm$^3$/atm-s,

$F_m = (3.81 \times 10^3) D^3 (T / M)^{.5} / (a P_a)$ (cm$^3$/atm-s), (Eq. B4)
$= (3.81 \times 10^3) (7.4243 \times 10^{-4})^3 (298 / 29)^{.5} / [(0.3531) (0.505)],$
$= (6.8501 \times 10^4) (7.4243 \times 10^{-4})^3,$
$= 2.8033 \times 10^{-5}$ cm$^3$/atm-s,

$L_u = (F_c + F_m) (P_u - P_d) (P_a / P_u)$ (cm$^3$/s), (Eq. B5)
$= (1.1583 \times 10^{-4} + 2.8033 \times 10^{-5})$ (cm$^3$/atm-s) $(1.0 - 0.01)$ (atm) $(0.505 / 1.0),$
$= (1.4386 \times 10^{-4})$ (cm$^3$/atm-s) (0.49995) (atm),
$= 7.1922 \times 10^{-5}$ cm$^3$/s.

The reference air leakage rate as defined in ANSI N14.5-1997, Sect. B.3, is the upstream leakage in air.

$L_{RN,Air} = 7.1922 \times 10^{-5}$ ref-cm$^3$/s. (For HEU oxide content)

The same equations can be used to calculate an allowable leakage rate using helium for leak testing.

$M = 4$ g/g-mol, (Molecular weight of helium)

$\mu = 0.0198$ cP, (Viscosity of helium at temperature)

$F_c = (2.49 \times 10^6)\, D^4 / (a\, \mu)$ (cm$^3$/atm-s), (Eq. B3)

$= (2.49 \times 10^6)\, (7.4243 \times 10^{-4})^4 / [(0.3531)\, (0.0198)]$,

$= (3.5619 \times 10^8)\, (7.4243 \times 10^{-4})^4$,

$= 1.0822 \times 10^{-4}$ cm$^3$/atm-s,

$F_m = (3.81 \times 10^3)\, D^3\, (T / M)^{.5} / (a\, P_a)$ (cm$^3$/atm-s), (Eq. B4)

$= (3.81 \times 10^3)\, (7.4243 \times 10^{-4})^3\, (298 / 4)^{.5} / [(0.3531)\, (0.505)]$,

$= (1.8444 \times 10^5)\, (7.4243 \times 10^{-4})^3$,

$= 7.5480 \times 10^{-5}$ cm$^3$/atm-s,

$L_u = (F_c + F_m)\, (P_u - P_d)\, (P_a / P_u)$ (cm$^3$/s), (Eq. B5)

$= (1.0822 \times 10^{-4} + 7.5480 \times 10^{-5})$ (cm$^3$/atm-s) $(1.0 - 0.01)$ (atm) $(0.505 / 1.0)$,

$= (1.8379 \times 10^{-4})$ (cm$^3$/atm-s) (0.49995) (atm),

$= 9.1841 \times 10^{-5}$ cm$^3$/s.

The allowable leakage rate using helium for leak testing is:

$L_{RN,\,He} = 9.1841 \times 10^{-5}$ cm$^3$/s.

**NCT Leakage Hole Diameter for the HEU Content during Air Transport at the Upper Temperature Limit [146.11°F (63.39°C)] per TS-G-1.1**

The following calculations determine the leakage hole diameter that generates the maximum allowable leakage rate during NCT. To keep these calculations conservative, the maximum values for temperature and pressure were used as steady-state conditions for NCT.

Input data for NCT at the upper temperature limit with air fill gas:

$L_N = 2.2878 \times 10^{-4}$ cm$^3$/s, (Maximum upstream leakage)

$P_u = 3.0641$ atm, (Upstream pressure = 45.03 psia)

$P_d = 0$ atm, [Downstream pressure = 0 psia, per 10 CFR 71.71(3)]

$a = 0.3531$ cm, (Leak path length, 0.139-in. O-ring section diameter)

$T = 336.54$ K, [Fill gas temperature = 146.11°F (63.39°C)]

$\mu = 0.02031$ cP, (Viscosity at temperature)

$M = 29$ g/g-mol. (Molecular weight of fill gas)

The average pressure is:

$P_a = (P_u + P_d) / 2$,

$= (3.0641 + 0.0000) / 2$,

$= 1.5320$ atm. (Average pressure during NCT)

According to ANSI N14.5-1997, the flow leakage hole diameter is unknown. Therefore, the mass-like leakage flow rate must be calculated to calculate the average leakage flow rate.

Q is the mass-like leakage for flow using the upstream leakage, $L_u$, and pressure, $P_u$:

$$Q = P_u L_u, \quad \text{(Eq. B1)}$$
$$L_u = L_N, \quad \text{(NCT leakage)}$$

$$Q = (3.0641)\ (\text{atm})\ (2.2878 \times 10^{-4})\ (\text{cm}^3/\text{s}),$$
$$= 7.0099 \times 10^{-4}\ \text{atm-cm}^3/\text{s}, \quad \text{(NCT mass-like leakage rate)}$$

$$Q = P_a L_a, \quad \text{(Eq. B1)}$$

$$L_a = Q / P_a,$$
$$= 7.0099 \times 10^{-4}\ (\text{atm-cm}^3/\text{s}) / (1.5320)\ (\text{atm}),$$
$$= 4.5755 \times 10^{-4}\ \text{cm}^3/\text{s}. \quad \text{(NCT average leakage rate)}$$

Solve Eqs. B2–B4 from ANSI N14.5-1997:

$$L_a = (F_c + F_m)\ (P_u - P_d)\ \text{cm}^3/\text{s}, \quad \text{(Eq. B2)}$$
$$= (F_c + F_m)\ (3.0641 - 0),$$
$$= (3.0641)\ (F_c + F_m)\ \text{cm}^3/\text{s},$$

$$F_c = (2.49 \times 10^6)\ D^4 / (a\ \mu)\ (\text{cm}^3/\text{atm-s}), \quad \text{(Eq. B3)}$$
$$= (2.49 \times 10^6)\ D^4 / [(0.3531)\ (0.02031)],$$
$$= (3.4723 \times 10^8)\ D^4\ \text{cm}^3/\text{atm-s},$$

$$F_m = (3.81 \times 10^3)\ D^3\ (T / M)^{.5} / (a\ P_a)\ (\text{cm}^3/\text{atm-s}), \quad \text{(Eq. B4)}$$
$$= (3.81 \times 10^3)\ D^3\ (336.54 / 29)^{.5} / [(0.3531)\ (1.5320)],$$
$$= (2.3995 \times 10^4)\ D^3\ \text{cm}^3/\text{atm-s}.$$

From the mass-like leakage calculation:

$$L_a = 4.5755 \times 10^{-4}\ \text{cm}^3/\text{s}. \quad \text{(NCT average leakage rate)}$$

Find the leakage hole diameter that sets:

$$L_2 = L_a.$$

Using the equations:

$$L_2 = (3.0641)\ (F_c + F_m)\ \text{cm}^3/\text{s},$$
$$F_c = (3.4723 \times 10^8)\ D^4\ \text{cm}^3/\text{atm-s},$$
$$F_m = (2.3995 \times 10^4)\ D^3\ \text{cm}^3/\text{atm-s}.$$

To get a better guess on a new D, use:

$$D = D_2\ (L_a / L_2)^{0.252}.$$

Now a guess must be made for $D_2$ to solve Eq. B2 for NCT:

$D_2$ = 0.001 cm, and solve for $L_a = 4.5755 \times 10^{-4}$ cm$^3$/s. (NCT average leakage rate)

| Diameter | $F_c$ | $F_m$ | $L_2$ | $L_a / L_2$ |
|---|---|---|---|---|
| 1.0000E-03 | 3.4723E-04 | 2.3995E-05 | 1.1375E-03 | 4.0225E-01 |
| 7.9494E-04 | 1.3866E-04 | 1.2054E-05 | 4.6180E-04 | 9.9079E-01 |
| 7.9309E-04 | 1.3737E-04 | 1.1970E-05 | 4.5760E-04 | 9.9989E-01 |
| 7.9307E-04 | 1.3736E-04 | 1.1969E-05 | 4.5755E-04 | 1.0000E+00 |

The NCT leakage hole diameter for the HEU oxide content:

$D = 7.9307 \times 10^{-4}$ cm. (NCT diameter)

**NCT Reference Air Leakage Rate for HEU Content Transported by Air**

The leakage hole diameter found for the maximum allowable leakage rate for NCT will be used to determine the reference air leakage rate. O-ring seal leakage testing must ensure that no leakage is greater than the leakage generated by the hole diameter $D = 7.9307 \times 10^{-4}$ cm. Therefore, the NCT reference leakage flow rate ($L_{R, N}$) must be calculated to determine the allowable test leakage rate.

Input data for NCT reference air leakage rate:

$D = 7.9307 \times 10^{-4}$ cm, (From NCT)
$a = 0.3531$ cm, (Leak path length, 0.139-in. O-ring section diameter)
$P_u = 1.0$ atm, (Upstream pressure)
$P_d = 0.01$ atm, (Downstream pressure)
$T = 298$ K, (Fill gas temperature, 77°F)
$M = 29$ g/g-mol, (Molecular weight of air)
$\mu = 0.0185$ cP, (Viscosity of air at reference temperature)

Calculate $P_a$:

$P_a = (P_u + P_d) / 2$,
$= (1.0 + 0.01) /2$,
$= 0.505$ atm, (NCT average pressure)

$F_c = (2.49 \times 10^6) D^4 / (a \mu)$ (cm$^3$/atm-s), (Eq. B3)
$= (2.49 \times 10^6) (7.9307 \times 10^{-4})^4 / [(0.3531) (0.0185)]$,
$= (3.8122 \times 10^8) (7.9307 \times 10^{-4})^4$,
$= 1.5080 \times 10^{-4}$ cm$^3$/atm-s,

$F_m = (3.81 \times 10^3) D^3 (T / M)^{.5} / (a P_a)$ (cm$^3$/atm-s), (Eq. B4)
$= (3.81 \times 10^3) (7.8970 \times 10^{-4})^3 (298 / 29)^{.5} / [(0.3531) (0.505)]$,
$= (6.8501 \times 10^4) (7.8970 \times 10^{-4})^3$,
$= 3.4168 \times 10^{-5}$ cm$^3$/atm-s,

$$L_u = (F_c + F_m)(P_u - P_d)(P_a / P_u)\ (cm^3/s), \quad \text{(Eq. B5)}$$
$$= (1.5080 \times 10^{-4} + 3.4168 \times 10^{-5})\ (cm^3/atm\text{-}s)\ (1.0 - 0.01)\ (atm)\ (0.505 / 1.0),$$
$$= (1.8497 \times 10^{-4})\ (cm^3/atm\text{-}s)\ (0.49995)\ (atm),$$
$$= 9.2475 \times 10^{-5}\ cm^3/s.$$

The reference air leakage rate as defined in ANSI N14.5-1997, Sect. B.3, is the upstream leakage in air.

$$L_{RN,Air} = 9.2475 \times 10^{-5}\ ref\text{-}cm^3/s. \quad \text{(For HEU oxide content)}$$

The same equations can be used to calculate an allowable leakage rate using helium for leak testing.

$$M = 4\ g/g\text{-}mol, \quad \text{(Molecular weight of helium)}$$
$$\mu = 0.0198\ cP, \quad \text{(Viscosity of helium at temperature)}$$

$$F_c = (2.49 \times 10^6)\ D^4 / (a\ \mu)\ (cm^3/atm\text{-}s), \quad \text{(Eq. B3)}$$
$$= (2.49 \times 10^6)\ (7.9307 \times 10^{-4})^4 / [(0.3531)\ (0.0198)],$$
$$= (3.5619 \times 10^8)\ (7.9307 \times 10^{-4})^4,$$
$$= 1.4090 \times 10^{-4}\ cm^3/atm\text{-}s,$$

$$F_m = (3.81 \times 10^3)\ D^3\ (T / M)^{.5} / (a\ P_a)\ (cm^3/atm\text{-}s), \quad \text{(Eq. B4)}$$
$$= (3.81 \times 10^3)\ (7.9307 \times 10^{-4})^3\ (298 / 4)^{.5} / [(0.3531)\ (0.505)],$$
$$= (1.8444 \times 10^5)\ (7.9307 \times 10^{-4})^3,$$
$$= 9.2000 \times 10^{-5}\ cm^3/atm\text{-}s,$$

$$L_u = (F_c + F_m)(P_u - P_d)(P_a / P_u)\ (cm^3/s), \quad \text{(Eq. B5)}$$
$$= (1.4090 \times 10^{-4} + 9.2000 \times 10^{-5})\ (cm^3/atm\text{-}s)\ (1.0 - 0.01)\ (atm)\ (0.505 / 1.0),$$
$$= (2.3290 \times 10^{-4})\ (cm^3/atm\text{-}s)\ (0.49995)\ (atm),$$
$$= 1.1644 \times 10^{-4}\ cm^3/s.$$

The allowable leakage rate using helium for leak testing is:

$$L_{RN,\,He} = 1.1644 \times 10^{-4}\ cm^3/s.$$

The design verification tests were conducted following compliance tests in accordance with 10 CFR 71.71 and 71.73. The effectiveness of this closure system has been demonstrated by the NCT and HAC tests, which show that the complete containment system, including welds and O-ring seals, meet the leaktight criterion as defined in ANSI N14.5-1997 after the conclusion of the test series documented in ORNL/NTRC-013 and ORNL/NTRC-047. This leaktight criterion is substantially below the above calculated results for air transport. Therefore, the requirements of 10 CFR Part 71.51(a)(1) are satisfied.

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# 5. SHIELDING EVALUATION

This section describes the shielding evaluation performed for the shipment of up to 36 kg of highly enriched uranium (HEU) metal or 24 kg of HEU oxide powder in the ES-3100 shipping package. The objective of this evaluation is to demonstrate, for both Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC), compliance of this package with the performance requirements specified in Title 10 Code of Federal Regulations (CFR) 71 and 49 CFR 173.

## 5.1 DESCRIPTION OF SHIELDING DESIGN

### 5.1.1 Design Features

The ES-3100 package for NCT consists of stainless-steel convenience cans loaded with HEU material, can spacer assemblies to support and position the convenience cans, the ES-3100 containment vessel, and an insulation-filled drum as shown in Appendix 1.3.1. None of the package materials are specifically designed for shielding gamma rays (photons), the primary contributor to external package dose rates. For HAC, it is assumed that the containment vessel and content remain intact but that all exterior packaging materials are removed. The geometry of the shielding analysis model is a conservative, cylindrical representation of the package. Two sets of contents have been investigated for the shielding analysis. These are 36 kg of HEU metal and 24 kg of HEU oxide powder. The analyses of these models have been performed such that the results and conclusions cover other proposed contents in an equivalent or conservative manner. For the source calculation, the uranium is enriched at 92% $^{235}U$ and is assumed to contain 0.6% $^{233}U$, 2.5% $^{237}Np$, 40-ppb (parts per billion) $^{232}U$, and 800-ppm (parts per million) weapons-grade plutonium to represent all other transuranic trace elements. The value of 800-ppm weapons-grade plutonium applies to ground transport only. Contents for air transport are limited to 40-ppm weapons-grade plutonium. There are two sources of the transuranic contamination in this HEU. First, much of this uranium originated from recycled material. Second, some uranium had plutonium components that were removed by machining or other processes, but left contamination. This contamination became mixed with the uranium as it was recast and used for other purposes.

### 5.1.2 Codes and Standards

Dose rates are calculated by converting the photon and neutron fluxes using the American National Standards Institute (ANSI) and American Nuclear Society (ANS) conversion factors (ANSI/ANS-6.11-1977).

### 5.1.3 Summary Table of Maximum Radiation Levels

The results of these shielding model evaluations, summarized in Tables 5.1 and 5.2, are the calculated dose rates at the locations indicated. The uncertainty associated with the results is one standard deviation of the mean (expressed as a percentage of the mean) of the Monte Carlo calculated results. As shown from the dose rates in the tables and the discussion in Sect. 5.4, the shielding evaluation demonstrates that the package meets all dose-rate limits for both NCT and HAC for all proposed contents.

**Table 5.1. Calculated external dose rates for the ES-3100 package with 36 kg of HEU metal contents**

**mSv/h (mrem/h) [a]**

| | Drum surface | | | One meter from surface [b] | | |
|---|---|---|---|---|---|---|
| | **Side** | **Top** | **Bottom** | **Side** | **Top** | **Bottom** |
| | | | **NCT** | | | |
| Photon | 0.8266 (82.66) ± 0.4% | 0.3750 (37.50) ± 0.5% | 0.8395 (83.95) ± 0.5% | 0.0568 (5.68) ± 0.1% | 0.01349 (1.349) ± 0.2% | 0.01470 (1.470) ± 0.2% |
| Neutron [c] | 0.0111 (1.11) ± 1.0% | 0.0009 (0.0959) ± 1.2% | 0.0249 (2.49) ± 1.0% | 0.00039 (0.039) ± 1.0% | 0.00017 (0.017) ± 1.0% | 0.00051 (0.051) ± 3.2% |
| Total | 0.8378 (83.78) ± 0.4% | 0.3759 (37.59) ± 0.5% | 0.8644 (86.44) ± 0.5% | 0.05717 (5.717) ± 0.1% [d] | 0.01366 (1.366) ± 0.2% | 0.01521 (1.521) ± 0.9% |
| Limit [e] | 2 (200) | 2 (200) | 2 (200) | 0.1 (10) | 0.1 (10) | 0.1 (10) |
| | | | **HAC** | | | |
| Photon | NA [f] | NA | NA | 0.1226 (12.26) ± 0.1% | 0.01491 (1.491) ± 0.4% | 0.01995 (1.995) ± 0.2% |
| Neutron [c] | NA | NA | NA | 0.00031 (0.031) ± 0.6% | 0.00008 (0.008) ±0.6% | 0.00021 (0.021) ± 0.6% |
| Total | NA | NA | NA | 0.1229 (12.29) ± 0.1% | 0.01499 (1.499) ± 0.4% | 0.02017 (2.017) ± 0.2% |
| Limit [g] | NA | NA | NA | 10 (1000) | 10 (1000) | 10 (1000) |

[a] MCNP5 Monte Carlo code results (LA-UR-03-1987).
[b] Drum for NCT and containment vessel for HAC.
[c] Includes secondary photon dose rate (<1% of neutron dose rates).
[d] The radiation shielding transport index is 5.8.
[e] 10 CFR 71.47(a) and 49 CFR 173.441(a).
[f] Not applicable.
[g] 10 CFR 71.51(a)(2).

**Table 5.2. Calculated external dose rates for the ES-3100 package with 24 kg of HEU oxide contents**

**mSv/h (mrem/h) [a]**

| | Drum surface | | | One meter from surface [b] | | |
|---|---|---|---|---|---|---|
| | **Side** | **Top** | **Bottom** | **Side [c]** | **Top** | **Bottom** |
| | | | **NCT** | | | |
| Photon | 0.7105 (71.17) ± 0.8% | 0.1345 (13.45) ± 0.6% | 0.5640 (56.40) ± 0.5% | 0.04868 (4.868) ± 0.1% | 0.01059 (1.059) ± 0.2% | 0.01334 (1.334) ± 0.2% |
| Neutron [d] | 0.00115 (0.115) ± 0.2% | 0.00094 (0.094) ± 0.4% | 0.00022 (0.022) ± 0.2% | 0.00005 (0.005) ± 0.1% | 0.00002 (0.002) ± 0.1% | 0.00005 (0.005) ± 0.1% |
| Total | 0.7117 (71.17) ± 0.8% | 0.1346 (13.46) ± 0.6% | 0.5663 (56.63) ± 0.5% | 0.04872 (4.872) ± 0.1% [e] | 0.01061 (1.061) ± 0.2% | 0.01339 (1.339) ± 0.2% |
| Limit [f] | 2 (200) | 2 (200) | 2 (200) | 0.1 (10) | 0.1 (10) | 0.1 (10) |
| | | | **HAC** | | | |
| Photon | NA [g] | NA | NA | 0.10566 (10.566) ± 0.1% | 0.01226 (1.226) ± 0.3% | 0.01643 (1.643) ± 0.3% |
| Neutron [d] | NA | NA | NA | 0.00006 (0.006) ± 0.1% | 0.00001 (0.001) ± 0.2% | 0.00003 (0.003) ± 0.2% |
| Total | NA | NA | NA | 0.10571 (10.571) ± 0.1% | 0.01227 (1.227) ± 0.3% | 0.01646 (1.646) ± 0.3% |
| Limit [h] | NA | NA | NA | 10 (1000) | 10 (1000) | 10 (1000) |

[a] MCNP5 Monte Carlo code results (LA-UR-03-1987).
[b] Drum for NCT and containment vessel for HAC.
[c] Increased by 14% to bound shell model dose rates.
[d] Includes secondary photon dose rate (<1% of neutron dose rates).
[e] The radiation shielding transport index is 4.9.
[f] 10 CFR 71.47(a) and 49 CFR 173.441(a).
[g] Not applicable.
[h] 10 CFR 71.51(a)(2).

## 5.2 SOURCE SPECIFICATION

The source for the calculated dose rates is from the decay and fission of the radioactive isotope contents. The isotopic content used in the shielding calculations is shown in Table 5.3. This composition was chosen to represent all proposed package contents described in Sect. 1.2.2. The uranium metal source is assumed to be the same as that for the oxides per unit HEU mass. Details of the source specifications and use in the dose rate calculations are given in the Sect. 5 appendices.

### 5.2.1 Gamma Source

The photon sources are calculated by the Standardized Computer Analysis for Licensing Evaluation (SCALE) module of ORIGEN-S (NUREG/CR-0200) as a function of photon energy (18 groups) and decay time. It is shown that the photon spectra around 10.5 years decay time provide maximum photon dose rates, and the spectra are given in Table 5.4. The production of secondary photons and bremsstrahlung photons is calculated as part of the shielding evaluation. The primary contribution to the dose rates in Tables 5.1 and 5.2 is from decay of the $^{232}U$ isotope (this applies to any mix of the other uranium isotopes in Table 5.3). In Table 5.4, Group 6 photons are from the decay chain of $^{232}U$. Group 18 photons were omitted from the source for the dose rate calculation due to negligible contribution from photons at these energies.

### 5.2.2 Neutron Source

The neutron spectra given in Table 5.5 are generated using ORIGEN-S as a function of neutron energy (the top 9 of 27 groups) and decay time. It is shown that the neutron spectra around 15.0 years decay time provide maximum neutron dose rates. Neutron source from the spontaneous fission and the (alpha, n) are included in Table 5.5 spectra. Induced fission neutrons and secondary photons are included in the dose rate calculations. Oxygen was not included in the uranium oxide source calculation, but the neutron source includes ($\alpha$, n) neutrons from the $UO_2$ default option in the ORIGEN-S code (NUREG/CR-0200). The production of neutrons from subcritical multiplication is calculated as part of the shielding evaluation by using the default option (i.e., the absence of the NONU card in the MCNP input file). If the NONU card is not used, all cells are given their regular treatment of real fission. The neutrons are captured by the fissile and fissionable materials producing neutron-induced fissions.

## 5.3 SHIELDING MODEL

Three dimensional geometric models are created to calculate the dose rates external to the ES-3100 shipping package when loaded with each of the configurations outlined in Sect. 5.3.1. The shielding model of the ES-3100 package is represented in the MCNP Monte Carlo radiation transport code to perform the photon and neutron transport and dose rate calculations (LA-UR-03-1987).

**Table 5.3. Radioisotope specification for all ES-3100 package analysis source calculations with HEU content and other nuclides per HEU unit weight**

| Isotope | wt % |
|---|---|
| $^{232}U$ | 0.000004 |
| $^{233}U$ | 0.600000 |
| $^{234}U$ | 2.000000 |
| $^{235}U$ | 92.000000 |
| $^{236}U$ | 1.000000 |
| $^{238}U$ | 4.399996 |
| $^{237}Np$ | 2.500000 |
| Pu [a] | 0.080000 |

[a] Nominal weapons-grade at 800-ppm plutonium by weight—see Appendix 5.5.1.

**Table 5.4. Photon source for one gram of HEU for all contents [a]**

| Group number | Energy range (MeV) | Source (photons/s) |
|---|---|---|
| 1 | 10.00–8.00 | $4.387 \times 10^{-5}$ |
| 2 | 8.00–6.50 | $2.130 \times 10^{-4}$ |
| 3 | 6.50–5.00 | $1.134 \times 10^{-3}$ |
| 4 | 5.00–4.00 | $2.958 \times 10^{-3}$ |
| 5 | 4.00–3.00 | $9.555 \times 10^{-3}$ |
| 6 | 3.00–2.50 | $1.005 \times 10^{+4}$ |
| 7 | 2.50–2.00 | $1.156 \times 10^{-1}$ |
| 8 | 2.00–1.66 | $5.227 \times 10^{+1}$ |
| 9 | 1.66–1.33 | $6.258 \times 10^{+2}$ |
| 10 | 1.33–1.00 | $2.224 \times 10^{+2}$ |
| 11 | 1.00–0.80 | $1.513 \times 10^{+3}$ |
| 12 | 0.80–0.60 | $2.755 \times 10^{+3}$ |
| 13 | 0.60–0.40 | $2.696 \times 10^{+4}$ |
| 14 | 0.40–0.30 | $2.830 \times 10^{+5}$ |
| 15 | 0.30–0.20 | $5.114 \times 10^{+4}$ |
| 16 | 0.20–0.10 | $1.293 \times 10^{+5}$ |
| 17 | 0.10–0.05 | $5.553 \times 10^{+5}$ |
| 18 [b] | 0.05–0.01 | - |
| **Total** | | **$1.061 \times 10^{+6}$** |

[a] ORIGEN-S code results at 10½ years decay.
[b] Omitted in the dose rate calculations.

**Table 5.5. Neutron source for one gram of HEU for all contents [a]**

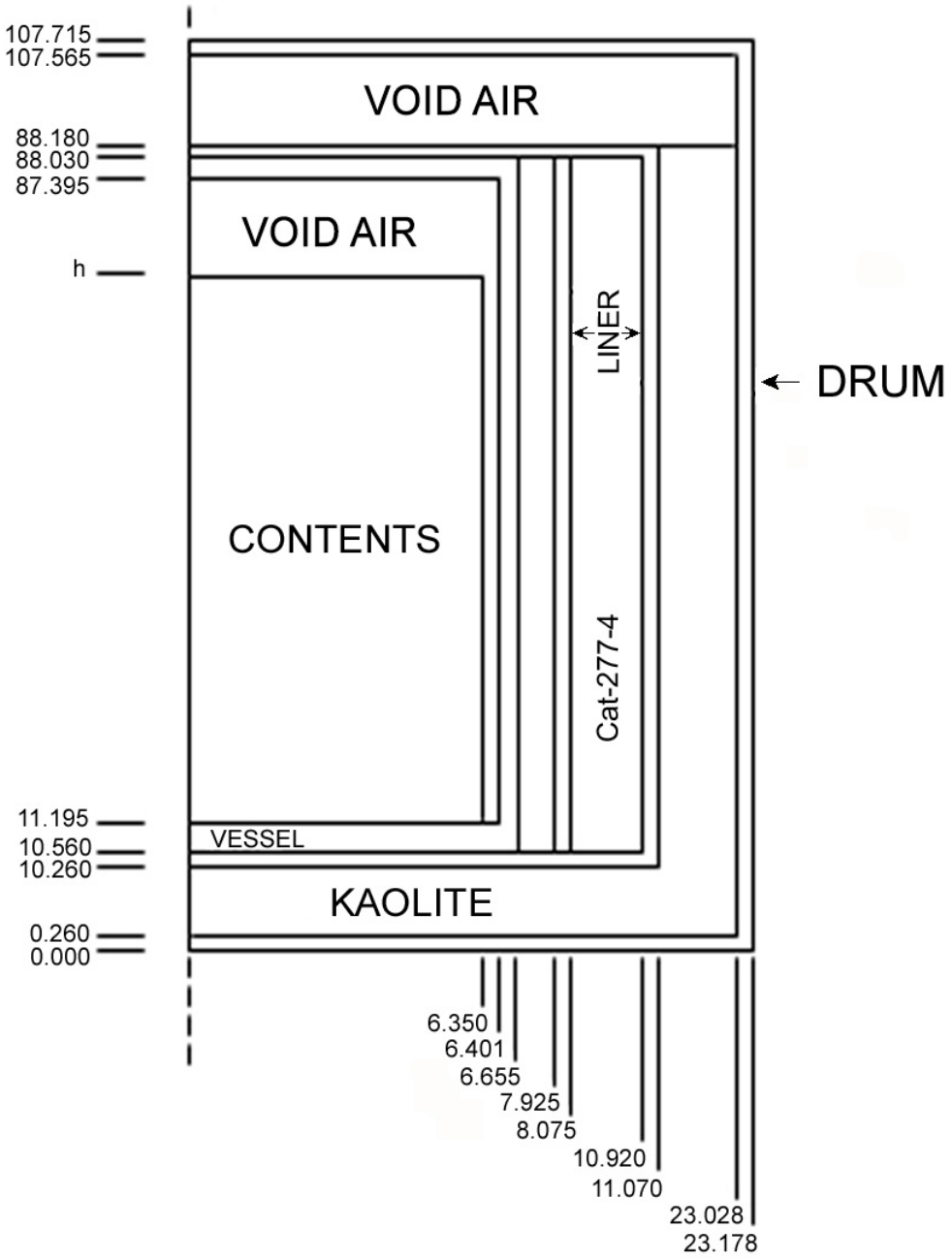
| Group number | Energy range (MeV) | Source in uranium metal and oxide (neutrons/s) |
|---|---|---|
| 1 | $2.00 \times 10^{+1} – 6.43 \times 10^{+0}$ | $6.994 \times 10^{-4}$ |
| 2 | $6.43 \times 10^{+0} – 3.00 \times 10^{+0}$ | $3.432 \times 10^{-2}$ |
| 3 | $3.00 \times 10^{+0} – 1.85 \times 10^{+0}$ | $1.002 \times 10^{-1}$ |
| 4 | $1.85 \times 10^{+0} – 1.40 \times 10^{+0}$ | $2.772 \times 10^{-2}$ |
| 5 | $1.40 \times 10^{+0} – 9.00 \times 10^{-1}$ | $2.098 \times 10^{-2}$ |
| 6 | $9.00 \times 10^{-1} – 4.00 \times 10^{-1}$ | $1.560 \times 10^{-2}$ |
| 7 | $4.00 \times 10^{-1} – 1.00 \times 10^{-1}$ | $8.946 \times 10^{-3}$ |
| 8 | $1.00 \times 10^{-1} – 1.70 \times 10^{-2}$ | $1.490 \times 10^{-3}$ |
| 9 | $1.70 \times 10^{-2} – 3.00 \times 10^{-3}$ | $1.016 \times 10^{-4}$ |
| 10–27 [b] | $3.00 \times 10^{-3} – 5.50 \times 10^{-4}$ | 0 |
| **Total** | | **$2.110 \times 10^{-1}$** |

[a] ORIGEN-S results at 15 years decay.
[b] Source is assumed to zero for Groups 10–27.

### 5.3.1 Configuration of Source and Shielding

The photon and neutron sources from the radioactive contents described in the previous section, and listed in Tables 5.4 and 5.5, are input into the MCNP code (LA-UR-03-1987) to calculate the ES-3100 external package dose rates given in Tables 5.1 and 5.2. The packaging component drawings are shown in Appendix 1.3.1. A cylindrical model of this package and proposed HEU material content is shown in Fig. 5.1 and Table 5.6. The dose rate detector locations relative to the package model exterior are listed in Table 5.7. For NCT, dose rates were calculated at detector locations representing the external surface of the drum (1 cm from the surface of the drum) and 1 m from the external surface of the drum. Point detectors are placed at 1 cm from the surface instead of closer to the surface (i.e., 0.1 cm) in order to provide good convergence in the MCNP calculations. It should be noted that the detector active area is more than 1 cm away from the surface of the drum when actual dose rate measurements are taken. Calculated dose rates at 1 cm from the drum surface are within 10% of the dose rate values calculated at 0.1 cm from the drum surface. These models are described in more detail in the input data and other information given in the Appendices 5.5.1 and 5.5.2.

Two proposed package contents have been analyzed: (1) 36 kg of HEU metal and (2) 24 kg of HEU oxide. The analyses of these models have been performed in a manner that covers all other proposed contents identified in Sect. 1.2.2 in an equivalent or conservative manner. Due to the simple source and packaging geometry, there are no radiation streaming paths from the source toward the package exterior. Each of the two models is analyzed for both photon and neutron sources, and for both NCT and HAC.




**Note:** See Tables 5.6–5.8 for data on the contents, materials, and detector locations (not to scale; all dimensions are in centimeters). For HAC, all material external to the containment vessel is omitted.

**Fig. 5.1. Cylindrical calculational model of the ES-3100 shipping package for NCT.**

**Table 5.6. Geometric data for the shielding analysis models of the ES-3100 shipping package as shown in Fig. 5.1 for NCT**

Each item is modeled as a cylinder or cylindrical shell. The content volume not identified (HEU metal photon shell model interior) is modeled as void/air. All materials interior to the containment vessel except the HEU material content are omitted. Each of the four content models is placed in the packaging to create four separate calculational models. All dimensions are in centimeters. For HAC, all material external to the containment vessel is omitted.

| | Material | Outer radius | Base reference height [a] | Height [b] (h) | Side wall thickness | Top thickness | Bottom thickness |
|---|---|---|---|---|---|---|---|
| **Content** | | | | | | | |
| HEU metal shell photon model | HEU | 6.35 | 11.195 | 76.2 | 0.6639 | - | - |
| HEU metal neutron model | HEU | 6.35 | 11.195 | 15.1003 | - | - | - |
| HEU oxide photon model | $UO_2$ | 6.35 | 11.195 | 63.5 | - | - | - |
| HEU oxide neutron model | $UO_2$ | 6.35 | 11.195 | 17.2864 | - | - | - |
| **Packaging (identical for all models)** | | | | | | | |
| Inner vessel gap | void/air | 6.4008 | 11.195 | 76.2 | 0.0508 | - | - |
| ES-3100 containment vessel [c] | SS304 [d] | 6.6548 | 10.56 | 77.47 | 0.254 | 0.635 | 0.635 |
| Outer vessel gap | void/air | 7.9248 | 10.56 | 77.47 | 1.27 | - | - |
| Inner Cat 277-4 liner | SS304 | 8.0748 | 10.56 | 77.47 | 0.15 | - | - |
| Criticality control material | Cat 277-4 | 10.9196 | 10.56 | 77.47 | 2.8448 | - | - |
| Outer Cat 277-4 liner | SS304 | 11.0696 | 10.26 | 77.92 | 0.15 | 0.15 | 0.3 |
| Upper insulation | Kaolite [e] | 23.0275 | 88.18 | 19.385 | - | - | - |
| Base and radial insulation | Kaolite | 23.0275 | 0.26 | 87.92 | 11.9579 | - | 10 |
| Drum | SS304 | 23.1775 | 0 | 107.715 | 0.15 | 0.15 | 0.26 |

[a] Measured from the lower drum base.
[b] Vessel interior content (and gap) height varies with density to preserve content mass.
[c] Upper flange and lid detail omitted.
[d] Type 304 stainless steel.
[e] Modeled as void.

**Table 5.7. Detector locations relative to the drum for NCT and to the containment vessel for HAC**

| | Radius (cm) | h [a] (cm) |
|---|---|---|
| NCT detectors | | |
| Side surface [b] | 24.1775 | 49.2950 |
| Top surface | 0.0000 | 108.7150 |
| Bottom surface | 0.0000 | −1.0000 |
| Side 1 meter [b] | 123.1775 | 49.2950 |
| Top 1 meter | 0.0000 | 207.7150 |
| Bottom 1 meter | 0.0000 | −100.0000 |
| HAC detectors | | |
| Side 1 meter [b] | 106.6548 | 49.2950 |
| Top 1 meter | 0.0000 | 188.0300 |
| Bottom 1 meter | 0.0000 | −89.4400 |

[a] Height above drum base.
[b] Surface side location is at the axial mid-point of the content; values shown are for the first content in Table 5.6.

In addition to the analyses for the dose rates shown in Tables 5.1 and 5.2, many preliminary and auxiliary calculations were made for each model to ensure that all proposed content loadings in the ES-3100 were covered. These extra analyses are necessary since only a content mass limit is specified for each shipment, and various geometric configurations must be investigated to determine if the maximum external package dose rates have been found. In some cases it is not possible, or practical, to find an exact maximum dose rate geometric configuration due to the statistical uncertainty of the calculation method, variations in model radius vs height, variable densities, etc. The presence of 800-ppm trace elements has no effect on the photon dose rates. Although it doubles the neutron dose rates, the neutron dose rate constitutes only 1.3% of the total dose rate. The dose rate values shown in Tables 5.1 and 5.2 are all at or near possible maximum values for the package specifications given in Sect. 1. All package models investigated, including the preliminary and auxiliary models, are conservative.

**Table 5.8. Shielding model material specifications for the ES-3100 package with HEU content**

Only the two principal uranium isotopes are used in the dose rate calculations. The uranium oxide density varies with the geometric model volume to preserve the 24-kg mass.

| Material | Density ($g/cm^3$) | Constituent | Weight percent |
|---|---|---|---|
| Uranium metal | 18.82 | $^{235}U$ | 95.00 |
| | | $^{238}U$ | 5.00 |
| $UO_2$ | 10.960 [a] | O | 11.98 |
| | | $^{235}U$ | 83.62 |
| | | $^{238}U$ | 4.40 |
| Stainless steel | 7.92 | Cr | 19.00 |
| | | Ni | 9.50 |
| | | Fe | 69.50 |
| | | Mn | 2.00 |
| Cat 277-4 | 1.682 | H | 4.62 |
| | | $^{10}B$ | 0.79 |
| | | $^{11}B$ | 3.44 |
| | | C | 1.51 |
| | | O | 60.00 |
| | | Mg | 0.38 |
| | | Al | 21.16 |
| | | Si | 1.32 |
| | | S | 0.15 |
| | | Na | 0.13 |
| | | Ca | 6.18 |
| | | Fe | 0.32 |
| Air | 0.001225 | N | 75.50 |
| | | O | 23.20 |
| | | Ar | 1.30 |
| Kaolite | 0.321 | O | 40.43 |
| | | Na | 1.45 |
| | | Mg | 7.86 |
| | | Al | 5.58 |
| | | Si | 16.12 |
| | | Ca | 23.40 |
| | | Fe | 5.16 |

[a] Theoretical density— a density of 2.984 $g/cm^3$ is used in the Table 5.6 geometric model for photons.

#### 5.3.1.1 Photon model for 36-kg HEU metal content

The HEU metal content in the ES-3100 may be many small, irregularly shaped pieces, each placed at some arbitrary orientation inside the convenience cans. Several conservative, regular geometry models have been devised to cover these and other proposed loadings. Some of these models violate, in a conservative manner, the volume capacity of a convenience can. The convenience cans and can spacers are omitted from the models.

The photon model for the dose rates shown in Table 5.1 is that given for the first content item in Table 5.6 (the HEU metal shell). Here, the content is a cylindrical shell the same height as the containment vessel model (76.2 cm). The inner radius of the shell, 5.6861 cm, was used to preserve the 36-kg HEU metal at 18.82 g/cm$^3$ for an outer radius of 6.35 cm. This case corresponds to a three-can loading configuration with a maximum of 12 kg in each 25.4-cm (10-in.)–tall can.

Several 36-kg HEU metal cylindrical shell photon dose rate models were evaluated at lesser heights than the containment vessel inside height (in each case the shell wall thickness was adjusted to preserve the mass). The 1-m side photon dose rate in Table 5.1 is the calculated value for the entire analysis that gave the largest overall fraction of the regulatory limit, 57% of the 10-mrem/h limit.

The cylindrical shell representation of the HEU metal content is a convenient, conservative model for multiple possible loading configurations inside the vessel. Some other, more complicated, geometric radial models were also analyzed in the previous version of the ES-3100 safety analysis report (Y/LF-717). The radial geometric cross-sections of these models are shown schematically in Fig. 5.2:

a. The cylindrical shell as described above.

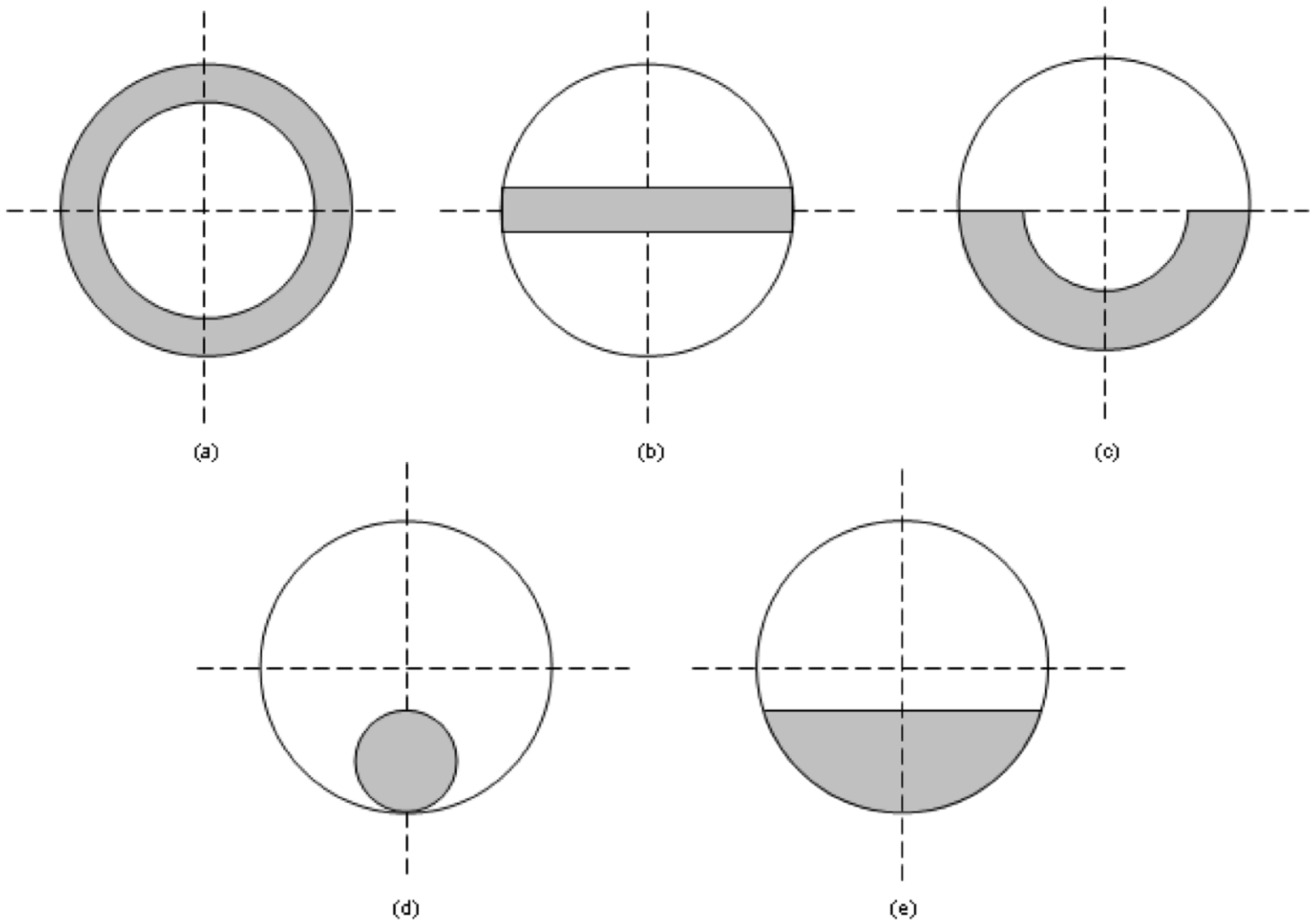
b. A vertical flat plate across the center of the vessel. The maximum calculated photon package surface dose rate for a plate of dimensions 1.9766 cm × 12.7 cm × 76.2 cm was 63 mrem/h.

c. A cylindrical hemi-shell. The maximum calculated package surface photon dose rate was 69 mrem/h for an outer radius of 6.35 cm, an inner radius of 4.0436 cm, and a height of 50.8 cm.

d. A single solid rod placed against the side wall of the vessel. The maximum calculated package surface dose rate for a rod of radius 3.0966 cm and a height of 63.5 cm was 48 mrem/h.

e. A cylindrical segment (the shape a liquid would assume in a horizontal vessel). The maximum calculated package surface dose rate was calculated to be 71 mrem/h for a radius of 6.35 cm, an inner flat surface 11.495 cm across, and a height of 63.5 cm.

The variations in dose rates described here are due to the variations in source-detector point geometry and the self-absorption of photons in the source material. It may be possible to devise other geometric configurations that could produce slightly higher dose rates. However, it can be said with some certainty that the calculated dose rates for 36-kg HEU metal or 24-kg HEU oxide content defined in Table 5.3 should not be close to the NCT or HAC limits.




**Note:** The 36-kg mass is conserved for each case. Detector locations were adjusted both vertically and radially from those given in Table 5.7 in the search for maximum external package dose rates for each case.

**Fig. 5.2. ES-3100 HEU metal content radial (top view) geometric models.**

#### 5.3.1.2 Neutron model for 36-kg HEU metal content

In the model for the neutron dose rates for the 36-kg HEU contents, it was assumed that all the uranium was a solid cylinder at the bottom of the vessel. The neutron results in Table 5.1 are from this configuration. This is a gross, conservative violation of a convenience can capacity, and no further investigation was made due to the low neutron dose rates obtained from this conservative model relative to the photon results.

#### 5.3.1.3 Photon model for 24-kg HEU oxide content

A package photon dose rate calculation model was created to apply to 24-kg HEU oxide for all three common uranium oxides—$UO_2$, $UO_3$, and $U_3O_8$. The theoretical densities for these oxides are 10.96 g/cm$^3$, 7.29 g/cm$^3$, and 8.30 g/cm$^3$, respectively. In the package loading models, the convenience can locations are completely filled with oxide powder, and the actual densities, always less than theoretical values, will be the oxide mass divided by the model can volume.

The dose rate model excludes the convenience cans and can spacers, and it is represented by a solid cylinder of oxide resting on the containment vessel interior base. The cylinder radius is 6.35 cm, and the height is variable. The density is adjusted for each calculation to preserve the 24-kg oxide mass. The HEU mass is 21.126 kg for $UO_2$, the largest uranium mass of the three oxides for 24 kg of HEU oxide. The photon dose rates in Table 5.2 are for a cylinder height of 63.5 cm. The 1-m dose rates and the surface dose rates are slightly higher for different heights of oxide cylinders. The bottom dose rates approach the side values in Table 5.2 when the cylinder is compressed to the $UO_2$ theoretical density at the vessel bottom. The cylindrical shell model of the HEU oxide contents with the same height as the containment vessel model (76.2 cm) and with different shell thicknesses obtained by varying the density of $UO_2$ from 10.96 to 2.5 g/cm$^3$ while maintaining an oxide mass of 24 kg has been analyzed. The side surface dose rates for different shell thicknesses are slightly lower than the side surface dose rate presented in Table 5.2 for the solid cylinder models of the HEU oxide contents. The dose rates at 1 m from the side surface for the shell models are as much as 14% higher than the dose rates at 1 m from the side surface for the solid cylinder models of the HEU oxide contents. Therefore, the dose rates at 1 m from the side surface for NCT and HAC for the solid cylinder model are increased by 14% in order to bound the dose rates predicted by the shell model. These adjusted dose rates at 1 m from the side surface are presented in Table 5.2. From the various analyses, it can be stated that no calculated HEU oxide photon dose rates should exceed 90 mrem/h on the package surface, 6 mrem/h at one meter, and 12 mrem/h for HAC.

#### 5.3.1.4 Neutron model for 24-kg HEU oxide content

The neutron model for the calculated values shown in Table 5.2 was for a solid cylinder of $UO_2$ at the containment vessel bottom. The density was 10.96 g/cm$^3$ and the height was 17.286 cm. The oxide mass in a cylindrical shape is the only analyzed configuration since the uranium oxides are in powder form.

#### 5.3.1.5 Packaging model conservative features

Several conservative features applying to all content models are included in the packaging model. All material dimensions, thicknesses, and densities for the packaging are modeled at or less than

specified or nominal values. All noncylindrical detail has been omitted from the shielding models (see packaging drawings in Appendix 1.3.1). All minor items, such as the silicone rubber pads supporting the ES-3100 containment vessel, have been omitted. It was determined from preliminary analysis that the maximum axial external dose rates would occur relative to the package lower surface. All contents were modeled to contact the containment vessel lower surface, and the upper containment vessel geometry, containment vessel lid, and upper packaging, insulation, lids, covers, etc., were conservatively simplified and/or modeled as void (see Fig. 5.1).

All models of the containment vessel interior contain HEU material content only. All convenience cans, can spacers, content wrappings, covers, supports, etc., are omitted. All contents are modeled as cylinders or cylindrical shells with the base resting on the lower containment vessel surface, with a maximum specified radius of 6.35 cm (the maximum allowable convenience can diameter is 5 in.), and with a height, inner radius (if any), and density adjusted for each specific model to preserve the content mass. In this conservative manner, it is possible to cover all specified combinations of can loadings and can and spacer placements with a minimum number of calculations. The geometric configuration of some of the cases investigated represents a situation where the maximum possible mass loading for a convenience can would be exceeded if the cans had been included in the model. However, the calculated dose rates from the models used will always exceed those from a model where the geometry is expanded so the can mass loadings are not exceeded and the internal containment vessel hardware is included. All the general, conservative items relative to the ES-3100 package shielding model are applied to each individual content model.

### 5.3.2 Material Properties

The material properties for the ES-3100 package shielding models are shown in Table 5.8. Kaolite is an insulation material, and Cat 277-4 is a criticality control material. Additional information on these two materials can be found in Sects. 1, 2, and 6.

## 5.4 SHIELDING EVALUATION

### 5.4.1 Methods

Two computer programs were used in the shielding evaluation. These included the ORIGEN-S computer code and the MCNP5 computer code. Both are stand-alone codes. Brief descriptions of the programs are presented below.

1. ORIGEN-S (NUREG/CR-0200) is a general depletion and decay code. Given an initial isotopic distribution, materials are decayed to provide time-dependent, energy-grouped photon and neutron sources.

2. MCNP (LA-UR-03-1987) is a general-purpose Monte Carlo transport code that treats multidimensional neutron, photon, and coupled problems. The cross section library used for the materials in this analysis is based on Evaluated Nuclear Data Files (ENDF)/B-VI.8.

A type 5 point detector tally was used for calculating the photon and neutron dose rates for all locations both for NCT and HAC. These dose rates are reported in Tables 5.1 and 5.2. Type 4 tally doses rates for neutrons and photons are also calculated from tally cells arranged around the package and at 1 m around the package for NCT. Type 4 tally cells estimate average gamma fluxes in a cell from particle tracks in that cell. Type 4 tally dose rates are used to provide information about the axial and radial profile of the dose rates.

### 5.4.2 Input and Output Data

The sample input files are shown in Appendices 5.5.1 and 5.5.2. The output dose rates are shown in Tables 5.1 and 5.2. A large number of particle histories were used to obtain reliable statistics. The results were judged to be acceptable by looking at the tally fluctuation chart and the relative error (fractional standard deviation) lower than the criterion (0.05 for point detectors).

### 5.4.3 Flux-to-Dose-Rate Conversion

Dose rates were calculated at the detector locations shown in Table 5.7 by converting the calculated photon and neutron fluxes using the ANSI/ANS conversion factors (ANSI/ANS-6.1.1). These factors for the energy groups used in the shielding evaluation are shown in Tables 5.9 and 5.10.

### 5.4.4 External Radiation Levels

The results of these shielding model evaluations, summarized in Tables 5.1 and 5.2, are the calculated dose rates at the locations indicated. As shown from the dose rates in the tables and the discussion in Sect. 5.3, the shielding evaluation demonstrates that the package meets all dose-rate limits for both NCT and HAC. The shielding analyses were done in a conservative manner applicable to all proposed ES-3100 package contents listed in Sect. 1.2.2.

In addition to the required external package dose rate calculations, auxiliary calculations were performed to give an upper bound estimate for the dose rate at the location of the containment vessel O-rings. The content model used is the same for neutrons and photons; a solid cylinder of 36-kg HEU located at the top of the containment vessel, similar to the neutron model described in Sect. 5.3.1.2 (except for the content location). The packaging model is the same as that described in Table 5.6 and Fig. 5.1. The stainless-steel components (containment vessel flange and lid assembly) beyond the 6.655-cm outer radius are modeled as void. The detector location is 0.1 cm off the containment vessel radial surface at the height of the lower lid surface (radius of 6.755 cm and height of 87.395 cm). The maximum calculated radiation level at the containment boundary O-ring is ~500 mrem/h (photon plus neutron dose rates including an uncertainty adjustment of three standard deviations). Using a 1-rad/rem conversion factor, which is applied to the photon dose rate and conservatively applied to the relatively low neutron dose rate, the maximum total dose rate at the O-ring location is calculated to be 0.5 rad/h.

**Table 5.9. ANSI/ANS-1977 photon flux-to-dose-rate conversion factors**

| Energy (MeV) | Factor (rem/h)/(photons/s/cm$^2$) |
|---|---|
| 0.01 | $3.96 \times 10^{-6}$ |
| 0.03 | $5.82 \times 10^{-7}$ |
| 0.05 | $2.90 \times 10^{-7}$ |
| 0.07 | $2.58 \times 10^{-7}$ |
| 0.10 | $2.83 \times 10^{-7}$ |
| 0.15 | $3.79 \times 10^{-7}$ |
| 0.20 | $5.01 \times 10^{-7}$ |
| 0.25 | $6.31 \times 10^{-7}$ |
| 0.30 | $7.59 \times 10^{-7}$ |
| 0.35 | $8.78 \times 10^{-7}$ |
| 0.40 | $9.85 \times 10^{-7}$ |
| 0.45 | $1.08 \times 10^{-6}$ |
| 0.50 | $1.17 \times 10^{-6}$ |
| 0.55 | $1.27 \times 10^{-6}$ |
| 0.60 | $1.36 \times 10^{-6}$ |
| 0.65 | $1.44 \times 10^{-6}$ |
| 0.70 | $1.52 \times 10^{-6}$ |
| 0.80 | $1.68 \times 10^{-6}$ |
| 1.00 | $1.98 \times 10^{-6}$ |
| 1.40 | $2.51 \times 10^{-6}$ |
| 1.80 | $2.99 \times 10^{-6}$ |
| 2.20 | $3.42 \times 10^{-6}$ |
| 2.60 | $3.82 \times 10^{-6}$ |
| 2.80 | $4.01 \times 10^{-6}$ |
| 3.25 | $4.41 \times 10^{-6}$ |
| 3.75 | $4.83 \times 10^{-6}$ |
| 4.25 | $5.23 \times 10^{-6}$ |
| 4.75 | $5.60 \times 10^{-6}$ |
| 5.00 | $5.80 \times 10^{-6}$ |
| 5.25 | $6.01 \times 10^{-6}$ |
| 5.75 | $6.37 \times 10^{-6}$ |
| 6.25 | $6.74 \times 10^{-6}$ |
| 6.75 | $7.11 \times 10^{-6}$ |
| 7.50 | $7.66 \times 10^{-6}$ |
| 9.00 | $8.77 \times 10^{-6}$ |
| 11.00 | $1.03 \times 10^{-6}$ |
| 13.00 | $1.18 \times 10^{-6}$ |
| 15.00 | $1.33 \times 10^{-6}$ |

**Table 5.10. ANSI/ANS-1977 neutron flux-to-dose-rate conversion factors**

| Energy (MeV) | Factor (rem/h)/(neutrons/s/cm$^2$) |
|---|---|
| $2.5 \times 10^{-8}$ | $3.67 \times 10^{-6}$ |
| $1.0 \times 10^{-7}$ | $3.67 \times 10^{-6}$ |
| $1.0 \times 10^{-6}$ | $4.46 \times 10^{-6}$ |
| $1.0 \times 10^{-5}$ | $4.54 \times 10^{-6}$ |
| $1.0 \times 10^{-4}$ | $4.18 \times 10^{-6}$ |
| $1.0 \times 10^{-3}$ | $3.76 \times 10^{-6}$ |
| $1.0 \times 10^{-2}$ | $3.56 \times 10^{-6}$ |
| $1.0 \times 10^{-1}$ | $2.17 \times 10^{-5}$ |
| $5.0 \times 10^{-1}$ | $9.26 \times 10^{-5}$ |
| 1.0 | $1.32 \times 10^{-4}$ |
| 2.5 | $1.25 \times 10^{-4}$ |
| 5.0 | $1.56 \times 10^{-4}$ |
| 7.0 | $1.47 \times 10^{-4}$ |
| 10.0 | $1.47 \times 10^{-4}$ |
| 14.0 | $2.08 \times 10^{-4}$ |
| 20.0 | $2.27 \times 10^{-4}$ |

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## 5.5 APPENDICES

5.5.1 Origen Input Data from Table 5.3

5.5.2 MCNP Input Files

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## Appendix 5.5.1

## Origen Input Data from Table 5.3

This file is for generation of the metal and oxide photon spectra in Table 5.4 and neutron data in Table 5.5. The concentration for each isotope is given based on 1 g of HEU.

```
#origen
0$$ 6 13 a8 26 e
1$$ 1 t
master photon
3$$ 21 0 1 -88 6 a16 2 a33 18
4** a4 1-70 t
35$$ 0 t
56$$ 0 10 a13 13 5 3 a17 2 e
57** 0 e t
es3100 uranium metal and oxides
one gram HEU
60** 8 9 10 10.5 11 12 15 20 40 50
65$$ a7 1 a25 1 a28 1 a31 1 a49 1 e
73$$ 922320 922340 922350 922360 922380
     922330 942380 942390 932370
     942400 942410 942420 952410
74** 0.4000-07 .020000 0.92000 .010000 0.04399996
     6.00-03 1.60-07 7.41-04 0.025
     5.20-05 4.48-06 3.20-07 2.40-06
75$$ 2 2 2 2 2 2 2 2 2 2 2 2
81$$ 2 0 26 1 e
82$$ 2 2 2 2 2 2 2 2 0 0
83** 10+6 8+6 6.5+6 5+6 4+6 3+6 2.5+6 2+6 1.66+6 1.33+6 1+6 .8+6
     .6+6 .4+6 .3+6 .2+6 .1+6 .05+6 .01+6 t
               8
               9
              10
              10.5
              11
              12
              15
              20
56$$ f0 t
end
```

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## Appendix 5.5.2

## MCNP Input Files

Included here are some of the input files used for the dose rate calculations for the results in Tables 5.1 and 5.2. For the HAC cases, all material external to the containment vessel is set to void/air, and the detectors are set one meter from the external vessel surface.

| File | Description |
|---|---|
| 5.5.2.1 | Normal Condition of Transport (NCT) for 36-kg metal neutron case |
| 5.5.2.2 | Normal Condition of Transport (NCT) for 24-kg oxide photon case |
| 5.5.2.3 | Hypothetical Accident Condition (HAC) for 36-kg metal photon case |
| 5.5.2.4 | Hypothetical Accident Condition (HAC) for 24-kg oxide neutron case |

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### 5.5.1.1 Normal Condition of Transport (NCT) for 36-kg metal neutron case

```
c    NCT configuration
c
c    all air spaces are made void
c    side, top, and bottom segmented detectors
c    surface detectors are placed 1 cm away from the surfaces
c    point detectors are also placed on the side, top, and bottom
c    changed importance for some cells
c    radius = 6.35 cm; height = 15.10 cm; density = 18.82 g/cm3
c    15 yr decay spectrum
c    n,p mode
c
c    --------------
c     Cell Cards
c    --------------
c
c  SPR-3 Fuel Material Original Deck from SNL
c
c   1     0              -1      imp:p=2  imp:n=2  $ inner most void
    2     1   -18.82     -2      imp:p=1  imp:n=1  $ fuel
    3     0               2 -3   imp:p=2  imp:n=2  $ void
    4     3   -7.92        3 -4   imp:p=2  imp:n=2  $ vessel
    5     0               4 -5   imp:p=2  imp:n=2  $ void
    6     3   -7.92        5 -6   imp:p=2  imp:n=2  $ ss liner
    7     4   -1.682       6 -7   imp:p=2  imp:n=2  $ cat-277-4
    9     3   -7.92        7 -8   imp:p=2  imp:n=2  $ ss liner
   10     5   -0.321       8 -9   imp:p=2  imp:n=2  $ kaolite
   11     0               9 -10  imp:p=2  imp:n=2  $ void
   12     3   -7.92       10 -11  imp:p=2  imp:n=2  $ drum
   13     6   -0.001225   11 -12  imp:p=4  imp:n=4  $ side void
   14     0               12 -13  imp:p=8  imp:n=8  $ side surface detectors
   15     6   -0.001225   13 -14  imp:p=16 imp:n=16 $ side void
   16     0               14 -15  imp:p=16 imp:n=16 $ side 1m surface detectors
   17     6   -0.001225   15 -16  imp:p=4  imp:n=4  $ bottom void
   18     0               16 -17  imp:p=8  imp:n=8  $ bottom surface detectors
   19     6   -0.001225   17 -18  imp:p=16 imp:n=16 $ bottom void
   20     0               18 -19  imp:p=16 imp:n=16 $ bottom 1m detectors
   21     6   -0.001225   19 -20  imp:p=1  imp:n=1  $ top void
   22     0               20 -21  imp:p=1  imp:n=1  $ top surface detectors
   23     6   -0.001225   21 -22  imp:p=1  imp:n=1  $ top void
   24     0               22 -23  imp:p=1  imp:n=1  $ top 1m detectors
   25     0               23 -99  imp:p=1  imp:n=1  $ inside boundary
   99     0               99      imp:p=0  imp:n=0  $ outside world

c    ------------------
c    Surface Cards
c    ------------------
   1   rcc  0.0 0.0 11.195  0.0 0.0 76.2      5.6861 $ void
   2   rcc  0.0 0.0 11.195  0.0 0.0 15.10     6.35   $ fuel
   3   rcc  0.0 0.0 11.195  0.0 0.0 76.2      6.4008 $ void
   4   rcc  0.0 0.0 10.560  0.0 0.0 77.47     6.6548 $ vessel
   5   rcc  0.0 0.0 10.560  0.0 0.0 77.47     7.9248 $ void
   6   rcc  0.0 0.0 10.560  0.0 0.0 77.47     8.0748 $ ss
   7   rcc  0.0 0.0 10.560  0.0 0.0 77.47    10.9196 $ cat-277-4
   8   rcc  0.0 0.0 10.260  0.0 0.0 77.92    11.0696 $ ss
   9   rcc  0.0 0.0  0.260  0.0 0.0 87.92    23.0275 $ kaolite
  10   rcc  0.0 0.0  0.260  0.0 0.0 107.305  23.0275 $ kaolite+top void
  11   rcc  0.0 0.0  0.000  0.0 0.0 107.715  23.1775 $ drum
  12   rcc  0.0 0.0  0.000  0.0 0.0 107.715  24.1775 $ drum side void
```

```
  13   rcc  0.0 0.0  0.000  0.0 0.0 107.715  24.35   $ side void (surface detectors)
  14   rcc  0.0 0.0  0.000  0.0 0.0 107.715 123.1775 $ side void
  15   rcc  0.0 0.0  0.000  0.0 0.0 107.715 123.35   $ side void (1m surface detectors)
  16   rcc  0.0 0.0 -1.0    0.0 0.0 108.715 123.35   $ bottom void
  17   rcc  0.0 0.0 -1.15   0.0 0.0 108.865 123.35   $ bottom void (surface bottom detectors)
  18   rcc  0.0 0.0 -100.0  0.0 0.0 207.715 123.35   $ bottom void
  19   rcc  0.0 0.0 -100.15 0.0 0.0 207.865 123.35   $ bottom void (1m bottom detectors)
  20   rcc  0.0 0.0 -100.15 0.0 0.0 208.865 123.35   $ top void
  21   rcc  0.0 0.0 -100.15 0.0 0.0 209.0   123.35   $ top void (surface top detectors)
  22   rcc  0.0 0.0 -100.15 0.0 0.0 307.865 123.35   $ top void
  23   rcc  0.0 0.0 -100.15 0.0 0.0 308.0   123.35   $ top void (1m top detectors)
  99   sph  0.0 0.0  0.000  999.0                     $ boundary
c
  201  pz   2
  202  pz   4
  203  pz   6
  204  pz   8
  205  pz   10
  206  pz   12
  207  pz   14
  208  pz   16
  209  pz   18
  210  pz   20
  211  pz   22
  212  pz   24
  213  pz   26
  214  pz   28
  215  pz   30
  216  pz   32
  217  pz   34
  218  pz   36
  219  pz   38
  220  pz   40
  221  pz   42
  222  pz   44
  223  pz   46
  224  pz   48
  225  pz   50
  226  pz   52
  227  pz   54
  228  pz   56
  229  pz   58
  230  pz   60
  231  pz   62
  232  pz   64
  233  pz   66
  234  pz   68
  235  pz   70
  236  pz   72
  237  pz   74
  238  pz   76
  239  pz   78
  240  pz   80
  241  pz   82
  242  pz   84
  243  pz   86
  244  pz   88
  245  pz   90
  246  pz   92
  247  pz   94
  248  pz   96
```

```
  249  pz   98
  250  pz   100
  251  pz   102
  252  pz   104
  253  pz   106
c
  301  cz    1
  302  cz    3
  303  cz    5
  304  cz    7
  305  cz    9
  306  cz   11
  307  cz   13
  308  cz   15
  309  cz   17
  310  cz   19
  311  cz   21
  312  cz   23.5

c    ----------------------
c    Data Cards
c    ----------------------
mode  n p
c
c      uranium metal (18.82 g/cc)
c
m1    92235  -0.95    $ U-235 95.00 wt%
      92238  -0.05    $ U-238  5.00 wt%
c
c      UO2 (10.960 gm/cc)
c
m2     8016  -0.1198  $ O     11.98 wt%
      92235  -0.8362  $ U-235 83.62 wt%
      92238  -0.0440  $ U-238  4.40 wt%
c
c      ss 304 (7.92 g/cc)
c
m3    24000  -0.1900  $ Cr 19.00 wt%
      28000  -0.0950  $ Ni  9.50 wt%
      26000  -0.6950  $ Fe 69.50 wt%
      25055  -0.0200  $ Mn  2.00 wt%
c
c      cat 277-4 (1.682 g/cc)
c
m4      1001  -0.0462  $ H      4.62 wt%
        5010  -0.0079  $ B-10   0.79 wt%
        5011  -0.0344  $ B-11   3.44 wt%
        6012  -0.0151  $ C      1.51 wt%
        8016  -0.6000  $ O     60.00 wt%
       12000  -0.0038  $ Mg     0.38 wt%
       13027  -0.2116  $ Al    21.16 wt%
       14000  -0.0132  $ Si     1.32 wt%
       16000  -0.0015  $ S      0.15 wt%
       11023  -0.0013  $ Na     0.13 wt%
       20000  -0.0618  $ Ca     6.18 wt%
       26000  -0.0032  $ Fe     0.32 wt%
c
c      kaolite (0.321 g/cc)
c
m5      8016  -0.4043  $ O     40.43 wt%
       11023  -0.0145  $ Na     1.45 wt%
```

```
       12000  -0.0786  $ Mg     7.86 wt%
       13027  -0.0558  $ Al     5.58 wt%
       14000  -0.1612  $ Si    16.12 wt%
       20000  -0.2340  $ Ca    23.40 wt%
       26000  -0.0516  $ Fe     5.16 wt%
c
c       air (1.225e-3 g/cc)
c
m6      7014  -0.755   $ N      75.5 wt%
        8016  -0.232   $ O      23.2 wt%
       18000  -0.013   $ Ar      1.3 wt%
c
c    source in ES-3100 Fuel Ring
c
sdef pos=0 0 11.195 erg=D1 RAD=D3 ext=D2 axs=0 0 1
c
c ORIGEN neutron Spectrum
c
c 4 mo
c si1 L   0.01
si1     3.00e-03     1.70e-02
        1.00e-01     4.00e-01     9.00e-01    1.40e+00     1.85e+00   3.00e+00
        6.43e+00     2.00e+01
c sp1 D   0.0
sp1     0.0          1.016e-04
        1.490e-03    8.946e-03   1.560e-02    2.098e-02   2.772e-02   1.002e-01
        3.432e-02    6.994e-04
si2 0.0 15.10
c  sp2 0 1
sp2 -21 0.0
si3   0.0  6.35
sp3   -21     1.0
phys:p  100  0  1
fcl:p 0 9r 1 0 1 0 1 0 1 0 1 0 0 0
c
c  segmented volume detectors
c
f4:n  14  16                 $ side segmented volume detectors
fm4   7.596e+06
fs4  -201 -202 -203 -204 -205 -206 -207 -208 -209 -210  &
     -211 -212 -213 -214 -215 -216 -217 -218 -219 -220  &
     -221 -222 -223 -224 -225 -226 -227 -228 -229 -230  &
     -231 -232 -233 -234 -235 -236 -237 -238 -239 -240  &
     -241 -242 -243 -244 -245 -246 -247 -248 -249 -250  &
     -251 -252 -253
c
f14:n  22  24                  $ top segmented volume detectors
c  neutron source multiplier -  2.110e-01 x 36e+03 * 1.0e+03 (mrem/rem)
c                              = 7.596e+06
fm14   7.596e+06
fs14  -301 -302 -303 -304 -305 -306 -307 -308 -309 -310 -311 -312
c
f24:n  18  20                  $ bottom segmented volume detectors
fm24   7.596e+06
fs24  -301 -302 -303 -304 -305 -306 -307 -308 -309 -310 -311 -312
c
c  point detectors  for neutrons
c
f5:n  24.1775 0.0 18.745 0.0     $ side surface detector
fm5    7.596e+06
f15:n  0.0 0.0 108.715 0.0       $ top surface detector
```

```
fm15   7.596e+06
f25:n  0.0 0.0 -1.0 0.0          $ bottom surface detector
fm25   7.596e+06
f35:n  123.1775 0.0 18.745 0.0   $ 1m from side surface detector
fm35   7.596e+06
f45:n  0.0 0.0 207.715 0.0       $ 1m from top surface detector
fm45   7.596e+06
f55:n  0.0 0.0 -100.0 0.0        $ 1m from bottom surface detector
fm55   7.596e+06
c
c  -315 -316 -317 -318 -319 -92 -94
c tf44 2 2j 1
fq0 f s d
c
c ANSI/ANS-6.1.1-1977 neutron flux to dose rate conversion factor
c                                        (rem/h)/(neutrons/s/cm2)
c
de0         2.5e-08   1.0e-07   1.0e-06   1.0e-05   1.0e-04   1.0e-03   1.0e-02
            1.0e-01   5.0e-01   1.0       2.5       5.0       7.0       10.0
            14.0      20.0
c
df0      3.67e-06  3.67e-06  4.46e-06  4.54e-06  4.18e-06  3.76e-06  3.56e-06
         2.17e-05  9.26e-05  1.32e-04  1.25e-04  1.56e-04  1.47e-04  1.47e-04
         2.08e-04  2.27e-04
c
c  point detectors  for secondary photons
c
f65:p  24.1775 0.0 18.745 0.0     $ side surface detector
fm65    7.596e+06
f75:p  0.0 0.0 108.715 0.0       $ top surface detector
fm75    7.596e+06
f85:p  0.0 0.0 -1.0 0.0          $ bottom surface detector
fm85    7.596e+06
f95:p  123.1775 0.0 18.745 0.0   $ 1m from side surface detector
fm95    7.596e+06
f105:p  0.0 0.0 207.715 0.0       $ 1m from top surface detector
fm105   7.596e+06
f115:p  0.0 0.0 -100.0 0.0        $ 1m from bottom surface detector
fm115   7.596e+06
c
c ANSI/ANS-6.1.1-1977 photon flux to dose rate conversion factor
c                                        (rem/h)/(photons/s/cm2)
c
de65        0.01   0.03   0.05   0.07   0.10   0.15   0.20
            0.25   0.30   0.35   0.40   0.45   0.50   0.55
            0.60   0.65   0.70   0.80   1.0    1.4    1.8
            2.2    2.6    2.8    3.25   3.75   4.25   4.75
            5.0    5.25   5.75   6.25   6.75   7.5    9.0
            11.0   13.0   15.0
c
df65      3.96e-06  5.82e-07  2.90e-07  2.58e-07  2.83e-07  3.79e-07  5.01e-07
         6.31e-07  7.59e-07  8.78e-07  9.85e-07  1.08e-06  1.17e-06  1.27e-06
         1.36e-06  1.44e-06  1.52e-06  1.68e-06  1.98e-06  2.51e-06  2.99e-06
         3.42e-06  3.82e-06  4.01e-06  4.41e-06  4.83e-06  5.23e-06  5.60e-06
         5.80e-06  6.01e-06  6.37e-06  6.74e-06  7.11e-06  7.66e-06  8.77e-06
         1.03e-05  1.18e-05  1.33e-05
c
de75        0.01   0.03   0.05   0.07   0.10   0.15   0.20
            0.25   0.30   0.35   0.40   0.45   0.50   0.55
            0.60   0.65   0.70   0.80   1.0    1.4    1.8
            2.2    2.6    2.8    3.25   3.75   4.25   4.75
```

```
           5.0    5.25   5.75   6.25   6.75   7.5    9.0
           11.0   13.0   15.0
c
df75      3.96e-06  5.82e-07  2.90e-07  2.58e-07  2.83e-07  3.79e-07  5.01e-07
         6.31e-07  7.59e-07  8.78e-07  9.85e-07  1.08e-06  1.17e-06  1.27e-06
         1.36e-06  1.44e-06  1.52e-06  1.68e-06  1.98e-06  2.51e-06  2.99e-06
         3.42e-06  3.82e-06  4.01e-06  4.41e-06  4.83e-06  5.23e-06  5.60e-06
         5.80e-06  6.01e-06  6.37e-06  6.74e-06  7.11e-06  7.66e-06  8.77e-06
         1.03e-05  1.18e-05  1.33e-05
c
de85        0.01   0.03   0.05   0.07   0.10   0.15   0.20
           0.25   0.30   0.35   0.40   0.45   0.50   0.55
           0.60   0.65   0.70   0.80   1.0    1.4    1.8
           2.2    2.6    2.8    3.25   3.75   4.25   4.75
           5.0    5.25   5.75   6.25   6.75   7.5    9.0
           11.0   13.0   15.0
c
df85      3.96e-06  5.82e-07  2.90e-07  2.58e-07  2.83e-07  3.79e-07  5.01e-07
         6.31e-07  7.59e-07  8.78e-07  9.85e-07  1.08e-06  1.17e-06  1.27e-06
         1.36e-06  1.44e-06  1.52e-06  1.68e-06  1.98e-06  2.51e-06  2.99e-06
         3.42e-06  3.82e-06  4.01e-06  4.41e-06  4.83e-06  5.23e-06  5.60e-06
         5.80e-06  6.01e-06  6.37e-06  6.74e-06  7.11e-06  7.66e-06  8.77e-06
         1.03e-05  1.18e-05  1.33e-05
c
de95        0.01   0.03   0.05   0.07   0.10   0.15   0.20
           0.25   0.30   0.35   0.40   0.45   0.50   0.55
           0.60   0.65   0.70   0.80   1.0    1.4    1.8
           2.2    2.6    2.8    3.25   3.75   4.25   4.75
           5.0    5.25   5.75   6.25   6.75   7.5    9.0
           11.0   13.0   15.0
c
df95      3.96e-06  5.82e-07  2.90e-07  2.58e-07  2.83e-07  3.79e-07  5.01e-07
         6.31e-07  7.59e-07  8.78e-07  9.85e-07  1.08e-06  1.17e-06  1.27e-06
         1.36e-06  1.44e-06  1.52e-06  1.68e-06  1.98e-06  2.51e-06  2.99e-06
         3.42e-06  3.82e-06  4.01e-06  4.41e-06  4.83e-06  5.23e-06  5.60e-06
         5.80e-06  6.01e-06  6.37e-06  6.74e-06  7.11e-06  7.66e-06  8.77e-06
         1.03e-05  1.18e-05  1.33e-05
c
de105        0.01   0.03   0.05   0.07   0.10   0.15   0.20
           0.25   0.30   0.35   0.40   0.45   0.50   0.55
           0.60   0.65   0.70   0.80   1.0    1.4    1.8
           2.2    2.6    2.8    3.25   3.75   4.25   4.75
           5.0    5.25   5.75   6.25   6.75   7.5    9.0
           11.0   13.0   15.0
c
df105      3.96e-06  5.82e-07  2.90e-07  2.58e-07  2.83e-07  3.79e-07  5.01e-07
         6.31e-07  7.59e-07  8.78e-07  9.85e-07  1.08e-06  1.17e-06  1.27e-06
         1.36e-06  1.44e-06  1.52e-06  1.68e-06  1.98e-06  2.51e-06  2.99e-06
         3.42e-06  3.82e-06  4.01e-06  4.41e-06  4.83e-06  5.23e-06  5.60e-06
         5.80e-06  6.01e-06  6.37e-06  6.74e-06  7.11e-06  7.66e-06  8.77e-06
         1.03e-05  1.18e-05  1.33e-05
c
de115        0.01   0.03   0.05   0.07   0.10   0.15   0.20
           0.25   0.30   0.35   0.40   0.45   0.50   0.55
           0.60   0.65   0.70   0.80   1.0    1.4    1.8
           2.2    2.6    2.8    3.25   3.75   4.25   4.75
           5.0    5.25   5.75   6.25   6.75   7.5    9.0
           11.0   13.0   15.0
c
df115      3.96e-06  5.82e-07  2.90e-07  2.58e-07  2.83e-07  3.79e-07  5.01e-07
         6.31e-07  7.59e-07  8.78e-07  9.85e-07  1.08e-06  1.17e-06  1.27e-06
```

```
         1.36e-06  1.44e-06  1.52e-06  1.68e-06  1.98e-06  2.51e-06  2.99e-06
         3.42e-06  3.82e-06  4.01e-06  4.41e-06  4.83e-06  5.23e-06  5.60e-06
         5.80e-06  6.01e-06  6.37e-06  6.74e-06  7.11e-06  7.66e-06  8.77e-06
         1.03e-05  1.18e-05  1.33e-05
prdmp  j  100000 0 10
ctme 300
```

### 5.5.1.2 Normal Condition of Transport (NCT) for 24-kg oxide photon case

```
op01.inp - ES-3100: NCT - with cylindrical type UO2 fuel configuration
c
c    NCT configuration
c
c    all air spaces are made void
c    side, top, and bottom segmented detectors
c    surface detectors are placed 1 cm away from the surfaces
c    point detectors are placed on the side, top, and bottom
c    800 ppm transuranics
c    used 10.5 year decay spectrum; 63.5 cm height
c
c    --------------
c     Cell Cards
c    --------------
c
c  SPR-3 Fuel Material Original Deck from SNL
c
c   1     0             -1      imp:p=2 $ inner most void
    2     2   -2.984    -2      imp:p=1 $ fuel
    3     0              2 -3   imp:p=2 $ void
    4     3   -7.92       3 -4   imp:p=2 $ vessel
    5     0              4 -5   imp:p=2 $ void
    6     3   -7.92       5 -6   imp:p=2 $ ss liner
    7     4   -1.682      6 -7   imp:p=2 $ cat-277-4
    9     3   -7.92       7 -8   imp:p=2 $ ss liner
   10     5   -0.321      8 -9   imp:p=2 $ kaolite
   11     0              9 -10  imp:p=2 $ void
   12     3   -7.92      10 -11  imp:p=2 $ drum
   13     6   -0.001225  11 -12  imp:p=4 $ side void
   14     0              12 -13  imp:p=8 $ side surface detectors
   15     6   -0.001225  13 -14  imp:p=16 $ side 1m void
   16     0              14 -15  imp:p=16 $ side 1m surface detectors
   17     6   -0.001225  15 -16  imp:p=4 $ bottom void
   18     0              16 -17  imp:p=8 $ bottom surface detectors
   19     6   -0.001225  17 -18  imp:p=16 $ bottom 1m void
   20     0              18 -19  imp:p=16 $ bottom 1m detectors
   21     6   -0.001225  19 -20  imp:p=1 $ top void
   22     0              20 -21  imp:p=1 $ top surface detectors
   23     6   -0.001225  21 -22  imp:p=1 $ top 1m void
   24     0              22 -23  imp:p=1 $ top 1m detectors
   25     0              23 -99  imp:p=1 $ inside boundary
   99     0              99      imp:p=0 $ outside world

c    ------------------
c    Surface Cards
c    ------------------
c  1   rcc  0.0 0.0 11.195  0.0 0.0 76.2      5.6861 $ void
   2   rcc  0.0 0.0 11.195  0.0 0.0 63.5      6.35   $ fuel
   3   rcc  0.0 0.0 11.195  0.0 0.0 76.2      6.4008 $ void
   4   rcc  0.0 0.0 10.560  0.0 0.0 77.47     6.6548 $ vessel
   5   rcc  0.0 0.0 10.560  0.0 0.0 77.47     7.9248 $ void
   6   rcc  0.0 0.0 10.560  0.0 0.0 77.47     8.0748 $ ss
```

```
   7   rcc  0.0 0.0 10.560  0.0 0.0 77.47    10.9196 $ cat-277-4
   8   rcc  0.0 0.0 10.260  0.0 0.0 77.92    11.0696 $ ss
   9   rcc  0.0 0.0  0.260  0.0 0.0 87.92    23.0275 $ kaolite
  10   rcc  0.0 0.0  0.260  0.0 0.0 107.305  23.0275 $ kaolite+top void
  11   rcc  0.0 0.0  0.000  0.0 0.0 107.715  23.1775 $ drum
  12   rcc  0.0 0.0  0.000  0.0 0.0 107.715  24.1775 $ drum
  13   rcc  0.0 0.0  0.000  0.0 0.0 107.715  24.35   $ side void (surface detectors)
  14   rcc  0.0 0.0  0.000  0.0 0.0 107.715 123.1775 $ side void
  15   rcc  0.0 0.0  0.000  0.0 0.0 107.715 123.35   $ side void (1m surface detectors)
  16   rcc  0.0 0.0 -1.0    0.0 0.0 108.715 123.35   $ bottom void
  17   rcc  0.0 0.0 -1.15   0.0 0.0 108.865 123.35   $ bottom void (surface bottom detectors)
  18   rcc  0.0 0.0 -100.0  0.0 0.0 207.715 123.35   $ bottom void
  19   rcc  0.0 0.0 -100.15 0.0 0.0 207.865 123.35   $ bottom void (1m bottom detectors)
  20   rcc  0.0 0.0 -100.15 0.0 0.0 208.865 123.35   $ top void
  21   rcc  0.0 0.0 -100.15 0.0 0.0 209.0   123.35   $ top void (surface top detectors)
  22   rcc  0.0 0.0 -100.15 0.0 0.0 307.865 123.35   $ top void
  23   rcc  0.0 0.0 -100.15 0.0 0.0 308.0   123.35   $ top void (1m top detectors)
  99   sph  0.0 0.0  0.000  999.0                     $ boundary
c
  201  pz   2
  202  pz   4
  203  pz   6
  204  pz   8
  205  pz   10
  206  pz   12
  207  pz   14
  208  pz   16
  209  pz   18
  210  pz   20
  211  pz   22
  212  pz   24
  213  pz   26
  214  pz   28
  215  pz   30
  216  pz   32
  217  pz   34
  218  pz   36
  219  pz   38
  220  pz   40
  221  pz   42
  222  pz   44
  223  pz   46
  224  pz   48
  225  pz   50
  226  pz   52
  227  pz   54
  228  pz   56
  229  pz   58
  230  pz   60
  231  pz   62
  232  pz   64
  233  pz   66
  234  pz   68
  235  pz   70
  236  pz   72
  237  pz   74
  238  pz   76
  239  pz   78
  240  pz   80
  241  pz   82
  242  pz   84
```

```
  243  pz   86
  244  pz   88
  245  pz   90
  246  pz   92
  247  pz   94
  248  pz   96
  249  pz   98
  250  pz   100
  251  pz   102
  252  pz   104
  253  pz   106
c
  301  cz    1
  302  cz    3
  303  cz    5
  304  cz    7
  305  cz    9
  306  cz   11
  307  cz   13
  308  cz   15
  309  cz   17
  310  cz   19
  311  cz   21
  312  cz   23.5

c    ----------------------
c    Data Cards
c    ----------------------
mode  p
c
c      uranium metal (18.82 g/cc)
c
m1    92235  -0.95    $ U-235 95.00 wt%
      92238  -0.05    $ U-238  5.00 wt%
c
c      UO2 (10.960 gm/cc)
c
m2     8016  -0.1198  $ O     11.98 wt%
      92235  -0.8362  $ U-235 83.62 wt%
      92238  -0.0440  $ U-238  4.40 wt%
c
c      ss 304 (7.92 g/cc)
c
m3    24000  -0.1900  $ Cr 19.00 wt%
      28000  -0.0950  $ Ni  9.50 wt%
      26000  -0.6950  $ Fe 69.50 wt%
      25000  -0.0200  $ Mn  2.00 wt%
c
c      cat 277-4 (1.682 g/cc)
c
m4      1001  -0.0462  $ H      4.62 wt%
        5010  -0.0079  $ B-10   0.79 wt%
        5011  -0.0344  $ B-11   3.44 wt%
        6012  -0.0151  $ C      1.51 wt%
        8016  -0.6000  $ O     60.00 wt%
       12000  -0.0038  $ Mg     0.38 wt%
       13027  -0.2116  $ Al    21.16 wt%
       14000  -0.0132  $ Si     1.32 wt%
       16000  -0.0015  $ S      0.15 wt%
       11023  -0.0013  $ Na     0.13 wt%
       20000  -0.0618  $ Ca     6.18 wt%
```

```
       26000  -0.0032  $ Fe     0.32 wt%
c
c      kaolite (0.321 g/cc)
c
m5      8016  -0.4043  $ O     40.43 wt%
       11023  -0.0145  $ Na     1.45 wt%
       12000  -0.0786  $ Mg     7.86 wt%
       13027  -0.0558  $ Al     5.58 wt%
       14000  -0.1612  $ Si    16.12 wt%
       20000  -0.2340  $ Ca    23.40 wt%
       26000  -0.0516  $ Fe     5.16 wt%
c
c       air (1.225e-3 g/cc)
c
m6      7014  -0.755   $ N      75.5 wt%
        8016  -0.232   $ O      23.2 wt%
       18000  -0.013   $ Ar      1.3 wt%
c
c    source in ES-3100 Fuel Ring
c
sdef pos=0 0 11.195 erg=D1 RAD=D3 ext=D2 axs=0 0 1
c
c       source = 1.061e+06 * 21.126e+03 * 1.0e+03 = 2.2415e+13
c
c ORIGEN Spectrum
c
si1     0.01
        0.05         0.10        0.20         0.30        0.40         0.60
        0.80         1.00        1.33         1.66        2.00         2.50
        3.00         4.00        5.00         6.50        8.00         10.00
sp1     0.0
        0.0          5.553e+05   1.293e+05    5.114e+04   2.830e+05   2.696e+04
        2.755e+03    1.513e+03   2.224e+02    6.258e+02   5.227e+01   1.156e-01
        1.005e+04    9.555e-03   2.958e-03    1.134e-03   2.130e-04   4.387e-05
si2 0.0 63.5
sp2 -21 0.0
si3   0.0  6.35
sp3   -21     1.0
c
c  segmented volume detectors
c
f4:p  14  16                  $ side segmented volume detectors
fm4   2.2415e+13
fs4  -201 -202 -203 -204 -205 -206 -207 -208 -209 -210  &
     -211 -212 -213 -214 -215 -216 -217 -218 -219 -220  &
     -221 -222 -223 -224 -225 -226 -227 -228 -229 -230  &
     -231 -232 -233 -234 -235 -236 -237 -238 -239 -240  &
     -241 -242 -243 -244 -245 -246 -247 -248 -249 -250  &
     -251 -252 -253
c
f14:p  22  24                  $ top segmented volume detectors
fm14   2.2415e+13
fs14  -301 -302 -303 -304 -305 -306 -307 -308 -309 -310 -311 -312
c
f24:p  18  20                  $ bottom segmented volume detectors
fm24   2.2415e+13
fs24  -301 -302 -303 -304 -305 -306 -307 -308 -309 -310 -311 -312
c
c  point detectors
c
f5:p   24.1775 0.0 42.945 0.0     $ side surface detector
```

```
fm5    2.2415e+13
f15:p  0.0 0.0 108.715 0.0       $ top surface detector
fm15   2.2415e+13
f25:p  0.0 0.0 -1.0 0.0          $ bottom surface detector
fm25   2.2415e+13
f35:p  123.1775 0.0 42.945 0.0   $ 1m from side surface detector
fm35   2.2415e+13
f45:p  0.0 0.0 207.715 0.0       $ 1m from top surface detector
fm45   2.2415e+13
f55:p  0.0 0.0 -100.0 0.0        $ 1m from bottom surface detector
fm55   2.2415e+13
c
fcl:p  0 9r 1 0 1 0 1 0 1 0 1 0 1 0 0 0
phys:p 100  0  1                 $ no coherent scattering
fq0 f s d
c
c ANSI/ANS-6.1.1-1977 photon flux to dose rate conversion factor
c                                          (rem/h)/(photons/s/cm2)
c
de0         0.01      0.03      0.05      0.07       0.1      0.15      0.20
            0.25      0.30      0.35      0.40      0.45      0.50      0.55
            0.60      0.65      0.70      0.8        1.0       1.4       1.8
            2.2       2.6       2.8       3.25      3.75      4.25      4.75
            5.00      5.25      5.75      6.25      6.75      7.50       9.0
            11.0      13.0      15.0
c
df0      3.96e-6   5.82e-7   2.90e-7   2.58e-7   2.83e-7   3.79e-7   5.01e-7
         6.31e-7   7.59e-7   8.78e-7   9.85e-7   1.08e-6   1.17e-6   1.27e-6
         1.36e-6   1.44e-6   1.52e-6   1.68e-6   1.98e-6   2.51e-6   2.99e-6
         3.42e-6   3.82e-6   4.01e-6   4.41e-6   4.83e-6   5.23e-6   5.60e-6
         5.80e-6   6.01e-6   6.37e-6   6.74e-6   7.11e-6   7.66e-6   8.77e-6
         1.03e-5   1.18e-5   1.33e-5
c
prdmp  j  100000 0 10
ctme 300
```

### 5.5.1.3 Hypothetical Accident Condition (HAC) for 36-kg metal photon case

```
mp04.inp - ES-3100: HAC - with shell type fuel configuration
c
c    HAC configuration
c
c    all air spaces are made void
c    side, top, and bottom segmented detectors
c    surface detectors are placed 1 cm away from the surfaces
c    point detectors are placed on the side, top, and bottom
c    800 ppm transuranics
c    10.5 yr decay photon spectrum
c
c    --------------
c     Cell Cards
c    --------------
c
c  SPR-3 Fuel Material Original Deck from SNL
c
    1     0             -1      imp:p=2 $ inner most void
    2     1   -18.82     1 -2   imp:p=1 $ fuel
    3     0              2 -3   imp:p=2 $ void
    4     3   -7.92      3 -4   imp:p=4 $ vessel
    5     6   -0.001225  4 -5   imp:p=8 $ void
    6     6   -0.001225  5 -6   imp:p=8 $ ss liner
```

```
    7     6   -0.001225   6 -7   imp:p=16 $ cat-277-4
    9     6   -0.001225   7 -8   imp:p=16 $ ss liner
   10     6   -0.001225   8 -9   imp:p=32 $ kaolite
   11     6   -0.001225   9 -10  imp:p=32 $ void
   12     6   -0.001225  10 -11  imp:p=64 $ drum
   25     0              11 -99  imp:p=64 $ inside boundary
   99     0              99      imp:p=0 $ outside world

c    ------------------
c    Surface Cards
c    ------------------
   1   rcc  0.0 0.0 11.195  0.0 0.0 76.2      5.6861 $ void
   2   rcc  0.0 0.0 11.195  0.0 0.0 76.2      6.35   $ fuel
   3   rcc  0.0 0.0 11.195  0.0 0.0 76.2      6.4008 $ void
   4   rcc  0.0 0.0 10.560  0.0 0.0 77.47     6.6548 $ vessel
   5   rcc  0.0 0.0 10.560  0.0 0.0 77.47     7.9248 $ void
   6   rcc  0.0 0.0 10.560  0.0 0.0 77.47     8.0748 $ ss
   7   rcc  0.0 0.0 10.560  0.0 0.0 77.47    10.9196 $ cat-277-4
   8   rcc  0.0 0.0 10.260  0.0 0.0 77.92    11.0696 $ ss
   9   rcc  0.0 0.0  0.260  0.0 0.0 87.92    23.0275 $ kaolite
  10   rcc  0.0 0.0  0.260  0.0 0.0 107.305  23.0275 $ kaolite+top void
  11   rcc  0.0 0.0  0.000  0.0 0.0 107.715  23.1775 $ drum
  99   sph  0.0 0.0  0.000  999.0                   $ boundary
c

c    ----------------------
c    Data Cards
c    ----------------------
mode  p
c
c      uranium metal (18.82 g/cc)
c
m1    92235  -0.95    $ U-235 95.00 wt%
      92238  -0.05    $ U-238  5.00 wt%
c
c      UO2 (10.960 gm/cc)
c
m2     8016  -0.1198  $ O     11.98 wt%
      92235  -0.8362  $ U-235 83.62 wt%
      92238  -0.0440  $ U-238  4.40 wt%
c
c      ss 304 (7.92 g/cc)
c
m3    24000  -0.1900  $ Cr 19.00 wt%
      28000  -0.0950  $ Ni  9.50 wt%
      26000  -0.6950  $ Fe 69.50 wt%
      25000  -0.0200  $ Mn  2.00 wt%
c
c      cat 277-4 (1.682 g/cc)
c
m4      1001  -0.0462  $ H      4.62 wt%
        5010  -0.0079  $ B-10   0.79 wt%
        5011  -0.0344  $ B-11   3.44 wt%
        6012  -0.0151  $ C      1.51 wt%
        8016  -0.6000  $ O     60.00 wt%
       12000  -0.0038  $ Mg     0.38 wt%
       13027  -0.2116  $ Al    21.16 wt%
       14000  -0.0132  $ Si     1.32 wt%
       16000  -0.0015  $ S      0.15 wt%
       11023  -0.0013  $ Na     0.13 wt%
       20000  -0.0618  $ Ca     6.18 wt%
```

```
       26000  -0.0032  $ Fe     0.32 wt%
c
c      kaolite (0.321 g/cc)
c
m5      8016  -0.4043  $ O     40.43 wt%
       11023  -0.0145  $ Na     1.45 wt%
       12000  -0.0786  $ Mg     7.86 wt%
       13027  -0.0558  $ Al     5.58 wt%
       14000  -0.1612  $ Si    16.12 wt%
       20000  -0.2340  $ Ca    23.40 wt%
       26000  -0.0516  $ Fe     5.16 wt%
c
c       air (1.225e-3 g/cc)
c
m6      7014  -0.755   $ N      75.5 wt%
        8016  -0.232   $ O      23.2 wt%
       18000  -0.013   $ Ar      1.3 wt%
c
c    source in ES-3100 Fuel Ring
c
c    source term = 1.061e06 * 36000 *1.0e3 = 3.8196e+13
c
sdef pos=0 0 11.195 erg=D1 RAD=D3 ext=D2 axs=0 0 1
c
c ORIGEN Spectrum
c
si1     0.01
        0.05         0.10        0.20         0.30        0.40         0.60
        0.80         1.00        1.33         1.66        2.00         2.50
        3.00         4.00        5.00         6.50        8.00         10.00
sp1     0.0
        0.0          5.553e+05   1.293e+05    5.114e+04   2.830e+05   2.696e+04
        2.755e+03    1.513e+03   2.224e+02    6.258e+02   5.227e+01   1.156e-01
        1.005e+04    9.555e-03   2.958e-03    1.134e-03   2.130e-04   4.387e-05
si2 0.0 76.2
sp2 -21 0.0
si3   5.6861  6.35
sp3   -21     1.0
phys:p 100  0  1                 $ no coherent scattering
fcl:p 0 0 0 0 1 1 1 1 1 1 1 0 0
c
c  point detectors
c
f35:p  106.6548 0.0 49.295 0.0   $ 1m from cv side surface
fm35   3.8196e+13
f45:p  0.0 0.0 188.03 0.0        $ 1m from cv top surface
fm45   3.8196e+13
f55:p  0.0 0.0 -89.44 0.0        $ 1m from cv bottom surface
fm55   3.8196e+13
c
fq0 f s d
c
c ANSI/ANS-6.1.1-1977 photon flux to dose rate conversion factor
c                                          (rem/h)/(photons/s/cm2)
c
de0         0.01      0.03      0.05      0.07       0.1      0.15      0.20
            0.25      0.30      0.35      0.40      0.45      0.50      0.55
            0.60      0.65      0.70      0.8        1.0       1.4       1.8
            2.2       2.6       2.8       3.25      3.75      4.25      4.75
            5.00      5.25      5.75      6.25      6.75      7.50       9.0
            11.0      13.0      15.0
```

```
c
df0      3.96e-6   5.82e-7   2.90e-7   2.58e-7   2.83e-7   3.79e-7   5.01e-7
         6.31e-7   7.59e-7   8.78e-7   9.85e-7   1.08e-6   1.17e-6   1.27e-6
         1.36e-6   1.44e-6   1.52e-6   1.68e-6   1.98e-6   2.51e-6   2.99e-6
         3.42e-6   3.82e-6   4.01e-6   4.41e-6   4.83e-6   5.23e-6   5.60e-6
         5.80e-6   6.01e-6   6.37e-6   6.74e-6   7.11e-6   7.66e-6   8.77e-6
         1.03e-5   1.18e-5   1.33e-5
c
prdmp  j  100000 0 10
ctme 180
```

### 5.5.1.4 Hypothetical Accident Condition (HAC) for 24-kg oxide neutron case

```
on05.inp - ES-3100: HAC- with UO2 soild cylindrical type fuel configuration
c
c    HAC configuration
c
c    all air spaces are made void
c    side, top, and bottom segmented detectors
c    surface detectors are placed 1 cm away from the surfaces
c    point detectors are also placed on the side, top, and bottom
c    changed importance for some cells
c    6.35 cm radius, 17.286 cm height, 10.96 g/cc density UO2 solid cylinder
c    15 year decay spectrum used
c    n,p mode
c
c    --------------
c     Cell Cards
c    --------------
c
c  SPR-3 Fuel Material Original Deck from SNL
c
    2     2   -10.96     -2      imp:p=1  imp:n=1  $ fuel
    3     0               2 -3   imp:p=2  imp:n=2  $ void
    4     3   -7.92       3 -4   imp:p=2  imp:n=2  $ vessel
    5     6   -0.001225   4 -5   imp:p=4  imp:n=4  $ void
    6     6   -0.001225   5 -6   imp:p=4  imp:n=4  $ ss liner
    7     6   -0.001225   6 -7   imp:p=4  imp:n=4  $ cat-277-4
    9     6   -0.001225   7 -8   imp:p=4  imp:n=4  $ ss liner
   10     6   -0.001225   8 -9   imp:p=4  imp:n=4  $ kaolite
   11     6   -0.001225   9 -10  imp:p=4  imp:n=4  $ void
   12     6   -0.001225  10 -11  imp:p=4  imp:n=4  $ drum
   13     0              11 -99  imp:p=8  imp:n=8  $ inside boundary
   99     0              99      imp:p=0  imp:n=0  $ outside world

c    ------------------
c    Surface Cards
c    ------------------
   2   rcc  0.0 0.0 11.195  0.0 0.0 17.286    6.35   $ fuel
   3   rcc  0.0 0.0 11.195  0.0 0.0 76.2      6.4008 $ void
   4   rcc  0.0 0.0 10.560  0.0 0.0 77.47     6.6548 $ vessel
   5   rcc  0.0 0.0 10.560  0.0 0.0 77.47     7.9248 $ void
   6   rcc  0.0 0.0 10.560  0.0 0.0 77.47     8.0748 $ ss
   7   rcc  0.0 0.0 10.560  0.0 0.0 77.47    10.9196 $ cat-277-4
   8   rcc  0.0 0.0 10.260  0.0 0.0 77.92    11.0696 $ ss
   9   rcc  0.0 0.0  0.260  0.0 0.0 87.92    23.0275 $ kaolite
  10   rcc  0.0 0.0  0.260  0.0 0.0 107.305  23.0275 $ kaolite+top void
  11   rcc  0.0 0.0  0.000  0.0 0.0 107.715  23.1775 $ drum
  99   sph  0.0 0.0  0.000  999.0                   $ boundary
c
c    ----------------------
```

```
c    Data Cards
c    ----------------------
mode  n p
c
c      uranium metal (18.82 g/cc)
c
m1    92235  -0.95    $ U-235 95.00 wt%
      92238  -0.05    $ U-238  5.00 wt%
c
c      UO2 (10.960 gm/cc used variable)
c
m2     8016  -0.1198  $ O     11.98 wt%
      92235  -0.8362  $ U-235 83.62 wt%
      92238  -0.0440  $ U-238  4.40 wt%
c
c      ss 304 (7.92 g/cc)
c
m3    24000  -0.1900  $ Cr 19.00 wt%
      28000  -0.0950  $ Ni  9.50 wt%
      26000  -0.6950  $ Fe 69.50 wt%
      25055  -0.0200  $ Mn  2.00 wt%
c
c      cat 277-4 (1.682 g/cc)
c
m4      1001  -0.0462  $ H      4.62 wt%
        5010  -0.0079  $ B-10   0.79 wt%
        5011  -0.0344  $ B-11   3.44 wt%
        6012  -0.0151  $ C      1.51 wt%
        8016  -0.6000  $ O     60.00 wt%
       12000  -0.0038  $ Mg     0.38 wt%
       13027  -0.2116  $ Al    21.16 wt%
       14000  -0.0132  $ Si     1.32 wt%
       16000  -0.0015  $ S      0.15 wt%
       11023  -0.0013  $ Na     0.13 wt%
       20000  -0.0618  $ Ca     6.18 wt%
       26000  -0.0032  $ Fe     0.32 wt%
c
c      kaolite (0.321 g/cc)
c
m5      8016  -0.4043  $ O     40.43 wt%
       11023  -0.0145  $ Na     1.45 wt%
       12000  -0.0786  $ Mg     7.86 wt%
       13027  -0.0558  $ Al     5.58 wt%
       14000  -0.1612  $ Si    16.12 wt%
       20000  -0.2340  $ Ca    23.40 wt%
       26000  -0.0516  $ Fe     5.16 wt%
c
c       air (1.225e-3 g/cc)
c
m6      7014  -0.755   $ N      75.5 wt%
        8016  -0.232   $ O      23.2 wt%
       18000  -0.013   $ Ar      1.3 wt%
c
c    source in ES-3100 Fuel Ring
c
c    source term = 2.110e-01 * 21.126 *1000 *1000 = 4.4576e+06 neutrons
c
sdef pos=0 0 11.195 erg=D1 RAD=D3 ext=D2 axs=0 0 1
c
c ORIGEN neutron Spectrum
c
```

```
c 4 mo
si1     3.00e-03     1.70e-02
        1.00e-01     4.00e-01     9.00e-01    1.40e+00     1.85e+00   3.00e+00
        6.43e+00     2.00e+01
sp1     0.0          1.016e-04
        1.490e-03    8.946e-03   1.560e-02    2.098e-02   2.772e-02   1.002e-01
        3.432e-02    6.994e-04
si2 0.0  17.286
sp2 -21 0.0
si3   0.0  6.35
sp3   -21     1.0
c
c  point detectors  for neutrons
c
f35:n  123.1775 0.0 19.838 0.0   $ 1m from cv side surface
fm35   4.4576e+06
f45:n  0.0 0.0 207.715 0.0       $ 1m from cv top surface
fm45   4.4576e+06
f55:n  0.0 0.0 -100.0 0.0        $ 1m from cv bottom surface
fm55   4.4576e+06
c
fcl:p 0 0 0 1 6r 0 0             $ forced collission in air
phys:p 100 0 1                   $ no coherent scattering
fq0 f s d
c
c ANSI/ANS-6.1.1-1977 neutron flux to dose rate conversion factor
c                                        (rem/h)/(neutrons/s/cm2)
c
de0         2.5e-08   1.0e-07   1.0e-06   1.0e-05   1.0e-04   1.0e-03   1.0e-02
            1.0e-01   5.0e-01   1.0       2.5       5.0       7.0       10.0
            14.0      20.0
c
df0      3.67e-06  3.67e-06  4.46e-06  4.54e-06  4.18e-06  3.76e-06  3.56e-06
         2.17e-05  9.26e-05  1.32e-04  1.25e-04  1.56e-04  1.47e-04  1.47e-04
         2.08e-04  2.27e-04
c
c  point detectors  for secondary photons
c
f95:p  106.6548 0.0 19.838 0.0    $ 1m from cv side surface
fm95   4.4576e+06
f105:p  0.0 0.0 188.03 0.0        $ 1m from cv top surface
fm105   4.4576e+06
f115:p  0.0 0.0 -89.44 0.0        $ 1m from cv bottom surface
fm115   4.4576e+06
c
c ANSI/ANS-6.1.1-1977 photon flux to dose rate conversion factor
c                                        (rem/h)/(photons/s/cm2)
c
de95        0.01   0.03   0.05   0.07   0.10   0.15   0.20
            0.25   0.30   0.35   0.40   0.45   0.50   0.55
            0.60   0.65   0.70   0.80   1.0    1.4    1.8
            2.2    2.6    2.8    3.25   3.75   4.25   4.75
            5.0    5.25   5.75   6.25   6.75   7.5    9.0
            11.0   13.0   15.0
c
df95      3.96e-06  5.82e-07  2.90e-07  2.58e-07  2.83e-07  3.79e-07  5.01e-07
         6.31e-07  7.59e-07  8.78e-07  9.85e-07  1.08e-06  1.17e-06  1.27e-06
         1.36e-06  1.44e-06  1.52e-06  1.68e-06  1.98e-06  2.51e-06  2.99e-06
         3.42e-06  3.82e-06  4.01e-06  4.41e-06  4.83e-06  5.23e-06  5.60e-06
         5.80e-06  6.01e-06  6.37e-06  6.74e-06  7.11e-06  7.66e-06  8.77e-06
         1.03e-05  1.18e-05  1.33e-05
```

```
c
de105        0.01   0.03   0.05   0.07   0.10   0.15   0.20
            0.25   0.30   0.35   0.40   0.45   0.50   0.55
            0.60   0.65   0.70   0.80   1.0    1.4    1.8
            2.2    2.6    2.8    3.25   3.75   4.25   4.75
            5.0    5.25   5.75   6.25   6.75   7.5    9.0
            11.0   13.0   15.0
c
df105      3.96e-06  5.82e-07  2.90e-07  2.58e-07  2.83e-07  3.79e-07  5.01e-07
          6.31e-07  7.59e-07  8.78e-07  9.85e-07  1.08e-06  1.17e-06  1.27e-06
          1.36e-06  1.44e-06  1.52e-06  1.68e-06  1.98e-06  2.51e-06  2.99e-06
          3.42e-06  3.82e-06  4.01e-06  4.41e-06  4.83e-06  5.23e-06  5.60e-06
          5.80e-06  6.01e-06  6.37e-06  6.74e-06  7.11e-06  7.66e-06  8.77e-06
          1.03e-05  1.18e-05  1.33e-05
c
de115        0.01   0.03   0.05   0.07   0.10   0.15   0.20
            0.25   0.30   0.35   0.40   0.45   0.50   0.55
            0.60   0.65   0.70   0.80   1.0    1.4    1.8
            2.2    2.6    2.8    3.25   3.75   4.25   4.75
            5.0    5.25   5.75   6.25   6.75   7.5    9.0
            11.0   13.0   15.0
c
df115      3.96e-06  5.82e-07  2.90e-07  2.58e-07  2.83e-07  3.79e-07  5.01e-07
          6.31e-07  7.59e-07  8.78e-07  9.85e-07  1.08e-06  1.17e-06  1.27e-06
          1.36e-06  1.44e-06  1.52e-06  1.68e-06  1.98e-06  2.51e-06  2.99e-06
          3.42e-06  3.82e-06  4.01e-06  4.41e-06  4.83e-06  5.23e-06  5.60e-06
          5.80e-06  6.01e-06  6.37e-06  6.74e-06  7.11e-06  7.66e-06  8.77e-06
          1.03e-05  1.18e-05  1.33e-05
prdmp  j  100000 0 10
ctme 90
```

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## SECTION 5 REFERENCES

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# 6. CRITICALITY EVALUATION

This section describes the criticality safety evaluation of the Y-12 National Security Complex (Y-12) Model ES-3100 package with solid highly enriched uranium (HEU) metal or alloys (specific information for alloys are addressed in Sects. 6.2.1, 6.2.4, 6.3.2, 6.4, 6.4.1, and 6.6.1), or HEU oxide, or highly enriched uranyl nitrate crystals (UNX). HEU metal or alloy may be in the form of solid shapes (cylinders, bars, buttons, billets, slugs, unirradiated TRIGA fuel), broken metal, turnings, fines, powder, or content of an unspecified geometric shape and characterized as broken metal. Distinguished from TRIGA contents, the research reactor related contents covered under this criticality evaluation are fuel elements or fuel components, broken metal, U alloys, or oxides.

A variety of similar materials from various reactor programs are being added under this revision of the criticality safety evaluation. These "additional/new" contents include bare, clad or canned uranium metal alloy or oxide in various shapes as pellets, rods, plates, bundled components and fuel assemblies. Compounds of uranium include uranium tetrafluoride, uranyl fluoride, uranium carbide, and uranium nitride. The physical form of these uranium compounds is described as powder, beads, and ash. Both content moisture and content uniformity are not defined.

Physical testing of Type-B fissile material packages for surface transportation conducted in accordance with the physical testing requirements of 10 CFR 71 is limited to the ES-3100 packaging and non-fissile dummy contents. Consequently, analytic methods are used to demonstrate compliance of the ES-3100 package with the applicable performance requirements in 10 CFR 71. The specific requirements investigated for compliance in this evaluation are contained in 10 CFR 71.55, "General Requirements of all Fissile Material Packages," and 10 CFR 71.59, "Standards for Arrays of Fissile Material Packages." Physical testing of Type-B fissile material packages transported by air is not conducted for the ES-3100. Analytic methods are also used to demonstrate compliance of the ES-3100 package with the requirements of 10 CFR 71.55(f). This is accomplished by demonstrating compliance of the package with the more stringent requirements of the International Atomic Energy Agency (IAEA) for situations where the conditions of the fissile material package following the tests cannot be demonstrated (TS-G-1.1, Sect. 680.2).

## 6.1 DESCRIPTION OF THE CRITICALITY DESIGN

### 6.1.1 Design Features

The principal design feature of interest in the criticality evaluation of the Model ES-3100 package is the containment/outer drum system (Drawing M2E801580A031, Appendix 1.3.7). The ES-3100 package uses a single containment system (Drawing M2E801580A011, Appendix 1.3.7) to contain the HEU contents. The containment is a high-integrity, watertight, post-load leak-testable, stainless-steel vessel (Fig. 1.3). The outer drum system (Drawing M2E801580A001, Appendix 1.3.7) is a recessed, double-compartment body with a removable top for insertion and removal of the containment vessel. The body weldment liner outer cavity and the top plug weldment contain Kaolite 1600 (Kaolite), a thermal insulation material that protects the containment vessel from thermal absorption, shock and impact. The body weldment liner inner cavity contains a neutron poison, "277-4," which serves as a strong neutron absorber. Other sections of this report (Sects. 2, 3, and 4) demonstrate the integrity of the ES-3100 package [i.e., that this single containment vessel remains intact and watertight under the Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC)].

Typical shipping configurations inside the ES-3100 containment vessel are illustrated in Fig. 1.4. The 277-4 canned spacers will only be used for contents shipped in metal convenience cans.

Three 4.25-in.-diam × 10.0-in.-tall or six 4.25-in.-diam × 4.88-in.-tall convenience cans separated by can pads may be placed inside the 31-in.-tall cavity of the ES-3100 containment vessel (Drawing M2E801580A035, Appendix 1.3.7). Other can arrangements fit inside the containment vessel, such as three 4.25-in.-diam × 8.75-in.-tall or five 4.25-in.-diam × 4.88-in.-tall convenience cans. Both of these can arrangements include can pads and 277-4 canned spacers with overall dimensions of 4.25-in. diam × 1.82-in. height (Drawing M2E801580A043, Appendix 1.3.7). Nickel alloy cans are ~3-in. diam × 4.75-in. tall. Up to three Teflon bottles (4.69-in. diam × 9.4-in. tall) or three polyethylene bottles (4.94-in. diam × 8.7-in. tall) will fit inside the containment vessel; however, 277-4 canned spacers are not used with these configurations. If closed convenience cans with an outer diameter >4.25 in. are used, at least 55 $in.^3$ of free or void volume must exist inside the containment vessel to allow for gas expansion and offgassing of material at temperatures associated with NCT or HAC.

A modified convenience can may be used to package the TRIGA and research reactor related contents that do not fit inside these containers. A 17.5-in.- or 30-in.-tall convenience can is constructed from two 4.25-in.-diam × 8.75-in.-tall or three 10-in. cans brazed together. The research reactor fuel elements and fuel components that cannot be packaged in these convenience cans due to their overall dimensions will be bundled together and protected on each end with an open-ended convenience can having an outer diameter ≤ 5 in. Solid form HEU contents (i.e., spheres, cylinders, bars, slugs, etc.) that will not fit in a 4.25-in. convenience can may be bagged only with no convenience can required around the content. For contents that are bagged only, stainless-steel metal scrubbers may be placed on the top and bottom of this assembly inside the containment vessel. For these bagged contents, the void volume requirement stated in Loading Restriction 8 (Sect. 1.2.2.8) must still be satisfied.

Credit is not taken in this criticality analysis for fissile material spacing provided by the presence of the convenience cans or bottles inside the containment vessel. These containers are not manufactured to the American Society of Mechanical Engineers *Boiler and Pressure Vessel Code*, Sect. III, Subsection NG, or better.

### 6.1.2 Codes and Standards

Testing conducted in accordance with the physical testing requirements of 10 CFR 71 demonstrated that water leakage into the containment is not a credible event under the NCT and HAC. As directed, credit for the high-integrity, watertight containment is not taken in this criticality evaluation per discussions held at public meetings at the U.S. Nuclear Regulatory Commission (Docket 71-9315).

Liquid HEU is not being shipped in the ES-3100. With the exception of UNX crystals, the other uranium contents being shipped are not soluble in water and do not form solutions. The hypothetical occurrence of uranyl nitrate solution is evaluated as a consequence of evaluating the presence of water inside the containment vessel. Thus, uranyl nitrate solution is evaluated even though it is not shipped as an approved package content in the ES-3100.

10 CFR 71.55(b) requires the evaluation of water leakage into the containment vessel or leakage of liquid contents out of the containment vessel and other conditions that produce maximum reactivity in the single package. For solid uranium contents, water leakage conditions are simulated by flooding all regions outside and inside of the containment vessel, including the sealed convenience cans. For liquid uranium "contents," water leakage conditions are simulated by flooding all regions outside the containment vessel except the containment vessel well. The uranyl nitrate (UN) solution resides inside both the containment vessel well and the containment vessel, including the Teflon bottles. Per 10 CFR 71.55(b), a flooded containment vessel under full water reflection is also evaluated. Under such leakage conditions, the calculated neutron multiplication factor ($k_{eff} + 2\sigma$) for the ES-3100 package with HEU contents is lower than the upper subcritical limit (USL) for a subcritical system. Water inleakage into the containment vessel or liquid content leakage out of the containment vessel will not produce

a criticality in the containment vessel of a disassembled package or an assembled single package. Therefore, the Model ES-3100 shipping package complies with all of the requirements of 10 CFR 71.55(b) and (d).

While the loss of containment is deemed incredible by merit of the results of the physical tests performed under 10 CFR 71.71 and 10 CFR 71.73, credit for the high-integrity, watertight containment is not taken in the single package analysis [10 CFR 71.55(d) and (e)]. Only partial credit is taken in the package array analysis (10 CFR 71.59). In both the single package and package array analyses, the containment vessel is flooded with water. This fictitious "evaluation" water provides moderation to such an extent as to cause maximum reactivity of the content consistent with the chemical and physical form of the material present. While UN crystals are soluble in water, leakage of UN solution out of the containment vessel for undamaged packages under 10 CFR 71.59 (a)(1) or damaged packages under 10 CFR 71.59 (a)(2) is not considered credible during NCT or HAC based on results for tests specified in 10 CFR 71.71 and 10 CFR 71.73. Because credit for the high-integrity, watertight containment is not fully taken in the criticality evaluation, the fissile mass loading limits are very conservative.

The NCT tests under 10 CFR 71.71 and the HAC tests under 10 CFR 71.73 demonstrate that containment is not breached. Nevertheless, containment vessel flooding is assumed in the criticality calculations performed for the derivation of fissile material loading limits. The 7.1–10.1 kg quantities of evaluation water in both the NCT and HAC criticality calculations are not actually present in the containment vessel. Simulation of this condition in the criticality calculations produces fissile material content that is more reactive than actual.

The 7.1–10.1 kg quantity of evaluation water does not necessarily bound reasonable amounts of hydrogenous packing material present inside the containment vessel when the fissile material is in particulate form (primarily HEU oxides and UNX crystals) or must be evaluated as particulate matter (broken metal). Packing materials include can pads, polyethylene bags, vinyl tape, and polyethylene or Teflon bottles, if used. An administrative criticality control is used to restrict the amount of hydrogenous packing material normally present inside the containment vessel (Item 7 in Sect. 6.2.4).

Under NCT and HAC, three parameters that affect criticality and may vary during transport of the Model ES-3100 package are the number of packages transported, the amount of water present in the package, and the volatile (organic material) contents of the package. The number of packages transported is limited by the criticality safety index (CSI) established by this criticality evaluation. Both the amount of water present in the package and the volatile (organic material) contents of the package are parameters for the following reasons. First, volatile materials can be driven off at the high temperatures of HAC. Second, the inherent water content of the Kaolite in NCT and the water absorption by the Kaolite in HAC are unknowns. These parameters determine a variety of competing effects that govern the fission process, including, but not limited to, mass, moderation, absorption, and reflection. To ensure that all effects are adequately included in this criticality evaluation, the range of these parameters is evaluated.

It is possible for accidents to be significantly more severe in the air transport mode than in the surface transport mode. Thus, the performance requirements for packages designed to be transported by air are more stringent. These requirements address separate aspects of the accident assessment and apply only to the criticality evaluation of an individual package under isolation (TS-G-1.1). For a fissile material package designed to be transported by air, 10 CFR 71.55(f) requires that the criticality evaluation demonstrate that the package be subcritical assuming reflection by 20 cm (7.9 in.) of water but no water inleakage when subjected to the sequential application of the HAC free drop and crush tests of 10 CFR 71.73(c)(1 and 2) and the modified puncture and thermal tests of 10 CFR 71.55(f)(1)(iii and iv). 10 CFR 71.55(f)(2) requires the criticality evaluation demonstrate that the package be subcritical,

assuming reflection by 20 cm (7.9 in.) of water but no water inleakage, when subjected to an impact on an unyielding surface of 90 m/s normal to the surface.

The ES-3100 package was not subjected to physical testing of Type-C fissile material packages transported by air as specified in IAEA TS-R-1, Sect. 680. Instead, analytic methods are used to demonstrate compliance of the ES-3100 package with the requirements of 10 CFR 71.55(f). This is accomplished by demonstrating compliance of the package with the more stringent requirements imposed by the IAEA for situations where the conditions of the fissile material package following the tests cannot be demonstrated (TS-G-1.1, Sect. 680.2). Section 680.2 of TS-G-1.1 states that worst-case assumptions regarding the geometric arrangement of the package and contents should be made in the criticality evaluation taking into account all moderating and structural components of the packaging. The assumptions should be in conformity with the potential worst-case effects of the mechanical and thermal tests, and all package orientations should be considered for the analysis. Subcriticality must be demonstrated after due consideration of such aspects as the efficiency of the moderator, loss of neutron absorbers, rearrangement of packaging components and contents, geometry changes, and temperature effects. Given that the requirements of 10 CFR 71.55(f) mirror the IAEA requirements of TS-R-1, Sect. 680, for Type B(U) fissile material packages, this approach is considered an acceptable one.

### 6.1.3 Summary of the Criticality Evaluation

The following criticality evaluation shows that the Model ES-3100 package with designated content satisfies the requirements of 10 CFR 71.55 and 71.59 for surface transport, and of 10 CFR 71.55(f) for air transport. Designated contents are **solid** HEU metal or alloy of specified shape (cylinders, bars, buttons, billets, slugs, and unirradiated TRIGA fuel), broken metal, turnings, fines, or powder; **solid** HEU metal or alloy of unspecified geometric shape and characterized as broken metal; HEU product or skull oxides; or UNX crystals. HEU skull oxides are distinguished from product oxides ($UO_2$, $U_3O_8$, or $UO_3$) as being a residue of graphite and oxidized uranium ($U_3O_8$) recovered in the casting process. The criticality evaluation of these contents is addressed in the main subsections of this chapter. The criticality evaluation of the "additional/new" contents from the various reactor programs not covered under the initial evaluation is addressed in Appendix 6.9.8 as explained therein.

Tables 6.1a–6.1f pertain to surface-only modes of transportation. The column headings across the tables identify content and 277-4 canned spacer configurations. The tables are organized into groups of rows, which identify the defining calculations for addressing the performance requirements of 10 CFR 71.55(b), 71.55(d), 71.55(e), or 71.59 (see "Conditions" column). The defining calculations are also discussed in Sects. 6.4, 6.5, or 6.6, as appropriate. The KENO V.a input listings for the calculations are provided in Appendix 6.9.7. The rows within the groups cite the specific requirements stated in the CFR paragraphs and provide details regarding how these conditions are addressed or treated in the defining calculations for each content and 277-4 canned spacer configuration listed in a table column. Results of the criticality evaluation are summarized in Tables 6.1a and 6.1b for **solid** HEU metal in the form of specified shape (cylinders, bars, buttons, billets, and slugs); Table 6.1c for HEU broken metal or **solid** HEU metal of unspecified geometric shape and characterized as broken metal; Table 6.1d for HEU metal in the form of turnings, fines, or powder; Table 6.1e for HEU product and skull oxide; and Table 6.1f for UNX crystals and unirradiated TRIGA reactor fuel elements.

**Table 6.1a. Summary of criticality evaluation for solid HEU metal cylinders and bars**

| Conditions | Cylinders (d ≤ 3.24 in.) no can spacers | Cylinders (d ≤ 3.24 in.) with can spacers | Square bars (l,w ≤ 2.29 in.) no can spacers | Cylinders (3.24 < d ≤ 4.25 in.) no can spacers | Cylinders (3.24 < d ≤ 4.25 in.) with can spacers |
|---|---|---|---|---|---|
| **General requirements for each fissile package (§71.55)** | | | | | |
| "A package used for shipment of fissile material must be so designed and constructed and its contents so limited that it would be subcritical if water were to leak into the containment system, . . . so that under the following conditions, maximum reactivity of the fissile material would be attained:" (Paragraph "b") | $k_{eff} + 2\sigma \leq 0.9228$ cvcrcyt11_21_1 | $k_{eff} + 2\sigma \leq 0.8866$ cvcrcyt11_36_2 | $k_{eff} + 2\sigma \leq 0.8787$ cvcrsqt11_36_1 | $k_{eff} + 2\sigma \leq 0.9215$ cvcrcyct11_17_1 | $k_{eff} + 2\sigma \leq 0.9202$ cvcrcyct11_32_2 |
| (1) the most reactive credible configuration consistent with the chemical and physical form of the material, | 3 stacked cylinders (d = 3.24 in.) 1 cylinder per convenience can, no can spacers, 21,000-g $^{235}U$ | 3 stacked cylinders (d = 3.24 in.) 1 cylinder per convenience can, with can spacers, 36,000-g $^{235}U$ | 3 stacked bars (l,w = 2.29 in.) 1 bar per convenience can, no can spacers, 36,000-g $^{235}U$ | 3 stacked cylinders (d = 4.25 in.) 1 cylinder per convenience can, no can spacers, 17,000-g $^{235}U$ | 3 stacked cylinders (d = 4.25 in.) 1 cylinder per convenience can, with can spacers, 32,000-g $^{235}U$ |
| (2) moderation by water to the most reactive credible extent, | Flooding of the containment vessel | Same | Same | Same | Same |
| (3) close full reflection of the containment system by water on all sides, or such greater reflection of the containment system as may be provided by the surrounding material of the packaging. | 30.48-cm $H_2O$ surrounding the containment vessel | Same | Same | Same | Same |

**Table 6.1a. Summary of criticality evaluation for solid HEU metal cylinders and bars**

| Conditions | Cylinders ($d \leq 3.24$ in.) no can spacers | Cylinders ($d \leq 3.24$ in.) with can spacers | Square bars ($l,w \leq 2.29$ in.) no can spacers | Cylinders ($3.24 < d \leq 4.25$ in.) no can spacers | Cylinders ($3.24 < d \leq 4.25$ in.) with can spacers |
|---|---|---|---|---|---|
| "A package used for shipment of fissile material must be so designed and constructed and its contents so limited under the tests specified in §71.71 (Normal Conditions of Transport) . . ." (Paragraph "d") | | | | | |
| (1) the contents would be subcritical, | $k_{eff} + 2\sigma \leq 0.9035$ ncsrcyt11_21_1_15 | $k_{eff} + 2\sigma \leq 0.8731$ ncsrcyt11_36_2_15 | $k_{eff} + 2\sigma \leq 0.8652$ ncsrsqt11_36_1_15 | $k_{eff} + 2\sigma \leq 0.8941$ ncsrcyct11_17_1_15 | $k_{eff} + 2\sigma \leq 0.8946$ ncsrcyct11_32_2_15 |
| (2) the geometric form of the package contents would not be substantially altered, | 3 stacked cylinders (d = 3.24 in.) 1 cylinder per convenience can, no can spacers, 21,000-g $^{235}U$ | 3 stacked cylinders (d = 3.24 in.) 1 cylinder per convenience can, with can spacers, 36,000-g $^{235}U$ | 3 stacked bars (l,w = 2.29 in.) 1 bar per convenience can, no can spacers, 36,000-g $^{235}U$ | 3 stacked cylinders (d = 4.25 in.) 1 cylinder per convenience can, no can spacers, 17,000-g $^{235}U$ | 3 stacked cylinders (d = 4.25 in.) 1 cylinder per convenience can, with can spacers, 32,000-g $^{235}U$ |
| (3) there would be no leakage of water into the containment system unless, in the evaluation of undamaged packages under §71.59(a)(1), it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material, | Moderation is present to such an extent as to cause maximum reactivity | Same | Same | Same | Same |
| (4) there will be no substantial reduction in the effectiveness of the packaging . . . . | 30.48-cm $H_2O$ surrounding the drum (d=18.37 in., h=43.5 in.) | Same | Same | Same | Same |

**Table 6.1a. Summary of criticality evaluation for solid HEU metal cylinders and bars**

| Conditions | Cylinders (d ≤ 3.24 in.) no can spacers | Cylinders (d ≤ 3.24 in.) with can spacers | Square bars (l,w ≤ 2.29 in.) no can spacers | Cylinders (3.24 < d ≤ 4.25 in.) no can spacers | Cylinders (3.24 < d ≤ 4.25 in.) with can spacers |
|---|---|---|---|---|---|
| "A package used for shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in §71.73 (Hypothetical Accident Conditions) the package would be subcritical. For this determination, it must be assumed that:" (Paragraph "e") | $k_{eff} + 2\sigma \leq 0.9044$ hcsrcyt12_21_1_15 | $k_{eff} + 2\sigma \leq 0.8734$ hcsrcyt12_36_2_15 | $k_{eff} + 2\sigma \leq 0.8642$ hcsrsqt12_36_1_15 | $k_{eff} + 2\sigma \leq 0.8979$ hcsrcyct12_17_1_15 | $k_{eff} + 2\sigma \leq 0.8977$ hcsrcyct12_32_2_15 |
| (1) the fissile material is in the most reactive credible configuration consistent with the chemical and physical form of the contents, | 3 stacked cylinders (d = 3.24 in.) 1 cylinder per convenience can, no can spacers, 21,000-g $^{235}U$ | 3 stacked cylinders (d = 3.24 in.) 1 cylinder per convenience can, with can spacers, 36,000-g $^{235}U$ | 3 stacked bars (l,w = 2.29 in.) 1 bar per convenience can, no can spacers, 36,000-g $^{235}U$ | 3 stacked cylinders (d = 4.25 in.) 1 cylinder per convenience can, no can spacers, 17,000-g $^{235}U$ | 3 stacked cylinders (d = 4.25 in.) 1 cylinder per convenience can, with can spacers, 32,000-g $^{235}U$ |
| (2) water moderation occurs to the most reactive credible extent consistent with the chemical and physical form of content, | Flooding of the package | Same | Same | Same | Same |
| (3) there is full reflection by water on all sides, as close as is consistent with the damage condition of the package. | 30.48-cm $H_2O$ surrounding the reduced diameter drum (d=17.20 in., h=43.5 in.) | Same | Same | Same | Same |

**Table 6.1a. Summary of criticality evaluation for solid HEU metal cylinders and bars**

| Conditions | Cylinders ($d \leq 3.24$ in.) no can spacers | Cylinders ($d \leq 3.24$ in.) with can spacers | Square bars ($l,w \leq 2.29$ in.) no can spacers | Cylinders ($3.24 < d \leq 4.25$ in.) no can spacers | Cylinders ($3.24 < d \leq 4.25$ in.) with can spacers |
|---|---|---|---|---|---|
| **Standards for arrays of fissile material packages (§71.59)** | | | | | |
| " . . . the designer of a fissile material package shall derive a number "N" based on all the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close reflection on all sides of the stack by water:" (Paragraph "a") | | | | | |
| **Transport index based on nuclear criticality control, CSI = 0.0** | **Load-limited to 18,000-g $^{235}$U, no can spacers** | **Load-limited to 30,000-g $^{235}$U, can spacers** | **Load-limited to 30,000-g $^{235}$U, no can spacers** | **Load-limited to 15,000-g $^{235}$U, no can spacers** | **Load-limited to 25,000-g $^{235}$U, can spacers** |
| (1) five times "N" undamaged packages with nothing between the packages would be subcritical, | $k_{eff} + 2\sigma \leq 0.9237$ nciacyt11_18_1_3 | $k_{eff} + 2\sigma \leq 0.9195$ nciacyt11_30_2_3 | $k_{eff} + 2\sigma \leq 0.9219$ nciasqt11_30_1_3 | $k_{eff} + 2\sigma \leq 0.8992$ nciacyct11_15_1_3 | $k_{eff} + 2\sigma \leq 0.9147$ nciacyct11_25_2_3 |
| (2) two times "N" damaged packages, if each package were subject to the tests specified in §71.73 (Hypothetical Accident Conditions) would be subcritical with optimum interspersed hydrogenous moderation, | $k_{eff} + 2\sigma \leq 0.9230$ hciacyt12_18_1_3 | $k_{eff} + 2\sigma \leq 0.9220$ hciacyt12_30_2_3 | $k_{eff} + 2\sigma \leq 0.9221$ hciasqt12_30_1_3 | $k_{eff} + 2\sigma \leq 0.8986$ hciacyct12_15_1_3 | $k_{eff} + 2\sigma \leq 0.9156$ hciacyct12_25_2_3 |
| (3) the value of "N" not <0.5. | $N(1,2) = \infty$ | Same | Same | Same | Same |
| **Transport index based on nuclear criticality control, CSI = 0.0** | | | **Load-limited to 36,000-g $^{235}$U, can spacers** | | |
| (1) five times "N" undamaged packages . . . . | | | $k_{eff} + 2\sigma \leq 0.8961$ nciasqt11_36_2_3 | | |
| (2) two times "N" damaged packages, . . . . | | | $k_{eff} + 2\sigma \leq 0.8946$ hciasqt12_36_2_3 | | |
| (3) the value of "N" . . . . | | | $N(1,2) = \infty$ | | |

**Table 6.1b. Summary of criticality evaluation for solid HEU metal slugs**

| Conditions | Slugs, no can spacers<br>enr. ≤ 100%<br>≤ 18,277-g $^{235}$U | Slugs with can spacers<br>80% < enr. ≤ 100%<br>< 36,555-g $^{235}$U | Slugs with can spacers<br>enr. ≤ 80%<br>< 36,555-g $^{235}$U |
|---|---|---|---|
| **General requirements for each fissile package (§71.55)** | | | |
| "A package used for shipment of fissile material must be so designed and constructed and its contents so limited that it would be subcritical if water were to leak into the containment system, . . . so that under the following conditions, maximum reactivity of the fissile material would be attained:" (Paragraph "b") | $k_{eff} + 2\sigma \leq 0.9098$<br>cvcr5st11_1_1 | $k_{eff} + 2\sigma \leq 0.9029$<br>cvcr5st11_2_2 | |
| (1) the most reactive credible configuration consistent with the chemical and physical form of the material, | Cluster of 5 slugs (d = 1.5625 in., h = 2.0625 in.) per convenience can, no can spacers, 18,277-g $^{235}$U | Cluster of 10 slugs stacked 2 high per convenience can, can spacers, 36,555-g $^{235}$U | |
| (2) moderation by water to the most reactive credible extent, | Flooding of the containment vessel | Same | |
| (3) close full reflection of the containment system by water on all sides, or such greater reflection of the containment system as may be provided by the surrounding material of the packaging. | 30.48-cm $H_2O$ surrounding the containment vessel | Same | |
| "A package used for shipment of fissile material must be so designed and constructed and its contents so limited under the tests specified in §71.71 (Normal Conditions of Transport) . . ." (Paragraph "d") | | | |
| (1) the contents would be subcritical, | $k_{eff} + 2\sigma \leq 0.8834$<br>ncsr5st11_1_1_15 | $k_{eff} + 2\sigma \leq 0.8781$<br>ncsr5st11_2_2_15 | |
| (2) the geometric form of the package contents would not be substantially altered, | Cluster of 5 slugs (d = 1.5625 in., h = 2.0625 in.) per convenience can, no can spacers, 18,277-g $^{235}$U | Cluster of 10 slugs stacked 2 high per convenience can, can spacers, 36,555-g $^{235}$U | |
| (3) there would be no leakage of water into the containment system unless, in the evaluation of undamaged packages under §71.59(a)(1), it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material, | Moderation is present to such an extent as to cause maximum reactivity | Same | |
| (4) there will be no substantial reduction in the effectiveness of the packaging . . . . | 30.48-cm $H_2O$ surrounding the drum (d=18.37 in., h=43.5 in.) | Same | |

**Table 6.1b. Summary of criticality evaluation for solid HEU metal slugs**

| Conditions | Slugs, no can spacers<br>enr. ≤ 100%<br>≤ 18,277-g $^{235}$U | Slugs with can spacers<br>80% < enr. ≤ 100%<br>< 36,555-g $^{235}$U | Slugs with can spacers<br>enr. ≤ 80%<br>< 36,555-g $^{235}$U |
|---|---|---|---|
| "A package used for shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in §71.73 (Hypothetical Accident Conditions) the package would be subcritical. For this determination, it must be assumed that:" (Paragraph "e") | $k_{eff} + 2\sigma \leq 0.8860$<br>hcsr5st12_1_1_15 | $k_{eff} + 2\sigma \leq 0.8772$<br>hcsr5st12_2_2_15 | |
| (1) the fissile material is in the most reactive credible configuration consistent with the chemical and physical form of the contents, | Cluster of 5 slugs (d = 1.5625 in., h = 2.0625 in.) per convenience can, no can spacers, 18,277-g $^{235}$U | Cluster of 10 slugs stacked 2 high per convenience can, can spacers, 36,555-g $^{235}$U | |
| (2) water moderation occurs to the most reactive credible extent consistent with the chemical and physical form of content, | Flooding of the package | | Same |
| (3) there is full reflection by water on all sides, as close as is consistent with the damage condition of the package. | 30.48-cm $H_2O$ surrounding the reduced diameter drum (d=17.20 in., h=43.5 in.) | | Same |

**Table 6.1b. Summary of criticality evaluation for solid HEU metal slugs**

| Conditions | Slugs, no can spacers<br>enr. ≤ 100%<br>≤ 18,277-g $^{235}$U | Slugs with can spacers<br>80% < enr. ≤ 100%<br>< 36,555-g $^{235}$U | Slugs with can spacers<br>enr. ≤ 80%<br>< 36,555-g $^{235}$U |
|---|---|---|---|
| **Standards for arrays of fissile material packages (§71.59)** | | | |
| " . . . the designer of a fissile material package shall derive a number "N" based on all the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close reflection on all sides of the stack by water: " (Paragraph "a") | | | |
| **Transport index based on nuclear criticality control, CSI = 0.0** | **Load-limited to<br>enr. ≤ 95%,<br>17,374-g $^{235}$U,<br>no can spacers** | **Load-limited to<br>80% < enr. ≤ 95%<br>24,324-g $^{235}$U,<br>can spacers** | **Load-limited to<br>enr. ≤ 80%,<br>29,318-g $^{235}$U,<br>can spacers** |
| (1) five times "N" undamaged packages with nothing between the packages would be subcritical, | $k_{eff} + 2\sigma \leq 0.9077$<br>ncia5st11_1_1_7_3 | $k_{eff} + 2\sigma \leq 0.8936$<br>ncia70st11_2_7_3 | $k_{eff} + 2\sigma \leq 0.9085$<br>ncia5est11_2_2_5_3 |
| (2) two times "N" damaged packages, if each package were subject to the tests specified in §71.73 (Hypothetical Accident Conditions) would be subcritical with optimum interspersed hydrogenous moderation, | $k_{eff} + 2\sigma \leq 0.9029$<br>hcia5est12_1_1_7_3 | $k_{eff} + 2\sigma \leq 0.8946$<br>hcia70st12_2_7_3 | $k_{eff} + 2\sigma \leq 0.9100$<br>hcia5est12_2_2_5_3 |
| (3) the value of "N" not <0.5. | N(1,2) = ∞ | Same | Same |
| **Transport index based on nuclear criticality control, CSI = 0.4** | **Load-limited to<br>enr. ≤ 95%,<br>17,374-g $^{235}$U,<br>no can spacers** | **Load-limited to<br>80% < enr. ≤ 95%<br>34,749-g $^{235}$U,<br>can spacers** | **Load-limited to<br>enr. ≤ 80%,<br>29,318-g $^{235}$U,<br>can spacers** |
| (1) five times "N" undamaged packages . . . . | Bounded by CSI=0 | $k_{eff} + 2\sigma \leq 0.9200$<br>ncf15est11_2_2_7_3 | $k_{eff} + 2\sigma \leq 0.8643$<br>ncf15est11_2_2_5_3 |
| (2) two times "N" damaged packages, . . . . | Bounded by CSI=0 | $k_{eff} + 2\sigma \leq 0.9056$<br>hcf25est12_2_2_7_3 | $k_{eff} + 2\sigma \leq 0.8556$<br>hcf25est12_2_2_5_3 |
| (3) the value of "N" . . . . | N(1,2) = 202/162 | Same | Same |

**Table 6.1c. Summary of criticality evaluation for HEU broken metal or solid HEU metal of unspecified geometric shape and characterized as broken metal**

| Conditions | 95% < enr. ≤ 100% ≤ 25,894-g $^{235}$U | 90% < enr. ≤95% ≤ 27,252-g $^{235}$U | 80% < enr. ≤90% ≤ 28,334-g $^{235}$U | 70% < enr. ≤80% ≤ 28,184-g $^{235}$U | 60% < enr. ≤70% ≤ 24,693-g $^{235}$U | enr. ≤60% ≤ 35,320-g U |
|---|---|---|---|---|---|---|
| **General requirements for each fissile package (§71.55)** | | | | | | |
| "A package used for shipment of fissile material must be so designed and constructed and its contents so limited that it would be subcritical if water were to leak into the containment system, . . . so that under the following conditions, maximum reactivity of the fissile material would be attained:" (Paragraph "b") | $k_{eff} + 2\sigma \leq 0.9181$ cvr3lha_26_1_8_15 | $k_{eff} + 2\sigma \leq 0.9206$ cvr3lha_29_1_7_15 | $k_{eff} + 2\sigma \leq 0.9224$ cvr3lha_32_1_6_15 | $k_{eff} + 2\sigma \leq 0.8927$ cvr3lha_36_1_5_15 | $k_{eff} + 2\sigma \leq 0.8620$ cvr3lha_36_1_4_15 | $k_{eff} + 2\sigma \leq 0.8289$ cvr3lha_36_1_3_15 |
| (1) the most reactive credible configuration consistent with the chemical and physical form of the material, | A mixture of HEU metal and water is homogenized over the internal volume of an assumed content lattice, one per can location. The square footprint of the content lattice is circumscribed by the inner wall of the containment vessel. The amount of water in the flooded containment vessel is calculated on the basis that the convenience can steel is replaced with water. Can pads and spacers not used. See Appendix 6.9.3, Sect. 6.9.3.1, for justification of the content model. | | | | | |
| (2) moderation by water to the most reactive credible extent, | Flooding of the containment vessel | | | | | |
| (3) close full reflection of the containment system by water on all sides, or such greater reflection of the containment system as may be provided by the surrounding material of the packaging. | 30.48-cm $H_2O$ surrounding the containment vessel | | | | | |

**Table 6.1c. Summary of criticality evaluation for HEU broken metal or solid HEU metal of unspecified geometric shape and characterized as broken metal**

| Conditions | 95% < enr. ≤ 100% ≤ 25,894-g $^{235}$U | 90% < enr. ≤95% ≤ 27,252-g $^{235}$U | 80% < enr. ≤90% ≤ 28,334-g $^{235}$U | 70% < enr. ≤80% ≤ 28,184-g $^{235}$U | 60% < enr. ≤70% ≤ 24,693-g $^{235}$U | enr. ≤60% ≤ 35,320-g U |
|---|---|---|---|---|---|---|
| "A package used for shipment of fissile material must be so designed and constructed and its contents so limited under the tests specified in §71.71 (Normal Conditions of Transport) . . ." (Paragraph "d") | | | | | | |
| (1) the contents would be subcritical, | | | $k_{eff} + 2\sigma \leq 0.8908$<br>ncsrbmt11_36_1_15 | | | |
| (2) the geometric form of the package contents would not be substantially altered, | A mixture of HEU metal and water is homogenized over the internal volume of the containment vessel. The amount of water in the flooded containment vessel is calculated on the basis that the convenience can steel is replaced with water. Can pads and spacers not used. | | | | | |
| (3) there would be no leakage of water into the containment system unless, in the evaluation of undamaged packages under §71.59(a)(1), it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material, | | | Moderation is present to such an extent as to cause maximum reactivity | | | |
| (4) there will be no substantial reduction in the effectiveness of the packaging . . . . | | | 30.48-cm $H_2O$ surrounding the drum (d = 18.37 in., h = 43.5 in.) | | | |

**Table 6.1c. Summary of criticality evaluation for HEU broken metal or solid HEU metal of unspecified geometric shape and characterized as broken metal**

| Conditions | 95% < enr. ≤ 100%<br>≤ 25,894-g $^{235}$U | 90% < enr. ≤95%<br>≤ 27,252-g $^{235}$U | 80% < enr. ≤90%<br>≤ 28,334-g $^{235}$U | 70% < enr. ≤80%<br>≤ 28,184-g $^{235}$U | 60% < enr. ≤70%<br>≤ 24,693-g $^{235}$U | enr. ≤60%<br>≤ 35,320-g U |
|---|---|---|---|---|---|---|
| "A package used for shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in §71.73 (Hypothetical Accident Conditions) the package would be subcritical. For this determination, it must be assumed that:" (Paragraph "e") | $k_{eff} + 2\sigma \leq 0.8912$<br>hcsrbmt12_36_1_15 | | | | | |
| (1) the fissile material is in the most reactive credible configuration consistent with the chemical and physical form of the contents, | A mixture of HEU metal and water is homogenized over the internal volume of the containment vessel. The amount of water in the flooded containment vessel is calculated on the basis that the convenience can steel is replaced with water. Can pads and spacers not used. | | | | | |
| (2) water moderation occurs to the most reactive credible extent consistent with the chemical and physical form of content, | Flooding of the package | | | | | |
| (3) there is full reflection by water on all sides, as close as is consistent with the damage condition of the package. | 30.48-cm $H_2O$ surrounding the reduced diameter drum (d = 17.20 in., h = 43.5 in.) | | | | | |

**Table 6.1c. Summary of criticality evaluation for HEU broken metal or solid HEU metal of unspecified geometric shape and characterized as broken metal**

| Conditions | 95% < enr. ≤ 100% ≤ 25,894-g $^{235}$U | 90% < enr. ≤95% ≤ 27,252-g $^{235}$U | 80% < enr. ≤90% ≤ 28,334-g $^{235}$U | 70% < enr. ≤80% ≤ 28,184-g $^{235}$U | 60% < enr. ≤70% ≤ 24,693-g $^{235}$U | enr. ≤60% ≤ 35,320-g U |
|---|---|---|---|---|---|---|
| **Standards for arrays of fissile material packages (§71.59)** | | | | | | |
| " . . . the designer of a fissile material package shall derive a number "N" based on all the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close reflection on all sides of the stack by water: " (Paragraph "a") | | | | | | |
| **Transport index based on nuclear criticality control, CSI = 0.0** | **Can spacers required** | **Can spacers required** | **Can spacers required** | **Load-limited to 2,967-g $^{235}$U, no can spacers** | **Load-limited to 3,249-g $^{235}$U, no can spacers** | **Load-limited to 5,577-g U, no can spacers** |
| (1) five times "N" undamaged packages with nothing between the packages would be subcritical, | Not applicable | Not applicable | Not applicable | $k_{eff} + 2\sigma \leq 0.9213$ nciabmt11_4_1_5_3 | $k_{eff} + 2\sigma \leq 0.9207$ nciabmt11_5_1_4_3 | $k_{eff} + 2\sigma \leq 0.9152$ nciabmt11_6_1_3_3 |
| (2) two times "N" damaged packages, if each package were subject to the tests specified in §71.73 (Hypothetical Accident Conditions) would be subcritical with optimum interspersed hydrogenous moderation, | Not applicable | Not applicable | Not applicable | $k_{eff} + 2\sigma \leq 0.9248$ hciabmt12_4_1_5_3 | $k_{eff} + 2\sigma \leq 0.9235$ hciabmt12_5_1_4_3 | $k_{eff} + 2\sigma \leq 0.9127$ hciabmt12_6_1_3_3 |
| (3) the value of "N" cannot be <0.5. | Not applicable | Not applicable | Not applicable | N(1,2) = ∞ | Same | Same |

**Table 6.1c. Summary of criticality evaluation for HEU broken metal or solid HEU metal of unspecified geometric shape and characterized as broken metal**

| Conditions | 95% < enr. ≤ 100% ≤ 25,894-g $^{235}$U | 90% < enr. ≤95% ≤ 27,252-g $^{235}$U | 80% < enr. ≤90% ≤ 28,334-g $^{235}$U | 70% < enr. ≤80% ≤ 28,184-g $^{235}$U | 60% < enr. ≤70% ≤ 24,693-g $^{235}$U | enr. ≤60% ≤ 35,320-g U |
|---|---|---|---|---|---|---|
| **Transport index based on nuclear criticality control, CSI = 0.0** | **Load-limited to 2,774-g $^{235}$U, can spacers** | **Load-limited to 3,516-g $^{235}$U, can spacers** | **Load-limited to 3,333-g $^{235}$U, can spacers** | **Load-limited to 4,450-g $^{235}$U, can spacers** | **Load-limited to 5,198-g $^{235}$U, can spacers** | **Load-limited to 11,154-g U, can spacers** |
| (1) five times "N" undamaged packages . . . | $k_{eff} + 2\sigma \leq 0.9041$ nciabmt11_3_2_8_3 | $k_{eff} + 2\sigma \leq 0.9199$ nciabmt11_4_2_7_3 | $k_{eff} + 2\sigma \leq 0.9084$ nciabmt11_4_2_6_3 | $k_{eff} + 2\sigma \leq 0.9224$ nciabmt11_6_2_5_3 | $k_{eff} + 2\sigma \leq 0.9218$ nciabmt11_8_2_4_3 | $k_{eff} + 2\sigma \leq 0.9181$ nciabmt11_12_2_3_3 |
| (2) two times "N" damaged packages, . . . . | $k_{eff} + 2\sigma \leq 0.9050$ hciabmt12_3_2_8_3 | $k_{eff} + 2\sigma \leq 0.9237$ hciabmt12_4_2_7_3 | $k_{eff} + 2\sigma \leq 0.9091$ hciabmt12_4_2_6_3 | $k_{eff} + 2\sigma \leq 0.9230$ hciabmt12_6_2_5_3 | $k_{eff} + 2\sigma \leq 0.9209$ hciabmt12_8_2_4_3 | $k_{eff} + 2\sigma \leq 0.9205$ hciabmt12_12_2_3_3 |
| (3) the value of "N" . . . | N(1,2) = ∞ | Same | Same | Same | Same | Same |
| **Transport index based on nuclear criticality control, CSI = 0.4** | **Can spacers required** | **Can spacers required** | **Can spacers required** | **Load-limited to 5,192-g $^{235}$U, no can spacers** | **Load-limited to 5,848-g $^{235}$U, no can spacers** | **Load-limited to 14,872-g U, no can spacers** |
| (1) five times "N" undamaged packages . . . . | Not applicable | Not applicable | Not applicable | $k_{eff} + 2\sigma \leq 0.9235$ ncf1bmt11_7_1_5_3 | $k_{eff} + 2\sigma \leq 0.9216$ ncf1bmt11_9_1_4_3 | $k_{eff} + 2\sigma \leq 0.9225$ ncf1bmt11_15_1_3_3 |
| (2) two times "N" damaged packages, . . . . | Not applicable | Not applicable | Not applicable | $k_{eff} + 2\sigma \leq 0.9064$ hcf2bmt12_8_1_5_3 | $k_{eff} + 2\sigma \leq 0.9118$ hcf2bmt12_12_1_4_3 | $k_{eff} + 2\sigma \leq 0.9072$ hcf2bmt12_18_1_3_3 |
| (3) the value of "N" . . . | Not applicable | Not applicable | Not applicable | N(1,2) = 202/162 | Same | Same |
| **Transport index based on nuclear criticality control, CSI = 0.4** | **Load-limited to 5,549-g $^{235}$U, can spacers** | **Load-limited to 6,154-g $^{235}$U, can spacers** | **Load-limited to 7,500-g $^{235}$U, can spacers** | **Load-limited to 8,900-g $^{235}$U, can spacers** | **Load-limited to 12,996-g $^{235}$U, can spacers** | **Load-limited to 28,813-g U, can spacers** |
| (1) five times "N" undamaged packages . . . . | $k_{eff} + 2\sigma \leq 0.9241$ ncf1bmt11_6_2_8_3 | $k_{eff} + 2\sigma \leq 0.9220$ ncf1bmt11_7_2_7_3 | $k_{eff} + 2\sigma \leq 0.9203$ ncf1bmt11_9_2_6_3 | $k_{eff} + 2\sigma \leq 0.9187$ ncf1bmt11_12_2_5_3 | $k_{eff} + 2\sigma \leq 0.9245$ ncf1bmt11_19_2_4_3 | $k_{eff} + 2\sigma \leq 0.9235$ ncf1bmt11_29_2_3_3 |
| (2) two times "N" damaged packages, . . . . | $k_{eff} + 2\sigma \leq 0.9244$ hcf2bmt12_8_2_8_3 | $k_{eff} + 2\sigma \leq 0.9232$ hcf2bmt12_11_2_7_3 | $k_{eff} + 2\sigma \leq 0.9192$ hcf2bmt12_12_2_6_3 | $k_{eff} + 2\sigma \leq 0.8964$ hcf2bmt12_12_2_5_3 | $k_{eff} + 2\sigma \leq 0.9005$ hcf2bmt12_19_2_4_3 | $k_{eff} + 2\sigma \leq 0.9112$ hcf2bmt12_36_2_3_3 |
| (3) the value of "N" . . . . | N(1,2) = 202/162 | Same | Same | Same | Same | Same |

**Table 6.1c. Summary of criticality evaluation for HEU broken metal or solid HEU metal of unspecified geometric shape and characterized as broken metal**

| Conditions | 95% < enr. ≤ 100% ≤ 25,894-g $^{235}$U | 90% < enr. ≤95% ≤ 27,252-g $^{235}$U | 80% < enr. ≤90% ≤ 28,334-g $^{235}$U | 70% < enr. ≤80% ≤ 28,184-g $^{235}$U | 60% < enr. ≤70% ≤ 24,693-g $^{235}$U | enr. ≤60% ≤ 35,320-g U |
|---|---|---|---|---|---|---|
| **Transport index based on nuclear criticality control, CSI = 0.8** | **Can spacers required** | **Can spacers required** | **Can spacers required** | **Load-limited to 8,900-g $^{235}$U, no can spacers** | **Load-limited to 13,646-g $^{235}$U, no can spacers** | **Load-limited to 28,814-g U, no can spacers** |
| (1) five times "N" undamaged packages . . . . | Not applicable | Not applicable | Not applicable | $k_{eff} + 2\sigma \leq 0.9216$ ncf2bmt11_12_1_5_3 | $k_{eff} + 2\sigma \leq 0.9234$ ncf2bmt11_20_1_4_3 | $k_{eff} + 2\sigma \leq 0.9205$ ncf2bmt11_29_1_3_3 |
| (2) two times "N" damaged packages, . . . . | Not applicable | Not applicable | Not applicable | $k_{eff} + 2\sigma \leq 0.9012$ hcf3bmt12_12_1_5_3 | $k_{eff} + 2\sigma \leq 0.9065$ hcf3bmt12_20_1_4_3 | $k_{eff} + 2\sigma \leq 0.9022$ hcf3bmt12_29_1_3_3 |
| (3) the value of "N" . . . . | Not applicable | Not applicable | Not applicable | Same | Same | Same |
| **Transport index based on nuclear criticality control, CSI = 0.8** | **Load-limited to 9,248-g $^{235}$U, can spacers** | **Load-limited to 10,549-g $^{235}$U, can spacers** | **Load-limited to 12,500-g $^{235}$U, can spacers** | **Load-limited to 16,317-g $^{235}$U, can spacers** | **Load-limited to 20,793-g $^{235}$U, can spacers** | **35,320-g U, can spacers** |
| (1) five times "N" undamaged packages . . . . | $k_{eff} + 2\sigma \leq 0.9233$ ncf2bmt11_10_2_8_3 | $k_{eff} + 2\sigma \leq 0.9221$ ncf2bmt11_12_2_7_3 | $k_{eff} + 2\sigma \leq 0.9220$ ncf2bmt11_14_2_6_3 | $k_{eff} + 2\sigma \leq 0.9193$ ncf2bmt11_21_2_5_3 | $k_{eff} + 2\sigma \leq 0.9233$ ncf2bmt11_30_2_4_3 | $k_{eff} + 2\sigma \leq 0.9064$ ncf2bmt11_36_2_3_3 |
| (2) two times "N" damaged packages, . . . . | $k_{eff} + 2\sigma \leq 0.9090$ hcf3bmt12_10_2_8_3 | $k_{eff} + 2\sigma \leq 0.9005$ hcf3bmt12_12_2_7_3 | $k_{eff} + 2\sigma \leq 0.9042$ hcf3bmt12_14_2_6_3 | $k_{eff} + 2\sigma \leq 0.9022$ hcf3bmt12_21_2_5_3 | $k_{eff} + 2\sigma \leq 0.9019$ hcf3bmt12_30_2_4_3 | $k_{eff} + 2\sigma \leq 0.8850$ hcf3bmt12_36_2_3_3 |
| (3) the value of "N" . . . . | N(1,2) = 64/73 | Same | Same | Same | Same | Same |
| **Transport index based on nuclear criticality control, CSI = 2.0 [a]** | **Can spacers required** | **Can spacers required** | **Can spacers required** | **Load-limited to 17,059-g $^{235}$U, no can spacers** | **Load-limited to 21,444-g $^{235}$U, no can spacers** | **35,320-g U, no can spacers** |
| (1) five times "N" undamaged packages . . . . | Not applicable | Not applicable | Not applicable | $k_{eff} + 2\sigma \leq 0.9223$ ncf3bmt11_22_1_5_3 | $k_{eff} + 2\sigma \leq 0.9216$ ncf3bmt11_31_1_4_3 | $k_{eff} + 2\sigma \leq 0.9045$ ncf3bmt11_36_1_3_3 |
| (2) two times "N" damaged packages, . . . . | Not applicable | Not applicable | Not applicable | $k_{eff} + 2\sigma \leq 0.8852$ hcf4bmt12_22_1_5_3 | $k_{eff} + 2\sigma \leq 0.8858$ hcf4bmt12_31_1_4_3 | $k_{eff} + 2\sigma \leq 0.8705$ hcf4bmt12_36_1_3_3 |
| (3) the value of "N" . . . . | Not applicable | Not applicable | Not applicable | N(1,2) = 29/25 | Same | Same |

**Table 6.1c. Summary of criticality evaluation for HEU broken metal or solid HEU metal of unspecified geometric shape and characterized as broken metal**

| Conditions | 95% < enr. ≤ 100% ≤ 25,894-g $^{235}$U | 90% < enr. ≤95% ≤ 27,252-g $^{235}$U | 80% < enr. ≤90% ≤ 28,334-g $^{235}$U | 70% < enr. ≤80% ≤ 28,184-g $^{235}$U | 60% < enr. ≤70% ≤ 24,693-g $^{235}$U | enr. ≤60% ≤ 35,320-g U |
|---|---|---|---|---|---|---|
| **Transport index based on nuclear criticality control, CSI = 2.0** [a] | **Load-limited to 13,872-g $^{235}$U, can spacers** | **Load-limited to 18,461-g $^{235}$U, can spacers** | **Load-limited to 20,000-g $^{235}$U, can spacers** | **Load-limited to 25,218-g $^{235}$U, can spacers** | **24,692-g $^{235}$U, can spacers** | **35,320-g U, can spacers** |
| (1) five times "N" undamaged packages . . . . | $k_{eff} + 2\sigma \leq 0.9204$ ncf3bmt11_14_2_8_3 | $k_{eff} + 2\sigma \leq 0.9239$ ncf3bmt11_20_2_7_3 | $k_{eff} + 2\sigma \leq 0.9213$ ncf3bmt11_23_2_6_3 | $k_{eff} + 2\sigma \leq 0.9216$ ncf3bmt11_32_2_5_3 | $k_{eff} + 2\sigma \leq 0.9035$ ncf3bmt11_36_2_4_3 | $k_{eff} + 2\sigma \leq 0.8745$ ncf3bmt11_36_2_3_3 |
| (2) two times "N" damaged packages, . . . . | $k_{eff} + 2\sigma \leq 0.8877$ hcf4bmt12_14_2_8_3 | $k_{eff} + 2\sigma \leq 0.8914$ hcf4bmt12_20_2_7_3 | $k_{eff} + 2\sigma \leq 0.8851$ hcf4bmt12_23_2_6_3 | $k_{eff} + 2\sigma \leq 0.8884$ hcf4bmt12_32_2_5_3 | $k_{eff} + 2\sigma \leq 0.8684$ hcf4bmt12_36_2_4_3 | $k_{eff} + 2\sigma \leq 0.8412$ hcf4bmt12_36_2_3_3 |
| (3) the value of "N" . . . . | N(1,2) = 29/25 | Same | Same | Same | Same | Same |
| **Transport index based on nuclear criticality control, CSI = 3.2 b** | **Can spacers required** | **Can spacers required** | **Can spacers required** | **Load-limited to 27,443-g $^{235}$U, no can spacers** | **24,692-g $^{235}$U, no can spacers** | **35,320-g U, no can spacers** |
| (1) five times "N" undamaged packages . . . . | Not applicable | Not applicable | Not applicable | $k_{eff} + 2\sigma \leq 0.9226$ ncf5bmt11_35_1_5_3 | $k_{eff} + 2\sigma \leq 0.9030$ ncf5bmt11_36_1_4_3 | $k_{eff} + 2\sigma \leq 0.8743$ ncf5bmt11_36_1_3_3 |
| (2) two times "N" damaged packages, . . . . | Not applicable | Not applicable | Not applicable | $k_{eff} + 2\sigma \leq 0.9052$ hcf5bmt12_35_1_5_3 | $k_{eff} + 2\sigma \leq 0.8819$ hcf5bmt12_36_1_4_3 | $k_{eff} + 2\sigma \leq 0.8542$ hcf5bmt12_36_1_3_3 |
| (3) the value of "N" . . . . | Not applicable | Not applicable | Not applicable | N(1,2) = 16/24 | Same | Same |
| **Transport index based on nuclear criticality control, CSI = 3.2** [b] | **Load-limited to 24,969-g $^{235}$U, can spacers** | **Load-limited to 26,373-g $^{235}$U, can spacers** | **28,334-g $^{235}$U, can spacers** | **28,184-g $^{235}$U, can spacers** | **24,692-g $^{235}$U, can spacers** | **35,320-g U, can spacers** |
| (1) five times "N" undamaged packages . . . . | $k_{eff} + 2\sigma \leq 0.9249$ nctf5bmt11_25_2_8_3 | $k_{eff} + 2\sigma \leq 0.9196$ nctf5bmt11_28_2_7_3 | $k_{eff} + 2\sigma \leq 0.9246$ nctf5bmt11_35_2_6_3 | $k_{eff} + 2\sigma \leq 0.8974$ nctf5bmt11_36_2_5_3 | $k_{eff} + 2\sigma \leq 0.8736$ nctf5bmt11_36_2_4_3 | $k_{eff} + 2\sigma \leq 0.8445$ nctf5bmt11_36_2_3_3 |
| (2) two times "N" damaged packages, . . . . | $k_{eff} + 2\sigma \leq 0.9089$ hctf5bmt12_25_2_8_3 | $k_{eff} + 2\sigma \leq 0.8981$ hctf5bmt12_28_2_7_3 | $k_{eff} + 2\sigma \leq 0.9032$ hctf5bmt12_35_2_6_3 | $k_{eff} + 2\sigma \leq 0.8804$ hctf5bmt12_36_2_5_3 | $k_{eff} + 2\sigma \leq 0.8532$ hctf5bmt12_36_2_4_3 | $k_{eff} + 2\sigma \leq 0.8265$ hctf5bmt12_36_2_3_3 |
| (3) the value of "N" . . . . | N(1,2) = 16/24 | Same | Same | Same | Same | Same |

[a] Neutron multiplication factors and "N" are shown for an NCT array size of 7×7×3 and an HAC array size of 5×5×2; both arrays are nearly cubic arrangements. An HAC array size is not available for CSI=1.8; therefore, CSI for NCT at 1.8 is rounded up to 2.0 as shown.

[b] Neutron multiplication factors and "N" are shown for an NCT array size of 27×3 and an HAC array size of 16×3; where packages in the planar dimension are in explicit triangular-pitch arrangement and stacked three high in the vertical direction. An NCT array size of 81 packages gives a CSI value of 3.12 (50 / 16), while an HAC array size of 48 packages gives a CSI value of 2.08 (50 / 24). The specified CSI value of 3.2 is the larger of the two numbers rounded up to the nearest tenth decimal place as shown.

**Table 6.1d. Summary of criticality evaluation for HEU metal turnings, fines, or powder**

| Conditions | 95% < enr. ≤ 100% ≤ 7,398-g $^{235}$U | 90% < enr. ≤ 95% ≤ 10,549-g $^{235}$U | 80% < enr. ≤ 90% ≤ 14,167-g $^{235}$U | 70% < enr. ≤ 80% ≤ 19,284-g $^{235}$U | 60% < enr. ≤ 70% ≤ 24,693-g $^{235}$U | enr. ≤ 60% ≤ 35,320-g U |
|---|---|---|---|---|---|---|
| **General requirements for each fissile package (§71.55)** | | | | | | |
| "A package used for shipment of fissile material must be so designed and constructed and its contents so limited that it would be subcritical if water were to leak into the containment system, . . . so that under the following conditions, maximum reactivity of the fissile material would be attained:" (Paragraph "b") | $k_{eff} + 2\sigma \leq 0.9226$ cvr3cha_8_1_8_15 | $k_{eff} + 2\sigma \leq 0.9245$ cvr3cha_12_1_7_15 | $k_{eff} + 2\sigma \leq 0.9243$ cvr3cha_16_1_6_15 | $k_{eff} + 2\sigma \leq 0.9225$ cvr3cha_25_1_5_15 | $k_{eff} + 2\sigma \leq 0.9198$ cvr3cha_36_1_4_15 | $k_{eff} + 2\sigma \leq 0.9004$ cvr3cha_36_1_3_15 |
| (1) the most reactive credible configuration consistent with the chemical and physical form of the material, | A mixture of water and HEU metal as turnings, fines, or powder is homogenized over the internal volume of the containment vessel. The amount of water in the flooded containment vessel is calculated on the basis that the convenience can steel is replaced with water. Can pads and spacers not used. See Appendix 6.9.3, Sect. 6.9.3.1, for justification of the content model. | | | | | |
| (2) moderation by water to the most reactive credible extent, | Flooding of the containment vessel | | | | | |
| (3) close full reflection of the containment system by water on all sides, or such greater reflection of the containment system as may be provided by the surrounding material of the packaging. | 30.48-cm $H_2O$ surrounding the containment vessel | | | | | |

**Table 6.1d. Summary of criticality evaluation for HEU metal turnings, fines, or powder**

| Conditions | 95% < enr. ≤ 100%<br>≤ 7,398-g $^{235}$U | 90% < enr. ≤ 95%<br>≤ 10,549-g $^{235}$U | 80% < enr. ≤ 90%<br>≤ 14,167-g $^{235}$U | 70% < enr. ≤ 80%<br>≤ 19,284-g $^{235}$U | 60% < enr. ≤ 70%<br>≤ 24,693-g $^{235}$U | enr. ≤ 60%<br>≤ 35,320-g U |
|---|---|---|---|---|---|---|
| "A package used for shipment of fissile material must be so designed and constructed and its contents so limited under the tests specified in §71.71 (Normal Conditions of Transport) . . ." (Paragraph "d") | | | | | | |
| (1) the contents would be subcritical, | $k_{eff} + 2\sigma \leq 0.8908$<br>ncsrbmt11_36_1_15 | | | | | |
| (2) the geometric form of the package contents would not be substantially altered, | A mixture of HEU metal and water is homogenized over the internal volume of the containment vessel. The amount of water in the flooded containment vessel is calculated on the basis that the convenience can steel is replaced with water. Can pads and spacers not used. | | | | | |
| (3) there would be no leakage of water into the containment system unless, in the evaluation of undamaged packages under §71.59(a)(1), it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material, | Moderation is present to such an extent as to cause maximum reactivity | | | | | |
| (4) there will be no substantial reduction in the effectiveness of the packaging . . . . | 30.48-cm $H_2O$ surrounding the drum (d = 18.37 in., h = 43.5 in.) | | | | | |

**Table 6.1d. Summary of criticality evaluation for HEU metal turnings, fines, or powder**

| Conditions | 95% < enr. ≤ 100% ≤ 7,398-g $^{235}$U | 90% < enr. ≤ 95% ≤ 10,549-g $^{235}$U | 80% < enr. ≤ 90% ≤ 14,167-g $^{235}$U | 70% < enr. ≤ 80% ≤ 19,284-g $^{235}$U | 60% < enr. ≤ 70% ≤ 24,693-g $^{235}$U | enr. ≤ 60% ≤ 35,320-g U |
|---|---|---|---|---|---|---|
| "A package used for shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in §71.73 (Hypothetical Accident Conditions) the package would be subcritical. For this determination, it must be assumed that:" (Paragraph "e") | $k_{eff} + 2\sigma \leq 0.8912$<br>hcsrbmt12_36_1_15 | | | | | |
| (1) the fissile material is in the most reactive credible configuration consistent with the chemical and physical form of the contents, | A mixture of HEU metal and water is homogenized over the internal volume of the containment vessel. The amount of water in the flooded containment vessel is calculated on the basis that the convenience can steel is replaced with water. Can pads and spacers not used. | | | | | |
| (2) water moderation occurs to the most reactive credible extent consistent with the chemical and physical form of content, | Flooding of the package | | | | | |
| (3) there is full reflection by water on all sides, as close as is consistent with the damage condition of the package. | 30.48-cm $H_2O$ surrounding the reduced diameter drum (d = 17.20 in., h = 43.5 in.) | | | | | |

**Table 6.1d. Summary of criticality evaluation for HEU metal turnings, fines, or powder**

| Conditions | 95% < enr. ≤ 100% ≤ 7,398-g $^{235}$U | 90% < enr. ≤ 95% ≤ 10,549-g $^{235}$U | 80% < enr. ≤ 90% ≤ 14,167-g $^{235}$U | 70% < enr. ≤ 80% ≤ 19,284-g $^{235}$U | 60% < enr. ≤ 70% ≤ 24,693-g $^{235}$U | enr. ≤ 60% ≤ 35,320-g U |
|---|---|---|---|---|---|---|
| **Standards for arrays of fissile material packages (§71.59)** | | | | | | |
| " . . . the designer of a fissile material package shall derive a number "N" based on all the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close reflection on all sides of the stack by water: " (Paragraph "a") | | | | | | |
| **Transport index based on nuclear criticality control, CSI = 0.0** | | | | **Load-limited to 2,967-g $^{235}$U, no can spacers** | **Load-limited to 3,249-g $^{235}$U, no can spacers** | **Load-limited to 5,577-g U, no can spacers** |
| (1) five times "N" undamaged packages with nothing between the packages would be subcritical, | Not allowed | Not allowed | Not allowed | $k_{eff} + 2\sigma \leq 0.9213$ nciabmt11_4_1_5_3 | $k_{eff} + 2\sigma \leq 0.9207$ nciabmt11_5_1_4_3 | $k_{eff} + 2\sigma \leq 0.9152$ nciabmt11_6_1_3_3 |
| (2) two times "N" damaged packages, if each package were subject to the tests specified in §71.73 (Hypothetical Accident Conditions) would be subcritical with optimum interspersed hydrogenous moderation, | Not allowed | Not allowed | Not allowed | $k_{eff} + 2\sigma \leq 0.9248$ hciabmt12_4_1_5_3 | $k_{eff} + 2\sigma \leq 0.9235$ hciabmt12_5_1_4_3 | $k_{eff} + 2\sigma \leq 0.9127$ hciabmt12_6_1_3_3 |
| (3) the value of "N" cannot be <0.5. | Not allowed | Not allowed | Not allowed | N(1,2) = ∞ | Same | Same |

**Table 6.1d. Summary of criticality evaluation for HEU metal turnings, fines, or powder**

| Conditions | 95% < enr. ≤ 100% ≤ 7,398-g $^{235}$U | 90% < enr. ≤ 95% ≤ 10,549-g $^{235}$U | 80% < enr. ≤ 90% ≤ 14,167-g $^{235}$U | 70% < enr. ≤ 80% ≤ 19,284-g $^{235}$U | 60% < enr. ≤ 70% ≤ 24,693-g $^{235}$U | enr. ≤ 60% ≤ 35,320-g U |
|---|---|---|---|---|---|---|
| **Transport index based on nuclear criticality control, CSI = 0.4** | | | | **Load-limited to 5,192-g $^{235}$U, no can spacers** | **Load-limited to 5,848-g $^{235}$U, no can spacers** | **Load-limited to 14,872-g U, no can spacers** |
| (1) five times "N" undamaged packages . . . . | Not allowed | Not allowed | Not allowed | $k_{eff} + 2\sigma \leq 0.9235$ ncf1bmt11_7_1_5_3 | $k_{eff} + 2\sigma \leq 0.9216$ ncf1bmt11_9_1_4_3 | $k_{eff} + 2\sigma \leq 0.9225$ ncf1bmt11_15_1_3_3 |
| (2) two times "N" damaged packages, . . . . | Not allowed | Not allowed | Not allowed | $k_{eff} + 2\sigma \leq 0.9064$ hcf2bmt12_8_1_5_3 | $k_{eff} + 2\sigma \leq 0.9118$ hcf2bmt12_12_1_4_3 | $k_{eff} + 2\sigma \leq 0.9072$ hcf2bmt12_18_1_3_3 |
| (3) the value of "N" . . . | Not allowed | Not allowed | Not allowed | N(1,2) = 202/162 | Same | Same |
| **Transport index based on nuclear criticality control, CSI = 0.8** | | | | **Load-limited to 8,900-g $^{235}$U, no can spacers** | **Load-limited to 13,646-g $^{235}$U, no can spacers** | **Load-limited to 28,814-g U, no can spacers** |
| (1) five times "N" undamaged packages . . . . | Not allowed | Not allowed | Not allowed | $k_{eff} + 2\sigma \leq 0.9216$ ncf2bmt11_12_1_5_3 | $k_{eff} + 2\sigma \leq 0.9234$ ncf2bmt11_20_1_4_3 | $k_{eff} + 2\sigma \leq 0.9205$ ncf2bmt11_29_1_3_3 |
| (2) two times "N" damaged packages, . . . . | Not allowed | Not allowed | Not allowed | $k_{eff} + 2\sigma \leq 0.9012$ hcf3bmt12_12_1_5_3 | $k_{eff} + 2\sigma \leq 0.9065$ hcf3bmt12_20_1_4_3 | $k_{eff} + 2\sigma \leq 0.9022$ hcf3bmt12_29_1_3_3 |
| (3) the value of "N" . . . . | Not allowed | Not allowed | Not allowed | Same | Same | Same |
| **Transport index based on nuclear criticality control, CSI = 2.0 [a]** | | | | **Load-limited to 17,059-g $^{235}$U, no can spacers** | **Load-limited to 21,444-g $^{235}$U, no can spacers** | **35,320-g U, no can spacers** |
| (1) five times "N" undamaged packages . . . . | Not allowed | Not allowed | Not allowed | $k_{eff} + 2\sigma \leq 0.9223$ ncf3bmt11_22_1_5_3 | $k_{eff} + 2\sigma \leq 0.9216$ ncf3bmt11_31_1_4_3 | $k_{eff} + 2\sigma \leq 0.9045$ ncf3bmt11_36_1_3_3 |
| (2) two times "N" damaged packages, . . . . | Not allowed | Not allowed | Not allowed | $k_{eff} + 2\sigma \leq 0.8852$ hcf4bmt12_22_1_5_3 | $k_{eff} + 2\sigma \leq 0.8858$ hcf4bmt12_31_1_4_3 | $k_{eff} + 2\sigma \leq 0.8705$ hcf4bmt12_36_1_3_3 |
| (3) the value of "N" . . . . | Not allowed | Not allowed | Not allowed | N(1,2) = 29/25 | Same | Same |

**Table 6.1d. Summary of criticality evaluation for HEU metal turnings, fines, or powder**

| Conditions | 95% < enr. ≤ 100% ≤ 7,398-g $^{235}$U | 90% < enr. ≤ 95% ≤ 10,549-g $^{235}$U | 80% < enr. ≤ 90% ≤ 14,167-g $^{235}$U | 70% < enr. ≤ 80% ≤ 19,284-g $^{235}$U | 60% < enr. ≤ 70% ≤ 24,693-g $^{235}$U | enr. ≤ 60% ≤ 35,320-g U |
|---|---|---|---|---|---|---|
| **Transport index based on nuclear criticality control, CSI = 3.2** [b] | | | | **Load-limited to 19,284-g $^{235}$U, no can spacers** | **24,692-g $^{235}$U, no can spacers** | **35,320-g U, no can spacers** |
| (1) five times "N" undamaged packages . . . . | Not allowed | Not allowed | Not allowed | $k_{eff} + 2\sigma \leq 0.9226$ nctf5bmt11_35_1_5_3 | $k_{eff} + 2\sigma \leq 0.9030$ nctf5bmt11_36_1_4_3 | $k_{eff} + 2\sigma \leq 0.8743$ nctf5bmt11_36_1_3_3 |
| (2) two times "N" damaged packages, . . . . | Not allowed | Not allowed | Not allowed | $k_{eff} + 2\sigma \leq 0.9052$ hctf5bmt12_35_1_5_3 | $k_{eff} + 2\sigma \leq 0.8819$ hctf5bmt12_36_1_4_3 | $k_{eff} + 2\sigma \leq 0.8542$ hctf5bmt12_36_1_3_3 |
| (3) the value of "N" . . . . | Not allowed | Not allowed | Not allowed | N(1,2) = 16/24 | Same | Same |

[a] Neutron multiplication factors and "N" are shown for an NCT array size of 7×7×3 and an HAC array size of 5×5×2; both arrays are nearly cubic arrangements. An HAC array size is not available for CSI=1.8; therefore, CSI for NCT at 1.8 is rounded up to 2.0 as shown.

[b] Neutron multiplication factors and "N" are shown for an NCT array size of 27×3 and an HAC array size of 16×3; where packages in the planar dimension are in explicit triangular-pitch arrangement and stacked three high in the vertical direction. An NCT array size of 81 packages gives a CSI value of 3.12 (50 / 16), while an HAC array size of 48 packages gives a CSI value of 2.08 (50 / 24). The specified CSI value of 3.2 is the larger of the two numbers rounded up to the nearest tenth decimal place as shown.

**Table 6.1e. Summary of criticality evaluation for HEU product and skull oxide**

| Conditions | HEU product oxide ≤ 21,125-g $^{235}$U | HEU skull oxide ≤ 15,673-g $^{235}$U and ≤ 921-g C |
|---|---|---|
| **General requirements for each fissile package (§71.55)** | | |
| "A package used for shipment of fissile material must be so designed and constructed and its contents so limited that it would be subcritical if water were to leak into the containment system, . . . so that under the following conditions, maximum reactivity of the fissile material would be attained:" (Paragraph "b") | $k_{eff} + 2\sigma \leq 0.9143$<br>cvcrpdoxt11_1_3_24_15 | $k_{eff} + 2\sigma \leq 0.8497$<br>cvcrsk3cc_9_15_17 |
| (1) the most reactive credible configuration consistent with the chemical and physical form of the material, | HEU oxide at the bulk density is assumed dispersed in the containment vessel, where the oxide fills the containment vessel to a height determined by the oxide mass. The oxide is saturated with water. Water fills the void region above the oxide content, but this amount of water is reduced by an amount equivalent to the volume occupied by can spacers. The can pads, spacer can, and convenience can steel are replaced by water. See Sect. 6.9.3.1 for justification of the content model. | Same |
| (2) moderation by water to the most reactive credible extent, | Flooding of the containment vessel | Same |
| (3) close full reflection of the containment system by water on all sides, or such greater reflection of the containment system as may be provided by the surrounding material of the packaging. | 30.48-cm $H_2O$ surrounding the containment vessel | Same |

**Table 6.1e. Summary of criticality evaluation for HEU product and skull oxide**

| Conditions | HEU product oxide ≤ 21,125-g $^{235}$U | HEU skull oxide ≤ 15,673-g $^{235}$U and ≤ 921-g C |
|---|---|---|
| "A package used for shipment of fissile material must be so designed and constructed and its contents so limited under the tests specified in §71.71 (Normal Conditions of Transport) . . ." (Paragraph "d") | | |
| (1) the contents would be subcritical, | $k_{eff} + 2\sigma \leq 0.8166$<br>ncsrpdoxt11_1_3_24 | $k_{eff} + 2\sigma \leq 0.7410$<br>ncsrsk_9_15 |
| (2) the geometric form of the package contents would not be substantially altered, | HEU oxide at the bulk density is assumed dispersed in the containment vessel, where the oxide fills the containment vessel to a height determined by the oxide mass. The oxide is saturated with water. Water fills the void region above the oxide content, but this amount of water is reduced by an amount equivalent to the volume occupied by can spacers. The can pads, spacer can, and convenience can steel are replaced by water. | Same |
| (3) there would be no leakage of water into the containment system unless, in the evaluation of undamaged packages under §71.59(a)(1), it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material, | Moderation is present to such an extent as to cause maximum reactivity | Same |
| (4) there will be no substantial reduction in the effectiveness of the packaging . . . . | 30.48-cm $H_2O$ surrounding the drum<br>(d = 18.37 in., h = 43.5 in.) | Same |

**Table 6.1e. Summary of criticality evaluation for HEU product and skull oxide**

| Conditions | HEU product oxide ≤ 21,125-g $^{235}$U | HEU skull oxide ≤ 15,673-g $^{235}$U and ≤ 921-g C |
|---|---|---|
| "A package used for shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in §71.73 (Hypothetical Accident Conditions) the package would be subcritical. For this determination, it must be assumed that:" (Paragraph "e") | $k_{eff} + 2\sigma \leq 0.8187$<br>hcsrpdoxt12_1_3_24 | $k_{eff} + 2\sigma \leq 0.7410$<br>hcsrsk_9_15 |
| (1) the fissile material is in the most reactive credible configuration consistent with the chemical and physical form of the contents, | HEU oxide at the bulk density is assumed dispersed in the containment vessel, where the oxide fills the containment vessel to a height determined by the oxide mass. The oxide is saturated with water. Water fills the void region above the oxide content, but this amount of water is reduced by an amount equivalent to the volume occupied by can spacers. The can pads, spacer can, and convenience can steel are replaced by water. | Same |
| (2) water moderation occurs to the most reactive credible extent consistent with the chemical and physical form of content, | Flooding of the package | Same |
| (3) there is full reflection by water on all sides, as close as is consistent with the damage condition of the package. | 30.48-cm $H_2O$ surrounding the reduced diameter drum (d = 17.20 in., h = 43.5 in.) | Same |

**Table 6.1e. Summary of criticality evaluation for HEU product and skull oxide**

| Conditions | HEU product oxide ≤ 21,125-g $^{235}$U | HEU skull oxide ≤ 15,673-g $^{235}$U and ≤ 921-g C |
|---|---|---|
| **Standards for arrays of fissile material packages (§71.59)** | | |
| " . . . the designer of a fissile material package shall derive a number "N" based on all the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close reflection on all sides of the stack by water: " (Paragraph "a") | | |
| **Transport index based on nuclear criticality control, CSI = 0.0** | **Load-limited to 9,682-g $^{235}$U, no can spacers** | **Load-limited to 15,673-g $^{235}$U, no can spacers** |
| (1) five times "N" undamaged packages with nothing between the packages would be subcritical, | $k_{eff} + 2\sigma \leq 0.9201$<br>nciapdoxt11_1_1_11_3 | $k_{eff} + 2\sigma \leq 0.7562$<br>nciask_9_15 |
| (2) two times "N" damaged packages, if each package were subject to the tests specified in §71.73 (Hypothetical Accident Conditions) would be subcritical with optimum interspersed hydrogenous moderation, | $k_{eff} + 2\sigma \leq 0.9247$<br>hciapdoxt12_1_1_11_3 | $k_{eff} + 2\sigma \leq 0.7599$<br>hciask_9_15 |
| (3) the value of "N" cannot be <0.5. | $N(1,2) = \infty$ | Same |

**Table 6.1f. Summary of criticality evaluation for UNX crystals and unirradiated TRIGA reactor fuel elements**

| Conditions | UNX crystals ≤ 11,303-g $^{235}U$ | unirradiated TRIGA fuel elements ≤ 921-g $^{235}U$ |
|---|---|---|
| **General requirements for each fissile package (§71.55)** | | |
| "A package used for shipment of fissile material must be so designed and constructed and its contents so limited that it would be subcritical if water were to leak into the containment system, . . . so that under the following conditions, maximum reactivity of the fissile material would be attained:" (Paragraph "b") | $k_{eff} + 2\sigma \leq 0.8630$<br>cvcrpunhct11_10_15 | $k_{eff} + 2\sigma \leq 0.5274$<br>cvcrtriga_1_15 |
| (1) the most reactive credible configuration consistent with the chemical and physical form of the material, | UNX crystals are homogenized with water over the internal volume of the containment vessel consistent with the high solubility properties of UNX. Can spacers are not used. Hydrogenous packing material represented by 500 g. | Three 5-in tall sectioned pieces of UZrHx from a cylindrical TRIGA fuel element per convenience can. Sectioned pieces arranged in triangular pitch. No can spacers. Convenience can steel replaced by water. |
| (2) moderation by water to the most reactive credible extent, | Flooding of the containment vessel | Same |
| (3) close full reflection of the containment system by water on all sides, or such greater reflection of the containment system as may be provided by the surrounding material of the packaging. | 30.48-cm $H_2O$ surrounding the containment vessel | Same |

**Table 6.1f. Summary of criticality evaluation for UNX crystals and unirradiated TRIGA reactor fuel elements**

| Conditions | UNX crystals<br>≤ 11,303-g $^{235}U$ | unirradiated TRIGA fuel elements<br>≤ 921-g $^{235}U$ |
|---|---|---|
| "A package used for shipment of fissile material must be so designed and constructed and its contents so limited under the tests specified in §71.71 (Normal Conditions of Transport) . . ." (Paragraph "d") | | |
| (1) the contents would be subcritical, | $k_{eff} + 2\sigma \leq 0.7526$<br>ncsrpunhct11_8_15 | $k_{eff} + 2\sigma \leq 0.4950$<br>ncsrtriga_1_15_15 |
| (2) the geometric form of the package contents would not be substantially altered, | UNX crystals are homogenized with water over the internal volume of the containment vessel consistent with the high solubility properties of UNX. Can spacers are not used. Hydrogenous packing material represented by 500 g. | Three 5-in tall sectioned pieces of UZrHx from a cylindrical TRIGA fuel element per convenience can. Sectioned pieces arranged in triangular pitch. No can spacers. Convenience can steel replaced by water. |
| (3) there would be no leakage of water into the containment system unless, in the evaluation of undamaged packages under §71.59(a)(1), it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material, | Moderation is present to such an extent as to cause maximum reactivity | Same |
| (4) there will be no substantial reduction in the effectiveness of the packaging . . . . | 30.48-cm $H_2O$ surrounding the drum<br>(d = 18.37 in., h = 43.5 in.) | Same |

**Table 6.1f. Summary of criticality evaluation for UNX crystals and unirradiated TRIGA reactor fuel elements**

| Conditions | UNX crystals ≤ 11,303-g $^{235}U$ | unirradiated TRIGA fuel elements ≤ 921-g $^{235}U$ |
|---|---|---|
| "A package used for shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in §71.73 (Hypothetical Accident Conditions) the package would be subcritical. For this determination, it must be assumed that:" (Paragraph "e") | $k_{eff} + 2\sigma \leq 0.8144$<br>icsrpunhct12_15_15 | $k_{eff} + 2\sigma \leq 0.4945$<br>hcsrtriga_1_15_15 |
| (1) the fissile material is in the most reactive credible configuration consistent with the chemical and physical form of the contents, | UNX crystals are homogenized with water over the internal volume of the containment vessel consistent with the high solubility properties of UNX. Can spacers are not used. Hydrogenous packing material represented by 500 g. | Three 5-in tall sectioned pieces of UZrHx from a cylindrical TRIGA fuel element per convenience can. Sectioned pieces arranged in triangular pitch. No can spacers. Convenience can steel replaced by water. |
| (2) water moderation occurs to the most reactive credible extent consistent with the chemical and physical form of content, | Flooding of the package | Same |
| (3) there is full reflection by water on all sides, as close as is consistent with the damage condition of the package. | 30.48-cm $H_2O$ surrounding the reduced diameter drum (d = 17.20 in., h = 43.5 in.) | Same |

**Table 6.1f. Summary of criticality evaluation for UNX crystals and unirradiated TRIGA reactor fuel elements**

| Conditions | UNX crystals ≤ 11,303-g $^{235}$U | unirradiated TRIGA fuel elements ≤ 921-g $^{235}$U |
|---|---|---|
| **Standards for arrays of fissile material packages (§71.59)** | | |
| " . . . the designer of a fissile material package shall derive a number "N" based on all the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close reflection on all sides of the stack by water: " (Paragraph "a") | | |
| **Transport index based on nuclear criticality control, CSI = 0.0** | **Load-limited to 3297-g $^{235}$U, no can spacers** | **No can spacers** |
| (1) five times "N" undamaged packages with nothing between the packages would be subcritical, | $k_{eff} + 2\sigma \leq 0.9199$<br>nciapunhct11_7_3 | $k_{eff} + 2\sigma \leq 0.5254$<br>nciatriga_1_15_3 |
| (2) two times "N" damaged packages, if each package were subject to the tests specified in §71.73 (Hypothetical Accident Conditions) would be subcritical with optimum interspersed hydrogenous moderation, | $k_{eff} + 2\sigma \leq 0.9180$<br>hciapunhct12_7_3 | $k_{eff} + 2\sigma \leq 0.5261$<br>hciatriga_1_15_3 |
| (3) the value of "N" cannot be <0.5. | N(1,2) = ∞ | Same |
| **Transport index based on nuclear criticality control, CSI = 0.0** | **Can spacers** | **Can spacers** |
| (1) five times "N" undamaged packages . . . . | Not applicable | $k_{eff} + 2\sigma \leq 0.4421$<br>nciatriga_2_15_3 |
| (2) two times "N" damaged packages, . . . . | Not applicable | $k_{eff} + 2\sigma \leq 0.4427$<br>hciatriga_2_15_3 |
| (3) the value of "N" . . . . | Not applicable | N(1,2) = ∞ |

**Table 6.1f. Summary of criticality evaluation for UNX crystals and unirradiated TRIGA reactor fuel elements**

| Conditions | UNX crystals ≤ 11,303-g $^{235}U$ | unirradiated TRIGA fuel elements ≤ 921-g $^{235}U$ |
|---|---|---|
| **Transport index based on nuclear criticality control, CSI = 0.4** | **Load-limited to 11,303-g $^{235}U$, no can spacers** | **No can spacers** |
| (1) five times "N" undamaged packages . . . . | $k_{eff} + 2\sigma \leq 0.8730$<br>ncf1punhct11_24_3 | Bounded by CSI=0 |
| (2) two times "N" damaged packages, . . . . | $k_{eff} + 2\sigma \leq 0.8423$<br>hcf2punhct12_24_3 | Bounded by CSI=0 |
| (3) the value of "N" . . . . | N(1,2) = 202/162 | Same |
| **Transport index based on nuclear criticality control, CSI = 0.4** | **Can spacers** | **Can spacers** |
| (1) five times "N" undamaged packages . . . . | Not applicable | Bounded by CSI=0 |
| (2) two times "N" damaged packages, . . . . | Not applicable | Bounded by CSI=0 |
| (3) the value of "N" . . . . | Not applicable | N(1,2) = 202/162 |

The evaluation limits for solid HEU metal shapes are listed in the column headings appearing to the right of the "Conditions" column of Table 6.1a. Limits expressed in terms of the diameter for a cylinder and the length-width of the geometric cross section for a square bar are established by the size of the convenience can opening through which these contents are inserted. Potential fissile ($^{235}$U) mass loading limits for these contents are given in the information blocks where a description of the content appears for the fissile material "in the most reactive credible configuration."

The fissile ($^{235}$U) or uranium masses listed in the column headings of Tables 6.1b–6.1f indicate evaluation limits for the associated content configurations. In the case of slugs (Table 6.1b), the $^{235}$U evaluation limits represent the fissile content contained in the slugs with maximum tolerances applied. In the case of broken metal (Table 6.1c), the $^{235}$U evaluation limits represent the maximum amount of $^{235}$U adequately subcritical in a flooded, reflected containment vessel as conservatively applied over the indicated range of enrichment. For HEU enrichments $\leq$ 60%, the 35.32-kg package limit on the amount of HEU to be shipped in an ES-3100 becomes the evaluation limit. Relative to the broken metal limits specified in Table 6.1c, the $^{235}$U evaluation limit permissible for HEU metal in the form of turnings, fines, or powder is reduced at the higher enrichments (Table 6.1d). For HEU oxide and UNX crystals (Tables 6.1e and 6.1f), the $^{235}$U evaluation limits correspond to the 24-kg package limit on the amount of HEU oxide or UNX crystals to be shipped. For HEU skull oxide (Table 6.1e), the $^{235}$U evaluation limit represents a maximum derived from the evaluation of an inventory at Y-12. For unirradiated TRIGA reactor fuel elements (Table 6.1f), the $^{235}$U evaluation limit represents a maximum for the fuel manufacturer's product line.

The NCT and HAC array analyses [10 CFR 71.59(a)(1) and (a)(2)] may reveal reductions in the potential loading limits for content and 277-4 canned spacer configurations initially identified in the single package calculations [10 CFR 71.55(b), (d), and (e)] of Tables 6.1a–6.1f. This occurs in order to achieve fissile material loadings which are at or below the subcritical safety limit. These reduced loading limits are identified as "**load-limited to**" values in the "CSI" rows.

Table 6.2a summarizes the fissile loading limits derived from Tables 6.1a–6.1f for surface-only transport mode. In establishing compliance with the fissile loading limit indicated in Table 6.2a for uranium alloys of aluminum, molybdenum, zirconium, stainless steel, titanium, tungsten, niobium, silicon, or vanadium, the content mass of $^{235}$U includes the mass of the non-uranium alloy constituents. The fissile loading limits pertaining to the air-transport mode summarized in Table 6.2b are derived from the air-transport analysis addressed in Sect. 6.7. Packages transported by air involve both surface and air modes of transportation. The loading limit for packages under mixed-mode transportation is taken as the most restrictive limit for either mode (surface or air transport).

The "no water inleakage" condition of 10 CFR 71.55(f)(1) and (f)(2) signifies that the hydrogenous material present in the package during air transport is limited to the amount present in the package when it is loaded on the aircraft for transport. The dry-baked Kaolite in the drum body weldment and drum top plug consists of vermiculite-cement constituents and 2,204.7 g of bound water. Potential sources of additional hydrogen moderator are the hydrogenous packing materials present inside the containment vessel, moisture inside the containment vessel well, and the moisture inside the Kaolite region of the package.

For establishing the loading limits for air transport, the total **free** water in wet Kaolite was conservatively evaluated up to 15 lb (6,803.8 g). Based on this evaluation, **free** water must be limited to 12 lb (5,443.1 g) for maintaining the required margin of subcriticality when shipping under the air transport loading limits specified in Table 6.2b. This requirement is specific to the Kaolite region of the ES-3100 package for two reasons. First, the hydrogenous packing material inside the containment vessel is limited to 500 g per the air transport evaluation. Second, the use of a drum covering and administrative controls (Sects. 7 and 7.1.3.1) will ensure dryness of the containment vessel well. Package operational controls and acceptance limits (Sects. 7 and 8) will ensure that a package to be used for air transport is qualified.

**Table 6.2a. HEU fissile material mass loading limits (with case name) for surface-only modes of transportation**

| Solid HEU metal of specified geometric shape [a] | | | | | | |
|---|---|---|---|---|---|---|
| **Transport index based on nuclear criticality control** | **Cylinders (d ≤ 3.24 in.)** | **Cylinders (3.24 in. < d ≤ 4.25 in.)** | **Bars** | **Slugs [b] enr. ≤ 95%** | **Slugs [c] 80% < enr. ≤ 95%** | **Slugs [c] enr. ≤ 80%** |
| **No can spacers** | | | | | | |
| CSI = 0.0 | 18,000-g $^{235}$U nciacyt11_18_1_3 | 15,000-g $^{235}$U nciacyct11_15_1_3 | 30,000-g $^{235}$U hciasqt12_30_1_3 | 17,374-g $^{235}$U ncia5st11_1_1_7_3 | – | – |
| **With can spacers** | | | | | | |
| CSI = 0.0 | 30,000-g $^{235}$U nciacyt11_30_2_3 | 25,000-g $^{235}$U nciacyct11_25_2_3 | 36,000-g $^{235}$U nciasqt11_36_2_3 | – | 24,324-g $^{235}$U hcia70st12_2_7_3 | 29,318-g $^{235}$U hcia5est12_2_2_5_3 |
| CSI = 0.4 | – | – | – | – | 34,749-g $^{235}$U [c] ncf15est11_2_2_7_3 | 29,318-g $^{235}$U ncf15est11_2_2_5_3 |

| HEU broken metal or solid HEU metal of unspecified geometric shape and characterized as broken metal [a] | | | | | | |
|---|---|---|---|---|---|---|
| **Transport index based on nuclear criticality control** | **95% < enr. ≤ 100%** | **90% < enr. ≤95%** | **80% < enr. ≤90%** | **70% < enr. ≤80%** | **60% < enr. ≤70%** | **Enr. ≤60%** |
| **No can spacers** | | | | | | |
| CSI = 0.0 | Can spacers required | Can spacers required | Can spacers required | 2,967-g $^{235}$U hciabmt12_4_1_5_3 | 3,249-g $^{235}$U hciabmt12_5_1_4_3 | 5,576-g U nciabmt11_6_1_3_3 |
| CSI = 0.4 | Can spacers required | Can spacers required | Can spacers required | 5,192-g $^{235}$U ncf1bmt11_7_1_5_3 | 5,848-g $^{235}$U ncf1bmt11_9_1_4_3 | 14,872-g U ncf1bmt11_15_1_3_3 |
| CSI = 0.8 | Can spacers required | Can spacers required | Can spacers required | 8,900-g $^{235}$U ncf2bmt11_12_1_5_3 | 13,646-g $^{235}$U ncf2bmt11_20_1_4_3 | 28,814-g U ncf2bmt11_29_1_3_3 |
| CSI = 2.0 | Can spacers required | Can spacers required | Can spacers required | 17,059-g $^{235}$U ncf3bmt11_22_1_5_3 | 21,444-g $^{235}$U ncf3bmt11_31_1_4_3 | 35,320-g U ncf3bmt11_36_1_3_3 |
| CSI = 3.2 | Can spacers required | Can spacers required | Can spacers required | 27,443-g $^{235}$U ncf5bmt11_35_1_5_3 | 24,692-g $^{235}$U ncf5bmt11_36_1_4_3 | 35,320-g U ncf5bmt11_36_1_3_3 |

**Table 6.2a. HEU fissile material mass loading limits (with case name) for surface-only modes of transportation**

| Transport index based on nuclear criticality control | 95% < enr. ≤ 100% | 90% < enr. ≤95% | 80% < enr. ≤90% | 70% < enr. ≤80% | 60% < enr. ≤70% | Enr. ≤60% |
|---|---|---|---|---|---|---|
| **With can spacers** | | | | | | |
| CSI = 0.0 | 2,774-g $^{235}$U hciabmt12_3_2_8_3 | 3,516-g $^{235}$U hciabmt12_4_2_7_3 | 3,333-g $^{235}$U hciabmt12_4_2_6_3 | 4,450-g $^{235}$U hciabmt12_6_2_5_3 | 5,198-g $^{235}$U nciabmt11_8_2_4_3 | 11,154-g U hciabmt12_12_2_3_3 |
| CSI = 0.4 | 5,549-g $^{235}$U ncf1bmt11_6_2_8_3 | 6,154-g $^{235}$U ncf1bmt11_7_2_7_3 | 7,500-g $^{235}$U ncf1bmt11_9_2_6_3 | 8,900-g $^{235}$U ncf1bmt11_12_2_5_3 | 12,996-g $^{235}$U ncf1bmt11_19_2_4_3 | 28,813-g U ncf1bmt11_29_2_3_3 |
| CSI = 0.8 | 9,248-g $^{235}$U ncf2bmt11_10_2_8_3 | 10,549-g $^{235}$U ncf2bmt11_12_2_7_3 | 12,500-g $^{235}$U ncf2bmt11_14_2_6_3 | 16,317-g $^{235}$U ncf2bmt11_21_2_5_3 | 20,793-g $^{235}$U ncf2bmt11_30_2_4_3 | 35,320-g U ncf2bmt11_36_2_3_3 |
| CSI = 2.0 | 13,872-g $^{235}$U ncf3bmt11_14_2_8_3 | 18,461-g $^{235}$U ncf3bmt11_20_2_7_3 | 20,000-g $^{235}$U ncf3bmt11_23_2_6_3 | 25,218-g $^{235}$U ncf3bmt11_32_2_5_3 | 24,692-g $^{235}$U ncf3bmt11_36_2_4_3 | 35,320-g U ncf3bmt11_36_2_3_3 |
| CSI = 3.2 | 24,969-g $^{235}$U ncf5bmt11_25_2_8_3 | 26,373-g $^{235}$U ncf5bmt11_28_2_7_3 | 28,334-g $^{235}$U [d] ncf5bmt11_35_2_6_3 | 28,184-g $^{235}$U ncf5bmt11_36_2_5_3 | 24,692-g $^{235}$U ncf5bmt11_36_2_4_3 | 35,320-g U ncf5bmt11_36_2_3_3 |

**HEU metal turnings, fines, or powder [a, e, f]**

| Transport index based on nuclear criticality control | 95% < enr. ≤ 100% | 90% < enr. ≤95% | 80% < enr. ≤90% | 70% < enr. ≤80% | 60% < enr. ≤70% | Enr. ≤60% |
|---|---|---|---|---|---|---|
| **No can spacers** | | | | | | |
| CSI = 0.0 | Not allowed | Not allowed | Not allowed | 2,967-g $^{235}$U hciabmt12_4_1_5_3 | 3,249-g $^{235}$U hciabmt12_5_1_4_3 | 5,576-g U nciabmt11_6_1_3_3 |
| CSI = 0.4 | Not allowed | Not allowed | Not allowed | 5,192-g $^{235}$U ncf1bmt11_7_1_5_3 | 5,848-g $^{235}$U ncf1bmt11_9_1_4_3 | 14,872-g U ncf1bmt11_15_1_3_3 |
| CSI = 0.8 | Not allowed | Not allowed | Not allowed | 8,900-g $^{235}$U ncf2bmt11_12_1_5_3 | 13,646-g $^{235}$U ncf2bmt11_20_1_4_3 | 28,814-g U ncf2bmt11_29_1_3_3 |
| CSI = 2.0 | Not allowed | Not allowed | Not allowed | 17,059-g $^{235}$U ncf3bmt11_22_1_5_3 | 21,444-g $^{235}$U ncf3bmt11_31_1_4_3 | 35,320-g U ncf3bmt11_36_1_3_3 |
| CSI = 3.2 | Not allowed | Not allowed | Not allowed | 19,284-g $^{235}$U ncf5bmt11_35_1_5_3 | 24,692-g $^{235}$U ncf5bmt11_36_1_4_3 | 35,320-g U ncf5bmt11_36_1_3_3 |

**Table 6.2a. HEU fissile material mass loading limits (with case name) for surface-only modes of transportation**

| HEU oxide, UNX crystals, and unirradiated TRIGA fuel elements | | | | | |
|---|---|---|---|---|---|
| **Transport index based on nuclear criticality control** | **HEU product oxide, no can spacers** | **HEU skull oxide, no can spacers** | **UNX crystals, no can spacers** | **Unirradiated TRIGA fuel elements, no can spacers [g]** | |
| | | | | **20% enr.** | **70% enr.** |
| CSI = 0.0 | 9,682-g $^{235}$U<br>hciapdoxt12_1_1_11_3 | 15,673-g $^{235}$U and 921-g C<br>nciask_9_15 | 3,297-g $^{235}$U<br>nciapunhct11_7_3 | 921-g $^{235}$U<br>nciatriga_1_15_3 | 408-g $^{235}$U<br>nciatriga70_1_15_3 |
| CSI = 0.4 | – | – | 11,303-g $^{235}$U<br>ncf1punhct11_24_3 | – | – |

[b] When can spacers **are not** used, the mass limit = 17,374-g $^{235}$U.

[c] When can spacers are used, a greater fissile mass limit is permissible based on enrichment. For CSI=0 and enrichments >80 wt %, the fissile mass must be reduced below the volumetric limit. For CSI=0.4, fissile mass is volumetrically limited by the size of the slugs. Note that within a fixed volume, the HEU mass increases slightly with decreasing enrichment.

[g] For ground transport, TRIGA reactor fuel element content will be limited to three fuel sections ("meats") per loaded convenience can and up to three loaded cans per package. The TRIGA fuel content may also be configured as clad fuel rods, each rod derived from a single TRIGA fuel element. A ~15-in.-long rod consists of the three fuel pellets and an exterior sheath of clad, where protruding clad at each end has been crimped in. Clad fuel rods will be packed into convenience cans, with a maximum of three fuel rods per loaded convenience can and one loaded can per containment vessel.

[a] Uranium alloys (uranium with aluminum, molybdenum, zirconium, stainless steel, titanium, tungsten, niobium, silicon, or vanadium) may be loaded to an appropriate mass limit where the content mass of $^{235}$U includes the mass of the non-uranium alloy constituents.

[d] Case **ncf5bmt11_35_2_6_3** (with a mass of 30.8340 kg) establishes the CSI value of 3.2. The more restrictive mass of 28.334 kg is from Case **cvr3lha_32_1_6_15** (Table 6.1c).

[e] More restrictive mass limits for uranium metal as turnings, fines, or powder are obtained from Cases **cvr3cha_8_1_8_15**, **cvr3cha_12_1_7_15**, **cvr3cha_16_1_6_15**, and **cvr3cha_25_1_4_4_15** (Table 6.1d).

[f] If the mass of metal or alloy turnings, fines, or powders is ≤ 50 g, then it may be shipped as the parent form (e.g., broken metal, reactor fuel, etc.).

**Table 6.2b. HEU fissile material mass loading limits for air mode of transportation [a]**

| Solid HEU metal or alloy, unirradiated TRIGA fuel elements [b] | | | | | |
|---|---|---|---|---|---|
| **Cylinders (3.24 ≤ d ≤ 4.25 in.)** | **Bars** | **Slugs** | **Broken metal, unspecified geometric shape and characterized as broken metal, turnings, fines, or powder [c]** | **Unirradiated TRIGA d** | |
| | | | | **20% enr.** | **70% enr.** |
| 7,000-g $^{235}U$ | 7,000-g $^{235}U$ | 7,000-g $^{235}U$ | 7,000-g $^{235}U$ | 921-g $^{235}U$ | 408-g $^{235}U$ |

| HEU oxide, UNX crystals | | |
|---|---|---|
| **HEU product oxide** | **HEU skull oxide** | **UNX crystals** |
| 5,281-g $^{235}U$ [e] | Not allowed | Not allowed |

[a] The loading limit for mixed mode transportation is taken as the most restrictive limit for either the surface or the air mode of transportation, Tables 6.2a or 6.2b.
[b] For air transport, TRIGA reactor fuel element content will be limited to fuel sections or clad fuel rods as described for surface-only modes of transportation in footnote "c" of Table 6.2a and the fissile mass limit specified herein, whichever is more limiting.
[c] Research reactor related contents of uranium metal or U-Al alloy are packaged for air transport under these specified limits.
[d] Research reactor related contents of $U_3O_8$-Al, $UO_2$, or $UO_2$-Mg are packaged for air transport under limits specified for unirradiated TRIGA fuel elements. Per package limits for these items are a maximum of 921-g $^{235}U$ at enrichments not exceeding 20 wt % and a maximum of 408-g $^{235}U$ for content enrichments greater than 20 wt %.
[e] Appendix 6.9.9 details air transport evaluation of HEU product oxide.

Research reactor fuel elements or fuel components are composed of U-Al, $U_3O_8$-Al, $UO_2$, or $UO_2$-Mg. Related materials are broken uranium metal, U-Al alloy, or oxides of $U_3O_8$, $U_3O_8$-Al, or $UO_2$-Mg. With the exception of the oxide and compounds, research reactor related contents are packaged for air transport under limits specified in Table 6.2b for HEU broken metal, solid HEU metal of unspecified geometric shape and characterized as broken metal, turnings, fines, or powder. The oxide and compounds are packaged for air transport under limits specified in Table 6.2b for unirradiated TRIGA fuel elements. Per package limits for these items are a maximum of 921-g $^{235}U$ at enrichments not exceeding 20 wt % and a maximum of 408-g $^{235}U$ for content enrichments greater than 20 wt %.

Table 6.9.8.2 (Appendix 6.9.8) summarizes the fissile material load limits for the "additional/new" contents from the various reactor programs not covered in Table 6.2a. The loading limits from Tables 6.2a and 6.9.8.2 are consolidated in Tables 1.3 and 1.3a.

The criticality evaluation demonstrates that the ES-3100 packaging with the HEU content satisfies the requirements for single packages and for arrays of fissile material packages when the packages are load-limited as specified in Tables 6.2a, 6.2b, and 6.9.8.2 (reproduced in Tables 1.3, 1.3a, and 1.3b) under the conditions identified in Sect. 6.2.4.

### 6.1.4 Criticality Safety Index

A CSI is assigned to the Model ES-3100 package on the basis of an adequate margin of subcriticality for the single package and arrays of packages for both NCT and HAC. Values for the CSI given in Tables 6.2a and 6.2b are based on the uranium and the $^{235}U$ mass of the content and on the presence of 277-4 canned spacers as defined in Sect. 6.2.2.

The CSI is determined from bounding calculations using KENO V.a models of the containment vessel, the single package, and arrays of packages (NUREG/CR-0200, Rev. 6). It is a dimensionless number used to limit the number of packages in a conveyance for nuclear criticality safety control. The CSI is the larger of the CSI values for NCT and for HAC. For NCT, the CSI is equal to 50 divided by the allowable number of packages "N" that can be shipped, where the allowable number of packages is one-fifth of the maximum array size that is calculated to be subcritical. For HAC, the CSI is equal to 50 divided by the allowable number of packages "N" that can be shipped, where the allowable number of packages is one-half of the maximum array size that is calculated to be subcritical. The CSI is a calculated number rounded up to the nearest first decimal.

The array sizes examined in this evaluation are infinite, 13×13×6, 9×9×4, 7×7×3, 5×5×2, explicit triangular pitch (ETP) 27×3 for NCT, ETP 16×3 for HAC, and the degenerate single unit. For NCT, the "N" and corresponding CSI values for arrays determined to be adequately subcritical are as follows: N = ∞, CSI = 0; N = 202, CSI = 0.3; N = 64, CSI = 0.8; N = 29, CSI = 1.8; N = 10, CSI = 5.0; and N = 16, CSI = 3.2. For HAC, the "N" and corresponding CSI values for arrays determined to be adequately subcritical are as follows: N = ∞, CSI = 0; N = 507, CSI = 0.1; N =162, CSI = 0.4; N = 73, CSI = 0.7; N = 25, CSI = 2.0; and N = 24, CSI = 2.1. Absent an exact correspondence of CSI values for the NCT and HAC, the following arrays results were selected for rounded CSI values as indicated in Tables 6.1a–6.1f:

- infinite arrays evaluated for both NCT and HAC [designated as "(1,2)"], where N(1,2) = for a CSI = 0;
- 13×13×6 evaluated for NCT and 9×9×4 evaluated for HAC where N(1,2) = (202,162) for a CSI = 0.4;
- 9×9×4 evaluated for NCT and 7×7×3 evaluated for HAC where N(1,2) = (64,73) for a CSI = 0.8;

- 7×7×3 evaluated for NCT and 5×5×2 evaluated for HAC where N(1,2) = (29,25) for a CSI = 2.0; and
- 27×3 evaluated for NCT and 16×3 evaluated for HAC where N(1,2) = (16,24) for a CSI = 3.2.

## 6.2 PACKAGE CONTENTS

The **package content** is defined as the HEU fissile material, bottles, convenience cans, canned spacers, can pads, and the associated packing materials (plastic bags, pads, tape, etc.) inside the ES-3100 containment vessel.

### 6.2.1 Fissile Material Contents

The per-package HEU mass loadings considered in the criticality evaluation range from 1000 to 36,000 g for uranium metal and from 1000 to 24,000 g for uranium oxide and UNX crystals. The HEU mass may include nonradioactive contaminants and trace elements or materials in the HEU.

The bounding types of HEU content evaluated in this criticality analysis are 4.25-in.- and 3.24-in.-diam cylinders; 2.29-in.-square bars; 1.5-in.-diam × 2-in.-tall slugs; cubes ranging from 0.25 to 1 in. on a side; broken metal pieces of unspecified geometric shapes; skull oxide; uranium oxide; UNX crystals; and unirradiated TRIGA reactor fuel elements.

The terms “broken metal” and “turnings, fines, or powder” are used to describe an HEU content without restrictions on shape or size other than a minimum size limit (spontaneous ignition), a maximum mass limit (criticality control), a minimum enrichment (the lower limit for HEU at 19 wt % $^{235}U$ in uranium), and the capacity limits of the convenience cans. The content geometry envelope encompasses regular, uniform shapes and sizes as well as irregular shapes and sizes. Broken metal pieces are distinguished from turnings, fines, or powder as having a surface-area-to-mass ratio of not greater than 1 $cm^2/g$ or must not pass through a 3/8-in. mesh sieve (or equivalent size-grading method). By this definition, turnings, fines, or powder are packed in cans that are sealed and the cans’ atmosphere is inerted for pyrophoric considerations.

The density of HEU metal ranges from 18.811 to 19.003 $g/cm^3$ for HEU metal, corresponding to enrichments ranging from 100 to 19 wt % $^{235}U$. Theoretical (crystalline) densities for HEU oxide are 10.96 $g/cm^3$, 8.30 $g/cm^3$, and 7.29 $g/cm^3$ for $UO_2$, $U_3O_8$, and $UO_3$, respectively. However, bulk densities of product oxide are typically on the order of 2.0 to 6.54 $g/cm^3$. With increased moderation of fissile mass possible at these lower densities, only “less-than-theoretical” mass loadings would actually be achieved. Skull oxides are a mixture of $U_3O_8$ and graphite, having densities on the order of 2.44 $g/cm^3$ for poured material and 2.78 $g/cm^3$ for tamped (packed) material. Combined water saturation and crystallization of the HEU oxide is not expected in the HAC because $UO_2$ is non-hygroscopic, and both $UO_3$ and $U_3O_8$ are only mildly hygroscopic. The density of UNX crystals varies depending on the degree of hydration. The most reactive form of UNX crystals considered for shipment in the ES-3100 is $UO_2(NO_3)\cdot xH_2O$ with 6 molecules of hydration, having a density of 2.79 $g/cm^3$. UNX crystals are highly soluble in nitric acid and mildly soluble in water. Dissolution of UNX crystals in water is assumed in this criticality evaluation. The content geometry envelope encompasses both regular, uniform clumps and densities, and irregular clumps and densities.

The ~40 stock items of TRIGA fuel are cataloged as one of the four basic types: a standard element, an instrumented element, a fuel follower control rod, or a cluster assembly. The active region of

TRIGA element consists of three 5-in long sections "fuel meats" of uranium zirconium hydride ($UZrH_x$). The "x" in $UZrH_x$ equals 1.6 in all cases except for two stock items where x = equals 1.0 and the fissile content is < 40-g $^{235}U$. The clad thickness is ~0.02 in. for a TRIGA fuel element with stainless steel cladding and ~0.03 in. for an element with aluminum cladding.

Solid form TRIGA fuel is either 20 or 70 wt % enriched in $^{235}U$ and has specific dimensional characteristics for its designed function. For the 20 wt % enriched TRIGA elements, the active fuel diameters are 1.44 in., 1.41 in., 1.40 in., 1.37 in., 1.34 in., or 1.31 in. The uranium weight fractions are 45 wt %, 30 wt %, 20 wt %, 12 wt %, and 8.5 wt %. The TRIGA element with a maximum fissile content of 307-g $^{235}U$ in 1,560-g U is 45 wt % U in $UZrH_x$ and has a computed density of ~8.6 g/cm$^3$ (Appendix 6.9.3.1). For the 70 wt % enriched TRIGA fuel, the active fuel diameter is 1.44 in. in the standard element and instrumented element, and 1.31 in. in the fuel follower control rod. Both the standard element and instrumented elements contain ~136-g $^{235}U$ in 194-g U while the fuel follower control rod contains ~113-g $^{235}U$ in 162-g U. The 70 wt % enriched TRIGA fuel is 8.5 wt % U in $UZrH_x$ and has a computed density of ~5.7 g/cm$^3$ (Appendix 6.9.3.1).

In preparation for shipment in the ES-3100, the unirradiated TRIGA fuel elements may be disassembled and the fuel sections removed from the thin-wall cladding. The TRIGA fuel may also be configured as clad fuel rods. Each clad fuel rod will be derived from a single TRIGA fuel element by removal of the stainless steel or aluminum clad beyond the plenum adjacent to the axial ends of the active fuel section. Each ~15-in.-long rod consists of the 3 fuel pellets and an exterior sheath of clad, where the protruding clad at each end has been crimped in.

The 0.02-in.-thick sheath of stainless steel clad adds ~179 g to the mass of the active fuel for the standard element or instrumented element with 1.48 in. overall diameter, and ~163 g to active fuel mass for the fuel follower control rod with 1.35 in. overall diameter. Allowance for 0.5 in. of residual stainless steel crimped on each end of the clad fuel rod adds ~11 to 12 g stainless steel to these amounts. Likewise, the 0.03-in.-thick sheath of aluminum clad adds ~90 g to the mass of the active fuel for the 1.47-in.-diam standard element or instrumented element. Allowance for 0.5 in. of residual aluminum crimped on each end of the clad fuel rod adds ~6 g aluminum.

Research reactor fuel elements or fuel components are composed of U-Al, $U_3O_8$-Al, $UO_2$, $UO_2$-Zr, $UO_2$-$ZrO_2$, or $UO_2$-Mg. Related materials include broken uranium metal, U-Al alloy, or oxides ($UO_2$, $UO_3$, $U_3O_8$, $U_3O_8$-Al, $UO_2$-$ZrO_2$, or $UO_2$-Mg). These items contain small quantities of fissile uranium typically ranging from 4.2-g $^{235}U$ to 2000-g $^{235}U$. The maximum enrichment is ~93%. Components are of various solid shapes (rods, square bars, plates, or tubes).

Skull oxides, uranium alloys of aluminum, molybdenum, or zirconium and unirradiated TRIGA reactor fuel elements are evaluated where composition data is for material in the as-manufactured condition. A maximum enrichment of 100 wt % is used for HEU metal, oxide and UNX crystals in the criticality calculations strictly for the purpose of maximizing reactivity, even though HEU enrichment ranges from 19 to 97.7 wt % $^{235}U$. Although mass loading limits for oxide and crystals are based on 100% enrichment, the actual enrichment is expected to be less than the stated maximum, with the remainder of the uranium being primarily $^{238}U$. The HEU mass may also include nonradioactive contaminants and trace elements or materials in the HEU.

No intact weapon part or component will be shipped in this package. Weapon parts or components that have been reduced to "broken metal pieces" or processed into HEU oxide and meet the additional content requirements identified in Sect. 6.2.4 may be shipped in this package.

### 6.2.2 Convenience Cans, Teflon and Polyethylene Bottles, and 277-4 Canned Spacers

HEU fissile material to be shipped in the ES-3100 package will be placed in stainless steel, tin-plated carbon steel, aluminum, or nickel alloy convenience cans, polyethylene or Teflon bottles, or polyethylene bagging. Can lids may be welded, press fit, slip lid, or crimp seal types; bottle lids are screw cap type. Convenience cans and bottles are used to hold the HEU for shipment in the ES-3100 package and to assure that the inside of the containment vessel does not become contaminated with HEU under NCT. The HEU metal or oxide content may be wrapped or bagged in polyethylene, and the convenience cans may also be wrapped in polyethylene to further reduce the possibility of radioactive contamination of the packaging. Nylon straps may be used for handling the nickel alloy cans. Masses of the convenience cans and packing materials are in addition to the fissile material mass.

Three 4.25-in.-diam × 10.0-in.-tall or six 4.25-in.-diam × 4.88-in.-tall convenience cans, separated by can pads, may be placed inside the 31-in.-tall cavity of the ES-3100 containment vessel (Fig. 1.4). The convenience cans may have press-fit or crimp-seal lids. The size of solid content placed inside a convenience can is physically limited by both the can opening and the usable height of the convenience can. Other can arrangements fit inside the containment vessel, such as three 4.25-in.-diam × 8.75-in.-tall convenience cans or five 4.25-in.-diam × 4.88-in.-tall convenience cans. Both of these can arrangements include can pads and 277-4 canned spacers. Nickel alloy cans to be used exclusively for HEU oxide content are ~3-in. diam × 4.75-in. tall. Three Teflon bottles (4.69-in. diam × 9.4-in. tall) or three polyethylene bottles (4.94-in. diam × 8.76-in. tall) fit inside the containment vessel; however, 277-4 canned spacers are not used with these configurations.

A modified convenience can may be used to package the TRIGA and research reactor fuel element and fuel components that do not fit inside these containers. A 17.5 in. or 30 in.-tall convenience can is constructed from two 4.25-in.-diam × 8.75-in.-tall or three 10-in. cans brazed together. The research reactor fuel elements and fuel components that cannot be packaged in these convenience cans due to their overall dimensions will be bundled together and protected on each end with an open-ended convenience can having an outer diameter $\leq$ 5 in.

The can pad and 277-4 canned spacer have overall dimensions of 4.25-in. diam × 1.82-in. height (Drawing M2E801580A043, Appendix 1.3.7). A stainless-steel spacer can with a lid has a usable cavity with dimensions of 4.13-in. diam × 1.37-in. height, which nominally allows for ~510 g of neutron poison material. If closed convenience cans with an outer diameter >4.25 in. are used, at least 55 in.$^3$ of free or void volume must exist inside the containment vessel to allow for gas expansion and offgassing of material at temperatures associated with NCT or HAC.

### 6.2.3 Packing Materials

Polyethylene bags may be used for contamination control to hold the HEU material that is packed into a convenience can. Realistically, the number of polyethylene bags used to bag content and wrap a convenience can would be six bags at most. Given that each bag weighs ~28 g, this results in a maximum of ~510 g of polyethylene per ES-3100 package. Possible additional sources of hydrogenous material inside the containment vessel include can pads and vinyl tape.

Polyethylene bottles (~85 g) may be used to pack HEU oxide; however, polyethylene bags are not used for packing HEU oxide. While polyethylene bags may be used to bag the 85 g polyethylene bottles, the amount of hydrogenous packing material inside the containment vessel is limited to an equivalent 500 g polyethylene. Non-metallic containers such as polyethylene or Teflon (~303 g) may be used to pack UNX crystals. Likewise, polyethylene bags are not used for packing the UNX crystals and the amount of hydrogenous packing material inside the containment vessel is limited to an equivalent 500 g polyethylene.

Normally, the H/X ratio inside the containment vessel is specified as an administrative control used to restrict both the amount of hydrogenous packing material normally used inside the containment vessel and other sources of moisture present in the fissile content. The total amount of hydrogen inside the containment vessel is used in the determination of package H/X ratio (i.e., the ratio of the number of hydrogen atoms "H" to the number of fissile atoms "X," where the hydrogen atoms are those of the content, including absorbed moisture and of the packing material both inside and outside of the convenience cans). However, containment vessel flooding is assumed in calculations performed for the derivation of fissile material loading limits. This simulated condition produces fissile material content that is more reactive than actual.

The 7.1–10.1 kg quantity of evaluation water required in both the NCT and HAC criticality calculations bounds reasonable amounts of hydrogenous packing material present inside the ES-3100 containment vessel for solid HEU metal content (cylinders, bars, buttons, slugs, unirradiated TRIGA fuel, and research-related fuel components fissile material). The hydrogenous packing material encompasses the solid fissile material but is not interspersed within it.

However, the 7.1–10.1 kg quantity of evaluation water does not necessarily bound reasonable amounts of hydrogenous packing material present inside the containment vessel when the fissile material is in particulate form (primarily HEU oxides and UNX crystals) or must be evaluated in particulate form (broken metal). An administrative criticality control is used to restrict the amount of hydrogenous packing material normally present inside the containment vessel (see Item 7 in Sect. 6.2.4).

### 6.2.4 Package Content Loading Restrictions

Loading restrictions based upon the results of the criticality safety calculations presented in Sects. 6.4 and 6.5 are as follows:

1. HEU fissile material to be shipped in the ES-3100 package must be placed in stainless steel, tin-plated carbon steel, aluminum, or nickel alloy convenience cans, polyethylene or Teflon bottles, or polyethylene bagging. Enriched uranium oxide in the form of $UO_2$-Mg will be shipped in glass bottles inside a metal convenience can. Any closure is allowed on the convenience can.

2. The content shall not exceed the "per package" fissile material mass loading limits specified in Tables 6.2a and 6.2b, and 277-4 canned spacers shall be used as indicated for criticality control. Research reactor related contents of uranium metal or U-Al alloy may be packaged for air transport under limits specified in Table 6.2b for HEU broken metal, solid HEU metal of unspecified geometric shape and characterized as broken metal, turnings, fines, or powder. The $^{235}U$ in HEU metal turnings, fines, or powder cannot exceed 80 wt % U, except for quantities of this material $\leq$ 50 g HEU as shown in Table 6.2a. Research reactor fuel elements and components may be packaged for air transport under limits specified in Table 6.2b for unirradiated TRIGA fuel elements. Per package limits for these items are a maximum of 921-g $^{235}U$ for content at enrichments not exceeding 20 wt % and a maximum of 408-g $^{235}U$ for content enrichments greater than 20 wt %.

3. Where 277-4 canned spacers are required, not greater than one-third of the permissible package content for that category indicated in Tables 6.2a or 6.2b shall be loaded in any vacancy between or adjacent to canned spacers inside the containment vessel. The content mass loading may be further restricted based on structural, mechanical, and practical considerations (see Sects. 1 and 2).

4. As shown in Fig. 1.4, the ES-3100 package may carry up to six loaded convenience cans. In situations where the plan for loading the containment vessel calls for the use of empty convenience cans to fill the containment vessel, empty cans and/or stainless-steel scrubbers may be used to fill the void space in the containment vessel. If empty cans are shipped, a minimum 0.32-cm

(0.125-in.)-diam hole must be placed through the lid to prevent over-pressurization of the can in the event of a thermal accident. These empty cans may be placed above or below the loaded cans.

5. The presence of uranium isotopes is limited on a weight-percent basis as follows: $^{232}U \leq 40$ ppb U, $^{233}U \leq 0.6$ wt % U, $^{234}U \leq 2.0$ wt % U, $^{235}U \leq 100.0$ wt % U, and $^{236}U \leq 40.0$ wt % U.

6. With the exception of slug content, unirradiated TRIGA reactor fuel element content, and research reactor related content, solid HEU metal or alloy content of specified geometric shape shall be one item per loaded convenience can. HEU metal or alloy content not covered by the specified geometric shapes (cylinder, bar, button, billet, slug, or unirradiated TRIGA fuel element contents) will be in either the "HEU broken metal or solid HEU metal of unspecified geometric shape and characterized as broken metal" category or in the "HEU metal turnings, fines, or powder" category, and so limited (Table 6.2a). Broken metal is distinguished from turnings, fines, or powder as having a surface-area-to-mass ratio of not greater than 1 $cm^2/g$ or must not pass through a 3/8-in. mesh sieve (or equivalent size-grading method).

7. The package content is defined as the HEU fissile material, bottles, the convenience cans, the can spacers, and the associated packing materials (plastic bags, pads, tape, etc.) inside the ES-3100 containment vessel. The amount of hydrogenous packing material inside the containment vessel shall not exceed an equivalent mass of 500 g polyethylene. The only hydrogenous packing materials that can be used in the containment vessel when shipping HEU broken metal content are those that have a hydrogen density less than or equal to water.

8. The mass of unidentified constituents of an HEU fissile material to be loaded into the ES-3100 will be counted against the fissile mass loading limit. The HEU fissile material will not contain unevaluated moderating materials.

9. Allowable HEU oxide densities are 2.0–6.54 $g/cm^3$.

10. For air transport, the total free water permitted in the ES-3100 packaging is limited to 12 lb (5,443.1 g).

## 6.3 GENERAL CONSIDERATIONS

The ES-3100 packaging configuration is shown on Drawing M2E801580A031 (Appendix 1.3.7). KENO V.a modeling of this configuration with the maximum allowable contents (Sect. 6.2) for a variety of array sizes and array conditions yields bounding calculations that determine the package's CSI (Tables 6.1a–6.1f). Can spacers are used as indicated in Table 6.2a and 6.2b for the purpose of reducing neutronic interaction between the contents of the package, aiding in maintaining the $k_{eff} + 2\sigma$ below the USL for the ES-3100 package. Key input listings are provided in Appendix 6.9.7.

The HEU content of a package is in one of the following forms: solid metal or alloy of a specified geometric shape; broken metal; turnings, fines, or powder; solid metal or alloy of unspecified geometric shape and characterized as broken metal; uranium or skull oxide; UNX crystals; or unirradiated TRIGA reactor fuel elements. The bounding types of HEU content evaluated in this criticality analysis are: 4.25-in.- and 3.24-in.-diam cylinders; 2.29-in.-square bars; 1.5-in.-diam × 2-in.-tall slugs; cubes ranging from 0.25 to 1 in. on a side; broken metal pieces of unspecified geometric shapes; product and skull oxide; UNH crystals; and unirradiated TRIGA reactor fuel elements. Uranyl nitrate hexahydrate (UNH) has a chemical formula of $UO_2(NO_3)_2 \cdot 6H_2O$. This most reactive form is used as the bounding composition for UNX crystals in the criticality evaluation. TRIGA fuel elements are 1.44-in.-diam × 15-in.-tall cylinders of $UZrH_x$ containing <310-g $^{235}U$. Fuel elements are sectioned into three equal length pieces. Calculations demonstrate that these contents are bounded by 3.24-in.-diam HEU metal cylinders. Evaluation of the 3.93-in.-diam × 9.5-in.-tall U-Al cylinders is covered under the evaluation

of the 4.25-in.-diam HEU metal cylinders. The evaluation of the U-Mo content is covered under the assessment of HEU contents at 95 wt % enrichment.

HEU metal shapes are distributed in an optimum arrangement in the flooded containment vessel. For the single package and the array calculations, the HEU broken metal is modeled as a homogeneous mixture of uranium metal and water filling the interior of a flooded containment vessel. This representation bounds the heterogeneous configuration of metal pieces interspersed with hydrogenous packing material inside of wrapped convenience cans (Appendix 6.9.3., Sect. 6.9.3.1). Water soluble UNH crystalline content is modeled as a homogeneous mixture of UN and water filling the interior of the containment vessel.

No credit is taken for the fissile material spacing, neutron absorption, or free volume reduction provided by the presence of can pads, spacer can steel, and convenience cans inside the containment vessel. Water is substituted for polyethylene bagging which may be in use as packing material for both the content placed inside the convenience can and the cans themselves. Pads of steel turnings rolled up into a disk-like shape may also be present in the ES-3100 package for use as cushioning and for reducing the free volume inside the convenience cans. This steel packing material acts as a neutron absorber and is excluded from the calculation model.

Criticality calculations are performed for the containment vessel under full water reflection whereby the water content inside the containment vessel is varied from dry to fully flooded conditions. These calculations demonstrate that the fully flooded condition is most reactive. The containment vessel is flooded in the single-unit calculation model and the infinite and finite array calculation models for both the NCT and HAC evaluations.

The KENO V.a models discussed in the following sections are the single-unit calculation model (Sect. 6.3.1.1), the infinite and finite array calculation models (Sect. 6.3.1.2), the HAC calculation models (Sect. 6.3.1.3), and the air transport models (Sect. 6.3.1.4). The single-unit calculation model is evaluated with a vacuum boundary condition and with full water reflection. The finite array calculation model is evaluated in arrays consisting of packages stacked in 13×13×6, 9×9×4, 7×7×3, 5×5×2, ETP 27×3 and ETP 16×3 arrangements with full water reflection at the array boundary. The ETP arrangements are used specifically for defining smaller array configurations with a high CSI value.

The geometry of the ES-3100 package is depicted in Drawing M2E801580A001 (Appendix 1.3.7). Calculation models of this geometry for evaluating NCT and HAC must be constructed for the single-unit, infinite array and finite arrays within the constraints and capabilities of KENO V.a. As shown in the drawing, the ES-3100 geometry is complex. Given KENO V.a's constraints and capabilities, two methods may be used to evaluate these complex geometries: simplify the geometries with conservative approximations or construct accurate geometries from simple components. Both methods yield valid results; however, the latter method is chosen for this analysis in order to maximize accuracy and to eliminate unnecessary conservatism.

### 6.3.1 Model Configuration

A detailed ES-3100 geometry model is accurately constructed using many simple geometric shapes. The selection of these components is governed by two of KENO V.a's geometry constraints: geometry regions must be composed of uniform and homogeneous materials and exterior regions must completely enclose interior regions. It is apparent from Drawing M2E801580A001 (Appendix 1.3.7) that these constraints could not be simultaneously applied to the entire ES-3100 package. However, these constraints could be applied to vertical segments of the package. Segments (i.e., simple components) are defined by starting at the bottom of the package and defining geometry regions radially outward until the drum surface is reached. A vertical segment is extended upward to the point where the KENO V.a constraints are violated. This vertical position is the termination point of a segment (i.e., the interface with the adjacent segment above it). The vertical segments are constructed accordingly, ignoring the minor variations in the

ES-3100 geometry (i.e., radii of curvature, beveled edges, nuts and bolts). The KENO V.a geometry model for the ES-3100 is then assembled from the vertical segments. The resulting calculation model geometry includes the HEU content, 277-4 canned spacers, the containment vessel, the stainless-steel liner, the inner-liner cavity filled with 277-4, the outer-liner cavity filled with Kaolite, the Kaolite top plug and steel shell, the silicon rubber spacers, and the stainless-steel drum.

#### 6.3.1.1 Single-unit packaging calculation model

The single-unit packaging calculation model is comprised of the geometry model, material compositions, and boundary conditions. Figures 6.1–6.5 depict section views of the geometry model used to evaluate a single ES-3100 package. Excluding minor variations in the ES-3100 geometry (i.e., radii of curvature, beveled edges, nuts and bolts), the single-unit packaging calculation model is an accurate representation of the ES-3100 geometry.

Figure 6.1 depicts a vertical section view of an ES-3100 package with the content of three loaded convenience cans and 277-4 can spacers inside the containment vessel. The fissile material contents shown are HEU cylinders, but convenience cans are not modeled. As illustrated in Fig. 6.1, credit is not taken for fissile material spacing provided by convenience cans inside the containment vessel. Appendix 6.9.1 provides wire-frame schematic and isometric diagrams depicting other fissile material contents considered in this criticality calculation.

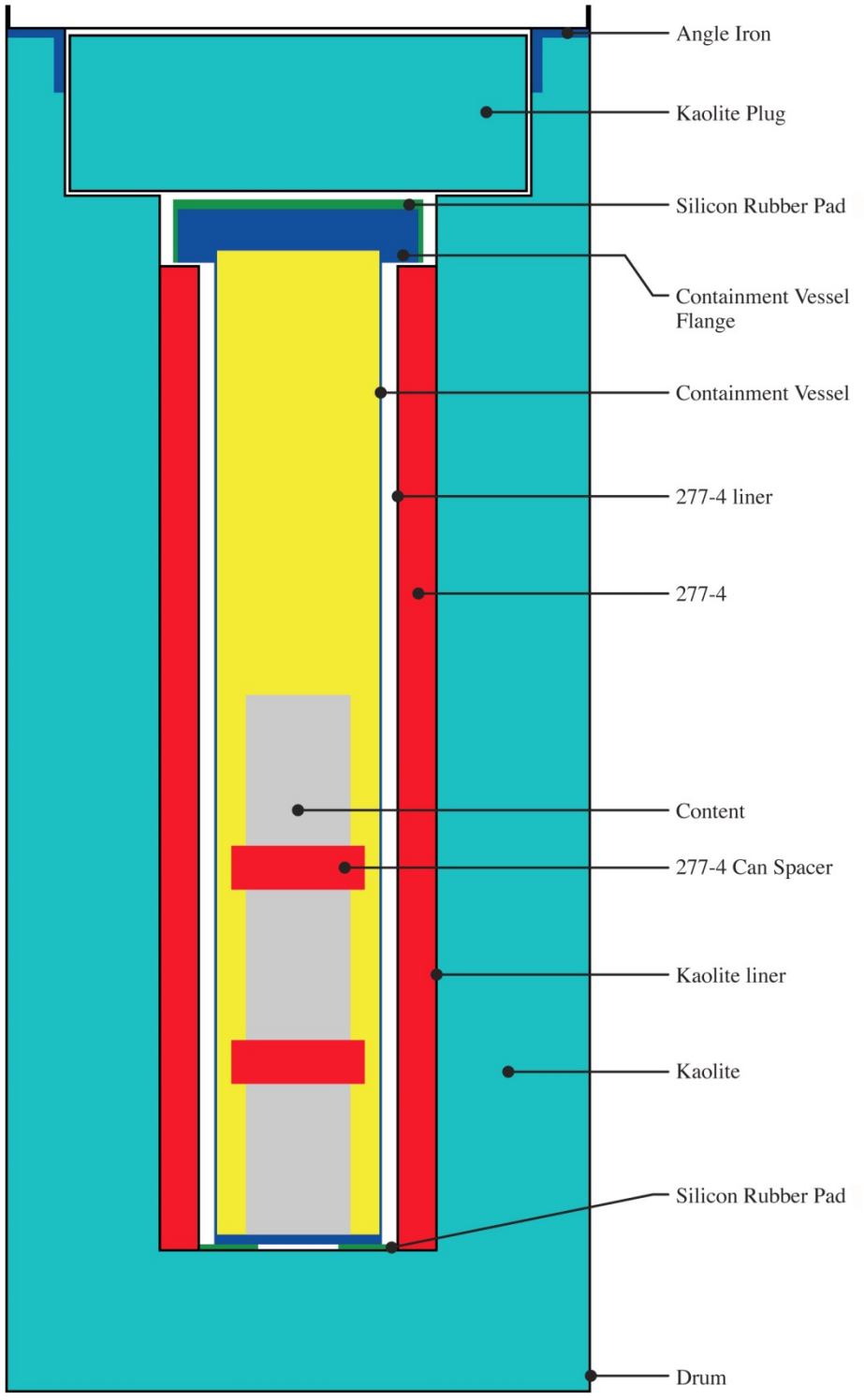
Figures 6.2–6.5 depict vertical section views at various elevations in the package. The dimensions and the material specifications of any element of the ES-3100 single-unit packaging model may be obtained directly from the KENO V.a input listings in Appendix 6.9.7. The vertical segments (KENO V.a geometry unit numbers) are denoted in parenthesis to the right of the dimensions. The dimensions are given in units of centimeters. Material specification data for the single-unit packaging calculation model are provided in Sect. 6.3.2.

The single-unit calculation model is evaluated as both a bare system (i.e., with a vacuum boundary condition) and as a reflected system with 30.48 cm (1 ft) of water surrounding the package for effectively infinite water reflection.

10 CFR 71.55(b) requires evaluation of water leakage into the containment system disregarding any performance capability demonstrated by physical testing per 10 CFR 71.71 and 71.73. In conjunction, 10 CFR 71.55(b)(3) also requires evaluation of the efficiency of the packaging as an external reflector to the containment vessel. The test case is defined as a flooded package. All regions within the water-reflected, single-unit packaging calculation model are flooded with water. The reference case is defined as a water-reflected flooded containment vessel. This calculation model is a modification of the water-reflected, single-unit packaging calculation model where all regions of the packaging external to the containment vessel are replaced with full density water.

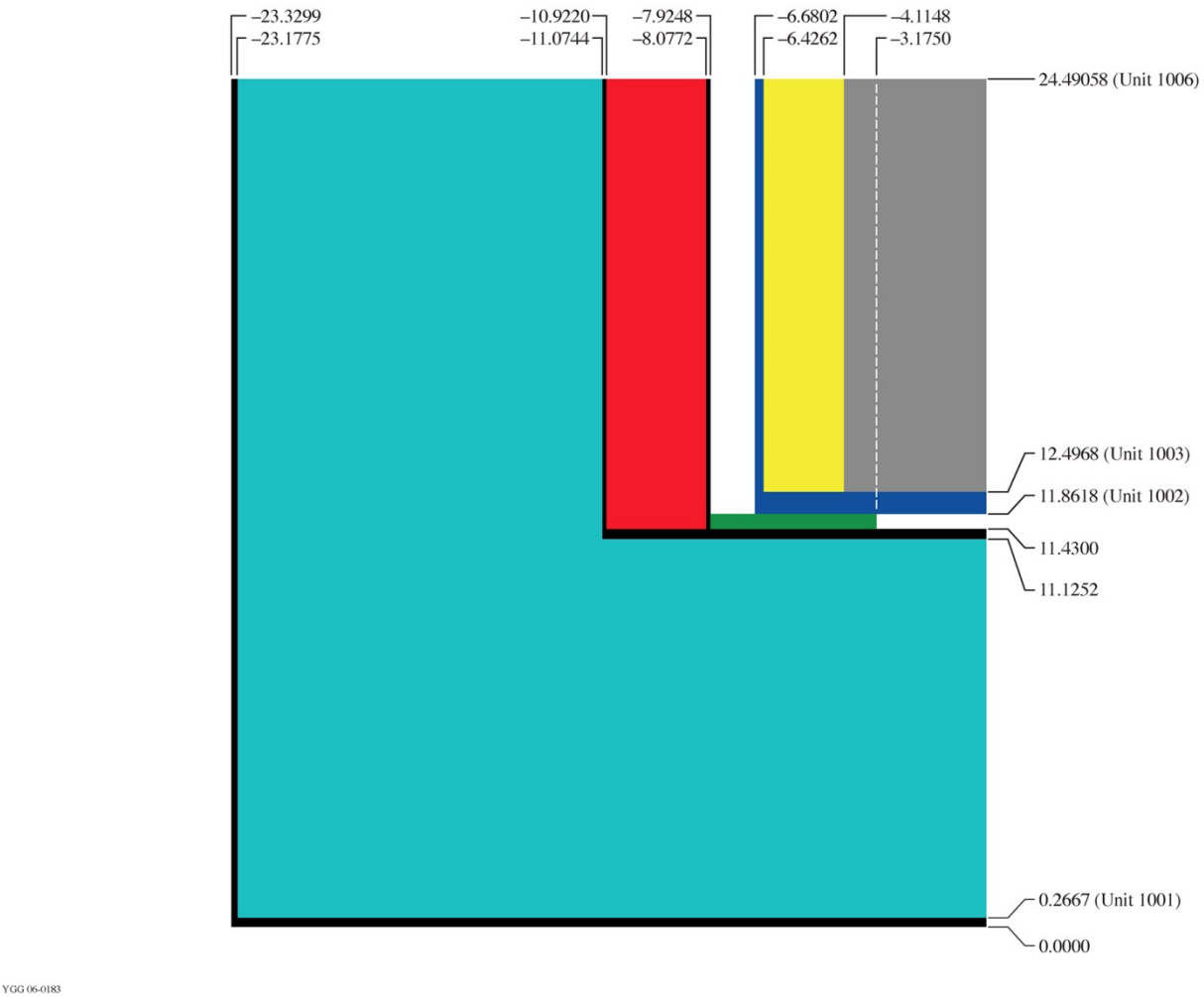
#### 6.3.1.2 Infinite and finite array packaging calculation models

Array packaging calculation models like the single-unit packaging calculation model are comprised of geometry, material compositions, and boundary conditions. Figures 6.6–6.10 depict section views of the geometry model used to evaluate an array of ES-3100 packages. The array geometry model incorporates a 7.0% reduction in the inside diameter of the ES-3100 drum. This reduction of the drum's inside diameter produces an array density equivalent to drums in a tightly packed, triangular pitch configuration (O'Dell). Since all array calculations in this evaluation use a square pitch package configuration, using the 7.0% reduction in diameter of uniform-shaped packages avoids the use of a nonconservative lattice arrangement in the array analysis.



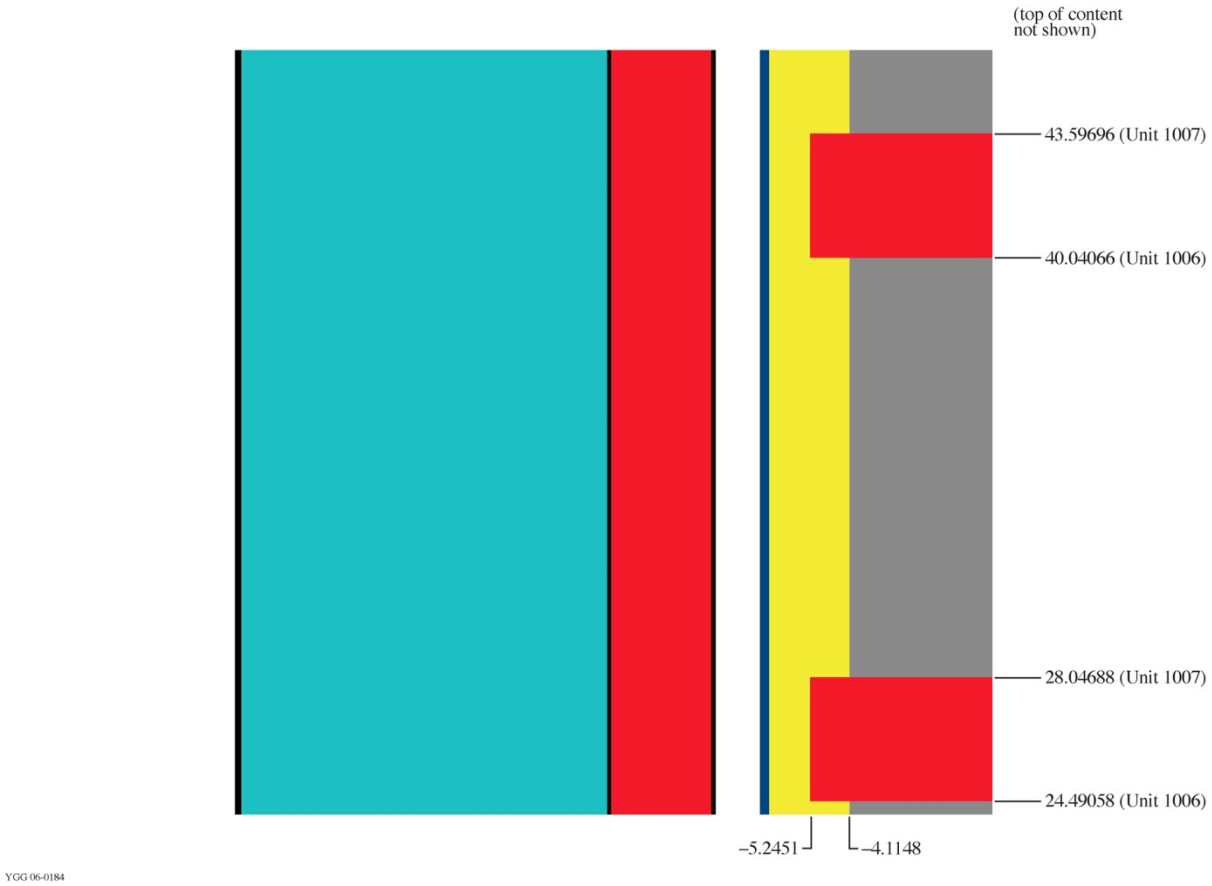

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**Fig. 6.1. R/Z section view of ES-3100 single-unit packaging model.**



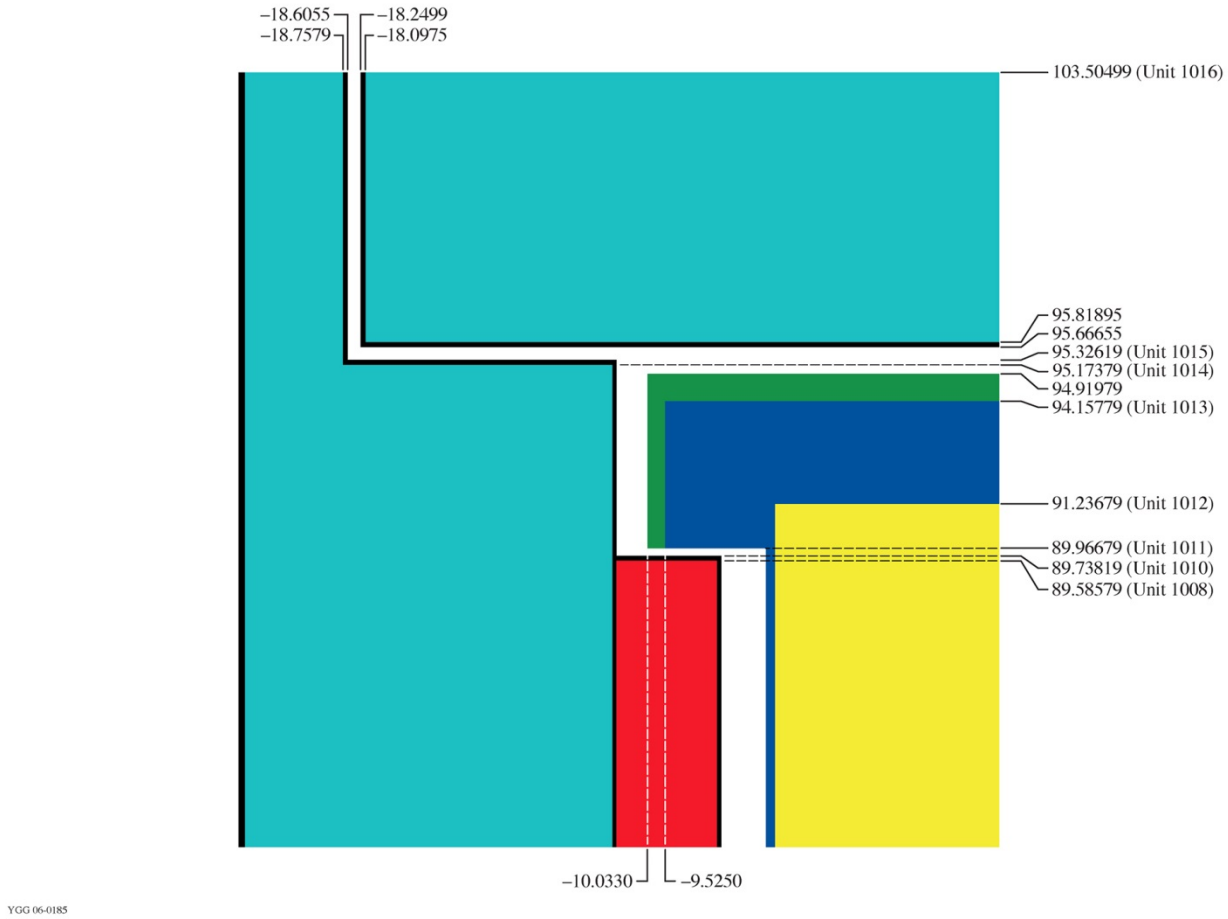

**Note:** Dimensions are in centimeters.

**Fig. 6.2. R/Z section view at bottom of ES-3100 single-unit packaging showing KENO V.a geometry units 1001–1003, and 1006 (partial).**



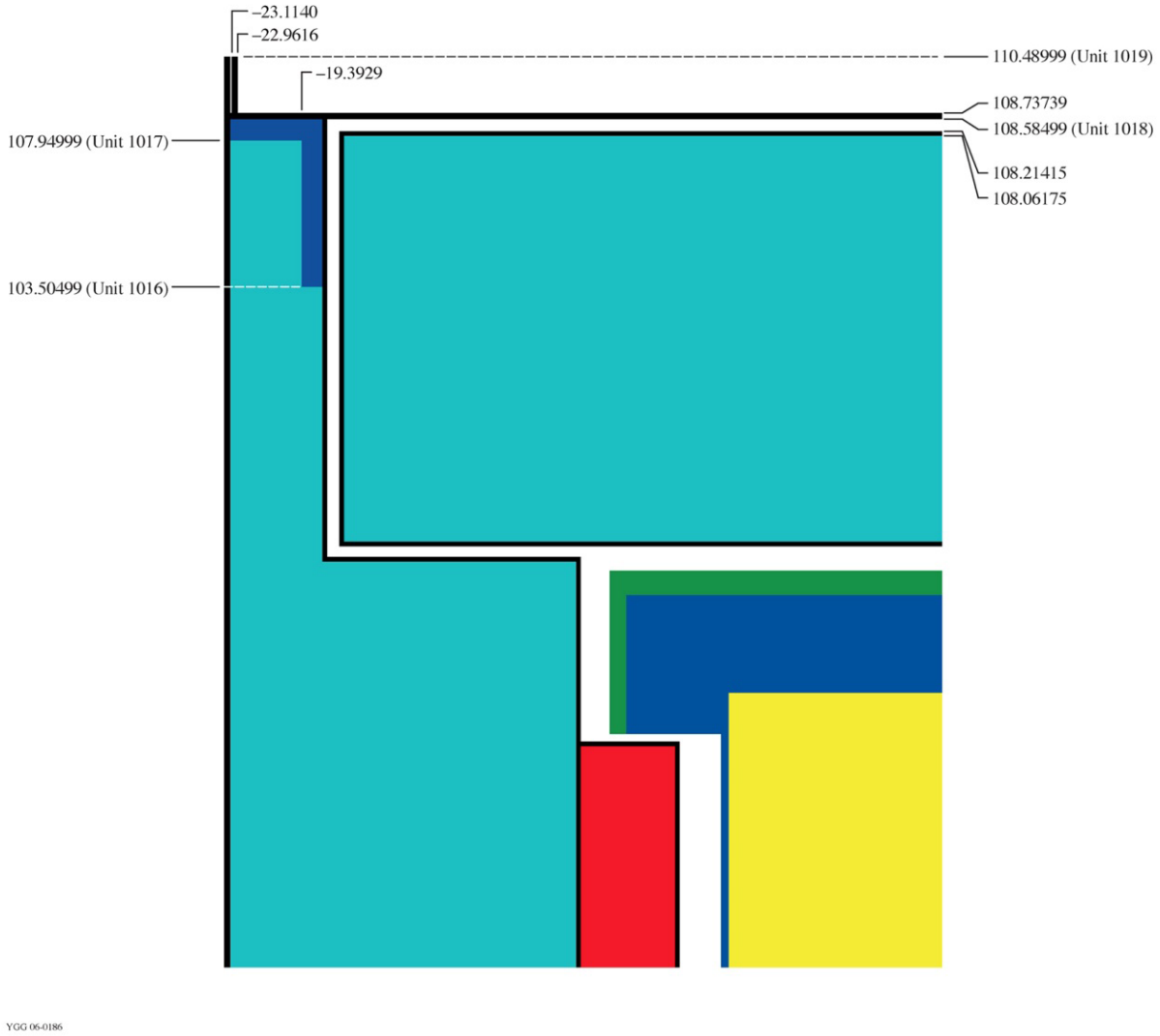

**Note:** Dimensions are in centimeters.

**Fig. 6.3. R/Z section view at center of the ES-3100 single-unit packaging showing KENO V.a geometry units 1006 (partial), 1007, and 1008 (partial).**



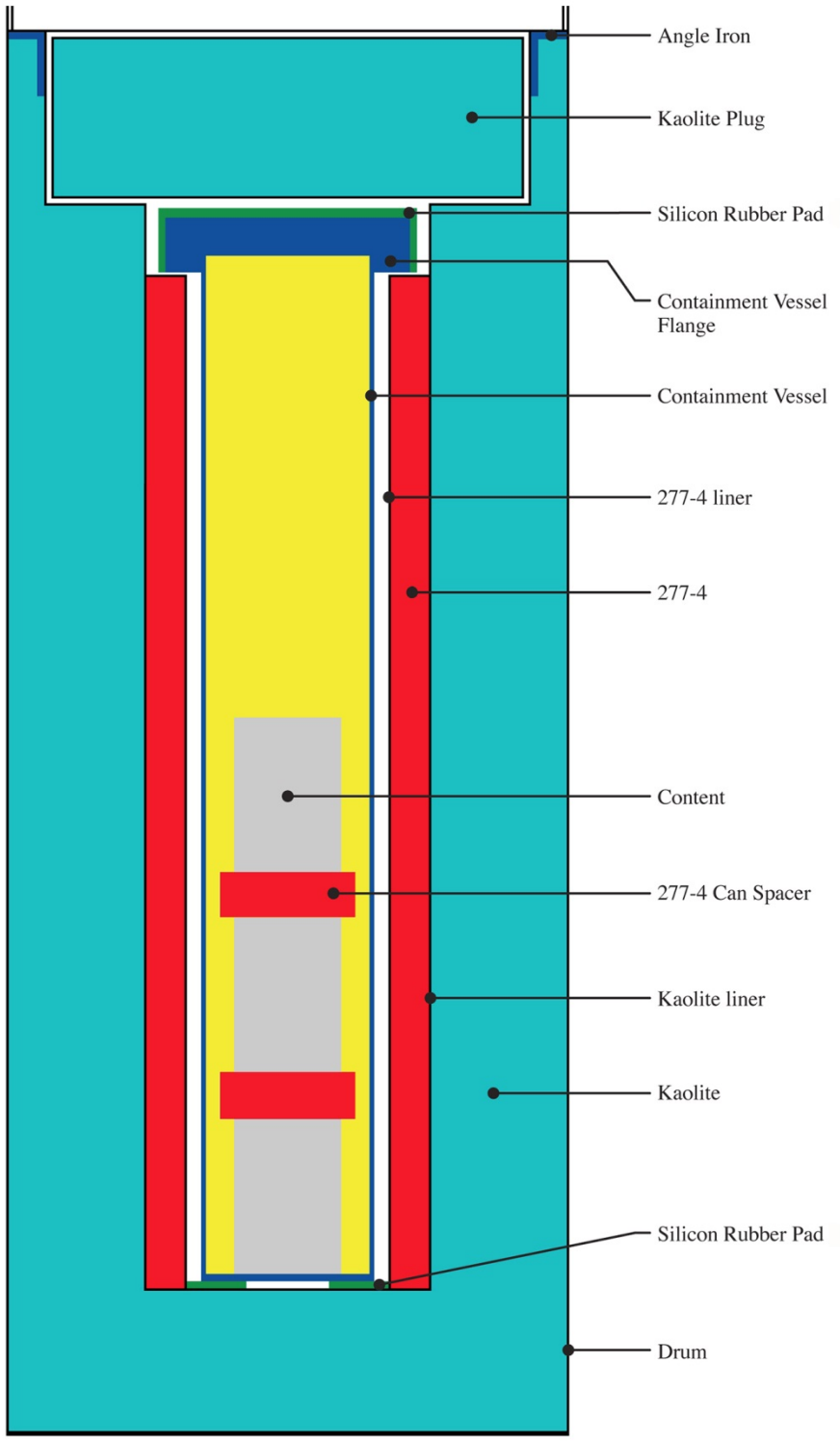

**Note:** Dimensions are in centimeters.

**Fig. 6.4. R/Z section view of near top of the ES-3100 single-unit packaging showing KENO V.a geometry units 1008 (partial) and 1010–1016.**



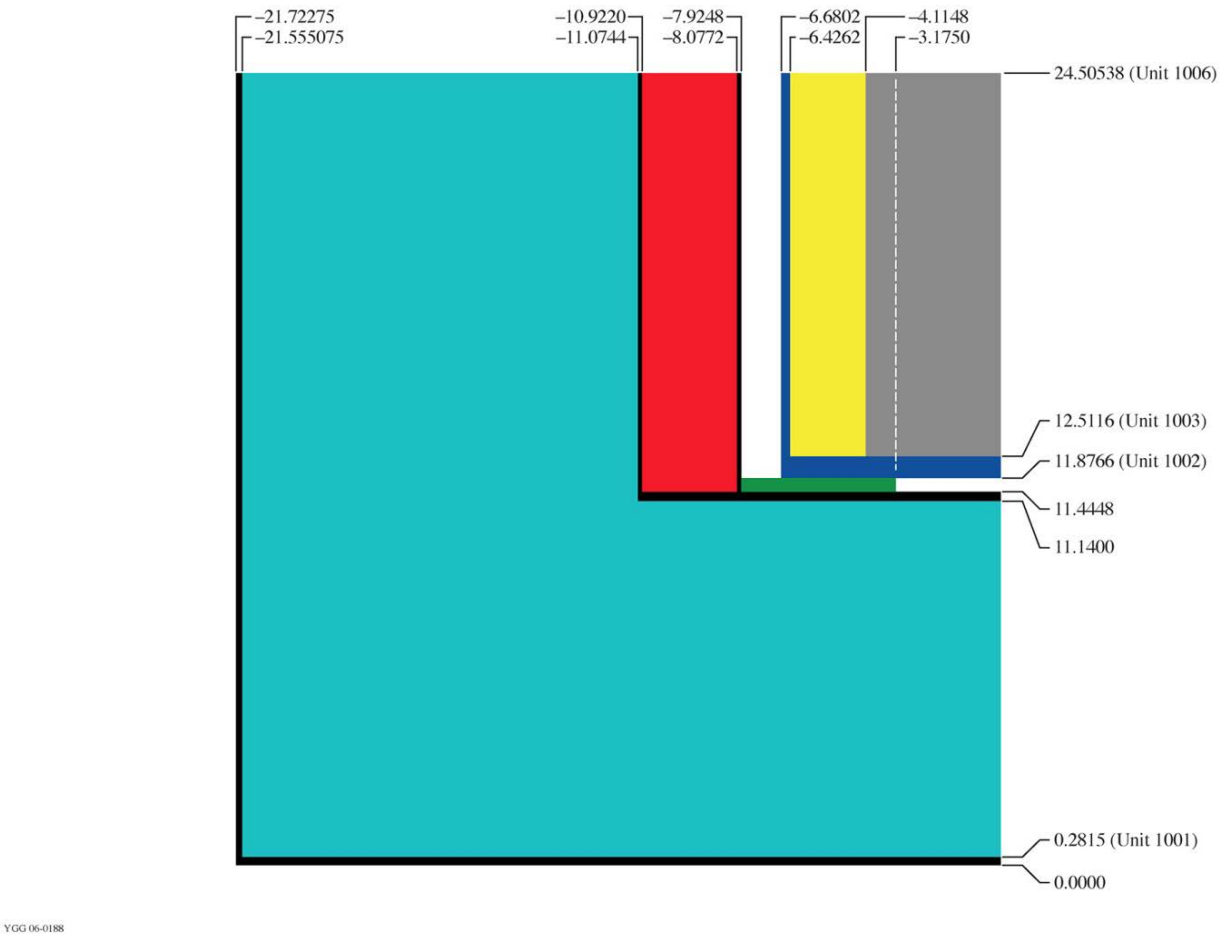

**Note:** Dimensions are in centimeters.

**Fig. 6.5. R/Z section view at the top of the ES-3100 single-unit packaging showing KENO V.a geometry units 1016–1019.**



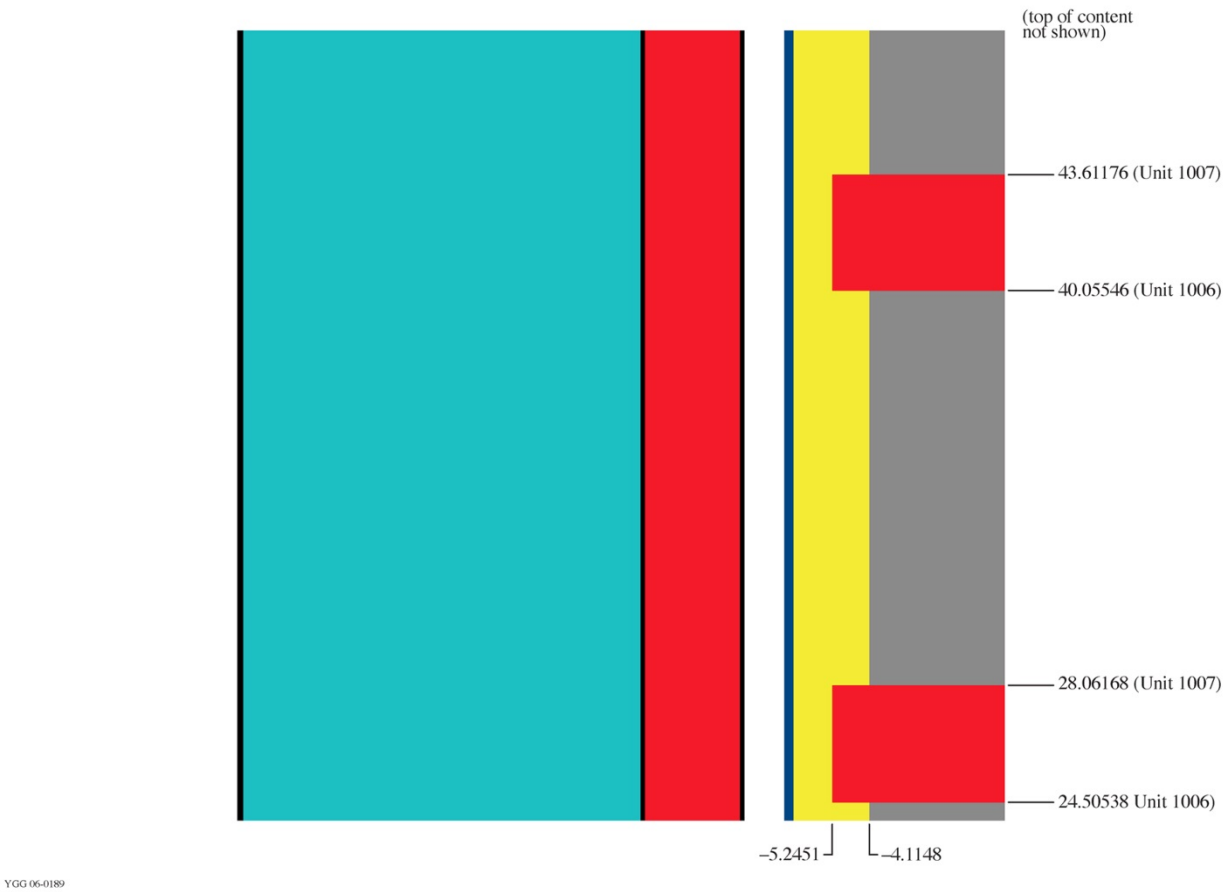

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**Fig. 6.6. R/Z section view of ES-3100 array packaging model with a 7% reduction in the drum's inner diameter.**



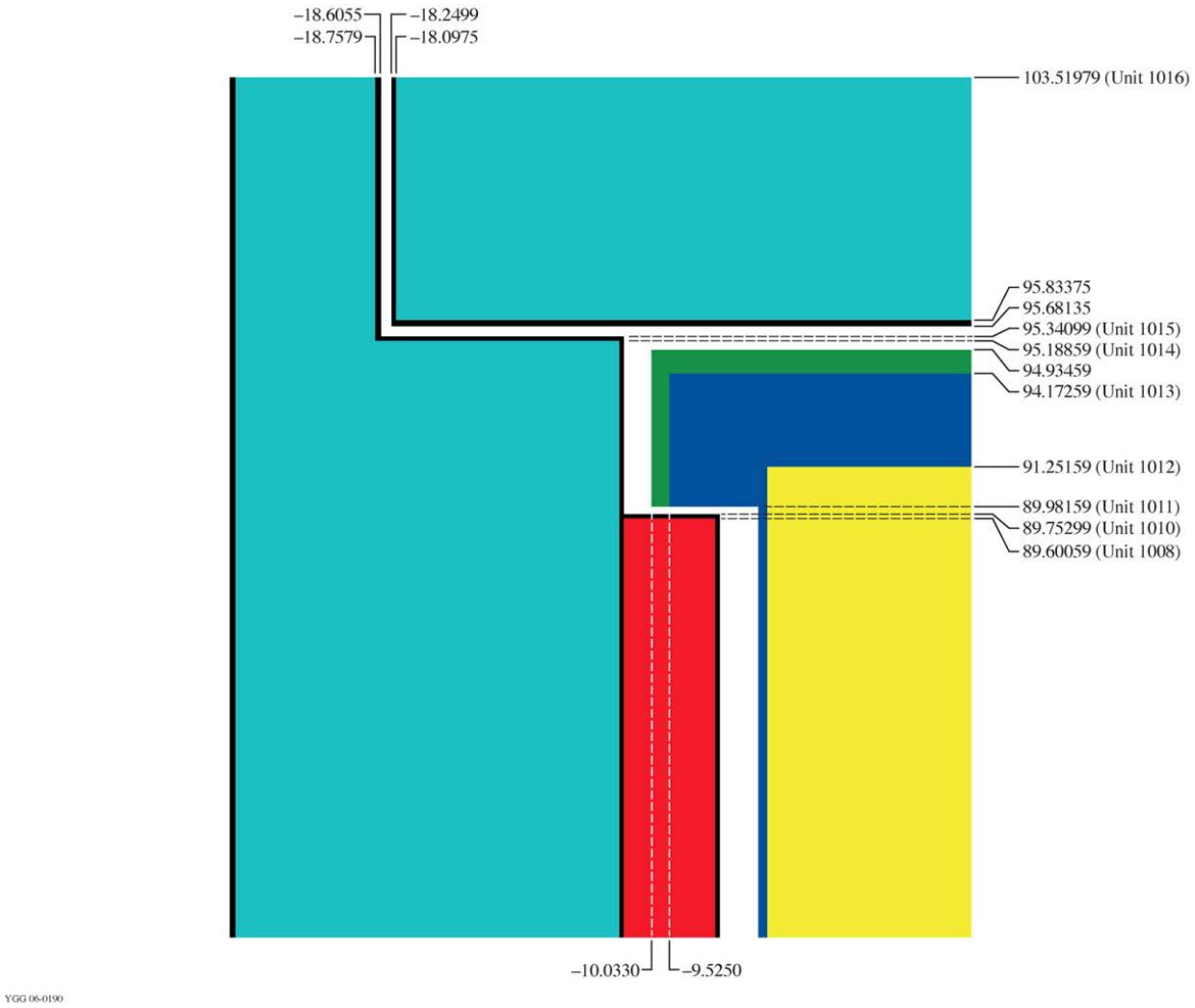

**Note:** Dimensions are in centimeters.

**Fig. 6.7. R/Z section view at the bottom of the ES-3100 array packaging showing KENO V.a geometry units 1001–1003, and 1006 (partial).**



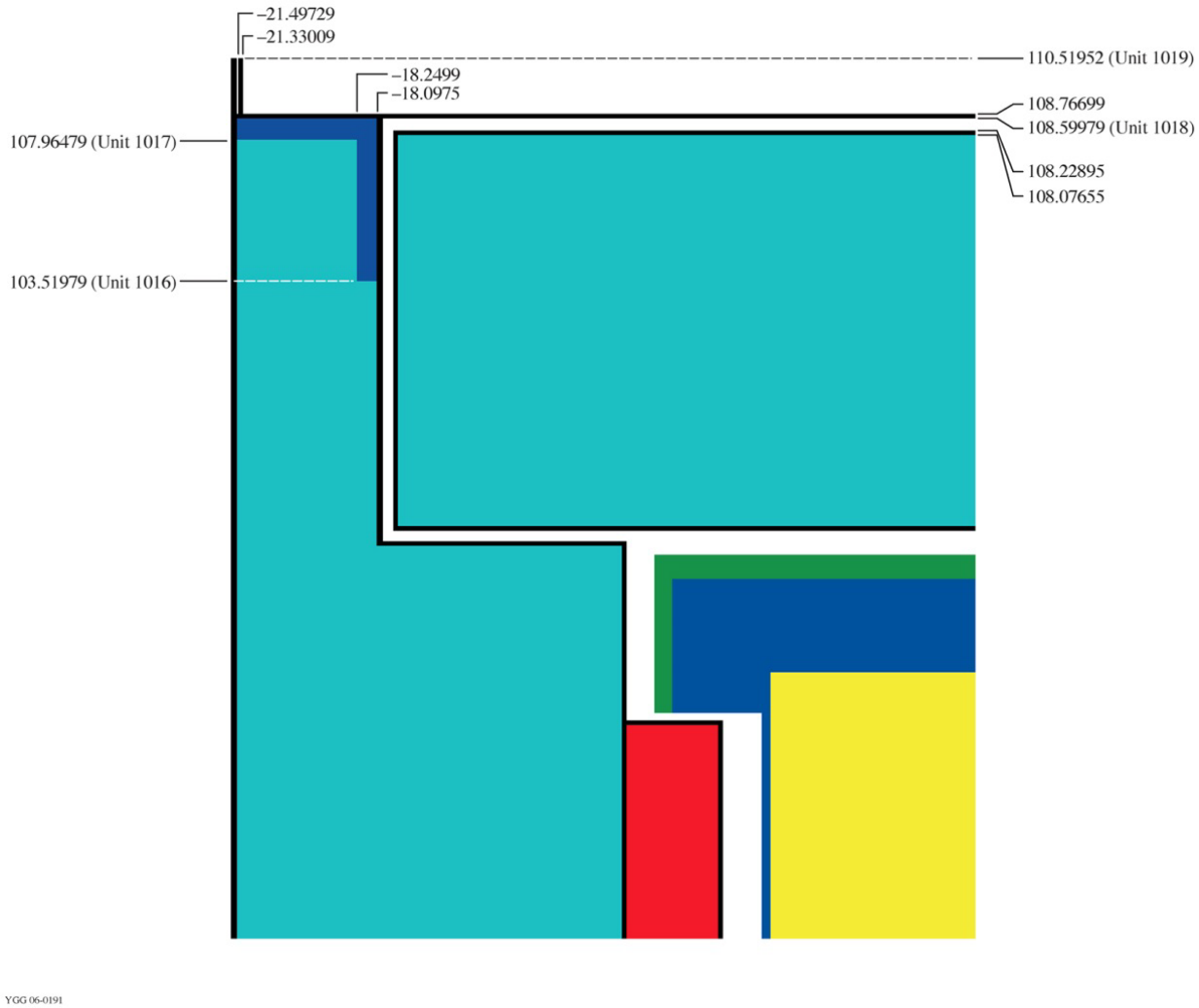

**Note:** Dimensions are in centimeters.

**Fig. 6.8. R/Z section view at the center of the ES-3100 array packaging showing KENO V.a geometry units 1006 (partial), 1007, and 1008 (partial).**




**Note:** Dimensions are in centimeters.

**Fig. 6.9. R/Z section view of near top of the ES-3100 array packaging showing KENO V.a geometry units 1008 (partial) and 1010–1016.**




**Note:** Dimensions are in centimeters.

**Fig. 6.10. R/Z section view at the top of the ES-3100 array packaging showing KENO V.a geometry units 1016–1019.**

As seen in Drawings M2E801580A002 and M2E801580A003 (Appendix 1.3.7), a 7.0% reduction of the inside diameter of the ES-3100 drum affects the masses of the drum, the modified 2 × 2 × ¼ in. angle (angle iron), and the Kaolite refractory material. Also, a 7.0% reduction in diameter affects the mass of interstitial water between the ES-3100 packages of a tightly packed array. To maintain the correct mass of these materials in the NCT array packaging calculation model, the drum's outside dimensions, the density of the steel in the angle iron, the density of Kaolite, and the density of interstitial water are modified. Excluding modifications required to simulate a triangular pitch and minor variations in the ES-3100 geometry (i.e., radii of curvature, beveled edges, nuts and bolts), the array geometry model is an accurate model of the ES-3100 geometry.

In the NCT array packaging calculation model, the drum outside diameter is 43.444550 cm (17.104154 in.) (21.722275-cm radius used as the input value), and the drum inside diameter is 43.11015 cm (16.972500 in.) (21.555075-cm radius). This inside diameter corresponds to 93% of the inside diameter of the ES-3100 drum. The thicknesses of the drum wall, the drum bottom flat cover, and the drum lid are uniformly increased in order to maintain the region volume and to conserve drum mass while the stainless steel density and volume fraction remain unchanged in the KENO V.a input specification. However, the region volume for the drum steel in the NCT array packaging calculation model is not equal to the volume in the single-unit packaging calculation model due to internal round-off in KENO V.a. Therefore, the volume fraction is changed from 1.0 to 0.99981 in the NCT array packaging calculation model for normalization of the drum mass.

The angle iron outside diameter is identical to the drum inside diameter. To maintain mass, the angle iron steel, the liner outer-cavity Kaolite, and interstitial water densities are modified by factors of 1.25705, 1.22252, and 1.16235, respectively. Excluding the modifications to drum and angle iron dimensions, the dimensions of any element of the ES-3100 array geometry model may be obtained directly from Appendix 6.9.7. Material specification data from the array calculation models are provided in Sect. 6.3.2.

O'Dell and Schlesser equate modeling triangular arrays with square pitch arrays, provided that the outer dimension of the array is reduced by a factor of 0.9306 and that the mass of materials is maintained. The actual reduction factors (ratio of the reduced radii to the single unit radii) for the Kaolite of the body weldment and for the angle iron is slightly <0.9306. Given that the array packages are closer than required by O'Dell and Schlesser, the array models are conservative with respect to their reduced radii.

The finite array calculation model is evaluated with arrays of packages stacked in 13×13×6, 9×9×4, 7×7×3, and 5×5×2 arrangements where the arrays are surrounded with 30 cm (~1 ft) of water as a boundary condition representative of full water reflection. These arrays are nearly cubic in shape for optimum reactivity of the array, thus eliminating the need for placing limitations on array configurations in terms of stack height, width, and depth.

The KENO V.a users manual (NUREG/CR-0200, Rev. 6) describes the input statements for an ETP model of cylinders in a close-pack array. This technique is adapted for modeling the ES-3100 in small compact array configurations. The ETP geometry model is much more complicated than the reduced-diameter approximation model described previously, but it yields smaller package configurations with correspondingly higher CSI values than the 7×7×3 and 5×5×2 package arrangements. Use of the ETP geometry specification allows for constructing compact package arrangements of 27×3 (27 packages in the horizontal plane stacked 3 packages high) and 16×3 packages.

#### 6.3.1.3 Calculation models for damaged packages

Sections 2, 3, and 4 of this report address the overall integrity of the Model ES-3100 package in tests for NCT and HAC (ORNL/NTRC-013). From a dimensional viewpoint, the only physical changes

of interest for criticality safety occurred as a result of the 9-m (30-ft) drop test, the crush test, and the 1-m (40-in.) puncture test. There was significant crushing of the drum rim at the point of impact from the 9-m (30-ft) drop test and an indentation on the drum side from the 1-m (40-in.) puncture test. Even though significant crushing of the drum mid-section and bottom occurs, the effective center-to-center spacing of the contents actually increases under HAC. Selective rearrangement of alternating packages would be required to achieve a more compact array; however, this event is not credible.

The deformation of the outer diameters of the drum as predicted by finite element analysis is presented in Table 6.3. These diameters measured along the 90–270° and 0–180° axes are specified at five node points located along the vertical axis of an upright package. These node points are designated in a downward direction from the top of the drum as "UR," "MUR," "MR," "MLR," and "LR." Equivalent circular diameters for representing the deformed drum in the calculation models for the HAC study (Appendix 6.9.2) are based on the assumption that the drum cross section at each deformation point is ellipsoidal.

**Table 6.3. Deformation of 18.37-in.-diam ES-3100 drum projected by finite element analysis Case "3100 RUN1HL Lower Bound Kaolite May 2004"**

| Deformation point | FEA node | Diameter at 90° (in.) | Diameter at 180° (in.) | Equivalent circular diameter (in.) |
|---|---|---|---|---|
| UR | 098194 | 20.02 | 15.60 | 17.67 |
| MUR | 100238 | 20.74 | 15.07 | 17.68 |
| MR | 101589 | 20.74 | 14.18 | 17.15 |
| MLR | 103012 | 22.00 | 13.44 | 17.20 |
| LR | 105786 | 20.92 | 12.92 | 16.44 |

The package water content in the void spaces external to the containment vessel and the interstitial spaces between drums is varied in the calculation model while maintaining the Kaolite in the dry condition. At a low moisture content where neutronic interaction between packages of an array is greatest, there is no statistically significant difference in the calculated neutron multiplication factor for package models based on the "MR," "MLR," and "LR" node points. At high moisture content where a statistically significant difference in the calculated neutron multiplication factor occurs, the packages of an array are nearly isolated. The slight increase in $k_{eff}$ at the smaller diameters is not numerically significant. A calculation model based on the "MLR" node point is used to represent HAC.

As concluded in Sect. 6.9.2.3, the criticality analysis of an array of HAC packages based on the "MLR" package model (diameter = 17.20 in.) in rectangular pitch bounds the analysis of damaged packages (diameter = 17.26 in.) in close-pack array configurations. Considering both the irregular shape of the deformed drums and the fact that overall (maximum) dimensions rather than a mean or minimum dimension for a damaged package would establish array spacing—this assumption is a reasonable one, and the model is conservative.

A reduced-diameter version of the "MLR" package model used for modeling a close-pack array configuration of HAC packages is not created. Instead, "MLR," the single-unit packaging model, is evaluated in a rectangular-pitch array configuration using appropriate boundary conditions. Consequently, the dimensions of the HAC array packaging calculation model do not differ from those of the HAC single-unit packaging calculation model. Therefore, the region volume of the drum and the atomic densities for the elemental constituents for the drum stainless steel are the same in both of the HAC calculation models.

The neutron poison, Kaolite refractory material, and stainless-steel components of the ES-3100 package were not significantly damaged during thermal testing. The principal material change of consequence that occurred during the thermal test was the loss of volatile material (Sect. 2.7.4). No loss of volatile material other than steam from the Kaolite was experienced during prototype testing of the Model ES-3100 package.

Physical damage is significant in terms of criticality safety when the amount of volatile hydrogenous material available for interstitial moderation is reduced. Conversely, the package could be saturated with water during water immersion conditions. Both possibilities affect only the amount of interstitial moderation. The representation of the changes to material composition from temperature extremes and water intrusion is addressed in Sect. 6.3.2.

In the case of broken metal content, the ETP geometry specification using the "MLR" package model (diameter = 17.20 in.) produces a 16×3 package configuration having a correspondingly higher CSI value than a 5×5×2 package arrangement. This allows for a greater fissile payload.

#### 6.3.1.4 Calculation models for catastrophically-damaged packages (air-transport)

It is possible for accidents to be substantially more severe in the air transport mode than in the surface transport mode. Thus, the performance requirements for packages designed to be transported by air are more stringent. U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 7.9 states that the criticality evaluation should evaluate a single package under the expanded accident conditions specific in 10 CFR 71.55(f).

For a fissile material package designed to be transported by air, 10 CFR 71.55(f)(1) requires the criticality evaluation demonstrate that the package be subcritical, assuming reflection by 20 cm (7.9 in.) of water but no water inleakage, when subjected to the sequential application of the HAC free drop and crush tests of 10 CFR 71.73(c)(1 and 2) and the modified puncture and thermal tests of 10 CFR 71.55(f)(1)(iii and iv). 10 CFR 71.55(f)(2) requires the criticality evaluation demonstrate that the package be subcritical, assuming reflection by 20 cm (7.9 in.) of water but no water inleakage, when subjected to an impact on an unyielding surface of 90 m/s normal to the surface.

The "no water inleakage" condition of 10 CFR 71.55(f)(1) and (f)(2) signifies that the hydrogenous material present in the package during air transport is limited to the amount present in the package when it is loaded on the aircraft for transport. Potential sources of hydrogen moderator are the hydrogenous packing materials present inside the containment vessel, moisture inside the containment vessel well, and the moisture inside the Kaolite region of the package. The use of hydrogenous packing material is limited to 500 g. Both the use of a drum covering and administrative controls (Sects. 7 and 7.1.3.1) will ensure dryness of the containment vessel well. Thus, the focus is on the Kaolite region of the ES-3100 package. The 53,420 g of dry-baked Kaolite in the drum body weldment and drum top plug consists of 51,214.9 g of vermiculite-cement constituents and 2,204.7 g of bound water. For establishing the loading limits for air transport, the total **free** water in wet Kaolite was conservatively evaluated up to 15 lb (6,803.8 g).

Physical testing of Type-B fissile material packages transported by air was not conducted for the ES-3100. In lieu of testing, criticality calculations are performed using calculation models that conform to the basic requirements of 10 CFR 71.55(f) regarding both the absence of water inleakage and reflection of the package by 20 cm of water. In addition, the air-transport calculation models incorporate features exhibiting the worst-case assumptions made regarding the geometric arrangement of the packaging and package contents. No credit is taken for the geometric form of the package content. Spherical geometry is used to represent the ultimate configuration of the ES-3100 package which undergoes catastrophic destruction.

The criticality analysis for air transport does not credit the ES-3100 for maintaining the geometry configuration of the packaged content. Fissile material is configured spherical in shape for optimization of neutron multiplication. Also, the criticality analysis does not credit the ES-3100 packaging for structural integrity of the containment and the confinement. The reactivity "enhancing" materials of the packaging may be interspersed with the fissile material content. However, selective removal of the neutron-absorbing material of the package (i.e., Kaolite and stainless steel) accompanied by retention of the moderating constituents of the neutron-absorbing material (i.e., bound water in the Kaolite) is not a credible condition. Moreover, a calculation model where the fissile material is homogenized with moderating material is only an appropriate representation when the fissile material content being shipped consists of numerous solid pieces uranium ("broken metal"), metal turnings, fines, powder, oxide, or crystals. Homogenization of fissile material with moderating material is not performed with exclusive preference given to specific constituents of the moderating material.

A set of six calculation models are constructed in order to determine the worst case or most reactive configuration with consideration given to the efficiency of moderators, loss of neutron absorbers, rearrangement of packaging components and contents, geometry changes, and temperature effects. The fissile material component is dry in each case.

Model 1 (Fig. 6.11) represents the fissile material content configured into a spherical core with a 20.0-cm thick water reflector. All ES-3100 packaging material (Kaolite, stainless steel, 277-4 neutron poison, etc.) is excluded from Model 1. The fissile material content considered in the calculation model consists of a specific material form: solid HEU metal (7–10 kg $^{235}$U); TRIGA fuel (10 kg $UZrH_x$ having 921-g $^{235}$U); or broken HEU metal ($\leq$ 7 kg $^{235}$U). The presence of hydrogenous packing material inside the containment vessel is also addressed in this calculation model. Five hundred grams of polyethylene is used to represent a maximum amount of hydrogenous packing material in the ES-3100. For 7 kg $^{235}$U HEU homogenized with 500 g of polyethylene, the radius of the core is 6.0238 cm. The parametric variation of both the $^{235}$U mass and the enrichment in Model 1 is used to establish a reference point for the evaluation neutron reflection and absorption effects on $k_{eff}$ provided by the stainless steel and Kaolite packaging materials, addressed separately in Models 2 and 3. Case names for Model 1 are designated with the prefix "atdmr" for the HEU solid and broken metal contents. Case names for TRIGA fuel at 19.7 and 70% enrichments are designated with the prefixes "atdzr" and "atdzr70," respectively.

Model 2 (Fig. 6.12) represents a spherical core of Model 1 blanketed by a variable-thickness shell of stainless steel, and a 20.0 cm thick water reflector external to the shell. The shell at maximum thickness corresponds to the 66,133 g stainless steel of the containment vessel and the liner and drum assembly. For 7 kg $^{235}$U HEU metal homogenized with 500 g of polyethylene, the radius of the core is 6.0238 cm while the outer radius of the stainless steel shell is 13.0198 cm. Case names for Model 2 are designated with the prefix "atdmsr" for HEU solid and broken metal content. Case names for TRIGA fuel are designated "atdzsr" and "atdzsr70."

Model 3 (Fig. 6.13) is configured the same as Model 2 with the exception that instead of stainless steel, the variable-thickness shell is composed of wet Kaolite. Maximum shell thickness corresponds to 60,223.4 g of wet Kaolite (53,419.6 g of dry-baked Kaolite plus 6,803.8 g of free water). For 7 kg $^{235}$U HEU metal homogenized with 500 g of polyethylene, the radius of the core is 6.0238 cm while the outer radius of the shell is 31.0802 cm. Case names for Model 3 are designated with the prefix "atdm15kr" for HEU solid and broken metal content. Case names for TRIGA fuel are designated "atdz15kr" and "atdz15kr70." The parametric variation of shell thickness in Models 2 and 3 is performed for the purpose of evaluating the effect on $k_{eff}$ of neutron reflection and absorption provided by each packaging material.

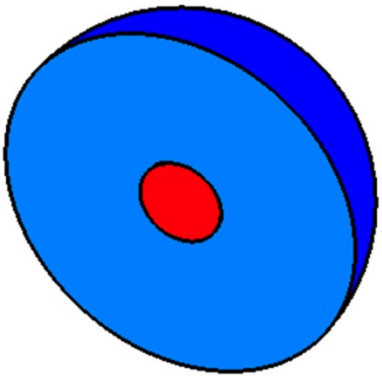


**Fig. 6.11. Model 1.**
7 kg $^{235}$U (red) reflected by 20 cm of water (blue).

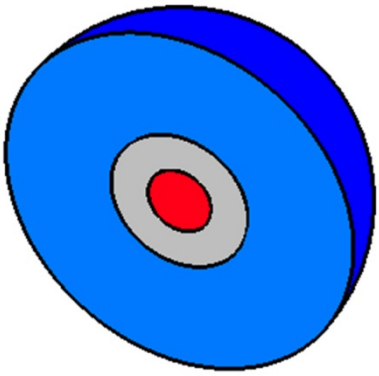


**Fig. 6.12. Model 2.**
7 kg $^{235}$U (red) blanketed by a stainless-steel shell (gray), reflected by 20 cm of water (blue).

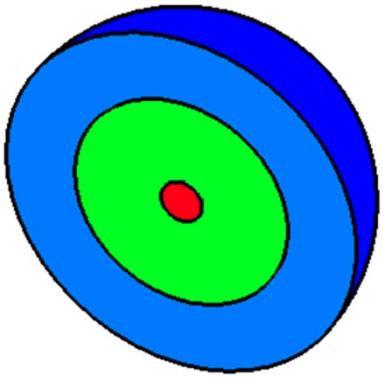


**Fig. 6.13. Model 3.**
7 kg $^{235}$U (red) blanketed by a wet-Kaolite shell (green), reflected by 20 cm of water (blue).

Models 1–3 are applicable for establishing loading limits for air transport packages having a single piece or several pieces of solid HEU metal where the integrity of the content is demonstrated based on package tests or dynamic impact simulations per Type-C test criteria. Otherwise, the criticality evaluation of additional accident models is required for those situations where: (1) data is not available or is inadequate for discounting fragmentation of the fissile content in the air transport accident, or (2) the fissile material is in a physical form (crystals, oxide, or multiple pieces of solids) having the potential to blend with the other material of the package in the air transport accident.

Model 4 (Fig. 6.14) depicts a spherical core of broken metal homogenized with wet Kaolite and hydrogenous packing materials inside the containment vessel represented by 500 g of polyethylene. A 20-cm thick water reflector blankets the spherical core. All other ES-3100 packaging material (stainless steel, 277-4 neutron poison, etc.) is excluded from Model 4. For 7 kg of HEU (7 kg of $^{235}$U), the radius of the homogenized core is 31.0803 cm with the amount of water in Kaolite ranging from 2,204.7 g in baked-dry Kaolite to 9,008.6 g in wet Kaolite. Model 4 also applies to TRIGA fuel content. Case names for Model 4 are designated with the prefix “athmp15kr” for the HEU solid and broken metal contents. Case names for TRIGA fuel at 19.7 and 70% enrichments are designated with the prefixes “athzp15kr” and “athzp15kr70,” respectively.

Model 5 (Fig. 6.15) is an extension of Model 3 applied to the case of TRIGA fuel and broken metal contents. Excess water from wet Kaolite is homogenized with the fissile material in the core. For 7 kg of HEU where 7 kg of $^{235}$U is homogenized with 500 g of polyethylene and 0 g of free water from wet Kaolite, the radius of the spherical core is 6.0238 cm. The exterior Kaolite shell containing 9,008.5 g of water and the 51,214.9 g of vermiculite-cement constituents, has an outer radius of 31.0802 cm. At the extreme condition where the entire 6,803.8 g of water from wet Kaolite is homogenized with the core, the radius of the spherical core is 12.2667 cm. The exterior shell of dry Kaolite, containing 2204.72 g of bound water and 51,214.35 g of vermiculite cement constituents, has an outer radius of 31.6319 cm. Case names for Model 5 are designated with the prefix “athmpw15kr” for the HEU solid and broken metal contents. Case names for TRIGA fuel at 19.7 and 70% enrichments are designated with the prefixes “athzpw15kr” and “athzpw15kr70”, respectively.

Model 6 (Fig. 6.16) is configured similarly to Model 4 with the exception that only a partial amount of broken metal resides in the homogenized core. The remainder of the fissile material is modeled as a shell external to the spherical core and internal to the 20.0 cm thick water reflector. The amount of fissile material in the homogenized core is varied in 500 g increments from the full amount

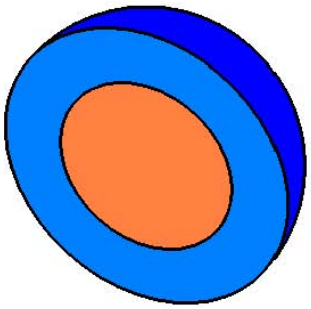


**Fig. 6.14. Model 4.** Homogenized sphere of 7 kg $^{235}$U, polyethylene, and wet-Kaolite (orange), reflected by 20 cm of water (blue).

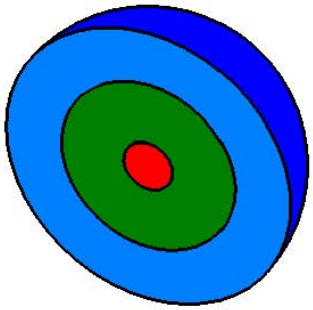


**Fig. 6.15. Model 5.** Homogenized sphere of 7 kg $^{235}$U, polyethylene, and excess moisture from wet-Kaolite (red), blanketed by Kaolite shell (green), reflected by 20 cm of water (blue).

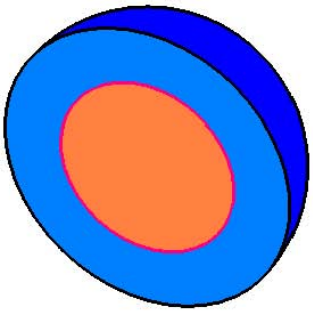


**Fig. 6.16. Model 6.** Homogenized sphere of 3.5 kg $^{235}$U, polyethylene, and wet-Kaolite (orange); blanketed by shell of 3.5 kg 235U, reflected by 20 cm of water (blue).

of Model 5 minus 500 g to a minimum amount of 500 g HEU. In the case of 7 kg of broken metal where 3.5 kg of $^{235}$U is homogenized with 500 g of polyethylene and wet Kaolite, the radius of the core is 31.0649 cm while the outer radius of the exterior 3.5 kg shell of $^{235}$U is 31.0804 cm. The same dimensions apply in the case of 7.0 kg of broken metal where 3.5 kg of $^{235}$U is homogenized with 500 g of polyethylene and dry Kaolite. In the case where 0.5 kg of $^{235}$U is homogenized with 500 g of polyethylene and wet Kaolite, the radius of core is 31.0518 cm while the outer radius of the exterior 6.5 kg shell of $^{235}$U is 31.0804 cm. In the case where 6.5 kg of $^{235}$U is homogenized with 500 g of polyethylene and wet Kaolite, the radius of core is 31.0781 cm while the outer radius of the exterior 0.5 kg shell of $^{235}$U is 31.0804 cm. Case names for Model 6 are designated with the prefix "athmpw15kmr" for the HEU solid and broken metal contents. Case names for TRIGA fuel at 19.7 and 70% enrichments are designated with the prefixes "athzpw15kmr" and "athzpw15kmr70," respectively. Model 6 addresses potential redistribution of fissile material consisting of multiple pieces, specifically the broken metal content. The parametric variation of shell thickness in Model 6 is performed for the purpose of evaluating the effect on $k_{eff}$ of moderation efficiency of the core and enhanced neutron multiplication of the shell.

Models 1–6 are applicable to air transport of the ES-3100 package given that the physical integrity of the fissile content following the air transport accident cannot be established, or that the physical form of fissile material content may be multiple solid pieces, turnings, fines, powder, or oxide.

### 6.3.2 Material Properties

Criticality calculation models include the definition of material compositions in the geometry model for both NCT and HAC. The materials which affect nuclear criticality safety and may be present in the ES-3100 package during these conditions are fissile material content (HEU metal, aluminum, molybdenum, and zirconium alloys of uranium, HEU product or skull oxide, UNX crystals, or $UZrH_x$), stainless steel, 277-4 neutron poison, Kaolite, silicon rubber, Teflon or polyethylene, and various amounts of water. Other materials are present in the package (e.g., tin-coated steel convenience cans, nylon bagging, rubber O-rings, and trace impurities). However, these other materials are not present in amounts that will significantly affect the reactivity of the package. Detailed discussion of the package content and packaging materials is contained in Appendix 6.9.3. Specific topics are summarized in this section as required to support the discussion of the criticality calculations presented in Sects. 6.4–6.6.

Cat 277-4 neutron poison is designed to maximize the hydrogen content necessary for thermalizing fast neutrons for capture in the boron constituent. Cat 277-4 is a formulation of the vendor's Cat 277-0, a boron carbide additive, and water. This mixture is cast and dried. "Loss On Drying" (LOD) tests are used to measure the amount of water in the as manufactured 277-4 casting. The as-manufactured neutron poison material at 100 lb/ft$^3$ and 31.8% LOD has a hydrogen concentration of 3.56 wt % and a natural boron concentration of 4.359 wt % (DAC-PKG-801624-A001, Table 5).

The testing of 277-4 reveals that the material will dehydrate at elevated temperatures. Test specimens were dried at 250°F for 168 hours to reach the NCT state, and weight measurements were taken. These specimens were subsequently heated to 320°F for 4 hours to reach the HAC state, and weight measurements were again taken. The compositions of 277-4 at NCT and HAC states were derived by adjustment of the formulation specification for measured losses taking into account the statistical variations in the data. Conservation of mass for non-volatiles was observed in the derivation of material specifications based upon testing. Given that hydrogen presence is key to the effectiveness of the neutron poison, conservative material specifications were derived for minimum hydrogen content and minimum material density.

The NCT material specification for 277-4 at minimum density (95.39 lb/ft$^3$) and minimum hydrogen (25.15% LOD) is given in Table 11 of DAC-PKG-801624-A001. The average density of 277-4 in the ES-3100 package used for NCT calculations in KENO V.a is 1.52797 g/cm$^3$; the boron constituent is 7.31015E-2 g/cm$^3$; the residual base is 1.07070 g/cm$^3$; and the water component is 3.84169E-01 g/cm$^3$ (Appendix 6.9.3, Table 6.9.3.3-2). The HAC material specification at minimum density (95.32 lb/ft$^3$) and minimum hydrogen (25.09% LOD) is given in Table 12 of DAC-PKG-801624-A001. The average density of 277-4 used for HAC calculations in KENO V.a is 1.52680 g/cm$^3$; the boron constituent is 7.31015E-2 g/cm$^3$; the residual base is 1.07071 g/cm$^3$; and the water component is 3.82995E-1 g/cm$^3$ (Appendix 6.9.3, Table 6.9.3.3-3).

A set of 20 canned spacer assemblies as-manufactured has an average weight of 591.55 g. On average, the weight of an empty can with a lid is 86.05 g, and the 277-4 is 505.5 g. On the basis of volumetric measurements, the neutron poison is ~10.075 oz or 297.95 cm$^3$. The resultant 277-4 density is 1.6966 g/cm$^3$. The corresponding minimum mass is 473.84 g (given that the 277-4 material inside the spacer can is ≥4.07-in. diam and 1.31-in. thickness). Based on model dimensions of 4.13-in. diam × 1.37-in. height and use of composition data from Table 11 of DAC-PKG-801624-A001 (as-manufactured material at minimum density and hydrogen), the mass of neutron poison in the calculation model of the canned spacer is conservatively modeled as 457.15 g.

The density of 277-4 in the liner inner cavity is further reduced by a factor of 0.966893 because the actual volume of neutron poison is 12,831.4 cm$^3$ in the package, but 13,270.8 cm$^3$ is used in the calculation model. Also, guidance in Sect. 6.5.3.2 of NUREG-1609 requires that 75% of elemental boron be used in the material specification. Consequently, the minimum weight of 277-4 in the liner inner cavity of the calculation models is 19.37 kg (42.71 lb) for NCT and 19.36 kg (42.67 lb) for HAC, determined from the input density and the volume of the 277-4 region calculated by KENO V.a.

Kaolite is a lightweight, low thermal conductivity, refractory material that is used in the ES-3100 package between the drum and the inner liner. Kaolite is formed by mixing a dry constituent powder with water, pouring the mixture into a casting form, and curing and baking the cast. For NCT, the average density of Kaolite in the Model ES-3100 package is 0.34438 g/cm$^3$, and the residual water is 0.01493 g/cm$^3$ (Appendix 6.9.3, Sect. 6.9.3.4). The nominal weights of Kaolite in the liner outer cavity and in the top plug as determined from the input density and the region volumes calculated by KENO V.a are 49.04 kg (108.1 lb) and 4.37 kg (9.63 lb), respectively.

Kaolite is a nonvolatile refractory material, not significantly damaged by thermal excursions associated with HAC. It is assumed that upon immersion, a cured and dried casting will absorb a quantity of water equal to that required during preparation. This assumption is valid because the casting is fully saturated with water prior to curing and baking, and the casting does not change volume significantly during baking. The maximum water content of Kaolite refractory material is the water content of manufacture (1.5 g water per gram dry Kaolite) equivalent to a density of 0.51655 g/cm$^3$. For the single package, water saturation in the Kaolite region maximizes the effect of self-reflection in the surrounding package. This condition is assumed in the NCT single package calculations. For an array of packages, neutronic interaction between packages is maximized when the minimum amount of water is present in the Kaolite, which occurs in the as-manufactured condition. A volume fraction of 1.0 in the material specification corresponds to the water-saturated condition, while a volume fraction of 0.0289 corresponds to the dry condition.

The fissile material content packed into the containment vessel is ordinarily dry. Given that a flooded containment vessel is assumed for both NCT and HAC, the concurrent condition where the water-saturated Kaolite is baked dry beyond the as-manufactured condition while the containment vessel remains flooded is considered not credible. Therefore, the as-manufactured condition is assumed for the Kaolite water content in the HAC array analysis.

As stated in Sect. 6.3.1.2, the drum thicknesses of the NCT single-unit packaging model is increased for producing the NCT array packaging calculation model. The intent is to maintain the drum region volume thereby conserving drum mass. However, the both the region volume of the drum and the atomic densities for the elemental constituents of stainless steel in the resulting NCT array packaging calculation model are not identical to corresponding values for the single-unit packaging calculation model. This is due to internal round-off in KENO V.a. (Even though the volume fraction is changed from 1.0 to 0.99981 in the KENO V.a input specification of the NCT array packaging calculation model for normalization of the drum's region volume, the atomic densities still differ by 0.019% due to round-off.)

The material compositions for the NCT array calculation models are identical to compositions for the NCT single-unit calculation models except as noted in Table 6.4. In the NCT array calculation model, the adjusted model densities for the Kaolite in the body weldment liner inner cavity (Mix. No. 12), the stainless steel of the angle iron (Mix. No. 18), and the drum steel (Mix. No. 19) compensate for the dimensional changes of the reduced-diameter model (93% ID of drum). A difference between the NCT specifications for Kaolite (Mix. Nos. 12 and 13) in the array and the single-unit models occurs in the water component. The dry state is represented in the array model for maximizing neutronic interaction between packages of an array, while the flooded state is represented in the single-unit model for maximizing reflection.

The material compositions for the HAC single-unit calculation model are identical to those for the NCT single-unit calculation models except as noted in Table 6.4. The adjusted model densities for 277-4 neutron poison in both the canned spacers (Mix. No. 2) and the inner-liner cavity (Mix. No. 11) represent the HAC discussed earlier in this section. In the HAC single-unit calculation model, the adjusted model densities for the Kaolite in the body weldment liner inner cavity (Mix. No. 12), the stainless steel of the angle iron (Mix. No. 18), and the drum steel (Mix. No. 19) correspond to dimensional changes resulting from damage. While the atomic densities for the HAC model differ from those for the NCT model, the component masses do not change because mass is conserved.

**Table 6.4. Material compositions used in the ES-3100 calculation models**

| Material | Mix. No. | Theoretical density input parameter ($g/cm^3$) [a] | Volume fraction | Constituent | Atomic weight | Weight fraction | Atomic density (atoms/b-cm) |
|---|---|---|---|---|---|---|---|
| **Fissile material contents** | | | | | | | |
| Uranium (solid metal) | 1 | 18.81109 | 1.0 | $^{235}U$ | 235.0441 | 1.00 | 4.81970E-02 |
| | | | | $^{238}U$ | 238.0510 | 0.00 | 0.0000E+00 |
| Uranium (solid metal) | 1 | 18.82298 | 1.0 | $^{235}U$ | 235.0441 | 0.95 | 4.58156E-02 |
| | | | | $^{238}U$ | 238.0510 | 0.05 | 2.38089E-03 |
| Uranium (solid metal) | 1 | 18.83488 | 1.0 | $^{235}U$ | 235.0441 | 0.90 | 4.34317E-02 |
| | | | | $^{238}U$ | 238.0510 | 0.10 | 4.76479E-03 |
| Uranium (solid metal) | 1 | 18.85873 | 1.0 | $^{235}U$ | 235.0441 | 0.80 | 3.86548E-02 |
| | | | | $^{238}U$ | 238.0510 | 0.20 | 9.54164E-03 |
| Uranium (solid metal) | 1 | 18.88264 | 1.0 | $^{235}U$ | 235.0441 | 0.70 | 3.38659E-02 |
| | | | | $^{238}U$ | 238.0510 | 0.30 | 1.43306E-02 |
| Uranium (solid metal) | 1 | 18.90661 | 1.0 | $^{235}U$ | 235.0441 | 0.60 | 2.90647E-02 |
| | | | | $^{238}U$ | 238.0510 | 0.40 | 1.91317E-02 |
| Uranium (solid metal) | 1 | 18.95474 | 1.0 | $^{235}U$ | 235.0441 | 0.40 | 1.94258E-02 |
| | | | | $^{238}U$ | 238.0510 | 0.60 | 2.87707E-02 |
| Uranium (solid metal) | 1 | 19.00554 | 1.0 | $^{235}U$ | 235.0441 | 0.19 | 9.25199E-03 |
| | | | | $^{238}U$ | 238.0510 | 0.81 | 3.89445E-02 |
| Uranium oxide ($UO_2$) | 1 | 6.94256 | 1.0 | H | 1.0077 | 0.6490 | 2.69208E-02 |
| | | | | O | 15.9904 | 16.4340 | 4.29699E-02 |
| | | | | $^{235}U$ | 235.0441 | 82.9170 | 1.47490E-02 |
| Uranium oxide ($U_3O_8$) | 1 | 6.75167 | 1.0 | H | 1.0077 | 0.3510 | 1.41552E-02 |
| | | | | O | 15.9904 | 17.6620 | 4.49101E-02 |
| | | | | $^{235}U$ | 235.0441 | 81.9870 | 1.41826E-02 |
| Uranium oxide ($UO_3$) | 1 | 6.64270 | 1.0 | H | 1.0077 | 0.1730 | 6.86795E-03 |
| | | | | O | 15.9904 | 18.0650 | 4.51925E-02 |
| | | | | $^{235}U$ | 235.0441 | 81.7620 | 1.39155E-02 |
| Skull oxide ($UO_3$+graphite) | 1 | 3.34850 | 1.0 | H | 1.0077 | 1.9000 | 3.80225E-02 |
| | | | | C | 12.0001 | 11.9173 | 2.00261E-02 |
| | | | | O | 15.9904 | 25.9923 | 3.27786E-02 |
| | | | | $^{235}U$ | 235.0441 | 56.0976 | 4.81282E-03 |
| | | | | $^{238}U$ | 238.0510 | 4.0929 | 3.46713E-04 |
| UNH crystals (24000.0 g) $[UO_2(NO_3)_2+6H_2O]$ | 1 | 2.50804 | 1.0 | H | 1.0077 | 2.9770 | 4.46274E-02 |
| | | | | N | 14.0033 | 5.2570 | 5.66985E-03 |
| | | | | O | 15.9904 | 47.6480 | 4.50055E-02 |
| | | | | $^{235}U$ | 235.0441 | 44.1180 | 2.83495E-03 |
| UNH crystals (9000.0 g) $[UO_2(NO_3)_2+6H_2O]$ | 1 | 1.56439 | 1.0 | H | 1.0077 | 6.2525 | 5.84562E-02 |
| | | | | N | 14.0033 | 3.1604 | 2.12620E-03 |
| | | | | O | 15.9904 | 64.0630 | 3.77431E-02 |
| | | | | $^{235}U$ | 235.0441 | 26.5240 | 1.06311E-03 |

**Table 6.4. Material compositions used in the ES-3100 calculation models**

| Material | Mix. No. | Theoretical density input parameter ($g/cm^3$) [a] | Volume fraction | Constituent | Atomic weight | Weight fraction | Atomic density (atoms/b-cm) |
|---|---|---|---|---|---|---|---|
| UNH crystals | 1 | 1.50149 | 1.0 | H | 1.0077 | 6.6172 | 5.93782E-02 |
| (8000.0 g) | | | | N | 14.0033 | 2.9270 | 1.89000E-03 |
| $[UO_2(NO_3)_2+6H_2O]$ | | | | O | 15.9904 | 65.8907 | 3.72591E-02 |
| | | | | $^{235}U$ | 235.0441 | 24.5651 | 9.45006E-04 |
| UNH crystals | 1 | 1.06111 | 1.0 | H | 1.0077 | 10.3811 | 6.58313E-02 |
| (1000.1 g) | | | | N | 14.0033 | 0.5178 | 2.36275E-04 |
| $[UO_2(NO_3)_2+6H_2O]$ | | | | O | 15.9904 | 84.7556 | 3.38697E-02 |
| | | | | $^{235}U$ | 235.0441 | 4.3455 | 9.45006E-04 |
| ~20% enriched UZrH | 1 | 8.65974 | 1.0 | H | 1.0078 | 0.9554 | 4.94386E-02 |
| (3466.7 g) | | | | Zr | 91.2196 | 54.0447 | 3.08972E-02 |
| | | | | $^{235}U$ | 235.0441 | 8.8558 | 1.96487E-03 |
| | | | | $^{238}U$ | 238.0510 | 36.1441 | 7.91816E-03 |
| ~70% enriched UZrH | 1 | 5.70132 | 1.0 | H | 1.0078 | 1.5894 | 5.41480E-02 |
| (2282.4 g) | | | | Zr | 91.2196 | 89.9107 | 3.38410E-02 |
| | | | | $^{235}U$ | 235.0441 | 5.9588 | 8.67175E-04 |
| | | | | $^{238}U$ | 238.0510 | 2.5413 | 3.69825E-04 |
| ~20% enr. $U_3O_8$-Al | 1 | 3.52015 | 1.0 | O | 15.9904 | 5.2477 | 6.95687E-03 |
| (12254.7 g) | | | | Al | 26.9818 | 65.5398 | 5.14922E-02 |
| | | | | $^{235}U$ | 235.0441 | 5.8425 | 5.26934E-04 |
| | | | | $^{238}U$ | 238.0510 | 23.3700 | 2.08111E-03 |
| ~70% enr. $U_3O_8$-Al | 1 | 3.52095 | 1.0 | O | 15.9904 | 5.2800 | 7.00127E-03 |
| (1995.7 g) | | | | Al | 26.9818 | 65.5141 | 5.14837E-02 |
| | | | | $^{235}U$ | 235.0441 | 20.4441 | 1.84427E-03 |
| | | | | $^{238}U$ | 238.0510 | 8.7618 | 7.80418E-04 |
| ~93% enr. $U_3O_8$-Al | 1 | 3.52132 | 1.0 | O | 15.9904 | 5.2950 | 7.02187E-03 |
| (1505.0 g) | | | | Al | 26.9818 | 65.5022 | 5.14798E-02 |
| | | | | $^{235}U$ | 235.0441 | 27.2170 | 2.45552E-03 |
| | | | | $^{238}U$ | 238.0510 | 1.9858 | 1.76895E-04 |
| ~9.9% enr. $UO_2$-Mg | 1 | 3.95984 | 1.0 | O | 15.9904 | 6.4032 | 9.54899E-03 |
| in Al clad | | | | Mg | 24.3048 | 7.6175 | 7.47379E-03 |
| (15231.1 g) | | | | Al | 26.9818 | 38.3916 | 3.39305E-02 |
| | | | | $^{235}U$ | 235.0441 | 4.7062 | 4.77464E-04 |
| | | | | $^{238}U$ | 238.0510 | 42.8815 | 4.29560E-03 |
| 20% enr. $UO_2$-Mg | 1 | 3.96017 | 1.0 | O | 15.9904 | 6.4110 | 9.56133E-03 |
| in Al clad | | | | Mg | 24.3048 | 7.6169 | 7.47379E-03 |
| (7523.6 g) | | | | Al | 26.9818 | 38.3885 | 3.39305E-02 |
| | | | | $^{235}U$ | 235.0441 | 9.5167 | 9.65604E-04 |
| | | | | $^{238}U$ | 238.0510 | 38.0670 | 3.81363E-03 |

**Table 6.4. Material compositions used in the ES-3100 calculation models**

| Material | Mix. No. | Theoretical density input parameter ($g/cm^3$) [a] | Volume fraction | Constituent | Atomic weight | Weight fraction | Atomic density (atoms/b-cm) |
|---|---|---|---|---|---|---|---|
| ~93% enr. $UO_2$-Mg | 1 | 3.96254 | 1.0 | O | 15.9904 | 6.4670 | 6.34806E-03 |
| in Al clad | | | | Mg | 24.3048 | 7.6123 | 4.91617E-03 |
| (1472.1 g) | | | | Al | 26.9818 | 38.3655 | 2.23190E-02 |
| | | | | $^{235}U$ | 235.0441 | 44.3215 | 2.95985E-03 |
| | | | | $^{238}U$ | 238.0510 | 3.2338 | 2.13227E-04 |
| **Single-unit calculation models (NCT)** | | | | | | | |
| 277-4 | 2 | 1.50970 | 1.0 | H | 1.0077 | 2.84745 | 2.56909E-02 |
| canned spacer | | | | $^{10}B$ | 10.0130 | 0.65907 | 5.98418E-04 |
| Table 11 data: [b] | | | | $^{11}B$ | 11.0096 | 2.97264 | 2.45475E-03 |
| as-manufactured, | | | | C | 12.0001 | 1.36094 | 1.03107E-03 |
| minimum density and | | | | N | 14.0033 | 0.01000 | 6.49252E-06 |
| hydrogen | | | | O | 15.9904 | 53.39650 | 3.03592E-02 |
| | | | | Na | 22.9895 | 0.08326 | 3.29274E-05 |
| | | | | Mg | 24.3048 | 0.23957 | 8.96150E-05 |
| | | | | Al | 26.9818 | 27.69370 | 9.33137E-03 |
| | | | | Si | 28.0853 | 1.74979 | 5.66427E-04 |
| | | | | S | 32.0634 | 0.21865 | 6.19983E-05 |
| | | | | Ca | 40.0803 | 8.39267 | 1.90373E-03 |
| | | | | Fe | 55.8447 | 0.37575 | 6.11714E-05 |
| Water-flooded containment vessel (CV) | 3 | 0.9982 | 1.0 | H | 1.0077 | 11.1909 | 6.67536E-02 |
| | | | | O | 15.9904 | 88.8091 | 3.33856E-02 |
| SS304 | 8 | 7.9400 | 1.0 | C | 12.0001 | 0.0800 | 3.18772E-04 |
| CV body | | | | Si | 28.0853 | 1.0000 | 1.70252E-03 |
| 16.60 lb | | | | P | 30.9741 | 0.0450 | 6.94680E-05 |
| but 15.74 lb used | | | | Cr | 51.9957 | 19.0000 | 1.74726E-02 |
| | | | | Mn | 54.9379 | 2.0000 | 1.74071E-03 |
| | | | | Fe | 55.8447 | 68.3750 | 5.85446E-02 |
| | | | | Ni | 58.6872 | 9.5000 | 7.74020E-03 |
| SS304 | 9 | 7.9400 | 0.97267 | C | 12.0001 | 0.0800 | 3.10060E-04 |
| CV lower flange | | | | Si | 28.0853 | 1.0000 | 1.65599E-03 |
| used 3.36 lb | | | | P | 30.9741 | 0.0450 | 6.75695E-05 |
| | | | | Cr | 51.9957 | 19.0000 | 1.69951E-02 |
| | | | | Mn | 54.9379 | 2.0000 | 1.69314E-03 |
| | | | | Fe | 55.8447 | 68.3750 | 5.69445E-02 |
| | | | | Ni | 58.6872 | 9.5000 | 7.52866E-03 |

**Table 6.4. Material compositions used in the ES-3100 calculation models**

| Material | Mix. No. | Theoretical density input parameter ($g/cm^3$) [a] | Volume fraction | Constituent | Atomic weight | Weight fraction | Atomic density (atoms/b-cm) |
|---|---|---|---|---|---|---|---|
| SS304 | 10 | 7.9400 | 0.94348 | C | 12.0001 | 0.0800 | 3.00755E-04 |
| CV upper flange | | | | Si | 28.0853 | 1.0000 | 1.60629E-03 |
| used 13.75 lb | | | | P | 30.9741 | 0.0450 | 6.55417E-05 |
| | | | | Cr | 51.9957 | 19.0000 | 1.64850E-02 |
| | | | | Mn | 54.9379 | 2.0000 | 1.64233E-03 |
| | | | | Fe | 55.8447 | 68.3750 | 5.52356E-02 |
| | | | | Ni | 58.6872 | 9.5000 | 7.30272E-03 |
| 277-4 | 11 | 1.45971 | 1.0 | H | 1.0077 | 2.84746 | 2.48404E-02 |
| filling CV | | | | $^{10}$B | 10.0130 | 0.65907 | 5.78606E-04 |
| inner-liner cavity | | | | $^{11}$B | 11.0096 | 2.97265 | 2.37348E-03 |
| Table 11 data: [b] | | | | C | 12.0001 | 1.36094 | 9.96935E-04 |
| as-manufactured, | | | | N | 14.0033 | 0.01000 | 6.27756E-06 |
| minimum density and | | | | O | 15.9904 | 53.39660 | 2.93541E-02 |
| hydrogen | | | | Na | 22.9895 | 0.08326 | 3.18372E-05 |
| | | | | Mg | 24.3048 | 0.23957 | 8.66479E-05 |
| | | | | Al | 26.9818 | 27.69360 | 9.02241E-03 |
| | | | | Si | 28.0853 | 1.74979 | 5.47673E-04 |
| | | | | S | 32.0634 | 0.21865 | 5.99456E-05 |
| | | | | Ca | 40.0803 | 8.39266 | 1.84069E-03 |
| | | | | Fe | 55.8447 | 0.37575 | 5.91461E-05 |
| Kaolite | 12 | (body weldment) | | | | | |
| $Al_2O_3$ | | 0.34864 | 0.096 | Al | 26.9818 | 52.9390 | 3.95461E-04 |
| | | | | O | 15.9904 | 47.0610 | — |
| $SiO_2$ | | 0.34864 | 0.367 | Si | 28.0853 | 46.7570 | 1.28281E-03 |
| | | | | O | 15.9904 | 53.2430 | — |
| $Fe_2O_3$ | | 0.34864 | 0.067 | Fe | 55.8447 | 69.9540 | 1.76211E-04 |
| | | | | O | 15.9904 | 30.0460 | — |
| $TiO_2$ | | 0.34864 | 0.012 | Ti | 47.8793 | 59.9530 | 3.15486E-05 |
| | | | | O | 15.9904 | 40.0470 | — |
| CaO | | 0.34864 | 0.307 | Ca | 40.0803 | 71.4810 | 1.14955E-03 |
| | | | | O | 15.9904 | 28.5180 | — |
| MgO | | 0.34864 | 0.131 | Mg | 24.3048 | 60.3170 | 6.82560E-04 |
| | | | | O | 15.9904 | 39.6830 | — |
| $Na_2O$ | | 0.34864 | 0.020 | Na | 22.9895 | 74.1960 | 1.35522E-04 |
| | | | | O | 15.9904 | 25.8040 | — |
| Total O | | — | — | — | 15.9904 | — | 5.39065E-03 |
| Water | 12 | 0.52294 | 1.0 | H | 1.0077 | 11.1909 | 3.49711E-02 |
| | | | | O | 15.9904 | 88.8091 | 1.74856E-02 |

**Table 6.4. Material compositions used in the ES-3100 calculation models**

| Material | Mix. No. | Theoretical density input parameter ($g/cm^3$) [a] | Volume fraction | Constituent | Atomic weight | Weight fraction | Atomic density (atoms/b-cm) |
|---|---|---|---|---|---|---|---|
| Kaolite | 13 | (top plug) | | | | | |
| $Al_2O_3$ | | 0.33241 | 0.096 | Al | 26.9818 | 52.9390 | 3.77052E-04 |
| | | | | O | 15.9904 | 47.0610 | — |
| $SiO_2$ | | 0.33241 | 0.367 | Si | 28.0853 | 46.7570 | 1.22309E-03 |
| | | | | O | 15.9904 | 53.2430 | — |
| $Fe_2O_3$ | | 0.33241 | 0.067 | Fe | 55.8447 | 69.9540 | 1.68008E-04 |
| | | | | O | 15.9904 | 30.0460 | — |
| $TiO_2$ | | 0.33241 | 0.012 | Ti | 47.8793 | 59.9530 | 3.00799E-05 |
| | | | | O | 15.9904 | 40.0470 | — |
| CaO | | 0.33241 | 0.307 | Ca | 40.0803 | 71.4810 | 1.09604E-03 |
| | | | | O | 15.9904 | 28.5180 | — |
| MgO | | 0.33241 | 0.131 | Mg | 24.3048 | 60.3170 | 6.50785E-04 |
| | | | | O | 15.9904 | 39.6830 | — |
| $Na_2O$ | | 0.33241 | 0.020 | Na | 22.9895 | 74.1960 | 1.29213E-04 |
| | | | | O | 15.9904 | 25.8040 | — |
| Total O | | — | — | — | 15.9904 | — | 5.13975E-03 |
| Water | 13 | 0.49860 | 1.0 | H | 1.0077 | 11.1909 | 3.33433E-02 |
| | | | | O | 15.9904 | 88.8091 | 1.66717E-02 |
| Silicon rubber pads | 14 | 1.21791 | 1.0 | H | 1.0077 | 8.1562 | 5.93660E-02 |
| | | | | C | 12.0001 | 32.3774 | 1.97887E-02 |
| | | | | O | 15.9904 | 21.5782 | 9.89729E-03 |
| | | | | Si | 28.0853 | 37.8882 | 9.89432E-03 |
| Water—CV well | 15 | 0.9982 | variable | H | 1.0077 | 11.1909 | variable |
| | | | | O | 15.9904 | 88.8091 | variable |
| SS304 liner | 16 | 7.94 | 1.0 | C | 12.0001 | 0.0800 | 3.18772E-04 |
| | | | | Si | 28.0853 | 1.0000 | 1.70252E-03 |
| | | | | P | 30.9741 | 0.0450 | 6.94680E-05 |
| | | | | Cr | 51.9957 | 19.0000 | 1.74726E-02 |
| | | | | Mn | 54.9379 | 2.0000 | 1.74071E-03 |
| | | | | Fe | 55.8447 | 68.3750 | 5.85446E-02 |
| | | | | Ni | 58.6872 | 9.5000 | 7.74020E-03 |
| SS304 plug cover used 9.907 lb | 17 | 7.94 | 1.06388 | C | 12.0001 | 0.0800 | 3.39135E-04 |
| | | | | Si | 28.0853 | 1.0000 | 1.81128E-03 |
| | | | | P | 30.9741 | 0.0450 | 7.39056E-05 |
| | | | | Cr | 51.9957 | 19.0000 | 1.85887E-02 |
| | | | | Mn | 54.9379 | 2.0000 | 1.85191E-03 |
| | | | | Fe | 55.8447 | 68.3750 | 6.22844E-02 |
| | | | | Ni | 58.6872 | 9.5000 | 8.23464E-03 |

**Table 6.4. Material compositions used in the ES-3100 calculation models**

| Material | Mix. No. | Theoretical density input parameter ($g/cm^3$) [a] | Volume fraction | Constituent | Atomic weight | Weight fraction | Atomic density (atoms/b-cm) |
|---|---|---|---|---|---|---|---|
| SS304 angle iron | 18 | 7.94 | 1.0 | C | 12.0001 | 0.0800 | 3.18772E-04 |
| | | | | Si | 28.0853 | 1.0000 | 1.70252E-03 |
| | | | | P | 30.9741 | 0.0450 | 6.94680E-05 |
| | | | | Cr | 51.9957 | 19.0000 | 1.74726E-02 |
| | | | | Mn | 54.9379 | 2.0000 | 1.74071E-03 |
| | | | | Fe | 55.8447 | 68.3750 | 5.85446E-02 |
| | | | | Ni | 58.6872 | 9.5000 | 7.74020E-03 |
| SS304 steel drum | 19 | 7.94 | 1.0 | C | 12.0001 | 0.0800 | 3.18772E-04 |
| | | | | Si | 28.0853 | 1.0000 | 1.70252E-03 |
| | | | | P | 30.9741 | 0.0450 | 6.94680E-05 |
| | | | | Cr | 51.9957 | 19.0000 | 1.74726E-02 |
| | | | | Mn | 54.9379 | 2.0000 | 1.74071E-03 |
| | | | | Fe | 55.8447 | 68.3750 | 5.85446E-02 |
| | | | | Ni | 58.6872 | 9.5000 | 7.74020E-03 |
| Water—interstitial | 20 | 0.9982 | variable | H | 1.0077 | 11.1909 | variable |
| | | | | O | 15.9904 | 88.8091 | variable |
| Water—reflector | 21 | 0.9982 | 1.0 | H | 1.0077 | 11.1909 | 6.67536E-02 |
| | | | | O | 15.9904 | 88.8091 | 3.33856E-02 |
| **Array calculation models (NCT) same as single-unit calculation models NCT except as follows:** | | | | | | | |
| Kaolite | 12 | (body weldment) | | | | | |
| $Al_2O_3$ | | 0.42622 | 0.096 | Al | 26.9818 | 52.9390 | 4.83460E-04 |
| | | | | O | 15.9904 | 47.0610 | — |
| $SiO_2$ | | 0.42622 | 0.367 | Si | 28.0853 | 46.7570 | 1.56821E-03 |
| | | | | O | 15.9904 | 53.2430 | — |
| $Fe_2O_3$ | | 0.42622 | 0.067 | Fe | 55.8447 | 69.9540 | 2.15422E-04 |
| | | | | O | 15.9904 | 30.0460 | — |
| $TiO_2$ | | 0.42622 | 0.012 | Ti | 47.8793 | 59.9530 | 3.85688E-05 |
| | | | | O | 15.9904 | 40.0470 | — |
| CaO | | 0.42622 | 0.307 | Ca | 40.0803 | 71.4810 | 1.40535E-03 |
| | | | | O | 15.9904 | 28.5180 | — |
| MgO | | 0.42622 | 0.131 | Mg | 24.3048 | 60.3170 | 8.34444E-04 |
| | | | | O | 15.9904 | 39.6830 | — |
| $Na_2O$ | | 0.42622 | 0.020 | Na | 22.9895 | 74.1960 | 1.65678E-04 |
| | | | | O | 15.9904 | 25.8040 | — |
| Total O | | — | — | — | 15.9904 | — | 6.58477E-03 |
| Water | 12 | 0.63931 | 0.0287 | H | 1.0077 | 11.1909 | 1.22702E-03 |
| | | | | O | 15.9904 | 88.8091 | 6.13510E-04 |
| Kaolite | 13 | (top plug) | | | | | |
| $Al_2O_3$ | | 0.33241 | 0.096 | Al | 26.9818 | 52.9390 | 3.77052E-04 |
| | | | | O | 15.9904 | 47.0610 | — |

**Table 6.4. Material compositions used in the ES-3100 calculation models**

| Material | Mix. No. | Theoretical density input parameter ($g/cm^3$) [a] | Volume fraction | Constituent | Atomic weight | Weight fraction | Atomic density (atoms/b-cm) |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | | 0.33241 | 0.367 | Si | 28.0853 | 46.7570 | 1.22309E-03 |
| | | | | O | 15.9904 | 53.2430 | — |
| $Fe_2O_3$ | | 0.33241 | 0.067 | Fe | 55.8447 | 69.9540 | 1.68008E-04 |
| | | | | O | 15.9904 | 30.0460 | — |
| $TiO_2$ | | 0.33241 | 0.012 | Ti | 47.8793 | 59.9530 | 3.00799E-05 |
| | | | | O | 15.9904 | 40.0470 | — |
| CaO | | 0.33241 | 0.307 | Ca | 40.0803 | 71.4810 | 1.09604E-03 |
| | | | | O | 15.9904 | 28.5180 | — |
| MgO | | 0.33241 | 0.131 | Mg | 24.3048 | 60.3170 | 6.50785E-04 |
| | | | | O | 15.9904 | 39.6830 | — |
| $Na_2O$ | | 0.33241 | 0.020 | Na | 22.9895 | 74.1960 | 1.29213E-04 |
| | | | | O | 15.9904 | 25.8040 | — |
| Total O | | — | — | — | 15.9904 | — | 5.13548E-03 |
| Water | 13 | 0.49860 | 0.0287 | H | 1.0077 | 11.1909 | 9.56954E-04 |
| | | | | O | 15.9904 | 88.8091 | 4.78477E-04 |
| SS304 angle iron | 18 | 7.94 | 1.25705 | C | 12.0001 | 0.0800 | 4.00712E-04 |
| | | | | Si | 28.0853 | 1.0000 | 2.14015E-03 |
| | | | | P | 30.9741 | 0.0450 | 8.73248E-05 |
| | | | | Cr | 51.9957 | 19.0000 | 2.19639E-02 |
| | | | | Mn | 54.9379 | 2.0000 | 2.18816E-03 |
| | | | | Fe | 55.8447 | 68.3750 | 7.35934E-02 |
| | | | | Ni | 58.6872 | 9.5000 | 9.72982E-03 |
| SS304 steel drum | 19 | 7.94 | 0.99981 | C | 12.0001 | 0.0800 | 3.18711E-04 |
| | | | | Si | 28.0853 | 1.0000 | 1.70220E-03 |
| | | | | P | 30.9741 | 0.0450 | 6.94548E-05 |
| | | | | Cr | 51.9957 | 19.0000 | 1.74693E-02 |
| | | | | Mn | 54.9379 | 2.0000 | 1.74038E-03 |
| | | | | Fe | 55.8447 | 68.3750 | 5.85334E-02 |
| | | | | Ni | 58.6872 | 9.5000 | 7.73873E-03 |
| Water—reflector | 21 | 1.16235 | 1.0 | H | 1.0077 | 11.1909 | 7.75911E-06 |
| | | | | O | 15.9904 | 88.8091 | 3.88058E-06 |

**Table 6.4. Material compositions used in the ES-3100 calculation models**

| Material | Mix. No. | Theoretical density input parameter ($g/cm^3$) [a] | Volume fraction | Constituent | Atomic weight | Weight fraction | Atomic density (atoms/b-cm) |
|---|---|---|---|---|---|---|---|
| **Single-unit calculation models (HAC) same as single-unit calculation models NCT except as follows:** | | | | | | | |
| 277-4 | 2 | 1.50853 | 1.0 | H | 1.0077 | 2.84094 | 2.56124E-02 |
| canned spacer | | | | $^{10}$B | 10.0130 | 0.65958 | 5.98418E-04 |
| Table 12 data: [b] | | | | $^{11}$B | 11.0096 | 2.97494 | 2.45475E-03 |
| as-manufactured, | | | | C | 12.0001 | 1.36193 | 1.03103E-03 |
| minimum density and | | | | N | 14.0033 | 0.01001 | 6.49258E-06 |
| hydrogen | | | | O | 15.9904 | 53.36920 | 3.03202E-02 |
| | | | | Na | 22.9895 | 0.08333 | 3.29277E-05 |
| | | | | Mg | 24.3048 | 0.23976 | 8.96158E-05 |
| | | | | Al | 26.9818 | 27.71520 | 9.33140E-03 |
| | | | | Si | 28.0853 | 1.75109 | 5.66409E-04 |
| | | | | S | 32.0634 | 0.21882 | 6.19989E-05 |
| | | | | Ca | 40.0803 | 8.39916 | 1.90373E-03 |
| | | | | Fe | 55.8447 | 0.37604 | 6.11720E-05 |
| 277-4 | 11 | 1.45858 | 1.0 | H | 1.0077 | 2.84097 | 2.47645E-02 |
| filling CV | | | | $^{10}$B | 10.0130 | 0.65959 | 5.78606E-04 |
| inner-liner cavity | | | | $^{11}$B | 11.0096 | 2.97496 | 2.37348E-03 |
| Table 12 data: [b] | | | | C | 12.0001 | 1.36193 | 9.96883E-04 |
| as-manufactured, | | | | N | 14.0033 | 0.01001 | 6.27756E-06 |
| minimum density and | | | | O | 15.9904 | 53.36930 | 2.93162E-02 |
| hydrogen | | | | Na | 22.9895 | 0.08333 | 3.18372E-05 |
| | | | | Mg | 24.3048 | 0.23976 | 8.66479E-05 |
| | | | | Al | 26.9818 | 27.71510 | 9.02236E-03 |
| | | | | Si | 28.0853 | 1.75109 | 5.47651E-04 |
| | | | | S | 32.0634 | 0.21882 | 5.99456E-05 |
| | | | | Ca | 40.0803 | 8.39913 | 1.84068E-03 |
| | | | | Fe | 55.8447 | 0.37604 | 5.91461E-05 |
| Kaolite | 12 | (body weldment) | | | | | |
| $Al_2O_3$ | | 0.41898 | 0.096 | Al | 26.9818 | 52.9390 | 4.75248E-04 |
| | | | | O | 15.9904 | 47.0610 | — |
| $SiO_2$ | | 0.41898 | 0.367 | Si | 28.0853 | 46.7570 | 1.54162E-03 |
| | | | | O | 15.9904 | 53.2430 | — |
| $Fe_2O_3$ | | 0.41898 | 0.067 | Fe | 55.8447 | 69.9540 | 2.11763E-04 |
| | | | | O | 15.9904 | 30.0460 | — |
| $TiO_2$ | | 0.41898 | 0.012 | Ti | 47.8793 | 59.9530 | 3.79136E-05 |
| | | | | O | 15.9904 | 40.0470 | — |
| CaO | | 0.41898 | 0.307 | Ca | 40.0803 | 71.4810 | 1.38148E-03 |
| | | | | O | 15.9904 | 28.5180 | — |
| MgO | | 0.41898 | 0.131 | Mg | 24.3048 | 60.3170 | 8.20270E-04 |
| | | | | O | 15.9904 | 39.6830 | — |

**Table 6.4. Material compositions used in the ES-3100 calculation models**

| Material | Mix. No. | Theoretical density input parameter ($g/cm^3$) [a] | Volume fraction | Constituent | Atomic weight | Weight fraction | Atomic density (atoms/b-cm) |
|---|---|---|---|---|---|---|---|
| $Na_2O$ | | 0.41898 | 0.020 | Na | 22.9895 | 74.1960 | 1.62864E-04 |
| | | | | O | 15.9904 | 25.8040 | — |
| Total O | | — | — | — | 15.9904 | — | 6.47830E-03 |
| Water | 12 | 0.62843 | 1.0 | H | 1.0077 | 11.1909 | 4.20256E-02 |
| | | | | O | 15.9904 | 88.8091 | 2.10128E-02 |
| SS304 angle iron | 18 | 7.94 | 1.23239 | C | 12.0001 | 0.0800 | 3.92851E-04 |
| | | | | Si | 28.0853 | 1.0000 | 2.09817E-03 |
| | | | | P | 30.9741 | 0.0450 | 8.56117E-05 |
| | | | | Cr | 51.9957 | 19.0000 | 2.15330E-02 |
| | | | | Mn | 54.9379 | 2.0000 | 2.14524E-03 |
| | | | | Fe | 55.8447 | 68.3750 | 7.21497E-02 |
| | | | | Ni | 58.6872 | 9.5000 | 9.53894E-03 |
| SS304 steel drum | 19 | 7.94 | 1.08401 | C | 12.0001 | 0.0800 | 3.45552E-04 |
| | | | | Si | 28.0853 | 1.0000 | 1.84555E-03 |
| | | | | P | 30.9741 | 0.0450 | 7.53040E-05 |
| | | | | Cr | 51.9957 | 19.0000 | 1.89405E-02 |
| | | | | Mn | 54.9379 | 2.0000 | 1.88695E-03 |
| | | | | Fe | 55.8447 | 68.3750 | 6.34629E-02 |
| | | | | Ni | 58.6872 | 9.5000 | 8.39045E-03 |
| **Array calculation models (HAC) same as single-unit calculation models HAC except as follows:** | | | | | | | |
| Kaolite | 12 | (body weldment) | | | | | |
| $Al_2O_3$ | | 0.41898 | 0.096 | Al | 26.9818 | 52.9390 | 4.75248E-04 |
| | | | | O | 15.9904 | 47.0610 | — |
| $SiO_2$ | | 0.41898 | 0.367 | Si | 28.0853 | 46.7570 | 1.54162E-03 |
| | | | | O | 15.9904 | 53.2430 | — |
| $Fe_2O_3$ | | 0.41898 | 0.067 | Fe | 55.8447 | 69.9540 | 2.11763E-04 |
| | | | | O | 15.9904 | 30.0460 | — |
| $TiO_2$ | | 0.41898 | 0.012 | Ti | 47.8793 | 59.9530 | 3.79136E-05 |
| | | | | O | 15.9904 | 40.0470 | — |
| CaO | | 0.41898 | 0.307 | Ca | 40.0803 | 71.4810 | 1.38148E-03 |
| | | | | O | 15.9904 | 28.5180 | — |
| MgO | | 0.41898 | 0.131 | Mg | 24.3048 | 60.3170 | 8.20270E-04 |
| | | | | O | 15.9904 | 39.6830 | — |
| $Na_2O$ | | 0.41898 | 0.020 | Na | 22.9895 | 74.1960 | 1.62864E-04 |
| | | | | O | 15.9904 | 25.8040 | — |
| Total O | | — | — | — | 15.9904 | — | 6.47293E-03 |
| Water | 12 | 0.62843 | 0.287 | H | 1.0077 | 11.1909 | 1.20613E-03 |
| | | | | O | 15.9904 | 88.8091 | 6.03065E-04 |

**Table 6.4. Material compositions used in the ES-3100 calculation models**

| Material | Mix. No. | Theoretical density input parameter ($g/cm^3$) [a] | Volume fraction | Constituent | Atomic weight | Weight fraction | Atomic density (atoms/b-cm) |
|---|---|---|---|---|---|---|---|
| Kaolite | 13 | (top plug) | | | | | |
| $Al_2O_3$ | | 0.33241 | 0.096 | Al | 26.9818 | 52.9390 | 3.77052E-04 |
| | | | | O | 15.9904 | 47.0610 | — |
| $SiO_2$ | | 0.33241 | 0.367 | Si | 28.0853 | 46.7570 | 1.22309E-03 |
| | | | | O | 15.9904 | 53.2430 | — |
| $Fe_2O_3$ | | 0.33241 | 0.067 | Fe | 55.8447 | 69.9540 | 1.68008E-04 |
| | | | | O | 15.9904 | 30.0460 | — |
| $TiO_2$ | | 0.33241 | 0.012 | Ti | 47.8793 | 59.9530 | 3.00799E-05 |
| | | | | O | 15.9904 | 40.0470 | — |
| CaO | | 0.33241 | 0.307 | Ca | 40.0803 | 71.4810 | 1.09604E-03 |
| | | | | O | 15.9904 | 28.5180 | — |
| MgO | | 0.33241 | 0.131 | Mg | 24.3048 | 60.3170 | 6.50785E-04 |
| | | | | O | 15.9904 | 39.6830 | — |
| $Na_2O$ | | 0.33241 | 0.020 | Na | 22.9895 | 74.1960 | 1.29213E-04 |
| | | | | O | 15.9904 | 25.8040 | — |
| Total O | | — | — | — | 15.9904 | — | 5.13548E-03 |
| Water | 13 | 0.49860 | 0.0287 | H | 1.0077 | 11.1909 | 9.56954E-04 |
| | | | | O | 15.9904 | 88.8091 | 4.78477E-04 |
| Water—reflector | 21 | 1.16235 | 1.0 | H | 1.0077 | 11.1909 | 7.75911E-06 |
| | | | | O | 15.9904 | 88.8091 | 3.88058E-06 |

[a] The theoretical density input parameter is specified for each material such that the required (or desired) mass of material is represented in the KENO V.a calculation model. The mass of material is computed by KENO V.a as the product of the theoretical density input parameter times the volume fraction times the volume of the geometry region in which the material resides in the calculation model.

[b] DAC-PKG-801624-A001.

The material compositions for the HAC array calculation model are identical to those for the NCT single-unit calculation models except as noted in Table 6.4. Also, the dimensions of the HAC array packaging calculation model do not differ from those of the HAC single-unit packaging calculation model. Therefore, both the region volumes and the atomic densities for the elemental constituents for Kaolite in the body weldment liner inner cavity are the same in both of the HAC calculation models. A difference between the HAC specifications for Kaolite (Mix. Nos. 12 and 13) in the array and the single-unit models occurs in the water component. The dry state is represented in the array model for maximizing neutronic interaction between packages of an array, while the flooded state is represented in the single-unit model for maximizing reflection.

The material composition used in the calculation model for the containment vessel, the drum liner, and the drum is Type 304 stainless steel at a density of 7.94 $g/cm^3$. The density and composition of the Type 304 stainless steel for the drum is taken from the Standard Composition Library of the Standardized Computer Analysis for Licensing Evaluation (SCALE) code system. The nominal weights of these components, as determined by input density and volume calculated by KENO V.a, are 14.9 kg (32.85 lb) for the containment vessel, 15.67 kg (34.55 lb) for the drum liner, and 25.44 kg (56.1 lb) for the drum.

Both the type and amount of hydrogenous packaging material used for packing the content in the containment vessel is unknown. Polyethylene with a density of 0.92 g/cm$^3$ and a molecular formula of $CH_2$ has the greatest hydrogen density of potential packing materials. Although polyethylene bags are generally used in packing for contamination control, the exact mass of the polyethylene bags used is unknown. Multiple bags may be used to package the contents and to enclose the convenience cans, or bags may be omitted altogether. Realistically, the number of polyethylene bags used to bag the contents and wrap a convenience can would be six bags at most. Given that each bag weighs ~28 g, this results in a maximum of ~510 g of polyethylene per ES-3100 package. For consistency with other sections of this document, a maximum of 500 g of polyethylene per ES-3100 is used in the criticality evaluation. Possible additional sources of hydrogenous material inside the containment vessel include can pads, vinyl tape, and polyethylene (~85 g) or Teflon (~303 g) bottles.

For the criticality calculations, the sources of hydrogen contained in packing materials are not distinguished from other sources of hydrogen inherent in the fissile material content. Therefore, packing material mass is defined as all sources of hydrogenous packing materials inside the containment vessel plus the actual moisture in the content as constituent (the bonded hydrogen in UNX crystals or impurities in the oxide). Given content moisture is not to exceed 6 wt %, the amount of hydrogenous material inside the containment vessel is not expected to exceed 2,400 g.

Containment vessel flooding is assumed in calculations performed for the derivation of fissile material loading limits. Even though both the NCT tests under 10 CFR 71.71 and the HAC tests under 10 CFR 71.73 demonstrate that containment is not breached, this simulated condition produces package configurations in the criticality calculations that are more reactive than the actual package configurations. The 7.1–10.1 kg quantities of evaluation water required in both the NCT and HAC criticality calculations bound reasonable amounts of hydrogenous material and inherent moisture of fissile material (primarily HEU oxides) present inside the containment vessel (2,400 g).

HAC alter only the amount of volatile hydrogenous material contained in the package external to the containment vessel (Sect. 2.7.3). High temperatures may reduce the hydrogenous material content of the Kaolite. Conversely, water intrusion may increase the hydrogenous material content in the package. Thus, the package's range of possible volatile hydrogenous material content varies from none, caused by high temperatures, to the maximum possible value caused by water intrusion.

Table 6.4 lists the material, density, atomic or isotopic constituent, and atomic or isotopic weight percent as basic data for materials used in the single-unit packaging and array calculation models in this criticality safety evaluation for NCT and HAC, respectively. Appendix 6.9.3 provides the rationale, justification, or both for using the basic data for computing atomic densities listed in Table 6.4.

### 6.3.3 Computer Codes and Cross-Section Libraries

The Criticality Safety Analysis Sequences within the SCALE modular code system provide automated, problem-dependent, cross-section processing followed by calculation of the neutron multiplication factor ($k_{eff}$) for the system being modeled (NUREG/CR-0200, Rev. 6). Initiated by "=csas25" appearing on the first line in the user input, the CSAS module runs the CSAS25 control sequence. The cross-section processing functional modules BONAMI (NUREG/CR-0200, Rev. 6) and NITAWL-II (NUREG/CR-0200, Rev. 6) are activated, providing resonance-corrected cross sections to the multigroup Monte Carlo functional module, KENO V.a (NUREG/CR-0200, Rev. 6). Using the processed cross sections, KENO V.a calculates the $k_{eff}$ of three-dimensional system models. The geometric modeling capabilities available in KENO V.a, coupled with the automated cross-section processing, allow complex, three-dimensional systems to be easily analyzed.

The CSAS25 control sequence and the 238-group ENDF/B-V cross-section library in SCALE are used for all calculations. The control sequence, functional modules, and cross-section library are summarized in the following paragraphs.

The CSAS25 control sequence reads user-specified input data, which include the required cross-section library, specifications for mixtures, information for resonance processing of nuclides (size, geometry, and temperature), and a detailed geometry model for KENO V.a. Physical and neutronic information not specified but required by the functional modules (such as theoretical density, molecular weights, and average resonance region background cross sections) is supplied by the Standard Composition Library or calculated by the Materials Information Processor. The Standard Composition Library (NUREG/CR-0200, Rev. 6) consists of a standard composition directory and table, an isotopic distribution directory and table, and a nuclide information table. The Materials Information Processor (NUREG/CR-0200, Rev. 6) checks the input data pertaining to cross-section preparation and prepares binary input files for the applicable functional modules BONAMI and NITAWL-II.

The standardized automated procedures process SCALE cross sections using the Bondarenko method (via BONAMI) and the Nordheim integral method (via NITAWL-II) to provide a resonance-corrected cross-section library based on the physical characteristics of the problem being analyzed.

BONAMI performs resonance shielding through the application of the Bondarenko shielding factor method. BONAMI reads the master format library and applies the Bondarenko correction to all nuclides that have Bondarenko data. BONAMI produces a Bondarenko-corrected master format library which is read by NITAWL-II.

NITAWL-II applies the Nordheim Integral Treatment to perform neutron cross-section processing in the resonance energy range for nuclides that have ENDF/B resonance parameter data. This technique involves the numerical integration of ENDF/B resonance parameters using a calculated flux distribution, which is based on the calculated collision density across each resonance and subsequent weighing of the reaction cross section to the desired broad group structure. In the CSAS sequence, NITAWL-II assembles the group-to-group transfer arrays from the elastic and inelastic scattering components and performs other tasks to produce a problem-dependent, working cross-section library which can be used by KENO.

KENO V.a, a multigroup Monte Carlo computer code, is used to determine $k_{eff}$ for multidimensional systems. The basic geometrical bodies allowed in KENO V.a for defining models are cuboids, spheres, cylinders, hemispheres, and hemicylinders. KENO V.a has the following major characteristics:

- enhanced geometry package that allows arrays to be defined and positioned throughout the model;
- $P_n$ scattering treatment;
- extended use of differential albedo reflection;
- printer plots for checking the input model;
- energy-dependent data supergrouping;
- restart capability; and
- origin specifications for cuboids, spheres, cylinders, hemicylinders, and hemispheres.

The 238-group ENDF/B-V master cross-section library in SCALE is activated in the CSAS25 control sequence by specifying 238GROUPNDF5 (238GR) as the cross-section library name. The 238-GROUP ENDF/B-V [neutron cross-section] library is a general-purpose criticality analysis library and the most complete library available in SCALE 4.4a. The library contains data for all nuclides (more than 300) available in ENDF/B-V processed by the AMPX-77 systems. It also contains data for ENDF/B-VI evaluations of $^{14}N$, $^{15}N$, $^{16}O$, $^{154}Eu$, and $^{155}Eu$. The library has 148 fast groups and 90 thermal groups (below 3 eV). Most resonance nuclides in the 238 group have resonance data (to be processed by NITAWL-II in the resolved resonance range) and Bondarenko factors (to be processed by BONAMI) for the unresolved range. The 238-group library contains resolved resonance data for s-wave, p-wave, and d-wave resonances **R** = 0, **R** = 1, and **R** = 2, respectively. These data can have a significant effect on results for under-moderated, intermediate-energy problems. Resonance structures in several light-to-intermediate mass "nonresonance" ENDF nuclides (i.e., $^{7}Li$, $^{19}F$, $^{27}Al$, $^{28}Si$) are accounted for using Bondarenko shielding factors. These structures can also be important in intermediate energy problems.

All nuclides in the 238-group library use the same weighting spectrum, consisting of:

- Maxwellian spectrum (peak at 300 K) from $10^{-5}$ to 0.125 eV,
- a 1/E spectrum from 0.125 eV to 67.4 keV,
- a fission spectrum (effective temperature at 1.273 MeV) from 67.4 keV to 10 MeV, and
- a 1/E spectrum from 10 to 20 MeV.

The $k_{eff}$ values for each KENO V.a case are based on 500,000 neutron histories produced by running for 215 generations with 2,500 neutrons per generation and truncating the first 15 generations of data. The convergence of the KENO V.a calculation is related to trends in the average calculated $k_{eff}$. In general, the KENO V.a output table of $k_{eff}$ by Generation Skipped is reviewed for trends. If no trends are observed, the calculation is accepted, and the reported value of $k_{eff}$ is the one with the most neutron histories. Usually there is no statistically significant difference between this result and the one with the smallest standard deviation.

No manual cross-section adjustment is performed for the criticality safety evaluation. The cross-section processing is performed automatically in the CSAS25 code sequence making use of the available cross-section treatment options, as appropriate.

The CSAS control module, the associated functional modules, cross sections, and databases used in this evaluation reside in the verified configuration control area designated **/vcc/scale4.4a** on a Hewlett Packard Series 9000 J Class workstation at the Y-12 Safety Analysis Engineering organization in Oak Ridge, Tennessee. The detailed input and computer output for the criticality safety evaluation of the ES-3100 shipping container with HEU reside in a configuration control area **/archive/ylf717_Rv2** on the workstation. Input listings of the key cases indicated in Tables 6.1a–6.1f are provided in Appendix 6.9.7.

### 6.3.4 Demonstration of Maximum Reactivity

Liquid HEU is not being shipped in the ES-3100. Only the uranyl nitrate crystal content being shipped in the ES-3100 is soluble in water. The hypothetical occurrence of uranyl nitrate solution is evaluated as a consequence of evaluating the presence of water inside the containment vessel.

As stated in Sect. 6.1.2, 10 CFR 71.55(b) requires the evaluation of water leakage into the containment vessel or leakage of liquid contents out of the containment vessel and other conditions that produce maximum reactivity in the single package. For solid uranium contents, water leakage conditions are simulated by flooding all regions outside and inside of the containment vessel, including the sealed convenience cans. For liquid uranium "contents", water leakage conditions are simulated by flooding all regions outside the containment vessel except the containment vessel well. Uranyl nitrate solution resides inside both the containment vessel, including the Teflon bottles, and the well external to the containment vessel. According to the 10 CFR 71.55(b) requirement, a flooded containment vessel under full water reflection is also evaluated.

While the loss of containment is deemed incredible by merit of the results of the physical tests performed under 10 CFR 71.71 and 10 CFR 71.73, credit for the high-integrity, watertight containment is not taken in the single package analysis [10 CFR 71.55(d) and (e)]. Only partial credit is taken in the package array analysis (10 CFR 71.59). In both the single package and package array analyses, the containment vessel is flooded with water. This fictitious "evaluation" water provides moderation to such an extent as to cause maximum reactivity of the content consistent with the chemical and physical form of the material present. Uranyl nitrate crystals are soluble in water. In both the evaluation of undamaged packages under 10 CFR 71.59(a)(1) and damaged packages under 10 CFR 71.59(a)(2), the leakage out of the containment vessel of content moderated to such an extent as to cause maximum reactivity consistent with the physical and chemical form of material is not considered credible during NCT or HAC, based on results for tests specified in 10 CFR 71.71 and 10 CFR 71.73.

Contents are generally dry, and only small quantities of hydrogenous packing materials are used. However, credit for the high-integrity, watertight containment is not taken in this criticality evaluation (Docket 71-9315). Fissile material loading is restricted such that if a containment vessel were flooded, it would be adequately subcritical under full water reflection. But instead of loading limits being established in accordance with conditions of confinement and containment as demonstrated under the NCT and HAC tests, these single-unit fissile material loading limits are severely reduced on the basis of the array calculations where all of the containment vessels of the packages in an array are assumed to be flooded, but each packaging is dry. This has the effect of maximizing both the neutron source and neutronic interaction between packages. Because credit for the high-integrity, watertight containment is not fully taken in this criticality evaluation, the fissile material mass loading limits developed as a result are very conservative.

Section 6.3.1 provides dimensional data for content and package models, and Sect. 6.3.2 provides material composition data used in the calculation models. Appendix 6.9.3 provides justification for the composition data used in the evaluation. These sections and this appendix describe how the packaging dimensions and materials are optimized to produce a conservative model by reducing neutron-absorbing materials and maximizing the reactivity of the fissile material content through the inclusion of water in the containment vessel.

As described in Sect. 6.3.1.1, a geometry region is defined by dimensions and the type of material contained therein. The amount of material within a region is quantified in terms of the density, material volume fraction, and the volume of the region (Sect. 6.3.2). The term "water fraction" means the fraction of the maximum specific gravity of water possible for any geometry region in the ES-3100 package. Therefore, the water content is the fraction of the maximum specific gravity of water possible in a material in the ES-3100 package when flooded.

The maximum value for the void regions (spaces external to the containment vessel) is 1.0 for both single-unit and array geometries. For the geometry regions containing Kaolite, the maximum values are 0.51655 for the single unit and 0.63931 for the array. For the geometry regions containing 277-4, the maximum value is 0.6942 for both the single-unit and array geometries. The same single-unit values are used in the array calculation models because the 277-4–bearing regions do not require adjustment for the close-pack approximation (Sect. 6.3.1.2).

In general, boundary condition specifications are not required in KENO V.a, so calculation models analyzed using KENO V.a require no special boundary conditions. However, in this evaluation, the infinite array cases use a single package with a reduced radius modeled with specular reflection on all faces of a surrounding cuboid. The energies and angular dependence of the neutrons are treated such that an infinite system with no neutron leakage is simulated.

For simplicity, the NCT and HAC sets of calculations were performed for selected ES-3100 array sizes by varying the water content of the ES-3100 package external to the containment vessel from zero to its maximum value. This technique bounds all NCT and HAC; however, only the relevant calculation results are used in determination of the CSI for criticality purposes.

Although four decimal places are shown for $k_{eff}$ values in result tables, the actual accuracy of the code, for a particular calculation, may be on the order of ± 0.02–0.03 based on the spread in results for benchmark calculations (Y/DD-896/R1 and Y/DD-972R1). Also, the standard deviation of the mean for a particular calculation is on the order of 0.001 for benchmark cases and somewhat higher for the package calculations. Therefore, numerical values are considered physically meaningful or significant to the third decimal place. The primary reason for reporting four (or five) decimal places for a calculation result is to confirm that the result reported actually originated from a given output file. A value of 0.925 is the USL used for this safety analysis report for packaging (Sect. 6.8.3).

## 6.4 SINGLE PACKAGE EVALUATION

The HEU content of a package is in one of the following forms: metal of a specified geometric shape; metal of an unspecified shape and characterized as broken metal; uranium oxide; or UNX crystals. The bounding types of HEU content evaluated in this criticality analysis are 3.24-in. and 4.25-in.-diam cylinders; 2.29-in.-square bars; 1.5-in.-diam × 2-in.-tall slugs; cubes ranging from 0.25 to 1 in. on a side; broken metal; metal turnings, fines, or powder; solid HEU metal of unspecified geometric shape and characterized as broken metal; product oxide; skull oxide; UNH crystals; and unirradiated TRIGA reactor fuel elements.

Dimensions for bounding calculation models of a TRIGA fuel section are 1.44 in. in diameter × 5 in. tall. The 20% enrichment fuel contains more fissile mass than the 70% enrichment fuel on account of a higher uranium weight fraction and associated material density. A 20 wt % enriched TRIGA fuel element with 45 wt % U contains ≤ 307-g $^{235}$U; whereas, a 70 wt % enriched TRIGA fuel with 8.5 wt % U contains ≤ 136-g $^{235}$U. The physical parameters which characterize the TRIGA fuel are enrichment, uranium weight fraction, and the fuel diameter (Appendix 6.9.3.1). These parameters are addressed in this section demonstrating that the calculation models are bounding in the criticality evaluation.

Alloys of uranium may include aluminum, molybdenum, or zirconium. Uranium-aluminum (U-Al) alloy is typically 70 to 95 wt % aluminum. Uranium-molybdenum (U-Mo) alloys are typically 1.5 to 12 wt % molybdenum. U-Mo alloys may be plated with, clad with, or contain traces of aluminum, gold, stainless steel, nickel, and/or chromium. The enrichment of U-Al, U-Mo, and U-Zr alloys range from 92.65 to 93.21 wt % $^{235}$U.

Where scattering media (aluminum, molybdenum, or zirconium) is counted as multiplying media ($^{235}$U), the alloy is conservatively assessed. Consider a canned content of U-Al which contains 940 g of uranium, 600 g of $^{235}$U, and 4070 g of aluminum. In determining compliance with a loading limit, the loading of this content would be on the basis that the material contains 4670-g $^{235}$U rather than 600-g $^{235}$U.

### 6.4.1 Solid HEU Metal of Specified Geometric Shapes

For bare and reflected single packages with HEU metal content, the neutron multiplication factor increases as a function of the $^{235}$U mass and the moisture fraction of the package external to the containment vessel (MOIFR). For example, consider the ES-3100 package loaded with three convenience cans for a total of 36,000-g $^{235}$U. Each press-fit lid type can contains a single 3.24-in.-diam, 12,000-g cylinder of $^{235}$U. The $k_{eff} + 2\sigma$ values in the bare package increase from 0.911 to 0.955 with increasing moisture fraction of the package external to the containment vessel (MOIFR), Cases **ncsbcyt11_36_1_1** through **ncsbcyt11_36_1_15** (Appendix 6.9.6, Table 6.9.6-2). The $k_{eff} + 2\sigma$ values increase from 0.918 to 0.955 with increasing MOIFR in the water-reflected package, Cases **ncsrcyt11_36_1_1** through **ncsrcyt11_36_1_15** (Appendix 6.9.6, Table 6.9.6-2). The addition of water to the package reduces the neutron leakage fraction (NLF), thereby increasing $k_{eff}$. Water reflection external to a flooded package is inconsequential to package reactivity as a comparison of results for Cases **ncsbcyt11_36_1_15** and **ncsrcyt11_36_1_15** indicates.

In this series of calculations using the ES-3100 package model with NCT geometry (Cases **ncsrcyt11_36_1_1** through **ncsrcyt11_36_1_15)**, the MOIFR is varied uniformly over the package model with the exception of the neutron poison of the body weldment liner inner cavity and the flooded containment vessel. The single-unit case with a MOIFR = 1.0 pertains specifically to the flooded drum under conditions specified in 10 CFR 71.55(b). This pseudo-HAC condition is more reactive than either the true NCT where both the containment vessel and Kaolite are dry [10 CFR 71.55(d)] or this evaluation for NCT where the containment vessel is flooded and the Kaolite is dry (in the as-manufactured condition, MOIFR ~ 0.0289). At MOIFR = 1.0, external water reflection of the package is inconsequential to package reactivity. Moisture in the Kaolite and in the recesses of the package acts as a close reflector that decreases neutron leakage away from the package.

The single-unit case with a MOIFR = 1E-20 pertains specifically to a package under pseudo-HAC where both the Kaolite and the recesses of the package do not contain **any** water or bound hydrogen. This configuration is less reactive than the cases for Kaolite in the as-manufactured condition or water-saturated Kaolite because water in the Kaolite will provide some neutron moderation and reflection of neutrons back into the content.

Single package reactivity changes slightly between the bare and reflected conditions, while NLF changes considerably over the range of water fractions. This behavior illustrates the dependence of package reactivity on internal conditions of the package. Bare packages with low MOIFR values manifest low reactivity ($k_{eff}$ = 0.911) and high neutron leakage (NLF = 0.47). These parameters indicate that fast neutrons scattered in the packaging do not slow down significantly but escape the package. Consequently, neutron interaction between these packages when they are configured into an array is high. Bare packages with MOIFR values >1E-2 manifest increasing $k_{eff}$ values (from 0.911 to 0.955) and reduced NLF values (from 0.47 to 0.18). The increase in $k_{eff}$ occurs due to water present in the regions of the package external to the content which reflects neutrons back into the HEU content that would otherwise escape the package.

A series of calculations are performed using the calculation model of a water-reflected containment vessel loaded with 3.24-in.–diam cylinders. The three cylinders are aligned as depicted in Fig. 6.9.1-1 (Appendix 6.9.1) but in very close proximity due to the omission of can spacers. A parametric variation of water density from zero to 1.0 sp gr inside the containment vessel is performed for establishing moderation by water to the most credible extent. The calculated $k_{eff} + 2\sigma$ values for Cases **cvcrcyt11_36_1_1** through **cvcrcyt11_36_1_15** (Appendix 6.9.6, Table 6.9.6-1) increase monotonically from 0.907 to 0.974 with increasing moisture fraction inside the containment vessel (MOCFR). Maximum reactivity of the fissile material occurs in the flooded containment vessel.

10 CFR 71.55(b)(3) requires evaluation of the efficiency of the packaging as an external reflector to the containment vessel. Comparison of the calculated $k_{eff} + 2\sigma$ value for Case **cvcrcyt11_36_1_15** to the value for Case **ncsrcyt11_36_1_15** reveals that the flooded containment vessel under full water reflection is a more reactive configuration than the containment vessel inside a flooded ES-3100 packaging. The ES-3100 package is not as efficient a reflector as full water reflection provided to the flooded containment vessel. For this reason, calculation results for the flooded containment vessel rather than a flooded package are reported in Tables 6.1a (and Tables 6.1b–6.1f) for the evaluation of 10 CFR 71.55(b) requirements.

Examination of the results for Cases **cvcrcyt11_36_1** through **cvcrcyt11_18_1** indicates that an adequately subcritical loading is achieved when the mass loading is limited to 21,000-g $^{235}U$ (Case **cvcrcyt11_21_1**). Case **cvcrcyt11_36_2** reveals that the 277-4 canned spacers are adequate for mass loading >18,000-g $^{235}U$ but ≤ 36,000-g $^{235}U$. These potential fissile ($^{235}U$) mass loading limits derived through the evaluation of 10 CFR 71.55(b) are listed in Table 6.1a in the information block where a description of the content appears for fissile material, "the most reactive credible configuration consistent with the chemical and physical form of the content." The finalized mass loading limit is derived at the conclusion of the array analysis for these content configurations.

The NCT tests under 10 CFR 71.71 and the HAC tests under 10 CFR 71.73 demonstrate that containment is not breached. Nevertheless, containment vessel flooding is assumed in the criticality calculations performed for the derivation of fissile material loading limits. The 7.1–10.1 kg quantities of evaluation water in both the NCT and HAC criticality calculations are not actually present in the containment vessel. Simulation of this condition in the criticality calculations produces fissile material content that is more reactive than actual. The evaluation water required in both the NCT and HAC criticality calculations bounds reasonable amounts of hydrogenous material present inside the containment vessel for solid HEU shapes.

Consider Case **cvcrcyt11_21_1** as the reference case where the calculated $k_{eff} + 2\sigma = 0.923$ (Table 6.9.6-1). The fissile material content is 21,000 g HEU metal at 100% enrichment and a density of 18.81109 g/cm$^3$. Three HEU cylinders (3.24-in. diam and 2.75425-in. tall) are stacked end-to-end starting at 0.0005 cm above the bottom of the containment vessel. The stack height is 20.98987 cm where each cylinder is separated by a 0.0001-cm–thick 277-4 canned spacer and 0.0012 cm of moderating material. Effectively, this configuration does not have 277-4 canned spacers, and no polyethylene is used in this calculation model. The water-filled cavity above the content is 57.74963 cm in height. As the input listing for Case **cvcrcyt11_21_1** (Appendix 6.9.7) indicates, ~9083 g of **evaluation** water fills the flooded containment vessel and the calculated H/X ratio is ~11.29. The calculated H/X ratio for the HEU content wrapped in 500 g polyethylene (hydrogenous packing material) inside a dry containment vessel is ~0.80.

Case **cvcrpcyt11_21_1** is the same as reference Case **cvcrcyt11_21_1,** except that 500-g polyethylene wraps three HEU cylinders with a uniform thickness of 0.54956 cm. The three wrapped HEU cylinders are stacked end-to-end starting at 0.0005 cm above the bottom of the containment vessel. Each wrapped cylinder is separated by a 0.0001-cm–thick 277-4 canned spacer and 0.0012 cm of moderating

material resulting in a stack height of 24.28733 cm. The water-filled cavity above the content is 57.74963 cm in height. At a density of 0.9200 g/cm$^3$, 500 g polyethylene adds 543.47826 cm$^3$ to the volume of the content and reduces the free volume of the containment vessel by an equal amount. As indicated in the case title card, 8540.1 g of **evaluation** water fills the flooded containment vessel. The 500 g polyethylene increases the overall H/X ratio inside the flooded containment vessel to 11.41. The calculated $k_{eff} + 2\sigma$ is 0.908 for this configuration (Table 6.9.6-1). While polyethylene having a greater hydrogen density than water is a slightly better moderating material than water, the presence of polyethylene in the calculation model provides separation between the fissile material resulting in a slight reduction in the calculated $k_{eff} + 2\sigma$ value. Case **cvdcrpcyt11_21_1** is the same as Case **cvcrpcyt11_21_1**, except that the containment vessel is dry. The calculated $k_{eff} + 2\sigma$ is 0.847 for Case **cvdcrpcyt11_21_1** (Table 6.9.6-1). The calculated $k_{eff} + 2\sigma$ value of 0.923 for reference Case **cvcrcyt11_21_1** without polyethylene is greater than the values for Cases **cvcrpcyt11_21_1** and **cvdcrpcyt11_21_1** with polyethylene. In the case of solid HEU shapes, the 7.1–10.1 kg quantities of evaluation water required in both the NCT and HAC criticality calculations bound reasonable amounts of hydrogenous material present inside the containment vessel.

Because convenience cans are not credited for providing configuration control in the containment vessel, it is possible for the fissile material to be spaced farther apart than shown in Fig. 6.9.1-1. A series of cases was run to evaluate the axial spacing of content inside the containment vessel. As shown in Table 6.9.6-3b, the separation distances between adjacent cylinders range from 0.0 to 8.75 in. (12.225 cm). Zero separation occurs when the base surfaces of adjacent cylinders are flush with the 277-4 canned spacer between them. Figure 6.9.1-1b depicts a section view of the containment vessel with 3.24-in.-diam cylinders at 4.826 and 0.254 cm separation. The calculated $k_{eff}+2\sigma$ values for Cases **ncsrcyat11_1_2_15** through **ncsrcyat11_12_2_15** (Table 6.9.6-3c) decrease with increasing separation distance. Loading configurations where solid HEU of specified geometric shape is axially positioned in contact with the can spacers are the most reactive ones.

Case **hcsrcyt12_36_1_15** (Appendix 6.9.6, Table 6.9.6-3) represents the HAC model of the damaged ES-3100 package, where the outer dimensions of the package are reduced accordingly and the entire package is flooded with the exception of the neutron poison of the body weldment liner inner cavity. The containment vessel well is flooded with water, and the Kaolite contains maximum water content. This single-unit case with a MOIFR = 1.0 pertains specifically to the flooded drum under conditions specified in 10 CFR 71.55(e). The $k_{eff} + 2\sigma = 0.955$ for this HAC. The changes in both the outer dimensions of the package and the compositions of the Kaolite and 277-4 due to HAC result in an ~0.002 change in the neutron multiplication factor.

Repeated for 4.25-in.-diam cylinders (Appendix 6.9.6, Tables 6.9.6-6 and 6.9.6-7); 2.29-in.-square bars (Tables 6.9.6-4 and 6.9.6-5); and 1.5-in.-diam × 2-in.-tall slugs (Tables 6.9.6-8 and 6.9.6-9), this type of analysis for the 3.24-in.-diam cylinders demonstrates that single packages with restricted fissile material ($^{235}$U) loading remain subcritical over the entire range of water content or MOIFR. HEU metal or alloy content not covered by the specified geometric shapes (cylinder, square bar, or slug contents) will be in the HEU broken metal category, and so limited.

Each TRIGA fuel element for shipment in the ES-3100 is to be disassembled. The active fuel consisting of three 5-in.-tall cylinders of $UZrH_{1.6}$ is to be packed into a metal-type convenience can (Sect. 6.2.1). The use of three loaded convenience cans in the ES-3100 is assumed in the criticality calculation models for ground transport. However, credit is only taken for vertical spacing provided by canned spacers when present. For configurations where canned spacers are not used, the TRIGA content is assumed stacked end-to-end. The three cylinders of the active fuel are modeled in triangular-pitch configuration within the radial boundary of the convenience can(s). The pitch used in the criticality calculation models for the NCT and HAC ground transport is 4.9809 cm (1.96 in.).

As shown in Table 6.9.6-19b, a set of parametric cases were run where the triangular pitch for the fuel content is varied from 1.44 in. (fuel sections touching) to 2.413 in. (fuel sections at maximum separation and touching the inner boundary of the convenience can). As shown in Fig. 6.17, the calculated $k_{eff}$ + 2σ values increase slightly from 0.48 to an asymptotic value of ~ 0.53 at a pitch of 2.121 in. or a foci of 3.1106 cm (Table 6.9.6-19b). The foci of 2.8757 cm. for the TRIGA fuel sections used in the criticality calculation models, corresponds to a 1.96-in. pitch. The calculated $k_{eff}$ + 2σ value is 0.527 for Case **cvcrtriga_1_15** (Table 6.9.6-19a) indicating that the configuration is in the range of optimum moderation. Moreover, the calculated $k_{eff}$ + 2σ value is substantially below the USL. The foci is the distance perpendicular from the containment vessel's vertical axis to the center of each fuel section. The value is obtained from the computer input listing on the comment line for geometry unit 1006 which reads: " -2.875700 minus-y location lower cylinder."

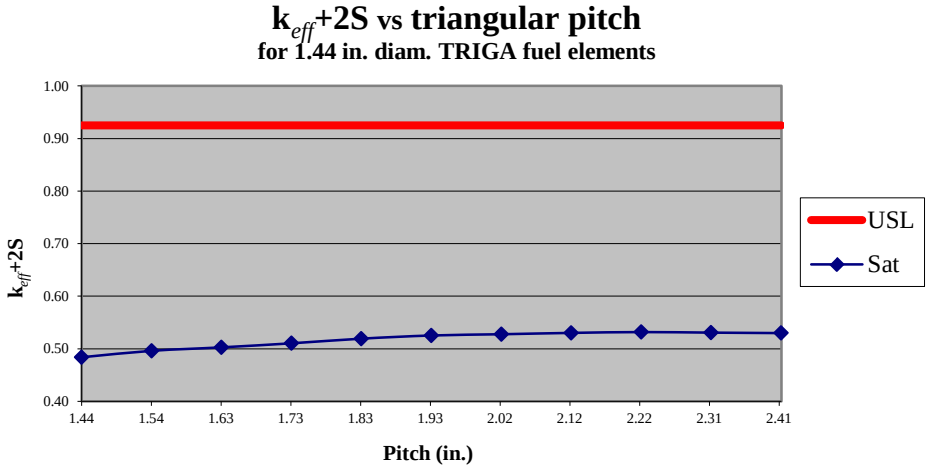



**Fig. 6.17. $k_{eff}$ + 2σ versus pitch for triangular arrangement of content in the containment vessel.**

Parametric cases were also run as a function of the moisture fraction ("mocfr") in the containment vessel. As shown in Fig. 6.18, the $k_{eff}$ + 2σ values decrease with decreasing water content in the containment vessel; and content spacing has less of an effect on $k_{eff}$ at lower at the lower fractions.

The first of the three physical parameters which characterize the TRIGA fuel is enrichment. Table 6.9.6-19a presents results for 20 % enriched and 70 % enriched TRIGA fuel where the diameter of the active fuel is 1.44 in. The calculated $k_{eff}$ + 2σ values for TRIGA fuel content at the lower enrichment is greater than for the fuel with the higher enrichment due to the greater quantity of fissile isotope present. The 20% enriched TRIGA fuel is considered the bounding content.

The second physical parameter which characterizes the TRIGA fuel is the uranium weight fraction. For a TRIGA fuel enriched to 20 wt % $^{235}U$ in U, the uranium weight fractions for the $UZrH_{1.6}$ fuel are: 45 wt %; 30 wt %; 20 wt %; 12 wt %; and 8.5 wt % U. A set of parametric cases were run where the uranium weight fraction is varied from the minimum value of 8.5 wt % to the maximum value of 45 wt %. Additionally, moderation in the containment vessel is varied from the dry to the flooded condition. As shown in Fig. 6.19, the $k_{eff}$ + 2σ values decrease with both decreasing uranium weight fraction and decreasing water content in the containment vessel. Details are provided in Table 6.9.6-19c.

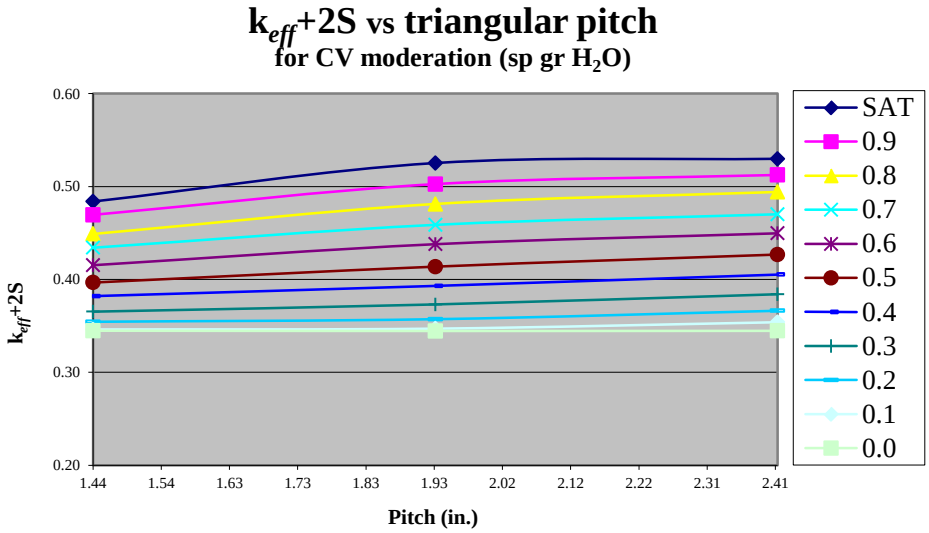



**Fig. 6.18. $k_{eff}$ + 2σ versus triangular pitch over range of containment vessel moderation.**

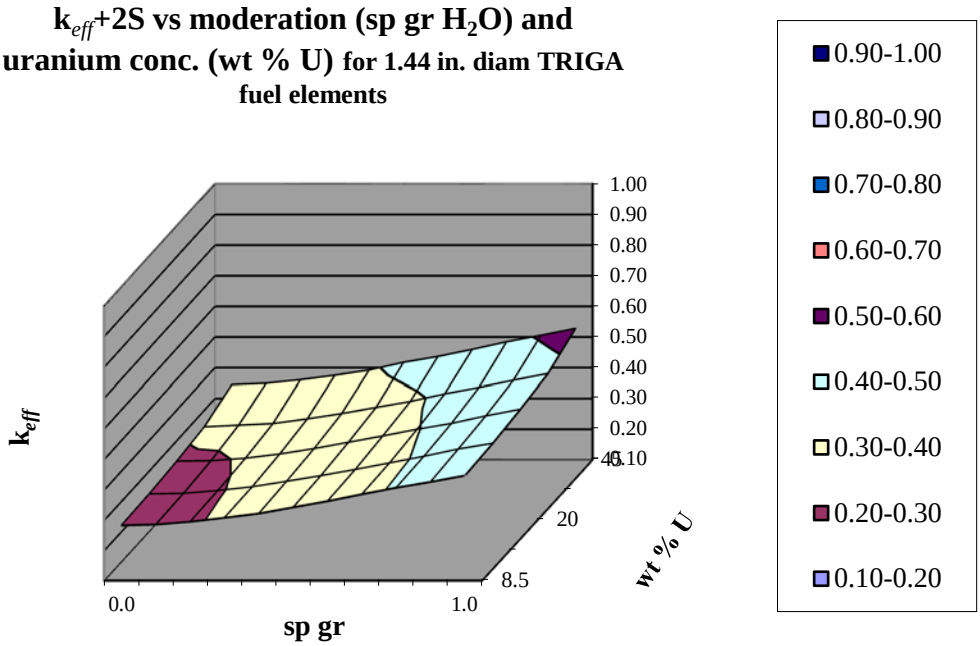



**Fig. 6.19. $k_{eff}$ + 2σ as a function of uranium weight fraction and moderation.**

Third physical parameter which characterizes the TRIGA fuel is active fuel diameter. The active fuel diameters are: 1.44 in.; 1.41 in.; 1.40 in.; 1.37 in.; 1.34in.; and 1.31 in. The smaller the diameter, the less the amount of $^{235}U$ is present resulting in lower $k_{eff} + 2\sigma$ values, as demonstrated later in this section.

Cases **cvcrtriga_1_1** through **cvcrtriga_1_15** (Appendix 6.9.6, Table 6.9.6-19a) represent the TRIGA fuel content in a flooded containment vessel, reflected by 30.48 cm of water. The flooded containment vessel under full water reflection is a more reactive configuration than the containment vessel inside of flooded ES-3100 packaging, Case **ncsrtriga_1_15_15** (Appendix 6.9.6, Table 6.9.6-20a). Further examination of the results in Table 6.9.6-20a indicates the content loading is adequately subcritical loading and that 277-4 canned spacers are not required for criticality control. Comparison of results for the NCT Case **ncsrtriga_1_15_15** and the HAC **hcsrtriga_1_15_15**, both with $k_{eff} + 2\sigma = 0.495$, reveal that changes to the packaging external to the containment vessel due to the HAC do not result in an appreciable change in the neutron multiplication factor for the single package.

Cases **ncsrtriga70_1_1_1** through **ncsrtriga70_1_15_15** (Appendix 6.9.6, Table 6.9.6-20b) represent the 70 % enriched TRIGA fuel content in a flooded ES-3100 package, reflected by 30.48 cm of water. Comparison of results for these cases with results for the 20 % enriched TRIGA fuel (Cases **ncsrtriga_1_1_1** through **ncsrtriga_1_15_15**) confirm that the 20 % enriched TRIGA fuel is the bounding content.

Cases **ncsrT70_131_1_1_15** through **ncsrT70_131_1_15_15** (Appendix 6.9.6, Table 6.9.6-20c) represent the 1.31-in.-diam TRIGA fuel content in a flooded ES-3100 package, reflected by 30.48 cm of water. Comparison of results for these cases with results for the larger 1.44-in.-diam TRIGA fuel content (Cases **ncsrtriga70_1_1_1** through ncsrtriga70_1_15_15) confirm that the 1.44-in.-diam TRIGA fuel is the bounding content.

10 CFR 71.55(d)(2) requires the geometric form of a package's content not be substantially altered under the NCT. Also, 10 CFR 7155(e)(1) requires that the package be adequately subcritical under HAC with the package contents in the most reactive credible configuration. However, conclusions about damage to the fuel content cannot be extrapolated from test data because a mock (test weight) content rather than actual TRIGA content is evaluated in the NCT and HAC tests of 10 CFR 71.71 and 10 CFR 71.73. Consequently, one way for addressing these requirements is to model the content in an extremely damaged condition and make a determination of subcriticality through a series of criticality calculations. Cases **ncsrt55d2_ 1_1_1**5 through **ncsrt55d2_1_15_15** (Appendix 6.9.6, Table 6.9.6-20d) represent TRIGA fuel content homogenized with variable density water over the free volume of the containment vessel, where the ES-3100 packaging is flooded and reflected by 30.48 cm of water. The variable density water ranges from the dry containment condition to the fully flooded condition. Credit for physical integrity of the content is not taken in this set of cases which model the substantially altered content. The calculation results in Table 6.9.6-20d indicate extremely damaged content (Case **ncsrt55d2_1_15_15** with $k_{eff} + 2\sigma = 0.611$) is more reactive than the unaltered configuration (Case **ncsrtriga_1_15_15** with $k_{eff} + 2\sigma = 0.403$). Nevertheless, both cases are adequately below the USL of 0.925 and the requirement of 10 CFR 71.55(d)(2) is satisfied. Given that changes external to the containment vessel due to the HAC do not result in an appreciable change in the neutron multiplication for the single package, similar results are expected for the cases demonstrating compliance with 10 CFR 7155(e)(1).

The shipping configuration for disassembled TRIGA fuel addressed in this subsection is not the only permissible shipping configuration for TRIGA fuel in the ES-3100. TRIGA fuel may also be configured as clad fuel rods (Appendix 6.9.3.1). Each 15-in.-long rod is derived from a single TRIGA fuel element. The clad fuel rod consists of the 3 fuel pellets and the exterior sheath of stainless steel or aluminum clad. Clad fuel rods are packed into stainless steel or tin-plated carbon steel convenience cans

with a maximum of three fuel rods per loaded convenience can. This shipping configuration requires that only one convenience can is loaded with clad fuel rods.

Except for a 0.02-in.-thick sheath of stainless steel clad added to the exterior surface of the $UZrH_{1.6}$, a calculation model for the clad fuel rod configuration is essentially the same as the NCT shipping configuration model for disassembled TRIGA fuel. A 0.02-in. thickness of stainless steel is insignificant for an external reflection. As illustrated in Fig. 6.24 (Sect. 6.7.2), stainless steel up to several cm in thickness acts as a neutron absorber. Several inches in thickness are required for neutron multiplication to increase from neutron reflection by the stainless steel. The NCT shipping configuration model for disassembled TRIGA fuel is bounding. The same applies for TRIGA fuel with aluminum clad.

A clad fuel rod with 1.44-in.-diam fuel pellets contains 2,282.4-g $UZrH_x$ (Appendix 6.9.3.1) and ~179 to 191 g of stainless steel. Stainless steel tends to act as a neutron absorber; moreover, its presence as clad in the TRIGA fuel content replaces water moderator otherwise present in the geometry configuration of TRIGA fuel meats. When stainless steel is homogenized with the $UZrH_{1.6}$ as in the calculation model for package content in the extremely damaged condition [10 CFR 71.55(d)(2) and 10 CFR 7155(e)(1)], the stainless steel acts more effectively as a neutron absorber. However, the amount of stainless steel added and water displaced is not expected to have a statistically significant affect on neutron multiplication. Thus, the HAC shipping configuration model for disassembled TRIGA fuel (bare fuel meats) is bounding.

A clad fuel rod with 1.41-in.-diam fuel pellets contains ~2,188-g $UZrH_x$ and ~90 to 96 g of aluminum. While aluminum tends to act as a neutron scatter, its presence in the TRIGA fuel content replaces water moderator otherwise present in the geometry configuration of TRIGA fuel meats. The amount of aluminum added and water displaced is not sufficient to have a statistically significant affect on neutron multiplication. Thus, the HAC shipping configuration model for disassembled TRIGA fuel is also bounding for aluminum clad TRIGA fuel content.

The TRIGA content is to be transported by air; consequently, additional discussion is included in Sect. 6.7.

The 1.5-in.–diam × 2-in.–tall slugs may be packed up to ten items per press-fit lid type convenience can and up to twelve items per crimp-lid type convenience can. With nominal dimensions, each slug weighs ~1,090 g. With +1/16-in. tolerance on both the diameter and height, each slug in the calculation model weighs ~1218 g. As described in Appendix 6.9.1, different arrangements of slugs in the convenience cans are possible. A configuration of slugs in a flooded reflected containment vessel must be shown to be adequately subcritical and so limited either by the use of 277-4 canned spacers, by limitation of fissile mass, or by both.

Several slug arrangements depicted in Fig. 6.9.1-4b are evaluated for demonstrating that the most conservative arrangement of slugs is being analyzed. The blue marker shown in Fig. 6.9.1-4c depicts the 4.13-in. diam of the canned spacer. Content within a configuration radius of 2.125 in. (5.4 cm) are within the boundary of the convenience can wall. The convenience cans are not modeled and contents are allowed to project beyond the convenience can wall boundary. The slugs are modeled only as 100 wt % $^{235}U$ for this portion of the criticality evaluation. Cases **cvcr5st11_1_1**, **cvcr5est11_1_1**, **cvcr50st11_1**, **cvcr5e0st11_1**, **cvcr5u0st11_1**, and **cvcr5l0st11_1** depict very different spacing arrangements with five slugs per convenience can, three cans per package. The statistical difference in the calculated "$k_{eff} + 2\sigma$" values is insignificant. Cases **cvcr6e0st11_1** and **cvcr6st11_1_1** depict arrangements with six slugs per convenience can, and Case **cvcr70st11_1** depicts seven slugs per convenience can. (Considerable deformation of the 4.25-in.–diam convenience can wall is required to achieve all but the simple pentagonal-ring arrangement of slugs.) Calculation results reveal the primary dependence of the "$k_{eff} + 2\sigma$" value is on the fissile mass loading and the secondary dependence is on the arrangement and spacing of slugs. The calculation results

presented in Table 6.9.6-8 (Appendix 6.9.6) for a flooded containment vessel indicate that only five slugs per convenience can (18,277-g $^{235}$U per package) may be loaded without the use of 277-4 canned spacers (Cases **cvcr5st11_1_1** and **cvcr5est11_1_1**). Further evaluation of the single package and array configurations are required. Also, results highlighted in red indicate that 277-4 canned spacers are required for the slug content.

The sensitivity of $k_{eff}$ to the space between slugs arranged in a pentagonal ring is evident in the calculation results for Cases **cvcr5st11_1_2** and **cvcr5est11_1_2,** which model content for three convenience cans, each location with two pentagonal rings (10 slugs) per can. These two configurations represent degrees of separation between adjacent neighbors in the pentagonal rings of 0.0 cm and 1.0 cm, respectively. The most reactive configuration occurs when the slugs are spaced 1.0 cm apart from direct contact with adjacent neighbors in the pentagonal rings. Because positioning devices are not used in the convenience cans to control spacing and prevent an optimal arrangement of contents from occurring, both calculation models for slug arrangement are the basis for additional calculations where 277-4 canned spacers may not be required.

Cases **cvcr5st11_2_1**, **cvcr5est11_2_1**, **cvcr50st11_2**, **cvcr5e0st11_2**, **cvcr5u0st11_2**, and **cvcr5l0st11_2** represent the different spacing arrangements with five slugs per convenience can, three cans per package, and cans separated by canned spacers. Likewise, Cases **cvcr6e0st11_2** and **cvcr6st11_2_1** represent arrangements with six slugs per convenience can, three can per package, and cans separated by can spacers. Case **cvcr70st11_2** represents seven slugs per convenience can. While the differences in the calculated "$k_{eff} + 2\sigma$" values for equal numbers of slugs per can are $\leq 0.006$, the "$k_{eff} + 2\sigma$" values are significantly below the USL. Again, the calculation results presented in Table 6.9.6-8 (Appendix 6.9.6) for these cases reveal the primary dependence of the "$k_{eff} + 2\sigma$" value is on fissile mass loading, and the secondary dependence is on the arrangement and spacing of slugs.

Case **cvcr6e0st11_2** models three sets of slugs, six slugs in a pentagonal ring with one slug in the center, and each set of slugs separated by a 277-4 canned spacer. Cases **cv0r6e0st11_2** and **cvwr6e0st11_2** are variations of the reference case where the 1.4-in. spacer is replaced with void in the first case and is replaced with water in the second case. Comparison of the "$k_{eff} + 2\sigma$" values between Cases **cvcr6e0st11_2** and **cv0r6e0st11_2** reveals that the spacers reduce $k_{eff}$ by ~ 0.03. Comparison of the "$k_{eff} + 2\sigma$" values for Cases **cvcr6e0st11_2** and **cvwr6e0st11_2** reveals that axial spacing of the content provided by the content cans inside the containment vessel serves to reduce $k_{eff}$.

The calculation results presented in Table 6.9.1-8 for a flooded containment vessel indicate that up to ten slugs per convenience can (36,555-g $^{235}$U per package) *might* be loaded when 277-4 canned spacers are used. Conceivable arrangements are considered in Cases **cvcr5st11_2_2**, **cvcr5est11_2_2**, **cvcr6e4st11_2**, and **cvcr73st11_2** (Table 6.9.6-8). Suitability is contingent on the results of single package and array calculations.

Cases **ncsr5est11_2_1_1** through **ncsr5est11_2_1_15** (Appendix 6.9.6, Table 6.9.6-9) model a reflected package with one pentagonal ring of slugs per content location with 277-4 canned spacers between content locations and HEU content at 100 wt % $^{235}$U. The $k_{eff} + 2\sigma$ values range from a low value of 0.688 to 0.736. These results show that the most reactive configuration is the flooded condition with MOIFR=1.0.

As shown by the cylindrical content calculation models, the ES-3100 package is not as an efficient reflector as full water reflection provided to the flooded containment vessel. This is also true for content loadings of one pentagonal ring of slugs per content location without 277-4 canned spacers between locations and HEU content at 100 wt % $^{235}$U. For Cases **cvcr5est11_1_1** and **ncsr5est11_1_1_15**, the $k_{eff} + 2\sigma$ values are 0.910 and 0.871, respectively. Likewise, the $k_{eff} + 2\sigma$ values

are 0.901 and 0.867 for content loadings of two pentagonal rings of slugs per content location with 277-4 canned spacers between locations, Cases **cvcr5est11_2_2** and **ncsr5est11_2_2_15**, respectively.

For the flooded containment vessel under full water reflection and loaded with the slugs in a pentagonal arrangement and 277-4 canned spacers between content locations, the $k_{eff} + 2\sigma$ value is 0.903, Case **cvcr5st11_2_2** [10 CFR 71.55(b)]. This value is below the USL value of 0.925. For packages with the required 1.4-in. spacers, the calculated $k_{eff} + 2\sigma$ value is 0.878 for the water-reflected package, Case **ncsr5st11_2_2_15** [10 CFR 71.55(d)]. Case **hcsr5st11_02_2_15** represents the HAC model of the damaged ES-3100 package, where the outer dimensions of the package are reduced accordingly and the entire package is flooded except the neutron poison of the body weldment liner inner cavity. This single-unit case with a MOIFR = 1.0 pertains specifically to the flooded drum under conditions specified in 10 CFR 71.55(e). The $k_{eff} + 2\sigma$ value is 0.872 for this HAC. The changes in both the outer dimensions of the package and the compositions of the Kaolite and 277-4 due to HAC result in an ~0.001 change in the neutron multiplication factor.

### 6.4.2 HEU Broken Metal; Solid HEU Metal with Unspecified Geometric Shape and Characterized as Broken Metal; or Turnings, Fines, or Powder

Broken metal pieces are distinguished from turnings, fines, or powder as having a surface-area-to-mass ratio of not greater than 1 $cm^2/g$ or must not pass through a 3/8-in. mesh sieve (or equivalent size-grading method). **In the containment vessel calculations**, broken metal is evaluated using the "lha" content model (Fig. 6.9.1-5c). The "lha" approximation model is derived from the "sqa" model (Figs. 6.9.1-5b) where HEU metal is homogenized with the water inside the rectangular lattice formed by an array of discretely modeled items of uniform size and shape (Appendix 6.9.1). The overall volume (and shape) of the content "envelope" containing the HEU and the amount of interstitial moderator between the actual pieces of HEU is preserved in the "lha" content model. This representation of discrete solid HEU broken metal in the containment vessel calculation model as fissile material homogenized with moderator is bounding (Table 6.9.3.1-2). **In the containment vessel calculations**, turnings, fines, and powder are evaluated using the "cha" content model (Fig. 6.9.1-5d) where HEU metal and the water inside a flooded containment vessel are homogenized as a uranium "solution" and dispersed over the internal volume of the containment vessel.

Credit for the presence of convenience cans is not taken in either the "lha" or the "cha" model. Content spacing provided by the convenience cans is absent in the models such that the canned spacer, if present, is located above the rectangular lattice (content envelop) between the convenience can locations (Fig. 6.9.1-5c). Credit for the presence of canned spacers is taken for broken metal but not for fines, turnings, and powder where the fissile material form is not conducive to maintaining spacer separation nor prevent gravitation of the canned spacers to the bottom of the containment vessel. For conservatism, the "cha" model was used to represent HEU metal content **in the single package calculations**.

Like packages with solid HEU metal shapes, the neutron multiplication factor for reflected single packages with HEU broken metal, turnings, fines, or powder increases as a function of the $^{235}U$ mass and the MOIFR. For example, consider the ES-3100 package loaded with three convenience cans for a total of 35,142-g $^{235}U$. The $k_{eff} + 2\sigma$ values range from 0.814 to 0.891 with increasing MOIFR in the water-reflected package [Cases **ncsrbmt11_36_1_1** through **ncsrbmt11_36_1_15** (Appendix 6.9.6, Table 6.9.6-11)]. The addition of water to the package reduces the NLF, thereby increasing $k_{eff}$.

For the containment vessel loaded with the broken metal content (excluding turnings, fines, or powder) and without 277-4 canned spacers between content locations, the $k_{eff} + 2\sigma$ values increase from 0.751 to 0.949 as the water content in the containment vessel increases [Cases **cvr3lha_36_1_8_1** through **cvr3lha_36_1_8_15** (Appendix 6.9.6, Table 6.9.6-10)]. Cases **cvr3lha_36_1_8_15** through **cvr3lha_36_1_1_15** model the flooded containment vessel with 35 kg of broken HEU metal where the

enrichment ranges from 100 to 19 wt % $^{235}U$. The $k_{eff} + 2\sigma$ values decrease from 0.949 to 0.657. The $k_{eff} + 2\sigma = 0.949$ for Case **cvr3lha_36_1_8_15** indicates that the 35,142-g $^{235}U$ mass loading at 100% enrichment with canned spacers absent must be reduced below 35,142-g $^{235}U$ for establishing a loading limit over the range of 95 to 100 wt % $^{235}U$. The result for Case **cvr3lha_26_1_8_15** indicates that for an enrichment of 100 wt % $^{235}U$, the mass loading over the range 95 < enr. ≤ 100 wt % $^{235}U$ cannot exceed 25,894-g $^{235}U$ in the absence of canned spacers. (The orange highlighted cases in Table 6.9.6-10 indicate potential fissile loading limits, or evaluation limits.)

The result for Case **cvr3lha_29_1_7_15** indicates that for an enrichment of 95 wt % $^{235}U$, the mass loading limit conservatively applied over the range 90 < enr. ≤ 95 wt % $^{235}U$ cannot exceed 27,252-g $^{235}U$ in the absence of canned spacers. Application of this 27,252-g $^{235}U$ limit to higher enrichment material is non-conservative, as illustrated by the result for Case **cvr3lha_28_1_8_15** where $k_{eff} + 2\sigma = 0.933$ for 100 wt % $^{235}U$. As the enrichment increases, the mass loading limit must decrease from 27,252-g to 25,894-g$^{235}U$ in this example due to less $^{238}U$ present for neutron absorption. Potential fissile loading limits for the reduced enrichment ranges are derived in a similar manner. For enrichments ≤ 60 wt % $^{235}U$, the containment vessel is load-limited to 35,320-g U. As enrichment drops from 60 to 19 wt % $^{235}U$, the $k_{eff} + 2\sigma$ values decrease from 0.829 to 0.657. The $^{235}U$ (or U) evaluation limits conservatively applied over the indicated ranges of enrichment are listed in the column headings of Table 6.1c. These evaluation limits represent the maximum amount of $^{235}U$ (or U) permissible in a flooded, reflected containment vessel for maintaining an adequate margin of subcriticality.

For the containment vessel loaded with the HEU metal content in the form of turnings, fines, or powder and without 277-4 canned spacers between content locations, the $k_{eff} + 2\sigma$ values increase from 0.613 to 0.983 as the water content in the containment vessel increases [Cases **cvr3cha_36_1_8_1** through **cvr3cha_36_1_8_15** (Appendix 6.9.6, Table 6.9.6-10)]. Cases **cvr3cha_36_1_8_15** through **cvr3cha_36_1_1_15** model the flooded containment vessel with 35.32 kg of HEU metal turnings, fines, or powder having an enrichment ranging from 100 to 19 wt % $^{235}U$. The $k_{eff} + 2\sigma$ values decrease from 0.983 to 0.791. The $k_{eff} + 2\sigma = 0.983$ for Case **cvr3cha_36_1_8_15** indicates that the 35,142-g $^{235}U$ mass loading at 100% enrichment without canned spacers must be reduced in order to be considered as a loading limit over the range of 95 to 100 wt % $^{235}U$. The result for Case **cvr3cha_8_1_8_15** indicates that for an enrichment of 100 wt % $^{235}U$, the mass loading conservatively applied over the range 95 < enr. ≤ 100 wt % $^{235}U$ cannot exceed 7,398-g $^{235}U$ in the absence of canned spacers.

The result for Case **cvr3cha_12_1_7_15** indicates that for an enrichment of 95 wt % $^{235}U$, the mass loading conservatively applied over the range 90 < enr. ≤ 95 wt % $^{235}U$ cannot exceed 10,549-g $^{235}U$ in the absence of canned spacers. Similarly, the application of this 10,549-g $^{235}U$ limit for HEU metal turnings, fines, or powder in the range 90 < enr. ≤ 95 wt % $^{235}U$ to higher enrichment material in the range 95 < enr. ≤ 100 wt % $^{235}U$ is non-conservative. As the enrichment increases, the mass loading limit must decrease from 10,549-g to 7,398-g $^{235}U$ in this example due to less $^{238}U$ present for neutron absorption. The result for Case **cvr3cha_16_1_6_15** indicates that for an enrichment of 90 wt % $^{235}U$, the mass loading conservatively applied over the range 80 < enr. ≤ 90 wt % $^{235}U$ cannot exceed 14,167-g $^{235}U$ in the absence of canned spacers. The result for Case **cvr3cha_25_1_5_15** indicates that for an enrichment of 80 wt % $^{235}U$, the mass loading conservatively applied over the range 70 < enr. ≤ 80 wt % $^{235}U$ cannot exceed 19,284-g $^{235}U$ in the absence of canned spacers. The result for Case **cvr3cha_36_1_4_15** indicates that for an enrichment of 70 wt % $^{235}U$, the mass loading conservatively applied over the range 60 < enr. ≤ 70 wt % $^{235}U$ cannot exceed 24,693-g $^{235}U$ in the absence of canned spacers. The result for Case **cvr3cha_36_1_3_15** indicates that for an enrichment of 60 wt % $^{235}U$, the mass loading conservatively applied over the range 40 < enr. ≤ 60 wt % $^{235}U$ cannot exceed 21,192-g $^{235}U$ in the absence of canned spacers. As enrichment drops from 60 to 19 wt % $^{235}U$, the $k_{eff} + 2\sigma$ values decrease from 0.900 to 0.791. However, the containment vessel is load-limited to 35,320-g U; therefore, the maximum permissible loadings shown for Cases **cvr3cha_36_1_2_15** and **cvr3cha_36_1_1_15** are not

achievable. For this reason, the uranium mass rather the fissile isotope mass (g $^{235}U$) is indicated as the potential mass loading limit for ≤ 60 wt % $^{235}U$. The $^{235}U$ (or U) evaluation limits conservatively applied over the indicated ranges of enrichment are listed in the column headings of Tables 6.1d. These evaluation limits represent the maximum amount of $^{235}U$ (or U) in the form of HEU metal turnings, fines, or powder permissible in a flooded, reflected containment vessel for maintaining an adequate margin of subcriticality.

The most reactive credible configuration consistent with the chemical and physical form of the material consists of the containment vessel under full water reflection but with 277-4 canned spacers absent between content locations. For the flooded containment vessel loaded with the HEU broken metal content (excluding turnings, fines, or powder), the $k_{eff} + 2\sigma = 0.918$ in Case **cvr3lha_26_1_8_15** [Table 6.1c, 10 CFR 71.55(b)]. For the flooded containment vessel loaded with HEU metal turnings, fines, or powder (excluding unspecified geometric shape and characterized as broken metal, or broken metal), the $k_{eff} + 2\sigma = 0.923$ in Case **cvr3cha_8_1_8_15** [Table 6.1d, 10 CFR 71.55(b)].

For single packages loaded with HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder), the calculated $k_{eff} + 2\sigma$ value for Case **ncsrbmt11_36_1_15** is 0.891 [Tables 6.1c and 6.1d, 10 CFR 71.55(d)]. Case **hcsrbmt12_36_1_15** (Appendix 6.9.6, Table 6.9.6-11) represents the HAC model of the damaged ES-3100 package, where the outer dimensions of the package are reduced accordingly and the entire package is flooded except the neutron poison of the body weldment liner inner cavity. This single-unit case with a MOIFR = 1.0 pertains specifically to the flooded drum under conditions specified in 10 CFR 71.55(e) (Tables 6.1c and 6.1d). The $k_{eff} + 2\sigma = 0.891$ for this HAC condition. The changes in both the outer dimensions of the package and the compositions of the Kaolite and 277-4 due to HAC does not result in detectible change in the neutron multiplication factor.

The finalized mass loading limits documented in Table 6.2a are derived from Tables 6.1c and 6.1d at the conclusion of the array analyses after consideration of other packing arrangements (i.e., single package under NCT and HAC and the various package array configurations under NCT and HAC).

### 6.4.3 HEU Oxide

HEU product oxide content is non-hygroscopic or mildly hygroscopic. While bulk densities of product oxides are typically on the order of 6.54 g/cm$^3$, the bulk density of HEU oxides considered for shipment in the ES-3100 ranges from 2.0 to 6.54 g/cm$^3$. HEU skull oxide is a less dense form of $U_3O_8$ intermixed with graphite. Of interest are those compositions with carbon/fissile uranium (C/$^{235}U$) ratios up to $2.3 \times 10^5$ μg C/g$^{235}U$. The quantity of fissile uranium is extremely low where even higher C/$^{235}U$ ratios are present.

HEU product oxide content may be packed in polyethylene bottles or metal convenience cans; HEU skull oxide content is packed in metal convenience cans. Polyethylene bottles and hydrogenous packing material are represented by 500 g polyethylene. While both the size and shape of the polyethylene bottles prevents the use of 277-4 canned spacers with product oxide loadings, the 10-in. height of the metal convenience cans eliminates the use of 277-4 canned spacers for product or skull oxide content packaged in these size cans. However, the convenience cans are not modeled in this criticality evaluation and this analysis is performed from the standpoint that metal-type convenience cans may be used for both oxide types.

HEU oxide content is not considered a “rigid” content like solid or broken HEU metal. For the calculation models of HEU oxides, the polyethylene is homogenized with the saturated bulk oxide. At a density of 0.9200 g/cm$^3$, polyethylene adds 543.47826 cm$^3$ to the volume of the saturated bulk oxide and

reduces the free volume of the containment vessel by an equal amount. The evaluation water in the void region of the containment vessel fills the volume of the containment vessel that not occupied by oxide content. (The void region of the containment vessel is defined as the containment vessel volume minus the oxide content volume.) Because of the differences in densities and compositions, product oxides are addressed separately from skull oxides.

Like packages with HEU metal or broken metal, the neutron multiplication factor for reflected single packages with HEU oxide increases as a function of increasing MOIFR and decreases with decreasing $^{235}U$ mass. For example, consider the ES-3100 package loaded with oxide at 6.54 g/cm$^3$ in three convenience cans for a total of 24,000-g $UO_2$ (21,125-g $^{235}U$). The $k_{eff} + 2\sigma$ values range from 0.724 to 0.804 with increasing MOIFR in the reflected package [Cases **ncsrpoxt11_1_24_1** through **ncsrpoxt11_1_24_15** (Table 6.9.6-13)]. The addition of water to the package reduces the NLF, thereby increasing $k_{eff}$. The flooded, reflected package is the most reactive single package configuration; consequently, MOIFR is treated as a constant rather than a variable in subsequent "**pdox**" cases.

Parametric calculations are performed for oxide content loadings in a flooded, reflected package by varying the oxide bulk density from 6.54 g/cm$^3$ to a lower value limited by the capacity of the convenience cans. The maximum content capacity of the ES-3100 is ~6,975 cm$^3$, where each of three 4.25-in.-diam × 10.0-in.-tall convenience cans has a capacity of ~2,375 cm$^3$. As shown in Table 6.9.6-13a, calculations for a loading of 24,000-g $UO_2$ are performed at bulk densities of 6.54 g/cm$^3$, 5.0 g/cm$^3$, and 4.0 g/cm$^3$, but not 3.0 g/cm$^3$ because the capacity of the convenience cans is exceeded for this mass loading. Note that Case **ncsrpoxt11_1_24_15** (Table 6.9.6-13) is identical to Case **ncsrpdoxt11_1_5_24** (Table 6.9.6-13a). Results for the parametric Cases **ncsrpdoxt11_1_*n*_24**, **ncsrpdoxt11_1_*n*_20**, and **ncsrpdoxt11_1_*n*_15** reveal the consistent increase in the $k_{eff} + 2\sigma$ values as the bulk density decreases. This increase in neutron multiplication is due to the increased moderation of the HEU oxide.

Cases **ncsrpdoxt11_1_*n*_14** for $UO_2$ (12,323-g $^{235}U$), **ncsrpdoxt11_2_*n*_14** for $U_3O_8$ (11,850-g $^{235}U$), and **ncsrpdoxt11_3_*n*_14** for $UO_3$ (11,627-g $^{235}U$) evaluate the ES-3100 package loaded with 14 kg oxide over the range of bulk density "*n*." The $k_{eff} + 2\sigma$ values reveal a consistent increase over the range of density. Results for Cases **ncsrpdoxt11_2_1_14** and **ncsrpdoxt11_3_1_14** indicate that both the $U_3O_8$ content ($k_{eff} + 2\sigma = 0.778$) and the $UO_3$ content ($k_{eff} + 2\sigma = 0.760$) are bounded by the $UO_2$ content ($k_{eff} + 2\sigma = 0.814$). Even though the capacity of the convenience cans is exceeded by 25 g, these cases are retained for the purpose of illustrating this point.

Results for a reflected containment vessel loaded with HEU oxide reveal the same trends in the $k_{eff} + 2\sigma$ values as do results for the reflected package; however, the $k_{eff} + 2\sigma$ values are ~0.1 greater in the containment vessel cases. For the flooded containment vessel loaded with $UO_2$, the $k_{eff} + 2\sigma$ values increase from 0.838 to 0.911 with decreasing bulk density [Cases **cvcrpdoxt11_1_5_14_15** through **cvcrpdoxt11_1_1_14_15** (Table 6.9.6-12 and Fig. 6.9.1-6)]. For the dry containment vessel, the $k_{eff} + 2\sigma$ values increase from 0.824 to 0.912 [Cases **cvcrpdoxt11_1_5_14_1** through **cvcrpdoxt11_1_1_14_1** (Table 6.9.6-12 and Fig. 6.9.1-6)]. Comparison of results for high density $UO_2$ oxide saturated with 862 g water reveals a small increase in $k_{eff} + 2\sigma$ from 0.824 to 0.838 due to flooding of the containment vessel. Comparison of results for low density $UO_2$ oxide saturated with 5,712 g water reveals an insignificant increase in $k_{eff} + 2\sigma$ due to flooding of the containment vessel, [Cases **cvcrpdoxt11_1_5_14_15** and **cvcrpdoxt11_1_5_14_1** (Table 6.9.6-12 and Fig. 6.9.1-6)].

Cases **cvcrpdoxt11_1_11_14_15** through **cvcrpdoxt11_1_1_14_15** demonstrate that the $k_{eff} + 2\sigma$ values decrease for decreased mass loadings of HEU oxide at constant bulk density.

For the flooded containment vessel under full water reflection containment, the $k_{eff} + 2\sigma$ value is 0.914, Case **cvcrpdoxt11_1_3_24_15** [10 CFR 71.55(b)]. The $k_{eff} + 2\sigma$ value is 0.817 for water-reflected package, Case **ncsrpdoxt11_1_3_24** [10 CFR 71.55(d)]. Case **hcsrpdoxt12_1_3_24** (Table 6.9.6-13a)

represents the HAC model of the damaged ES-3100 package, where the outer dimensions of the package are reduced accordingly and the entire package is flooded except the neutron poison of the body weldment liner inner cavity. This single-unit case pertains specifically to the flooded drum under conditions specified in 10 CFR 71.55(e). The $k_{eff} + 2\sigma$ value is 0.819 for this HAC condition. The changes in both the outer dimensions of the package and the compositions of the Kaolite and 277-4 due to HAC result in an ~0.002 change in the neutron multiplication factor.

Cases **cvcrsk3cc_1_15_17** through **cvcrsk3cc_10_15_17** (Appendix 6.9.6, Table 6.9.6-17) evaluate the 10 skull oxide compositions identified Table 6.9.3.1-3b, where the containment vessel is loaded with 3 convenience cans. The fissile enrichment is ~70 wt % $^{235}U$ for contents "**sk3cc_1**" through "**sk3cc_5**" and ~38 wt % $^{235}U$ for contents "**sk3cc_6**" through "**sk3cc_8**." The observed maximums of 7.1 kg skull oxide and ~93.2 wt % $^{235}U$ enrichment present in 292 convenience cans are the basis for the hypothetical contents "**sk3cc_9**" and "**sk3cc_10**," where unidentified material is treated as $^{235}U$ and the carbon content is either maximized or minimized. Content "**sk3cc_10**" differs from "**sk3cc_9**" in that 921 g of graphite in the skull oxide is replaced with 921-g $^{235}U$ in the form of $U_3O_8$. Content "**sk3cc_10**" is more representative of high enrichment skull oxides where < 85 g of graphite is present. For each of the 10 content models, 513 g of the skull oxide content is modeled as polyethylene, representing the potential use of hydrogenous packing material. The $U_3O_8$ content ranges from 8 to 21 kg, while the $^{235}U$ content ranges from 3.7 to 16.4 kg. The graphite content ranges from 0 to 921-g C, and the C/$^{235}U$ ratio ranges from 0 to 223,432 μg C/g $^{235}U$. For Cases **cvcrsk3cc_1_15_17** through **cvcrsk3cc_10_15_17** at both saturation moisture and full graphite content, the $k_{eff} + 2\sigma$ values range from 0.759 to 0.855 in the flooded, water-reflected containment vessel. Cases **cvcrsk3cc_9_15_17** and **cvcrsk3cc_10_15_17** reveal that $k_{eff} + 2\sigma$ increases slightly when the 921 g of carbon in the skull oxide is replaced with 726-g $^{235}U$ in the form of $U_3O_8$.

Cases **cvcrsk3cc_4_1_1** through **cvcrsk3cc_4_*m*_*g*** evaluate the effects of moisture and skull oxide graphite content on reactivity. The case designator "***m***" ranges from 1 to 15, signifying the variation in moisture; "***g***" ranges from 1 to 17, signifying the variation in graphite. Examination of results indicates that moisture content has a predominate effect on the neutron multiplication factor, while variation in graphite content has a minor effect. The peak $k_{eff} + 2\sigma$ value occurs at saturated moisture and full graphite content.

Cases **ncsrsk_1_15** through **ncsrsk_10_15** (Appendix 6.9.6, Table 6.9.6-18a) model the 10 skull oxide compositions in a flooded containment vessel in a water reflected package. The $k_{eff} + 2\sigma$ values range from 0.641 to 0.745. Likewise, Cases **hcsrsk_1_15** through **hcsrsk_10_15** (Appendix 6.9.6, Table 6.9.6-18b) evaluate infinite arrays damage packages. The $k_{eff} + 2\sigma$ values ranging from 0.658 to 0.767 are not statistically significantly different from the NCT case results.

Cases **ncsrsk_9_1** through **ncsrsk_9_15** evaluate the bounding skull oxide content containing ~19.9 kg $U_3O_8$ and 921 g graphite, where the saturation moisture is varied from 0 to 3801 g water. Likewise, Cases **ncsrsk_10_1** through **ncsrsk_10_15** evaluate the skull oxide content containing ~20.8 kg $U_3O_8$ where the 921 g of graphite in the skull oxide is replaced with 726-g $^{235}U$ in the form of $U_3O_8$. The $k_{eff} + 2\sigma$ values range from 0.403 to 0.741 in the former set of cases and range from 0.404 to 0.746 in the latter set of cases. The $k_{eff} + 2\sigma$ values are well below the USL value of 0.925, indicating that canned spacers are not required for criticality control. Moreover, these results indicate that moisture content has a predominate effect on the neutron multiplication factor, while the graphite content has an insignificant effect.

### 6.4.4 UNH Crystals

UNH crystal content is to be packed in Teflon bottles, which may be placed in polyethylene bags. The Teflon bottles are not credited for containing the UNH crystal content. The 277-4 canned spacers are

not used in this packing configuration. Teflon is polytetrafluoroethylene (or polyethylene tetrafluoride) having a monomer formula of $C_2F_4$ with a melting point of ~280°C (536°F). Teflon will not melt at the much lower containment vessel inner wall temperatures associated with NCT and HAC. The use of Teflon and polyethylene packing material is conservatively represented by 500 g of polyethylene in the calculation model. UNH crystal content is not considered a "rigid" content like solid or broken HEU metal. Like HEU oxide content, the UNH crystal content is homogenized with the polyethylene.

Unlike the other HEU contents, UNH crystals are soluble in water. The most reactive content condition occurs at an optimum solution concentration derived from the UNH crystal loading and the volume of water flooding the containment vessel. Both flooding of the containment vessel and a reduced loading of UNH crystals going into solution is required to achieve the most reactive configuration.

Consider a flooded containment vessel with the UNH crystals in solution and no polyethylene. For Cases **cvcrunhct11_24_1** through **cvcrunhct11_1_1** (Table 6.9.6-14), the $k_{eff} + 2\sigma$ values range from 0.823 to 0.609 and optimum concentration occurs at ~9,000-g UNH (Case **cvcrunhct11_9_1**, $k_{eff} + 2\sigma = 0.857$). Consider a flooded containment vessel with a solution of UNH crystals homogenized with 500 g polyethylene. For Cases **cvcrpunhct11_24_15** through **cvcrpunhct11_1_15** (Table 6.9.6-14), the $k_{eff} + 2\sigma$ values range from 0.827 to 0.613 and optimum concentration occurs at ~10,000-g UNH (Case **cvcrpunhct11_10_15**, $k_{eff} + 2\sigma = 0.863$). The replacement of water with 500 g of polyethylene in the latter set of cases results in changes to the neutron multiplication factor on the order of ~0.004 to 0.006. The concentration for a 24,000 g loading in both set of cases is 1,106-g $^{235}U$ per liter of flooded containment vessel. In the calculation of the uranium concentration, the solution volume is not reduced by the volume of polyethylene because polyethylene is homogenized with UNH in the solution.

For Cases **cvcrpunhct11_24_1** through **cvcrpunhct11_1_1** (Table 6.9.6-14), the homogenized UNH crystals and polyethylene are dispersed over a dry containment vessel. The $k_{eff} + 2\sigma$ values range from 0.769 to 0.251 as the mass loading decreases. Comparison with results for corresponding Cases **cvcrpunhct11_24_15** through **cvcrpunhct11_1_15** for a flooded containment vessel reveals that the most reactive content condition occurs for UNH in the solution state.

For Cases **cvcrbpunhct11_24_15** through **cvcrbpunhct11_1_15** (Table 6.9.6-14), homogenized UNH crystals and polyethylene are settled on the bottom of the containment vessel and the residual volume above it is flooded. The $k_{eff} + 2\sigma$ values range from 0.817 to 0.553 as the mass loading decreases. For Cases **cvcrbpunhct11_24_1** through **cvcrbpunhct11_1_1**, the residual volume above the content is dry. Likewise, the $k_{eff} + 2\sigma$ values range from 0.815 to 0.478 as the mass loading decreases.

Comparison of results for corresponding Cases **cvdrpunhct11_*n*_1** and **cvcrbpunhct11_*n*_15** reveal greater changes in the $k_{eff}$ values occurring at the lower mass loadings when dispersed content is settled to the bottom of the containment vessel. Nevertheless, interspersed moderation has a dominant effect on $k_{eff}$ occurring when settled content goes into solution (Case **cvcrbpunhct11_10_15** vs Case **cvcrpunhct11_10_15**).

Similar to packages loaded with HEU metal, broken metal, or oxide, the neutron multiplication factor for a reflected single package with UNH crystals increases as a function of MOIFR. Consider the ES-3100 package loaded with bottles for a total of 24,000-g UNH crystals (11,303-g $^{235}U$). For Cases **ncsrunhct11_24_1_1** through **ncsrunhct11_24_1_15** (Table 6.9.6-15), the $k_{eff} + 2\sigma$ values range from 0.605 to 0.702 with increasing MOIFR in the water-reflected package. For Cases **ncsrpunhct11_24_1** and **ncsrpunhct11_24_15** (Table 6.9.6-15), the $k_{eff} + 2\sigma$ values range from 0.609 to 0.708 with increasing MOIFR in the water-reflected package. These cases confirm that the replacement of water with 500 g of polyethylene results in changes to the neutron multiplication factor on the order of ~0.004 to 0.006.

For a flooded containment vessel with UNH crystals in solution, the $k_{eff} + 2\sigma$ values range from 0.702 to 0.646 [Cases **ncsrunhct11_24_1_15** through **ncsrunhct11_2_1_15** (Table 6.9.6-15)]. Similarly, for a flooded containment vessel with a solution of UNH crystals homogenized with 500 g of polyethylene, the $k_{eff} + 2\sigma$ values range from 0.708 to 0.545 [Cases **ncsrpunhct11_24_15** through **ncsrpunhct11_1_15** (Table 6.9.6-15)]. At optimal concentration (~8,000-g UNH), the calculated $k_{eff} + 2\sigma$ value is 0.863 for Case **cvcrpunhct11_10_15** and $k_{eff} + 2\sigma = 0.753$ for Case **ncsrpunhct11_8_15**. The water-reflected containment vessel is more reactive than the water-reflected package; therefore, the result for Case **cvcrpunhct11_10_15** is reported [10 CFR 71.55(b)]. The result for Case **ncsrpunhct11_8_15** having the maximum $k_{eff} + 2\sigma$ value is reported for the NCT water-reflected package [10 CFR 71.55(d)].

Unlike solid HEU metal and oxide content, which are confined to the containment vessel and only water leakage into the containment vessel need be considered, the evaluation of UNH crystal content for compliance with 10 CFR 71.55(b) also requires that the leakage of liquid HEU contents out of the containment be addressed. This is because UNH crystals are soluble in water and would dissolve in the water flooding the containment vessel and the containment vessel well. For a content loading of 24,000-g UNH, the uranium concentration inside the containment vessel drops from 1,106-g $^{235}$U/L to 710-g $^{235}$U/L. Optimum solution concentrations occurs for fissile mass loadings of ~15,000-g UNH. In the calculation of the uranium concentration, the solution volume is not reduced by the volume of polyethylene because polyethylene is homogenized with UNH in the solution.

Cases **hcsrpunhct12_8_15** (Table 6.9.6-15) and **icsrpunhct12_15_15** (Table 6.9.6-16) represent the HAC model of the damaged ES-3100 package where the outer dimensions of the package are reduced accordingly. For Case **hcsrpunhct12_8_15**, the dilution of the UNH crystals is confined to the containment vessel, and maximum reactivity occurs at ~8000-g UNH homogenized with 500 g polyethylene. For Case **icsrpunhct12_15_15**, UNH crystals are dissolved in the water flooding the containment vessel and the containment vessel well. The fissile material is uniformly distributed over the volume of the containment vessel and the well, but the polyethylene is confined to the containment vessel. Maximum reactivity occurs at ~15,000-g UNH. These single-unit cases with a MOIFR = 1.0 pertain specifically to the flooded drum under conditions specified in 10 CFR 71.55(e), where the $k_{eff} + 2\sigma$ values are 0.752 and 0.814 for this HAC condition. The result for Case **icsrpunhct12_15_15** having the maximum $k_{eff} + 2\sigma$ value is reported for the HAC water-reflected package [10 CFR 71.55(e)].

## 6.5 EVALUATION OF PACKAGE ARRAYS UNDER NORMAL CONDITIONS OF TRANSPORT

For the NCT array evaluation of ES-3100 packages, the package content is confined within the containment vessel, consistent with the result of the tests specified in §71.71 (Normal Conditions of Transport). The array sizes examined in this evaluation are infinite, 13×13×6, 9×9×4, 7×7×3, 5×5×2, ETP 27×3, and the degenerate single unit. The "N" and corresponding CSI values for arrays determined to be adequately subcritical are as follows: $N = \infty$, CSI = 0; N = 202, CSI = 0.3; N = 64, CSI = 0.8; N = 29, CSI = 1.7; and N = 16, CSI = 3.2. All arrays, except the infinite array, are reflected with 30 cm (1 ft) of water. These arrays are nearly cubic in shape for optimum array reactivity, thus eliminating the need for placing criticality controls on package arrangements in terms of stack height, width, and depth of an array. The array configurations and the range of water contents (Table 6.4) evaluated bound all possible packaging arrangements and moderation conditions for NCT.

### 6.5.1 Solid HEU Metal of Specified Geometric Shapes

For infinite and finite arrays of packages with HEU metal, the neutron multiplication factor increases as a function of the $^{235}$U mass and decreases as a function of MOIFR. For example, consider the ES-3100 package loaded with three convenience cans for a total of 36,000-g $^{235}$U where each can

contains a 3.24-in.-diam cylinder. For package content without 277-4 canned spacers, the $k_{eff} + 2\sigma$ values range from 1.027 to 0.963 with increasing MOIFR in the package [Cases **nciacyt11_36_1_1** through **nciacyt11_36_1_15** (Appendix 6.9.6, Table 6.9.6-3)]. For package content with 277-4 canned spacers, the $k_{eff} + 2\sigma$ values range from 0.957 to 0.880 with increasing MOIFR in the package [Cases **nciacyt11_36_2_1** through **nciacyt11_36_2_15** (Appendix 6.9.6, Table 6.9.6-3)].

The effect of increasing the water content of the array is straightforward. As interspersed water is added to the packages of an array, two reactivity effects occur in series. The first effect is the tendency for reactivity to remain constant due to controlled neutron interaction between the packages of the array. For an infinite array where neutrons cannot escape from the system, neutrons are scattered about the array. In the MOIFR range of 1E-20 to 1E-02, both the interspersed moderator inside the packages of the dry array and the interstitial moderator between the package drums of the array are not sufficient for neutron thermalization and absorption to occur in the adjacent packaging materials. However, hydrogen in the 277-4 provides moderation, and neutrons are absorbed in the interspersed boron of this neutron poison. This results in a subcritical system with near constant neutron multiplication factors over the range of MOIFR. The second effect is the tendency for reactivity to decrease due to internal moderation in packages of the array. The introduction of water above ~0.01 MOIFR shows the effect of isolating the individual array units from each other. The neutron multiplication factor approaches $k_{eff}$ for the single, water-reflected unit at a full-content water fraction (MOIFR = 1.0).

The array case with a water fraction of MOIFR = 1E-04 pertains specifically to packages under NCT where the Kaolite and recesses of the package external to the containment vessel do not contain any residual moisture. This NCT case is more reactive than all other NCT cases where more moisture is present in the Kaolite and recesses of the package. Interspersed water between the containment vessels in the array will reduce neutronic interaction between the flooded contents because neutrons are absorbed in the hydrogen of the water. As more water is added, the packages of the array become isolated, and array reactivity ($k_{eff} + 2\sigma = 0.880$, Case **nciacyt11_36_2_1**5) approaches the reactivity of the single unit ($k_{eff} + 2\sigma = 0.873$, Case **ncsrcyt11_36_2_1**5).

Repeated for 4.25-in.-diam cylinders (Appendix 6.9.6, Table 6.9.6-7); 2.29-in. -square bars (Table 6.9.6-5); and 1.5-in.-diam × 2-in.-tall slugs (Table 6.9.6-9), this type of analysis for the 3.24-in.-diam cylinders demonstrates that arrays of packages with restricted fissile material ($^{235}U$) loading remain subcritical over the entire range of water content or MOIFR. HEU metal or alloy content not covered by the specified geometric shapes (cylinder, square bar, or slug contents) will be in the HEU broken metal category, and so limited.

Cases **nciatriga_1_1_3** through **nciatriga_1_15_3** (Appendix 6.9.6, Table 6.9.6-20a) represent infinite arrays of packages containing the bounding TRIGA fuel content (20 % enrichment with 45 wt % U containing 307-g $^{235}U$), without 277-4 canned spacers. The MOIFR is set at 1.0E-04 such that neutronic interaction between packages is maximized. For these cases, the $k_{eff} + 2\sigma$ values increase from 0.218 to 0.525 as MOIFR increases. The $k_{eff} + 2\sigma = 0.525$ for Case **nciatriga_1_15_3** is substantially below the USL value of 0.925, indicating that canned spacers are not required for criticality control.

As stated in Sect. 6.4.1, 10 CFR 71.55(d)(2) requires the geometric form of a package's content not be substantially altered under the NCT. Similarly, 10 CFR 71.55(e)(1) requires that the package be adequately subcritical under HAC with the package contents in the most reactive credible configuration. Even though visible signs of damage to the metal convenience can have not been observed resulting from the regulatory tests, conclusions about damage to the TRIGA fuel content are not extrapolated from test data. The regulatory requirements are addressed by modeling the TRIGA fuel content in an extremely damaged condition. A series of criticality calculations is performed for making a determination of subcriticality. Cases **nciat55d2_1_1_3** through **ncia55d2_1_15_3** (Appendix 6.9.6, Table 6.9.6-20d)

represent TRIGA fuel content homogenized with variable density water over the free volume of the containment vessel. The packaging is flooded in each ES-3100 package of the infinite array. The variable density water ranges from the dry containment condition to the fully flooded condition. Credit for physical integrity of the content is not taken in this set of cases which model the substantially altered content. The calculation results in Table 6.9.6-20d indicate extremely damaged content (Case **nciat55d2_1_15_3** with $k_{eff} + 2\sigma = 0.716$) is more reactive than the unaltered configuration (Case **nciatriga_1_15_3** with $k_{eff} + 2\sigma = 0.442$). Nevertheless, both cases are adequately below the USL of 0.925 and the requirement of 10 CFR 71.55(d)(2) is satisfied. Given that changes external to the containment vessel due to the HAC do not result in an appreciable change in neutron multiplication for an array of packages, similar results are expected for the cases demonstrating compliance with 10 CFR 71.55(e)(1).

For TRIGA fuel content as clad fuel rods, the amount of cladding added (stainless steel as a neutron absorber or aluminum as a neutron scatter) and corresponding amount of water moderator displaced by the cladding is not expected to have a statistically significant affect on the calculated $k_{eff}$. Thus, the NCT shipping configuration model for disassembled TRIGA fuel (bare fuel meats) bounds shipping configuration model for TRIGA fuel configured as clad fuel rods (Appendix 6.9.3.1).

The array results for three slug configurations presented in Table 6.9.6-9 (Appendix 6.9.6) are for five or ten slugs touching or spaced apart in a pentagonal ring (Cases **ncia5st11** and **ncia5est11**) and for seven slugs formed by a hexagonal ring of slugs with one slug in the center of the ring **(ncia70st11**). These cases are used to establish the mass loading limitations, which in turn limit the number of slugs in the package to less than the number required to assemble a critical configuration.

Cases **ncia5est11_1_1_8_3** through **ncia5est11_1_1_1_3** (Appendix 6.9.6, Table 6.9.6-9) represent infinite arrays of packages containing 18,277-g U without 277-4 canned spacers. For these cases, the $k_{eff} + 2\sigma$ values increase from 0.550 to 0.924 as the enrichment is increased from 19.0 wt % to 100.0 wt % $^{235}$U. The $k_{eff} + 2\sigma$ value is 0.924 for Case **ncia5est11_1_1_8_3**, which is below the USL of 0.925. Likewise, the $k_{eff} + 2\sigma$ values for Cases **ncia5st11_1_1_8_3** through **ncia5st11_1_1_1_3** increase from 0.521 to 0.929 as the enrichment is increased. However, the $k_{eff} + 2\sigma$ value is 0.929 for Case **ncia5st11_1_1_8_3**, which is slightly above the USL of 0.925. For simplification of the criticality evaluation, the maximum enrichment is limited to 95% and the corresponding fissile mass limit is 17,374-g $^{235}$U. For Cases **ncia5st11_1_1_7_3** and **ncia5est11_1_1_7_3**, the $k_{eff} + 2\sigma$ values are below the USL. Moreover, the values are not statistically different.

Cases **ncia70st11_2_8_3** through **ncia70st11_2_1_3** (Appendix 6.9.6, Table 6.9.6-9) represent infinite arrays of packages containing 25,588-g U with 277-4 canned spacers. For these cases, the $k_{eff} + 2\sigma$ values increase from 0.473 to 0.915 as the enrichment is increased from 19.0 wt % to 100.0 wt % $^{235}$U. The $k_{eff} + 2\sigma$ value of 0.894 for Case **ncia70st11_2_7_3** at the 95% enrichment limit is adequately below the USL of 0.925.

Cases **ncia5est11_2_2_8_3** through **ncia5est11_2_2_1_3** (Appendix 6.9.6, Table 6.9.6-9) represent infinite arrays of packages containing 36,555-g $^{235}$U with 277-4 canned spacers. For these cases, the $k_{eff} + 2\sigma$ values increase from 0.583 to 0.983 as the enrichment is increased from 19.0 wt % to 100.0 wt % $^{235}$U. At 80 wt % $^{235}$U, the $k_{eff} + 2\sigma$ value (0.908) for Case **ncia5est11_2_2_5_3** with spaced-apart slugs is just below the USL. Similarly, Case **ncia5st11_2_2_5_3** with touching slugs has a calculated $k_{eff} + 2\sigma$ value of 0.902. Therefore, a restriction on mass and enrichment for slug content is that for $\leq$ 80 wt % $^{235}$U, the mass of $^{235}$U in the package must not exceed 29,318 g as a prerequisite for the shipment of the package slug content and with 277-4 canned spacers under a CSI = 0.0.

Cases **ncf15est11_2_2_8_3** through **ncf15est11_2_2_1_3** (Appendix 6.9.6, Table 6.9.6-9) represent a 13 × 13 × 6 array of packages containing 36,555-g $^{235}$U with 277-4 canned spacers for

which the corresponding rounded CSI = 0.4. For these cases, the $k_{eff} + 2\sigma$ values increase from 0.548 to 0.938 as the enrichment is increased from 19.0 wt % to 100.0 wt % $^{235}$U. Case **ncf15est11_2_2_7_3** at 95 wt % $^{235}$U with $k_{eff} + 2\sigma = 0.920$ is below the USL of 0.925 to permit increasing the limit on enrichment for mass loadings of ≤ 34.7 kg uranium metal.

The CSI determinations provided in this section are contingent upon satisfactory results under the HAC evaluation (Sect. 6.6.1).

### 6.5.2 HEU Broken Metal; Solid HEU Metal of Unspecified Geometric Shape and Characterized as Broken Metal; or Turnings, Fines, or Powder

The $^{235}$U (or U) evaluation limits listed in the column headings of Tables 6.1c and 6.1d represent the maximum amount of $^{235}$U (or U) permissible in a flooded, reflected containment vessel for maintaining an adequate margin of subcritically. These potential loading limits are taken into consideration for the determination of the fissile mass loading limit specified for a given CSI over a specified enrichment range. Under the subheading "Standards for arrays of fissile material packages (§ 71.59)," the fissile mass loading limits are identified for HEU broken metal in Table 6.1c and for HEU metal turnings, fines, or powder in Table 6.1d.

Consider the enrichment range >95 to 100 wt % $^{235}$U. Comparison of results in Table 6.9.6-10 for Case **cvr3lha_26_1_8_15** (broken metal without canned spacers) and for Case **cvr3lha_36_2_8_15** (broken metal with canned spacers) reveals a considerable increase in the fissile mass loading from 25,894-g to 35,142-g $^{235}$U is possible when 277-4 canned spacers are used. This result suggests the possibility of canned spacers not being required for certain packaging array configurations with broken metal. However, the comparison of results for Case **cvr3cha_8_1_8_15** without canned spacers and Case **cvr3cha_10_2_8_15** with canned spacers indicates only a minor increase from 7,398-g to 9,248-g $^{235}$U in the fissile mass loading of metal turnings, fines, or powder might be possible if 277-4 canned spacers are used. The evaluation of the NCT and HAC array configuration for establishing the CSI = 0 for the ES-3100 package with broken metal (Table 6.9.6-11) reveals that 277-4 canned spacers are required in packages with enrichments >80% (Cases **nciabmt11_4_1_5_3** and **hciabmt12_4_1_5_3**). This requirement for the presence of canned spacers extends to packages with HEU metal content in the form of turnings, fines, or powder. **However, credit for the presence of canned spacers required for criticality safety cannot be taken when determining the loading limits for HEU metal turnings, fines, or powder (Sect. 6.4.2). Therefore, HEU metal turnings, fines, or powder having enrichments >80% cannot be shipped in the ES-3100 package.**

Like arrays of packages with solid HEU metal shapes, the neutron multiplication factor for arrays of packages with HEU broken metal, turnings, fines, or powder decreases as a function of MOIFR and increases as a function of the $^{235}$U mass. Consider the ES-3100 package loaded with three convenience cans for a total of 35,142-g $^{235}$U and no canned spacers between content locations. The $k_{eff} + 2\sigma$ values range from 1.138 to 0.913 with increasing MOIFR [Cases **nciabmt11_36_1_8_1** through **nciabmt11_36_1_8_15** (Appendix 6.9.6, Table 6.9.6-11)]. The introduction of water above MOIFR = 0.01 shows the effect of isolating the individual array units from each other. Array reactivity ($k_{eff} + 2\sigma = 0.913$) approaches the reactivity of the water-saturated, water-reflected single package Case **ncsrbmt11_36_1_15** ($k_{eff} + 2\sigma = 0.891$).

In the series of calculations using the ES-3100 package model with NCT geometry (Cases **nciabmt11_1_*n*_*m*_3** through **nciabmt11_*36*_*n*_*m*_3**), the enrichment of the content is varied from 19 wt % to 100 wt % $^{235}$U. These array cases with a water fraction of MOIFR = 1E-04 pertain specifically to NCT packages where both the neutron poison of the body weldment liner inner cavity and the Kaolite are dry (in the as-manufactured condition) and both the recesses of the package external to the containment vessel and the interstitial space between the drums of the array do not contain any

residual moisture. As stated before, this NCT case is more reactive than all other NCT cases where more moisture is present in the Kaolite and recesses of the package. Increased interspersed water between the containment vessels in the array will reduce neutronic interaction between the flooded contents to a point where the packages of the array become isolated.

Evaluation of arrays of packages with HEU broken metal and canned spacers present. For enrichments <95 wt % $^{235}$U, the maximum amount of $^{235}$U permissible in a flooded ES-3100 package is 25,894-g $^{235}$U of the broken metal. With 277-4 canned spacers present in the NCT package, the potential fissile mass loading limit for broken metal with enrichments >95% to 100 wt % $^{235}$U and for a CSI = 0 must be limited to 2,774-g $^{235}$U (Case **nciabmt11_3_2_8_3**) in order for the $k_{eff} + 2\sigma$ value (= 0.904) to be below the USL of 0.925. Suitability of this 2,774-g $^{235}$U fissile mass loading limit for a CSI = 0, which is based on an infinite array of NCT packages, is contingent upon the infinite array of damaged packages also being adequately subcritical for HAC (Sect. 6.6.2).

The loading limits for solid HEU metal of unspecified geometric shape or for HEU broken metal are summarized in Table 6.2a based on array calculations performed using the uniform dispersal approximation "**cha**" model (Fig. 6.9.1-5d). The calculation results on which the determination of the loading limits is based are summarized in Table 6.1c.

As discussed in Appendix 6.9.1, the "**cha**" model is a first-order approximation model. The 500 g polyethylene representing the use of hydrogenous packing material is replaced with water in the flooded containment vessel. Broken metal and water is homogenized as a uranium "solution" and uniformly dispersed over the entire volume of the containment vessel. The vertical location of the 277-4 canned spacers inside the containment vessel is based on a fixed HEU packing fraction of ~0.59. The use of this large packing fraction results in minimum separation between canned spacers, which minimizes the size of the lower and middle content locations and maximizes the size of the upper content location. Reactivity of the containment vessel is driven by the oversized upper content location having a proportionately greater amount of fissile material. Conversely, the use of a small packing fraction (~0.2) in the "**cha**" model would result in greater separation between the canned spacers, which increases the size of the lower and middle content locations while reducing the size of the upper content location. Reactivity of the containment vessel would decrease as the proportions of fissile material in the content regions equalize. Calculations based on a packing fraction of ~0.59 bound similar cases based on lower packing fractions.

The "**cha**" model is characteristic of the situation where the dimensions of the broken metal pieces are sufficiently small to allow pieces of HEU to pass between the void spaces formed between the inner wall of the containment vessel and the exterior wall of the canned spacers.

As shown in Fig. 6.9.3.1-3, HEU broken metal content typically consists of irregular pieces, sufficiently large (0.5 in. to several inches on a side), that will not pass between the 277-4 canned spacer locations. The packing fraction calculation model "**fl**" and the dispersed content calculation model "**fd**" better represent broken metal content which does not pass between the canned spacer locations. Inside the containment vessel, the content locations between canned spacers are established based on a variable packing fraction for HEU broken metal ranging from 0.2 to 0.6. The 500 g polyethylene is included in the flooded containment vessel. HEU broken metal, polyethylene and water are homogenized as a uranium "solution" residing within the content locations (Figs. 6.9.1-5e and 6.9.1-5f) rather than distributed uniformly over the containment vessel (Fig. 6.9.1-5d). The "**fl**" model defines the upper content location based on packing fraction while the "**fd**" model defines the upper content location as the entire region above the upper canned spacer.

NCT cases for the "**fl**" and "**fd**" calculation models are documented in Table 6.9.6-11b. The reference case results based on the uniform dispersal approximation "**cha**" model are highlighted.

The corresponding cases for the packaging fraction ("**fl**") and for the dispersed content ("**fd**") calculation models are given in the rows below the reference case. Consider Case **nciabmt11_4_1_5_3** where the quantity of HEU content in the model is calculated based on a discrete number of 1-in. cubes. The HEU in corresponding Cases **nciapbmflt11_1_*n*_4_5** and **nciapbmfdt11_1_*n*_4_5** is not limited to fractional kilogram quantities based on whole cubes as in Case **nciabmt11_4_1_5_3**. Instead, the intended whole kilogram quantities of HEU are evaluated as a function of the packing fraction ("***n***") in the ". . . flt11_1_***n***_ . . ." and ". . . fdt11_1_***n***_ . . ." cases.

An increase of ~0.08 in the $k_{eff} + 2\sigma$ value is observed as the packing fraction is reduced and more water is homogenized with the fissile material, (i.e., Cases **nciapbmtfl11_1_6_4_5** through **nciapbmtfl11_1_2_4_5**, Table 6.9.6-11b). As the packing fraction is reduced and the volume of the content location increases accordingly, neutron multiplication increases due to increased moderation of the fissile material. A considerable increase of ~0.22 in the $k_{eff} + 2\sigma$ value is observed when fissile material in the upper can location is homogenized with water in the upper content location and dispersed over that region, (i.e., Case **nciapbmtfl11_1_6_4_5** vs Case **nciapbmtfd11_1_6_4_5**, Table 6.9.6-11b). Nevertheless, the $k_{eff} + 2\sigma$ values for the packaging fraction "**fl**" and dispersed content calculation "**fd**" models are lower than values for the corresponding uniform dispersal approximation "**cha**" model. The "**cha**" model evaluated without polyethylene bounds results for the more realistic "**fl**" and "**fd**" models evaluated with 500 g polyethylene and the HEU content of the package confined to the specific content locations.

Powder, particulate, or small pieces of HEU potentially present in broken metal are capable of passing between content locations. The quantity of this material, potentially present, represents a small fraction of the total HEU broken metal content. The placement of a limit on content size for criticality control is adopted as a package content loading restriction (Sect. 6.2.4, Item 6). Moreover, the loading limits for broken metal content established based on the "**cha**" model are retained, recognizing that the use of polyethylene is not addressed in "**cha**" model. Therefore, the only hydrogenous packing materials that can be used in the containment vessel when broken metal content is present are those that have a hydrogen density less than or equal to water (Sect. 6.2.4, Item 7).

Evaluation of arrays of packages with HEU broken metal, turnings, fines, or powder, and no canned spacers. For enrichments 70 to 80 wt % $^{235}U$, the maximum amount of $^{235}U$ permissible in a flooded ES-3100 package is 27,443-g $^{235}U$ for broken metal or 19,284-g $^{235}U$ for metal turnings, fines, or powder. Without 277-4 canned spacers present in the NCT package containing broken metal, turnings, fines, or powder, the potential fissile mass loading limit over the range 70 to 80 wt % $^{235}U$ and for a CSI = 0 must be 2,967-g $^{235}U$ (Case **nciabmt11_4_1_5_3**) in order for the $k_{eff} + 2\sigma$ value (0.921) to be below the USL of 0.925. Suitability of this 2,967-g $^{235}U$ fissile mass loading limit for a CSI = 0, which is based on an infinite array of NCT packages, is contingent upon an infinite array of damaged packages also being adequately subcritical for HAC (Sect. 6.6.2).

Repetitious use of the evaluation technique. This evaluation technique for determination of mass loading limits for enrichment intervals is repeated over the range of HEU enrichments identified in Tables 6.1c and 6.1d. At HEU enrichments ≤ 60 wt % $^{235}U$, the evaluated package mass loading limit of 35.32-kg uranium is achieved, so further delineation of fissile mass loading limits by g $^{235}U$ is not required.

### 6.5.3 HEU Oxide

Like packages with HEU metal or broken metal, the neutron multiplication factor for an NCT array of packages with HEU product oxide decreases as a function of decreasing $^{235}U$ mass [parametric Cases **nciapdoxt11_1_*n*_24_3**, **nciapdoxt11_1_*n*_20_3**, **nciapdoxt11_1_*n*_15_3**, **nciapdoxt11_1_*n*_12_3**, **nciapdoxt11_1_*n*_11_3**, and **nciapdoxt11_1_1_10_3** through **nciapdoxt11_1_1_6_3** (Table 6.9.6-13b)]. For these NCT cases, the MOIFR is set at 1.0E-04 such that neutronic interaction between packages of an array is maximized. Results for the parametric

cases reveal the same consistent increase in the $k_{eff} + 2\sigma$ values with decreasing bulk density as observed in the single package calculation results (Sect. 6.4.3). Results for Cases **nciapdoxt11_1_*n*_11_3** and **nciapdoxt11_1_1_10_3** through **nciapdoxt11_1_1_6_3** demonstrate that over the range of HEU oxide bulk densities from 6.54 to 2.0 g/cm$^3$, the $k_{eff} + 2\sigma$ values are below the USL of 0.925.

Cases **nciask_1_15** through **nciask_10_15** (Appendix 6.9.6, Table 6.9.6-18) evaluate infinite arrays of packages having the 10 skull oxide compositions described in Sect. 6.4.3. The MOIFR is set at 1.0E-04 such that neutronic interaction between packages is maximized. The $k_{eff} + 2\sigma$ values, ranging from 0.656 to 0.764, are substantially below the below the USL value of 0.925, indicating that canned spacers are not required for criticality control.

The CSI is 0.0 for an infinite array of packages having product oxide content with a bulk density ≥2.0 g/cm$^3$ and with a maximum of 9,682-g $^{235}$U or having skull oxide content with a maximum of 16,399-g $^{235}$U and 921 g graphite. The suitability of this determination is contingent upon satisfactory results under the HAC evaluation (Sect. 6.6.3).

### 6.5.4 UNH Crystals

Unlike the HEU metal, broken metal, or oxide content, UNH crystals are soluble in water (Sect. 6.4.4). The most reactive content condition occurs at an optimum solution concentration derived from the UNH crystal loading and the volume of water flooding the containment vessel. Both flooding of the containment vessel and a reduced loading of UNH crystals going into solution is required to achieve the most reactive configuration.

Similar to packages with HEU metal, broken metal, or oxide, the neutron multiplication factor for an array of packages with UNH crystals decreases as a function of increasing MOIFR. Cases **nciaunhct11_8_24_1_1** through **nciaunhct11_8_24_1_15** for content without polyethylene and Cases **nciapunhct11_24_1** and **nciapunhct11_24_15** for content with 500 g polyethylene (Table 6.9.6-15) reveal the effect of isolating the individual array units from each other with the introduction of water above ~0.01 MOIFR. Array reactivity ($k_{eff} + 2\sigma = 0.721$ without polyethylene and 0.729 with polyethylene) approaches the reactivity of the water-saturated, water-reflected single-unit package ($k_{eff} + 2\sigma = 0.702$ without polyethylene and 0.708 with polyethylene).

In a series of NCT calculations (Cases **nciapunhct11_*nn*_3**), the $k_{eff} + 2\sigma$ values are above the USL of 0.925 for mass loadings between 8,000 and 24,000-g UNH crystals. Credit is not taken for water tightness that is demonstrated by the NCT (and HAC) tests. Therefore, mass loading is limited to 7,000-g UNH crystals. The CSI is 0.0 [10 CFR 71.59(a)(1) and 10 CFR 71.59(b)] for ES-3100 packages having a maximum of 3,297-g $^{235}$U. The suitability of this determination depends upon satisfactory results under the HAC evaluation of Sect. 6.6.4 [10 CFR 71.59(a)(2) and 10 CFR 71.59(b)].

The $k_{eff} + 2\sigma$ values are expected to range from subcritical to critical for array configurations where UNH crystals are dissolved in the water flooding the containment vessel and the containment vessel well. This requires intrusion of water into the containment vessel, dissolving of UNH crystals in the influent, and leakage of solution out of the containment vessels in each package of an array (catastrophic failure of all packages in an infinite array). Given that loss of containment is deemed not credible by merit of the 10 CFR 71.71 and 10 CFR 71.73 tests performed on the ES-3100, this accident condition is not credible.

For Cases **ncf1punhct12_*nn*_3**, the $k_{eff} + 2\sigma$ values are below the USL of 0.925. Given that the results for NCT and HAC (Sect. 6.6.4) are adequately subcritical, packages may be shipped under a CSI = 0.4 for packages with a maximum of 24,000-g UNH crystals [10 CFR 71.59(a)(1) and

10 CFR 71.59(b)]. Likewise, the suitability of this determination depends upon satisfactory results under the HAC evaluation of Sect. 6.6.4.

## 6.6 EVALUATION OF PACKAGE ARRAYS UNDER HYPOTHETICAL ACCIDENT CONDITIONS

Except for UNH crystals, the package content is confined within the containment vessel for the HAC array evaluation of ES-3100 packages, consistent with the result of the tests specified in 10 CFR 71.73 (Hypothetical Accident Conditions). The array sizes examined in this evaluation are infinite, 13×13×6, 9×9×4, 7×7×3, 5×5×2, ETP 16×3, and the degenerate single unit. The "N" and corresponding CSI values for arrays determined to be adequately subcritical are as follows: N = ∞, CSI = 0; N =162, CSI = 0.4; N = 73, CSI = 0.7; N = 25, CSI = 2.0; and N = 24, CSI = 2.1. All arrays, except the infinite array, are reflected with 30 cm (1 ft) of water. These array are nearly cubic in shape for optimum reactivity of the array, thus eliminating the need for placing criticality controls on package arrangements in terms of stack height, width, and depth of an array. The array configurations and the range of water contents (Table 6.4) evaluated bound all possible packaging arrangements and moderation conditions for HAC.

For the single damaged package, and for infinite and finite arrays of damaged packages with HEU metal, HEU oxide, or UNH crystal content, the neutron multiplication factor changes as a function of the $^{235}U$ mass, MOIFR, or applicable solution concentration in the same manner as in an array of undamaged packages.

### 6.6.1 Solid HEU Metal of Specified Geometric Shapes

For infinite and finite arrays of damaged packages with HEU metal, the neutron multiplication factor increases as a function of the $^{235}U$ mass and decreases as a function of MOIFR. For example, consider the ES-3100 package loaded with three convenience cans that contain a 3.24-in.-diam cylinder with 12,000-g $^{235}U$ for a total of 36,000-g $^{235}U$. For package content without 277-4 canned spacers, the $k_{eff} + 2\sigma$ values range from 1.027 to 0.967 with increasing MOIFR in the damaged packages [Cases **hciacyct12_36_1_1** through **hciacyt12_36_1_15** (Appendix 6.9.6, Table 6.9.6-3)]. For package content with 277-4 canned spacers, the $k_{eff} + 2\sigma$ values range from 0.956 to 0.884 with increasing MOIFR in the damaged package [Cases **hciacyt12_36_2_1** through **hciacyt12_36_2_15** (Appendix 6.9.6, Table 6.9.6-3)].

The introduction of water above ~0.01 MOIFR shows the effect of isolating the individual array units from each other. The neutron multiplication factor approaches $k_{eff}$ for the single, water-reflected unit at a full content-water fraction (MOIFR = 1.0). Comparison of these results with the corresponding NCT cases (Sect. 6.5.1) indicates no significant differences. This result is as expected given that the neutron multiplication in an infinite array is independent of pitch between fissile contents but is dependent on changes in mass and moderation in the array. The changes in both the outer dimensions and the compositions of the Kaolite and 277-4 of the ES-3100 package due to HAC result in changes to the neutron multiplication factor on the order of ~0.001 to 0.002.

Repeated for 4.25-in.-diam cylinders (Appendix 6.9.6, Table 6.9.6-7); 2.29-in.-square bars (Table 6.9.6-5); and 1.5-in.-diam × 2-in.-tall slugs (Table 6.9.6-9), this type of analysis for the 3.24-in.-diam cylinders demonstrates that arrays of damaged packages with restricted fissile material ($^{235}U$) loading remain subcritical over the entire range of water content or MOIFR. HEU metal or alloy content not covered by the specified geometric shapes (cylinder, square bar, or slug contents) will be in the HEU broken metal category, and so limited.

Cases **hciatriga_1_1_3** through **hciatriga_1_15_3** (Appendix 6.9.6, Table 6.9.6-20) represent infinite arrays of damaged packages containing the bounding TRIGA fuel content (20 % enrichment with 45 wt % U containing 307-g $^{235}$U), without 277-4 canned spacers. For these cases, the $k_{eff} + 2\sigma$ values increase from 0.218 to 0.526 as MOIFR increases. The $k_{eff} + 2\sigma = 0.526$ for Case **hciatriga_1_15_3** is substantially below the USL of 0.925, indicating that canned spacers are not required for criticality control. Given that the results for NCT (Sect. 6.5.2) and HAC are adequately subcritical, packages with TRIGA fuel content ≤ 921-g $^{235}$U may be shipped under a CSI = 0.

As stated in Sect. 6.5.1, calculation results presented in Table 6.9.6-20d for an infinite array of ES-3100 packages (NCT packaging with extremely damaged TRIGA fuel content) is substantially below the USL of 0.925. Similar results are expected for an infinite array of ES-3100 packages (HAC packaging with extremely damaged TRIGA fuel content) given that changes external to the containment vessel due to the HAC do not result in an appreciable change in the neutron multiplication for the an array of packages. Therefore, the 10 CFR 71.55(e)(1) requirement that the package be adequately subcritical under HAC with the package contents in the most reactive credible configuration is satisfied.

The array results for three slug configurations presented in Table 6.9.6-9 (Appendix 6.9.6) are for five or ten slugs touching or spaced apart in a pentagonal ring (Cases **hcia5st12** and **hcia5est12**) and for seven slugs formed by a hexagonal ring of slugs with one slug in the center of the ring **(hcia70st12**). These cases are used to establish the mass loading limitations for damaged packages, which in turn limit the number of slugs in the package to less than the number required to assemble a critical configuration.

Cases **hcia5est12_1_1_8_3** through **hcia5est12_1_1_1_3** and Cases **hcia5st12_1_1_8_3** through **hcia5st12_1_1_1_3** (Appendix 6.9.6, Table 6.9.6-9) represent infinite arrays of damaged packages containing 18,277-g U without 277-4 canned spacers. Infinite array Cases **hcia70st11_2_8_3** through **hcia70st11_2_1_3** represent damaged packages containing 25,588-g U with 277-4 canned spacers while Cases **hcia5est12_2_2_8_3** through **hcia5est12_2_2_1_3** represent damaged packages containing 36,558-g U also with 277-4 canned spacers. Cases **hcf25est12_2_2_8_3** through **hcf25est12_2_2_1_3** represent a 9 × 9 × 4 array of damaged packages containing 36,558-g U with 277-4 canned spacers. The $k_{eff} + 2\sigma$ values for these cases representing arrays of damaged packages are slightly less than values for the corresponding cases representing undamaged packages. (The changes in both the outer dimensions of the package and the compositions of the Kaolite and 277-4 due to HAC result in an ~0.001 change in the neutron multiplication factor.) Therefore, the prospective CSI values determined in the NCT evaluation (Sect. 6.5.1) for arrays of undamaged packages with slug content are controlling.

### 6.6.2 HEU Broken Metal; Solid HEU Metal of Unspecified Geometric Shape and Characterized as Broken Metal; or Turnings, Fines, or Powder

The evaluation of various HAC array configurations for establishing the CSI for packages with broken metal (Table 6.9.6-11) reveals that 277-4 canned spacers are required in packages with enrichments >80%. As discussed in Sect. 6.4.2, credit for the presence of canned spacers required for criticality safety cannot be taken when determining the loading limits for HEU metal turnings, fines, or powder. Therefore, HEU metal turnings, fines, or powder having enrichments >80% cannot be shipped in the ES-3100 package.

Like arrays of packages with solid HEU metal shapes, the neutron multiplication factor for arrays of packages with HEU broken metal, turnings, fines, or powder decreases as a function of MOIFR and increases as a function of the $^{235}$U mass. Consider the ES-3100 package loaded with three convenience cans for a total of 35,142-g $^{235}$U with no canned spacers between content locations. The $k_{eff} + 2\sigma$ values range from 1.14 to 0.939 with increasing MOIFR, Cases **hciabmt12_36_1_8_1** through **hciabmt12_36_1_8_15** (Appendix 6.9.6, Table 6.9.6-11). The introduction of water above MOIFR = 0.01 shows the effect of isolating the individual array units from each other. Array reactivity

($k_{eff}$ + 2σ = 0.939) approaches the reactivity of the water-saturated, water-reflected single package ($k_{eff}$ + 2σ = 0.891, Case **hcsrbmt12_36_1_15**, Table 6.9.6-11).

Cases **hciabmt12_1_*nn_mm*_3** through **hciabmt12_36_*nn_mm*_3** model the ES-3100 with the reduced-diameter HAC package model where the enrichment of the content is varied from 60 wt % to 100 wt % $^{235}$U. These array cases with MOIFR = 1E-04 pertain specifically to HAC packages where the neutron poison of the body weldment liner inner cavity is at 90% moisture content, but the Kaolite is dry (in the as-manufactured condition), and neither recess of the package external to the containment vessel and the interstitial space between the drums of the array contains any residual moisture. As stated before, this HAC case is more reactive than all other HAC cases where more moisture is present in the Kaolite and recesses of the package. Increasing the interspersed water between the containment vessels in the array will reduce neutronic interaction between the flooded contents to a point where the packages of the array become isolated.

Evaluation of arrays of packages with HEU broken metal and canned spacers present. For enrichments < 95 wt % $^{235}$U, the maximum amount of $^{235}$U permissible in a flooded ES-3100 package is 25,894-g $^{235}$U in the broken metal. With 277-4 canned spacers present in the HAC package, the potential fissile mass loading limit for broken metal >95 to 100 wt % $^{235}$U and for a CSI = 0 must be limited to 2,774-g $^{235}$U (Case **hciabmt12_3_2_8_3**) in order for the $k_{eff}$ + 2σ value (= 0.905) to be below the USL of 0.925. Given that the results for NCT (Sect. 6.5.2) and HAC are adequately subcritical, packages ≤ 2,774-g $^{235}$U and enrichment >95 wt % $^{235}$U may be shipped under a CSI = 0.

The loading limits for solid HEU metal of unspecified geometric shape or for HEU broken metal are summarized in Table 6.2a based on array calculations performed using the uniform dispersal approximation "**cha**" model (Fig. 6.9.1-5d). The calculation results on which the determination of the loading limits is based are summarized in Table 6.1c.

As discussed in Sect. 6.5.2, criticality calculations with the "**cha**" model for a packing fraction of ~0.59 bound similar cases at the lower packing fractions. The "**cha**" model is characteristic of the situation where the dimensions of the broken metal pieces are sufficiently small to allow for HEU to pass between void space formed between the inner wall of the containment vessel and the exterior wall of each canned spacer.

As shown in Fig. 6.9.3.1-3, HEU broken metal content typically consists of irregular pieces, sufficiently large (0.5 in. to several inches on a side), that will not pass between the 277-4 canned spacer locations. The packing fraction calculation model "**fl**" and the dispersed content calculation model "**fd**" better represent broken metal content which does not pass between the canned spacer locations.

HAC cases are documented in Table 6.9.6-11c. The reference case results based on the uniform dispersal approximation "**cha**" model are highlighted. The corresponding cases for the packaging fraction ("**fl**") and for the dispersed content ("**fd**") calculation models are given in the rows below the reference case.

An increase of ~0.08 in the $k_{eff}$ + 2σ value is observed as the packing fraction is reduced and more water is homogenized with the fissile material (i.e., Cases **hciapbmtfl11_1_6_4_5** through **hciapbmtfl11_1_2_4_5**, Table 6.9.6-11c). As the packing fraction is reduced and the volume of the content location is increased, moderation of the fissile material increases. A considerable increase of ~0.22 in the $k_{eff}$ + 2σ value is observed when fissile material in the upper can location is homogenized with water in the upper content location and dispersed over that region (i.e., Case **hciapbmtfl11_1_6_4_5** vs Case **hciapbmtfd11_1_6_4_5**, Table 6.9.6-11c). Nevertheless, the $k_{eff}$ + 2σ values for the packaging fraction "**fl**" and dispersed content calculation "**fd**" models are lower than values for the corresponding uniform dispersal approximation "**cha**" model. The "**cha**" model evaluated without polyethylene bounds

results for the more realistic "**fl**" and "**fd**" models evaluated with 500 g polyethylene and the HEU content of the package confined to the specific content locations.

Powder, particulate, or small pieces of HEU potentially present in broken metal are capable of passing between content locations. The quantity of this material, potentially present, represents a small fraction of the total HEU broken metal content. The placement of a limit on content size for criticality control is adopted as a package content loading restriction (Sect. 6.2.4, Item 6). Moreover, the loading limits for broken metal content established based on the "**cha**" model are retained, recognizing that the use of polyethylene is not addressed in "**cha**" model. Therefore, the only hydrogenous packing materials that can be used in the containment vessel when broken metal content is present are those that have a hydrogen density less than or equal to water (Sect. 6.2.4, Item 7).

Evaluation of arrays of packages with HEU broken metal, turnings, fines, or powder, and no canned spacers. For enrichments >70 and ≤ 80 wt % $^{235}$U, the maximum amount of $^{235}$U permissible in a flooded ES-3100 package is 27,443-g $^{235}$U for broken metal or 19,284-g $^{235}$U for metal turnings, fines, or powder. Without 277-4 canned spacers present in the HAC package containing broken metal, turnings, fines, or powder, the potential fissile mass loading limit over the range >70 and ≤80 wt % $^{235}$U and for a CSI = 0 must be 2,967-g $^{235}$U (Case **hciabmt12_4_1_5_3**) in order for the $k_{eff} + 2\sigma$ value (0.925) to be at the USL of 0.925. Given that the results for NCT (Sect. 6.5.2) and HAC are adequately subcritical, packages ≤ 2,967-g $^{235}$U and enrichment >70 and ≤ 80 wt % $^{235}$U may be shipped under a CSI = 0.

Repetition of the evaluation technique. This evaluation technique for determination of mass loading limits for enrichment intervals is repeated over the range of HEU enrichments identified in Tables 6.1c and 6.1d. At HEU enrichments ≤ 60 wt % $^{235}$U, the evaluated package mass loading limit of 35.32-kg uranium is achieved, so further delineation of fissile mass loading limits by g $^{235}$U is not required.

### 6.6.3 HEU Oxide

Like packages with HEU metal or broken metal, the neutron multiplication factor for an array of HAC packages with HEU product oxide decreases as a function of decreasing $^{235}$U mass [parametric Cases **hciapdoxt11_1_*n*_24_3**, **hciapdoxt11_1_*n*_20_3**, **hciapdoxt11_1_*n*_15_3**, **hciapdoxt11_1_*n*_12_3**, **hciapdoxt11_1_*n*_11_3**, and **hciapdoxt11_1_1_10_3** through **hciapdoxt11_1_1_6_3** (Table 6.9.6-13b)]. For these HAC cases, the MOIFR is set at 1.0E-04 such that neutronic interaction between packages of an array is maximized. Results for the parametric cases reveal the same consistent increase in the $k_{eff} + 2\sigma$ values with decreasing bulk density as observed in the single package calculation results (Sect. 6.4.3). Results for Cases **hciapdoxt11_1_*n*_11_3** and **hciapdoxt11_1_1_10_3** through **hciapdoxt11_1_1_6_3** demonstrate that over the range of HEU oxide bulk densities from 6.54 to 2.0 g/cm$^3$, the $k_{eff} + 2\sigma$ values are below the USL of 0.925. Given that the results for NCT (Sect. 6.5.3) and HAC are adequately subcritical, packages may be shipped under a CSI = 0.0 for an infinite array of packages having product oxide with a maximum of 9,682-g $^{235}$U.

Cases **hciask_1_15** through **hciask_10_15** (Appendix 6.9.6, Table 6.9.6-18b) evaluate infinite arrays of damaged packages having the 10 skull oxide compositions described in Sect. 6.4.3. The differences between the HAC case results and the NCT case results are not statistically significant. The $k_{eff} + 2\sigma$ values, ranging from 0.658 to 0.767, are substantially below the USL value of 0.925. Given that the results for NCT (Sect. 6.5.3) and HAC are adequately subcritical, packages may be shipped under a CSI = 0.0 for an infinite array of packages having skull oxide content with a maximum of 16,399-g $^{235}$U and 921 g graphite.

### 6.6.4 UNH Crystals

Unlike the HEU metal, broken metal, or oxide content, UNH crystals are soluble in water (Sect. 6.4.4). The most reactive content condition occurs at an optimum solution concentration derived from the UNH crystal loading and the volume of water flooding the containment vessel. Both flooding of the containment vessel and a reduced loading of UNH crystals going into solution is required to achieve the most reactive configuration.

Similar to packages with HEU metal, broken metal, or oxide, the neutron multiplication factor for an array of damaged packages with UNH crystals decreases as a function of increasing MOIFR. Cases **hciaunhct12_8_24_1_1** through **hciaunhct12_8_24_1_15** for content without polyethylene and Cases **hciapunhct12_24_1** and **hciapunhct12_24_15** for content with 500 g polyethylene (Table 6.9.6-15) reveal the effect of isolating the individual array units from each other with the introduction of water above ~0.01 MOIFR. Array reactivity ($k_{eff} + 2\sigma = 0.729$ without polyethylene and 0.733 with polyethylene) approaches the reactivity of the water-saturated, water-reflected unit single package ($k_{eff} + 2\sigma = 0.704$ without polyethylene and 0.711 with polyethylene).

In a series of HAC calculations (Cases **hciapunhct11_*nn*_3**), the calculated $k_{eff} + 2\sigma$ values are below the USL of 0.925 for loading with <8,000-g UNH crystals. Given that the results for NCT (Sect. 6.5.4) and HAC are adequately subcritical, the CSI is 0.0 [10 CFR 71.59(a)(2) and 10 CFR 71.59(b)] for packages having a maximum of 3,297-g $^{235}U$.

The $k_{eff} + 2\sigma$ values are expected to range from subcritical to critical for array configurations where UNH crystals are dissolved in the water flooding the containment vessel and the containment vessel well. This requires intrusion of water into the containment vessel, dissolving of UNH crystals in the influent, and leakage of solution out of the containment vessels in each package of an array. The leakage out of the containment vessel of content moderated "to such an extent as to cause maximum reactivity consistent with the physical and chemical form of material" is not considered credible HAC based on results for tests specified in 10 CFR 71.73.

In a series of HAC calculations (Cases **hcf2punhct12_*nn*_3**), the calculated $k_{eff} + 2\sigma$ values are below the USL of 0.925. Given that the results for NCT (Sect. 6.5.4) and HAC are adequately subcritical, packages may be shipped under a CSI = 0.4 for packages with a maximum of 24,000-g UNH crystals.

## 6.7 FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT

A series of calculations is performed for determining the most reactive configuration of the content and surrounding packaging material in an ES-3100 package that undergoes catastrophic destruction. Fissile content mass loadings that remain under the USL for these catastrophic events are identified. Subcriticality is demonstrated after due consideration of such aspects as the efficiency of moderator, loss of neutron absorbers, rearrangement of packaging components and contents, geometry changes and temperature effects. The six calculation models used in this evaluation are described in Sect. 6.3.1.4. Key model dimensions and parameters are tabulated in Tables 6.9.6-21 through 6.9.6-23, Appendix 6.9.6.

### 6.7.1 Results for HEU Metal (Excluding TRIGA Fuel Elements)

In this section, "HEU metal" refers to HEU metal content of specified geometric shape (cylinder, bar, or slug), of an unspecified geometric shape (characterized as broken metal), or broken metal. The uranium is homogenized with hydrogenous packaging material and evaluated as a distinct lump ("fissile core") that is not mixed with other packing or packaging materials.

Cases **atdmr_10_8** through **atdmr_7_1** (Table 6.9.6-21, Appendix 6.9.6) pertain to Model 1 (Fig. 6.11, Sect. 6.3.1.4). HEU metal of three convenience cans is homogenized with 500 g of polyethylene, representing the potential use of hydrogenous packing materials in the ES-3100. The fissile core is configured into a spherical shape with an exterior 20 cm water reflector. As shown in Fig. 6.20 and Table 6.9.6-21, the $k_{eff} + 2\sigma$ values decrease as a function of both enrichment and $^{235}U$ mass. The $k_{eff} + 2\sigma$ values are substantially below the USL of 0.925. The $k_{eff} + 2\sigma$ value for 7 kg of HEU at 100 % enrichment is 0.791.

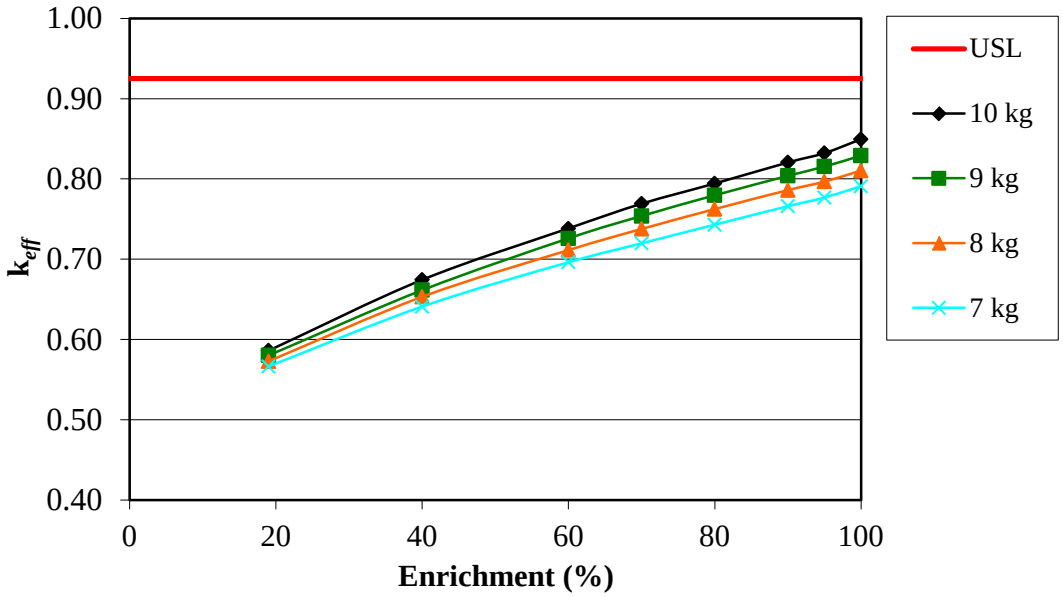



**Fig. 6.20. $k_{eff}$ vs enrichment (wt % $^{235}U$) for HEU ranging from 7 to 10 kg.**

Cases **atdmsr_7_8_11** through **atdmsr_7_1_1** (Table 6.9.6-21, Appendix 6.9.6) pertain to Model 2 (Fig. 6.12, Sect. 6.3.1.4). The fissile core of Model 1 is blanketed with a variable thickness stainless steel shell and an exterior 20 cm water reflector. As shown in Fig. 6.21 and Table 6.9.6-21, the maximum $k_{eff} + 2\sigma$ values occur at zero stainless steel thickness. The $k_{eff} + 2\sigma$ value for 7 kg of HEU at 100% enrichment and zero stainless steel thickness is 0.791. The $k_{eff} + 2\sigma$ values decrease to minimum values for steel thicknesses of 2.49 cm over the range of 100% enrichment to 19% enrichment while the NLF decreases from ~ 0.07 to 0.05. The NLF further decreases to a value of 0.03 as stainless steel is added up to the 66,133 g amount of the containment vessel, and the liner and drum assembly. At maximum stainless steel thickness, the $k_{eff} + 2\sigma$ values increase to within 0.02 of the values for zero stainless steel thickness. The stainless steel of the ES-3100 packaging is not as effective a reflector as the 20 cm water surrounding the core. The overall effect of adding the stainless steel of the ES-3100 packaging to the configuration is the reduction in the neutron multiplication factor for the system. The $k_{eff} + 2\sigma$ values are substantially below the USL of 0.925.

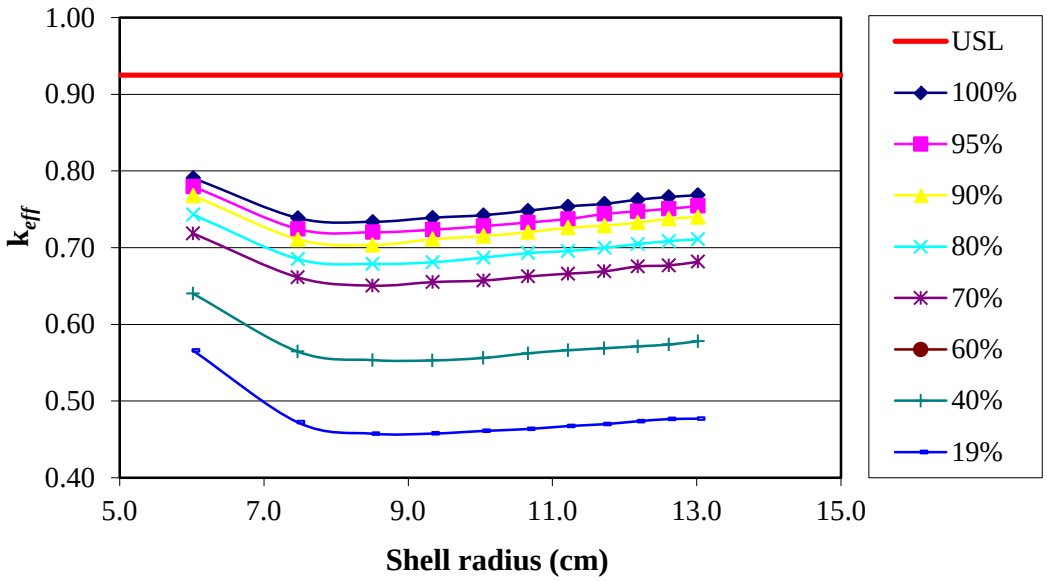



**Fig. 6.21. $k_{eff}$ vs stainless steel shell radius (cm) for 7 kg HEU with enrichments ranging from 19 to 100 wt % $^{235}$U.**

Cases **atdm15kr_7_8_6** through **atdm15kr_7_1_1** (Table 6.9.6-21, Appendix 6.9.6) pertain to Model 3 (Fig. 6.13, Sect. 6.3.1.4). The fissile core of Model 1 is blanketed with a variable thickness wet-Kaolite shell and an exterior 20 cm water reflector. As explained in Sect. 6.3.1.4, wet Kaolite to a maximum of 60,223 g consists of the dry Kaolite [51,214.9 g vermiculite-cement and 2,204.7 g bound water from inside the body weldment outer liner and the drum top plug] and up to 6,803.8 g free water—moisture which dampens the Kaolite and may also be present in the containment vessel well. As shown in Fig. 6.22 and Table 6.9.6-21, the maximum $k_{eff} + 2\sigma$ values at various enrichments occur at zero shell-thickness for the wet Kaolite. Consider the curve for 7 kg of HEU at 100 % enrichment where $k_{eff} + 2\sigma = 0.790$. At a shell radius of ~ 23 cm (24,089.2 g wet Kaolite with a shell thickness of ~ 17 cm), $k_{eff} + 2\sigma$ becomes quasi-asymptotic and the decrease in the NLF from ~ 0.07 to 0.05 is slight. With the addition of ~8.1 cm of wet Kaolite to the shell, the NLF decreases further from 0.05 to 0.04. The $k_{eff} + 2\sigma$ value decreases to a minimum value at a shell radius of 31.08 cm (60,223 g wet Kaolite with a steel thickness of 25.06 cm). In the range of 17 to 25 cm shell thickness, the quasi-asymptotic values for $k_{eff} + 2\sigma$ are ~ 0.04 below maximum $k_{eff} + 2\sigma$ values occurring at zero Kaolite thickness. To summarize, a significant drop in the neutron multiplication factor is observed for the addition of the initial 17 cm of wet-Kaolite shell to the fissile core, but an asymptotic value is not reached. With increasing build-up in the shell thickness, neutron multiplication decreases rather than increases, and the decrease in neutron leakage from the system is small. This behavior occurs because water at saturation levels, which is required for the Kaolite to act as a modest reflector, is not present in the wet Kaolite.

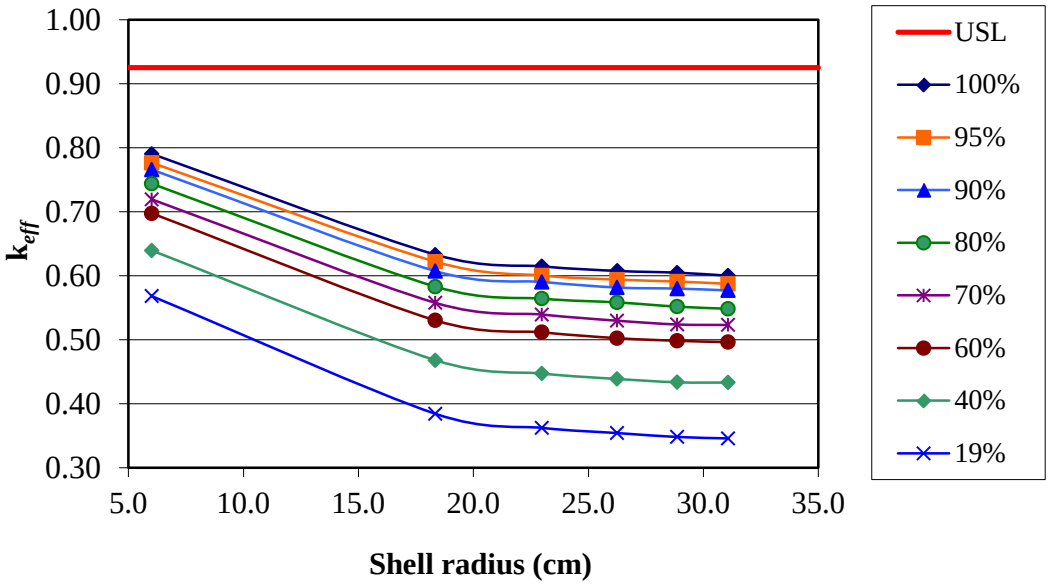



**Fig. 6.22. $k_{eff}$ vs wet Kaolite shell radius (cm) for 7 kg HEU with enrichments ranging from 19 to 100 wt % $^{235}U$.**

Cases **atdmdkr_7_8_6** through **atdmdkr_7_8_1** (Table 6.9.6-21, Appendix 6.9.6) pertain to Model 3 (Fig. 6.13, Sect. 6.3.1.4), where dry Kaolite is being evaluated consistent with test results of 10 CFR 71.55(d). As explained in Sect. 6.3.1.4, 53,419.1 g of dry Kaolite contained inside the body weldment outer liner and the drum top plug is NCT Kaolite (51,214.9 g vermiculite-cement and 2,204.7 g bound water). Only 7 kg of HEU at 100% enrichment is evaluated in the "atdmdkr" cases. As shown in Fig. 6.23 and Table 6.9.6-21, the behavior in $k_{eff} + 2\sigma$ for dry Kaolite where the value decreases to a minimum at a shell radius of 31.08 cm (shell thickness of 25.06 cm) is the same as for wet Kaolite. The $k_{eff} + 2\sigma$ values for the system with dry or wet Kaolite are substantially below the USL of 0.925. The decrease in NLF from ~ 0.07 to 0.05 for dry Kaolite is slightly less than from ~ 0.07 to 0.04 for wet Kaolite. The overall effect of adding dry or wet Kaolite to the system is the reduction in neutron multiplication in the system. NCT Kaolite of the ES-3100 packaging or wet Kaolite is not as effective a reflector as the 20 cm water surrounding the core. The absence of water in the Kaolite minimizes its effect.

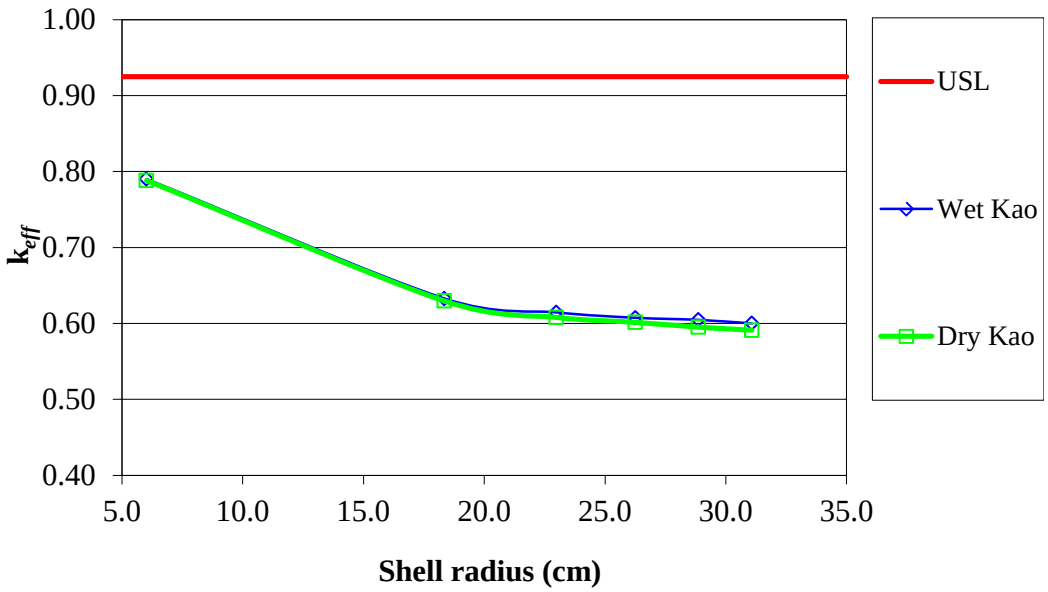



**Fig. 6.23. $k_{eff}$ vs shell radius for wet and dry Kaolite for 7 kg HEU at 100% enrichment.**

A uranium alloy is conservatively assessed when scattering media (aluminum or molybdenum) is treated as multiplying media ($^{235}U$) in the calculation models. Thus, limits established for HEU metal apply to the alloy.

### 6.7.2 Results for TRIGA Fuel Elements, Three Pieces per Convenience Can

Case **atdzr** pertains to Model 1 (Fig. 6.11, Sect. 6.3.1.4), in which 10.4 kg of $UZrH_x$ (921-g $^{235}U$) of three TRIGA fuel elements is homogenized with 500 g polyethylene. The fissile core is configured into a spherical shape with an exterior 20 cm water reflector. The $k_{eff} + 2\sigma$ value of 0.679 (Table 6.9.6-22a, Appendix 6.9.6) is substantially below the USL of 0.925. Similarly, Case **atdzr_70** pertains to Model 1, in which 6.85 kg of $UZrH_x$ (408-g $^{235}U$) of three TRIGA fuel elements is homogenized with 500 g polyethylene. The fissile core is configured into a spherical shape with an exterior 20 cm water reflector. The $k_{eff} + 2\sigma$ value is 0.682 (Table 6.9.6-22b, Appendix 6.9.6). The statistical difference between the $k_{eff} + 2\sigma$ values for Cases **atdzr** and **atdzr_70** is not significant.

Cases **atdzsr_11** through **atdzsr_1** pertain to Model 2 (Fig. 6.12, Sect. 6.3.1.4). The fissile core of Model 1 is blanketed with a variable thickness stainless steel shell with an exterior 20 cm water reflector. As shown in Fig. 6.24 and Table 6.9.6-22a (Appendix 6.9.6), the maximum $k_{eff} + 2\sigma$ value occurs at zero steel thickness. The $k_{eff} + 2\sigma$ value for 10.4 kg of $UZrH_x$ and zero stainless steel thickness is 0.678. The $k_{eff} + 2\sigma$ value decreases to minimum value for a stainless steel thickness of 1.87 cm while the NLF decreases from ~ 0.06 to 0.04. The NLF decreases to 0.03 as stainless steel is added up to the 66,133 g amount of the containment vessel and the liner and drum assembly. At maximum stainless steel thickness, the $k_{eff} + 2\sigma$ values increase to within 0.058 of the values for zero stainless steel thickness. The overall effect of adding stainless steel to the system is the reduction in neutron multiplication in the system. The $k_{eff} + 2\sigma$ values are substantially below the USL of 0.925.

Cases **atdzsr70_11** through **atdzsr70_1** for 6,847 g of $UZrH_x$ at 70% enrichment having 408-g $^{235}U$ also pertain to Model 2 (Fig. 6.12, Sect. 6.3.1.4). Case results (Table 6.9.6-22b, Appendix 6.9.6) manifest the same behavior as results for corresponding Cases **atdzsr_11** through **atdzsr_1** for 10.4 kg of $UZrH_x$ at 20% enrichment having 921-g $^{235}U$.

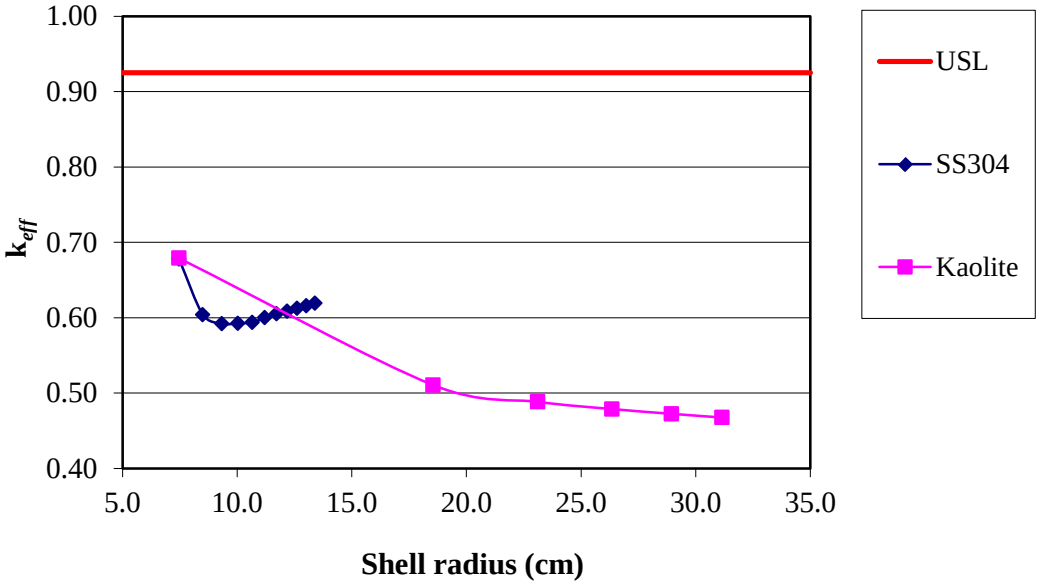



**Fig. 6.24. $k_{eff}$ vs shell radius (cm) for 10.4 kg core of $UZrH_x$ with stainless steel or wet Kaolite shell.**

Cases **atdz15kr_6** through **atdz15kr_1** pertain to Model 3 (Fig. 6.13, Sect. 6.3.1.4). The fissile core of Model 1 is blanketed with a variable thickness wet-Kaolite shell with an exterior 20 cm water reflector. As explained in Sect. 6.3.1.4, wet Kaolite to a maximum of 60,223 g consists of the dry Kaolite [51,214.9 g vermiculite-cement and 2,204.7 g bound water from inside the body weldment outer liner and the drum top plug] and up to 6,803.8 g free water—moisture which dampens the Kaolite and may also be present in the containment vessel well. As shown in Fig. 6.24 and Table 6.9.6-22a (Appendix 6.9.6), the maximum $k_{eff} + 2\sigma$ value occurs at zero shell-thickness for the wet Kaolite. The $k_{eff} + 2\sigma = 0.679$ for 10.4 kg of $UZrH_x$. At a shell radius of ~23 cm (24,089.2 g wet Kaolite with a shell thickness of ~ 17 cm), $k_{eff} + 2\sigma$ becomes quasi-asymptotic and the decrease in the NLF from ~ 0.06 to 0.05 is slight. With the addition of ~8.1 cm of wet Kaolite to the shell, the NLF decreases further from 0.05 to 0.04. The $k_{eff} + 2\sigma$ value decreases to a minimum value at a shell radius of 31.08 cm (60,223 g wet Kaolite with a steel thickness of 25.06 cm). The quasi-asymptotic values for $k_{eff} + 2\sigma$ are ~ 0.21 below the maximum $k_{eff} + 2\sigma$ value occurring at zero Kaolite thickness. To summarize, a significant drop in the neutron multiplication factor is observed for the addition of the initial 17 cm of wet-Kaolite shell to the fissile core, but an asymptotic value is not reached. With increasing build-up in the shell thickness, neutron multiplication decreases rather than increases, and the decrease in neutron leakage from the system is small. This behavior occurs because water at saturation levels, which is required for the Kaolite to act as a modest reflector, is not present in the wet Kaolite.

Dry Kaolite is consistent with test results of 10 CFR 71.55(d). As explained in Sect. 6.3.1.4, 53,419.1 g of dry Kaolite contained inside the body weldment outer liner and the drum top plug is NCT Kaolite (51,214.9 g vermiculite-cement and 2,204.7 g bound water). Demonstrated for HEU metal in Sect. 6.7.1, the behavior in $k_{eff} + 2\sigma$ where the value decreases to a minimum at a shell radius of 31.08 cm (shell thickness of 25.06 cm) is the same in dry Kaolite as for wet Kaolite. The overall effect of adding

dry or wet Kaolite to the system is the reduction in neutron multiplication in the system. NCT Kaolite of the ES-3100 packaging or wet Kaolite is not as effective a reflector as the 20 cm water surrounding the core. The absence of water in the Kaolite minimizes its effect. The $k_{eff} + 2\sigma$ values for Model 3 with dry or wet Kaolite are substantially below the USL of 0.925.

Cases **atdz15kr70_6** through **atdz15kr70_1** for 6,847 g of $UZrH_x$ at 70% enrichment having 408-g $^{235}U$ also pertain to Model 3 (Fig. 6.13, Sect. 6.3.1.4). Case results (Table 6.9.6-22b, Appendix 6.9.6) manifest the same behavior as results for corresponding Cases **atdz15kr_6** through **atdz15kr_1** for 10.4 kg of $UZrH_x$ at 20% enrichment having 921-g $^{235}U$.

Cases **athzp15kr_5** through **athzp15kr_1** pertain to Model 4 (Fig. 6.14, Sect. 6.3.1.4). The homogenized core consists of 10.4 kg of $UZrH_x$ at 19.7% enrichment having 921-g $^{235}U$, 500 g of polyethylene, and Kaolite. For this set of parametric cases, the Kaolite water content ranges from the wet condition (9,008.5 g water) to the dry condition (2,204.7 g water) [Table 6.9.6-22a, Appendix 6.9.6]. For Model 4, the overall radius at 31.1484 cm is constant for several reasons. First, the 500 g of polyethylene has a fixed volume. Second, the Kaolite is a porous material and its volume does not change appreciably as the material is dried out or absorbs water.

Cases **athzp15kr70_6** through **athzp15kr70_1** for 6,847 g of $UZrH_x$ at 70% enrichment having 408-g $^{235}U$ also pertain to Model 4 (Fig. 6.14, Sect. 6.3.1.4). While the $k_{eff} + 2\sigma$ values are lower, the results for these cases (Table 6.9.6-22b, Appendix 6.9.6) manifest the same behavior as corresponding Cases **athzp15kr_6** through **athzp15kr_1** for 10.4 kg of $UZrH_x$ at 20% enrichment having 921-g $^{235}U$.

As shown in Fig. 6.25 and Tables 6.9.6-22a and 6.9.6-22b, a gradual increase in $k_{eff} + 2\sigma$ occurs from dry condition to the wet condition. The homogenization of the Kaolite shell and the fissile material core from Model 3 produces two competing effects in Model 4:

- homogenization expands the fissile material core resulting in a decrease in neutron multiplication (from $k_{eff} + 2ó = 0.4675$ in Case **atdz15kr_6** to $k_{eff} + 2ó = 0.3577$ in Case **athzp15kr_5**), and

- the increase in the free water content of the Kaolite (and containment vessel well) increases neutron multiplication in the core (from $k_{eff} + 2ó = 0.3100$ in Case **athpz15kr_1** to $k_{eff} + 2ó = 0.3577$ in Case **athzp15kr_5**).

Consequently, the scenario of water penetration of fissile material core under Model 5 requires evaluation.

Cases **athzpw15kr_5** through **athzpw15kr_1** pertain to Model 5 (Fig. 6.15, Sect. 6.3.1.4). Model 5 is a variation of Model 3, which represents a fissile material core blanketed with wet Kaolite and reflected by 20 cm of water. In Model 5, excess water from the wet Kaolite shell is assumed to migrate into the homogenized core. The homogenized core consists of 10.4 kg of $UZrH_x$ at 19.7% enrichment having 921-g $^{235}U$, 500 g of polyethylene, and excess water from the wet Kaolite. The water content of the Kaolite shell ranges from the wet condition (9,008.5 g water) to the dry condition (2,204.7 g water) [Table 6.9.6-22a, Appendix 6.9.6]. As excess water migrates from the wet Kaolite shell into the homogenized core, the core radius expands from 7.4677 to 12.6903 cm. However, the volume of the Kaolite shell remains constant because the Kaolite is a porous material and its volume does not change appreciably as the material loses or gains water. Consequently, the overall radius of the system increases from 31.1484 to 31.6977 cm.

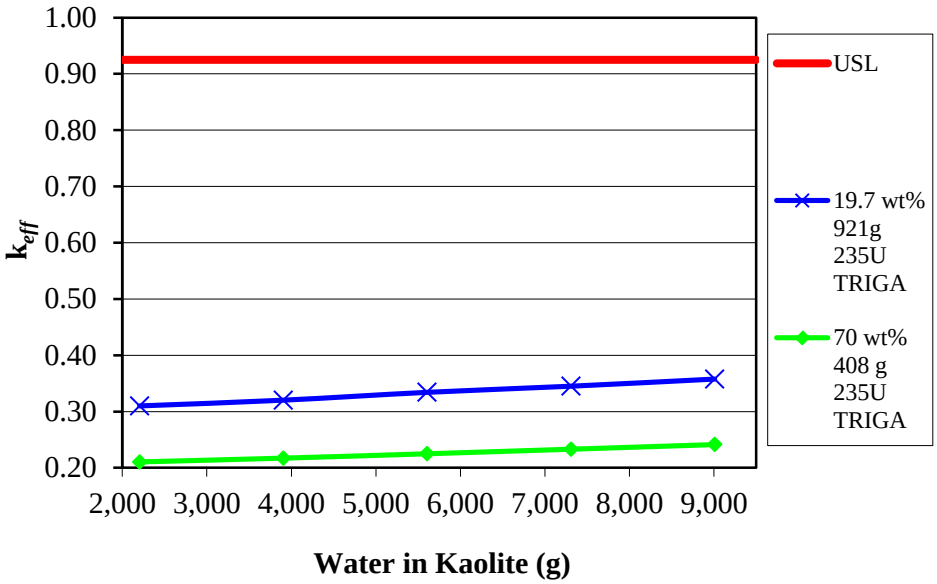



**Fig. 6.25. $k_{eff}$ vs water content (g) for homogenized core of $UZrH_x$, 500 g polyethylene and Kaolite where the Kaolite water content ranges from the dry to the wet condition.**

Cases **athzpw15kr70_6** through **athzpw15kr70_1** for 6,847 g of $UZrH_x$ at 70% enrichment having 408-g $^{235}U$ also pertain to Model 5 (Fig. 6.15, Sect. 6.3.1.4). While the $k_{eff} + 2\sigma$ values are lower, the results for these cases (Table 6.9.6-22b, Appendix 6.9.6) manifest the same behavior as corresponding Cases **athzpw15kr_6** through **athzpw15kr_1** for 10.4 kg of $UZrH_x$ at 20% enrichment having 921-g $^{235}U$.

As shown in Fig. 6.26 and Tables 6.9.6-22a and 6.9.6-22b (Appendix 6.9.6), the $k_{eff} + 2\sigma$ values increase to maximums of 0.8078 and 0.7215 with the addition of the entire 6,803.9 g of water from wet Kaolite into the fissile material core. The $k_{eff} + 2\sigma$ values are substantially below the USL of 0.925. The homogenized core is under moderated because sufficient water is not present in the wet Kaolite and containment vessel well to reach the point of optimum moderation. The total free water is conservatively evaluated up to 15 lb (6,803.9 g).

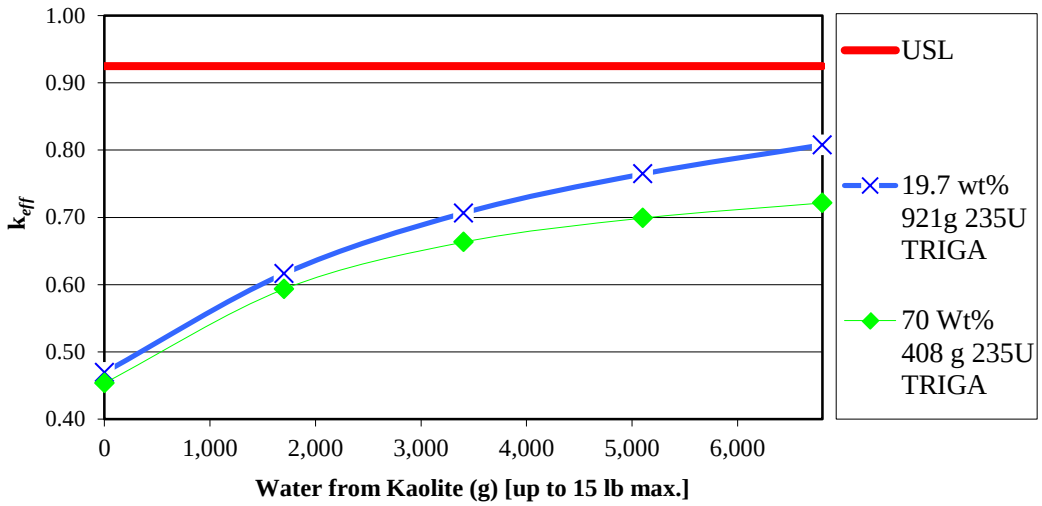



**Fig. 6.26. $k_{eff}$ vs excess water (g) from wet Kaolite for fissile core blanketed with a variable thickness Kaolite shell.**

In the absence of 10 CFR 71.55(f) test data or dynamic impact simulations per Type-C test criteria, the assumption of water penetration of the fissile material core is valid under the severe air transport evaluation criteria. Model 5 is applicable to air transport of the ES-3100 package given that the geometric form of the TRIGA fuel content following the air transport accident cannot be established.

Case results are presented in Table 6.9.6-22c (Cases **athopw15kr20_1** through **athopw15kr20_5**, Cases **athopw15kr70_1** through **athopw15kr70_5**, and Cases **athopw15kr93_1** through **athopw15kr93_5**) for $U_3O_8$-Al at the TRIGA content limits of 921-g $^{235}U$ for 20% enrichment and 408-g $^{235}U$ for 70% and 93.2% enrichments, respectively. As shown in Fig. 6.27 and Table 6.9.6-22c (Appendix 6.9.6), the $k_{eff} + 2\sigma$ values for $U_3O_8$-Al are exceeded by values for TRIGA content; therefore, the TRIGA loading limits are bounding for the research reactor related contents of $U_3O_8$ and $U_3O_8$-Al oxide.

Case results are presented in Table 6.9.6-22d (Cases **athupw15kr09_1** through **athupw15kr09_5**, Cases **athupw15kr20_1** through **athupw15kr20_5**, and Cases **athupw15kr93_1** through **athupw15kr93_5**) for $UO_2$-Mg in Al cladding at content limits of 921-g $^{235}U$ for 9.89% and 20% and 408-g $^{235}U$ for 93.2% enrichment, respectively. Cases **athbpw15kr93_1** through **athbpwskr93_5** for $UO_2$ are at content limits of 408-g $^{235}U$ for 93.2% enrichment. As shown in Fig. 6.28 and Table 6.9.6-22d (Appendix 6.9.6), the $k_{eff} + 2\sigma$ values for research reactor contents of $UO_2$-Mg or $UO_2$ exceed values for TRIGA content. These values are well below the USL; therefore, the TRIGA loading limits may be applied to the research reactor related contents of $UO_2$ and $UO_2$-Mg oxide.

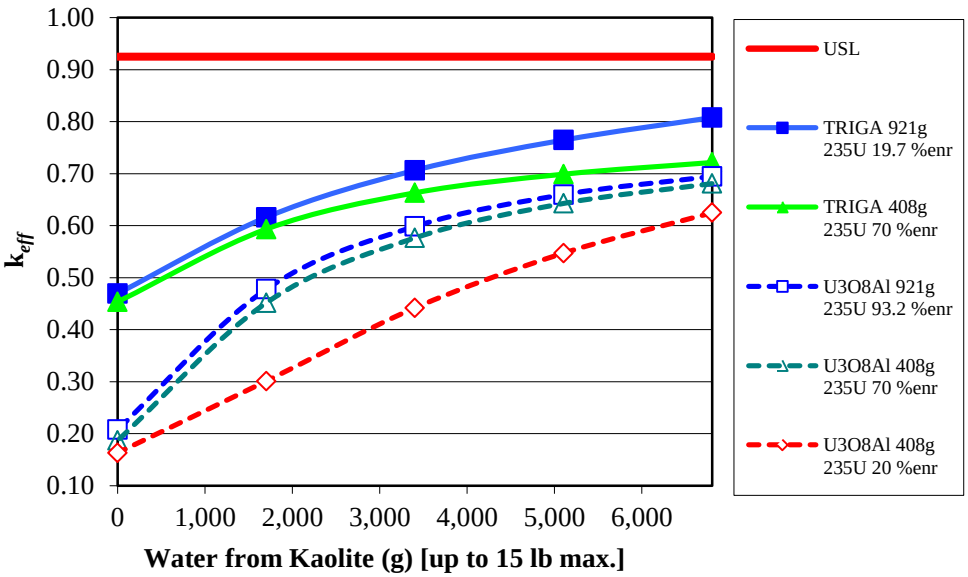



**Fig. 6.27. $k_{eff}$ vs excess water (g) from wet Kaolite for fissile material core blanketed with a variable thickness Kaolite shell.**

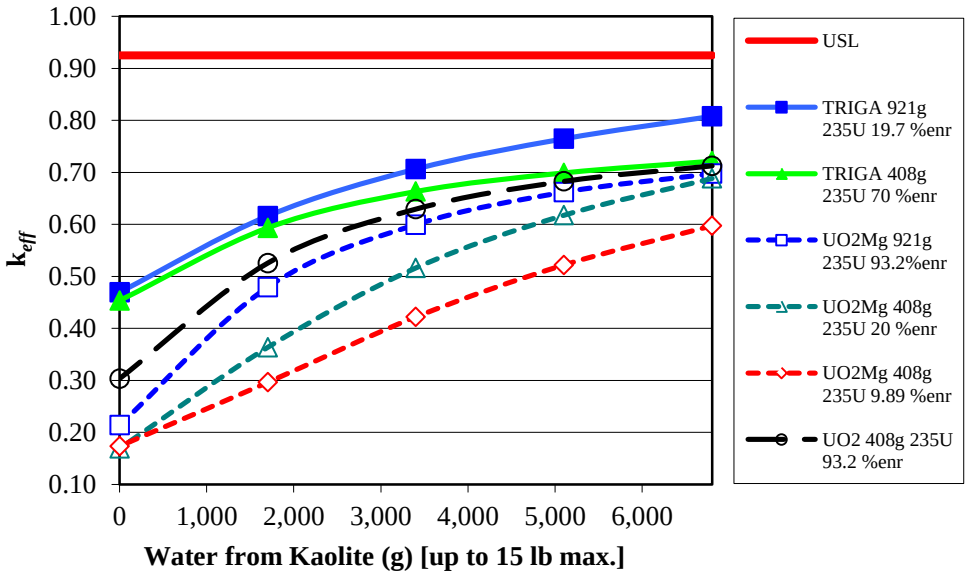



**Fig. 6.28. $k_{eff}$ vs excess water (g) from wet Kaolite for fissile material core blanketed with a variable thickness Kaolite shell.**

Model 6 (Fig. 6.16, Sect. 6.3.1.4) pertains to the case where fissile material from the homogenized core of Model 4 forms a shell external to the core. Given that the total amount of fissile material is limited to 921-g $^{235}U$, the quantity is not sufficient to form a critical configuration. As shown in Section 6.7.3, this is apparent even if kilogram quantities of additional fissile material were located in the shell adjacent to the core.

### 6.7.3 Results for HEU Broken Metal, Turnings, Fines, or Powder

The results for Models 1–3 presented in Sect. 6.7.1 address HEU metal evaluated as a fissile core uranium metal and hydrogenous packing material surrounded by but not mixed with other materials. Results for Models 4–6 presented in this section address HEU metal evaluated as a fissile core but where the integrity of the fissile core is lost. Preferential mixing of the fissile core with packing material (non-hydrogenous) and packaging material (stainless steel, Kaolite) is evaluated. Also, reconfiguration of the fissile core is evaluated. This evaluation addresses broken metal, metal turnings, fines, and powder. HEU oxide content for air transport is addressed in Appendix 6.9.9.

Cases **athmp15kr_12_8_5** through **athmp15kr_12_8_1** and Cases **athmp15kr_12_1_5** through **athmp15kr_12_1_1** (Table 6.9.6-23, Appendix 6.9.6) pertain to Model 4 (Fig. 6.14, Sect. 6.3.1.4). In the former set of cases, the homogenized core consists of 7 kg of HEU metal at 100% enrichment, 500 g of polyethylene, and Kaolite. In the latter set of cases, the homogenized core consists of 35 kg of HEU metal at 20% enrichment having 7 kg $^{235}U$, 500 g of polyethylene, and Kaolite. For these sets of parametric cases, the Kaolite water content ranges from the wet condition (9,008.5 g water) to the dry condition (2,204.7 g water) [Table 6.9.6-23, Appendix 6.9.6]. For Model 4, the overall radius is 31.0803 cm for homogenized core with 100% enrichment and is 31.2009 cm for homogenized core with 20% enrichment. The core radius is constant with changing moisture conditions for the following reasons. First, the 500 g of polyethylene has a fixed volume. Second, the Kaolite is a porous material and its volume does not change appreciably as the material is dried out or absorbs water.

As shown in Fig. 6.29 and Table 6.9.6-23, a gradual increase in the $k_{eff} + 2\sigma$ value occurs from the dry condition to the wet condition. The homogenization of the Kaolite shell and the fissile material core from Model 3 produces two competing effects in Model 4:

- homogenization expands the fissile material core resulting in a slight decrease in neutron multiplication (from $k_{eff} + 2ó = 0.6001$ in Case **atdm15kr_7_8_6** to $k_{eff} + 2ó = 0.5909$ in Case **athmp15kr_12_8_5**) and

- the increase in the free water content of the Kaolite (and containment vessel well) increases neutron multiplication in the core (from $k_{eff} + 2ó = 0.5024$ in Case **athmp15kr_1** to $k_{eff} + 2ó = 0.5909$ in Case **athmp15kr_5**).

Consequently, the scenario of water penetration of fissile material core under Model 5 requires evaluation.

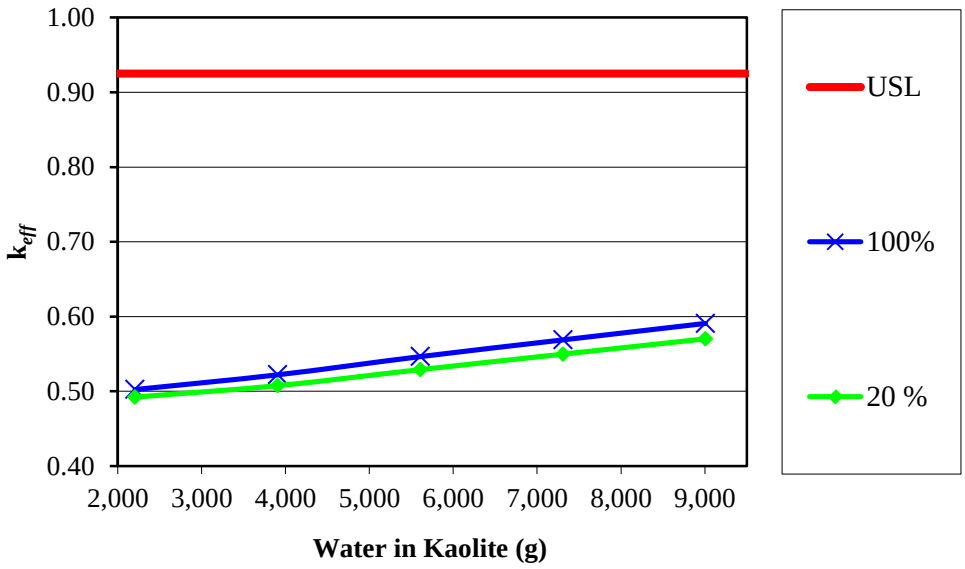



**Fig. 6.29. $k_{eff}$ vs water content (g) for homogenized core of HEU with 7 kg $^{235}U$, 500 g polyethylene, and Kaolite where the Kaolite water content ranges from the dry to the wet condition.**

Cases **athmpw15kr_12_8_5** through **athmpw15kr12_8_1**, Cases **athmpw13kr_12_8_5** through **athmpw13kr12_8_1**, and Cases **athzpw12kr70_5** through **athzpw12kr70_1** pertain to Model 5 (Fig. 6.15, Sect. 6.3.1.4). Model 5 is a variation of Model 3, which represents a fissile material core blanketed with wet Kaolite and reflected by 20 cm of water. In Model 5, excess water from the wet Kaolite shell is assumed to migrate into the homogenized core. In each set of cases, the homogenized core consists of HEU metal loading of 7 kg $^{235}U$ for uranium at 100% enrichment, 500 g of polyethylene, and excess water from the wet Kaolite. In the three sets of cases "**athmpw15kr**," "**athmpw13kr**," and "**athmpw12kr**," the corresponding amounts of free water for the wet condition are 15 lb (6,803.9 g), 13 lb (5,896.7 g), and 12 lb (5,443.1 g), respectively. For all of these sets of parametric cases, the water content of the Kaolite shell ranges from the wet condition (9,008.5 g water or 8,101.4 g or 7,647.8 g) to the dry condition (2,204.7 g water) [Table 6.9.6-23, Appendix 6.9.6]. As excess water migrates from the wet Kaolite shell into the homogenized core, the radius for either fuel type expands accordingly but the volume of the Kaolite shell remains constant. Consequently, the overall radius of the system increases. As stated previously, the 500 g of polyethylene has a fixed volume. Also, Kaolite is a porous material and its volume does not change appreciably as the material looses or gains water.

As shown in Fig. 6.30 and Table 6.9.6-23 (Appendix 6.9.6), the $k_{eff} + 2\sigma$ values increase to maximums of 0.9062, 0.9272, and 0.9596 with the addition to the fissile core of the entire 12 lb, 13 lb, and 15 lb amounts of free water from wet Kaolite. The homogenized core is under moderated because sufficient water is not present in the wet Kaolite and containment vessel well to reach the point of optimum moderation. However, $k_{eff} + 2\sigma$ exceeds the USL of 0.925 for those cases where the total free water is greater than 12 lb (5,443.1 g). This signifies the fissile mass loading limit for HEU is 7 kg $^{235}U$ and the range of excess water cannot exceed 12 lb from the Kaolite and the containment vessel well in order for the content to be shipped by air transport. Therefore, the evaluation of Model 6 is focused on this limit.

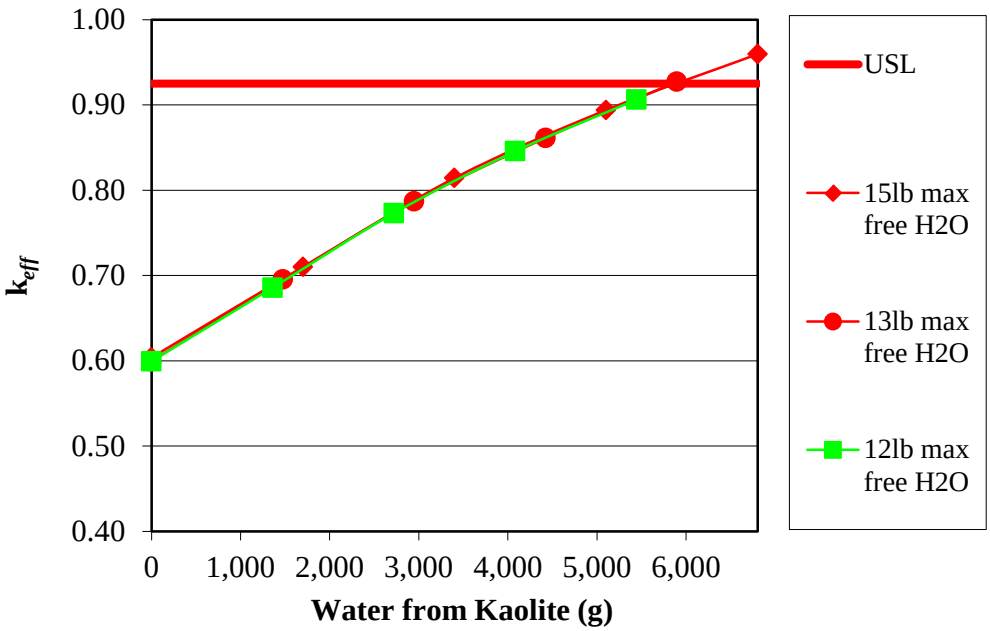
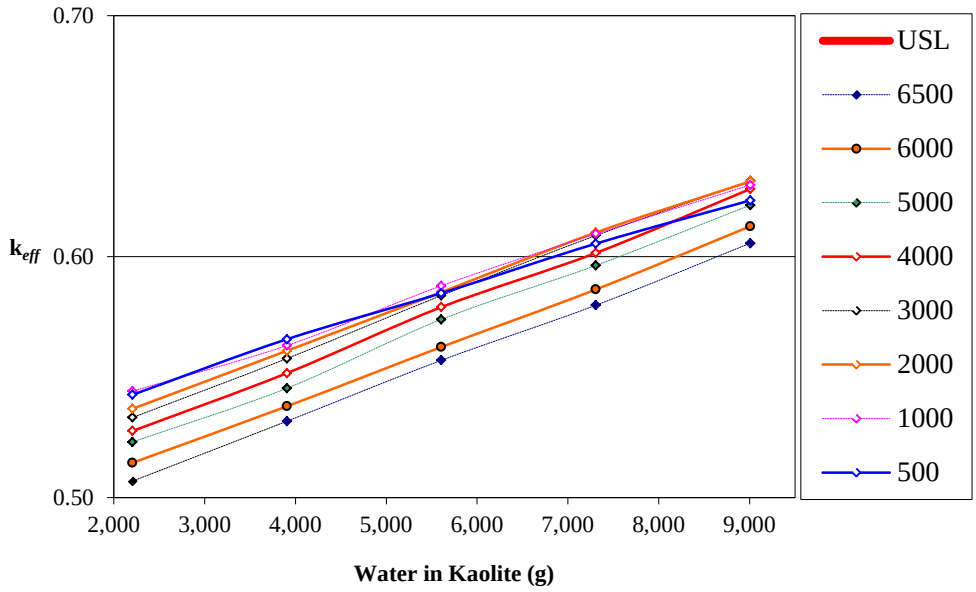



**Fig. 6.30. $k_{eff}$ vs excess water (g) from wet Kaolite for fissile core blanketed with a variable thickness Kaolite shell.**

Cases **athmp15kmr_13_1_8_5** through **athmp15kmr_1_13_8_1** (Table 6.9.6-23, Appendix 6.9.6) pertain to Model 6 (Fig. 6.16, Sect. 6.3.1.4), where fissile material from the homogenized core of Model 4 forms a shell external to the core. The homogenized core consists of HEU at 100% enrichment, 500 g polyethylene, and Kaolite. In a series of cases, the amount of HEU in the shell is varied from 500 g to 6,500-g $^{235}U$ in 500 g increments and the remainder of the 7 kg $^{235}U$ is contained in the homogenized core. For these sets of parametric cases, the Kaolite water content ranges from the wet condition (9,008.5 g water) to the dry condition (2,204.7 g water). As shown in Fig. 6.31, all $k_{eff} + 2\sigma$ values are adequately below the USL of 0.925.

As stated previously, uranium alloy is conservatively assessed when alloy constituents, such as aluminum, molybdenum, zirconium, stainless steel, titanium, tungsten, niobium, silicon, or vanadium, are modeled as $^{235}U$. Thus, limits established for HEU metal apply to the uranium alloys where the content mass of $^{235}U$ includes the mass of the non-uranium alloy constituents.




**Note:** Total quantity of HEU is 7-kg $^{235}U$ where the shell ranges from 500-g to 6,500-g $^{235}U$ and the remainder of the HEU is contained in the homogenized core.

**Fig. 6.31. $k_{eff}$ vs water (g) in Kaolite for homogenized core of HEU at 100% enrichment, 500-g polyethylene, and wet Kaolite encompassed by shell of $^{235}U$.**

### 6.7.4 Conclusions

Given that the results for catastrophic damage are adequately subcritical, ES-3100 packages may be shipped via air transport with:

- up to 7-kg $^{235}U$ HEU metal in the form of solid shapes (cylinders, bars, billets, buttons, or slugs), broken metal, metal turnings, fines, powder, or as an unspecified geometric shape (characterized as broken metal) unless a lesser amount is determined by ground transport consideration (Table 6.2a);
- up to 7-kg $^{235}U$ in HEU where the content mass of $^{235}U$ includes the mass of the non-uranium alloy constituents;
- three fuel sections ("meats") of $UZrH_x$ per loaded convenience can and up to three loaded cans per package where the $^{235}U$ does not exceed 921 g at 20% enrichment or 408-g $^{235}U$ at 70%;
- ~15-in.-long clad fuel rods, each rod derived from a single TRIGA fuel element, and where per package $^{235}U$ does not exceed 921 g at 20% enrichment or 408-g $^{235}U$ at 70%; or
- research reactor related contents of $U_3O_8$-Al, $UO_2$, and $UO_2$-Mg where the per package $^{235}U$ content does not exceed 921 g at enrichments less than or equal to 20% or 408-g $^{235}U$ at enrichments greater than 20%.

## 6.8 BENCHMARK EXPERIMENTS

### 6.8.1 Applicability of Benchmark Experiments

The criticality validation is specific to uranium, plutonium, and uranium-233 systems encompassing a substantial subset of the database used to prepare the Organization for Economic Cooperation and Development (OECD) Handbook, Volumes I–VI. The benchmark specifications are intended for use by criticality safety engineers to validate the application of criticality calculation techniques such as SCALE 4.4a. Example calculations presented in the handbook do not constitute a validation of the codes or cross-section data sets by themselves, but the Handbook information can be and has been used to validate SCALE 4.4a by competent nuclear criticality safety persons.

The data from the benchmark experiments involving uranium represent a sufficiently wide range of enrichments and physical and chemical forms to cover many existing or presently planned activities for Y-12. These include enriched uranium with $^{235}U$ only and natural and depleted uranium, as well as highly enriched uranium, intermediate enriched uranium, and low enriched uranium. Data analyzed from critical experiments in this validation include systems having fast, intermediate, and thermal neutron energy spectra, and they include materials in various physical and chemical forms such as uranium metals, solutions, and oxide compounds. With the benchmark experiments that are directly applicable to uranium systems, there is a high level of confidence that the calculated results presented in this evaluation are sufficiently accurate to establish the safety of the package under both NCT and HAC. This conclusion is based on the validation of the code and cross-section library described in Sect. 6.3.3.

### 6.8.2 Details of Benchmark Calculations

The validation of CSAS25 control module of SCALE 4.4a with the 238-group ENDF/B-V cross-section library is documented in Y/DD-896/R1 and Y/DD-972R1. Y/DD-896/R1 addresses the establishment of bias, bias trends, and uncertainty associated with the use of SCALE 4.4a for performance of criticality calculations. This evaluation is directed at uranium systems consisting of fissile and fissionable material in metallic, solution, and other physical forms, as well as plutonium and $^{233}U$ systems, as described in the OECD Handbook [NEA/NSC/DOC(95)03]. The focus is on comparison of $k_{eff}$ with the associated experimental results for establishment of bias, bias trends, and uncertainty as a final step. Compiled data for 1217 critical experiments are used as the basis for the calculation models. The calculated results from SCALE 4.4a using the 238-group ENDF/B-V cross-section library have been compared with reported results for the benchmark experiments. Comparison of results demonstrates that SCALE 4.4a run on the SAE HP J-5600 unclassified workstation (CMODB) produces the same results within the statistical uncertainty of the Monte Carlo calculations as reported by the OECD for the experiments.

Y/DD-972R1 addresses determining USL and for incorporating uncertainty and margin into this USL. Y/DD-972R1 establishes subcritical limits determined through an evaluation of statistical parameters of calculation results for critical experiments. The correlating parameters (i.e., mass, enrichment, geometry, absorption, moderation, reflection) and values for applying additional margin to the subcritical limits are application dependent. The determination of correlating parameters and additional margin is an integral part of the process analysis for a particular application. For the critical experiment results, no correlation between calculation results and neutron energy causing fission was found. As such, this document does not specify “final” USL values as has been done in the past.

### 6.8.3 Bias Determination

The USL is based on the non-parametric statistics-based lower tolerance limit (LTL) for greater than 0.99/99% where there is a probability of greater than 0.99 that 99% of the population is greater than

a specified result, reduced by additional margin. From Table 1 of Y/DD-972R1, the LTL combining bias and bias uncertainty is 0.975 for uranium systems, including HEU metal. Tables 4.2, 4.3, and 4.4 of Y/DD-896/R1 list the maximum (positive) and minimum (negative) biases for HEU (metal, compound, solution), IEU (metal, compound) and LEU (compound, solution) systems. Since the positive bias is conservatively treated as a "zero" bias in the validation analysis, the negative bias is applied to determine the USL for the systems. The minimum bias for the HEU, IEU, and LEU systems is given as −0.14356, −0.0055 and −0.0247, respectively.

The minimum result for the HEU systems is from one of four k-infinite models, which are somewhat different than the actual benchmark experiments. As discussed in Sect 5.3 of Y/DD-896/R1, four outlier results are for benchmark experiments that were modeled infinite in extent. The models required additional interpretation and adjustment form the actual finite experiment configuration to create an infinite benchmark model. After eliminating the outlier models from the bias determination, the minimum bias determined from data in Table 4.2 (Y/DD-896/R1) is −0.0203 for HEU systems.

The global minimum bias for these uranium systems [−0.0247 (conservatively rounded to −0.025)] is applied to all uranium enrichments. Ordinarily, the USL would be 0.955 where an additional margin of subcriticality of 0.02 is subtracted from the LTL of 0.975. However, NUREG/CR-5661 provides guidance that the USL should be established with a minimum margin of subcriticality of 0.05. Thus, the USL is equal to 0.95 plus the minimum bias (−0.025), giving a value of 0.925.

## 6.9 APPENDICES

6.9.1 Fissile Content and Packaging Models

6.9.2 HAC Package Model

6.9.3 Package Material Compositions

6.9.4 Qualification of a Neutron-absorber Material for the ES-3100

6.9.5 Miscellaneous Information and Data

6.9.6 Abridged Summary Tables of Criticality Calculation Results

6.9.7 Input Listings of ES-3100 Calculation Models for Select Cases

6.9.8 Criticality Evaluation of Additional/New Contents

6.9.9 Criticality Evaluation of HEU Oxide Product Content for Air Transportation

6.9.10 Analysis of HEU Oxide ($U_3O_8$) with Carbon Concentrations for Shipment in the ES-3100

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# Appendix 6.9.1

# Fissile Content and Packaging Models

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## Appendix 6.9.1

## Fissile Content and Packaging Models

Calculation model for solid HEU metal, 3.24-in.-diam cylinders. Figure 6.9.1-1 depicts the wire-mesh view of the 3.24-in.-diam highly enriched uranium (HEU) cylindrical content configuration inside the containment vessel. The interstitial water has been removed for illustration purposes. As can be seen from Fig. 6.9.1-1, the cylindrical content model contains one cylinder per convenience can and 1.4-in.-thick 277-4 canned spacers between the can locations. Cylinders are at the maximum diameter that will fit through the opening of a press-fit lid type convenience can. The cylindrical content shown is at the maximum mass loading; the height of the cylinders may change depending upon the mass loading. Figure 6.9.1-1b depicts a section view of the containment vessel with 3.24-in.-diam cylinders at 4.826 and 0.254 cm separation.

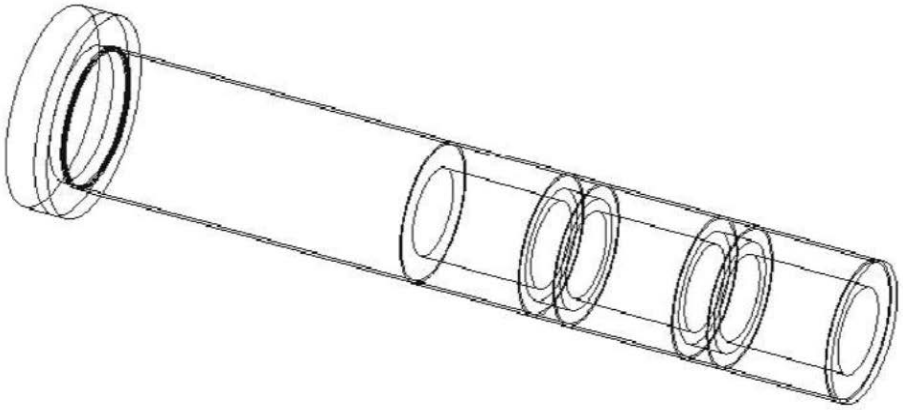


**Fig. 6.9.1-1. Containment vessel containing 3.24-in.-diam cylinders and 1.4-in.-thick 277-4 canned spacers.**

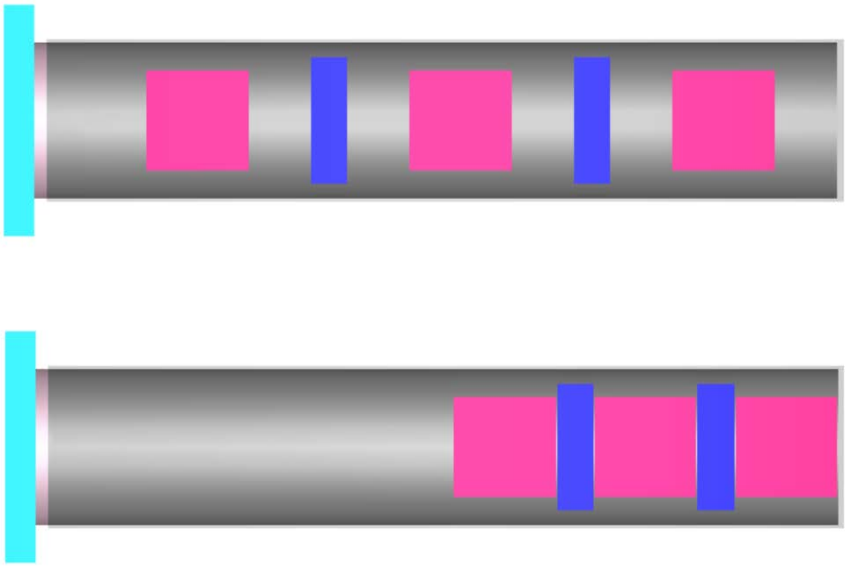


**Fig. 6.9.1-1b. Section view of the containment vessel depicting 4.826 and 0.254 cm separation distances for 3.24-in.-diam cylinders (pink) with 1.4-in.-thick canned spacers (blue).**

Calculation model for solid HEU metal, 4.25-in.-diam cylinders. Figure 6.9.1-2 depicts the wire-mesh view of the 4.25-in.-diam HEU cylindrical content configuration inside the containment vessel. The interstitial water has been removed for illustration purposes. As can be seen from Fig. 6.9.1-2, the cylindrical content model contains one cylinder per convenience can and 1.4-in.-thick 277-4 canned spacers between the can locations. Cylinders are at the maximum diameter that will fit through the opening of a crimp-seal lid type convenience can. The cylindrical content shown is at the maximum mass loading; the height of the cylinders may change depending upon the mass loading.

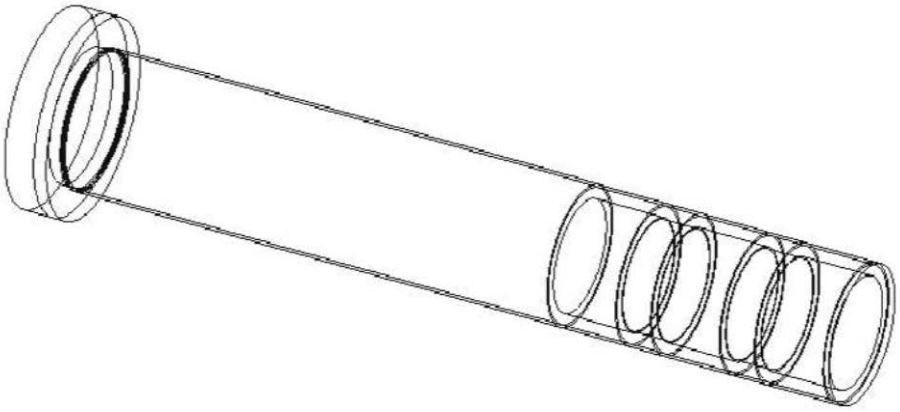


**Fig. 6.9.1-2. Containment vessel containing 4.25-in.-diam cylinders and 1.4-in.-thick 277-4 canned spacers.**

Calculation model for solid HEU metal, bars. Figure 6.9.1-3 depicts the wire-mesh view of the 2.29-in.-square HEU bar content configuration inside the containment vessel. The interstitial water inside the containment vessel has been removed for illustration purposes. The square bar content model contains one bar per convenience can and 1.4-in.-thick 277-4 canned spacers between the can locations. The 2.29-in.-square bar is the largest size that will fit through the 3.24-in.-diam opening of a press-fit lid type convenience can. Similar to the cylindrical model, the height of the square bar is dependent upon the HEU mass.

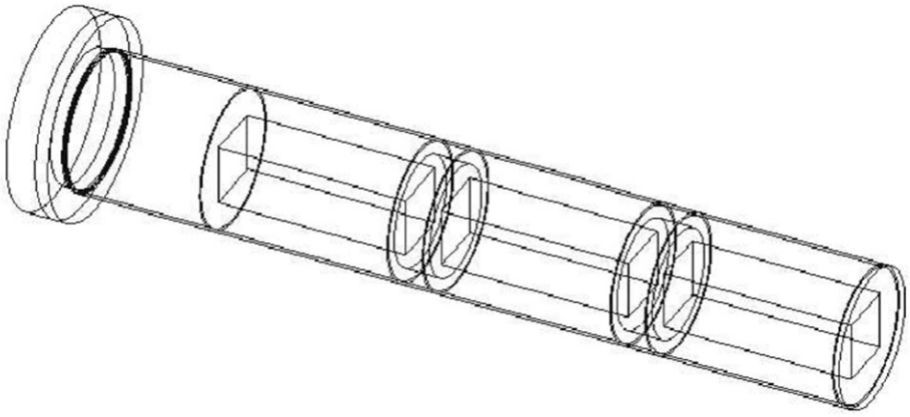


**Fig. 6.9.1-3. Containment vessel containing 2.29-in.-square bars and 1.4-in.-thick 277-4 canned spacers.**

Calculation model for solid HEU metal, slugs. Figure 6.9.1-4 depicts the wire-mesh view of a pentagonal ring configuration of the 1.5-in.-diam × 2.0-in.-tall slugs inside the containment vessel. The axial centerline of each slug is located 1.27598 in. from the origin of the pentagon such that a tight fitting configuration of slugs is modeled (i.e., there are no gaps between adjacent slugs). The slug content model contains two rings of the 1.5-in.-diam × 2.0-in.-tall slugs per convenience can and the 277-4 canned spacers between the convenience cans locations. The interstitial water inside the containment vessel has been removed for illustration purposes. Figure 6.9.1-4b depicts typical slug configurations that were evaluated.

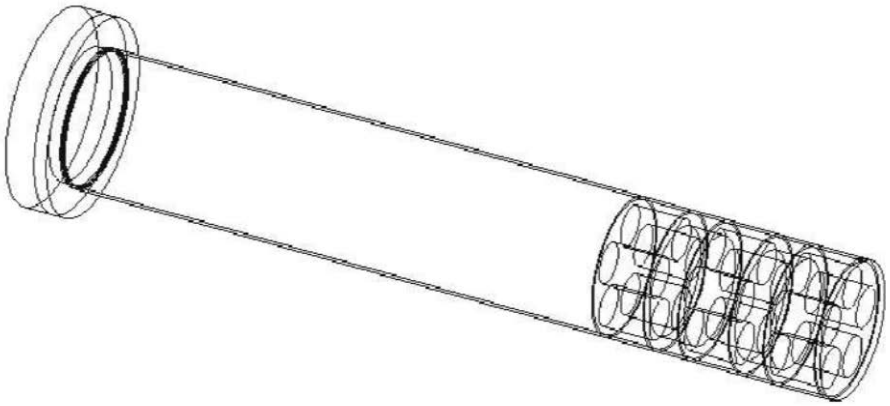
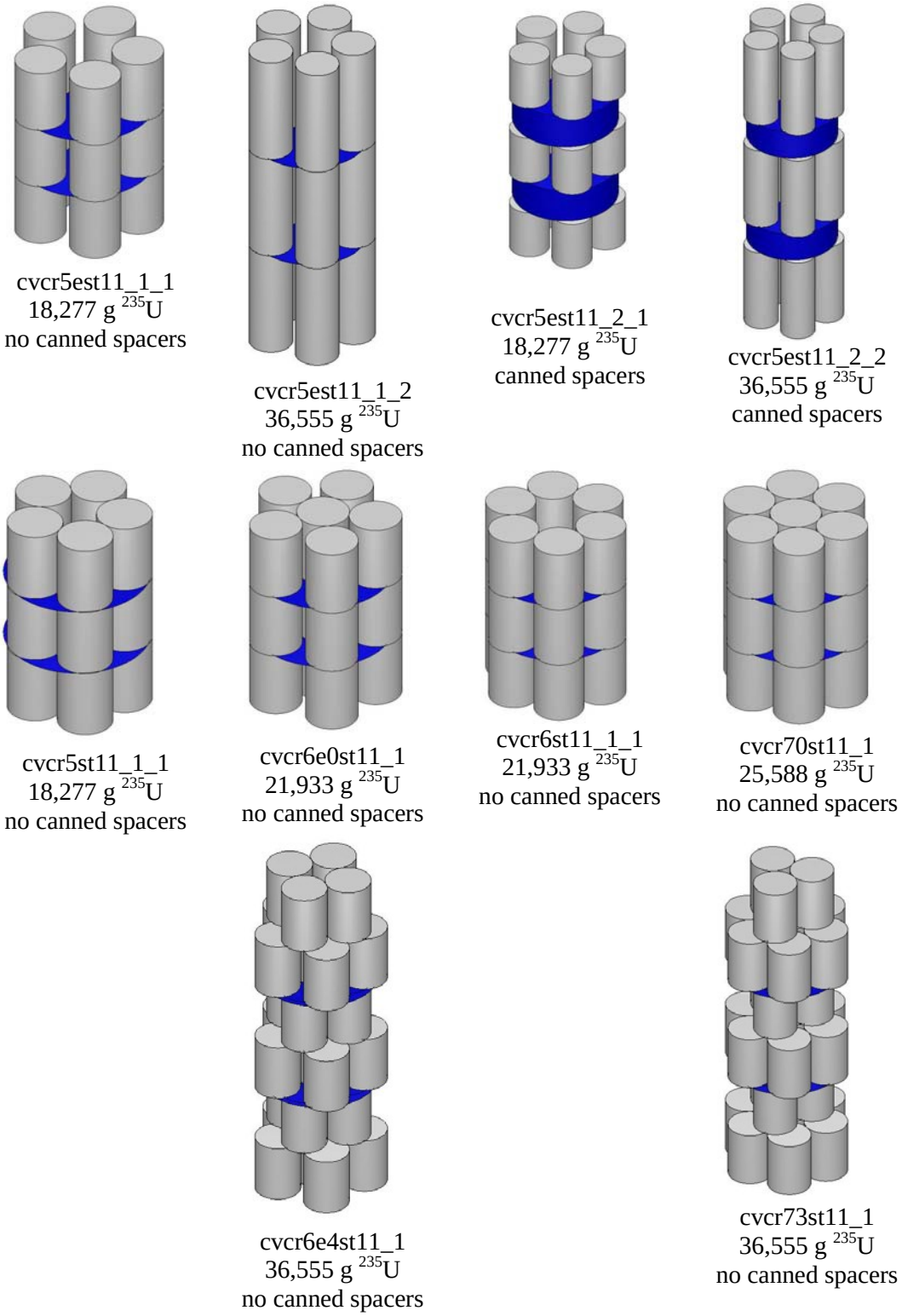


**Fig. 6.9.1-4. Containment vessel containing the 1.5-in.-diam × 2.0-in.–tall slugs in a pentagonal ring configuration with 0.0-cm spacing between slugs and 1.4-in.-thick 277-4 canned spacers.**

A 1.5-in.–diam × 2.0-in.–tall slug was modeled with a maximum tolerance of 1/16 in. applied to both the radius and height. The resulting dimensions are 1.984375 cm in radius and 5.23875 cm in height; the calculated volume of a single slug is 64.80746 $cm^3$. For 100% enriched uranium (density = 18.81109 $g/cm^3$), the calculated mass of 15 slugs is 18,286.5 g. Subsequently, the radius of each slug was reduced by 0.0005 cm thus eliminating a geometry intersection error in KENO V.a which occurs when the hole option is used to place slugs into an encompassing piece of the geometry unit. In the case of a pentagonal ring with spaced-apart slugs (Case **cvcr5est11_1_1**, Fig. 6.9.1-4b), the calculated volume reported for 15 slugs in KENO V.a is 971.622 $cm^3$ and the corresponding mass is 18277.3 g or 1,218.5 g per slug. This reduction in mass of 0.6333 g per slug is insignificant when considering the mass of a slug is nominally 1,089 g.

The maximum tolerance slug was also used in other slug geometry configurations, such as, “cvcr5s”, “cvcr6e0s”, “cvcr6s”, “cvcr70s”, “cvcr6e4s”, and “cvcr73s” orientations shown in Fig. 6.9.1-4b. For the pentagonal geometry configuration with slugs stacked two high in a ring (Case **cvcr5est11_1_2** or **cvcr5st11_1_2**), the model volume and mass of the slugs are twice the values of the single ring (Case **cvcr5est11_1_1** or **cvcr5st11_1_1**). For a pentagonal geometry configuration with a central slug (“cvcr6e0s”) and the hexagonal geometry configuration (“cvcr6"), the calculated volume reported in KENO V.a is 1,165.95 $cm^3$ and the corresponding mass is 21,932.7 g. For a hexagonal geometry configuration with a central slug (“cvcr70s”), the calculated volume reported in KENO V.a is 1,360.27 $cm^3$ and the corresponding mass is 25,588.2 g. For the compact ten-slug-per-can configurations (“cvcr5est”, “cvcr5est”, “cvcr6e4s”, and “cvcr73s”), the calculated volume reported in KENO V.a is 1,943.24 $cm^3$, and the corresponding mass is 36,554.6 g.




**Note:** Blue marker depicted for configurations without 1.4-in.-thick 277-4 canned spacers.

**Fig. 6.9.1-4b. Isometric views for typical slug configurations.**

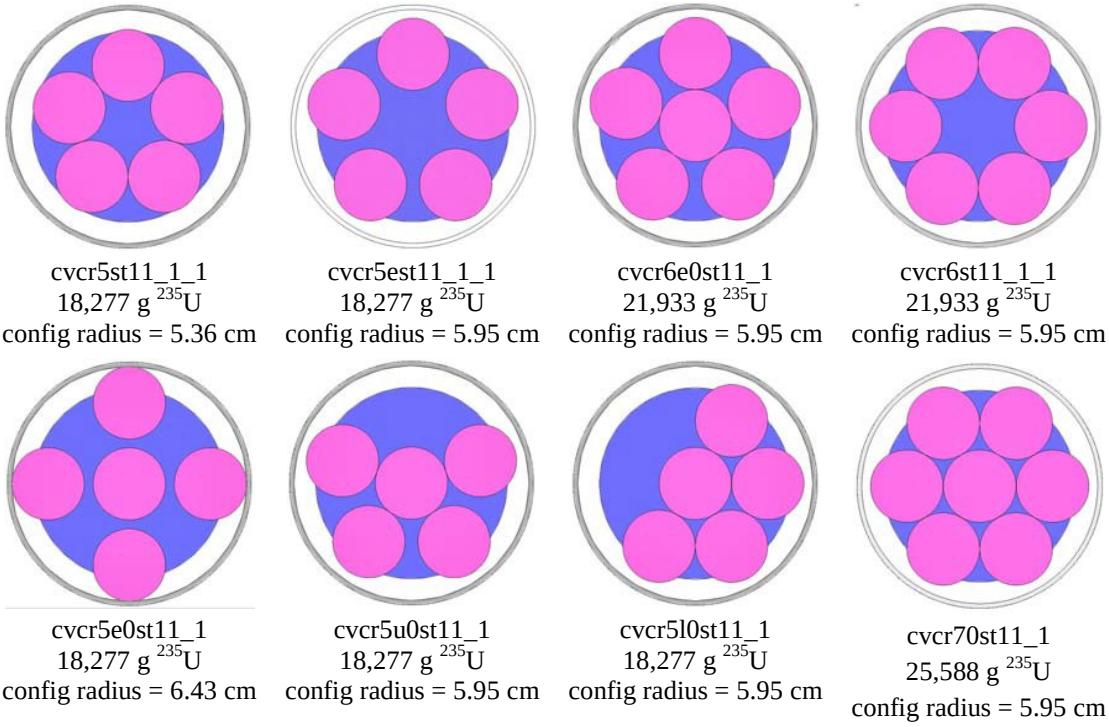
Several slug arrangements were evaluated for demonstrating that the most conservative arrangement of slugs has been analyzed. Figure 6.9.1-4c depicts radial section views of the containment vessel showing the slugs (pink) in relation to the footprint (blue) for a 4.25-in.–diam (5.3975-cm) convenience can. Cases **cvcr5st11_1_1**, **cvcr5est11_1_1**, **cvcr5e0st11_1**, **cvcr5u0st11_1**, and **cvcr5l0st11_1** depict different arrangements with five slugs per convenience can, three cans per package. Cases **cvcr6e0st11_1_1** and **cvcr6st11_1_1** depict arrangements with six slugs per convenience can, and Case **cvcr70st11_1** depicts seven slugs per convenience can. (Considerable deformation of a 4.25-in.–diam convenience can wall is required to achieve all but the simple pentagonal-ring arrangement of slugs.) The 277-4 canned spacers are not present in these calculation models.

Calculation models for solid HEU metal of unspecified geometric shapes characterized as broken metal. The intended use of the "broken metal" category is for shipment of solid HEU metal of unspecified geometric shape characterized as broken metal, packed in 4.25-in.-diam convenience cans where the packing fraction would not exceed 0.59. The packing fraction is a parameter which characterizes the volume that broken metal occupies. A typical broken metal content is depicted in Fig. 6.9.3.1-3 where the packing fraction for content in a convenience can ranges from 0.2 to ~0.6.

In the criticality evaluation of broken metal, convenience cans are not credited for containing the content nor for maintaining spacing between the 277-4 canned spacers. Consequently, the shape and size of the broken metal pieces establishes the separation between canned spacers which in turn determines the size of the HEU content locations inside the containment vessel. Given the irregular shape of broken metal, the packing fraction is the parameter which quantifies the volume of space that the broken metal occupies. The use of a large packing fraction (~0.6) results in minimum separation between canned spacers which minimizes the size of the lower and middle content locations and maximizes the size of the upper content location. Reactivity of the containment vessel is driven by the oversized upper content location. Conversely, the use of a small packing fraction (~0.2) results in greater separation between the canned spacers which increases the size of the lower and middle content locations while reducing the size of the upper content location. Reactivity of the containment vessel decreases accordingly.

The "**sqa**", "**lha**", and "**cha**" calculation models are devised for evaluating broken metal in the idealized forms described in the following paragraphs. The heights of the lower can locations and separation between the first and second 277-4 canned spacers inside the containment vessel are conservatively established on the basis that broken metal is confined within a rectangular lattice formed by the unit cells of fissile material having a packing fraction of ~0.59.

In the "sqa" model for HEU broken metal, a uniform-size metal cube is contained inside a unit cell of content. The unit cells are configured into arrays with one array for each can location inside the containment vessel. HEU metal cubes ranging in size from 1.0 to 0.25 in. are correspondingly arranged into 3 × 3, 6 × 6, or 12 × 12 configurations with ***N*** layers stacked vertically. A rectangular lattice of unit cells is defined by a square prism circumscribed by the wall of the containment vessel with an inner diameter of 5.06 in. (12.8524 cm). The width and depth of the square base is 3.57796 in. (9.08802 cm). The height of the lattice is determined by both the size of a cube and the number of layers of cubes required for a given HEU mass loading.




**Note:** Blue marker depicts 4.25-in.–diam wall of the convenience can.

**Fig. 6.9.1-4c. Plan view of slug configurations in the confines of the containment vessel.**

Figure 6.9.1-5 depicts a wire mesh view of the containment vessel and lid with three 12 × 12 × 18 arrays of HEU content separated by 277-4 canned spacers. Figure 6.9.1-5b depicts an isometric view of this same content with the **evaluation** water surrounding the HEU removed for illustration. The corner unit cells touch the inside wall of the containment vessel. The HEU cubes are centered within the individual unit cells and uniform spacing between cubes is modeled. The 277-4 canned spacers are modeled as cylindrical disks with dimensions of 4.13-in. diam × 1.37-in. height.

Uranium mass is reduced in the calculation model by removing one or more cubes from the array and filling these vacancies with water. The location of the 277-4 canned spacers between the arrays of cubes decreases as complete layers of cubes are removed from each array. The volume of the containment vessel above the top layer of the top array of cubes is filled with full-density water.

In the “lha” model of HEU broken metal, the metal cubes of the “sqa” model are homogeneously mixed with **evaluation** water within the square prism of the “sqa” model. Figure 6.9.1-5c depicts an isometric view of the “lha” model. The boundaries of each square prism shown in the figure are defined by the 12 × 12 × 18 array of unit cells of the explicit “sqa” model. Each prism contains the same mass of HEU and **evaluation** water that the respective explicit cube model contains. The volume outside the prisms and the canned spacers is filled with full density water.

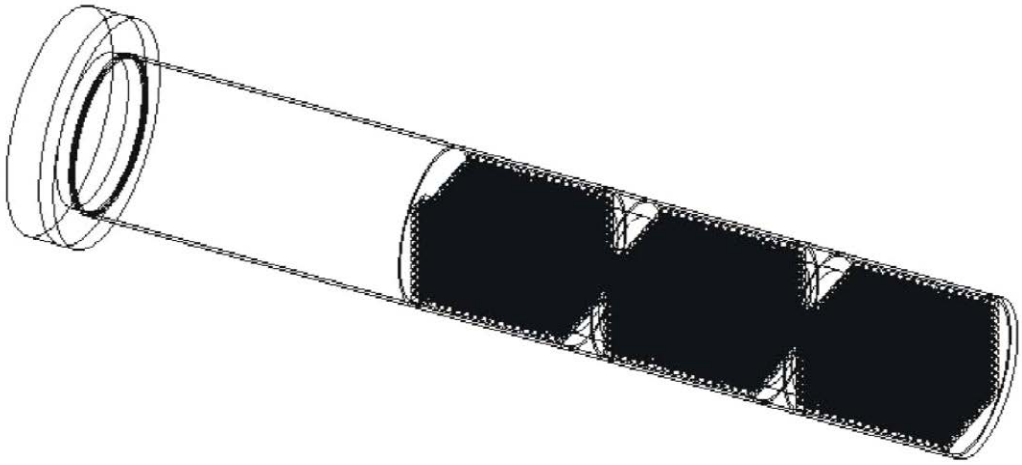


**Fig. 6.9.1-5. Wire mesh view of the "sqa" model with three 12 × 12 × 18 lattices of HEU broken metal as 1-in. cubes separated by 1.4-in. 277-4 canned spacers.**

In the "cha" model of HEU broken metal, the metal cubes of the "sqa" model are homogeneously mixed with the **evaluation** water within the free volume of the containment vessel. Figure 6.9.1-5d depicts an isometric view of the "cha" model. The 277-4 canned spacers are positioned for similarity with the "sqa" and "lha" models using the height of the prism, defined in this case by the 12 × 12 × 18 array of unit cells of the explicit "sqa" model. The mass of HEU and **evaluation** water of the explicit "sqa" model is preserved.

Once the locations of the canned spacers in the containment vessel are established based on the height of the square prism, the HEU broken metal and evaluation water inside the containment vessel are homogenized over the internal volume of the 12.8524-cm-diam containment vessel not being occupied by the canned spacers. The homogenization of fissile material with moderator to represent discrete solid HEU metal of unspecified geometric shape characterized as broken metal is unquestionably bounding only when the overall volume (and shape) containing HEU and interstitial moderator between the pieces of HEU is preserved in the approximation model.

In the "cha" model, the uniform dispersal of the homogenized HEU and evaluation water over the residual internal volume of the containment vessel has the effect of relocating $^{235}U$ from the two lower can locations into the upper can location. When the 277-4 canned spacers are present, the neutronic coupling of can locations is weak and the reactivity of the packaged content is determined by the reactivity of the largest can location. This model may not be conservative when canned spacers are absent because nothing would prevent settling of content inside the containment vessel into a single mass given that the convenience cans are not credited for containing the content nor for maintaining spacing between the contents of each can.

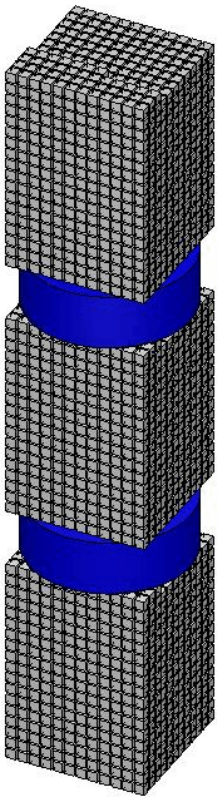


**Fig. 6.9.1-5b. Detailed isometric view of the explicit "sqa" model for HEU broken metal. Three 12 × 12 × 18 lattices of 1-in. cubes separated by 1.4-in. 277-4 spacers are shown.**

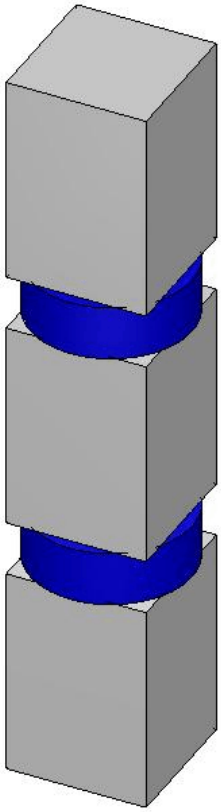


**Fig. 6.9.1-5c. Isometric view of the homogeneous "lha" model with HEU homogeneously mixed with evaluation water within the rectangular lattices formed by the units cells.**

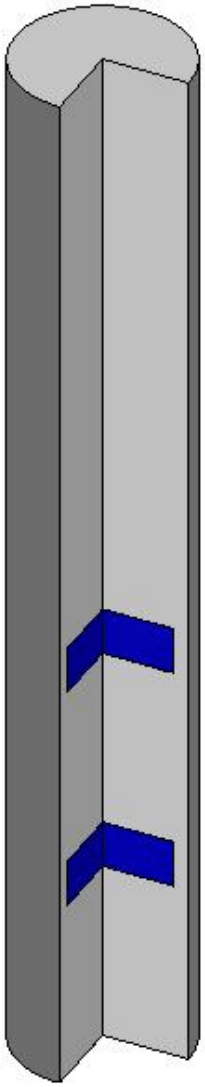


**Fig. 6.9.1-5d. Isometric view of the homogeneous "cha" model with HEU homogeneously mixed with evaluation water within the interior of the containment vessel.**

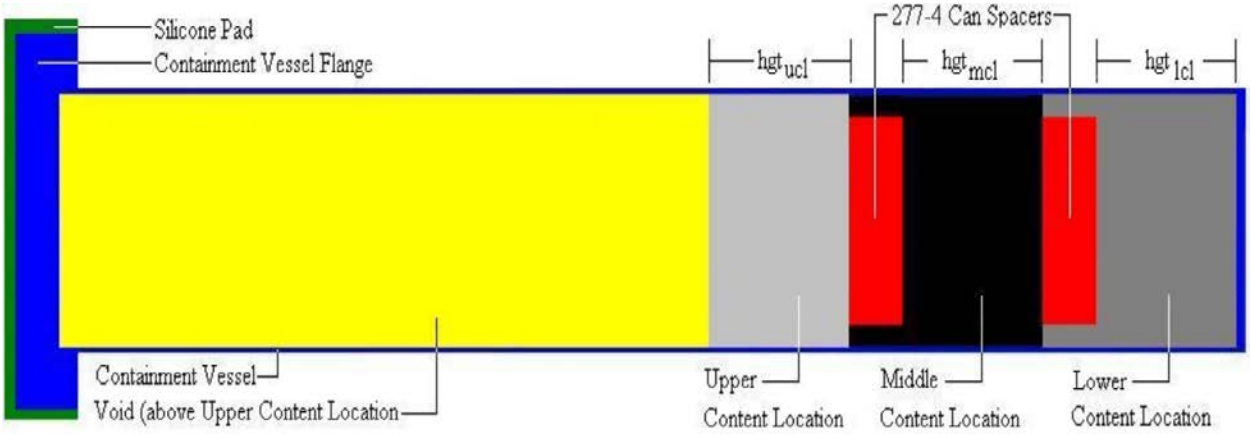
As stated in Sect. 6.9.3.1, the "cha" model is used to represent broken metal in single packages and the array of packages under NCT and HAC. For addressing the issue that the uniform dispersal approximation model ("cha") may not be conservative, especially when the 277-4 canned spacers are absent, the settling of content may be evaluated by establishing the material geometry and composition based on a maximum packing fraction. The packing fraction calculation model is described for this purpose.

In the packing fraction model, the material within a variable height can location is evaluated over the range of packing fractions from loosely packed material (PF ~0.2) to densely packed material (PF ~0.6). The height of can locations is determined based on the packing fraction instead of the fictitious cube stacking algorithm which was used in the "cha" uniform dispersal approximation model. The height of can locations used in the packing fraction calculation model is given by the following formula:

$$hgt = [(HEU_{vol} / PF) + Poly_{vol}] / CV_{area}$$

(500 grams of polyethylene is included in the calculation model to represent the potential use of packing material.)

Fig. 6.9.1-5e depicts a section view of the containment vessel for the packing fraction calculation model. The height of the lower, middle, and upper can locations are equal. Only in the upper location does the can location coincide with the content location. The "**fl**" is used in the case name to designate calculations are based on the packing fraction model.




**Note:** The height (hgt) of the upper, middle, and lower can locations are determined by the HEU packing fraction.

**Fig. 6.9.1-5e. Section view of the containment vessel for the packaging fraction calculation model depicting the content locations for broken metal.**

The volume fractions for material constituents in the middle and lower content locations are calculated as follows:

$$VF_{HEU} = HEU_{vol} / (hgt \times CV_{area} + Spacer_{void})$$

where $HEU_{vol}$ is the volume of HEU at theoretical density and $Spacer_{void}$ is the volume of the void region between the CV wall an the can spacer assumed filled with evaluation water.

$$VF_{H2O} = [(HEU_{vol} / PF) - HEU_{vol} + Spacer_{void}] / (hgt \times CV_{area} + Spacer_{void})$$
$$VF_{Poly} = Poly_{vol} / (hgt \times CV_{area} + Spacer_{void})$$

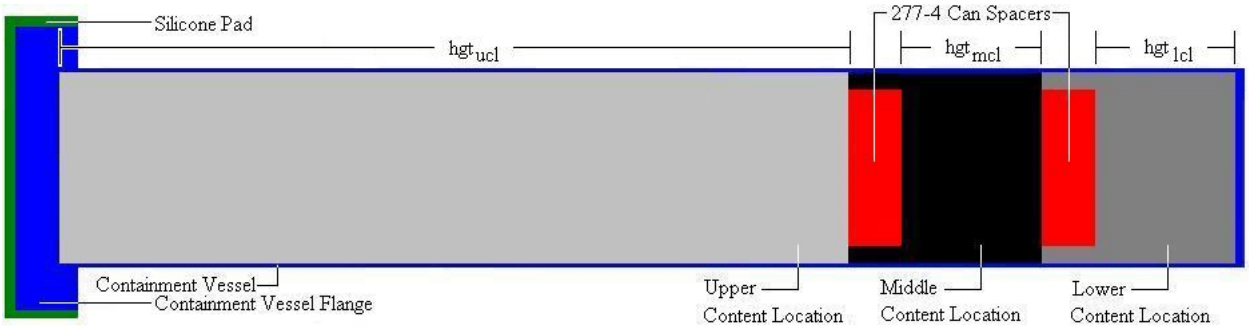
The volume fractions for material constituents in the upper content location are calculated as follows:

$$VF_{HEU} = HEU_{vol} / (hgt \times CV_{area})$$
$$VF_{H2O} = [(HEU_{vol} / PF) - HEU_{vol}] / (hgt \times CV_{area})$$
$$VF_{Poly} = Poly_{vol} / (hgt \times CV_{area})$$

The void region above the upper content location ($Vol_{above}$) is filled with full density water.

In addressing the issue that the uniform dispersal approximation "cha" model may not be conservative because homogenization of HEU is performed over a much larger volume and shape than the HEU content conceivably occupies, the effect of dispersing content within a can location may be evaluated using a variation of the packing fraction calculation model. The dispersed content calculation model is described for this purpose.

In the dispersed content calculation model, the HEU, the polyethylene, and the evaluation water of the upper content location is homogenized over the entire volume of this location. Figure 6.9.1-5f depicts a section view of the containment vessel for the dispersed content calculation model. The height of the lower and middle content locations are equal while the height of the upper content location extends to the top of the containment vessel cavity. The "**fd**" designation in the case name is used to identify the dispersed content calculation model.




**Note:** The height (hgt) of the middle and lower content locations are determined by the HEU packing fraction. The height of the upper content location extends to the top of the containment vessel cavity.

**Fig. 6.9.1-5f. Section view of the containment vessel in the dispersed content calculation model depicting the content locations for broken metal.**

The volume fractions for material constituents in the middle and lower content locations are specified the same as in the "**fl**" model. However, the volume fractions for material constituents dispersed into the upper content location are calculated as follows:

$$VF_{HEU} = HEU_{vol} / (hgt \times CV_{area} + Vol_{above})$$

where $Vol_{above}$ is the void region above the upper can location into which the content is dispersed.

$$VF_{H2O} = [(HEU_{vol} / PF) - HEU_{vol} + Vol_{above}] / (hgt \times CV_{area} + Vol_{above})$$
$$VF_{H2O} = Poly_{vol} / (hgt \times CV_{area} + Vol_{above})$$

For example, consider reference Case **hciabmt12_4_1_5_3** (Table 6.9.6-11) which defines the loading limit for broken metal in the 70% < enr. ≤ 80% range where canned spacers are not used in the containment vessel. In revised Case **hciapbmflt12_1_6_4_5**, HEU broken metal with a packing fraction of 0.6, the 500 g of polyethylene and evaluation water in each can location is homogenized over the content location. Case **hciapbmflt12_1_2_4_5** is the same as Case **hciapbmflt12_1_6_4_5**, except the packing fraction is 0.2. In Case **hciapbmfdt12_1_6_4_5**, HEU broken metal with a packing fraction of 0.6, the 500 g of polyethylene and evaluation water in each content location is homogenized over the content location. Case **hciapbmfdt12_1_2_4_5** is the same as Case **hciapbmfdt12_1_6_4_5,** except the packing fraction is 0.2. Table 6.9.1.0 provides details for the packing fraction and dispersed content calculation models.

**Table 6.9.1.0. Details for the packing fraction "fl" and dispersed content "fd" calculation models**

| Location | Height (cm) | Material | Density × VF × region volume | HEU (g) | Water (g) | Polyethylene (g) |
|---|---|---|---|---|---|---|
| **Case hciapbmflt12_1_6_4_5, packing fraction = 0.6** | | | | | | |
| Lower | 2.30470 | HEU | (18.85873)(0.23645)(299.031) | 1333.4 | | |
| | | Water | (0.9982)(1.5773e-01)(299.031) | | 47.1 | |
| | | Poly | (0.9200)(6.0582e-01)(299.031) | | | 166.7 |
| Spacer | 0.00030 | Water | (0.9982)(8.64286E-03) | | 0.0 | |
| Middle | 2.30470 | HEU | (18.85873)(0.23645)(299.031) | 1333.4 | | |
| | | Water | (0.9982)(1.5773e-01)(299.031) | | 47.1 | |
| | | Poly | (0.9200)(6.0582e-01)(299.031) | | | 166.7 |
| Spacer | 0.00030 | Water | (0.9982)(8.64286E-03) | | 0.0 | |
| Top | 2.30470 | HEU | (18.85873)(0.23647)(299.001) | 1333.4 | | |
| | | Water | (0.9982)(1.5765e-01)(299.001) | | 47.1 | |
| | | Poly | (0.9200)(6.0588e-01)(299.001) | | | 166.7 |
| Above | 71.82530 | Water | (0.9982)(1.0)(9318.28) | | 9301.5 | |
| **Total** | **78.74000** | | | **4000.2** | **9442.8** | **500.0** |
| **Case hciapbmflt12_1_2_4_5, packing fraction = 0.2** | | | | | | |
| Lower | 4.12133 | HEU | (18.85873)(0.13223)(534.713) | 1333.4 | | |
| | | Water | (0.9982)(5.2897e-01)(534.713) | | 282.3 | |
| | | Poly | (0.9200)(3.3880e-01)(534.713) | | | 166.7 |
| Spacer | 0.00030 | Water | (0.9982)(8.64286E-03) | | 0.0 | |
| Middle | 4.12133 | HEU | (18.85873)(0.13223)(534.713) | 1333.4 | | |
| | | Water | (0.9982)(5.2897e-01)(534.713) | | 282.3 | |
| | | Poly | (0.9200)(3.3880e-01)(534.713) | | | 166.7 |
| Spacer | 0.00030 | Water | (0.9982)(8.64286E-03) | | 0.0 | |

**Table 6.9.1.0. Details for the packing fraction "fl" and dispersed content "fd" calculation models**

| Location | Height (cm) | Material | Density × VF × region volume | HEU (g) | Water (g) | Polyethylene (g) |
|---|---|---|---|---|---|---|
| Top | 4.12133 | HEU | (18.85873)(0.13224)(534.682) | 1333.4 | | |
| | | Water | (0.9982)(5.2895e-01)(534.682) | | 282.3 | |
| | | Poly | (0.9200)(3.3882e-01)(534.682) | | | 166.7 |
| Above | 66.37541 | Water | (0.9982)(1.0)(8.61124E+03) | | 8595.7 | |
| **Total** | **78.74000** | | | **4000.2** | **9442.7** | **500.0** |
| **Case hciapbmfdt12_1_6_4_5, packing fraction = 0.6** | | | | | | |
| Lower | 2.30470 | HEU | (18.85873)(0.23645)(299.031) | 1333.4 | | |
| | | Water | (0.9982)(1.5773e-01)(299.031) | | 47.1 | |
| | | Poly | (0.9200)(6.0582e-01)(299.031) | | | 166.7 |
| Spacer | 0.00030 | Water | (0.9982)(8.64286E-03) | | 0.0 | |
| Middle | 2.30470 | HEU | (18.85873)(0.23645)(299.031) | 1333.4 | | |
| | | Water | (0.9982)(1.5773e-01)(299.031) | | 47.1 | |
| | | Poly | (0.9200)(6.0582e-01)(299.031) | | | 166.7 |
| Spacer | 0.00030 | Water | (0.9982)(8.64286E-03) | | 0.0 | |
| Top | 74.13000 | HEU | (18.85873)(0.00735)(9617.28) | 1333.4 | | |
| | | Water | (0.9982)(9.7381e-01)(9617.28) | | 9348.5 | |
| | | Poly | (0.9200)(1.8837e-02)(9617.28) | | | 166.7 |
| **Total** | **78.74000** | | | **4000.2** | **9442.7** | **500.0** |
| **Case hciapbmfdt12_1_2_4_5, packing fraction = 0.2** | | | | | | |
| Lower | 4.12133 | HEU | (18.85873)(0.13223)(534.713) | 1333.4 | | |
| | | Water | (0.9982)(5.2897e-01)(534.713) | | 282.3 | |
| | | Poly | (0.9200)(3.3880e-01)(534.713) | | | 166.7 |
| Spacer | 0.00030 | Water | (0.9982)(8.64286E-03) | | 0.0 | |
| Middle | 4.12133 | HEU | (18.85873)(0.13223)(534.713) | 1333.4 | | |
| | | Water | (0.9982)(5.2897e-01)(534.713) | | 282.3 | |
| | | Poly | (0.9200)(3.3880e-01)(534.713) | | | 166.7 |
| Spacer | 0.00030 | Water | (0.9982)(8.64286E-03) | | 0.0 | |
| Top | 4.12133 | HEU | (18.8587)(0.00773)(9145.92) | 1333.3 | | |
| | | Water | (0.9982)(9.7246e-01)(9145.92) | | 8878.0 | |
| | | Poly | (0.9200)(1.9808e-02)(9145.92) | | | 166.7 |
| **Total** | **12.36459** | | | **4000.1** | **9442.7** | **500.0** |

Powder, particulate, or small pieces of HEU potentially present in broken metal are capable of passing between content locations. The quantity of this material represents a small fraction of the total broken metal content. The placement of a limit on content size for criticality control is adopted as a package content loading restriction (Sect. 6.2.4, Item 6).

Calculation model for solid HEU of unspecified geometric shape, HEU oxides. Figure 6.9.1-6 depicts the wire-mesh view of the HEU oxide content inside the containment vessel. The interstitial water inside the containment vessel has been removed for illustration purposes. The HEU oxide mixture at bulk density is located at the bottom of the containment vessel and fills the space to the wall of the containment vessel. The height of the HEU oxide mixture is dependant upon the mass loading.

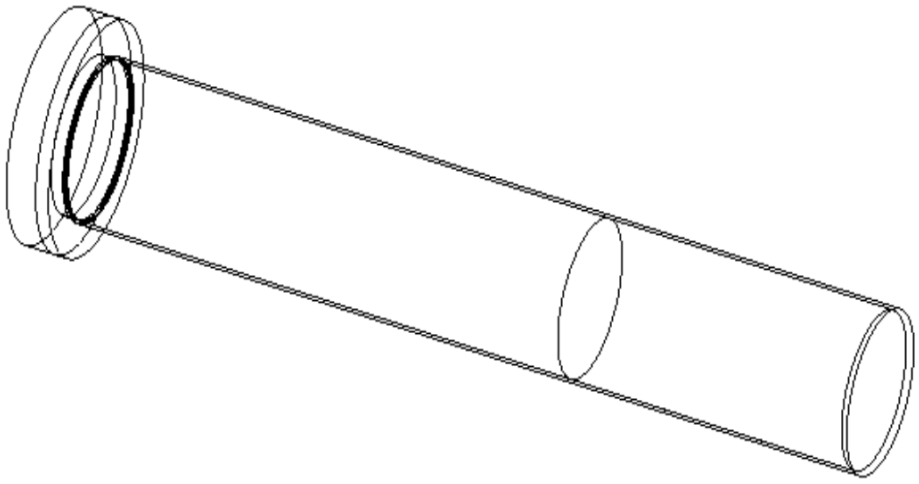


**Fig. 6.9.1-6. Wire-mesh view of the containment vessel containing the HEU oxide mixture.**

HEU product oxide is assumed to be saturated with water in the criticality calculation models. Maximum saturation in the oxide material occurs in a volume defined as the difference between the specific volume of bulk oxide and the minimum specific volume of the product oxide. Product oxide has a bulk density of 6.54 g/cm$^3$ or a specific volume of 0.152905 cm$^3$/g (Sect. 6.9.3.1). $UO_2$ has a theoretical density of 10.96 g/cm$^3$ or a minimum specific volume of 0.091241 cm$^3$/g. Therefore, the maximum volume per gram of $UO_2$ available for saturation by water is 0.061664 cm$^3$/g. Additionally, an assumed maximum of 500 g of polyethylene is homogenized with the water-saturated product oxide. The homogenized oxide containing polyethylene (density = 0.92 g/cm$^3$) occupies an additional 543.47826 cm$^3$.

The height of polyethylene homogenized with water-saturated product oxide inside the containment vessel is calculated by dividing the volume of the homogenized oxide by the internal area of the base of the containment vessel. The area of the base is 129.73536 cm$^2$ for the containment vessel with an inner diameter of 5.06 in. (12.8524 cm). The height of the void space above the homogenized oxide is calculated by subtracting the homogenized oxide height from the 78.84-cm (31.0-in.) inside height of the containment vessel.

As an example, consider Case **cvcrpoxt11_1_21_15** where 21,000 g of $UO_2$ (18,484.3 g $^{235}U$) is saturated with 1,292.62 g water (Table 6.9.6-12). The calculated H/X ratio for the water saturated product oxide is 1.83. The water-saturated product oxide homogenized with 500 g of polyethylene rises to a height of ~28.93955 cm inside the containment vessel. The 6,460.87 cm$^3$ of void space is flooded with 6449.2 g of evaluation water, such that the calculated H/X ratio inside the containment vessel is 11.84. The 500 g of polyethylene adds 0.90 to the calculated H/X ratio of water-saturated product oxide. The calculated H/X ratio for the water-saturated product oxide homogenized with 500 g of polyethylene in a dry containment vessel is 1.83 + 0.90 = 2.73 (Case **cvcrpoxt11_1_21_1**). In all cases, the H/X ratio is a computed value rather than an evaluation parameter.

The same modeling technique is applied to product oxides of $U_3O_8$ and $UO_3$. $U_3O_8$ has a theoretical density of 8.30 g/cm$^3$ or a minimum specific volume of 0.120482 cm$^3$/g. $UO_3$ has a theoretical density of 7.29 g/cm$^3$ or a minimum specific volume of 0.137174 cm$^3$/g. The maximum volumes per gram of $U_3O_8$ and $UO_3$ available for saturation by water are 0.032423 cm$^3$/g and 0.015731 cm$^3$/g, respectively.

The eight skull oxide content compositions described in Table 6.9.3.1-3b for evaluating skull oxide are derived from 292 samples of canned skull oxide. Two additional compositions are listed in the table for addressing skull oxides with an enrichment of 93.2 wt %. The skull oxide content is assumed to be $U_3O_8$ plus polyethylene, graphite, and unidentified material. A maximum of 513 g of polyethylene is assumed to be present in the skull oxide content. The volume of skull oxide content in the containment vessel (**vsoc**) is calculated as the grams of skull oxide content (**gsoc**) divided by the bulk density of the skull oxide content (**densoc**). The height of skull oxide content inside the containment vessel is calculated by dividing the volume of skull oxide content (**vsoc**) by the internal area of the base of the containment vessel (129.73536 cm$^3$).

Calculation model for solid HEU of unspecified geometric shape, UNH crystals. Figure 6.9.1-7 depicts the wire-mesh view of the UNH crystal content inside the containment vessel. A solution of UNH crystals dissolved in water fills the entire volume of the containment vessel.

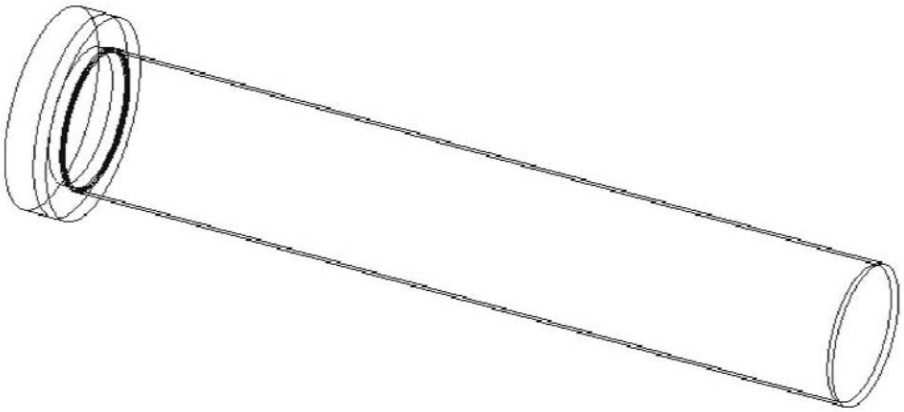


**Fig. 6.9.1-7. Wire mesh view of the containment vessel containing the UNH crystal mixture.**

Table 6.9.1.1 provides details of the calculation models used to establish the mass loading limits identified in Table 6.2a for surface-only modes of transportation. The table provides exact dimensions of the fissile material used in the analyses; the mass of fissile material, enrichment, and density of the fissile material used in the analysis; moderating properties of materials inside the containment vessel (water, hydrogenous packing material, represented by polyethylene, etc.), moderator density and h/x ratios; and arrangement of the fissile material including amount of spacing (if any) between the fissile material and/or 277-4 canned spacers. In the creation of a generalized geometry model for treatment of 277-4 canned spacers, the use of a non-zero thickness spacer was required by KENO V.a. An insignificant thickness of 0.0001 cm was used for representing this imaginary region.

**Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a**

| Case | Dimensions (cm) | Enrichment (wt % $^{235}U$) | Density ($g/cm^3$) |
|---|---|---|---|
| **Cylinders (d ≤ 3.24 in.)** | | | |
| **nciacyt11_18_1_3** | r = 4.1148 cm<br>h = 5.99639 cm | 100 | 18.81109 |
| The moderator is full density water (0.9982 $g/cm^3$) surrounding three stacked cylindrical contents. The contents have an overall stack height of 17.99171 cm (7.08335 in.). No polyethylene was used in this model. Each cylindrical content is separated by a 0.0001 cm 277-4 canned spacer and 0.0012 cm of moderating material. The bottom cylinder has a 0.0005 cm gap between it and the bottom of the containment vessel. The contents sit in the exact center on the bottom of the CV. Therefore, the cylinder content has 2.3114 cm of moderating material around each side and 60.74779 cm of moderating material above. The modeled material masses are: 18 kg $^{235}U$, 9.2418 kg $H_2O$, resulting in an h/x ratio of ~13.40. | | | |
| **nciacyt11_30_2_3** | r = 4.11480 cm<br>h = 9.99399 cm | 100 | 18.81109 |
| The moderator is full density water (0.9982 $g/cm^3$) surrounding three stacked cylindrical contents separated by 277-4 canned spacers between each cylindrical content. The contents (uranium and spacers) have an overall stack height of 37.09657 cm (14.60495 in.). No polyethylene was used in this model. Each cylindrical content is separated by a 3.5561 cm spacer and 0.0012 cm of moderating material. The bottom cylinder has a 0.0005 cm gap between it and the bottom of the containment vessel. The contents sit in the exact center on the bottom of the CV. Therefore, the cylinder content has 2.3114 cm of moderating material around each side and 41.64293 cm of moderating material above. The modeled material masses are: 30 kg $^{235}U$, 7.9915 kg $H_2O$, resulting in an h/x ratio of ~6.95. | | | |
| **Cylinders (3.24 in. < d ≤ 4.25 in.)** | | | |
| **nciacyct11_15_1_3** | r = 5.39750 cm<br>h = 2.90416 cm | 100 | 18.81109 |
| The moderator is full density water (0.9982 $g/cm^3$) surrounding three stacked cylindrical contents separated by 277-4 canned spacers. The contents have an overall stack height of 8.71508 cm (3.43133 in.). No polyethylene was used in this model. Each cylindrical content is separated by a 0.0001 cm spacer and 0.0012 cm of moderating material. The bottom cylinder has a 0.0005 cm gap between it and the bottom of the containment vessel. The contents sit in the exact center on the bottom of the CV. Therefore, the cylinder content has 1.0287 cm of moderating material around each side and 70.02442 cm of moderating material above. The modeled material masses are: 15 kg $^{235}U$, 9.4010 kg $H_2O$, resulting in an h/x ratio of ~16.36. | | | |
| **nciacyct11_25_2_3** | r = 5.39750 cm<br>h = 4.84031 cm | 100 | 18.81109 |
| The moderator is full density water (0.9982 $g/cm^3$) surrounding three stacked cylindrical contents separated by 277-4 canned spacers. The contents have an overall stack height of 21.63433 cm (8.517453 in.). No polyethylene was used in this model. Each cylindrical content is separated by a 3.5561 cm spacer and 0.0012 cm of moderating material. The bottom cylinder has a 0.0005 cm gap between it and the bottom of the containment vessel. The contents sit in the exact center on the bottom of the CV. Therefore, the cylinder content has 1.0287 cm of moderating material around each side and 57.10417 cm of moderating material above. The modeled material masses are: 25 kg $^{235}U$, 8.2568 kg $H_2O$, resulting in an h/x ratio of ~8.62. | | | |

**Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a**

| Case | Dimensions (cm) | Enrichment (wt % $^{235}U$) | Density ($g/cm^3$) |
|---|---|---|---|
| **Bars** | | | |
| **hciasqt12_30_1_3** | x = 5.81920 cm<br>y = 5.81920 cm<br>z = 15.69855 cm | 100 | 18.81109 |
| The moderator is full density water (0.9982 $g/cm^3$) surrounding three stacked square or cuboid contents separated by 277-4 canned spacers. The contents have an overall stack height of 47.09825 cm (18.54262 in.). No polyethylene was used in this model. Each cuboid content is separated by a 0.0001 cm spacer and 0.0012 cm of moderating material. The bottom cuboid has a 0.0005 cm gap between it and the bottom of the containment vessel. The contents sit in the exact center on the bottom of the CV. Therefore, the cuboid content is surrounded by moderating material ranging from 3.6166 to 2.4144 cm (center to outer edge) and 31.64125 cm of moderating material above. The modeled material masses are: 30 kg $^{235}U$, 8.6050 kg $H_2O$, resulting in an h/x ratio of ~7.49. | | | |
| **nciasqt11_36_2_3** | x = 5.81920 cm<br>y = 5.81920 cm<br>z = 18.83826 cm | 100 | 18.81109 |
| The moderator is full density water (0.9982 $g/cm^3$) surrounding three stacked square or cuboid contents separated by 277-4 canned spacers. The contents have an overall stack height of 63.62938 cm (25.05094 in.). No polyethylene was used in this model. Each cuboid content is separated by a 3.5561 cm spacer and 0.0012 cm of moderating material. The bottom cuboid has a 0.0005 cm gap between it and the bottom of the containment vessel. Therefore, the cuboid content is surrounded by moderating material ranging from 3.6166 to 2.4144 cm (center to outer edge) and 15.11012 cm of moderating material above. The modeled material masses are: 36 kg $^{235}U$, 7.6731 kg $H_2O$, resulting in an h/x ratio of ~5.56. | | | |
| **Slugs (enr. ≤ 95%–no can spacers)** | | | |
| **ncia5st11_1_1_7_3** | r = 1.983875 cm<br>h = 5.23875 cm | 95 | 18.82298 |
| The moderator is full density water (0.9982 $g/cm^3$) surrounding three stacked pentagonal rings of slug content separated by 277-4 canned spacers. (Slugs are inserted into the cylindrical geometry segment of the containment vessel using the hole option.) The contents have an overall stack height of 15.71885 cm (6.18852 in.). No polyethylene is used in this model. Each ring is separated by a 0.0001 cm spacer and 0.0012 cm of moderating material. The bottom ring of slugs has a 0.0005 cm gap between it and the bottom of the containment vessel. Above the stack of slugs is 63.02065 cm of moderating material. The modeled material masses are: 18.288 kg U (17.374 kg $^{235}U$), 9.2269 kg $H_2O$, resulting in an h/x ratio of ~13.86. The loading arrangement of slugs is depicted in Fig. 6.9.1-4b for the Case **cvcr5st11_1_1**. | | | |
| **Slugs (80% < enr. ≤ 95%–with can spacers)** | | | |
| **hcia70st12_2_7_3** | r = 1.983875 cm<br>h = 5.23875 cm | 95 | 18.82298 |
| The moderator is full density water (0.9982 $g/cm^3$) surrounding three stacked rings of slugs, each ring with a central slug surrounded by slugs in a hexagonal pattern. (Slugs are inserted into the cylindrical geometry segment of the containment vessel using the hole option.) Each ring is separated by a 277-4 canned spacer. The contents (uranium and spacers) have an overall stack height of 22.83085 cm (8.98852 in.). No polyethylene was used in this model. Each ring is separated by a 3.5561 cm spacer and 0.0012 cm of moderating material. The bottom ring has a 0.0005 cm gap between it and the bottom of the containment vessel. The stack of slugs has 55.90865 cm of moderating material above. The modeled material masses are: 25.604 kg U (24.324 kg $^{235}U$), 8.2253 kg $H_2O$, resulting in an h/x ratio of ~8.83. The loading arrangement of slugs is similar to that depicted in Fig. 6.9.1-4b for the Case **cvcr70st11_1** except that the canned spacers are present. | | | |

**Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a**

| Case | Dimensions (cm) | Enrichment (wt % $^{235}$U) | Density (g/cm$^3$) |
|---|---|---|---|
| **ncf15est11_2_2_7_3** | r = 1.983875 cm<br>h = 5.23875 cm | 95 | 18.82298 |
| The moderator is full density water (0.9982 g/cm$^3$) surrounding three rings of double stacked slugs, each ring separated by a 277-4 canned spacer. (Slugs are inserted into the cylindrical geometry segment of the containment vessel using the hole option.) The contents (uranium and spacers) have an overall stack height of 22.83085 cm (8.98852 in.). No polyethylene was used in this model. Each ring is separated by a 3.5561 cm spacer and 0.0012 cm of moderating material. The bottom ring has a 0.0005 cm gap between it and the bottom of the containment vessel. The stack of slugs has 55.90865 cm of moderating material above. The modeled material masses are: 36.578 kg U (34.749 kg $^{235}$U), 7.6434 kg $H_2O$, resulting in an h/x ratio of ~5.74. The loading arrangement of slugs is depicted in Fig. 6.9.1-4b for the Case **cvcr5est11_2_2**. | | | |
| **Slugs (enr. ≤ 80%–with can spacers)** | | | |
| **hcia5est12_2_2_5_3** | r = 1.983875 cm<br>h = 5.23875 cm | 80 | 18.85873 |
| The moderator is full density water (0.9982 g/cm$^3$) surrounding three rings of double stacked slugs, each ring separated by a 277-4 canned spacer. (Slugs are inserted into the cylindrical geometry segment of the containment vessel using the hole option.) The contents (uranium and spacers) have an overall stack height of 22.83085 cm (8.98852 in.). No polyethylene was used in this model. Each ring is separated by a 3.5561 cm spacer and 0.0012 cm of moderating material. The bottom ring has a 0.0005 cm gap between it and the bottom of the containment vessel. The stack of slugs has 55.90865 cm of moderating material above. The modeled material masses are: 36.647 kg U (29.318 kg $^{235}$U), 7.6434 kg $H_2O$, resulting in an h/x ratio of ~6.80. The loading arrangement of slugs is depicted in Fig. 6.9.1-4b for the Case **cvcr5est11_2_2**. | | | |
| **ncf15est11_2_2_5_3** | r = 1.983875 cm<br>h = 5.23875 cm | 80 | 18.85873 |
| The moderator is full density water (0.9982 g/cm$^3$) surrounding three rings of double stacked slugs, each ring separated by a 277-4 canned spacer. (Slugs are inserted into the cylindrical geometry segment of the containment vessel using the hole option.) The contents (uranium and spacers) have an overall stack height of 22.83085 cm (8.98852 in.). No polyethylene was used in this model. Each ring is separated by a 3.5561 cm spacer and 0.0012 cm of moderating material. The bottom ring has a 0.0005 cm gap between it and the bottom of the containment vessel. The stack of slugs has 55.90865 cm of moderating material above. The modeled material masses are: 36.647 kg U (29.318 kg $^{235}$U), 7.6434 kg $H_2O$, resulting in an h/x ratio of ~6.80. The loading arrangement of slugs is depicted in Fig. 6.9.1-4b for the Case **cvcr5est11_2_2**. | | | |
| **Broken Metal for CSI=0.0** | | | |
| **hciabmt12_4_1_5_3** | r = 6.52620 cm<br>h = 78.74000 cm | 80 | 18.85873 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 3.7085 kg U (2.9668 kg $^{235}$U), 10.0007 kg $H_2O$, resulting in an h/x ratio of ~87.98. | | | |

**Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a**

| Case | Dimensions (cm) | Enrichment (wt % $^{235}U$) | Density ($g/cm^3$) |
|---|---|---|---|
| **hciabmt12_5_1_4_3** | r = 6.52620 cm<br>h = 78.74000 cm | 70 | 18.88264 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 4.6415 kg U (3.2490 kg $^{235}U$), 9.9516 kg $H_2O$, resulting in an h/x ratio of ~79.95. | | | |
| **nciabmt11_6_1_3_3** | r = 6.52620 cm<br>h = 78.74000 cm | 60 | 18.90661 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 5.5768 kg U (3.3461 kg $^{235}U$), 9.9025 kg $H_2O$, resulting in an h/x ratio of ~77.24. | | | |
| **hciabmt12_3_2_8_3** | r = 6.52620 cm<br>h = 78.74000 cm | 100 | 18.81109 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 2.7743 kg $^{235}U$, 9.4362 kg $H_2O$, resulting in an h/x ratio of ~88.78. | | | |
| **hciabmt12_4_2_7_3** | r = 6.52620 cm<br>h = 78.74000 cm | 95 | 18.82298 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 3.7014 kg U (3.5164 kg $^{235}U$), 9.3871 kg $H_2O$, resulting in an h/x ratio of ~69.68. | | | |
| **hciabmt12_4_2_6_3** | r = 6.52620 cm<br>h = 78.74000 cm | 90 | 18.83488 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 3.7038 kg U (3.3334 kg $^{235}U$), 9.3871 kg $H_2O$, resulting in an h/x ratio of ~73.50. | | | |

**Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a**

| Case | Dimensions (cm) | Enrichment (wt % $^{235}U$) | Density ($g/cm^3$) |
|---|---|---|---|
| **hciabmt12_6_2_5_3** | r = 6.52620 cm<br>h = 78.74000 cm | 80 | 18.85873 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 5.5627 kg U (4.4502 kg $^{235}U$), 9.2890 kg $H_2O$, resulting in an h/x ratio of ~54.48. | | | |
| **nciabmt11_8_2_4_3** | r = 6.52620 cm<br>h = 78.74000 cm | 70 | 18.88264 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 7.4263 kg U (5.1984 kg $^{235}U$), 9.1908 kg $H_2O$, resulting in an h/x ratio of ~46.15. | | | |
| **hciabmt12_12_2_3_3** | r = 6.52620 cm<br>h = 78.74000 cm | 60 | 18.90661 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 11.1537 kg U (6.6922 kg $^{235}U$), 8.9945 kg $H_2O$, resulting in an h/x ratio of ~35.08. | | | |
| **Broken Metal for CSI=0.4** | | | |
| **ncf1bmt11_7_1_5_3** | r = 6.52620 cm<br>h = 78.74000 cm | 80 | 18.85873 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 6.4898 kg U (5.1919 kg $^{235}U$), 9.8535 kg $H_2O$, resulting in an h/x ratio of ~49.54. | | | |
| **ncf1bmt11_9_1_4_3** | r = 6.52620 cm<br>h = 78.74000 cm | 70 | 18.88264 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 8.3546 kg U (5.8482 kg $^{235}U$), 9.7553 kg $H_2O$, resulting in an h/x ratio of ~43.54. | | | |

**Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a**

| Case | Dimensions (cm) | Enrichment (wt % $^{235}U$) | Density ($g/cm^3$) |
|---|---|---|---|
| **ncf1bmt11_15_1_3_3** | r = 6.52620 cm<br>h = 78.74000 cm | 60 | 18.90661 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 14.8715 kg U (8.9229 kg $^{235}U$), 9.4118 kg $H_2O$, resulting in an h/x ratio of ~27.53. | | | |
| **ncf1bmt11_6_2_8_3** | r = 6.52620 cm<br>h = 78.74000 cm | 100 | 18.81109 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 5.5487 kg $^{235}U$, 9.2890 kg $H_2O$, resulting in an h/x ratio of ~43.70. | | | |
| **ncf1bmt11_7_2_7_3** | r = 6.52620 cm<br>h = 78.74000 cm | 95 | 18.82298 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 6.4775 kg U (6.1536 kg $^{235}U$), 9.2399 kg $H_2O$, resulting in an h/x ratio of ~39.19. | | | |
| **ncf1bmt11_9_2_6_3** | r = 6.52620 cm<br>h = 78.74000 cm | 90 | 18.83488 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 8.3335 kg U (7.5002 kg $^{235}U$), 9.1417 kg $H_2O$, resulting in an h/x ratio of ~31.81. | | | |
| **ncf1bmt11_12_2_5_3** | r = 6.52620 cm<br>h = 78.74000 cm | 80 | 18.85873 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 11.1254 kg U (8.9003 kg $^{235}U$), 8.9945 kg $H_2O$, resulting in an h/x ratio of ~26.38. | | | |

**Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a**

| Case | Dimensions (cm) | Enrichment (wt % $^{235}U$) | Density ($g/cm^3$) |
|---|---|---|---|
| **ncf1bmt11_19_2_4_3** | r = 6.52620 cm<br>h = 78.74000 cm | 70 | 18.88264 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 18.5659 kg U (12.9961 kg $^{235}U$), 8.6019 kg $H_2O$, resulting in an h/x ratio of ~17.28. | | | |
| **ncf1bmt11_29_2_3_3** | r = 6.52620 cm<br>h = 78.74000 cm | 60 | 18.90661 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 28.8136 kg U (17.2882 kg $^{235}U$), 8.0621 kg $H_2O$, resulting in an h/x ratio of ~12.17. | | | |
| **Broken metal for CSI=0.8** | | | |
| **ncf2bmt11_12_1_5_3** | r = 6.52620 cm<br>h = 78.74000 cm | 80 | 18.85873 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 11.1254 kg U (8.9003 kg $^{235}U$), 9.6081 kg $H_2O$, resulting in an h/x ratio of ~28.18. | | | |
| **ncf2bmt11_20_1_4_3** | r = 6.52620 cm<br>h = 78.74000 cm | 70 | 18.88264 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 19.4942 kg U (13.6459 kg $^{235}U$), 9.1664 kg $H_2O$, resulting in an h/x ratio of ~17.53. | | | |
| **ncf2bmt11_29_1_3_3** | r = 6.52620 cm<br>h = 78.74000 cm | 60 | 18.90661 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 28.8136 kg U (17.2882 kg $^{235}U$), 8.6757 kg $H_2O$, resulting in an h/x ratio of ~13.10. | | | |

**Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a**

| Case | Dimensions (cm) | Enrichment (wt % $^{235}U$) | Density ($g/cm^3$) |
|---|---|---|---|
| **ncf2bmt11_10_2_8_3** | r = 6.52620 cm<br>h = 78.74000 cm | 100 | 18.81109 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 9.2478 kg $^{235}U$, 9.0927 kg $H_2O$, resulting in an h/x ratio of ~25.66. | | | |
| **ncf2bmt11_12_2_7_3** | r = 6.52620 cm<br>h = 78.74000 cm | 95 | 18.82298 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 11.1043 kg U (10.5491 kg $^{235}U$), 8.9945 kg $H_2O$, resulting in an h/x ratio of ~22.25. | | | |
| **ncf2bmt11_14_2_6_3** | r = 6.52620 cm<br>h = 78.74000 cm | 90 | 18.83488 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 13.8892 kg U (12.5003 kg $^{235}U$), 8.8473 kg $H_2O$, resulting in an h/x ratio of ~31.81. | | | |
| **ncf2bmt11_21_2_5_3** | r = 6.52620 cm<br>h = 78.74000 cm | 80 | 18.85873 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 20.3966 kg U (16.3173 kg $^{235}U$), 8.5038 kg $H_2O$, resulting in an h/x ratio of ~13.60. | | | |
| **ncf2bmt11_30_2_4_3** | r = 6.52620 cm<br>h = 78.74000 cm | 70 | 18.88264 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 29.7054 kg U (20.7938 kg $^{235}U$), 8.0131 kg $H_2O$, resulting in an h/x ratio of ~10.06. | | | |

**Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a**

| Case | Dimensions (cm) | Enrichment (wt % $^{235}U$) | Density ($g/cm^3$) |
|---|---|---|---|
| **ncf2bmt11_36_2_3_3** | r = 6.52620 cm<br>h = 78.74000 cm | 60 | 18.90661 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 35.3199 kg U (21.1920 kg $^{235}U$), 7.7186 kg $H_2O$, resulting in an h/x ratio of ~9.51. | | | |
| **Broken metal for CSI=2.0** | | | |
| **ncf3bmt11_22_1_5_3** | r = 6.52620 cm<br>h = 78.74000 cm | 80 | 18.85873 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 21.3237 kg U (17.0590 kg $^{235}U$), 9.0683 kg $H_2O$, resulting in an h/x ratio of ~13.87. | | | |
| **ncf3bmt11_31_1_4_3** | r = 6.52620 cm<br>h = 78.74000 cm | 70 | 18.88264 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 30.6337 kg U (21.4436 kg $^{235}U$), 8.5776 kg $H_2O$, resulting in an h/x ratio of ~10.44. | | | |
| **ncf3bmt11_36_1_3_3** | r = 6.52620 cm<br>h = 78.74000 cm | 60 | 18.90661 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 35.3199 kg U (21.1920 kg $^{235}U$), 8.3322 kg $H_2O$, resulting in an h/x ratio of ~10.26. | | | |
| **ncf3bmt11_14_2_8_3** | r = 6.52620 cm<br>h = 78.74000 cm | 100 | 18.81109 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 13.8716 kg $^{235}U$, 8.8473 kg $H_2O$, resulting in an h/x ratio of ~16.65. | | | |

**Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a**

| Case | Dimensions (cm) | Enrichment (wt % $^{235}U$) | Density ($g/cm^3$) |
|---|---|---|---|
| **ncf3bmt11_20_2_7_3** | r = 6.52620 cm<br>h = 78.74000 cm | 95 | 18.82298 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 19.4326 kg U (18.4609 kg $^{235}U$), 8.5529 kg $H_2O$, resulting in an h/x ratio of ~12.09. | | | |
| **ncf3bmt11_23_2_6_3** | r = 6.52620 cm<br>h = 78.74000 cm | 90 | 18.83488 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 22.2227 kg U (20.0004 kg $^{235}U$), 8.4057 kg $H_2O$, resulting in an h/x ratio of ~10.97. | | | |
| **ncf3bmt11_32_2_5_3** | r = 6.52620 cm<br>h = 78.74000 cm | 80 | 18.85873 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 31.5220 kg U (25.2176 kg $^{235}U$), 7.9149 kg $H_2O$, resulting in an h/x ratio of ~8.19. | | | |
| **ncf3bmt11_36_2_4_3** | r = 6.52620 cm<br>h = 78.74000 cm | 70 | 18.88264 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 35.2751 kg U (24.6926 kg $^{235}U$), 7.7186 kg $H_2O$, resulting in an h/x ratio of ~8.16. | | | |
| **ncf3bmt11_36_2_3_3** | r = 6.52620 cm<br>h = 78.74000 cm | 60 | 18.90661 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 35.3199 kg U (21.1920 kg $^{235}U$), 7.7186 kg $H_2O$, resulting in an h/x ratio of ~9.51. | | | |

**Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a**

| Case | Dimensions (cm) | Enrichment (wt % $^{235}U$) | Density ($g/cm^3$) |
|---|---|---|---|
| **Broken metal for CSI=3.2** | | | |
| **ncf5bmt11_35_1_5_3** | r = 6.52620 cm<br>h = 78.74000 cm | 80 | 18.85873 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 34.3034 kg U (27.4427 kg $^{235}U$), 8.3813 kg $H_2O$, resulting in an h/x ratio of ~7.97. | | | |
| **ncf5bmt11_36_1_4_3** | r = 6.52620 cm<br>h = 78.74000 cm | 70 | 18.88264 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 35.2751 kg U (24.6926 kg $^{235}U$), 8.3322 kg $H_2O$, resulting in an h/x ratio of ~8.81. | | | |
| **ncf5bmt11_36_1_3_3** | r = 6.52620 cm<br>h = 78.74000 cm | 60 | 18.90661 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 35.3199 kg U (21.1920 kg $^{235}U$), 8.3322 kg $H_2O$, resulting in an h/x ratio of ~10.26. | | | |
| **ncf5bmt11_25_2_8_3** | r = 6.52620 cm<br>h = 78.74000 cm | 100 | 18.81109 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 24.9689 kg $^{235}U$, 8.2584 kg $H_2O$, resulting in an h/x ratio of ~8.63. | | | |
| **ncf5bmt11_28_2_7_3** | r = 6.52620 cm<br>h = 78.74000 cm | 95 | 18.82298 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 27.7608 kg U (26.3728 kg $^{235}U$), 8.1112 kg $H_2O$, resulting in an h/x ratio of ~8.03. | | | |

**Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a**

| Case | Dimensions (cm) | Enrichment (wt % $^{235}U$) | Density ($g/cm^3$) |
|---|---|---|---|
| **ncf5bmt11_35_2_6_3** | r = 6.52620 cm<br>h = 78.74000 cm | 90 | 18.83488 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 34.2600 kg U (30.8340 kg $^{235}U$), 7.7677 kg $H_2O$, resulting in an h/x ratio of ~6.58. | | | |
| **ncf5bmt11_36_2_5_3** | r = 6.52620 cm<br>h = 78.74000 cm | 80 | 18.85873 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 35.2305 kg U (28.1844 kg $^{235}U$), 7.7186 kg $H_2O$, resulting in an h/x ratio of ~7.15. | | | |
| **ncf5bmt11_36_2_4_3** | r = 6.52620 cm<br>h = 78.74000 cm | 70 | 18.88264 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 35.2751 kg U (24.6926 kg $^{235}U$), 7.7186 kg $H_2O$, resulting in an h/x ratio of ~8.16. | | | |
| **ncf5bmt11_36_2_3_3** | r = 6.52620 cm<br>h = 78.74000 cm | 60 | 18.90661 |
| The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of $1.0 \times 10^{-4}$ over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 35.3199 kg U (21.1920 kg $^{235}U$), 7.7186 kg $H_2O$, resulting in an h/x ratio of ~9.51. | | | |
| **Product oxide** | | | |
| **hciapdoxt12_1_1_11_3** | r = 6.42620 cm<br>h = 46.58351 cm | 100 | 2.00000 |
| Water-saturated HEU product oxide with 500 g polyethylene (0.9200 $g/cm^3$) is dispersed within the containment vessel to a height determined by the mass of the product oxide, polyethylene, and saturation moisture. The product oxide is saturated with 4.488 kg $H_2O$ of full density water (0.9982 $g/cm^3$). Since the product oxide content is assumed to be dispersed within the containment vessel, there are no gaps between the content and the containment vessel wall or bottom. There are 32.15649 cm of moderator above the product oxide content. No 277-4 canned spacers are used in this analysis. The modeled material masses are: 11.00 kg $UO_2$ (9.638 kg $^{235}U$), 8,652.6 kg $H_2O$, and 500 g polyethylene resulting in an h/x ratio of ~25.06. | | | |

**Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a**

| Case | Dimensions (cm) | Enrichment (wt % $^{235}U$) | Density ($g/cm^3$) |
|---|---|---|---|
| **Skull oxide** | | | |
| **nciask_9_15** | r = 6.42620 cm<br>h = 28.18623 cm | 100 | 6.54000 |
| The skull oxide is dispersed within the containment vessel to a height determined by the mass of the skull oxide. The skull oxide is saturated with a moderator of full density water (0.9982 $g/cm^3$). No polyethylene is used in this analysis. Since the skull oxide content is assumed to be dispersed within the containment vessel, there are no gaps between the content and the containment vessel wall or bottom. There are 50.55377 cm of moderator above the skull oxide content. No 277-4 canned spacers are used in this analysis. The modeled material masses are: 21.3000 kg skull oxide, 19.8653 kg $U_3O_8$, 15.6728 kg $^{235}U$, 3.8014 kg $H_2O$, resulting in an h/x ratio of ~7.43. | | | |
| **UNX crystals** | | | |
| **nciapunhct11_7_3** | r = 6.42620 cm<br>h = 78.74000 cm | 100 | 2.79329 |
| The UNX crystals are homogenized with 1515.7 g full density water (0.9982 $g/cm^3$) and 500 g polyethylene (0.9200 $g/cm^3$) dispersed over the entire inner volume of the containment vessel. There is no gap between the homogenized UNX content and the containment vessel bottom or sides. Since the content is homogenized over the inner volume of the containment vessel, no moderating material is above the content. No 277-4 canned spacers are used in this model. The modeled material masses are 7.0 kg UNX crystals (3.2968 kg $^{235}U$), 8.6886 kg $H_2O$, and 500 g polyethylene resulting in an h/x ratio of ~73.73. | | | |
| **ncf1punhct11_24_3** | r = 6.42620 cm<br>h = 78.74000 cm | 100 | 2.79329 |
| The UNX crystals are homogenized with 5,196.7 g full density water (0.9982 $g/cm^3$) and 500 g polyethylene (0.9200 $g/cm^3$) dispersed over the entire inner volume of the containment vessel. There is no gap between the homogenized UNX crystals and the containment vessel bottom or sides. Since the content is homogenized over the inner volume of the containment vessel, no moderating material is above the content. No 277-4 canned spacers are used in this model. The modeled material masses are 24.0 kg UNX crystals (11.3031 kg $^{235}U$), 6.2746 kg $H_2O$, and 500 g polyethylene, resulting in an h/x ratio of ~15.97. | | | |
| **TRIGA fuel** | | | |
| **nciatriga_1_15_3** | r = 1.8288 cm<br>h = 12.7000 cm | 20 | 8.65974 |
| The moderator is full density water (0.9982 $g/cm^3$) surrounding three stacked "bundles" of three Triga fuel elements separated by 277-4 canned spacers. The content has an overall height of 38.10310 cm (15.00122 in.). No polyethylene was used in this model. Each content is separated by a 0.0001 cm spacer and 0.0012 cm of moderating material. The bottom content has a 0.0005 cm gap between it and the bottom of the containment vessel. The contents sit in the exact center on the bottom of the CV. The modeled material masses are 10.4 kg $UZrH_x$, 0.9210 kg $^{235}U$, and 8.9982 kg $H_2O$, resulting in an h/x ratio of ~255.01. | | | |
| **nciatriga70_1_15_3** | r = 1.8288 cm<br>h = 12.7000 cm | 70 | 5.70132 |
| The moderator is full density water (0.9982 $g/cm^3$) surrounding three stacked "bundles" of three Triga fuel elements separated by 277-4 canned spacers. The content has an overall height of 38.10310 cm (15.00122 in.). No polyethylene was used in this model. Each content is separated by a 0.0001 cm spacer and 0.0012 cm of moderating material. The bottom content has a 0.0005 cm gap between it and the bottom of the containment vessel. The contents sit in the exact center on the bottom of the CV. The modeled material masses are 6.8471 kg $UZrH_x$, 0.4080 kg $^{235}U$, and 8.9982 kg $H_2O$, resulting in an h/x ratio of ~575.64. | | | |

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# Appendix 6.9.2

# HAC Package Model

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## Appendix 6.9.2

## HAC Package Model

### 6.9.2.1 Prediction of HAC Damage in the ES-3100 Package

Finite element analysis of an ES-3100 package under Hypothetical Accident Conditions (HAC) is used to predict the deformed outer diameters of the drum at node points along the vertical axis of an upright package. Selected node points are designated in a downward direction from the top of the drum as "UR," "MUR," "MR," "MLR," and "LR." Table 6.9.2.1-1 lists diameters at the five node points measured along the 90–270° and 0–180° axes. These dimensions represent major and minor axes at each deformation point on the assumption that the drum cross section is ellipsoidal. A corresponding equivalent circular diameter is also listed for each node point in Table 6.9.2.1-1.

A set of KENO V.a calculation models based on reduced package diameters at the "MR," "MLR," and "LR" deformation points are derived from the Normal Conditions of Transport (NCT) geometry model. These geometry models are evaluated for the purpose of establishing a bounding geometry model for representing the ES-3100 package under HAC. The primary changes made to the KENO V.a geometry input statements in the NCT model are reductions in the drum's radii. The change to the drum's inner radius also affects the outer radius of both the angle iron and the Kaolite located inside the containment vessel outer liner. The volume fractions for these materials are adjusted in the KENO V.a calculation models so that material masses of the affected package components are conserved. Table 6.9.2.1-2 provides data for transforming the KENO V.a calculation model from an NCT model into an HAC model.

### 6.9.2.2 Criticality Calculations

Sets of criticality calculations are performed for the "MR," "MLR," and "LR" models at five different package water contents over the range of HAC. The five package water contents of the void spaces external to the containment vessel and the interstitial space between drums are as follows: 1e-20 spg water, 1e-04 spg water, 0.1 spg water, 0.3 spg water, and 1.0 spg water. The water content in the Kaolite corresponds to the dry condition (VF= 0.0287) where neutronic interaction between the packages of an array is maximized.

An infinite array of packages is evaluated in order to eliminate any biases arising from spectral leakage effects in the reflector of the finite array. The $k_{eff}$ values for each KENO V.a case are based on 500,000 neutron histories produced by running for 215 generations with 2,500 neutrons per generation and truncating the first 15 generations of data. Each package modeled has 36 kg of 100% enriched uranium in the form of broken metal content.

Each case is rerun using a different starting random number in order to produce sets of computed $k_{eff}$ values that are statistically independent. The random starting number, the mean value ($k_{eff}$), and the corresponding standard error ($s_i$) computed for ten individual runs are shown in Tables 6.9.2.2-1, -2, and -3. The same statistical method (described in DAC-FS-900000-A014) used in the evaluation of Kaolite models (Appendix 6.9.3, Sect. 6.9.3.4) is also used here for determining whether or not differences in neutronic performance between the package models are statistically significant.

**Table 6.9.2.1-1. Deformation of the ES-3100 drum at five node points, projected by finite element analysis "Case 3100 RUN1HL Lower Bound Kaolite May 2004"**

| Deformation point | FEA node | Diameter at 90° (in.) | Diameter at 180° (in.) | Equivalent circular diameter | |
|---|---|---|---|---|---|
| | | | | (in.) | (cm) |
| UR | 098194 | 20.02 | 15.60 | 17.6724 | 44.8878 |
| MUR | 100238 | 20.74 | 15.07 | 17.6791 | 44.9050 |
| MR | 101589 | 20.74 | 14.18 | 17.1492 | 43.5588 |
| MLR | 103012 | 22.00 | 13.44 | 17.1954 | 43.6762 |
| LR | 105786 | 20.92 | 12.92 | 16.4404 | 41.7586 |

**Table 6.9.2.1-2. Parameter changes for converting an NCT package model into an HAC package model**

| Parameter | Reference NCT package model | HAC model at MR node point of package | HAC model at MLR node point of package | HAC model at LR node point of package |
|---|---|---|---|---|
| **Package model dimension** | | | | |
| $OR_{Drum}$ (cm) | 23.32990 | 21.77942 | 21.83809 | 20.87929 |
| $IR_{Drum}$ (cm) | 23.17750 | 21.62702 | 21.68569 | 20.72689 |
| $th_{Drum\ wall}$ (cm) | 0.15240 | 0.15240 | 0.15240 | 0.15240 |
| $OR_{Lid}$ (cm) | 23.11400 | 21.56352 | 21.62219 | 20.66339 |
| $IR_{Lid}$ (cm) | 22.96160 | 21.41112 | 21.46979 | 20.51099 |
| $th_{Kaolite}$ (cm) | 12.10310 | 10.55262 | 10.61129 | 9.65249 |
| **Kaolite of the body weldment inner liner** | | | | |
| Mass (g) | 117,563.0 | 97,080.4 | 97,829.7 | 85,839.8 |
| Volume ($cm^3$) | 134,888.0 | 111,387.0 | 112,246.0 | 98,489.5 |
| Volume fraction multiplier [a] | – | 1.21099 | 1.20171 | 1.36956 |
| VF for water component of Kaolite | 0.52294 | 0.63327 [b] | 0.62843 [b] | 0.71620 [b] |
| VF for dry mix component of Kaolite | 0.34864 | 0.42220 [b] | 0.41897 [b] | 0.47749 [b] |
| **Angle iron** | | | | |
| Mass (g) | 5,621.76 | 4,521.40 | 4,561.66 | 3,917.54 |
| Volume ($cm^3$) | 708.030 | 569.446 | 574.516 | 493.393 |
| VF | 1.0 | 1.24337 | 1.23239 | 1.43502 |
| **Drum steel** | | | | |
| Mass (g) | 25,446.3 | 23,397.6 | 23,474.2 | 22,231.2 |
| Volume ($cm^3$) | 3,204.82 | 2,946.80 | 2,956.50 | 2,799.90 |
| VF | 1.0 | 1.08756 | 1.08401 | 1.14462 |

[a] Volume fraction multiplier is an NCT density multiplier for conserving mass in components having modified volumes in the HAC calculation models.

[b] Volume Fraction (VF) for Kaolite components calculated by multiplying the VF used in the NCT model by volume fraction multiplier for the HAC model.

**Table 6.9.2.2-1. Neutron multiplication factors with standard deviations for the ES-3100 package models at the "MR" and "MLR" node points**

| MOIFR | Random number | "A" cases | $k_{eff}$ | s | "B" cases | $k_{eff}$ | s |
|---|---|---|---|---|---|---|---|
| 1.0E-20 | 109E77866CF6 | mrandnum_01_01 | 1.04965 | 0.00119 | mlrrandnum_01_01 | 1.05024 | 0.00139 |
| 1.0E-20 | 16AA4A58735C | mrandnum_01_02 | 1.05132 | 0.00131 | mlrrandnum_01_02 | 1.05051 | 0.00135 |
| 1.0E-20 | 1814171B652A | mrandnum_01_03 | 1.05368 | 0.00123 | mlrrandnum_01_03 | 1.05121 | 0.00128 |
| 1.0E-20 | 1A423B9472C7 | mrandnum_01_04 | 1.05165 | 0.00145 | mlrrandnum_01_04 | 1.04954 | 0.00120 |
| 1.0E-20 | 20E876D82248 | mrandnum_01_05 | 1.05344 | 0.00106 | mlrrandnum_01_05 | 1.05249 | 0.00110 |
| 1.0E-20 | 3F6E65CA7440 | mrandnum_01_06 | 1.05188 | 0.00157 | mlrrandnum_01_06 | 1.04924 | 0.00132 |
| 1.0E-20 | 479D21DB7509 | mrandnum_01_07 | 1.05149 | 0.00148 | mlrrandnum_01_07 | 1.05105 | 0.00111 |
| 1.0E-20 | 55D4371D3A23 | mrandnum_01_08 | 1.05083 | 0.00113 | mlrrandnum_01_08 | 1.05039 | 0.00129 |
| 1.0E-20 | 6E1A14672B8F | mrandnum_01_09 | 1.04910 | 0.00106 | mlrrandnum_01_09 | 1.05161 | 0.00125 |
| 1.0E-20 | 77A0308C0E44 | mrandnum_01_10 | 1.05254 | 0.00106 | mlrrandnum_01_10 | 1.05041 | 0.00129 |
| | | | | | | | |
| 1.0E-04 | 109E77866CF6 | mrandnum_03_01 | 1.04994 | 0.00132 | mlrrandnum_03_01 | 1.05108 | 0.00151 |
| 1.0E-04 | 16AA4A58735C | mrandnum_03_02 | 1.05023 | 0.00118 | mlrrandnum_03_02 | 1.05245 | 0.00116 |
| 1.0E-04 | 1814171B652A | mrandnum_03_03 | 1.05090 | 0.00139 | mlrrandnum_03_03 | 1.05169 | 0.00138 |
| 1.0E-04 | 1A423B9472C7 | mrandnum_03_04 | 1.05072 | 0.00115 | mlrrandnum_03_04 | 1.05303 | 0.00102 |
| 1.0E-04 | 20E876D82248 | mrandnum_03_05 | 1.05052 | 0.00119 | mlrrandnum_03_05 | 1.05191 | 0.00115 |
| 1.0E-04 | 3F6E65CA7440 | mrandnum_03_06 | 1.05383 | 0.00131 | mlrrandnum_03_06 | 1.05017 | 0.00110 |
| 1.0E-04 | 479D21DB7509 | mrandnum_03_07 | 1.05205 | 0.00153 | mlrrandnum_03_07 | 1.05232 | 0.00128 |
| 1.0E-04 | 55D4371D3A23 | mrandnum_03_08 | 1.05343 | 0.00106 | mlrrandnum_03_08 | 1.05100 | 0.00144 |
| 1.0E-04 | 6E1A14672B8F | mrandnum_03_09 | 1.04831 | 0.00132 | mlrrandnum_03_09 | 1.05046 | 0.00145 |
| 1.0E-04 | 77A0308C0E44 | mrandnum_03_10 | 1.05353 | 0.00111 | mlrrandnum_03_10 | 1.05130 | 0.00134 |
| | | | | | | | |
| 0.10 | 109E77866CF6 | mrandnum_06_01 | 0.97948 | 0.00120 | mlrrandnum_06_01 | 0.98071 | 0.00129 |
| 0.10 | 16AA4A58735C | mrandnum_06_02 | 0.98104 | 0.00125 | mlrrandnum_06_02 | 0.98006 | 0.00110 |
| 0.10 | 1814171B652A | mrandnum_06_03 | 0.98056 | 0.00134 | mlrrandnum_06_03 | 0.98043 | 0.00116 |
| 0.10 | 1A423B9472C7 | mrandnum_06_04 | 0.97895 | 0.00114 | mlrrandnum_06_04 | 0.98253 | 0.00109 |
| 0.10 | 20E876D82248 | mrandnum_06_05 | 0.98058 | 0.00113 | mlrrandnum_06_05 | 0.98256 | 0.00135 |
| 0.10 | 3F6E65CA7440 | mrandnum_06_06 | 0.97966 | 0.00119 | mlrrandnum_06_06 | 0.98093 | 0.00127 |
| 0.10 | 479D21DB7509 | mrandnum_06_07 | 0.97953 | 0.00145 | mlrrandnum_06_07 | 0.97959 | 0.00127 |
| 0.10 | 55D4371D3A23 | mrandnum_06_08 | 0.97993 | 0.00130 | mlrrandnum_06_08 | 0.98033 | 0.00111 |
| 0.10 | 6E1A14672B8F | mrandnum_06_09 | 0.97972 | 0.00138 | mlrrandnum_06_09 | 0.97940 | 0.00117 |
| 0.10 | 77A0308C0E44 | mrandnum_06_10 | 0.98157 | 0.00134 | mlrrandnum_06_10 | 0.98318 | 0.00134 |
| | | | | | | | |
| 0.30 | 109E77866CF6 | mrandnum_08_01 | 0.93412 | 0.00118 | mlrrandnum_08_01 | 0.93254 | 0.00147 |
| 0.30 | 16AA4A58735C | mrandnum_08_02 | 0.93227 | 0.00138 | mlrrandnum_08_02 | 0.93186 | 0.00142 |
| 0.30 | 1814171B652A | mrandnum_08_03 | 0.93390 | 0.00131 | mlrrandnum_08_03 | 0.93200 | 0.00135 |
| 0.30 | 1A423B9472C7 | mrandnum_08_04 | 0.93252 | 0.00144 | mlrrandnum_08_04 | 0.93197 | 0.00150 |
| 0.30 | 20E876D82248 | mrandnum_08_05 | 0.93334 | 0.00132 | mlrrandnum_08_05 | 0.93601 | 0.00124 |
| 0.30 | 3F6E65CA7440 | mrandnum_08_06 | 0.93168 | 0.00132 | mlrrandnum_08_06 | 0.93249 | 0.00118 |
| 0.30 | 479D21DB7509 | mrandnum_08_07 | 0.93514 | 0.00123 | mlrrandnum_08_07 | 0.93299 | 0.00128 |
| 0.30 | 55D4371D3A23 | mrandnum_08_08 | 0.93564 | 0.00132 | mlrrandnum_08_08 | 0.93500 | 0.00133 |
| 0.30 | 6E1A14672B8F | mrandnum_08_09 | 0.93597 | 0.00136 | mlrrandnum_08_09 | 0.93201 | 0.00122 |
| 0.30 | 77A0308C0E44 | mrandnum_08_10 | 0.93525 | 0.00128 | mlrrandnum_08_10 | 0.93238 | 0.00153 |

**Table 6.9.2.2-1. Neutron multiplication factors with standard deviations for the ES-3100 package models at the "MR" and "MLR" node points**

| MOIFR | Random number | "A" cases | $k_{eff}$ | s | "B" cases | $k_{eff}$ | s |
|---|---|---|---|---|---|---|---|
| 1.00 | 109E77866CF6 | mrandnum_15_01 | 0.93103 | 0.00139 | mlrrandnum_15_01 | 0.93180 | 0.00126 |
| 1.00 | 16AA4A58735C | mrandnum_15_02 | 0.93082 | 0.00131 | mlrrandnum_15_02 | 0.93020 | 0.00159 |
| 1.00 | 1814171B652A | mrandnum_15_03 | 0.92890 | 0.00148 | mlrrandnum_15_03 | 0.92956 | 0.00117 |
| 1.00 | 1A423B9472C7 | mrandnum_15_04 | 0.93062 | 0.00145 | mlrrandnum_15_04 | 0.92837 | 0.00165 |
| 1.00 | 20E876D82248 | mrandnum_15_05 | 0.93055 | 0.00125 | mlrrandnum_15_05 | 0.93220 | 0.00120 |
| 1.00 | 3F6E65CA7440 | mrandnum_15_06 | 0.92950 | 0.00117 | mlrrandnum_15_06 | 0.93177 | 0.00141 |
| 1.00 | 479D21DB7509 | mrandnum_15_07 | 0.92952 | 0.00116 | mlrrandnum_15_07 | 0.93217 | 0.00144 |
| 1.00 | 55D4371D3A23 | mrandnum_15_08 | 0.92805 | 0.00154 | mlrrandnum_15_08 | 0.92921 | 0.00125 |
| 1.00 | 6E1A14672B8F | mrandnum_15_09 | 0.93117 | 0.00140 | mlrrandnum_15_09 | 0.92980 | 0.00177 |
| 1.00 | 77A0308C0E44 | mrandnum_15_10 | 0.93218 | 0.00120 | mlrrandnum_15_10 | 0.93070 | 0.00126 |

**Table 6.9.2.2-2.Neutron multiplication factors with standard deviations for the ES-3100 package models at the "MLR" and "LR" node points**

| MOIFR | Random number | "A" cases | $k_{eff}$ | s | "B" cases | $k_{eff}$ | s |
|---|---|---|---|---|---|---|---|
| 1.0E-20 | 109E77866CF6 | mlrrandnum_01_01 | 1.05024 | 0.00139 | lrrandnum_01_01 | 1.05093 | 0.00133 |
| 1.0E-20 | 16AA4A58735C | mlrrandnum_01_02 | 1.05051 | 0.00135 | lrrandnum_01_02 | 1.05009 | 0.00118 |
| 1.0E-20 | 1814171B652A | mlrrandnum_01_03 | 1.05121 | 0.00128 | lrrandnum_01_03 | 1.05057 | 0.00118 |
| 1.0E-20 | 1A423B9472C7 | mlrrandnum_01_04 | 1.04954 | 0.00120 | lrrandnum_01_04 | 1.05066 | 0.00120 |
| 1.0E-20 | 20E876D82248 | mlrrandnum_01_05 | 1.05249 | 0.00110 | lrrandnum_01_05 | 1.04882 | 0.00129 |
| 1.0E-20 | 3F6E65CA7440 | mlrrandnum_01_06 | 1.04924 | 0.00132 | lrrandnum_01_06 | 1.05316 | 0.00127 |
| 1.0E-20 | 479D21DB7509 | mlrrandnum_01_07 | 1.05105 | 0.00111 | lrrandnum_01_07 | 1.05229 | 0.00134 |
| 1.0E-20 | 55D4371D3A23 | mlrrandnum_01_08 | 1.05039 | 0.00129 | lrrandnum_01_08 | 1.05186 | 0.00131 |
| 1.0E-20 | 6E1A14672B8F | mlrrandnum_01_09 | 1.05161 | 0.00125 | lrrandnum_01_09 | 1.05236 | 0.00113 |
| 1.0E-20 | 77A0308C0E44 | mlrrandnum_01_10 | 1.05041 | 0.00129 | lrrandnum_01_10 | 1.05098 | 0.00120 |
| | | | | | | | |
| 1.0E-04 | 109E77866CF6 | mlrrandnum_03_01 | 1.05108 | 0.00151 | lrrandnum_03_01 | 1.05122 | 0.00123 |
| 1.0E-04 | 16AA4A58735C | mlrrandnum_03_02 | 1.05245 | 0.00116 | lrrandnum_03_02 | 1.05324 | 0.00121 |
| 1.0E-04 | 1814171B652A | mlrrandnum_03_03 | 1.05169 | 0.00138 | lrrandnum_03_03 | 1.05143 | 0.00123 |
| 1.0E-04 | 1A423B9472C7 | mlrrandnum_03_04 | 1.05303 | 0.00102 | lrrandnum_03_04 | 1.05048 | 0.00121 |
| 1.0E-04 | 20E876D82248 | mlrrandnum_03_05 | 1.05191 | 0.00115 | lrrandnum_03_05 | 1.05095 | 0.00137 |
| 1.0E-04 | 3F6E65CA7440 | mlrrandnum_03_06 | 1.05017 | 0.00110 | lrrandnum_03_06 | 1.05029 | 0.00119 |
| 1.0E-04 | 479D21DB7509 | mlrrandnum_03_07 | 1.05232 | 0.00128 | lrrandnum_03_07 | 1.05124 | 0.00108 |
| 1.0E-04 | 55D4371D3A23 | mlrrandnum_03_08 | 1.05100 | 0.00144 | lrrandnum_03_08 | 1.05080 | 0.00116 |
| 1.0E-04 | 6E1A14672B8F | mlrrandnum_03_09 | 1.05046 | 0.00145 | lrrandnum_03_09 | 1.05074 | 0.00122 |
| 1.0E-04 | 77A0308C0E44 | mlrrandnum_03_10 | 1.05130 | 0.00134 | lrrandnum_03_10 | 1.05094 | 0.00111 |
| | | | | | | | |
| 0.1 | 109E77866CF6 | mlrrandnum_06_01 | 0.98071 | 0.00129 | lrrandnum_06_01 | 0.98315 | 0.00118 |
| 0.1 | 16AA4A58735C | mlrrandnum_06_02 | 0.98006 | 0.00110 | lrrandnum_06_02 | 0.98605 | 0.00124 |
| 0.1 | 1814171B652A | mlrrandnum_06_03 | 0.98043 | 0.00116 | lrrandnum_06_03 | 0.98690 | 0.00120 |

**Table 6.9.2.2-2.Neutron multiplication factors with standard deviations for the ES-3100 package models at the "MLR" and "LR" node points**

| MOIFR | Random number | "A" cases | $k_{eff}$ | s | "B" cases | $k_{eff}$ | s |
|---|---|---|---|---|---|---|---|
| 0.1 | 1A423B9472C7 | mlrrandnum_06_04 | 0.98253 | 0.00109 | lrrandnum_06_04 | 0.98347 | 0.00126 |
| 0.1 | 20E876D82248 | mlrrandnum_06_05 | 0.98256 | 0.00135 | lrrandnum_06_05 | 0.98770 | 0.00124 |
| 0.1 | 3F6E65CA7440 | mlrrandnum_06_06 | 0.98093 | 0.00127 | lrrandnum_06_06 | 0.98734 | 0.00140 |
| 0.1 | 479D21DB7509 | mlrrandnum_06_07 | 0.97959 | 0.00127 | lrrandnum_06_07 | 0.98417 | 0.00133 |
| 0.1 | 55D4371D3A23 | mlrrandnum_06_08 | 0.98033 | 0.00111 | lrrandnum_06_08 | 0.98712 | 0.00136 |
| 0.1 | 6E1A14672B8F | mlrrandnum_06_09 | 0.97940 | 0.00117 | lrrandnum_06_09 | 0.98533 | 0.00142 |
| 0.1 | 77A0308C0E44 | mlrrandnum_06_10 | 0.98318 | 0.00134 | lrrandnum_06_10 | 0.98412 | 0.00116 |
| | | | | | | | |
| 0.3 | 109E77866CF6 | mlrrandnum_08_01 | 0.93254 | 0.00147 | lrrandnum_08_01 | 0.93910 | 0.00146 |
| 0.3 | 16AA4A58735C | mlrrandnum_08_02 | 0.93186 | 0.00142 | lrrandnum_08_02 | 0.93757 | 0.00117 |
| 0.3 | 1814171B652A | mlrrandnum_08_03 | 0.93200 | 0.00135 | lrrandnum_08_03 | 0.93940 | 0.00146 |
| 0.3 | 1A423B9472C7 | mlrrandnum_08_04 | 0.93197 | 0.00150 | lrrandnum_08_04 | 0.93676 | 0.00130 |
| 0.3 | 20E876D82248 | mlrrandnum_08_05 | 0.93601 | 0.00124 | lrrandnum_08_05 | 0.93851 | 0.00111 |
| 0.3 | 3F6E65CA7440 | mlrrandnum_08_06 | 0.93249 | 0.00118 | lrrandnum_08_06 | 0.93914 | 0.00149 |
| 0.3 | 479D21DB7509 | mlrrandnum_08_07 | 0.93299 | 0.00128 | lrrandnum_08_07 | 0.94011 | 0.00131 |
| 0.3 | 55D4371D3A23 | mlrrandnum_08_08 | 0.93500 | 0.00133 | lrrandnum_08_08 | 0.93900 | 0.00139 |
| 0.3 | 6E1A14672B8F | mlrrandnum_08_09 | 0.93201 | 0.00122 | lrrandnum_08_09 | 0.93781 | 0.00117 |
| 0.3 | 77A0308C0E44 | mlrrandnum_08_10 | 0.93238 | 0.00153 | lrrandnum_08_10 | 0.93965 | 0.00118 |
| | | | | | | | |
| 1.0 | 109E77866CF6 | mlrrandnum_15_01 | 0.93180 | 0.00126 | lrrandnum_15_01 | 0.93344 | 0.00126 |
| 1.0 | 16AA4A58735C | mlrrandnum_15_02 | 0.93020 | 0.00159 | lrrandnum_15_02 | 0.93281 | 0.00121 |
| 1.0 | 1814171B652A | mlrrandnum_15_03 | 0.92956 | 0.00117 | lrrandnum_15_03 | 0.93468 | 0.00132 |
| 1.0 | 1A423B9472C7 | mlrrandnum_15_04 | 0.92837 | 0.00165 | lrrandnum_15_04 | 0.93592 | 0.00126 |
| 1.0 | 20E876D82248 | mlrrandnum_15_05 | 0.93220 | 0.00120 | lrrandnum_15_05 | 0.93251 | 0.00143 |
| 1.0 | 3F6E65CA7440 | mlrrandnum_15_06 | 0.93177 | 0.00141 | lrrandnum_15_06 | 0.93374 | 0.00121 |
| 1.0 | 479D21DB7509 | mlrrandnum_15_07 | 0.93217 | 0.00144 | lrrandnum_15_07 | 0.93572 | 0.00138 |
| 1.0 | 55D4371D3A23 | mlrrandnum_15_08 | 0.92921 | 0.00125 | lrrandnum_15_08 | 0.93498 | 0.00145 |
| 1.0 | 6E1A14672B8F | mlrrandnum_15_09 | 0.92980 | 0.00177 | lrrandnum_15_09 | 0.93224 | 0.00114 |
| 1.0 | 77A0308C0E44 | mlrrandnum_15_10 | 0.93070 | 0.00126 | lrrandnum_15_10 | 0.93158 | 0.00131 |

**Table 6.9.2.2-3. Neutron multiplication factors with standard deviations for the ES-3100 package models at the "MR" and "LR" node points**

| MOIFR | Random number | "A" cases | $k_{eff}$ | s | "B" cases | $k_{eff}$ | s |
|---|---|---|---|---|---|---|---|
| 1.0E-20 | 109E77866CF6 | mrandnum_01_01 | 1.04965 | 0.00119 | lrrandnum_01_01 | 1.05093 | 0.00133 |
| 1.0E-20 | 16AA4A58735C | mrandnum_01_02 | 1.05132 | 0.00131 | lrrandnum_01_02 | 1.05009 | 0.00118 |
| 1.0E-20 | 1814171B652A | mrandnum_01_03 | 1.05368 | 0.00123 | lrrandnum_01_03 | 1.05057 | 0.00118 |
| 1.0E-20 | 1A423B9472C7 | mrandnum_01_04 | 1.05165 | 0.00145 | lrrandnum_01_04 | 1.05066 | 0.00120 |
| 1.0E-20 | 20E876D82248 | mrandnum_01_05 | 1.05344 | 0.00106 | lrrandnum_01_05 | 1.04882 | 0.00129 |
| 1.0E-20 | 3F6E65CA7440 | mrandnum_01_06 | 1.05188 | 0.00157 | lrrandnum_01_06 | 1.05316 | 0.00127 |
| 1.0E-20 | 479D21DB7509 | mrandnum_01_07 | 1.05149 | 0.00148 | lrrandnum_01_07 | 1.05229 | 0.00134 |
| 1.0E-20 | 55D4371D3A23 | mrandnum_01_08 | 1.05083 | 0.00113 | lrrandnum_01_08 | 1.05186 | 0.00131 |
| 1.0E-20 | 6E1A14672B8F | mrandnum_01_09 | 1.04910 | 0.00106 | lrrandnum_01_09 | 1.05236 | 0.00113 |
| 1.0E-20 | 77A0308C0E44 | mrandnum_01_10 | 1.05254 | 0.00106 | lrrandnum_01_10 | 1.05098 | 0.00120 |
| | | | | | | | |
| 1.0E-04 | 109E77866CF6 | mrandnum_03_01 | 1.04994 | 0.00132 | lrrandnum_03_01 | 1.05122 | 0.00123 |
| 1.0E-04 | 16AA4A58735C | mrandnum_03_02 | 1.05023 | 0.00118 | lrrandnum_03_02 | 1.05324 | 0.00121 |
| 1.0E-04 | 1814171B652A | mrandnum_03_03 | 1.05090 | 0.00139 | lrrandnum_03_03 | 1.05143 | 0.00123 |
| 1.0E-04 | 1A423B9472C7 | mrandnum_03_04 | 1.05072 | 0.00115 | lrrandnum_03_04 | 1.05048 | 0.00121 |
| 1.0E-04 | 20E876D82248 | mrandnum_03_05 | 1.05052 | 0.00119 | lrrandnum_03_05 | 1.05095 | 0.00137 |
| 1.0E-04 | 3F6E65CA7440 | mrandnum_03_06 | 1.05383 | 0.00131 | lrrandnum_03_06 | 1.05029 | 0.00119 |
| 1.0E-04 | 479D21DB7509 | mrandnum_03_07 | 1.05205 | 0.00153 | lrrandnum_03_07 | 1.05124 | 0.00108 |
| 1.0E-04 | 55D4371D3A23 | mrandnum_03_08 | 1.05343 | 0.00106 | lrrandnum_03_08 | 1.05080 | 0.00116 |
| 1.0E-04 | 6E1A14672B8F | mrandnum_03_09 | 1.04831 | 0.00132 | lrrandnum_03_09 | 1.05074 | 0.00122 |
| 1.0E-04 | 77A0308C0E44 | mrandnum_03_10 | 1.05353 | 0.00111 | lrrandnum_03_10 | 1.05094 | 0.00111 |
| | | | | | | | |
| 0.10 | 109E77866CF6 | mrandnum_06_01 | 0.97948 | 0.00120 | lrrandnum_06_01 | 0.98315 | 0.00118 |
| 0.10 | 16AA4A58735C | mrandnum_06_02 | 0.98104 | 0.00125 | lrrandnum_06_02 | 0.98605 | 0.00124 |
| 0.10 | 1814171B652A | mrandnum_06_03 | 0.98056 | 0.00134 | lrrandnum_06_03 | 0.98690 | 0.00120 |
| 0.10 | 1A423B9472C7 | mrandnum_06_04 | 0.97895 | 0.00114 | lrrandnum_06_04 | 0.98347 | 0.00126 |
| 0.10 | 20E876D82248 | mrandnum_06_05 | 0.98058 | 0.00113 | lrrandnum_06_05 | 0.98770 | 0.00124 |
| 0.10 | 3F6E65CA7440 | mrandnum_06_06 | 0.97966 | 0.00119 | lrrandnum_06_06 | 0.98734 | 0.00140 |
| 0.10 | 479D21DB7509 | mrandnum_06_07 | 0.97953 | 0.00145 | lrrandnum_06_07 | 0.98417 | 0.00133 |
| 0.10 | 55D4371D3A23 | mrandnum_06_08 | 0.97993 | 0.00130 | lrrandnum_06_08 | 0.98712 | 0.00136 |
| 0.10 | 6E1A14672B8F | mrandnum_06_09 | 0.97972 | 0.00138 | lrrandnum_06_09 | 0.98533 | 0.00142 |
| 0.10 | 77A0308C0E44 | mrandnum_06_10 | 0.98157 | 0.00134 | lrrandnum_06_10 | 0.98412 | 0.00116 |
| | | | | | | | |
| 0.30 | 109E77866CF6 | mrandnum_08_01 | 0.93412 | 0.00118 | lrrandnum_08_01 | 0.93910 | 0.00146 |
| 0.30 | 16AA4A58735C | mrandnum_08_02 | 0.93227 | 0.00138 | lrrandnum_08_02 | 0.93757 | 0.00117 |
| 0.30 | 1814171B652A | mrandnum_08_03 | 0.93390 | 0.00131 | lrrandnum_08_03 | 0.93940 | 0.00146 |
| 0.30 | 1A423B9472C7 | mrandnum_08_04 | 0.93252 | 0.00144 | lrrandnum_08_04 | 0.93676 | 0.00130 |
| 0.30 | 20E876D82248 | mrandnum_08_05 | 0.93334 | 0.00132 | lrrandnum_08_05 | 0.93851 | 0.00111 |
| 0.30 | 3F6E65CA7440 | mrandnum_08_06 | 0.93168 | 0.00132 | lrrandnum_08_06 | 0.93914 | 0.00149 |
| 0.30 | 479D21DB7509 | mrandnum_08_07 | 0.93514 | 0.00123 | lrrandnum_08_07 | 0.94011 | 0.00131 |
| 0.30 | 55D4371D3A23 | mrandnum_08_08 | 0.93564 | 0.00132 | lrrandnum_08_08 | 0.93900 | 0.00139 |
| 0.30 | 6E1A14672B8F | mrandnum_08_09 | 0.93597 | 0.00136 | lrrandnum_08_09 | 0.93781 | 0.00117 |
| 0.30 | 77A0308C0E44 | mrandnum_08_10 | 0.93525 | 0.00128 | lrrandnum_08_10 | 0.93965 | 0.00118 |

**Table 6.9.2.2-3. Neutron multiplication factors with standard deviations for the ES-3100 package models at the "MR" and "LR" node points**

| MOIFR | Random number | "A" cases | $k_{eff}$ | s | "B" cases | $k_{eff}$ | s |
|---|---|---|---|---|---|---|---|
| 1.00 | 109E77866CF6 | mrandnum_15_01 | 0.93103 | 0.00139 | lrrandnum_15_01 | 0.93344 | 0.00126 |
| 1.00 | 16AA4A58735C | mrandnum_15_02 | 0.93082 | 0.00131 | lrrandnum_15_02 | 0.93281 | 0.00121 |
| 1.00 | 1814171B652A | mrandnum_15_03 | 0.92890 | 0.00148 | lrrandnum_15_03 | 0.93468 | 0.00132 |
| 1.00 | 1A423B9472C7 | mrandnum_15_04 | 0.93062 | 0.00145 | lrrandnum_15_04 | 0.93592 | 0.00126 |
| 1.00 | 20E876D82248 | mrandnum_15_05 | 0.93055 | 0.00125 | lrrandnum_15_05 | 0.93251 | 0.00143 |
| 1.00 | 3F6E65CA7440 | mrandnum_15_06 | 0.92950 | 0.00117 | lrrandnum_15_06 | 0.93374 | 0.00121 |
| 1.00 | 479D21DB7509 | mrandnum_15_07 | 0.92952 | 0.00116 | lrrandnum_15_07 | 0.93572 | 0.00138 |
| 1.00 | 55D4371D3A23 | mrandnum_15_08 | 0.92805 | 0.00154 | lrrandnum_15_08 | 0.93498 | 0.00145 |
| 1.00 | 6E1A14672B8F | mrandnum_15_09 | 0.93117 | 0.00140 | lrrandnum_15_09 | 0.93224 | 0.00114 |
| 1.00 | 77A0308C0E44 | mrandnum_15_10 | 0.93218 | 0.00120 | lrrandnum_15_10 | 0.93158 | 0.00131 |

### 6.9.2.3 Statistical Evaluation

An evaluation of KENO V.a calculation results is made to determine if there is a statistically significant difference between the mean $k_{eff}$ for the "MR" and "MLR" models, for the "MLR" and "LR" models, and for the "MR" and "LR" models. Cases are classified into five groups based on the amount of water assumed to be present in the shipping package. The symbol "I" is used to specify the case. The mean difference and standard deviation for each of the five sets of pair-wise differences are defined as follows:

(a) $d_i = (k_{effBi} \quad k_{effAi})/n$ and

(b) $s_{di} = \sqrt{[\, n\Sigma d_i^{\,2} \quad (\Sigma d_i)^2 \,] / n(n-1)}$ (conservatively defined for the t-test appropriate for small sample sizes),

where $A_i$ and $B_i$ denote the model types, and n denotes the sample size of ten. It is reasonable to assume that the paired differences have been randomly selected from a normally distributed population of paired differences with mean ($\mu_d$) and standard deviation ($\sigma_d$), then the sampling distribution of

$$(d - \mu_d) / (s_d/\sqrt{n})$$

is a *t* distribution having n-1 degrees of freedom.

The evaluation of the mean differences ($d_i$) for the 10 sets of cases is accomplished through hypothesis testing, a statistical tool used to provide evidence that a difference exists or does not exist. The $t_i$ values are given in Table 6.9.2.3-1. A value of 3.25 is obtained from the standard table for critical values for the t distribution from which the decision to accept or reject the null hypothesis $H_0$ is made with a Type I error probability ($\alpha$) of 0.01.

For $|t| < 3.25$, the $H_o$ hypothesis is not rejected. Acceptance of the null hypothesis is the result of insufficient evidence to reject it. Thus, it can be concluded that the mean estimates of the difference in $k_{eff}$ between the "MR" and "MLR" calculation models, between the "MLR" and "LR" calculation models, and between the "MR" and "LR" calculation models are not statistically significant for the dry condition where neutronic interaction between packages is significant. Also, the mean estimate of the difference in $k_{eff}$ between the "MR" and "MLR" calculation models is not statistically significant for wet or flooded conditions where the packages of the array become isolated.

**Table 6.9.2.3-1. T-test values for establishing the statistical significance of the differences in calculated $k_{eff}$ values for the ES-3100 package models at the "MR," "MLR," and "LR" node points**

| MOIFR | "MR" cases ($k_{eff}$) | "MLR" cases ($k_{eff}$) | di | Sdi | ta |
|---|---|---|---|---|---|
| 1.0E-20 | 1.05154 | 1.05075 | 0.00089 | 1.58991E-03 | 1.77 |
| 1.0E-04 | 1.05146 | 1.05165 | -0.00019 | 2.17840E-03 | -0.28 |
| 0.1 | 0.98008 | 0.98091 | -0.00087 | 1.33870E-03 | -2.06 |
| 0.3 | 0.93404 | 0.93300 | 0.00106 | 1.88912E-03 | 1.77 |
| 1.0 | 0.93030 | 0.93067 | -0.00034 | 1.68664E-03 | -0.65 |

| MOIFR | "MLR" cases ($k_{eff}$) | "LR" cases ($k_{eff}$) | di | Sdi | t |
|---|---|---|---|---|---|
| 1.0E-20 | 1.05075 | 1.05116 | -0.00050 | 1.92087E-03 | -0.83 |
| 1.0E-04 | 1.05165 | 1.05113 | 0.00041 | 9.36819E-04 | 1.38 |
| 0.1 | 0.98091 | 0.98546 | -0.00456 | 2.28535E-03 | -6.31 |
| 0.3 | 0.93300 | 0.93863 | -0.00578 | 1.59574E-03 | -11.45 |
| 1.0 | 0.93067 | 0.93369 | -0.00318 | 2.30797E-03 | -4.36 |

| MOIFR | "MR" cases ($k_{eff}$) | "LR" cases ($k_{eff}$) | di | Sdi | t |
|---|---|---|---|---|---|
| 1.0E-20 | 1.05154 | 1.05116 | 0.00039 | 2.35840E-03 | 0.52 |
| 1.0E-04 | 1.05146 | 1.05113 | 0.00021 | 2.19813E-03 | 0.31 |
| 0.10 | 0.98008 | 0.98546 | -0.00543 | 1.66324E-03 | -10.33 |
| 0.30 | 0.93404 | 0.93863 | -0.00472 | 1.46294E-03 | -10.21 |
| 1.00 | 0.93030 | 0.93369 | -0.00353 | 2.50750E-03 | -4.45 |

[a] critical value = 3.25 for 10 cases.

For $|t| > 3.25$, the $H_o$ hypothesis is rejected. Therefore, it can be concluded that the mean estimate of the difference in $k_{eff}$ between the "MLR" and "LR" calculation models, and between the "MR" and "LR" calculation models, is statistically significant for wet or flooded conditions where the packages of the array become isolated. The negative t-values indicate that the calculated $k_{eff}$ value for the "LR" model is slightly higher than for the "MR" and "MLR" models. This result is consistent with an expected increase in $k_{eff}$ due to "tighter or closer" water reflector surrounding the package content.

Although flattening of the side of the package represents a reduction in the diameter of the drum, the points at which minimum flattening occurs provide an indication of the reduction of lattice spacing between packages of an array under HAC. The composite of the minimum deformation points at perpendicular axes (90–270° and 0–180°) represents the modified lattice spacing in an array of ES-3100 packages. As illustrated in Table 6.9.2.3-2, the equivalent diameter of the package for "composite" lattice spacing is not significantly different from the 18.37-in. diam of the pre-test package. Even though significant crushing of the drum midsection and bottom occurs, the effective center-to-center spacing of the contents actually increases under HAC. Selective rearrangement of alternating packages would be required to achieve a more compact array; however, this event is not credible.

As described in Sect. 6.3.1.2, a close-pack (triangular-pitch) array of packages would be represented by a reduced package in a rectangular-pitch configuration. For HAC, the 17.26-in. reduced diameter for the "composite close-pack" package is slightly larger than the 17.20-in. diam of the "MLR" calculation model used in the HAC calculations of Sect. 6.6. Therefore, packages evaluated with the "MLR" calculation model of packages in a rectangular-pitch configuration are deemed adequate for the HAC criticality evaluation. Considering both the irregular shape of the deformed drums and that array spacing is determined by overall (maximum) dimensions rather than by mean or minimum dimensions of a damaged package, the use of the "MLR" model for representing the ES-3100 package under HAC is conservative and bounding.

**Table 6.9.2.3-2. Deformation of the ES-3100 drum projected by finite element analysis "Case 3100 RUN1HL Lower Bound Kaolite May 2004"**

| | FEA node | Diameter at 90° (in.) | Diameter at 180° (in.) | Equivalent circular diameter (in.) |
|---|---|---|---|---|
| Composite | 103012/098194 | 22.00 | 15.60 | 18.56 |
| Pre-test drum | - | 18.37 | 18.37 | |
| Pre-test, close-pack | - | 17.08 | 17.08 | |
| Composite, close-pack | 103012/098194 | - | - | 17.26 |

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# Appendix 6.9.3

# Package Material Compositions

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## Appendix 6.9.3

## Package Material Compositions

Table 6.4 (Sect. 6.3.2) provides basic information for deriving the compositions for the ES-3100 package (Figs. 6.1 and 6.2). The atomic densities presented in Table 6.4 can be verified using additional information provided in Appendix 6.9.5. The following sections provide the rationale, the justification, or both for the material compositions used in the criticality calculations.

### 6.9.3.1 HEU, Unirradiated TRIGA, and Research Reactor Related Contents

HEU considered for shipment in the ES-3100 is categorized into the following material forms: highly enriched uranium (HEU) solid or broken metal; HEU oxide; uranyl nitrate hexahydrate (UNH) crystals. In the interest of adding conservatism, uranium is modeled as $^{235}U$ and $^{238}U$, while the $^{234}U$ and $^{236}U$ isotopes are excluded. Any positive change in neutron multiplication represented by the presence of the $^{234}U$ is covered by the higher than actual $^{235}U$ content (Rothe). The theoretical density of 100 wt % $^{235}U$ HEU is 18.8111 g/cm$^3$. This value is determined by adjusting the density of natural uranium included in the SCALE Standard Composition Library with 100 wt % weight factors. The theoretical density of HEU oxide types are 10.96 g/cm$^3$ for $UO_2$, 8.30 g/cm$^3$ for $U_3O_8$, and 7.29 g/cm$^3$ for $UO_3$. The theoretical density of UNH crystals is 2.79 g/cm$^3$. Table 6.9.3.1-1 provides details of the calculated weight percentages input to KENO V.a calculated on the basis of the stoichiometric formula of $UO_2(NO_3)_2$+$6H_2O$ and crystalline density. The maximum enrichment considered in the analysis is 100 wt % $^{235}U$, although actual material enrichments are lower. The unirradiated solid form TRIGA fuel is uranium zirconium hydride ($UZrH_x$) where "x" is $\leq 2$, having a density of 8.65 g/cm$^3$. Research reactor related contents are fuel elements or fuel components, broken metal, U-Al alloy, or oxides. These contents are described at the end of this subsection.

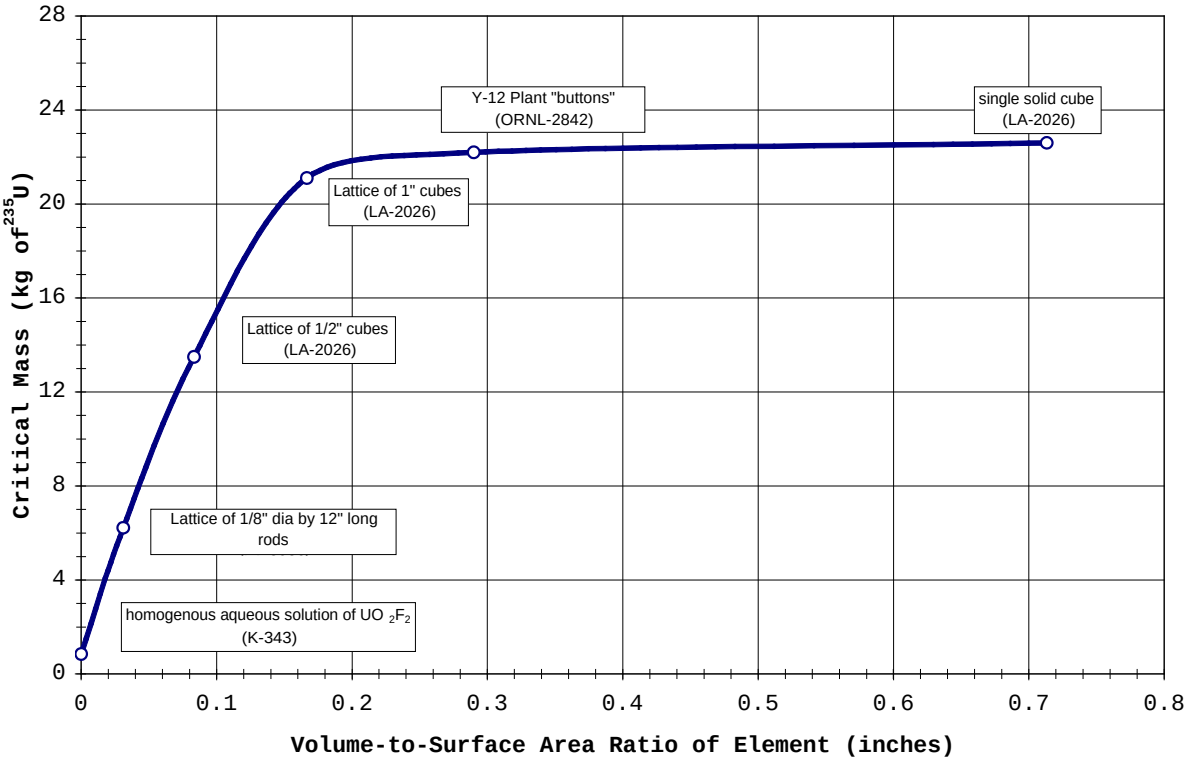
**Table 6.9.3.1-1. Calculation of constituent weight-percentage values for uranyl nitrate hexahydrate crystals used in KENO V.a calculation models**

| Avogadro No. ($N_o$) | 6.0221370E+23 | | | | | |
|---|---|---|---|---|---|---|
| **UNH** | | | | | | |
| $UO_2(NO_3)_2$+$6H_2O$ | Atoms/Molecule | At. wt [a] | Mole. wt. | wt % | calc. Ni | NiAi |
| Hydrogen | 12 | 1.0078 | 12.0936 | 2.4233 | 4.0401E+22 | 4.0716E+22 |
| Nitrogen | 2 | 14.0031 | 28.0062 | 5.6117 | 6.7333E+21 | 9.4286E+22 |
| Oxygen | 14 | 15.9949 | 223.9286 | 44.8690 | 4.7132E+22 | 7.5388E+23 |
| U-235 | | 235.0441 | | 100.0000 | | |
| U-238 | | 238.0510 | | 0.0000 | | |
| Uranium | 1 | 235.0441 | 235.0441 | 47.0962 | 3.3666E+21 | 7.9130E+23 |
| | | | 499.0725 | 100.0002 | | |
| summations | | | | 100.0002 | 9.7633E+22 | 1.6802E+24 |
| At. wt. material | | | | | | |
| assumed density | 2.7900 | | | | | |
| den.=($\sum N_i A_i$)/$N_o$ | | | | | | 2.7900 |

[a] Source: Nuclides and Isotopes, Chart of the Nuclides, 14th ed., General Electric Company, 1989.

HEU broken metal. The critical mass of fissile material is dependent on factors such as the form and shape of the material, bulk density if the material is broken into pieces, and the enrichment. Broken metal can be compared to the minimum critical mass of submerged metal lattices of regular-shaped fissile material. Using experimental data, the approximation of a heterogeneous mixture of fissile material and moderator to a homogeneous mixture is justified as follows.

Figure 6.9.3.1-1 depicts the experimentally determined minimum critical mass of U (~ 94) lattices immersed in water as a function of the volume-to-surface area ratio of the fissile element (TID-7028). The critical mass is shown to increase from 850 g to 21 kg over the range of volume-to-surface ratios from 0 to 0.18 in. The critical mass is nearly constant in the range of volume-to-surface ratios from 0.18 to 0.8 in. For pieces greater than 1-in. cubes, the minimum critical mass will not be less than 21 kg. For smaller pieces, the minimum critical mass is a nearly linear function of the volume-to-surface-area ratio of the fissile element.

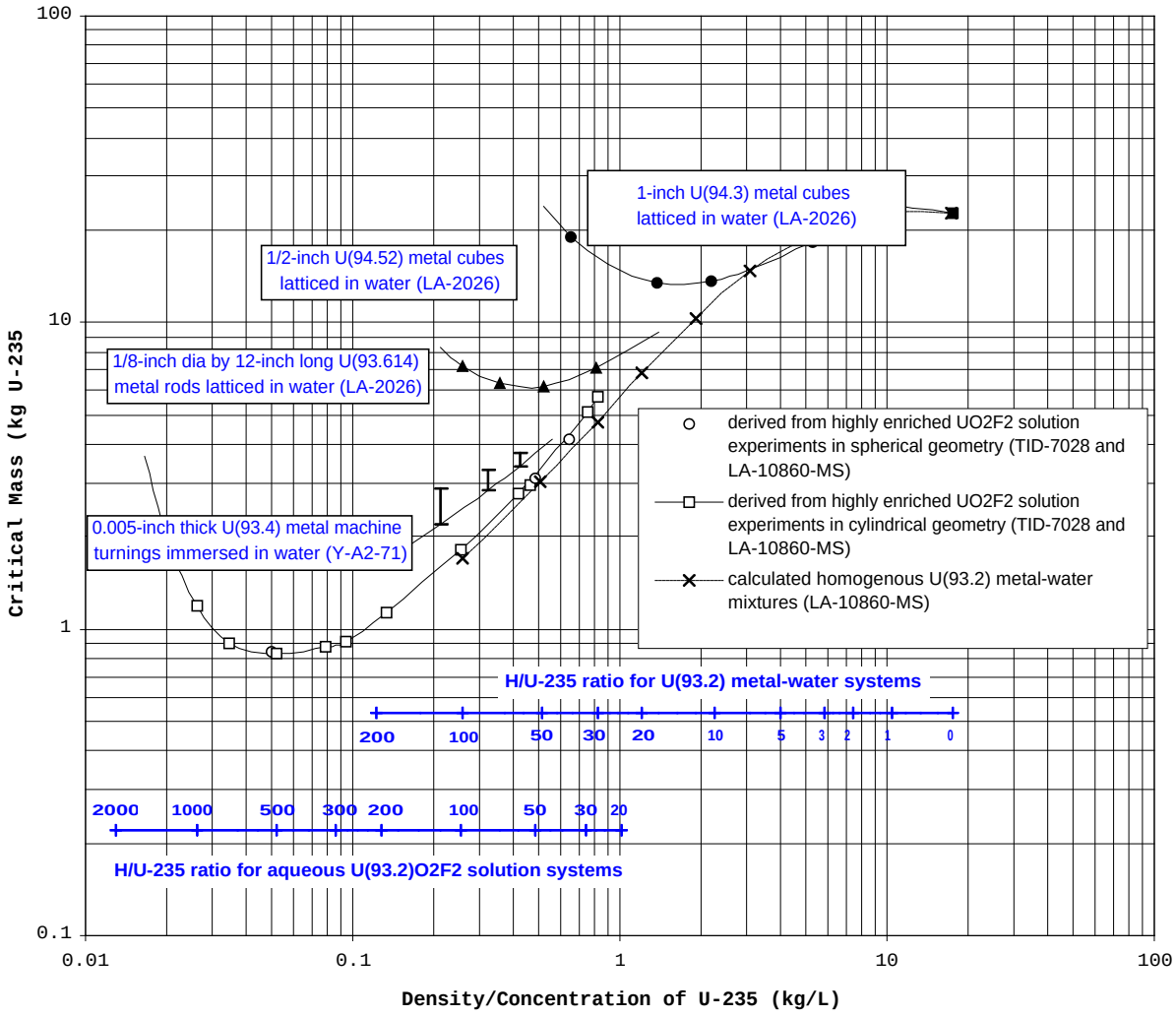



*Source*: H. C. Paxton et al., *Critical Dimensions of Systems Containing 235U*, TID-7028, Los Alamos Scientific Lab. and Oak Ridge Natl. Lab., June 1964, Fig. 19. Y-12 data have been added.

**Fig. 6.9.3.1-1. Experimentally determined minimum critical mass U(~94) metal lattices immersed in water as a function of volume-to-surface area ratio of fissile material.**

Figure 6.9.3.1-2 depicts the experimentally determined minimum critical mass of U (~ 94) metal water and solution systems as a function of the concentration of $^{235}$U. The figure with added data reveals that: (1) a minimum critical mass exists for each metal lattice system plotted, and (2) as the bulk density of uranium or the uranium concentration increases, the curves for the critical mass of metal lattice systems converge with the curve for highly enriched solution experiments or the curve for calculated homogeneous metal water mixtures. Conversely stated, the critical mass is greater for a heterogenous system than for a homogeneous system, and this difference increases as the H/X ratio increases.

Therefore, the practice of approximating a heterogeneous mixture of fissile material and moderator as a homogeneous mixture is justifiable and also conservative at the higher H/X ratios.




*Sources*: A. W. Krass, *Survey of Experimental Data Concerning the Critical Mass of Highly Enriched Uranium–Water Systems*, CCG-365, Lockheed Martin Energy Systems, Inc., Oak Ridge Y-12 Plant, July 13, 2000, Fig. 1. Y-12 data added.

**Fig. 6.9.3.1-2. Experimentally determined minimum critical mass of U(~94) metal water and solution systems as a function of the concentration of $^{235}$U.**

Approximating broken metal as a homogeneous mixture of uranium and water requires a defined space within which masses of the components are conserved. This space is generally characterized by a lattice constructed of unit cells and defined by the dimensions of the fissile material being approximated.

The broken HEU metal consists of large, irregular pieces ranging from 0.5 in. to several inches on a side as shown in Fig. 6.9.3.1-3. A lattice of cubes is chosen to represent broken metal inside the ES-3100 containment vessel. Due to the constraints of KENO V.a, an idealized configuration is defined by a square lattice circumscribed by the inner wall of the containment vessel. Water fills the truncated cylindrical regions between the inner wall of the containment vessel and the vertical faces of the lattice. Two additional models are developed to evaluate conservatism at various stages of model approximations for broken metal.



**Fig. 6.9.3.1-3. Pan of HEU broken metal.**

Together, these models include an explicit arrangement of HEU metal cubes forming a compact rectangular lattice inside the containment vessel, HEU metal homogeneously mixed with water within the rectangular lattice formed by the unit cells, and HEU metal homogeneously mixed with water within the volume of the containment vessel.

Parameters varied in each of these three models include (1) the cube size in the explicit model from 1.0 in. to 0.25 in. on a side, (2) water moderation inside the containment vessel from dry to the fully flooded condition, (3) enrichment from 100.0 wt % $^{235}$U to 20.0 wt % $^{235}$U, (4) thickness of the 277-4 canned spacers located between each convenience can, and (5) the mass of the uranium metal at each content location. One-quarter inch, 0.5-in., and 1.0-in. cubes are selected to evaluate "approach-to-homogeneity" of broken metal in this idealized form. The corresponding array configurations for 0.25-in., 0.5-in., and 1.0-in. cubes are 12 × 12 × N, 6 × 6 × N, and 3 × 3 × N. The N-th layer of unit cells for a given mass loading may not all contain HEU metal; the empty cells are filled with water. Nevertheless, a slight variation still arises in the total mass of HEU metal between these array configurations given whole cubes are contained in the calculation models.

The results for the calculation models representing the various configurations of broken uranium metal are shown in the Table 6.9.3.1-2. As the explicitly modeled cubes become smaller in size, the calculated $k_{eff}$ values for the explicit "sqa" models approach values for the "lha" models where HEU metal cubes are homogenized with water within the rectangular lattice formed by the unit cells of the array. A representative or converged $k_{eff}$ value is 0.87 for increasing by smaller cubes based on calculation results for the "lha" models. The "lha" results indicate a slight difference between the $k_{eff}$ values for the three array sizes; these differences are attributed to the difference in the HEU for the arrays of whole cubes.

Calculation results reveal that the explicit ("sqa") model of HEU broken metal in a water moderated lattice is bounded by the homogeneous mixture ("lha") model of HEU metal and water. Calculation results for the "cha" models, where arrays of cubes are fully homogenized with the water for

**Table 6.9.3.1-2. Summary for evaluation of HEU broken metal models (95 wt % $^{235}U$) in a flooded containment vessel, 1.4-in. canned spacers and full water reflection of containment vessel**

| Array type | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|
| **Discrete array of cubes ("sqa" cases)** | | | | | | | |
| $3 \times 3 \times n$ | 35,164 | 33,406 | 7,719 | 6.03 | 0.8352 | 0.0012 | 0.84 |
| $6 \times 6 \times n$ | 35,973 | 34,175 | 7,676 | 5.86 | 0.8559 | 0.0011 | 0.86 |
| $12 \times 12 \times n$ | 35,988 | 34,188 | 7,765 | 5.86 | 0.8603 | 0.0012 | 0.86 |
| **Cubes homogenized within footprint of lattice ("lha" cases)** | | | | | | | |
| $3 \times 3 \times n$ | 35,164 | 33,406 | 7,719 | 6.03 | 0.8586 | 0.0011 | 0.86 |
| $6 \times 6 \times n$ | 35,973 | 34,175 | 7,675 | 5.86 | 0.8650 | 0.0012 | 0.87 |
| $12 \times 12 \times n$ | 35,988 | 34,188 | 7,675 | 5.86 | 0.8677 | 0.0010 | 0.87 |
| **Cubes homogenized within containment vessel ("cha" cases)** | | | | | | | |
| $3 \times 3 \times n$ | 35,164 | 33,406 | 7,719 | 6.03 | 0.9427 | 0.0013 | 0.95 |
| $6 \times 6 \times n$ | 35,973 | 34,175 | 7,676 | 5.86 | 0.9495 | 0.0015 | 0.95 |
| $12 \times 12 \times n$ | 35,988 | 34,188 | 7,675 | 5.86 | 0.9517 | 0.0016 | 0.95 |

the flooded containment vessel, indicate the highest $k_{eff}$ values. The neutron multiplication factor jumps from 0.87 to 0.95. The "cha" model is deemed to be overly conservative when applied to broken metal for the following reasons:

- HEU metal does not dissolve in water.
- HEU metal is not in an oxide or powder form that will absorb moisture or readily mix and become homogenized with the water inside the flooded containment vessel.
- Because HEU metal is much denser than water, it will not float and become distributed throughout a flooded containment vessel; instead it will gravitate toward the bottom of the containment vessel.

However, the "cha" model is deemed an appropriate content model for the criticality evaluation when applied to HEU metal powder where fissile uranium as particulate is more fully homogenized with water than large pieces of broken metal and where fissile uranium could be in suspension. For simplicity, the "cha" model is chosen to represent HEU broken metal or metal powder inside a flooded containment vessel under full water reflection and as content in a single package or in arrays of packages under NCT and HAC. Details regarding the "sqa," "lha," and "cha" calculation models are presented in Appendix 6.9.1.

HEU Oxide. Theoretical (crystalline) densities for HEU oxide are 10.96 g/cm$^3$, 8.30 g/cm$^3$, and 7.29 g/cm$^3$ for $UO_2$, $U_3O_8$, and $UO_3$, respectively. While bulk densities of product oxides with enrichments ranging from 19 to 100 wt % $^{235}U$ are typically on the order of 6.54 g/cm$^3$, the bulk density of HEU oxides considered for shipment in the ES-3100 ranges from 2.0 to 6.54 g/cm$^3$. Therefore, only less-than-theoretical mass loadings would actually be achieved. Skull oxides are a mixture of graphite and $U_3O_8$ with densities on the order of 2.44 g/cm$^3$ for poured material and 2.78 g/cm$^3$ for tapped material. The combined water saturation and crystallization of the HEU oxide are not expected in the HAC, given that $UO_2$ and $UO_3$ are non-hygroscopic while $U_3O_8$ is only mildly hygroscopic. Table 6.9.3.1-3 provides summary data for 292 samples of canned skull oxide.

**Table 6.9.3.1-3. Summary data for 292 samples of skull oxide**

| Statistic | wt % U | wt % $^{235}$U | µg C/g U | µg C /g $^{235}$U | Net wt (g) | U wt (g) | $^{235}$U wt (g) |
|---|---|---|---|---|---|---|---|
| Maximum | 84.52 | 93.19 | 171,000 | 252,861 | **7,072** | 5,938 | 4,165 |
| Minimum | 12.93 | 20.28 | 13 | 17 | 442 | 312 | 221 |
| Median | 81.66 | 37.62 | 5,590 | 13,910 | 4,448 | 3,541 | 1,414 |
| Mean | 79.64 | 45.02 | 16,968 | 41,333 | 4,419 | 3,532 | 1,563 |
| Std dev | 6.87 | 16.40 | 24,304 | 59,027 | 745 | 698 | 606 |

Values of wt % U, wt % $^{235}$U, µg C/g U, etc. for a given statistic (maximum, minimum, medium, or mean) do not occur simultaneously in a specific sample. Inspection of sample data reveals the following characteristics:

(1) the fissile material content is ≤ 221 g $^{235}$U in samples with concentrations up to 252,861 µg C/g$^{235}$U,
(2) the enrichment is 93.2 wt % $^{235}$U for samples with concentrations in the range of 12,600 to 18,600 µg C/gU,
(3) the enrichment ranges from 60 to 70.2 wt % $^{235}$U for samples with concentrations in the range of 3,231 to 87,720 µg C/gU, and
(4) the enrichment ranges from 37 to 38 wt % $^{235}$U for samples with concentrations in the range of 400 to 233,366 µg C/gU.

Eight skull oxide compositions representative of 292 samples of canned skull oxide were selected for establishing the bounding content calculation models. The skull oxide content is assumed to be $U_3O_8$ plus graphite, polyethylene, and unidentified material. Two additional compositions were derived for addressing skull oxides with an enrichment of 93.2 wt % $^{235}$U where unidentified material is treated as $^{235}$U and the carbon content is either maximized or minimized. Treatment of the unidentified material as fissile material in the criticality analysis assures that its presence in skull oxide does not increase reactivity beyond what is considered in the bounding analysis.

The composition of the skull oxide content is given in terms of the following parameters: the grams skull oxide content in a content can (**gramskul**), the content bulk density (**densoc**), the wt % uranium in skull oxide content (**wtpuskul**), the wt % $^{235}$U in uranium (**wtpu25u**), and the grams of graphite in the content can (**gramg**). Values for the content specification parameters are provided in Table 6.9.3.1-3b.

**Table 6.9.3.1-3b. Content specification parameters for skull oxide content**

| Content | gramskul (g) | densoc (g/cm$^3$) | wtpuskul (wt %) | wtpu25u (wt %) | gramg (g) |
|---|---|---|---|---|---|
| sk_01 | 3863 | 1.899 | 58.92 | 69.78 | 139 |
| sk_02 | 4978 | 2.447 | 66.15 | 69.42 | 168 |
| sk_03 | 4607 | 1.981 | 72.77 | 69.88 | 124 |
| sk_04 | 5082 | 2.186 | 82.77 | 70.07 | 20 |
| sk_05 | 7072 | 3.042 | 83.97 | 69.91 | 9 |
| sk_06 | 5037 | 2.476 | 72.53 | 37.61 | 307 |
| sk_07 | 4385 | 2.156 | 75.15 | 37.55 | 203 |
| sk_08 | 4550 | 2.237 | 72.57 | 37.73 | 87 |
| sk_09 | 7100 | 3.054 | 78.95 | 93.20 | 307 |
| sk_10 | 7100 | 3.054 | 82.61 | 93.20 | 1.0E-05 |

The information in Table 6.9.3.1-3c is derived from the content specification parameters of Table 1-3b on the assumption that 513 g of polyethylene is present in the skull oxide content in three content locations inside the containment vessel.

The amount of skull oxide content (Column 2, Table 6.9.3.1-3c) is **gsoc** = 3.0 × **gramskul**.

The amount of uranium in the skull oxide content (Column 6, Table 6.9.3.1-3c) is **gusoc** = **gsoc** × **wtpuskul** / 100.0.

The amount of $^{235}U$ (Column 7, Table 6.9.3.1-3c) is **gr235** = **gusoc** × **wtpu25u** / 100.0.

The amount of graphite in the skull oxide content (Column 8, Table 6.9.3.1-3c) is **ggsoc** = 3.0 × **gramg**.

The micrograms graphite per gram uranium in skull oxide content (Column 9, Table 6.9.3.1-3c) is **mggraphgu** = **ggsoc** × 1.0e6 / **gusoc**.

The amount of $U_3O_8$ in the skull oxide content (**guox**) [Column 3, Table 6.9.3.1-3c] is **guox** = **gusoc** / **wtpuuox**,

where **gusoc** (Column 6, Table 6.9.3.1-3c),
**wtpuuox** is the weight percent uranium in uranium oxide, and
**wtpuuox** = **mwu** / **(mwu** + **mwo**),

where **mwu** = (3){(235.0441 × wtpu25u) + [238.0510 × (100 − wtpu25u)]} /100.0 and
**mwo** = (8)(15.9949).

The amount of unidentified material in skull oxide content (**gramunid**) [Column 12, Table 6.9.3.1-3c] is **gramunid** = (**gsoc** − **guox** − **ggsoc** − **grampoly**)

Skull oxide content is assumed to be saturated with water. The amount of saturation moisture (**gmsatm**) [Column 4, Table 6.9.3.1-3c] is **gmsatm** = 0.9982 × **volsatm**,

where **volsatm** is the volume of saturation moisture in the skull oxide content and
**volsatm** = **vsox** − **volminsox**

The volume of skull oxide (**vsox**) in the containment vessel is **vsox** = (**gsoc** / **densoc**) − (**grampoly** / **denpoly**),

where **gsoc** (Column 2, Table 6.9.3.1-3c),
**densoc** is the bulk density of skull oxide content,
**grampoly** is the 513 g of polyethylene, and
**denpoly** is the density of polyethylene, 0.92 g/cm$^3$.

The minimum volume of skull oxide (**volminsox**) in the containment vessel is **volminsox** = (**gsoc** − **grampoly** − **gramunid**) / **dnsoxtheo**,

where **gsoc** (column 2, Table 6.9.3.1-3c),
**grampoly** (513 g),
**gramunid** (column 12, Table 6.9.3.1-3c), and
**dnsoxtheo** is the theoretical density of skull oxide.

**Table 6.9.3.1-3c. Canned skull oxide (SO) content for ES-3100 calculation models, assuming 513 g polyethylene present and can spacers absent.**

| Content | SO (g) | UOx (g) | Sat. $H_2O$ (g) | SO h/x | U (g) | $^{235}U$ (g) | C (g) | µg C/ g $^{235}U$ | CV $H_2O$ (g) | CV h/x | Unident (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| sk_01 | 11,589 | 8,063 | 4,468 | 28.09 | 6,828 | 4,765 | 417 | 87,518 | 4,105 | 50.58 | 2,596 [a] |
| sk_02 | 14,934 | 11,665 | 4,015 | 17.79 | 9,879 | 6,858 | 504 | 73,492 | 4,105 | 33.41 | 2,252 [a] |
| sk_03 | 13,821 | 11,876 | 4,893 | 20.62 | 10,058 | 7,028 | 372 | 52,930 | 3,233 | 32.62 | 1,060 [a] |
| sk_04 | 15,246 | 14,900 | 4,599 | 15.52 | 12,619 | 8,842 | 60 | 6,786 | 3,235 | 25.07 | -227 [b] |
| sk_05 | 21,216 | 21,036 | 3,869 | 9.49 | 17,815 | 12,455 | 27 | 2,168 | 3,235 | 16.27 | -360 [b] |
| sk_06 | 15,111 | 12,933 | 3,765 | 28.02 | 10,960 | 4,122 | 921 | 223,432 | 4,105 | 54.01 | 744 [a] |
| sk_07 | 13,155 | 11,666 | 3,989 | 32.68 | 9,886 | 3,712 | 609 | 164,054 | 4,106 | 61.55 | 367 [a] |
| sk_08 | 13,650 | 11,689 | 4,068 | 33.01 | 9,906 | 3,737 | 261 | 69,834 | 4,106 | 61.69 | 1,187 [a] |
| sk_09 | 21,300 | 19,865 | 3,801 | 7.43 | 16,816 | 15,673 | 921 | 58,764 | 3,235 | 12.82 | 1 |
| sk_10 | 21,300 | 20,786 | 3,905 | 7.27 | 17,596 | 16,399 | 0 | 0 | 3,235 | 12.41 | 1 |

[a] Positive value specifies grams of miscellaneous neutron-absorber elements in content, modeled as water.
[b] Negative value specifies grams of excess polyethylene included in the content model.

The theoretical density of skull oxide (**dnsoxtheo**) is **dnsoxtheo** = (**ggsoc** + **guox**) / [(**ggsoc** / **dnctheo**) + (**guox** / **dnuoxtheo**)],

where **ggsoc** (Column 8, Table 6.9.3.1-3c),
**guox** (Column 3, Table 6.9.3.1-3c),
**dnuoxtheo** is the theoretical density of $U_3O_8$, 8.3 g/cm$^3$, and
**dnctheo** is the theoretical density of graphite, 4.2 g/cm$^3$.

The hydrogen to fissile uranium ratio of canned skull (Column 5, Table 6.9.3.1-3c) is **sochtox** = {[(**gmsatm** × **wtphwat**) + (**grampoly** × **wtphpoly**)] × **atwu25**} / (**gr235** × **atwth** × 100.0),

where **gmsatm** (column 4, Table 6.9.3.1-3c)**,**
**wtphwat** is the weight percent hydrogen in water, 11.1913%,
**grampoly** (513 g),
**wtphpoly** is the weight percent hydrogen in polyethylene, 14.3811%,
**atwu25** is the atomic weight of $^{235}U$, 235.0441,
**gr235** (column 7, Table 6.9.3.1-3c), and
**atwth** is the atomic weight of hydrogen, 1.0078.

The amount of water in the voided region of the CV (column 10, Table 6.9.3.1-3c) is **gwatcv** = 0.9982 × **volvcv**,

where **volvcv** is the void volume of the CV and
**volvcv** = (**cvarea** × **cvih**) − (**gsoc** / **densoc**),

where **cvarea** is the internal area (129.73536 cm$^2$) of the CV,
**cvih** is the internal height (78.74 cm),
**gsoc** (column 2, Table 6.9.3.1-3c), and
**densoc** (Table 6.9.3.1-3b).

The hydrogen to fissile uranium ratio inside the containment vessel (Column 11, Table 6.9.3.1-3c) is
**htox** = ⟨{[(**gmsatm** + **gwatcv**) × **wtphwat**] + [**grampoly** × **wtphpoly**]}
× **atwu25**⟩ / (**gr235** × **atwth** × 100.0),

where **gmsatm** (column 4, Table 6.9.3.1-3c),
**gwatcv** is the amount of water in the voided region of CV,
**wtphwat** is the weight percent hydrogen in water, 11.1913%,
**grampoly** (513 g),
**wtphpoly** is the weight percent hydrogen in polyethylene, 14.3811%,
**atwu25** is the atomic weight of $^{235}U$, 235.0441,
**gr235** (Column 7, Table 6.9.3.1-3c), and
**atwth** is the atomic weight of hydrogen, 1.0078.

Unirradiated TRIGA reactor fuel. TRIGA fuel is uranium zirconium hydride ($UZrH_x$), an alloy of uranium metal homogeneously dispersed as fine particles in a zirconium hydride matrix. The fuel is stable because uranium hydride does not form to any considerable extent. Moreover, uranium hydride has never been detected in the photomicrographic evaluations of TRIGA fuel.

The General Atomics catalog of stock items lists ~40 TRIGA fuel elements classified into four basic types: standard element, instrumented element, fuel-follower control rod, or cluster assembly. The TRIGA element active fuel region consists of three 5-in long sections "fuel meats" of $UZrH_x$. The H/Z atom ratio "x" in $UZrH_x$ equals 1.6 in all cases except for two stock items. For these cases, x = equals 1.0 and the fissile content is < 40 g $^{235}U$. The unirradiated solid form TRIGA fuel is identified as either 20 % enriched or 70 % enriched, and has dimensions and material properties specific to its design function.

The fuel diameter for the 20 % enriched TRIGA elements is either 1.44 in., 1.41 in., 1.40 in., 1.37 in., 1.34 in., or 1.31 in. The uranium composition of the fuel is 45 wt %, 30 wt %, 20 wt %, 12 wt %, and 8.5 wt %. As illustrated in Table 6.9.3.1.4-a, the TRIGA element with a maximum fissile content of 307 g $^{235}U$ in 1,560 g U, 45 wt% U in $UZrH_x$, and a H/Zr atom ratio of 1.6 has a computed fuel density of ~8.66 g/cm$^3$. The calculated number density ($N_i$) for each element or isotope is also given. The TRIGA fuel element with a fuel diameter of 1.44 in. contains 3,466.7 g $UZrH_x$. Further evaluation of the manufacturers data reveals that fuel density is proportional to the uranium weight fraction. Calculated density values are: 8.6597 g/cm$^3$ for 45 wt% U in $UZrH_x$, 6.8995 g/cm$^3$ for 30 wt% U in $UZrH_x$, 6.2825 g/cm$^3$ for 20 wt% U in $UZrH_x$, 5.9328 g/cm$^3$ for 12 wt% U in $UZrH_x$, and 5.7895 g/cm$^3$ for 8.5 wt% U in $UZrH_x$.

The active fuel diameter for 70 % enriched TRIGA fuel is 1.44 in. in both the standard element and instrumented element, and 1.31 in. in the fuel follower control rod. The uranium composition of the fuel is 8.5 wt %. The standard element and instrumented elements contain ~136 g $^{235}U$ in 194 g U while the fuel follower control rod contains ~113 g $^{235}U$ in 162 g U. As the calculation in Table 6.9.3.1.4-b illustrates, the 70 wt % enriched TRIGA fuel has a computed density of ~5.70 g/cm$^3$. The TRIGA fuel element with a fuel diameter of 1.44 in. contains 2,282.4 g $UZrH_x$ while the element with a fuel diameter of 1.31 in. contains 1,888.9 g $UZrH_x$.

The clad thickness is ~0.02 in. for a TRIGA fuel element with stainless steel cladding and ~0.03 in. for an element with aluminum cladding. In preparation for shipment in the ES-3100, a TRIGA fuel element is disassembled, the fuel meats are removed from the thin cladding and packed into convenience cans.

**Table 6.9.3.1-4a. Calculation of constituent weight-percentage values for 20 wt % enriched uranium-zirconium hydride content in KENO V.a calculation models**

| Avogadro No. ($N_o$) = | 6.0221370E+23 | | | | | | |
|---|---|---|---|---|---|---|---|
| **U($ZrH_x$)** | | | | | | | |
| **atom** | **wt %** | **x** | **mass (g)** | **at. wt.** | | **calc. $N_i$** | **$N_iA_i$** |
| Hydrogen | 0.9554 | 1.6 | | 1.00780 | 1.6125 | 4.9439E+22 | 4.9824E+22 |
| Zirconium | 54.0447 | 1 | | 91.21960 | 91.2196 | 3.0897E+22 | 2.8184E+24 |
| u-235 | 19.6795 | | 307.0 | 235.04410 | | | |
| u-238 | 80.3205 | | | 238.05099 | | | |
| uranium | 45.0000 | | 1560.0 | 237.45318 | 75.9535 | 9.8830E+21 | 2.3468E+24 |
| | 100.0001 | | | | 168.7856 | | |
| summations | 100.0001 | | | | | 9.0219E+22 | 5.2150E+24 |
| At. wt molecule | | | | | | | |
| Volume ($cm^3$) | 400.3200 | | | | | | |
| Mass (g) | 3466.66667 | | | | | | |
| density ($g/cm^3$) | 8.65974 | | | | | | |
| den.=($\sum N_iA_i)/N_o$ | | | | | | | 8.6597 |

**Table 6.9.3.1-4b. Calculation of constituent weight-percentage values for 70 wt % enriched uranium-zirconium hydride content in KENO V.a calculation models**

| Avogadro No. ($N_o$) = | 6.0221370E+23 | | | | | | |
|---|---|---|---|---|---|---|---|
| **U($ZrH_x$)** | | | | | | | |
| **atom** | **wt %** | **x** | **mass (g)** | **at. wt** | | **calc. $N_i$** | **$N_iA_i$** |
| Hydrogen | 1.5894 | 1.6 | | 1.00780 | 1.6125 | 5.4148E+22 | 5.4571E+22 |
| Zirconium | 89.9107 | 1 | | 91.21960 | 91.2196 | 3.3841E+22 | 3.0870E+24 |
| u-235 | 70.1031 | | 136.0 | 235.04410 | | | |
| u-238 | 29.8969 | | | 238.05099 | | | |
| uranium | 8.5000 | | 194.0 | 235.93508 | 8.6237 | 1.2370E+21 | 2.9184E+23 |
| | 100.0001 | | | | 101.4558 | | |
| summations | 100.0001 | | | | | 8.9227E+22 | 3.4334E+24 |
| At. wt molecule | | | | | | | |
| Volume ($cm^3$) | 400.3200 | | | | | | |
| Mass (g) | 2282.35294 | | | | | | |
| density ($g/cm^3$) | 5.70132 | | | | | | |
| den.=($\sum N_iA_i)/N_o$ | | | | | | | 5.7013 |

The TRIGA fuel may also be configured as clad fuel rods. Each clad fuel rod will be derived from a single TRIGA fuel element by removal of the stainless steel or aluminum clad extending beyond the plenum adjacent to the axial ends of the active fuel section. Each ~15-in.-long rod consists of the 3 fuel pellets and an

exterior sheath of stainless steel or aluminum clad, where the protruding clad at each end has been crimped in. The fuel rods will be packed into stainless steel or tin-plated carbon steel convenience cans, with a maximum of three fuel rods per loaded convenience can. This shipping configuration requires a minimum of two convenience cans; where only one convenience can is loaded with clad fuel rods. The loaded can is 17.5-in. tall while the empty one is 8.75-in. tall. Although can spacers are not required for criticality control, can spacers or stainless steel pads may be used to take up free volume over the 31 in. internal height of the containment vessel. The maximum quantity of fissile material per package is 408 g $^{235}U$.

The clad fuel rod with 1.44-in.-diam fuel pellets contains 2,282.4-g $_{UZrHx}$ while rod with the 1.31-in.-diam fuel pellets contains 1,888.9-g $UZrH_x$. The 0.02-in.-thick sheath of stainless steel clad adds ~179 g to the mass of the active fuel for the 1.48-in.-diam standard element or instrumented element, and ~163 g to active fuel mass for the 1.35-in.-diam fuel follower control rod. Allowance for ½ in. of residual stainless steel crimped on each end of the clad fuel rod adds ~11–12-g stainless steel to these amounts. Likewise, the 0.03 in thick sheath of aluminum clad adds ~90 g to the mass of the active fuel for the 1.47-in.-diam standard element or instrumented element. Allowance for ½ in. of residual aluminum crimped on each end of the clad fuel rod adds ~6-g aluminum.

Research reactor fuel elements or fuel components are composed of U-Al, $U_3O_8$-Al, or $UO_2$-Mg. These items contain small quantities of fissile uranium typically ranging from 4.2–152-g $^{235}U$. The maximum enrichment is ~93%. Components are of various solid shapes (rods, square bars, plates, or tubes) where diameters typically range from 0.18 to 4.0 in. and cross-sections typically range from 0.05 × 1.28 in. for an individual piece and 3.14 × 3.0 in. for an assembly of pieces. The active length for the various solid shapes ranges from 19.7 to 24 in.

$U_3O_8$-Al fuel elements are evaluated for demonstrating that research reactor related oxide contents are bounded by limits specified for TRIGA content. An aluminum-clad THAR plate (0.224 × 7.23 × 60.96 cm) contains ~101.52212 g of uranium and the enrichment is 20% $^{235}U$. Table 6.9.3.1-4c presents the calculation of density values at enrichments of 20%, 70%, and 93.2% $^{235}U$ using plate dimensions, uranium mass, and theoretical density values of 8.3 g/cm$^3$ for $U_3O_8$ and 2.702 g/cm$^3$ for aluminum.

**Table 6.9.3.1-4c. Calculation of constituent weight-percentage and content density values for 20 wt %, 70 wt %, and 93.2 wt % enriched uranium oxide-aluminum content in KENO V.a calculation models [a]**

| | Plate dimension | (cm) | Element | at. wt. | wt % | Density (g/cm$^3$) | Mass (g) | |
|---|---|---|---|---|---|---|---|---|
| | thickness | 0.224 | Al | 26.9818 | 100 | 2.702 | - | |
| | width | 7.230 | $U_3O_8$ | variable | 100 | 8.3 | - | |
| | length | 60.960 | U | - | - | - | 101.52212 | |

| Isotope | at. wt. | wt % | Isotope | at. wt. | wt % | Isotope | at. wt. | wt % |
|---|---|---|---|---|---|---|---|---|
| $^{235}U$ | 235.0442 | 20.0 | $^{235}U$ | 235.0442 | 70.0 | $^{235}U$ | 235.0442 | 93.2 |
| $^{238}U$ | 238.0510 | 80.0 | $^{238}U$ | 238.0510 | 30.0 | $^{238}U$ | 238.0510 | 6.8 |
| U | 237.4435 | 84.77161 | U | 235.9382 | 84.68933 | U | 235.2463 | 84.65121 |
| O | 15.9954 | 15.22839 | O | 15.9954 | 15.31067 | O | 15.9954 | 15.34879 |
| $U_3O_8$ | 840.2937 | 100.0 | $U_3O_8$ | 835.7779 | 100.0 | $U_3O_8$ | 833.7020 | 100.0 |

| Enrichment (%) | $U_3O_8$ (g) | Vol $_{U3O8}$ (cm$^3$) | Vol $_{Al}$ (cm$^3$) | Vol $_{Total}$ (cm$^3$) | Al (g) | wt % $_{U3O8}$ | wt % $_{Al}$ | Density (g/cm$^3$) |
|---|---|---|---|---|---|---|---|---|
| 20 | 119.75958 | 14.42886 | 84.29707 | 98.72594 | 227.77069 | 34.46019 | 65.53981 | 3.52015 |
| 70 | 119.87593 | 14.44288 | 84.28306 | 98.72594 | 227.73282 | 34.48588 | 65.51412 | 3.52095 |
| 93.2 | 119.92992 | 14.44939 | 84.27655 | 98.72594 | 227.71524 | 34.49780 | 65.50220 | 3.52132 |

[a] Actual material at 20% enrichment, hypothetical materials at 70% and 93.2% enrichments.

A $UO_2$-Mg fuel element is evaluated for demonstrating that this form of research reactor related content is also bounded by limits specified for TRIGA content. An aluminum-clad EK-10 fuel rod (2.54 cm diameter and 139.7 cm length) contains ~92.35 g of uranium dioxide, 13.03 g of magnesium and 65.7 g of aluminum as cladding. The $^{235}U$ content is 8.05 g with a corresponding enrichment of 9.89%. Table 6.9.3.1-4d presents the calculation of density values at enrichments of 9.89%, 20%, and 93.2% $^{235}U$ using rod dimensions, material masses and theoretical density values of 10.96 g/cm$^3$ for $UO_2$ and 2.702 g/cm$^3$ for aluminum. For $UO_2$ content at 93.2% $^{235}U$, an oxide density of 6.54 g/cm$^3$ is assumed consistent with bulk densities observed for product oxides with enrichments ranging from 19–100 wt % $^{235}U$.

**Table 6.9.3.1-4d. Calculation of constituent weight-percentage and content density values used in KENO V.a calculation models for 9.89 wt %, 20 wt %, and 93.2 wt % enriched uranium dioxide-magnesium, aluminum clad content, and for 93.2 wt % enriched uranium dioxide content [a]**

| | | $UO_2$-Mg | | | | Active | Overall | $UO_2$ | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Diam (cm) | | 0.69017 | 1.00000 | | |
| | | | | Length (cm) | | 50.50000 | 55.00000 | | |
| | | | | Vol (cm$^3$) | | 11.85982 | 43.19690 | | |
| | | 9.88 wt % $^{235}U$ | | 20 wt % $^{235}U$ | | 93.2 wt % $^{235}U$ | | 93.2 wt % $^{235}U$ | |
| | at. wt. | wt % | Mass (g) | wt % | Mass (g) | wt % | Mass (g) | wt % | Mass (g) |
| $^{235}U$ | 235.04420 | 9.88943 | 8.050 | 20.00000 | 16.280 | 93.20000 | 75.865 | 93.20000 | 408.000 |
| $^{238}U$ | 238.05100 | 90.11057 | 73.350 | 80.00000 | 65.120 | 6.80000 | 5.535 | 6.80000 | 29.768 |
| U | 237.75020 | 88.14018 | 81.400 | 88.12668 | 81.400 | 88.02906 | 81.400 | 88.02906 | 437.767 |
| O | 15.99540 | 11.85982 | 10.953 | 11.87332 | 10.967 | 11.97094 | 11.069 | 11.97094 | 59.531 |
| $UO_2$ | 269.74100 | | 92.353 | | 92.367 | | 92.469 | | 497.298 |
| Mg | 24.30480 | 100.00 | 13.030 | 100.00 | 13.030 | 100.00 | 13.030 | - | - |
| Al | 26.98180 | 100.00 | 65.670 | 100.00 | 65.670 | 100.00 | 65.670 | - | - |
| Total | | | **171.053** | | **171.067** | | **171.169** | | **497.298** |
| wt % U | | 47.58759 | | 47.58369 | | 47.55534 | | 88.02906 | |
| wt % O | | 6.40328 | | 6.41096 | | 6.46671 | | 11.97094 | |
| wt % Mg | | 7.61752 | | 7.61690 | | 7.61236 | | - | |
| wt % Al | | 38.39161 | | 38.38846 | | 38.36559 | | - | |
| Density (g/cm$^3$) | | 3.95984 | | 3.96017 | | 2.60651 | | 6.95000 | |

[a] "per rod" values cited for $UO_2$-Mg. Actual material at 9.9% enrichment, hypothetical materials at 20% and 93.2% enrichments. Bulk values cited for $UO_2$.

### 6.9.3.2 Type 304 Stainless Steel

The metallic components of the ES-3100 package are composed of Type 304 stainless steel. These include the containment vessel, the convenience cans, the drum liner, and the drum. Type 304 stainless steel with a density of 7.9400 g/cm$^3$ is included as a material in the SCALE Standard Composition Library.

### 6.9.3.3 277-4 Neutron Absorber

Catalog No. 277-0 dry mix is a proprietary mixture for producing a heat-resistant shielding material which combines the most effective shielding components into a single homogeneous composite. The shielding composite material is designed to maximize the hydrogen content necessary for

thermalizing fast neutrons for capture in the boron constituent. Widely used in nuclear power plant applications, the heat-resistant shielding material is capable of retaining a significant portion of its shielding properties up to 230°C (450°F). The recommended operating limit is 350°F, which is well above HAC temperatures expected inside the body weldment liner inner cavity and canned spacers.

The 277-4 neutron-absorber material used in the ES-3100 is a formulation of Cat 277-0 dry mix, a boron carbide additive, and water. 277-4 is produced through a quality-controlled batch process of dry blending, wet mixing, vibration casting, and timed cure (Equipment Specification JS-YMN3-801580-A005, Appendix 1.3.5). "Loss On Drying" (LOD) tests are used to measure the amount of water in the as-manufactured 277-4 casting. The as-manufactured 277-4 at 100 $lb/ft^3$ and 31.8 % LOD has a hydrogen concentration of 3.56 wt % and a natural boron concentration of 4.359 wt % (DAC-PKG-801624-A001, Table 5).

The ability of 277-4 to perform its function depends upon the masses of hydrogen and $^{10}B$ locked inside the high alumina borated cement cast into the body weldment liner inner cavity and the spacer cans. A calculated amount of boron carbide is added to Cat 277-0 dry mix for producing as-manufactured 277-4 material with a volumetric isotopic concentration $>7.621 \times 10^{20}$ $at/cm^3$ of $^{10}B$. The additive is boron carbide ($B_4C$) with small amount of a frit-like compound and trace amounts of unaccounted elements (0.17 wt %). Boron carbide has a theoretical density from 2.45 to 2.52 $g/cm^3$. 277-4 contains a large amount of hydrated alumina, also known as aluminum trihydrate [$Al(OH)_3$]. It is a nonabrasive powder with a specific gravity of 2.42. Given that both materials are of like density and similar particle size, separation and in homogeneity of 277-4 material is not expected during the controlled vibration casting process.

Table 6.9.3.3-1 provides detailed elemental composition data derived for as-manufactured neutron-absorber material at 100 $lb/ft^3$ and 31.8% LOD. This material description allows for clear specification of reduced boron and water contents required in the evaluation of NCT and HAC. As shown in Table 6.9.3.3-1, both the water and boron components are extracted from the material specification for the neutron absorber, and the constituent weight percents are recalculated accordingly (green box). 277-4 is specified in KENO V.a as three arbitrary materials: **arbmnpmx** with a density of 1.02276 $g/cm^3$, **arbmnph2o** with a density of 0.509253 $g/cm^3$, and **arbmboron** with a density of 6.98257E-02 $g/cm^3$. Model densities for 277-4 inside the body weldment liner inner cavity are reduced by a factor of 0.966893 to account for a material gap at the top of the liner. This material description allows for clear specification of reduced boron and water contents required in the evaluation of NCT and HAC.

The testing of 277-4 reveals that the material will dehydrate at elevated temperatures. Test specimens were dried at 250°F for 168 hours to reach the NCT state, and weight measurements were taken. These specimens where subsequently heated to 320°F for 4 hours to reach the HAC state, and weight measurements were again taken. The compositions of 277-4 at NCT and HAC states were derived by adjustment of the formulation specification for measured losses taking into account the statistical variations in the data. Conservation of mass for nonvolatile materials was observed in the derivation of material specifications based upon testing. Given that hydrogen must be present for the neutron absorber to be effective, conservative material specifications were derived for minimum hydrogen content and minimum material density.

Tables 6.9.3.3-2 and 6.9.3.3-3 respectively provide NCT and HAC composition data for as-manufactured 277-4 material at minimum density and hydrogen content. Respectively, Tables 6.9.3.3-4 and 6.9.3.3-5 provide NCT and HAC composition data or as-manufactured neutron-absorber material at minimum density and boron content. Because the amount of $^{10}B$ present in the neutron-absorber material is near saturation, a change in the hydrogen concentration has a major effect on the neutron multiplication factor, while a change in the amount of boron has a minor effect.

The neutron-absorbing material used in the ES-3100 Shipping Package will perform as analyzed. The analysis of 277-4 with criticality calculations is adequate in lieu of neutron transmission testing for the demonstration of acceptable performance by experimental means. Criticality calculations show boron content is adequate and $k_{eff}$ is not dependent on absolute (microscopic) homogeneity. Geometry characteristics of the ES-3100 system preclude the need for uniformity in boron areal density as a prerequisite for criticality safety control. The neutron-absorbing material will be fabricated under strict quality control and accepted for use under an NQA-1 compliant quality assurance (QA) program. A QA-approved mixing process provides a method for creating an exact mix for the neutron absorber during ES-3100 fabrication. An important part of this QA-approved process is a 277-4 material verification and acceptance testing program. The following discussion elaborates on these key points:

The analysis of 277-4 with criticality calculations is adequate in lieu of neutron transmission testing for the demonstration of acceptable performance. Early on in the licensing process, BoroBond 4 ™ was selected as the neutron-absorber material for use in the ES-3100 package. The decision to use BoroBond 4 ™ in the ES-3100 was made because of favorable experience with its use in the Highly Enriched Uranium Materials Facility Rackable Can Storage Box (RCSB). From an economic standpoint, however, BoroBond 4 ™ proved not to be a viable option for the small quantities needed for the ES-3100 project. 277-4 neutron-absorber material, which has very similar nuclear material properties to BoroBond 4 ™, was then selected as an alternative.

Both the RCSB and the ES-3100 are fast systems in the normal condition when the HEU fissile material is essentially unmoderated. A key factor for an effective neutron absorber is that hydrogen should be present for moderation, and it should be interspersed with $^{10}B$, thus promoting neutron capture. The potential for neutron streaming through an absorber is significant when a hydrogenous moderator is absent, as in the case of an aluminum boron-carbide matrix (a Boral alloy).

BoroBond 4 is a ceramicrete material with slightly greater than 4 wt % boron carbide ($B_4C$). The boron carbide powder is micro encapsulated by the crystalline matrix of the ceramic; therefore, leaching out the boron is not feasible. In BoroBond 4, 100 wt % of the $B_4C$ has a particle size <500 µm; 90 wt % of the other constituents range from <164 µm to <36 µm. Given the differences in particle size, the potential for separation in the mixing process is real.

Some of the questions regarding the use of 277-4 as a neutron poison in the ES-3100 were previously addressed regarding the use of BoroBond 4 in the RCSB. Radiography was performed on BoroBond 4 samples ranging in thickness from 1.0 to 1.5 in. Inspections revealed little or no visual differences, indicating uniformity of the BoroBond 4. For 277-4 where the $B_4C$ grit is on the order of 100 µm, the potential for separation is reduced.

**Table 6.9.3.3-1. Calculation of constituent weight-percentage values used in KENO V.a calculation models for as-manufactured 277-4 at minimum acceptable density and boron content**

| | | | arbmboron | arbmnpmx | arbmnph2o | | | **arbmboron** | **arbmnpmx** | **arbmnph2o** |
|---|---|---|---|---|---|---|---|---|---|---|
| 31.8% LOD | At. wt | lb/ft$^3$ | lb/ft$^3$ | lb/ft$^3$ | lb/ft$^3$ | | **NID** | **wt %** | **wt %** | **wt %** |
| H | 1.0078 | 3.5579 | | | 3.5579 | H | 1001 | | | 11.1913% |
| B10 | 10.0129 | 0.7911 | 0.7911 | | | B10 | 5010 | 18.1482% | | |
| B11 | 11.0093 | 3.5680 | 3.5680 | | | B11 | 5011 | 81.8518% | | |
| C | 12.0000 | 1.2251 | | 1.2251 | | C | 6012 | | 1.9187% | |
| N | 14.0031 | 0.0090 | | 0.0090 | | N | 7014 | | 0.0141% | |
| O | 15.9949 | 55.9620 | | 27.7281 | 28.2339 | O | 8016 | | 43.4275% | 88.8087% |
| Na | 22.9895 | 0.0750 | | 0.0750 | | Na | 11023 | | 0.1175% | |
| Mg | 24.3051 | 0.2156 | | 0.2156 | | Mg | 12000 | | 0.3377% | |
| Al | 26.9818 | 24.9306 | | 24.9306 | | Al | 13027 | | 39.0461% | |
| Si | 28.0853 | 1.5752 | | 1.5752 | | Si | 14000 | | 2.4671% | |
| S | 32.0636 | 0.1969 | | 0.1969 | | S | 16000 | | 0.3084% | |
| Ca | 40.0803 | 7.5553 | | 7.5553 | | Ca | 20000 | | 11.8331% | |
| Fe | 55.8447 | 0.3383 | | 0.3383 | | Fe | 24000 | | 0.5298% | |
| Totals | | 100.0000 | 4.3591 | 63.8491 | 31.7918 | | | 100.00% | 100.00% | 100.00% |
| $H_2O$ | 18.0105 | | | | | | | | | |
| density (g/cm$^3$) | | 1.601838E+00 | 6.982572E-02 | 1.022759E+00 | 5.092532E-01 | spacer density (g/cm$^3$) | 1.601838E+00 | 6.98257E-02 | 1.02276E+00 | 5.09253E-01 |
| | | | | | | liner density (g/cm$^3$) | 1.548806E+00 | 6.75140E-02 | 9.88899E-01 | 4.92393E-01 |
| | | | | | | liner den. multiplier | 0.966893 | | | |

*Source*: G. A. Byington, *Mixing Weights and Elemental Composition of 277-4 Neutron Poison Used in the ES-3100*, DAC-PKG-801624-A001, BWXT Y-12, Y-12 National Security Complex, Jan. 25, 2006, Table 5.

**Table 6.9.3.3-2. Calculation of constituent weight-percentage values used in KENO V.a calculation models for NCT as-manufactured 277-4 at minimum density and hydrogen content**

| | | | arbmboron | arbmnpmx | arbmnph2o | | | **arbmboron** | **arbmnpmx** | **arbmnph2o** |
|---|---|---|---|---|---|---|---|---|---|---|
| | At. wt | lb/ft$^3$ | lb/ft$^3$ | lb/ft$^3$ | lb/ft$^3$ | | **NID** | **wt %** | **wt %** | **wt %** |
| H | 1.0078 | 2.6840 | | | 2.6840 | H | 1001 | | | 11.1913% |
| B10 | 10.0129 | 0.8282 | 0.8282 | | | B10 | 5010 | 18.1479% | | |
| B11 | 11.0093 | 3.7354 | 3.7354 | | | B11 | 5011 | 81.8520% | | |
| C | 12.0000 | 1.2826 | | 1.2826 | | C | 6012 | | 1.9189% | |
| N | 14.0031 | 0.0094 | | 0.0094 | | N | 7014 | | 0.0141% | |
| O | 15.9949 | 50.3252 | | 29.0262 | | O | 8016 | | 43.4251% | |
| O | 15.9949 | | | | 21.2990 | O | 8016 | | | 88.8087% |
| Na | 22.9895 | 0.0785 | | 0.0785 | | Na | 11023 | | 0.1174% | |
| Mg | 24.3051 | 0.2258 | | 0.2258 | | Mg | 12000 | | 0.3378% | |
| Al | 26.9818 | 26.1004 | | 26.1004 | | Al | 13027 | | 39.0479% | |
| Si | 28.0853 | 1.6491 | | 1.6491 | | Si | 14000 | | 2.4672% | |
| S | 32.0636 | 0.2061 | | 0.2061 | | S | 16000 | | 0.3083% | |
| Ca | 40.0803 | 7.9098 | | 7.9098 | | Ca | 20000 | | 11.8336% | |
| Fe | 55.8447 | 0.3541 | | 0.3541 | | Fe | 24000 | | 0.5298% | |
| Totals | | 95.3886 | 4.5636 | 66.8420 | 23.9830 | | | 100.00% | 100.00% | 100.00% |
| $H_2O$ | 18.0105 | | | | | | | | | |
| density (g/cm$^3$) | | 1.527971E+00 | 7.310148E-02 | 1.070700E+00 | 3.841692E-01 | spacer density (g/cm$^3$) | 1.527971E+00 | 7.31015E-02 | 1.07070E+00 | 3.84169E-01 |
| | | | | | | liner density (g/cm$^3$) | 1.477385E+00 | 7.06813E-02 | 1.03525E+00 | 3.71451E-01 |
| | | | | | | liner den. multiplier | 0.966893 | | | |

*Source*: G. A. Byington, *Mixing Weights and Elemental Composition of 277-4 Neutron Poison Used in the ES-3100*, DAC-PKG-801624-A001, BWXT Y-12, Y-12 National Security Complex, Jan. 25, 2006, Table 11.

**Table 6.9.3.3-3. Calculation of constituent weight-percentage values used in KENO V.a calculation models for HAC as-manufactured 277-4 at minimum density and hydrogen content**

| | | | arbmboron | arbmnpmx | arbmnph2o | | | **arbmboron** | **arbmnpmx** | **arbmnph2o** |
|---|---|---|---|---|---|---|---|---|---|---|
| | At. wt | lb/ft$^3$ | lb/ft$^3$ | lb/ft$^3$ | lb/ft$^3$ | | **NID** | **wt %** | **wt %** | **wt %** |
| H | 1.0078 | 2.6758 | | | 2.6758 | H | 1001 | | | 11.1913% |
| B10 | 10.0129 | 0.8282 | 0.8282 | | | N10 | 5010 | 18.1479% | | |
| B11 | 11.0093 | 3.7354 | 3.7354 | | | N11 | 5011 | 81.8520% | | |
| C | 12.0000 | 1.2826 | | 1.2826 | | V | 6012 | | 1.9188% | |
| N | 14.0031 | 0.0094 | | 0.0094 | | N | 7014 | | 0.0141% | |
| O | 15.9949 | 50.2605 | | 29.0265 | | O | 8016 | | 43.4254% | |
| O | 15.9949 | | | | 21.2340 | O | 8016 | | | 88.8087% |
| Na | 22.9895 | 0.0785 | | 0.0785 | | Na | 11023 | | 0.1174% | |
| Mg | 24.3051 | 0.2258 | | 0.2258 | | ,g | 12000 | | 0.3378% | |
| Al | 26.9818 | 26.1004 | | 26.1004 | | Al | 13027 | | 39.0477% | |
| Si | 28.0853 | 1.6491 | | 1.6491 | | Si | 14000 | | 2.4671% | |
| S | 32.0636 | 0.2061 | | 0.2061 | | S | 16000 | | 0.3083% | |
| Ca | 40.0803 | 7.9098 | | 7.9098 | | Ca | 20000 | | 11.8335% | |
| Fe | 55.8447 | 0.3541 | | 0.3541 | | Fe | 24000 | | 0.5298% | |
| Totals | | 95.3157 | 4.5636 | 66.8423 | 23.9098 | | | 100.00% | 100.00% | 100.00% |
| $H_2O$ | 18.0105 | | | | | | | | | |
| density (g/cm$^3$) | | 1.52680E+00 | 7.31015E-02 | 1.07071E+00 | 3.82995E-01 | spacer density (g/cm$^3$) | 1.52680E+00 | 7.31015E-02 | 1.07071E+00 | 3.82995E-01 |
| | | | | | | liner density (g/cm$^3$) | 1.47626E+00 | 7.06813E-02 | 1.03526E+00 | 3.70316E-01 |
| | | | | | | liner den. multiplier | 0.966893 | | | |

*Source*: G. A. Byington, *Mixing Weights and Elemental Composition of 277-4 Neutron Poison Used in the ES-3100*, DAC-PKG-801624-A001, BWXT Y-12, Y-12 National Security Complex, Jan. 25, 2006, Table 12.

**Table 6.9.3.3-4. Calculation of constituent weight-percentage values used in KENO V.a calculation models for NCT as-manufactured 277-4 at minimum density and boron content**

| | | | arbmboron | arbmnpmx | arbmnph2o | | | **arbmboron** | **arbmnpmx** | **arbmnph2o** |
|---|---|---|---|---|---|---|---|---|---|---|
| | At. wt | lb/ft$^3$ | lb/ft$^3$ | lb/ft$^3$ | lb/ft$^3$ | | **NID** | **wt %** | **wt %** | **wt %** |
| H | 1.0078 | 2.9617 | | | 2.9617 | H | 1001 | | | 11.1913% |
| B10 | 10.0129 | 0.7911 | 0.7911 | | | B10 | 5010 | 18.1482% | | |
| B11 | 11.0093 | 3.5680 | 3.5680 | | | B11 | 5011 | 81.8517% | | |
| C | 12.0000 | 1.2251 | | 1.2251 | | C | 6012 | | 1.9188% | |
| N | 14.0031 | 0.0090 | | 0.0090 | | N | 7014 | | 0.0141% | |
| O | 15.9949 | 51.2291 | | 27.7264 | | O | 8016 | | 43.4260% | |
| O | 15.9949 | | | | 23.5027 | O | 8016 | | | 88.8087% |
| Na | 22.9895 | 0.0750 | | 0.0750 | | Na | 11023 | | 0.1175% | |
| Mg | 24.3051 | 0.2156 | | 0.2156 | | Mg | 12000 | | 0.3377% | |
| Al | 26.9818 | 24.9306 | | 24.9306 | | Al | 13027 | | 39.0472% | |
| Si | 28.0853 | 1.5752 | | 1.5752 | | Si | 14000 | | 2.4671% | |
| S | 32.0636 | 0.1969 | | 0.1969 | | S | 16000 | | 0.3084% | |
| Ca | 40.0803 | 7.5553 | | 7.5553 | | Ca | 20000 | | 11.8334% | |
| Fe | 55.8447 | 0.3383 | | 0.3383 | | Fe | 24000 | | 0.5299% | |
| Totals | | 94.6709 | 4.3591 | 63.8474 | 26.4644 | | | 100.00% | 100.00% | 100.00% |
| $H_2O$ | 18.0105 | | | | | | | | | |
| density (g/cm$^3$) | | 1.516474E+00 | 6.982572E-02 | 1.022731E+00 | 4.239172E-01 | spacer density (g/cm$^3$) | 1.516474E+00 | 6.98257E-02 | 1.02273E+00 | 4.23917E-01 |
| | | | | | | liner density (g/cm$^3$) | 1.466269E+00 | 6.75140E-02 | 9.88872E-01 | 4.09883E-01 |
| | | | | | | liner den. multiplier | 0.966893 | | | |

*Source*: G. A. Byington, *Mixing Weights and Elemental Composition of 277-4 Neutron Poison Used in the ES-3100*, DAC-PKG-801624-A001, BWXT Y-12, Y-12 National Security Complex, Jan. 25, 2006, Table 13.

**Table 6.9.3.3-5. Calculation of constituent weight-percentage values used in KENO V.a calculation models for HAC as-manufactured 277-4 at minimum density and boron content**

| | | | arbmboron | arbmnpmx | arbmnph2o |
|---|---|---|---|---|---|
| | At. wt | lb/ft$^3$ | lb/ft$^3$ | lb/ft$^3$ | lb/ft$^3$ |
| H | 1.0078 | 2.9524 | | | 2.9524 |
| B10 | 10.0129 | 0.7911 | 0.7911 | | |
| B11 | 11.0093 | 3.5680 | 3.5680 | | |
| C | 12.0000 | 1.2251 | | 1.2251 | |
| N | 14.0031 | 0.0090 | | 0.0090 | |
| O | 15.9949 | 51.1551 | | 27.7262 | |
| O | 15.9949 | | | | 23.4289 |
| Na | 22.9895 | 0.0750 | | 0.0750 | |
| Mg | 24.3051 | 0.2156 | | 0.2156 | |
| Al | 26.9818 | 24.9306 | | 24.9306 | |
| Si | 28.0853 | 1.5752 | | 1.5752 | |
| S | 32.0636 | 0.1969 | | 0.1969 | |
| Ca | 40.0803 | 7.5553 | | 7.5553 | |
| Fe | 55.8447 | 0.3383 | | 0.3383 | |
| Totals | | 94.5876 | 4.3591 | 63.8472 | 26.3813 |
| $H_2O$ | 18.0105 | | | | |
| density (g/cm$^3$) | | 1.515140E+00 | 6.982572E-02 | 1.022728E+00 | 4.225861E-01 |
| | | | | | |

| | | **arbmboron** | **arbmnpmx** | **arbmnph2o** |
|---|---|---|---|---|
| | **NID** | **wt %** | **wt %** | **wt %** |
| H | 1001 | | | 11.1913% |
| B10 | 5010 | 18.1482% | | |
| B11 | 5011 | 81.8517% | | |
| C | 6012 | | 1.9188% | |
| N | 7014 | | 0.0141% | |
| O | 8016 | | 43.4258% | |
| O | 8016 | | | 88.8087% |
| Na | 11023 | | 0.1175% | |
| Mg | 12000 | | 0.3377% | |
| Al | 13027 | | 39.0473% | |
| Si | 14000 | | 2.4671% | |
| S | 16000 | | 0.3084% | |
| Ca | 20000 | | 11.8334% | |
| Fe | 24000 | | 0.5299% | |
| | | 100.00% | 100.00% | 100.00% |
| | | | | |
| spacer density (g/cm$^3$) | 1.515140E+00 | 6.98257E-02 | 1.02273E+00 | 4.22586E-01 |
| liner density (g/cm$^3$) | 1.464979E+00 | 6.75140E-02 | 9.88869E-01 | 4.08596E-01 |
| liner den. multiplier | 0.966893 | | | |

*Source*: G. A. Byington, *Mixing Weights and Elemental Composition of 277-4 Neutron Poison Used in the ES-3100*, DAC-PKG-801624-A001, BWXT Y-12, Y-12 National Security Complex, Jan. 25, 2006, Table 14.

Measurements from neutron transmission tests on BoroBond 4 ™ for determination of areal density indicated greater boron content than was physically present. This is due to the presence of elements besides the aluminum and boron (principally hydrogen, oxygen and other low and intermediate-Z elements). Given the similarity of 277-4 to BoroBond 4 ™ (a ceramic-cement composite shielding material, with a similar elemental composition, more uniform particle size, and the same boron content), the 75% credit for boron content applied in the ES-3100 criticality calculations is an adequate enough correction for the efficiency of the material.

Criticality calculations show boron content is adequate and $k_{eff}$ is not dependent on absolute (microscopic) homogeneity. The boron concentration calculations presented here model an infinite array of ES-3100 packages with the boron concentration of Cat 277-4 uniformly varied inside the body weldment inner liner. While the Cat 277-4 described herein is an earlier formulation of the neutron-absorber material, the behavior characteristics being demonstrated for Cat 277-4 apply to the revised formulation, 277-4.

Credit for only 75% of the boron is taken in the specification of Cat 277-4. Each package in the array contains 2.774 kg of $^{235}U$ in broken metal form uniformly distributed inside the containment vessel. The presence of just the hydrogenous cement matrix in the inner liner reduces $k_{eff}$ to 1.132 from a value of 1.35 without the cement matrix. As an initial 1 wt % natural boron is added to the high alumina cement system (Table 6.9.3.3-6), the calculated $k_{eff}$ based on 75% of the boron present drops significantly. Cat 277-4 with 4.2284 wt % natural boron in the minimum cast density of 100 lb/ft$^3$ (1.60 g/cc) has an acceptable mixture concentration, generating a $k_{eff}$ of 0.88. The saturation value for boron content is reached at ~8 wt %. This near doubling of the boron content results in ~4% decrease in $k_{eff}$ to an asymptotic value of ~0.85.

The density of Cat 277-4 is the sum of constituent densities: the boron density, the base-material density, and the water density. In the calculation model, the density of water in Cat 277-4 is 0.48210 g/cm$^3$ (not shown in Table 6.9.3.3-6). Canned spacers are omitted from the calculation model. Credit for only 75% of the boron is taken in each parametric calculation. The volume of the 277-4 in the body weldment inner liner cavity is $1.32708 \times 10^4$ cm$^3$.

**Table 6.9.3.3-6. Effect of boron concentration on array neutron multiplication**

| 100%B (wt %) | Boron density (g/cm$^3$) | Base material density (g/cm$^3$) | NP277-4 mass (g) | Case name | $k_{eff} \pm 2\sigma$ (@75% B) |
|---|---|---|---|---|---|
| 0.01 | 0.00016 | 1.11775 | 2.12326E+04 | nbiabm_kvsb_1 | 1.13199 +/- 0.00138 |
| 0.1 | 0.0016 | 1.11631 | 2.12279E+04 | nbiabm_kvsb_2 | 1.07944 +/- 0.00145 |
| 1 | 0.016 | 1.10191 | 2.11801E+04 | nbiabm_kvsb_3 | 0.95564 +/- 0.00129 |
| 2 | 0.032 | 1.08591 | 2.11270E+04 | nbiabm_kvsb_4 | 0.91708 +/- 0.00135 |
| 3 | 0.048 | 1.06991 | 2.10739E+04 | nbiabm_kvsb_5 | 0.89396 +/- 0.00117 |
| 4.2284 | 0.068614 | 1.04930 | 2.10056E+04 | nbiabm_kvsb_6 | 0.87985 +/- 0.00145 |
| 6 | 9.6000E-02 | 1.02191 | 2.09147E+04 | nbiabm_kvsb_7 | 0.86029 +/- 0.00151 |
| 8 | 1.2800E-01 | 0.98991 | 2.08085E+04 | nbiabm_kvsb_8 | 0.84769 +/- 0.00150 |
| 10 | 0.16 | 0.95791 | 2.07024E+04 | nbiabm_kvsb_9 | 0.84086 +/- 0.00142 |

NUREG 1609 recommended that only 75% of the minimum boron density be credited in criticality evaluation in order to address the issue of non-homogeneity of 10B in the neutron-absorber material. The boron non-homogenity calculations presented here model an infinite array of ES-3100

packages with the boron concentration of Cat 277-4 varying along the vertical height of the body weldment inner liner. However, the total amount of boron in each package is fixed. Each package in the array contains 2.774 kg of 235U in broken metal form uniformly distributed inside the containment vessel. Two sets of calculations are evaluated with this model to address the effects of boron distribution in the ES-3100 inner liner.

In one set of cases, the inner cavity is divided vertically into three equal-volume regions. The density in one region is increased to 95% of the minimum boron density, while the boron density in the other two regions is decreased to 65%, thus preserving the amount of neutron-absorber material in the package. In the other set of cases, the inner cavity is divided vertically into four equal volume regions, but two regions are combined. This creates two quarter-sized regions and one half-size region. The density in the half-size region is increased to 95% of the minimum boron density, while the density in the quarter-sized regions is decreased to 55%, thus preserving the amount of neutron absorber in the package. In both sets of calculations, the high-density region was shifted upward in the package to examine the effect of boron distribution.

As shown in Figs. 6.9.3.3-2 and 6.9.3.3-3, the effect of non-homogeneity of boron in the ES-3100 liner on $k_{eff}$ is not statistically significant. The "65% - 95% - 65%" nonhomogeneous boron distribution represents a relative standard deviation of 23.1% in boron concentration. Given the controls on method of manufacture and installation of the neutron-absorber material, these calculated conditions bound the expected physical distribution of boron with a large degree of conservatism.

Geometry characteristics of the ES-3100 system preclude the need for uniformity in boron areal density as a prerequisite for criticality safety control. The U.S. Nuclear Regulatory Commission provides crucial guidance in SFST-ISG-15 for controlling areal density in a geometry configuration where one-dimensional effects are significant, such as a distributed source separated by thin Boral sheets (aluminum and boron carbide) which range in thickness from 0.075 to 0.4 in. In this example, Boral aluminum sheets are placed between fissile fuel rods just a few inches away and only become efficient when the low-enriched fissile material is placed in a sea of hydrogenous moderator. The cylindrical thickness of the ES-3100 cast neutron-absorber material (Cat 277-4) is 1.12 in., which is about three times thicker than the largest Boral sheet. Its purpose in the ES-3100 is to provide criticality safety control for arrays of packages.

In the ES-3100, the proposed fissile mass loads are separated by at least one drum diameter (19.36 in.). Drawing M2E801580A031 in Appendix 1.3.7 shows the cross-section view of the many different layers of materials that are between the fissile mass loads in adjacent packages in an array. The direct neutron transport path between dispersed fissile material (assuming a neutron passes through the following thickness of materials at a normal angle to the closest neighboring package) is:

- fissile material,
- 0.100 in. Type 304 stainless-steel containment vessel wall,
- air gap,
- 0.06 in. Type 304 stainless-steel inner liner wall,
- 1.12 in. of 277-4 neutron-absorber material,
- 0.06 in. Type 304 stainless-steel outer liner wall,
- 4.77 in. of Kaolite,
- 0.06 in. Type 304 stainless-steel outer drum wall, and
- air gap,

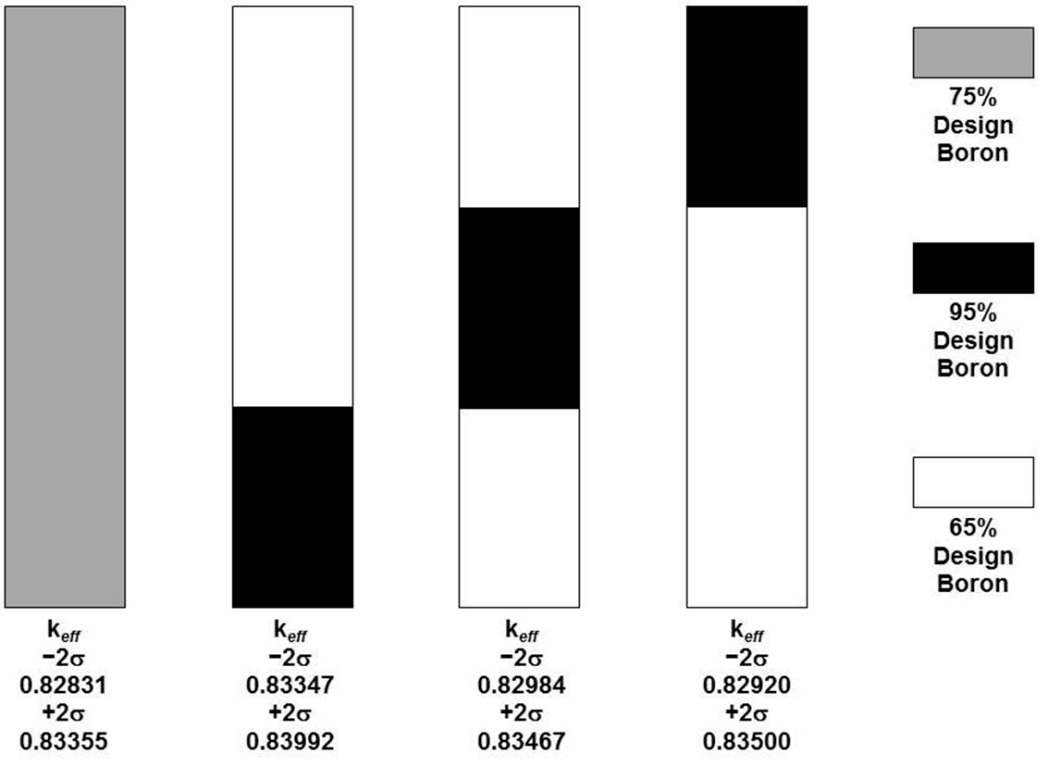



**Fig. 6.9.3.3-2. Three equal-region models for evaluation of non-homogeneity in the boron distribution.**

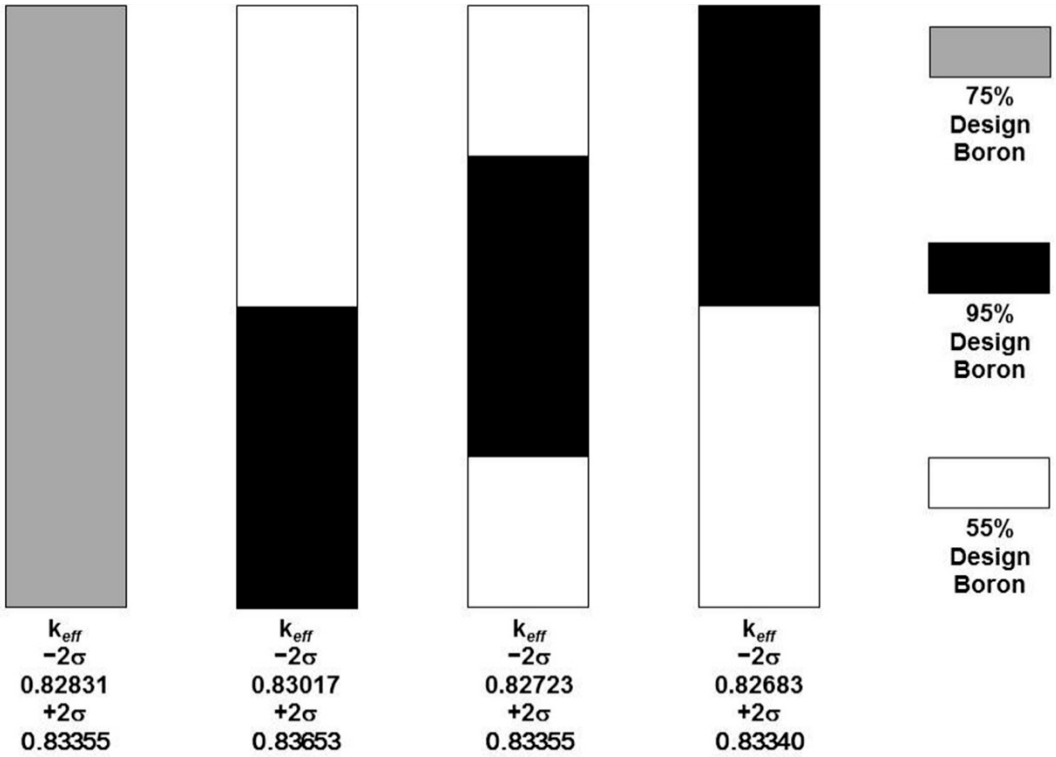



**Fig. 6.9.3.3-3. Non-uniform region model for evaluation of non-homogeneity in the boron distribution.**

followed by the reverse:

- 0.06 in. stainless-steel outer drum wall,
- 4.77 in. of Kaolite,
- 0.06 in. Type 304 stainless-steel outer liner wall,
- 1.12 in. of 277-4 neutron-absorber material,
- 0.06 in. Type 304 stainless-steel inner liner wall,
- air gap,
- 0.100 in. Type 304 stainless-steel containment vessel wall, and
- back into a fissile material.

At the shortest distance between fissile materials, neutrons travel through the 1.12 in. (2.8448 cm) of 277-4 neutron-absorber material and 0.28 in. (0.7112 cm) of Type 304 stainless steel at least twice, with the high probability of several neutron scattering collisions along the way. Thus, the mean free path in the package is much smaller than the separation between the fissile material of adjacent packages.

In contrast to a Boral sheet application, the neutron-absorber component of the ES-3100 package physically represents a significant fraction of the total container volume and is large in comparison to the potential fissile material volume. Furthermore, the neutron-absorber component consists of boron dispersed throughout a hydraulic cement matrix with a high neutron scattering potential. The net result is that sensitivity to angular and spatial variations in the areal density of $^{10}B$ in the neutron-absorber volume is eliminated.

The calculation model for a 277-4 canned spacer was developed based on available information at the time of the initial design. The dimensions of the 277-4 filler are 4.13 in. for the diameter and 1.4 in. for the height with a resultant volume of 307.34 $cm^3$. Based on a density of 95.3886 $lb/ft^3$ (1.527971 $g/cm^3$), the amount of 277-4 represented in the calculation model is 469.61 g. As shown on Drawing M2E801580A043 (Appendix 1.3.7), the outer diameter of the stainless-steel can is 4.13 ± 0.09 in. and the height for the 277-4 filler is 1.37 ± 0.06 in. The wall thickness for the 30 gauge stainless steel is 0.012 in. The actual minimum volume of the 277-4 filler is 271.93 $cm^3$ based on this acceptance criteria. For cast material having a nominal density of 105 $lb/ft^3$ (1.68193 $g/cm^3$), the actual minimum amount of 277-4 present in a canned spacer is 457.36 g. An excess 12.25 g of neutron poison in the calculation model on which criticality safety is based is insignificant. Nevertheless, results of additional calculations are presented for demonstrating this fact.

A set of Cases **hciabmt12** establishing loading limits for broken metal were selected from Table 6.9.6-11. These cases based on the nominal 277-4 canned spacer were rerun using SCALE5 and are identified in Table 6.9.6-11d as reference Cases **5hciabmt12**. The corresponding cases for revised calculation model with 277-4 canned spacer sized per the minimal acceptance criteria are identified in Table 6.9.6-11d as Cases **5_401by131**. The minimum dimensions of the 277-4 filler in these cases are 4.01 in. for the diameter and 1.31 in. for the height; the amount of amount of 277-4 represented is 415 g. A statistically significant difference between case results for a configuration with the nominal canned spacer and one with the minimum-sized spacer occurs if the absolute value of the quantity "$\mathbf{(\Delta k_{eff}+2\sigma)/\sigma}$" is >3. As shown in Table 6.9.6-11d, the differences are statistically insignificant; therefore, loadings limits are adequate for content configurations with the canned spacer sized per the minimum acceptance criteria.

<u>The neutron-absorbing material will be fabricated under strict quality control and accepted for use under an NQA-1 compliant QA program.</u> The original equipment specification for the production of 277-4 neutron-absorber material used a proprietary mixture from the Thermo Electron Corporation that combined high alumina cement and a boron grit (Cat 277-4). The manufacturing process for the neutron

absorber was revised in order to obtain details necessary for material characterization and to achieve process control for ensuring consistency of absorber material among lots.

A two-part system of dry-blend components is now employed rather than relying on a single base material (a premixed powder of high alumina cement and boron grit). The vendor's proprietary high-alumina cement without boron grit (Cat 277-0) is mixed with boron carbide by the ES-3100 manufacturer under strict quality controls. A single batch is mixed on a per package basis. The boron carbide used in this process is strictly controlled. Boron carbide is specified as Type 1 material per ASTM C 750, "Nuclear-Grade Boron Carbide Powder." The particle size is controlled in accordance with JS-YMN5-801580-A003, Sect. 3.3.1.2.

The new formulation designated "277-4" is produced through a quality-controlled batch process of dry blending, wet mixing, vibration casting, and timed cure (JS-YMN3-801580-A005, Appendix 1.3.5). The plan is to control the purity, boron carbide particle size, chemistry, measurements, weights, mixing, recording, casting, and testing using one batch per each shipping package (and its two companion spacer cans). A design analysis calculation shows all of the calculations used in mixing and determines (from the minimum acceptable chemical purities) the volumetric densities in g/cm$^3$ and an areal density in g/cm$^3$ of $^{10}$B (DAC-PKG-801624-A001). These values will prove the acceptability of the mixing specifications.

An important part of this approach is a QA-approved 277-4 material verification and acceptance testing program. The applicant plans on performing 100% acceptance testing on the criticality safety significant properties of density, $^{10}$B interaction (neutron absorption), and hydrogen content. The acceptance density shall be the as cast density in the drum to 105−5+10 lb/ft$^3$ and shall be determined as shown in Appendix 1.3.5. To test the other properties, two companion sample cans shall be cast from each batch used to cast a shipping container (the manufacturer will cast a fresh batch for each shipping container). The companion sample cans shall also have their density verified. The $^{10}$B interaction will be tested in the manner described in Appendix A of the 277-4 specification (Appendix 1.3.5). Initially, a new set of 277-4–certified cans will be cast using the newly proposed casting specification with the QA plan described previously. Then, on a companion sample can for each batch pour, a prompt gamma-ray neutron activation analysis (PGNAA) test will be used to neutronically test the $^{10}$B for absorption. To pass the PGNAA test, the sample can results must be within the results obtained for the 277-4 certified standards, in units of Average Net Count rate (ANC/second) ±3 standard deviations. The second companion sample can will be used to test for hydrogen content using an LOD test as described in Appendix 1.3.5. Upon successful completion of the density, PGNAA, and LOD testing, the ES-3100 neutron-absorber material will be accepted for use.

### 6.9.3.4 Kaolite 1600

Kaolite 1600, manufactured by Thermal Ceramics of Augusta, Georgia [telephone number (404) 796-4200], is a super-lightweight, low thermal conductivity, castable material designed for backup insulation up to 1600°F. The material is obtained as a dry powder with the chemical composition given in Table 6.9.3.4-1. The powder is mixed with water in a water-to-powder ratio of 14.5 qt per 20-lb bag. The mixture is poured into the drum body weldment or top plug, vibrated to eliminate voids, and then dried and fired to form the finished product (Y/EN-5984). The density of the fired material is ~25 lb/ft$^3$. It is assumed that the wet mixture contains the maximum water possible. This value (14.5 qt per 20 lb) is therefore used to determine the maximum water content of the fired product,

$$S.G._{max} = \frac{14.5\ qt}{20\ lb\ dry} \times \frac{25\ lb}{ft^3} \times \frac{0.946\ L}{1\ qt} \times \frac{998.2\ g}{L} \times \frac{35.32\ ft^3}{10^6\ cm^3} = \frac{0.6045\ g}{cm^3}$$

**Table 6.9.3.4-1. Kaolite 1600 chemical composition, percent fired basis**

| Component | Weight percent | Component | Weight percent |
|---|---|---|---|
| $Al_2O_3$ | 9.6 | CaO | 30.7 |
| $SiO_2$ | 36.7 | MgO | 13.1 |
| $Fe_2O_3$ | 6.7 | $Na_2O$ | 2.0 |
| $TiO_2$ | 1.2 | | |

Tables 6.9.3.4-2 and 6.9.3.4-3 provide detailed information regarding the weight measurements taken during the casting of Kaolite 1600 for the production of a series of drum body weldment and top plug parts for a similar package (the CNS Model ES-2100). The mean values for the amount of Kaolite and water present after baking are 107.08 lb of Kaolite and 4.8 lb of water in the drum body weldment, and 16.99 lb of Kaolite and 0.58 lb of water in the top plug. An ES-2100 package contains, on the average, 124.07 lb (56,276.91 g) of Kaolite and 5.38 lb (2,440.32 g) of water. Given that the average volume is 5.72 $ft^3$, the average density of Kaolite is 22.63 $lb/ft^3$ (0.3625 $g/cm^3$).

The volume of the Kaolite region in the KENO models is $1.63417 \times 5$ $cm^3$. For NCT, the density of Kaolite is 0.34438 $g/cm^3$, and the density of water is 0.01493 $g/cm^3$. The data in Tables 6.9.3.4-2 and 6.9.3.4-3 indicate that the Kaolite may have as little as 1.90 lb (861.82 g) of water after baking (Part Serial Number 97) such that the corresponding density of water is 0.00527 $g/cm^3$. For the water-flooded HAC, the amount of water is assumed not to exceed the amount present before baking. The package would contain on the average 186.10 lb (84,413.1 g) of water such that the corresponding density is 0.51655 $g/cm^3$. The full range of NCT and HAC conditions would be covered by a variation of water in the Kaolite from 0 $g/cm^3$ to 0.51655 $g/cm^3$ in a calculation model.

The Kaolite components of ES-3100 shipping package had not been manufactured at the time this criticality safety evaluation was performed. Given the lack of production data for ES-3100 Kaolite, a material specification (mass and density) was derived from data for ES-2100 production units. This specification, denoted “as-manufactured” (AM) Kaolite, was used for the ES-3100 criticality calculations. This ES-2100 shipping package is similar in design to the ES-3100 currently being evaluated.

The Kaolite production process was re-evaluated and improved following the production of ES-3100 units (Y/DW-1890). Test samples were produced. These were classified into three groups: high density, medium density, and low density. The predominate number of samples fell into the medium density category (22.04 $lb/ft^3$), representing the expected, improved Kaolite production process (Y/DW-1890, Table 5). A material specification for use in criticality calculations was derived from the medium density “test sample” (TS) Kaolite data. However, the TS data are based on small sample volumes, whereas the AM data represents the entire package. Taking into consideration both the potential for scaling error and the uncertainty of how representative the test samples are of the manufactured ES-2100 units, the criticality safety packaging analysts chose to utilize the material specification derived from AM data rather than TS data in the criticality calculations for the ES-3100 safety analysis report for packaging.

**Table 6.9.3.4-2. Fabrication data, before and after baking the drum body weldment parts of the ES-2100 shipping package**

| Part Serial Number | Clean and empty (lb) | Filled with water (lb) | Before baking (lb) | After baking (lb) | Density after baking (lb/ft$^3$) | Water conditions (lb) | Volume (ft$^3$) | Before baking | | | After baking | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Kaolite and water (lb) | Kaolite (lb) | Water (lb) | Kaolite and water (lb) | Kaolite (lb) | Water (lb) |
| 97 | 87.5 | 393.5 | 356.5 | 197.0 | 22.29 | 306.00 | 4.91 | 269.00 | 107.60 | 161.40 | 109.50 | 107.60 | 1.90 |
| 98 | 87.5 | 393.5 | 356.5 | 198.5 | 22.60 | 306.00 | 4.91 | 269.00 | 107.60 | 161.40 | 111.00 | 107.60 | 3.40 |
| 54 | 87.5 | 395.0 | 356.5 | 199.0 | 22.59 | 307.50 | 4.94 | 269.00 | 107.60 | 161.40 | 111.50 | 107.60 | 3.90 |
| 87 | 87.5 | 394.0 | 353.5 | 196.5 | 22.16 | 306.50 | 4.92 | 266.00 | 106.40 | 159.60 | 109.00 | 106.40 | 2.60 |
| 2 | 88.0 | 394.0 | 360.0 | 202.5 | 23.31 | 306.00 | 4.91 | 272.00 | 108.80 | 163.20 | 114.50 | 108.80 | 5.70 |
| 4 | 88.0 | 395.5 | 360.0 | 203.0 | 23.30 | 307.50 | 4.94 | 272.00 | 108.80 | 163.20 | 115.00 | 108.80 | 6.20 |
| 42 | 88.0 | 394.5 | 356.5 | 199.5 | 22.66 | 306.50 | 4.92 | 268.50 | 107.40 | 161.10 | 111.50 | 107.40 | 4.10 |
| 43 | 88.0 | 396.0 | 357.5 | 198.0 | 22.25 | 308.00 | 4.94 | 269.50 | 107.80 | 161.70 | 110.00 | 107.80 | 2.20 |
| 94 | 87.0 | 393.5 | 361.5 | 205.0 | 23.99 | 306.50 | 4.92 | 274.50 | 109.80 | 164.70 | 118.00 | 109.80 | 8.20 |
| 35 | 88.0 | 394.5 | 363.5 | 208.0 | 24.39 | 306.50 | 4.92 | 275.50 | 110.20 | 165.30 | 120.00 | 110.20 | 9.80 |
| 3 | 87.0 | 393.0 | 364.0 | 206.0 | 24.23 | 306.00 | 4.91 | 277.00 | 110.80 | 166.20 | 119.00 | 110.80 | 8.20 |
| 44 | 88.0 | 394.0 | 356.5 | 204.5 | 23.72 | 306.00 | 4.91 | 268.50 | 107.40 | 161.10 | 116.50 | 107.40 | 9.10 |
| 32 | 88.0 | 396.0 | 355.0 | 198.5 | 22.35 | 308.00 | 4.94 | 267.00 | 106.80 | 160.20 | 110.50 | 106.80 | 3.70 |
| 33 | 87.5 | 394.0 | 351.0 | 197.5 | 22.36 | 306.50 | 4.92 | 263.50 | 105.40 | 158.10 | 110.00 | 105.40 | 4.60 |
| 58 | 87.5 | 394.5 | 351.5 | 196.5 | 22.12 | 307.00 | 4.93 | 264.00 | 105.60 | 158.40 | 109.00 | 105.60 | 3.40 |
| 4 | 87.5 | 394.0 | 343.0 | 192.5 | 21.34 | 306.50 | 4.92 | 255.50 | 102.20 | 153.30 | 105.00 | 102.20 | 2.80 |
| 22 | 87.5 | 394.5 | 352.0 | 196.0 | 22.02 | 307.00 | 4.93 | 264.50 | 105.80 | 158.70 | 108.50 | 105.80 | 2.70 |
| 27 | 88.0 | 395.5 | 352.5 | 196.5 | 21.98 | 307.50 | 4.94 | 264.50 | 105.80 | 158.70 | 108.50 | 105.80 | 2.70 |
| 28 | 87.5 | 394.5 | 350.5 | 199.0 | 22.63 | 307.00 | 4.93 | 263.00 | 105.20 | 157.80 | 111.50 | 105.20 | 6.30 |
| 30 | 87.5 | 395.0 | 352.0 | 200.0 | 22.79 | 307.50 | 4.94 | 264.50 | 105.80 | 158.70 | 112.50 | 105.80 | 6.70 |
| 27 | 88.0 | 395.5 | 352.5 | 196.5 | 21.98 | 307.50 | 4.94 | 264.50 | 105.80 | 158.70 | 108.50 | 105.80 | 2.70 |
| Mean | 87.67 | 394.50 | 355.36 | 199.55 | 22.72 | 306.83 | 4.93 | 267.69 | 107.08 | 160.61 | 111.88 | 107.08 | 4.80 |
| Std. dev. | | | | | 0.8132 | | | | | | 100% | 95.71% | 4.29% |
| Computed on means | | | | | 22.72 | 306.83 | 4.93 | 267.69 | 107.08 | 160.61 | 111.88 | 107.08 | 4.80 |

**Table 6.9.3.4-3. Fabrication data, before and after baking the top plug parts of the ES-2100 shipping package**

| Part Serial Number | Clean and empty (lb) | Filled with water (lb) | Before baking (lb) | After baking (lb) | Density after baking (lb/ft$^3$) | Water conditions (lb) | Volume (ft$^3$) | Before baking | | | After baking | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Kaolite and water (lb) | Kaolite (lb) | Water (lb) | Kaolite and water (lb) | Kaolite (lb) | Water (lb) |
| 97 | 10.5 | 60.0 | 53.5 | 28.5 | 22.65 | 49.50 | 0.79 | 43.00 | 17.20 | 25.80 | 18.00 | 17.20 | 0.80 |
| 83 | 10.5 | 59.0 | 50.5 | 27.0 | 50.50 | 27.00 | 50.50 | 27.00 | 16.00 | 24.00 | 16.00 | 24.00 | 16.00 |
| 86 | 10.5 | 60.0 | 50.5 | 27.5 | 21.40 | 49.50 | 0.79 | 40.00 | 16.00 | 24.00 | 17.00 | 16.00 | 1.00 |
| 87 | 10.5 | 59.0 | 53.0 | 28.5 | 23.12 | 48.50 | 0.78 | 42.50 | 17.00 | 25.50 | 18.00 | 17.00 | 1.00 |
| 28 | 11.0 | 59.0 | 53.0 | 28.5 | 22.71 | 48.00 | 0.77 | 42.00 | 16.80 | 25.20 | 17.50 | 16.80 | 0.70 |
| 23 | 10.5 | 59.5 | 52.5 | 28.0 | 22.25 | 49.00 | 0.79 | 42.00 | 16.80 | 25.20 | 17.50 | 16.80 | 0.70 |
| 24 | 10.5 | 59.0 | 53.5 | 28.5 | 23.12 | 48.50 | 0.78 | 43.00 | 17.20 | 25.80 | 18.00 | 17.20 | 0.80 |
| 25 | 10.5 | 58.5 | 54.0 | 29.0 | 24.01 | 48.00 | 0.77 | 43.50 | 17.40 | 26.10 | 18.50 | 17.40 | 1.10 |
| 26 | 10.5 | 59.0 | 54.0 | 29.0 | 23.76 | 48.50 | 0.78 | 43.50 | 17.40 | 26.10 | 18.50 | 17.40 | 1.10 |
| 27 | 10.5 | 60.0 | 54.5 | 29.0 | 23.28 | 49.50 | 0.79 | 44.00 | 17.60 | 26.40 | 18.50 | 17.60 | 0.90 |
| 0 | 10.5 | 60.0 | 52.0 | 27.0 | 20.77 | 49.50 | 0.79 | 41.50 | 16.60 | 24.90 | 16.50 | 16.60 | -0.10a |
| 20 | 10.5 | 60.0 | 53.5 | 28.0 | 22.03 | 49.50 | 0.79 | 43.00 | 17.20 | 25.80 | 17.50 | 17.20 | 0.30 |
| 22 | 10.5 | 60.0 | 54.0 | 28.5 | 22.65 | 49.50 | 0.79 | 43.50 | 17.40 | 26.10 | 18.00 | 17.40 | 0.60 |
| 21 | 10.5 | 61.0 | 53.0 | 28.0 | 21.59 | 50.50 | 0.81 | 42.50 | 17.00 | 25.50 | 17.50 | 17.00 | 0.50 |
| 19 | 10.5 | 60.0 | 53.0 | 27.5 | 21.40 | 49.50 | 0.79 | 42.50 | 17.00 | 25.50 | 17.00 | 17.00 | 0.00 |
| 11 | 10.5 | 60.0 | 52.5 | 28.0 | 22.03 | 49.50 | 0.79 | 42.00 | 16.80 | 25.20 | 17.50 | 16.80 | 0.70 |
| 14 | 10.5 | 60.0 | 52.5 | 27.5 | 21.40 | 49.50 | 0.79 | 42.00 | 16.80 | 25.20 | 17.00 | 16.80 | 0.20 |
| 15 | 10.5 | 60.5 | 54.0 | 28.0 | 21.81 | 50.00 | 0.80 | 43.50 | 17.40 | 26.10 | 17.50 | 17.40 | 0.10 |
| 16 | 10.5 | 59.0 | 52.0 | 27.5 | 21.84 | 48.50 | 0.78 | 41.50 | 16.60 | 24.90 | 17.00 | 16.60 | 0.40 |
| 17 | 10.5 | 60.5 | 54.5 | 28.5 | 22.43 | 50.00 | 0.80 | 44.00 | 17.60 | 26.40 | 18.00 | 17.60 | 0.40 |
| Mean | 10.53 | 59.70 | 53.00 | 28.10 | 23.74 | 48.10 | 3.28 | 42.48 | 16.99 | 25.49 | 17.58 | 16.99 | 0.59 |
| Std. dev. | | | | | 6.3565 | | | | | | 100% | 96.67% | 3.33% |
| Computed on means | | | | | 22.27 | 49.18 | 0.79 | 42.48 | 16.99 | 25.49 | 17.58 | 16.99 | 0.59 |

[a] No explanation is given for the negative amount of water in Part 0. Also, the smaller percentage of water present in the top plug compared with to the drum body weldment is attributed to the larger surface-to-volume ratio, which results in better drying of the parts.

A set of criticality calculations was performed for each of the packaging material specifications (i.e., the TS and the AM Kaolite) using three package water contents to represent the range of NCT and HAC. Y-12 statisticians were asked to determine whether or not the observed differences in neutronic performance are statistically significant for a package modeled with the TS specification versus one modeled with the AM specification. The purpose of this discussion is to summarize this comparison (DAC-FS-900000-A014) and draw conclusions.

Criticality Calculations. Each case is rerun using a different starting random number in order to produce computed $k_{eff}$ values that are statistically independent. Table 6.9.3.4-4 presents the random starting number, the mean value ($k_{eff}$) and corresponding standard error ($s_i$) computed for 10 individual runs of each case.

Three sets of criticality calculations were run for both the AM Kaolite and TS Kaolite. One set of calculations is for dry Kaolite (i.e., low water content, IS = 1e-04 sp gr water); another set is for normal moisture Kaolite (i.e., NCT water content); and the third set is for flooded Kaolite (i.e., high water content, IS = 1.0 sp gr water). These conditions span the range of NCT and HAC addressed in the criticality evaluation. An infinite array of packages was evaluated in order to eliminate any biases arising from spectral leakage effects in the reflector of the finite array. Each package was modeled having 36 kg of 100% enriched uranium in the form of 3.24-in.-diam cylinder content. The $k_{eff}$ values for each KENO V.a case are based on 500,000 neutron histories produced by running for 215 generations with 2,500 neutrons per generation and truncating the first 15 generations of data.

Statistical evaluation. A review of KENO V.a calculation results was made to determine if a statistically significant difference exists between the mean $k_{eff}$ for the TS Kaolite specification and the AM Kaolite material specifications used in the criticality evaluation of the ES-3100 shipping package. Case results were classified into three groups (i.e., low water content, medium water content, or high water content) depending on the amount of water present in the ES-3100 shipping package. The symbol "I" is used to specify the group. The mean difference and standard deviation for each of the three (3) sets of pair-wise differences was defined as follows:

(a) $d_i = (k_{effBi} - k_{effAi})/n$ and

(b) $s_{di} = \sqrt{[\, n\Sigma d_i^{\,2} - (\Sigma d_i)^2 \,] / n(n-1)}$ (conservatively defined for the t-test appropriate for small sample sizes)

where $A_i$ denotes the TS by group classification, $B_i$ the AM by group classification, and n the sample size of ten (10). It is reasonable to assume that the paired differences have been randomly selected from a normally distributed population of paired differences with mean $\mu_d$ and standard deviation $\sigma_d$. Therefore, the sampling distribution of

$$(d - \mu_d) / (s_d/\sqrt{n})$$

is a *t*-distribution having n-1 degrees of freedom.

**Table 6.9.3.4-4. Data for the statistical evaluation of "as-manufactured"and "test sample" Kaolite**

| As-manufactured Kaolite | | | | Test sample Kaolite | | | |
|---|---|---|---|---|---|---|---|
| **Case name** | **Random number** | **$k_{eff}$** | **$s_i$** | **Case name** | **Random number** | **$k_{eff}$** | **$s_i$** |
| **Group 1 – Low water content** | | | | | | | |
| esrandnum_01_01_in | 109E77866CF | 1.00274 | 0.00138 | mdrandnum_01_01_in | 109E77866CF | 1.00170 | 0.00125 |
| esrandnum_01_02_in | 16AA4A58735 | 1.00224 | 0.00120 | mdrandnum_01_02_in | 16AA4A58735 | 1.00416 | 0.00116 |
| esrandnum_01_03_in | 1814171B652 | 1.00121 | 0.00107 | mdrandnum_01_03_in | 1814171B652 | 1.00208 | 0.00125 |
| esrandnum_01_04_in | 1A423B9472C | 1.00367 | 0.00118 | mdrandnum_01_04_in | 1A423B9472C | 1.00271 | 0.00131 |
| esrandnum_01_05_in | 20E876D8224 | 1.00290 | 0.00133 | mdrandnum_01_05_in | 20E876D8224 | 1.00406 | 0.00125 |
| esrandnum_01_06_in | 3F6E65CA744 | 1.00266 | 0.00137 | mdrandnum_01_06_in | 3F6E65CA744 | 1.00418 | 0.00124 |
| esrandnum_01_07_in | 479D21DB750 | 1.00393 | 0.00108 | mdrandnum_01_07_in | 479D21DB750 | 1.00193 | 0.00133 |
| esrandnum_01_08_in | 55D4371D3A2 | 1.00313 | 0.00113 | mdrandnum_01_08_in | 55D4371D3A2 | 1.00196 | 0.00105 |
| esrandnum_01_09_in | 6E1A14672B8 | 1.00343 | 0.00119 | mdrandnum_01_09_in | 6E1A14672B8 | 1.00503 | 0.00118 |
| esrandnum_01_10_in | 77A0308C0E4 | 1.00229 | 0.00113 | mdrandnum_01_10_in | 77A0308C0E4 | 1.00358 | 0.00108 |
| **Group 2 – NCT medium density** | | | | | | | |
| esrandnum_06_01_in | 109E77866CF | 0.99025 | 0.00119 | mdrandnum_06_01_in | 109E77866CF | 0.98323 | 0.00118 |
| esrandnum_06_02_in | 16AA4A58735 | 0.98863 | 0.00128 | mdrandnum_06_02_in | 16AA4A58735 | 0.98630 | 0.00108 |
| esrandnum_06_03_in | 1814171B652 | 0.98811 | 0.00120 | mdrandnum_06_03_in | 1814171B652 | 0.98328 | 0.00125 |
| esrandnum_06_04_in | 1A423B9472C | 0.98933 | 0.00114 | mdrandnum_06_04_in | 1A423B9472C | 0.98487 | 0.00112 |
| esrandnum_06_05_in | 20E876D8224 | 0.98869 | 0.00103 | mdrandnum_06_05_in | 20E876D8224 | 0.98559 | 0.00109 |
| esrandnum_06_06_in | 3F6E65CA744 | 0.98854 | 0.00117 | mdrandnum_06_06_in | 3F6E65CA744 | 0.98412 | 0.00106 |
| esrandnum_06_07_in | 479D21DB750 | 0.98900 | 0.00119 | mdrandnum_06_07_in | 479D21DB750 | 0.98395 | 0.00118 |
| esrandnum_06_08_in | 55D4371D3A2 | 0.98844 | 0.00113 | mdrandnum_06_08_in | 55D4371D3A2 | 0.98546 | 0.00114 |
| esrandnum_06_09_in | 6E1A14672B8 | 0.99007 | 0.00126 | mdrandnum_06_09_in | 6E1A14672B8 | 0.98424 | 0.00121 |
| esrandnum_06_10_in | 77A0308C0E4 | 0.99028 | 0.00122 | mdrandnum_06_10_in | 77A0308C0E4 | 0.98465 | 0.00118 |
| **Group 3 – High water content** | | | | | | | |
| esrandnum_09_01_in | 109E77866CF | 0.92872 | 0.00118 | mdrandnum_09_01_in | 109E77866CF | 0.92800 | 0.00123 |
| esrandnum_09_02_in | 16AA4A58735 | 0.92800 | 0.00110 | mdrandnum_09_02_in | 16AA4A58735 | 0.92817 | 0.00107 |
| esrandnum_09_03_in | 1814171B652 | 0.92844 | 0.00118 | mdrandnum_09_03_in | 1814171B652 | 0.92770 | 0.00115 |
| esrandnum_09_04_in | 1A423B9472C | 0.92780 | 0.00123 | mdrandnum_09_04_in | 1A423B9472C | 0.92763 | 0.00126 |
| esrandnum_09_05_in | 20E876D8224 | 0.92783 | 0.00134 | mdrandnum_09_05_in | 20E876D8224 | 0.92584 | 0.00105 |
| esrandnum_09_06_in | 3F6E65CA744 | 0.92809 | 0.00128 | mdrandnum_09_06_in | 3F6E65CA744 | 0.92853 | 0.00112 |
| esrandnum_09_07_in | 479D21DB750 | 0.92725 | 0.00111 | mdrandnum_09_07_in | 479D21DB750 | 0.92682 | 0.00111 |
| esrandnum_09_08_in | 55D4371D3A2 | 0.92622 | 0.00126 | mdrandnum_09_08_in | 55D4371D3A2 | 0.92706 | 0.00116 |
| esrandnum_09_09_in | 6E1A14672B8 | 0.92925 | 0.00132 | mdrandnum_09_09_in | 6E1A14672B8 | 0.92733 | 0.00110 |
| esrandnum_09_10_in | 77A0308C0E4 | 0.92757 | 0.00114 | mdrandnum_09_10_in | 77A0308C0E4 | 0.92886 | 0.00132 |

The evaluation of the mean differences (di) for the 10 set of cases is accomplished through hypothesis testing, a statistical tool used to provide evidence that a difference exists or does not exist. The ti values are 0.70, 10.0 and 0.95 for dry Kaolite, for NCT Kaolite, and for flooded Kaolite, respectively. A value of 3.25 is obtained from the standard table for critical values for the t distribution, from which the decision to accept or reject the null hypothesis H0 is made with a Type I error probability ($\alpha$) of 0.01. For t <3.25, the Ho hypothesis is not rejected. Acceptance of the null hypothesis is the result of insufficient evidence to reject it. Thus, it can be concluded that the mean estimate of the difference of the AM Kaolite is not significantly different from the mean of the TS Kaolite for both dry and flooded Kaolite. For t >3.25, the Ho hypothesis is rejected. Therefore, it can be concluded that the mean estimate of the difference of the AM Kaolite is significantly different from the mean of the TS Kaolite for the normal moisture Kaolite. The mean $k_{eff}$ for AM Kaolite is significantly greater than the mean $k_{eff}$ of the TS Kaolite; therefore, the use of the AM specification in the ES-3100 criticality calculations is conservative and bounding. Details of the statistical evaluation are documented in Reference DAC-FS-900000-A014.

### 6.9.3.5 Water

Water is used in various regions of the models to simulate HAC as an interstitial moderator and as a reflector. When used at full density, the density of water is 0.9982 g/cm$^3$ (NUREG/CR-0200, Rev. 6).

### 6.9.3.6 Calculation of Equivalent Water Mass for Polyethylene

In the calculation models for evaluation of NCT, water may be substituted for the polyethylene composition of bags present in the package. Based on hydrogen density, 1285.14 g of water are equivalent to 1000 g of polyethylene for nuclear criticality safety calculations. The equivalent water mass is calculated as follows:

$$1 \text{ kg polyethylene} = \frac{1000 \text{ g}}{0.92 \text{ g/cm}^3} = 1087.0197 \text{ cm}^3$$

$$\text{H number density} = \frac{(0.92)\,(4)\,(6.02252 \times 10^{23})}{(28.0312)\,(10^{24})} = 7.906502 \times 10^{-2} \text{ at/bn-cm}$$

$$\text{H in 1 kg} = (1087.0197 \text{ cm}^3)\,(7.906502 \times 10^{-2}) = 85.945234 \text{ at-cm}^2/\text{bn}$$

Hydrogen in 1 kg of polyethylene [$(CH_2)_2$, molecular weight = 28.0312; density = 0.92]:

Grams of water [$H_2O$, molecular weight = 18.0110; density = 0.9982] with hydrogen content equivalent to 1 kg of polyethylene:

$$\text{equivalent g of } H_2O = \frac{(85.945234)\,(18.0110)\,(10^{24})}{(2)\,(6.02252 \times 10^{23})} = 1285.1427 \text{ g}$$

# Appendix 6.9.4

# Qualification of a Neutron-absorber Material for the ES-3100

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## Appendix 6.9.4

## Qualification of a Neutron-absorber Material for the ES-3100

### 6.9.4.1 Introduction

277-4 is a formulation of Thermo Electron Corporation's Cat. 277-0, a boron carbide additive and water. 277-4 is a neutron radiation shielding product and is one of several materials in its class that have been evaluated as a candidate neutron-absorber system for a variety of nuclear criticality safety applications by the Y-12 National Security Complex (Y-12). This class of materials is characterized as a dispersion of $^{nat}B_4C$ particulate[1] throughout a hardened hydraulic cement or binder, resulting in a high-hydrogen, borated material system. It offers many advantages for typical Y-12 applications over other classes of materials such as borated aluminum because a neutron moderator and neutron absorber are both integral to the solid material system itself. The separate addition of another neutron moderating material such as water or polyethylene is not required in order for it to function effectively.

Computational methods of analysis in simple geometry permit direct comparison of neutron-absorber system performance for nuclear criticality safety applications. The measure of comparison is the neutron interaction potential between two parallel 0.745-cm-thick slabs of infinite extent of $^{235}U$ metal at a density of 18.81 g/cm$^3$. The slabs are separated by a variable thickness of material and reflected by a 60-cm thickness of the same material (Fig. 6.9.4.1-1). Each material is modeled as an idealized homogeneous mixture of elements based on nominal density and constituent proportions (Table 6.9.4.1-1). The result is expressed in terms of calculated $k_{eff}$ [2] as influenced by the thickness of the candidate material between the two parallel slabs (see Fig. 6.9.4.1-2).

The least effective neutron-absorber material systems are those with low hydrogen content and low neutron absorption cross section (e.g., ordinary concrete). The performance of concrete that contains $^{nat}B_4C$ particulate (e.g., borated concrete) is improved, but it is still hindered by its low hydrogen content. This is a function of the proportion and type of cement in the typical concrete mixture (i.e., a low proportion of lime- and silica-based Portland cement). Ordinary water is also included for comparison because of its high hydrogen content, but its performance is also limited by a low total mass density and low neutron absorption cross section.

As expected, materials with high hydrogen content and high boron content (e.g., 277-4, borated ceramics, and borated polymers) are predicted to be the most effective neutron-absorber systems. Although the mechanical and thermal properties of such systems can vary significantly, their nuclear properties are dictated almost exclusively by the relative proportion and content of $^{10}B$ and H and the total mass density of the material system. These things being equal, the nuclear performance of any material in this class (i.e., 277-4, borated ceramics, and borated polymers) is representative of the others.

[1] 277-4 is an improved variant of the Cat 277 product ca. 2000 which was originally formulated as a dispersion of $^{nat}$Borosilicate glass granules rather than the current practice of using $^{nat}B_4C$ particulate.

[2] SCALE 4.4a, CSAS25 code sequence for KENO V.a with the 238-group ENDF B-IV neutron cross-section library on the Y-12 SAE Hewlett-Packard J5600 workstation (CMODB).

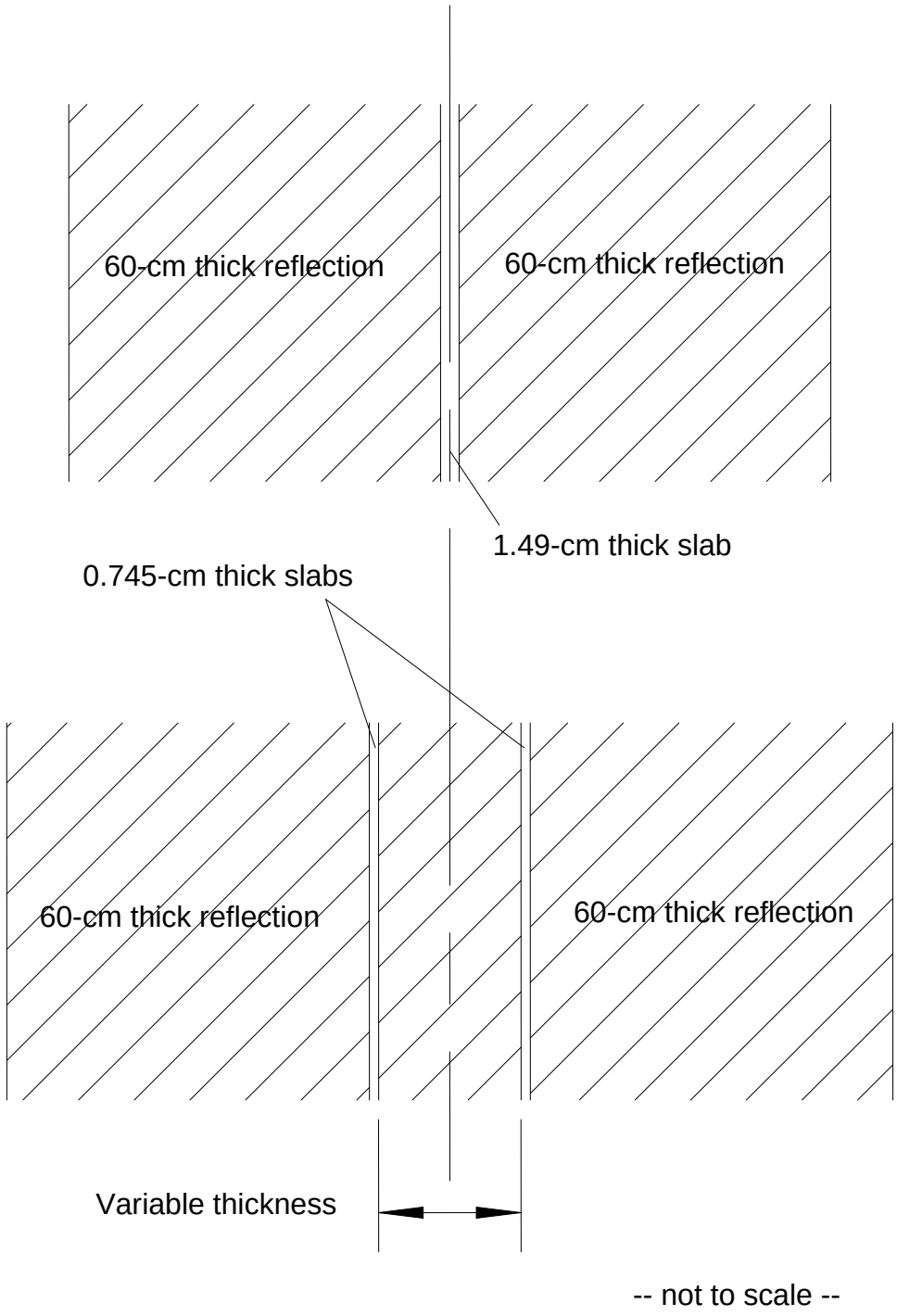



**Fig. 6.9.4.1-1. Physical model of parallel $^{235}U$ metal slabs of infinite extent reflected and separated by various candidate neutron-absorber materials.**

**Table 6.9.4.1-1. Nominal elemental and isotopic compositions of idealized material models for comparison of various neutron absorbers (atoms/barn·cm)**

| | Ordinary concrete A 2.147 g/cm$^3$ | Ordinary concrete B 2.299 g/cm$^3$ | Water 0.9982 g/cm$^3$ | Borated concrete 2.563 g/cm$^3$ | Cat 277a 1.68 g/cm$^3$ | Borated ceramic 1.91 g/cm$^3$ | Borated polymer 1.717 g/cm$^3$ | $^{235}$U metal 18.81 g/cm$^3$ |
|---|---|---|---|---|---|---|---|---|
| H | 4.2581E-03 | 8.5010E-03 | 6.6751E-02 | 4.2900E-03 | 3.3800E-02 | 2.7200E-02 | 5.7600E-02 | |
| B-10 | | | | 1.7600E-04 | 2.8400E-04 | 2.6500E-03 | 9.4600E-04 | |
| B-11 | | | | 6.8100E-04 | 1.1800E-03 | 1.1000E-02 | 3.9200E-03 | |
| C | 1.1348E-02 | 2.0217E-02 | | 9.0000E-04 | | 4.2600E-03 | 2.3500E-02 | |
| N | | | | | | | 1.3800E-03 | |
| O | 4.0370E-02 | 3.5511E-02 | 3.3376E-02 | 4.2400E-02 | 3.7100E-02 | 3.2900E-02 | 2.5900E-02 | |
| Na | 7.9356E-05 | 1.6299E-05 | | 6.7100E-05 | 2.6000E-04 | 7.9200E-05 | | |
| Mg | 5.0111E-03 | 1.8602E-03 | | 2.3000E-04 | 2.0800E-04 | 2.3300E-03 | | |
| Al | 3.7660E-04 | 5.5580E-04 | | 2.2900E-03 | 8.9700E-03 | 1.7400E-03 | 7.7000E-03 | |
| Si | 1.9382E-03 | 1.7000E-03 | | 1.1800E-02 | 7.6700E-04 | 3.2300E-03 | | |
| P | | | | | | 2.1200E-03 | | |
| S | 1.0013E-04 | | | 9.6300E-05 | 6.0000E-05 | 7.7800E-05 | | |
| Cl | 1.9074E-05 | | | | | | | |
| K | 3.1231E-04 | 4.0300E-05 | | 3.1600E-04 | | 2.3100E-03 | | |
| Ca | 7.3008E-03 | 1.1101E-02 | | 3.1200E-03 | 2.2300E-03 | 2.4600E-04 | | |
| Ti | 4.0183E-05 | | | | | 7.0800E-05 | | |
| Mn | 1.2050E-05 | | | 1.4000E-04 | | | | |
| Fe | 1.2954E-04 | 1.9301E-04 | | 4.6200E-03 | 4.8900E-05 | 5.2000E-04 | | |
| U-235 | | | | | | | | 4.8200E-02 |

[a] The $^{10}$B content of this material model for Cat 277 is based on its ca. 2000 formulation using crushed borosilicate glass rather than the current practice of using $^{nat}B_4C$ particulate. This particular formulation is roughly equivalent to ~2% $^{nat}B_4C$ particulate (i.e., equivalent $^{10}$B content, by weight). For otherwise identical H and B-10 content, this difference is unimportant relative to its nuclear performance as an idealized homogeneous mixture of elements. However, the current use of more than 5% $^{nat}B_4C$ particulate (by weight) is preferred due to reasons relating to the method of preparation, chemical reaction, and placement of 277-4 and uniformity of $^{10}$B distribution in the cured product. As with all the materials in this class, the amount of H and $^{10}$B in the finished product is determined by the relative proportions of its major constituents, which are tailored to the requirements of the specific application.

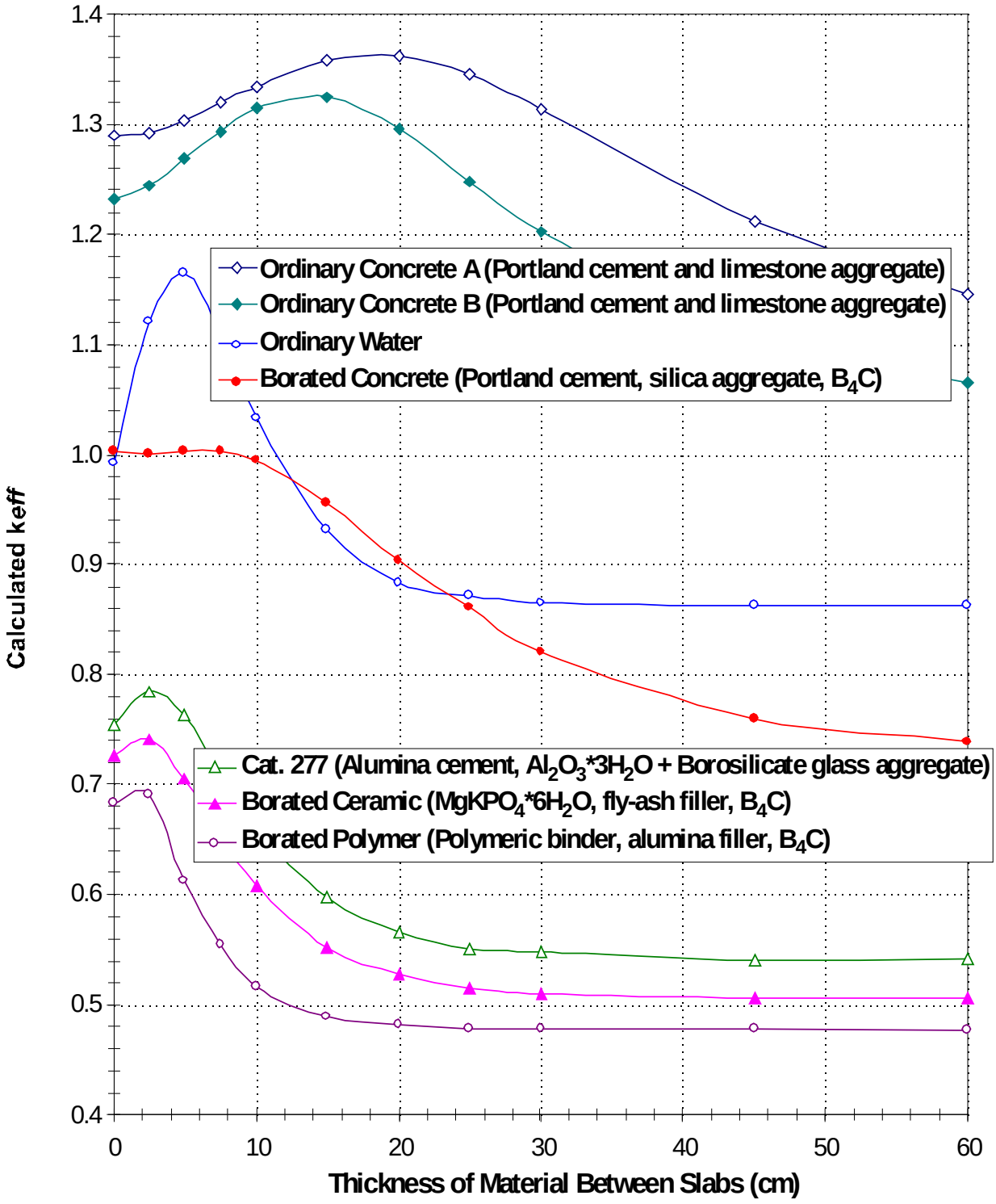



**Fig. 6.9.4.1-2. The effect of various materials on neutron interaction between parallel slabs of $^{235}U$ metal of infinite extent.**

### 6.9.4.2 Performance Testing

To investigate the performance of this class of neutron-absorbing materials further, Y-12 has studied neutron radiography and neutron transmission measurements on several samples of a borated ceramic. Like 277-4, the borated ceramic is also a dispersion of $^{nat}B_4C$ particulate throughout a hardened hydraulic crystalline solid material matrix for which the binder phase is $MgKPO_4 \cdot 6H_2O$ rather than the hydrates of CaO and $Al_2O_3$. In fact, the more finely divided $^{nat}B_4C$ particulate specified for 277-4 is a slight advantage over the modestly coarser particulate in the borated ceramic. As shown below in Table 6.9.4.2-1, the relative proportion and content of H and $^{10}B$ and their total mass density are very similar. The small differences between the nuclear properties of their associated low- and intermediate-Z elements (i.e., oxides of Mg, Al, P, K, and Ca) are negligible. Thus, performance and the most significant factors affecting performance are nearly identical for both materials, so the results of neutron radiography and neutron transmission for the borated ceramic samples are judged applicable to 277-4 specimens of similar dimension.

**Table 6.9.4.2-1. Comparison of nominal values for 277-4 and borated ceramic samples subjected to neutron radiography and neutron transmission testing.**

| Attribute | Cat 277 original formulation ca. 2000 | 277-4 ES-3100 formulation as cured | Borated ceramic samples for testing |
|---|---|---|---|
| Principal binder phase(s) | Hydrates of CaO and $Al_2O_3$ | Hydrates of CaO and $Al_2O_3$ | $MgKPO_4 \cdot 6H_2O$ |
| Neutron absorber | $^{nat}$Borosilicate glass granules | $^{nat}B_4C$ particulate | $^{nat}B_4C$ particulate |
| Particle Size | 90 wt % <2360 μm<br>65 wt % <1180 μm<br>40 wt % <600 μm<br>15 wt % <102 μm<br>0 wt % <150 μm | 100 wt % <102 μm | 100 wt % <559 μm<br>90 wt % <356 μm<br>40 wt % <254 μm<br>3 wt % <122 μm<br>0 wt % <63 μm |
| Filler Material(s) | $Al_2O_3 \cdot 3H_2O$ | $Al_2O_3 \cdot 3H_2O$ | Class F Coal Fly-ash |
| Total Mass Density | 1.68 g/cm$^3$ | 1.60 g/cm$^3$ | 1.91 g/cm$^3$ |
| Total $H_2O$ content | 0.51 g/cm$^3$ | 0.51 g/cm$^3$ | 0.49 g/cm$^3$ |
| Total $^{10}B$ content | 0.005 g/cm$^3$ | 0.013 g/cm$^3$ | 0.012 g/cm$^3$ |

Samples were prepared from sectioned pieces of a single specimen from a vertically oriented mold measuring 10 × 10 × ~30 cm tall, as illustrated in Fig. 6.9.4.2-1 (nominally 4 × 4 × 12 in. tall). One specimen was prepared by the normal method of mixing and preparation for the borated ceramic material. Sectioning the first specimen resulted in two thick samples designated “1 of 2” and “2 of 2” which each measured 10-cm wide by ~30-cm long by ~2.4-cm thick (nominally 1-in. thick). A second specimen was prepared by abnormal methods intended to produce non-homogeneity (i.e., poorly mixed using retardants followed by excessive and extended vibration of the mold after installation). Sectioning this specimen resulted in two thin samples designated “062d1bc” and “062d1bd” which each measured 10-cm wide by ~30-cm long by ~1.2-cm thick (nominally 0.5-in. thick). The samples were delivered to the Breazeale Nuclear Reactor Building at Pennsylvania State University for inspection. Upon completion of inspection for all four samples as received, a thick sample “1 of 2” and a thin sample “062d1bc” were dehydrated by heating to 140°C to eliminate interference by hydrogen, and all four samples were tested again.

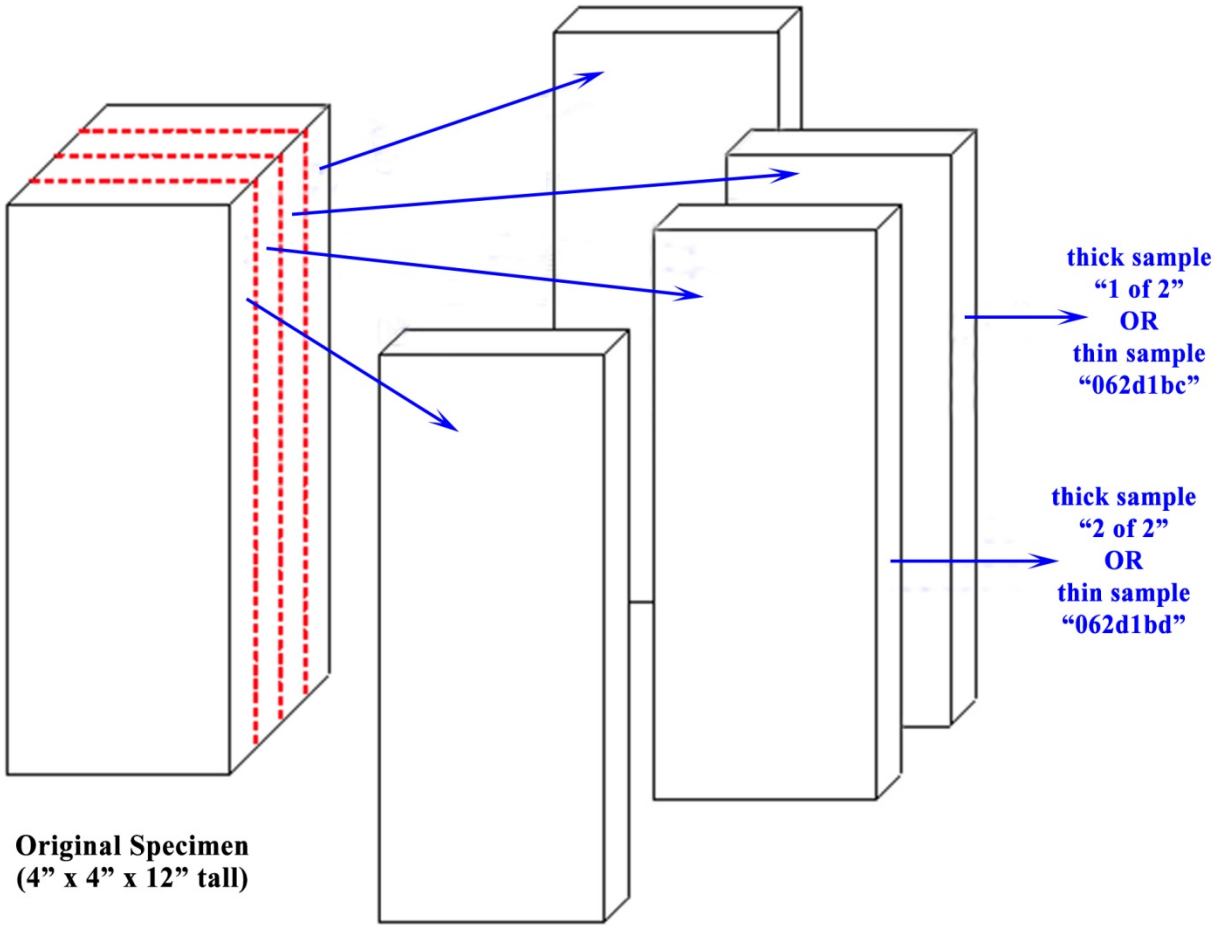



**Fig. 6.9.4.2-1. Illustration of sectioning plan for borated ceramic samples for neutron radiography and neutron transmission measurements.**

All four samples were qualitatively inspected for visual defects and subjected to neutron radiographic inspection. The inspections were intended to identify any variations in image luminance, which would indicate a variation in homogeneity and density. Neutron transmission measurements were calibrated to results for thin $ZrB_2$ reference coupons sandwiched with thick aluminum metal. The $^{10}B$ areal densities of the thin reference coupons ranged from 5.32 mg/cm$^2$ to 57.04 mg/cm$^2$ over a total $ZrB_2$ + Al reference thickness of 24.21–24.98 mm. By comparison, the thick samples contain an idealized $^{10}B$ areal density of 28.8 mg/cm$^2$ (i.e., 0.012 g/cm$^3$ over a 2.4-cm thickness), and the thin samples contain an idealized $^{10}B$ areal density of 14.4 mg/cm$^2$ (i.e., 0.012 g/cm$^3$ over a 1.2-cm thickness).

Radiographic examination of both thick samples "1 of 2" and "2 of 2" indicated uniformity of composition and density (see Fig. 6.9.4.2-2). Even after dehydration of thick sample "1 of 2," radioscopic examination indicated uniformity of composition and density. Initial neutron transmission results for both thick samples "1 of 2" and "2 of 2" indicated that neutron transmission was very low. In fact, the interference due to the hydrogen content implies an equivalent $^{10}B$ areal density measurement of ~67 ± 4 mg/cm$^2$. This is more than twice the actual physical value of 28.8 mg/cm$^2$. Only after thick sample of "1 of 2" is dehydrated and tested again do the results of neutron transmission measurements more accurately reflect the actual physical $^{10}B$ content. In fact, the average measured value of 27.419 mg/cm$^2$ at eleven points along the long axis of the dehydrated sample "1 of 2" is more than 95% of the actual physical value of 28.8 mg/cm$^2$ and varies no more than a few percent from one end to the other (see Tables 6.9.4.2-2 and 6.9.4.2-3).

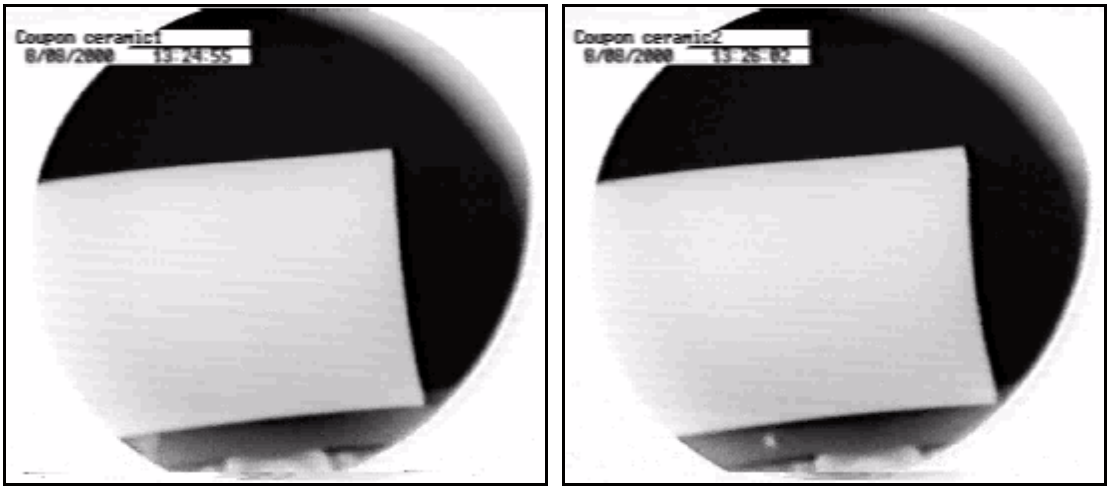



**Fig. 6.9.4.2-2. Radiographic images of thick samples "1 of 2" (left) and "2 of 2" (right) indicating uniformity of composition and density.**

**Table 6.9.4.2-2. Results of neutron transmission measurements of thick samples**

| | Equivalent $^{10}B$ areal density ($mg/cm^2$) | | |
|---|---|---|---|
| | **End** | **Center** | **End** |
| sample "1 of 2" | 66.419 | 68.673 | 71.003 |
| sample "2 of 2" | 65.0 | 68.25 | 69.708 |
| sample "1 of 2" (dehydrated) | 27.586 | 27.191 | 28.555 |
| sample "2 of 2" (re-test) | 63.687 | 65.966 | 65.572 |

**Table 6.9.4.2-3. Neutron transmission measurements of thick sample "1 of 2" after dehydration**

| Point of measurement (uniform intervals from one end to the other) | Equivalent $^{10}B$ areal density ($mg/cm^2$) | Deviation from average (%) |
|---|---|---|
| 1 | 27.586 | +0.6 % |
| 2 | 26.909 | -1.9 % |
| 3 | 27.039 | -1.4 % |
| 4 | 27.358 | -0.2 % |
| 5 | 27.286 | -0.5 % |
| 6 | 27.191 | -0.8 % |
| 7 | 27.375 | -0.2 % |
| 8 | 27.179 | -0.8 % |
| 9 | 27.236 | -0.7 % |
| 10 | 27.897 | -0.9 % |
| 11 | 28.555 | +4.1 % |
| **Average** | **27.419** | |

Radiographic examination of both thin samples “062d1bc” and “062d1bd” indicates areas of nonuniformity and spots of lower neutron attenuation, along with greater dissimilarity between the samples themselves (see Fig. 6.9.4.2-3). Many of these areas and spots remained evident by radiographic examination even after dehydration of thin sample “062d1bc” and are attributed to physical voids revealed during visual inspection. Again, initial neutron transmission measurements implied a greater-than-actual equivalent $^{10}B$ areal density due to the interference of hydrogen (i.e., measured values averaged ~23.3 mg $^{10}B/cm^2$ rather than the actual value of 14.4 mg $^{10}B/cm^2$).

Measurements repeated after dehydration of sample “062d1bc” more correctly estimate the equivalent $^{10}B$ areal density to be ~11.1 mg/cm$^2$, which is ~77% of the actual physical $^{10}B$ content. Again, the relative values vary only a few percent from one end of the sample to the other (see Table 6.9.4.2-4). However, the measured values of a dehydrated sample in this case are known to be biased low. First, the total thicknesses of the $ZrB_2$ + Al reference coupons for calibration were ~24.21 to 24.98-mm compared to the 1.2-cm thickness of “062d1bc.” Second, the total mass density of the sample is ~1.4 to 1.5 g/cm$^3$ after dehydration compared to an Al mass density of ~2.7 g/cm$^3$ for the $ZrB_2$ + Al reference coupons. This indicates that even the performance of the thin samples (i.e., 1.2-cm thickness) exhibiting non-uniformity of composition and density is only marginally reduced from that of the idealized, homogeneous material model with respect to neutron absorber efficiency.

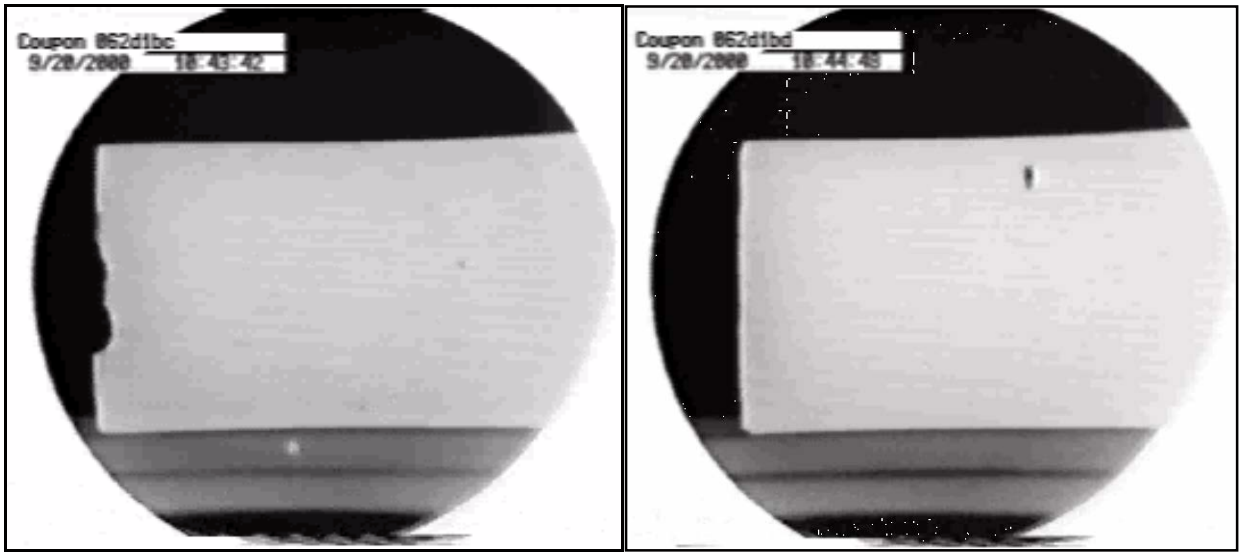



**Fig. 6.9.4.2-3. Radiographic images of thin samples “062d1bc” (left) and “062d1bd” (right) indicating non-uniformity of composition and density and dissimilarity of samples.**

**Table 6.9.4.2-4. Neutron transmission results for dehydrated thin sample "062d1bc" and re-test of thin sample "062d1bd"**

| Position of measurement (see Fig. 6.9.4.2-4) | Minimum equivalent $^{10}B$ areal density (mg/cm$^2$) | | | |
|---|---|---|---|---|
| | Dehydrated thin sample "062d1bc" | | Re-test of thin sample "062d1bd" | |
| | Line A | Line B | Line A | Line B |
| 1 | 12.227 | 11.781 | 25.909 | 25.154 |
| 2 | 11.776 | 11.462 | 24.390 | 25.344 |
| 3 | 11.388 | 11.252 | 24.257 | 24.645 |
| 4 | 10.554 | 10.462 | 25.341 | 24.885 |
| 5 | 10.432 | 10.528 | 24.646 | 25.483 |
| 6 | 10.754 | 11.728 | 25.450 | 25.712 |
| 7 | 10.396 | 11.534 | 25.761 | 23.063 |
| 8 | 11.166 | 10.221 | 24.522 | 25.257 |
| 9 | 10.875 | 10.459 | 23.113 | 23.882 |
| 10 | 11.051 | 10.676 | 25.270 | 23.724 |
| 11 | 11.258 | 11.214 | 24.922 | 25.355 |
| **Combined average** | **11.1** | | **24.8** | |

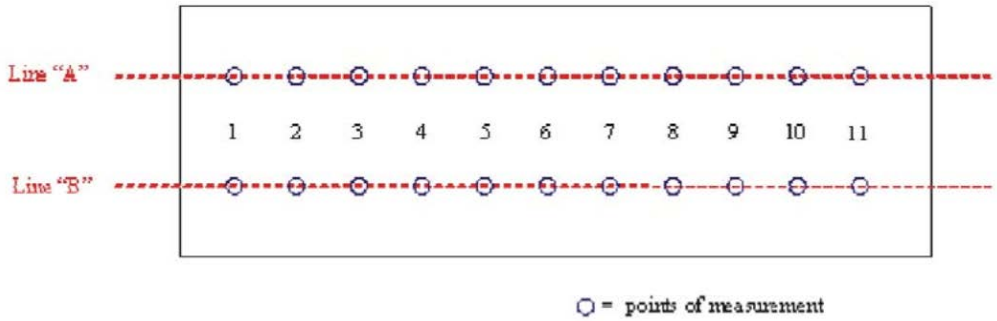



**Fig. 6.9.4-6. Illustration of measurement plan for neutron transmission measurements of thin samples "062d1bc" and "062d1bd."**

### 6.9.4.2.3 Conclusions

Provided that 277-4 is prepared in a controlled manner to ensure the proper specification and proportioning of batch constituents, thorough mixing of the wet slurry, and correct placement and installation to prevent large physical voids, a credible technical justification exists to credit no less than 75% of the $^{nat}B_4C$ particulate and its other constituents, by weight, as an idealized homogeneous mixture for nuclear criticality safety analysis of the ES-3100. There is no evidence of non-homogeneity, neutron self-shielding effects, or neutron streaming effects in borated hydraulic cement or ceramic material systems for thicknesses of 2.4-cm or more. The qualification of 277-4 for use in the design and construction of the ES-3100 described herein is based on sound nuclear engineering principles and direct application of performance test results for such material systems.

# Appendix 6.9.5

## Miscellaneous Information and Data

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## Appendix 6.9.5

## Miscellaneous Information and Data

Table 6.9.5.1 provides the atomic weights of the elements and isotopes of the materials used in this criticality safety evaluation. Atomic weights and isotopic weight percents of the naturally occurring materials are those taken from the Materials Information Processor in the SCALE Standard Composition Library.

Table 6.9.5.2 provides the molecular weights and weight percents of the corresponding elements and isotopes of the various compounds. The weight percents shown in this table are the input to KENO V.a (NUREG/CR-0200, Rev. 6).

Table 6.9.5.3 provides equations for determining atomic densities. These equations were derived based on the assumption that all constituents in the mixture are volume additive. Although these equations with their corresponding subscripts are for mixtures of elements, isotopes, or both, all except Equation (2) can be applied to compounds if the user substitutes certain subscript notations and meaning changes. For example, in Equations (1a) and (1b), the atomic weight becomes the molecular weight and the subscript "m" for mixture changes to the subscript "c" for compound. Likewise, in Equations (3a) and (3b), the atomic weight becomes the molecular weight, and the atom fraction ($n_i$) becomes the stoichiometric proportion of the elements making up the molecule. In Equations (3)–(5), the atom fraction ($n_i$) becomes the stoichiometric proportion (the element number subscript in the molecular formula), whose sum does not equal unity. Equation (2) is applicable only to the theoretical density of mixtures; it does not apply to the density of compounds.

**Table 6.9.5.1. Atomic weights**

| Element or isotope | Atomic weight |
|---|---|
| H | 1.0078 |
| C | 12.0000 |
| O | 15.9954 |
| N | 14.0033 |
| Na | 22.9895 |
| Mg | 24.3051 |
| Al | 26.9818 |
| Si | 28.0853 |
| Ca | 40.0803 |
| Ti | 47.8789 |
| Cr | 51.9957 |
| Mn | 54.9380 |
| Fe | 55.8447 |
| Ni | 58.6868 |
| Zr | 91.2196 |
| $^{235}U$ | 235.0442 |
| $^{238}U$ | 238.0510 |

**Table 6.9.5.2. Molecular weights**

| Compound | | Molecular or atomic weight | Weight percent in compound | Stoichiometric composition |
|---|---|---|---|---|
| Kaolite 1600™ | | | | |
| | Alumina | - | 9.6 | $Al_2O_3$ |
| | Al | 26.9818 | 52.92507 | |
| | O | 15.9954 | 47.07493 | |
| | Silica | - | 36.7 | $SiO_2$ |
| | Si | 28.0853 | 46.74349 | |
| | O | 15.9954 | 53.25651 | |
| | Ferric Oxide | - | 6.7 | $Fe_2O_3$ |
| | Fe | 55.8447 | 69.94330 | |
| | O | 15.9954 | 30.05670 | |
| | Titanium Oxide | - | 1.2 | $TiO_2$ |
| | Ti | 47.8789 | 59.95084 | |
| | O | 15.9954 | 40.04916 | |
| | Calcium Oxide | - | 30.7 | CaO |
| | Ca | 40.0803 | 71.47009 | |
| | O | 15.9954 | 28.52991 | |
| | Magnesium Oxide | - | 13.1 | MgO |
| | Mg | 24.3051 | 60.30359 | |
| | O | 15.9954 | 39.69641 | |
| | Alkalies | - | 2.0 | $Na_2O$ |
| | Na | 22.9895 | 74.18575 | |
| | O | 15.9954 | 25.81425 | |

**Table 6.9.5.3. Useful equations**

$$N_m = \rho_m N_o / A_m \quad (1a)$$

$$N_i = w_i \rho_m N_o / A_i \quad (1b)$$

$$\rho_m = 1/\Sigma w_i/\rho_i \quad (2)$$

$$A_m = 1/\Sigma w_i/A_i \quad (3a)$$

$$= \Sigma n_i A_i \quad (3b)$$

$$w_i = m_i/m_m \quad (4a)$$

$$= n_i A_i/\Sigma n_i A_i \quad (4b)$$

$$n_i = N_i/N_m \quad (5a)$$

$$= (w_i/A_i)/\Sigma(w_i/A_i) \quad (5b)$$

where

$N_o$ = $0.602252 \times 10^{24}$ (atoms/mol) Avogadro's number,
$N$ = atom density (atoms/cm$^3$), $N_m = \Sigma N_i$ ,
$\rho$ = density (g/cm$^3$),
$A$ = atomic mass (g-mol),
$w$ = weight fraction, $\Sigma w_i = 1$,
$n$ = atom fraction, $\Sigma n_i = 1$,
subscript "m" = of the mixture,
subscript "i" = $i^{th}$ component of the mixture,
(atoms/cm$^3$)$(1/10^{24})$ = atoms/barn-cm.

# Appendix 6.9.6

## Abridged Summary Tables of Criticality Calculation Results

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## Appendix 6.9.6

## Abridged Summary Tables of Criticality Calculation Results

This appendix contains the summary tables for calculation results identified in Sects. 6.4, 6.5, 6.6, and 6.7 of this document. The CV calculation model is a modification of the water-reflected, single-unit package calculation model where the packaging regions external to the containment vessel are replaced with full density water. The index is as follows:

**Cylinder Content**

Table 6.9.6-1 Results for the 3.24-in.-diam cylinder HEU content in CV calculation model.

Table 6.9.6-2 Results for the 3.24-in.-diam cylinder HEU content in bare and water reflected package calculation models.

Table 6.9.6-3 Results for the 3.24-in.-diam cylinder HEU content in package calculation models.

Table 6.9.6-3b Results for spacing of 3.24 in.-diameter cylinder HEU metal content in CV calculation model.

Table 6.9.6-3c Results for spacing of 3.24 in.-diameter cylinder HEU metal content in packaging calculation model.

**Square Bar Content**

Table 6.9.6-4 Results for the 2.29-in square bar HEU content in CV calculation model.

Table 6.9.6-5 Results for the 2.29-in square bar HEU content in packaging calculation model.

**Cylinder Content**

Table 6.9.6-6 Results for the 4.25-in.-diam cylinder HEU content in CV calculation model.

Table 6.9.6-7 Results for the 4.25-in.-diam cylinder HEU content in packaging calculation models.

**Slugs Content**

Table 6.9.6-8 Results for 1.5-in.-diam × 2.0-in.-tall slug HEU metal content in CV calculation model.

Table 6.9.6-9 Results for the 1.5-in.-diam × 2.0-in.-tall slug HEU metal content in packaging calculation model.

**Broken Metal Content**

Table 6.9.6-10 Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model

Table 6.9.6-11 Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model

Table 6.9.6-11b Comparison of NCT results for HEU broken metal content in ES-3100 NCT packaging calculation models

Table 6.9.6-11c Comparison of HAC results for HEU broken metal content in ES-3100 HAC packaging calculation models

Table 6.9.6-11d Comparison of results for the 277-4 canned spacer under the nominal and the minimal acceptance criteria for HEU broken metal content in ES-3100 HAC packaging calculation models

**Heu Product Oxide Content**

Table 6.9.6-12 Results for HEU oxide content in CV calculation model.

Table 6.9.6-13 Results for HEU product oxide content at 6.54 g/cm$^3$ in single-unit packaging calculation model.

Table 6.9.6-13a Results for HEU oxide content in single-unit packaging calculation model.

Table 6.9.6-13b Results for HEU oxide content in array packaging calculation model.

**UNX Crystal Content**

Table 6.9.6-14 Results for UNX crystal content in CV calculation model.

Table 6.9.6-15 Results for UNX crystal content in packaging calculation model.

Table 6.9.6-16 Results for leakage of UNX crystal content out of containment vessel.

**HEU Skull Oxide Content**

Table 6.9.6-17 Results for skull oxide (SO) content in CV calculation model.

Table 6.9.6-18a NCT results for SO content in packaging calculation model.

Table 6.9.6-18b HAC results for SO content in packaging calculation model.

**Unirradiated TRIGA Reactor Fuel Element Content**

Table 6.9.6-19a Results for $UZrH_x$ content in CV calculation model.

Table 6.9.6-19b Results for $UZrH_x$ content spacing in CV calculation model.

Table 6.9.6-19c Results for $UZrH_x$ content uranium weight fraction in CV calculation model.

Table 6.9.6-20a Results for $UZrH_x$ content at 19.7 wt % $^{235}U$ in packaging calculation model.

Table 6.9.6-20b Results for $UZrH_x$ content at 70.1 wt % $^{235}U$ in packaging calculation model.

Table 6.9.6-20c Results for 1.31 in. Smaller diameter $UZrH_x$ at 70.1 wt % $^{235}U$ content in packaging calculation model.

Table 6.9.6-20d Results for 1.31 in. smaller diameter $UZrH_x$ at 19.7 wt % $^{235}U$ content in packaging calculation model.

**Air Transport Content**

Table 6.9.6-21 Results for solid HEU metal content for air transportation.

Table 6.9.6-22a Results for TRIGA ($UZrH_x$) fuel element content at 19.7 wt % $^{235}U$ for air transportation.

Table 6.9.6-22b Results for TRIGA ($UZrH_x$) fuel element content at 70.1 wt % $^{235}U$ for air transportation.

Table 6.9.6-22c Results for research reactor fuel ($U_3O_8$-Al) content for air transportation.

Table 6.9.6-22d Results for research reactor fuel ($UO_2$-Mg) content for air transportation.

Table 6.9.6-23 Results for HEU broken metal content for air transport.

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**Table 6.9.6-1. Results for 3.24 in.-diameter cylinder HEU metal content in CV calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| **flooded containment vessel, reflected** | | | | | | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | |
| cvcrcyt11_36_1_1 | 0.0 | 36000 | 36000 | 0 | 0.00 | 1.0E-20 | 0.90460 | 0.00107 | 0.90673 |
| cvcrcyt11_36_1_6 | 0.0 | 36000 | 36000 | 829 | 0.60 | 1.0E-01 | 0.90726 | 0.00124 | 0.90973 |
| cvcrcyt11_36_1_7 | 0.0 | 36000 | 36000 | 1657 | 1.20 | 2.0E-01 | 0.91182 | 0.00120 | 0.91422 |
| cvcrcyt11_36_1_8 | 0.0 | 36000 | 36000 | 2486 | 1.80 | 3.0E-01 | 0.91690 | 0.00139 | 0.91967 |
| cvcrcyt11_36_1_9 | 0.0 | 36000 | 36000 | 3315 | 2.40 | 4.0E-01 | 0.92263 | 0.00119 | 0.92500 |
| cvcrcyt11_36_1_10 | 0.0 | 36000 | 36000 | 4143 | 3.00 | 5.0E-01 | 0.92840 | 0.00115 | 0.93071 |
| cvcrcyt11_36_1_11 | 0.0 | 36000 | 36000 | 4972 | 3.60 | 6.0E-01 | 0.93827 | 0.00112 | 0.94050 |
| cvcrcyt11_36_1_12 | 0.0 | 36000 | 36000 | 5801 | 4.21 | 7.0E-01 | 0.94633 | 0.00127 | 0.94886 |
| cvcrcyt11_36_1_13 | 0.0 | 36000 | 36000 | 6629 | 4.81 | 8.0E-01 | 0.95397 | 0.00120 | 0.95636 |
| cvcrcyt11_36_1_14 | 0.0 | 36000 | 36000 | 7458 | 5.41 | 9.0E-01 | 0.96276 | 0.00137 | 0.96551 |
| cvcrcyt11_36_1_15 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E+00 | 0.97121 | 0.00125 | 0.97371 |
| | | | | | | | | | |
| cvcrcyt11_36_1 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E+00 | 0.97121 | 0.00125 | 0.97371 |
| cvcrcyt11_35_1 | 0.0 | 35000 | 35000 | 8340 | 6.22 | 1.0E+00 | 0.96937 | 0.00120 | 0.97177 |
| cvcrcyt11_34_1 | 0.0 | 34000 | 34000 | 8393 | 6.44 | 1.0E+00 | 0.96886 | 0.00120 | 0.97126 |
| cvcrcyt11_33_1 | 0.0 | 33000 | 33000 | 8446 | 6.68 | 1.0E+00 | 0.96531 | 0.00111 | 0.96754 |
| cvcrcyt11_32_1 | 0.0 | 32000 | 32000 | 8499 | 6.93 | 1.0E+00 | 0.96360 | 0.00120 | 0.96600 |
| cvcrcyt11_31_1 | 0.0 | 31000 | 31000 | 8552 | 7.20 | 1.0E+00 | 0.95960 | 0.00122 | 0.96205 |
| cvcrcyt11_30_1 | 0.0 | 30000 | 30000 | 8605 | 7.49 | 1.0E+00 | 0.95842 | 0.00128 | 0.96097 |
| cvcrcyt11_29_1 | 0.0 | 29000 | 29000 | 8658 | 7.79 | 1.0E+00 | 0.95488 | 0.00115 | 0.95717 |
| cvcrcyt11_28_1 | 0.0 | 28000 | 28000 | 8711 | 8.12 | 1.0E+00 | 0.95409 | 0.00118 | 0.95645 |
| cvcrcyt11_27_1 | 0.0 | 27000 | 27000 | 8764 | 8.47 | 1.0E+00 | 0.94797 | 0.00113 | 0.95023 |
| cvcrcyt11_26_1 | 0.0 | 26000 | 26000 | 8817 | 8.85 | 1.0E+00 | 0.94376 | 0.00124 | 0.94623 |

**Table 6.9.6-1. Results for 3.24 in.-diameter cylinder HEU metal content in CV calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| cvcrcyt11_25_1 | 0.0 | 25000 | 25000 | 8870 | 9.26 | 1.0E+00 | 0.94075 | 0.00141 | 0.94357 |
| cvcrcyt11_24_1 | 0.0 | 24000 | 24000 | 8923 | 9.70 | 1.0E+00 | 0.93510 | 0.00133 | 0.93776 |
| cvcrcyt11_23_1 | 0.0 | 23000 | 23000 | 8977 | 10.19 | 1.0E+00 | 0.93038 | 0.00130 | 0.93298 |
| cvcrcyt11_22_1 | 0.0 | 22000 | 22000 | 9030 | 10.71 | 1.0E+00 | 0.92658 | 0.00106 | 0.92870 |
| cvcrcyt11_21_1 | 0.0 | 21000 | 21000 | 9083 | 11.29 | 1.0E+00 | 0.92046 | 0.00118 | 0.92282 |
| cvcrcyt11_20_1 | 0.0 | 20000 | 20000 | 9136 | 11.92 | 1.0E+00 | 0.91168 | 0.00125 | 0.91418 |
| cvcrcyt11_19_1 | 0.0 | 19000 | 19000 | 9189 | 12.62 | 1.0E+00 | 0.90618 | 0.00128 | 0.90874 |
| cvcrcyt11_18_1 | 0.0 | 18000 | 18000 | 9242 | 13.40 | 1.0E+00 | 0.89978 | 0.00124 | 0.90226 |
| **with can spacers (np thickness=1.4 in.)** | | | | | | | | | |
| cvcrcyt11_36_2_1 | 1.4 | 36000 | 36000 | 0 | 0.00 | 1.0E-20 | 0.83041 | 0.00103 | 0.83248 |
| cvcrcyt11_36_2_6 | 1.4 | 36000 | 36000 | 767 | 0.56 | 1.0E-01 | 0.82885 | 0.00106 | 0.83096 |
| cvcrcyt11_36_2_7 | 1.4 | 36000 | 36000 | 1535 | 1.11 | 2.0E-01 | 0.83022 | 0.00104 | 0.83230 |
| cvcrcyt11_36_2_8 | 1.4 | 36000 | 36000 | 2302 | 1.67 | 3.0E-01 | 0.83492 | 0.00104 | 0.83699 |
| cvcrcyt11_36_2_9 | 1.4 | 36000 | 36000 | 3069 | 2.23 | 4.0E-01 | 0.84066 | 0.00123 | 0.84311 |
| cvcrcyt11_36_2_10 | 1.4 | 36000 | 36000 | 3837 | 2.78 | 5.0E-01 | 0.84789 | 0.00102 | 0.84993 |
| cvcrcyt11_36_2_11 | 1.4 | 36000 | 36000 | 4604 | 3.34 | 6.0E-01 | 0.85423 | 0.00101 | 0.85624 |
| cvcrcyt11_36_2_12 | 1.4 | 36000 | 36000 | 5371 | 3.89 | 7.0E-01 | 0.86190 | 0.00106 | 0.86403 |
| cvcrcyt11_36_2_13 | 1.4 | 36000 | 36000 | 6139 | 4.45 | 8.0E-01 | 0.86687 | 0.00118 | 0.86923 |
| cvcrcyt11_36_2_14 | 1.4 | 36000 | 36000 | 6906 | 5.01 | 9.0E-01 | 0.87589 | 0.00113 | 0.87816 |
| cvcrcyt11_36_2_15 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E+00 | 0.88436 | 0.00111 | 0.88657 |
| | | | | | | | | | |
| cvcrcyt11_36_2 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E+00 | 0.88436 | 0.00111 | 0.88657 |
| cvcrcyt11_35_2 | 1.4 | 35000 | 35000 | 7726 | 5.76 | 1.0E+00 | 0.88274 | 0.00108 | 0.88491 |
| cvcrcyt11_34_2 | 1.4 | 34000 | 34000 | 7779 | 5.97 | 1.0E+00 | 0.87740 | 0.00119 | 0.87977 |
| cvcrcyt11_33_2 | 1.4 | 33000 | 33000 | 7832 | 6.19 | 1.0E+00 | 0.87234 | 0.00112 | 0.87459 |

**Table 6.9.6-1. Results for 3.24 in.-diameter cylinder HEU metal content in CV calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| cvcrcyt11_32_2 | 1.4 | 32000 | 32000 | 7885 | 6.43 | 1.0E+00 | 0.86817 | 0.00108 | 0.87033 |
| cvcrcyt11_31_2 | 1.4 | 31000 | 31000 | 7938 | 6.68 | 1.0E+00 | 0.86047 | 0.00124 | 0.86295 |
| cvcrcyt11_30_2 | 1.4 | 30000 | 30000 | 7992 | 6.95 | 1.0E+00 | 0.85525 | 0.00117 | 0.85760 |
| **flooded containment vessel, reflected, no can spacers (np thickness = 0.0 in.)** | | | | | | | | | |
| **no polyethylene** | | | | | | | | | |
| cvcrcyt11_21_1 | 0.0 | 21000 | 21000 | 9083 | 11.29 | 1.0E+00 | 0.92046 | 0.00118 | 0.92282 |
| **500 g polyethylene** | | | | | | | | | |
| cvcrpcyt11_21_1 | 0.0 | 21000 | 21000 | 8540 | 11.41 | 1.0E+00 | 0.90599 | 0.00107 | 0.90814 |
| **dry containment vessel, reflected, no can spacers (np thickness = 0.0 in.)** | | | | | | | | | |
| **500 g polyethylene** | | | | | | | | | |
| cvdcrpcyt11_21_1 | 0.0 | 21000 | 21000 | 0 | 0.80 | 1.0E+00 | 0.84505 | 0.00105 | 0.84716 |

**Table 6.9.6-2. Results for 3.24 in.-diameter cylinder HEU metal content in bare and water reflected packaging calculation models**

| case name | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | nlf | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | nlf | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **content in flooded CV, single package bare** | | | | | | | | | | **content in flooded CV, single package reflected** | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | **no can spacers (np thickness = 0.0 in.)** | | | | |
| ncsbcyt11_36_1_1 | 36000 | 36000 | 8287 | 6.01 | 1.0E-20 | 0.4744 | 0.90856 | 0.00115 | 0.91087 | ncsrcyt11_36_1_1 | 0.0021 | 0.91542 | 0.00120 | 0.91782 |
| ncsbcyt11_36_1_2 | 36000 | 36000 | 8287 | 6.01 | 1.0E-05 | 0.4749 | 0.90825 | 0.00100 | 0.91026 | ncsrcyt11_36_1_2 | 0.0021 | 0.91477 | 0.00123 | 0.91724 |
| ncsbcyt11_36_1_3 | 36000 | 36000 | 8287 | 6.01 | 1.0E-04 | 0.4747 | 0.90817 | 0.00121 | 0.91059 | ncsrcyt11_36_1_3 | 0.0022 | 0.91550 | 0.00111 | 0.91772 |
| ncsbcyt11_36_1_4 | 36000 | 36000 | 8287 | 6.01 | 1.0E-03 | 0.4744 | 0.90926 | 0.00134 | 0.91194 | ncsrcyt11_36_1_4 | 0.0022 | 0.91636 | 0.00117 | 0.91869 |
| ncsbcyt11_36_1_5 | 36000 | 36000 | 8287 | 6.01 | 1.0E-02 | 0.4730 | 0.90883 | 0.00108 | 0.91100 | ncsrcyt11_36_1_5 | 0.0022 | 0.91537 | 0.00109 | 0.91755 |
| ncsbcyt11_36_1_6 | 36000 | 36000 | 8287 | 6.01 | 1.0E-01 | 0.4510 | 0.91550 | 0.00112 | 0.91774 | ncsrcyt11_36_1_6 | 0.0019 | 0.92121 | 0.00133 | 0.92386 |

**Table 6.9.6-2. Results for 3.24 in.-diameter cylinder HEU metal content in bare and water reflected packaging calculation models**

| case name | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | nlf | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | nlf | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncsbcyt11_36_1_8 | 36000 | 36000 | 8287 | 6.01 | 3.0E-01 | 0.3899 | 0.92546 | 0.00134 | 0.92814 | ncsrcyt11_36_1_8 | 0.0016 | 0.92807 | 0.00112 | 0.93032 |
| ncsbcyt11_36_1_15 | 36000 | 36000 | 8287 | 6.01 | 1.0E+00 | 0.1823 | 0.95215 | 0.00119 | 0.95454 | ncsrcyt11_36_1_15 | 0.0007 | 0.95213 | 0.00129 | 0.95472 |
| | | | | | | | | | | | | | | |
| ncsbcyt11_36_1_15 | 36000 | 36000 | 8287 | 6.01 | 1.0E+00 | 0.1823 | 0.95215 | 0.00119 | 0.95454 | ncsrcyt11_36_1_15 | 0.0007 | 0.95213 | 0.00129 | 0.95472 |
| ncsbcyt11_35_1_15 | 35000 | 35000 | 8340 | 6.22 | 1.0E+00 | 0.1838 | 0.94834 | 0.00122 | 0.95077 | ncsrcyt11_35_1_15 | 0.0008 | 0.94870 | 0.00107 | 0.95083 |
| ncsbcyt11_34_1_15 | 34000 | 34000 | 8393 | 6.44 | 1.0E+00 | 0.1842 | 0.94748 | 0.00113 | 0.94975 | ncsrcyt11_34_1_15 | 0.0008 | 0.94742 | 0.00124 | 0.94990 |
| ncsbcyt11_33_1_15 | 33000 | 33000 | 8446 | 6.68 | 1.0E+00 | 0.1853 | 0.94613 | 0.00118 | 0.94850 | ncsrcyt11_33_1_15 | 0.0008 | 0.94478 | 0.00119 | 0.94716 |
| ncsbcyt11_32_1_15 | 32000 | 32000 | 8499 | 6.93 | 1.0E+00 | 0.1863 | 0.94237 | 0.00106 | 0.94448 | ncsrcyt11_32_1_15 | 0.0007 | 0.94247 | 0.00111 | 0.94468 |
| ncsbcyt11_31_1_15 | 31000 | 31000 | 8552 | 7.20 | 1.0E+00 | 0.1867 | 0.94052 | 0.00106 | 0.94264 | ncsrcyt11_31_1_15 | 0.0008 | 0.94091 | 0.00107 | 0.94306 |
| ncsbcyt11_30_1_15 | 30000 | 30000 | 8605 | 7.49 | 1.0E+00 | 0.1882 | 0.93819 | 0.00110 | 0.94039 | ncsrcyt11_30_1_15 | 0.0007 | 0.94139 | 0.00137 | 0.94412 |
| ncsbcyt11_29_1_15 | 29000 | 29000 | 8658 | 7.79 | 1.0E+00 | 0.1894 | 0.93483 | 0.00104 | 0.93692 | ncsrcyt11_29_1_15 | 0.0007 | 0.93406 | 0.00108 | 0.93622 |
| ncsbcyt11_28_1_15 | 28000 | 28000 | 8711 | 8.12 | 1.0E+00 | 0.1894 | 0.93339 | 0.00102 | 0.93543 | ncsrcyt11_28_1_15 | 0.0008 | 0.93012 | 0.00124 | 0.93261 |
| ncsbcyt11_27_1_15 | 27000 | 27000 | 8764 | 8.47 | 1.0E+00 | 0.1911 | 0.92636 | 0.00112 | 0.92860 | ncsrcyt11_27_1_15 | 0.0008 | 0.92820 | 0.00122 | 0.93064 |
| ncsbcyt11_26_1_15 | 26000 | 26000 | 8817 | 8.85 | 1.0E+00 | 0.1919 | 0.92366 | 0.00115 | 0.92597 | ncsrcyt11_26_1_15 | 0.0008 | 0.92396 | 0.00141 | 0.92679 |
| ncsbcyt11_25_1_15 | 25000 | 25000 | 8870 | 9.26 | 1.0E+00 | 0.1928 | 0.92122 | 0.00122 | 0.92366 | ncsrcyt11_25_1_15 | 0.0008 | 0.91761 | 0.00102 | 0.91966 |
| ncsbcyt11_24_1_15 | 24000 | 24000 | 8923 | 9.70 | 1.0E+00 | 0.1948 | 0.91432 | 0.00108 | 0.91648 | ncsrcyt11_24_1_15 | 0.0008 | 0.91466 | 0.00107 | 0.91680 |
| ncsbcyt11_23_1_15 | 23000 | 23000 | 8977 | 10.19 | 1.0E+00 | 0.1965 | 0.91055 | 0.00130 | 0.91314 | ncsrcyt11_23_1_15 | 0.0008 | 0.91172 | 0.00116 | 0.91403 |
| ncsbcyt11_22_1_15 | 22000 | 22000 | 9030 | 10.71 | 1.0E+00 | 0.1969 | 0.90695 | 0.00121 | 0.90936 | ncsrcyt11_22_1_15 | 0.0008 | 0.90680 | 0.00153 | 0.90986 |
| ncsbcyt11_21_1_15 | 21000 | 21000 | 9083 | 11.29 | 1.0E+00 | 0.1984 | 0.90241 | 0.00124 | 0.90490 | ncsrcyt11_21_1_15 | 0.0009 | 0.90125 | 0.00113 | 0.90352 |
| ncsbcyt11_20_1_15 | 20000 | 20000 | 9136 | 11.92 | 1.0E+00 | 0.2007 | 0.89477 | 0.00125 | 0.89726 | ncsrcyt11_20_1_15 | 0.0009 | 0.89481 | 0.00109 | 0.89698 |
| ncsbcyt11_19_1_15 | 19000 | 19000 | 9189 | 12.62 | 1.0E+00 | 0.2026 | 0.88819 | 0.00113 | 0.89044 | ncsrcyt11_19_1_15 | 0.0008 | 0.88857 | 0.00136 | 0.89129 |
| ncsbcyt11_18_1_15 | 18000 | 18000 | 9242 | 13.40 | 1.0E+00 | 0.2037 | 0.88255 | 0.00126 | 0.88507 | ncsrcyt11_18_1_15 | 0.0008 | 0.88157 | 0.00127 | 0.88410 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | **with can spacers (np thickness = 1.4 in.)** | | | | |
| ncsbcyt11_36_2_1 | 36000 | 36000 | 7673 | 5.56 | 1.0E-20 | 0.4882 | 0.83390 | 0.00106 | 0.83603 | ncsrcyt11_36_2_1 | 0.0022 | 0.83904 | 0.00110 | 0.84125 |
| ncsbcyt11_36_2_2 | 36000 | 36000 | 7673 | 5.56 | 1.0E-05 | 0.4879 | 0.83481 | 0.00142 | 0.83764 | ncsrcyt11_36_2_2 | 0.0021 | 0.84122 | 0.00110 | 0.84342 |

**Table 6.9.6-2. Results for 3.24 in.-diameter cylinder HEU metal content in bare and water reflected packaging calculation models**

| case name | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | nlf | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | nlf | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncsbcyt11_36_2_3 | 36000 | 36000 | 7673 | 5.56 | 1.0E-04 | 0.4883 | 0.83383 | 0.00100 | 0.83583 | ncsrcyt11_36_2_3 | 0.0022 | 0.84013 | 0.00106 | 0.84225 |
| ncsbcyt11_36_2_4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-03 | 0.4880 | 0.83530 | 0.00126 | 0.83783 | ncsrcyt11_36_2_4 | 0.0022 | 0.84001 | 0.00112 | 0.84224 |
| ncsbcyt11_36_2_5 | 36000 | 36000 | 7673 | 5.56 | 1.0E-02 | 0.4861 | 0.83461 | 0.00120 | 0.83702 | ncsrcyt11_36_2_5 | 0.0021 | 0.84128 | 0.00115 | 0.84359 |
| ncsbcyt11_36_2_6 | 36000 | 36000 | 7673 | 5.56 | 1.0E-01 | 0.4642 | 0.83979 | 0.00110 | 0.84199 | ncsrcyt11_36_2_6 | 0.0020 | 0.84524 | 0.00116 | 0.84755 |
| ncsbcyt11_36_2_8 | 36000 | 36000 | 7673 | 5.56 | 3.0E-01 | 0.4000 | 0.84736 | 0.00123 | 0.84982 | ncsrcyt11_36_2_8 | 0.0016 | 0.84947 | 0.00103 | 0.85153 |
| ncsbcyt11_36_2_15 | 36000 | 36000 | 7673 | 5.56 | 1.0E+00 | 0.1881 | 0.87048 | 0.00109 | 0.87266 | ncsrcyt11_36_2_15 | 0.0008 | 0.87062 | 0.00122 | 0.87305 |
| | | | | | | | | | | | | | | |
| ncsbcyt11_36_2_15 | 36000 | 36000 | 7673 | 5.56 | 1.0E+00 | 0.1881 | 0.87048 | 0.00109 | 0.87266 | ncsrcyt11_36_2_15 | 0.0008 | 0.87062 | 0.00122 | 0.87305 |
| ncsbcyt11_35_2_15 | 35000 | 35000 | 7726 | 5.76 | 1.0E+00 | 0.1879 | 0.86609 | 0.00114 | 0.86836 | ncsrcyt11_35_2_15 | 0.0007 | 0.86649 | 0.00118 | 0.86886 |
| ncsbcyt11_34_2_15 | 34000 | 34000 | 7779 | 5.97 | 1.0E+00 | 0.1885 | 0.86151 | 0.00103 | 0.86358 | ncsrcyt11_34_2_15 | 0.0008 | 0.86038 | 0.00129 | 0.86296 |
| ncsbcyt11_33_2_15 | 33000 | 33000 | 7832 | 6.19 | 1.0E+00 | 0.1901 | 0.85729 | 0.00099 | 0.85927 | ncsrcyt11_33_2_15 | 0.0007 | 0.85903 | 0.00106 | 0.86115 |
| ncsbcyt11_32_2_15 | 32000 | 32000 | 7885 | 6.43 | 1.0E+00 | 0.1908 | 0.85350 | 0.00116 | 0.85582 | ncsrcyt11_32_2_15 | 0.0007 | 0.85357 | 0.00108 | 0.85573 |
| ncsbcyt11_31_2_15 | 31000 | 31000 | 7938 | 6.68 | 1.0E+00 | 0.1922 | 0.84914 | 0.00108 | 0.85129 | ncsrcyt11_31_2_15 | 0.0008 | 0.84895 | 0.00123 | 0.85142 |
| ncsbcyt11_30_2_15 | 30000 | 30000 | 7992 | 6.95 | 1.0E+00 | 0.1913 | 0.84250 | 0.00100 | 0.84450 | ncsrcyt11_30_2_15 | 0.0008 | 0.84343 | 0.00114 | 0.84572 |

**Table 6.9.6-3. Results for 3.24 in.-diameter cylinder HEU metal content in packaging calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **content in flooded containment vessel, single package reflected** | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | **HAC** | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | |
| ncsrcyt11_36_1_1 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-20 | 0.91542 | 0.00120 | 0.91782 | hcsrcyt12_36_1_1 | 0.91636 | 0.00117 | 0.91869 |
| ncsrcyt11_36_1_2 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-05 | 0.91477 | 0.00123 | 0.91724 | hcsrcyt12_36_1_2 | 0.91593 | 0.00138 | 0.91869 |

**Table 6.9.6-3. Results for 3.24 in.-diameter cylinder HEU metal content in packaging calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncsrcyt11_36_1_3 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-04 | 0.91550 | 0.00111 | 0.91772 | hcsrcyt12_36_1_3 | 0.91660 | 0.00134 | 0.91929 |
| ncsrcyt11_36_1_4 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-03 | 0.91636 | 0.00117 | 0.91869 | hcsrcyt12_36_1_4 | 0.91565 | 0.00122 | 0.91810 |
| ncsrcyt11_36_1_5 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-02 | 0.91537 | 0.00109 | 0.91755 | hcsrcyt12_36_1_5 | 0.91489 | 0.00120 | 0.91729 |
| ncsrcyt11_36_1_6 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-01 | 0.92121 | 0.00133 | 0.92386 | hcsrcyt12_36_1_6 | 0.92198 | 0.00104 | 0.92407 |
| ncsrcyt11_36_1_8 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 3.0E-01 | 0.92807 | 0.00112 | 0.93032 | hcsrcyt12_36_1_8 | 0.92950 | 0.00125 | 0.93201 |
| ncsrcyt11_36_1_15 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E+00 | 0.95213 | 0.00129 | 0.95472 | hcsrcyt12_36_1_15 | 0.95112 | 0.00120 | 0.95353 |
| | | | | | | | | | | | | | |
| ncsrcyt11_36_1_15 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E+00 | 0.95213 | 0.00129 | 0.95472 | hcsrcyt12_36_1_15 | 0.95112 | 0.00120 | 0.95353 |
| ncsrcyt11_35_1_15 | 0.0 | 35000 | 35000 | 8340 | 6.22 | 1.0E+00 | 0.94870 | 0.00107 | 0.95083 | hcsrcyt12_35_1_15 | 0.94915 | 0.00120 | 0.95155 |
| ncsrcyt11_34_1_15 | 0.0 | 34000 | 34000 | 8393 | 6.44 | 1.0E+00 | 0.94742 | 0.00124 | 0.94990 | hcsrcyt12_34_1_15 | 0.94863 | 0.00113 | 0.95088 |
| ncsrcyt11_33_1_15 | 0.0 | 33000 | 33000 | 8446 | 6.68 | 1.0E+00 | 0.94478 | 0.00119 | 0.94716 | hcsrcyt12_33_1_15 | 0.94610 | 0.00123 | 0.94856 |
| ncsrcyt11_32_1_15 | 0.0 | 32000 | 32000 | 8499 | 6.93 | 1.0E+00 | 0.94247 | 0.00111 | 0.94468 | hcsrcyt12_32_1_15 | 0.94528 | 0.00141 | 0.94810 |
| ncsrcyt11_31_1_15 | 0.0 | 31000 | 31000 | 8552 | 7.20 | 1.0E+00 | 0.94091 | 0.00107 | 0.94306 | hcsrcyt12_31_1_15 | 0.94090 | 0.00107 | 0.94304 |
| ncsrcyt11_30_1_15 | 0.0 | 30000 | 30000 | 8605 | 7.49 | 1.0E+00 | 0.94139 | 0.00137 | 0.94412 | hcsrcyt12_30_1_15 | 0.94035 | 0.00120 | 0.94275 |
| ncsrcyt11_29_1_15 | 0.0 | 29000 | 29000 | 8658 | 7.79 | 1.0E+00 | 0.93406 | 0.00108 | 0.93622 | hcsrcyt12_29_1_15 | 0.93540 | 0.00112 | 0.93765 |
| ncsrcyt11_28_1_15 | 0.0 | 28000 | 28000 | 8711 | 8.12 | 1.0E+00 | 0.93012 | 0.00124 | 0.93261 | hcsrcyt12_28_1_15 | 0.93239 | 0.00118 | 0.93475 |
| ncsrcyt11_27_1_15 | 0.0 | 27000 | 27000 | 8764 | 8.47 | 1.0E+00 | 0.92820 | 0.00122 | 0.93064 | hcsrcyt12_27_1_15 | 0.93043 | 0.00144 | 0.93331 |
| ncsrcyt11_26_1_15 | 0.0 | 26000 | 26000 | 8817 | 8.85 | 1.0E+00 | 0.92396 | 0.00141 | 0.92679 | hcsrcyt12_26_1_15 | 0.92632 | 0.00119 | 0.92870 |
| ncsrcyt11_25_1_15 | 0.0 | 25000 | 25000 | 8870 | 9.26 | 1.0E+00 | 0.91761 | 0.00102 | 0.91966 | hcsrcyt12_25_1_15 | 0.92218 | 0.00109 | 0.92436 |
| ncsrcyt11_24_1_15 | 0.0 | 24000 | 24000 | 8923 | 9.70 | 1.0E+00 | 0.91466 | 0.00107 | 0.91680 | hcsrcyt12_24_1_15 | 0.91688 | 0.00117 | 0.91922 |
| ncsrcyt11_23_1_15 | 0.0 | 23000 | 23000 | 8977 | 10.19 | 1.0E+00 | 0.91172 | 0.00116 | 0.91403 | hcsrcyt12_23_1_15 | 0.91134 | 0.00119 | 0.91371 |
| ncsrcyt11_22_1_15 | 0.0 | 22000 | 22000 | 9030 | 10.71 | 1.0E+00 | 0.90680 | 0.00153 | 0.90986 | hcsrcyt12_22_1_15 | 0.90850 | 0.00113 | 0.91077 |
| ncsrcyt11_21_1_15 | 0.0 | 21000 | 21000 | 9083 | 11.29 | 1.0E+00 | 0.90125 | 0.00113 | 0.90352 | hcsrcyt12_21_1_15 | 0.90188 | 0.00124 | 0.90437 |
| ncsrcyt11_20_1_15 | 0.0 | 20000 | 20000 | 9136 | 11.92 | 1.0E+00 | 0.89481 | 0.00109 | 0.89698 | hcsrcyt12_20_1_15 | 0.89612 | 0.00115 | 0.89842 |

**Table 6.9.6-3. Results for 3.24 in.-diameter cylinder HEU metal content in packaging calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncsrcyt11_19_1_15 | 0.0 | 19000 | 19000 | 9189 | 12.62 | 1.0E+00 | 0.88857 | 0.00136 | 0.89129 | hcsrcyt12_19_1_15 | 0.89080 | 0.00122 | 0.89323 |
| ncsrcyt11_18_1_15 | 0.0 | 18000 | 18000 | 9242 | 13.40 | 1.0E+00 | 0.88157 | 0.00127 | 0.88410 | hcsrcyt12_18_1_15 | 0.88276 | 0.00128 | 0.88532 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | | |
| ncsrcyt11_36_2_1 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-20 | 0.83904 | 0.00110 | 0.84125 | hcsrcyt12_36_2_1 | 0.84250 | 0.00103 | 0.84456 |
| ncsrcyt11_36_2_2 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-05 | 0.84122 | 0.00110 | 0.84342 | hcsrcyt12_36_2_2 | 0.84146 | 0.00118 | 0.84382 |
| ncsrcyt11_36_2_3 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-04 | 0.84013 | 0.00106 | 0.84225 | hcsrcyt12_36_2_3 | 0.84182 | 0.00105 | 0.84392 |
| ncsrcyt11_36_2_4 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-03 | 0.84001 | 0.00112 | 0.84224 | hcsrcyt12_36_2_4 | 0.83975 | 0.00103 | 0.84181 |
| ncsrcyt11_36_2_5 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-02 | 0.84128 | 0.00115 | 0.84359 | hcsrcyt12_36_2_5 | 0.84070 | 0.00129 | 0.84328 |
| ncsrcyt11_36_2_6 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-01 | 0.84524 | 0.00116 | 0.84755 | hcsrcyt12_36_2_6 | 0.84484 | 0.00127 | 0.84738 |
| ncsrcyt11_36_2_8 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 3.0E-01 | 0.84947 | 0.00103 | 0.85153 | hcsrcyt12_36_2_8 | 0.85159 | 0.00102 | 0.85364 |
| ncsrcyt11_36_2_15 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E+00 | 0.87062 | 0.00122 | 0.87305 | hcsrcyt12_36_2_15 | 0.87110 | 0.00117 | 0.87344 |
| | | | | | | | | | | | | | |
| ncsrcyt11_36_2_15 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E+00 | 0.87062 | 0.00122 | 0.87305 | hcsrcyt12_36_2_15 | 0.87110 | 0.00117 | 0.87344 |
| ncsrcyt11_35_2_15 | 1.4 | 35000 | 35000 | 7726 | 5.76 | 1.0E+00 | 0.86649 | 0.00118 | 0.86886 | hcsrcyt12_35_2_15 | 0.86666 | 0.00110 | 0.86886 |
| ncsrcyt11_34_2_15 | 1.4 | 34000 | 34000 | 7779 | 5.97 | 1.0E+00 | 0.86038 | 0.00129 | 0.86296 | hcsrcyt12_34_2_15 | 0.86109 | 0.00117 | 0.86343 |
| ncsrcyt11_33_2_15 | 1.4 | 33000 | 33000 | 7832 | 6.19 | 1.0E+00 | 0.85903 | 0.00106 | 0.86115 | hcsrcyt12_33_2_15 | 0.86022 | 0.00123 | 0.86267 |
| ncsrcyt11_32_2_15 | 1.4 | 32000 | 32000 | 7885 | 6.43 | 1.0E+00 | 0.85357 | 0.00108 | 0.85573 | hcsrcyt12_32_2_15 | 0.85544 | 0.00096 | 0.85736 |
| ncsrcyt11_31_2_15 | 1.4 | 31000 | 31000 | 7938 | 6.68 | 1.0E+00 | 0.84895 | 0.00123 | 0.85142 | hcsrcyt12_31_2_15 | 0.84745 | 0.00105 | 0.84956 |
| ncsrcyt11_30_2_15 | 1.4 | 30000 | 30000 | 7992 | 6.95 | 1.0E+00 | 0.84343 | 0.00114 | 0.84572 | hcsrcyt12_30_2_15 | 0.84390 | 0.00112 | 0.84615 |
| **content in flooded containment vessel, array packaging model for CSI=0.0** | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | **HAC** | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | |
| nciacyt11_36_1_1 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-20 | 1.02410 | 0.00125 | 1.02660 | hciacyt12_36_1_1 | 1.02427 | 0.00120 | 1.02667 |
| nciacyt11_36_1_2 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-05 | 1.02380 | 0.00124 | 1.02628 | hciacyt12_36_1_2 | 1.02384 | 0.00130 | 1.02644 |
| nciacyt11_36_1_3 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-04 | 1.02208 | 0.00111 | 1.02430 | hciacyt12_36_1_3 | 1.02390 | 0.00135 | 1.02660 |

**Table 6.9.6-3. Results for 3.24 in.-diameter cylinder HEU metal content in packaging calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| nciacyt11_36_1_4 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-03 | 1.02276 | 0.00134 | 1.02545 | hciacyt12_36_1_4 | 1.02441 | 0.00122 | 1.02684 |
| nciacyt11_36_1_5 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-02 | 1.01749 | 0.00124 | 1.01997 | hciacyt12_36_1_5 | 1.01867 | 0.00114 | 1.02094 |
| nciacyt11_36_1_6 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-01 | 0.98560 | 0.00118 | 0.98797 | hciacyt12_36_1_6 | 0.98825 | 0.00112 | 0.99048 |
| nciacyt11_36_1_8 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 3.0E-01 | 0.96228 | 0.00116 | 0.96461 | hciacyt12_36_1_8 | 0.96519 | 0.00122 | 0.96763 |
| nciacyt11_36_1_15 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E+00 | 0.96088 | 0.00119 | 0.96326 | hciacyt12_36_1_15 | 0.96417 | 0.00119 | 0.96655 |
| | | | | | | | | | | | | | |
| nciacyt11_36_1_3 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-04 | 1.02208 | 0.00111 | 1.02430 | hciacyt12_36_1_3 | 1.02390 | 0.00135 | 1.02660 |
| nciacyt11_35_1_3 | 0.0 | 35000 | 35000 | 8340 | 6.22 | 1.0E-04 | 1.01930 | 0.00118 | 1.02166 | hciacyt12_35_1_3 | 1.01912 | 0.00127 | 1.02165 |
| nciacyt11_34_1_3 | 0.0 | 34000 | 34000 | 8393 | 6.44 | 1.0E-04 | 1.01654 | 0.00130 | 1.01914 | hciacyt12_34_1_3 | 1.01860 | 0.00104 | 1.02068 |
| nciacyt11_33_1_3 | 0.0 | 33000 | 33000 | 8446 | 6.68 | 1.0E-04 | 1.01121 | 0.00116 | 1.01353 | hciacyt12_33_1_3 | 1.01077 | 0.00142 | 1.01361 |
| nciacyt11_32_1_3 | 0.0 | 32000 | 32000 | 8499 | 6.93 | 1.0E-04 | 1.00876 | 0.00134 | 1.01144 | hciacyt12_32_1_3 | 1.00943 | 0.00114 | 1.01171 |
| nciacyt11_31_1_3 | 0.0 | 31000 | 31000 | 8552 | 7.20 | 1.0E-04 | 1.00544 | 0.00116 | 1.00777 | hciacyt12_31_1_3 | 1.00148 | 0.00102 | 1.00353 |
| nciacyt11_30_1_3 | 0.0 | 30000 | 30000 | 8605 | 7.49 | 1.0E-04 | 0.99921 | 0.00131 | 1.00182 | hciacyt12_30_1_3 | 0.99963 | 0.00138 | 1.00238 |
| nciacyt11_29_1_3 | 0.0 | 29000 | 29000 | 8658 | 7.79 | 1.0E-04 | 0.99494 | 0.00121 | 0.99736 | hciacyt12_29_1_3 | 0.99453 | 0.00117 | 0.99687 |
| nciacyt11_28_1_3 | 0.0 | 28000 | 28000 | 8711 | 8.12 | 1.0E-04 | 0.98905 | 0.00124 | 0.99152 | hciacyt12_28_1_3 | 0.99159 | 0.00123 | 0.99405 |
| nciacyt11_27_1_3 | 0.0 | 27000 | 27000 | 8764 | 8.47 | 1.0E-04 | 0.98520 | 0.00115 | 0.98750 | hciacyt12_27_1_3 | 0.98720 | 0.00122 | 0.98963 |
| nciacyt11_26_1_3 | 0.0 | 26000 | 26000 | 8817 | 8.85 | 1.0E-04 | 0.97887 | 0.00117 | 0.98120 | hciacyt12_26_1_3 | 0.97870 | 0.00130 | 0.98129 |
| nciacyt11_25_1_3 | 0.0 | 25000 | 25000 | 8870 | 9.26 | 1.0E-04 | 0.97441 | 0.00118 | 0.97676 | hciacyt12_25_1_3 | 0.97501 | 0.00106 | 0.97713 |
| nciacyt11_24_1_3 | 0.0 | 24000 | 24000 | 8923 | 9.70 | 1.0E-04 | 0.96997 | 0.00115 | 0.97228 | hciacyt12_24_1_3 | 0.96945 | 0.00122 | 0.97188 |
| nciacyt11_23_1_3 | 0.0 | 23000 | 23000 | 8977 | 10.19 | 1.0E-04 | 0.96203 | 0.00122 | 0.96447 | hciacyt12_23_1_3 | 0.96228 | 0.00121 | 0.96469 |
| nciacyt11_22_1_3 | 0.0 | 22000 | 22000 | 9030 | 10.71 | 1.0E-04 | 0.95256 | 0.00110 | 0.95475 | hciacyt12_22_1_3 | 0.95313 | 0.00138 | 0.95589 |
| nciacyt11_21_1_3 | 0.0 | 21000 | 21000 | 9083 | 11.29 | 1.0E-04 | 0.94755 | 0.00114 | 0.94982 | hciacyt12_21_1_3 | 0.94735 | 0.00121 | 0.94976 |
| nciacyt11_20_1_3 | 0.0 | 20000 | 20000 | 9136 | 11.92 | 1.0E-04 | 0.93967 | 0.00124 | 0.94215 | hciacyt12_20_1_3 | 0.94131 | 0.00113 | 0.94357 |
| nciacyt11_19_1_3 | 0.0 | 19000 | 19000 | 9189 | 12.62 | 1.0E-04 | 0.93107 | 0.00113 | 0.93334 | hciacyt12_19_1_3 | 0.92967 | 0.00120 | 0.93207 |
| nciacyt11_18_1_3 | 0.0 | 18000 | 18000 | 9242 | 13.40 | 1.0E-04 | 0.92165 | 0.00100 | 0.92366 | hciacyt12_18_1_3 | 0.92083 | 0.00110 | 0.92302 |

**Table 6.9.6-3. Results for 3.24 in.-diameter cylinder HEU metal content in packaging calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| nciacyt11_15_1_3 | 0.0 | 15000 | 15000 | 9401 | 16.36 | 1.0E-04 | 0.88925 | 0.00111 | 0.89146 | hciacyt12_15_1_3 | 0.88802 | 0.00116 | 0.89034 |
| nciacyt11_12_1_3 | 0.0 | 12000 | 12000 | 9560 | 20.79 | 1.0E-04 | 0.84430 | 0.00103 | 0.84636 | hciacyt12_12_1_3 | 0.84558 | 0.00110 | 0.84777 |
| nciacyt11_9_1_3 | 0.0 | 9000 | 9000 | 9719 | 28.19 | 1.0E-04 | 0.78552 | 0.00116 | 0.78784 | hciacyt12_9_1_3 | 0.78464 | 0.00132 | 0.78728 |
| nciacyt11_6_1_3 | 0.0 | 6000 | 6000 | 9879 | 42.97 | 1.0E-04 | 0.69176 | 0.00119 | 0.69414 | hciacyt12_6_1_3 | 0.69169 | 0.00122 | 0.69413 |
| nciacyt11_3_1_3 | 0.0 | 3000 | 3000 | 10038 | 87.33 | 1.0E-04 | 0.53217 | 0.00084 | 0.53385 | hciacyt12_3_1_3 | 0.53298 | 0.00091 | 0.53481 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | | |
| nciacyt11_36_2_1 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-20 | 0.95474 | 0.00109 | 0.95693 | hciacyt12_36_2_1 | 0.95429 | 0.00106 | 0.95641 |
| nciacyt11_36_2_2 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-05 | 0.95402 | 0.00119 | 0.95640 | hciacyt12_36_2_2 | 0.95522 | 0.00105 | 0.95732 |
| nciacyt11_36_2_3 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-04 | 0.95362 | 0.00105 | 0.95571 | hciacyt12_36_2_3 | 0.95319 | 0.00139 | 0.95596 |
| nciacyt11_36_2_4 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-03 | 0.95222 | 0.00128 | 0.95478 | hciacyt12_36_2_4 | 0.95333 | 0.00116 | 0.95564 |
| nciacyt11_36_2_5 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-02 | 0.94649 | 0.00110 | 0.94869 | hciacyt12_36_2_5 | 0.94837 | 0.00124 | 0.95084 |
| nciacyt11_36_2_6 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-01 | 0.91268 | 0.00128 | 0.91524 | hciacyt12_36_2_6 | 0.91591 | 0.00121 | 0.91834 |
| nciacyt11_36_2_8 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 3.0E-01 | 0.88453 | 0.00140 | 0.88733 | hciacyt12_36_2_8 | 0.89062 | 0.00119 | 0.89300 |
| nciacyt11_36_2_15 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E+00 | 0.87822 | 0.00106 | 0.88034 | hciacyt12_36_2_15 | 0.88152 | 0.00135 | 0.88423 |
| | | | | | | | | | | | | | |
| nciacyt11_36_2_3 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-04 | 0.95362 | 0.00105 | 0.95571 | hciacyt12_36_2_3 | 0.95319 | 0.00139 | 0.95596 |
| nciacyt11_35_2_3 | 1.4 | 35000 | 35000 | 7726 | 5.76 | 1.0E-04 | 0.94906 | 0.00125 | 0.95156 | hciacyt12_35_2_3 | 0.94788 | 0.00129 | 0.95046 |
| nciacyt11_34_2_3 | 1.4 | 34000 | 34000 | 7779 | 5.97 | 1.0E-04 | 0.94393 | 0.00136 | 0.94664 | hciacyt12_34_2_3 | 0.94428 | 0.00130 | 0.94687 |
| nciacyt11_33_2_3 | 1.4 | 33000 | 33000 | 7832 | 6.19 | 1.0E-04 | 0.93703 | 0.00114 | 0.93930 | hciacyt12_33_2_3 | 0.93708 | 0.00122 | 0.93952 |
| nciacyt11_32_2_3 | 1.4 | 32000 | 32000 | 7885 | 6.43 | 1.0E-04 | 0.92940 | 0.00125 | 0.93191 | hciacyt12_32_2_3 | 0.93065 | 0.00109 | 0.93283 |
| nciacyt11_31_2_3 | 1.4 | 31000 | 31000 | 7938 | 6.68 | 1.0E-04 | 0.92483 | 0.00119 | 0.92721 | hciacyt12_31_2_3 | 0.92625 | 0.00125 | 0.92874 |
| nciacyt11_30_2_3 | 1.4 | 30000 | 30000 | 7992 | 6.95 | 1.0E-04 | 0.91737 | 0.00106 | 0.91949 | hciacyt12_30_2_3 | 0.91983 | 0.00107 | 0.92198 |
| nciacyt11_29_2_3 | 1.4 | 29000 | 29000 | 8045 | 7.24 | 1.0E-04 | 0.91253 | 0.00116 | 0.91484 | hciacyt12_29_2_3 | 0.91204 | 0.00107 | 0.91419 |
| nciacyt11_28_2_3 | 1.4 | 28000 | 28000 | 8098 | 7.55 | 1.0E-04 | 0.90504 | 0.00117 | 0.90737 | hciacyt12_28_2_3 | 0.90515 | 0.00100 | 0.90716 |
| nciacyt11_27_2_3 | 1.4 | 27000 | 27000 | 8151 | 7.88 | 1.0E-04 | 0.89967 | 0.00121 | 0.90208 | hciacyt12_27_2_3 | 0.89749 | 0.00097 | 0.89942 |

**Table 6.9.6-3. Results for 3.24 in.-diameter cylinder HEU metal content in packaging calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| nciacyt11_26_2_3 | 1.4 | 26000 | 26000 | 8204 | 8.24 | 1.0E-04 | 0.89129 | 0.00107 | 0.89343 | hciacyt12_26_2_3 | 0.88997 | 0.00124 | 0.89246 |
| nciacyt11_25_2_3 | 1.4 | 25000 | 25000 | 8257 | 8.62 | 1.0E-04 | 0.88183 | 0.00104 | 0.88391 | hciacyt12_25_2_3 | 0.88253 | 0.00129 | 0.88511 |
| nciacyt11_24_2_3 | 1.4 | 24000 | 24000 | 8310 | 9.04 | 1.0E-04 | 0.87406 | 0.00117 | 0.87640 | hciacyt12_24_2_3 | 0.87448 | 0.00117 | 0.87681 |
| nciacyt11_23_2_3 | 1.4 | 23000 | 23000 | 8363 | 9.49 | 1.0E-04 | 0.86345 | 0.00109 | 0.86564 | hciacyt12_23_2_3 | 0.86388 | 0.00119 | 0.86626 |
| nciacyt11_22_2_3 | 1.4 | 22000 | 22000 | 8416 | 9.98 | 1.0E-04 | 0.85413 | 0.00107 | 0.85627 | hciacyt12_22_2_3 | 0.85333 | 0.00109 | 0.85551 |
| nciacyt11_21_2_3 | 1.4 | 21000 | 21000 | 8469 | 10.53 | 1.0E-04 | 0.84424 | 0.00109 | 0.84642 | hciacyt12_21_2_3 | 0.84414 | 0.00111 | 0.84636 |
| nciacyt11_20_2_3 | 1.4 | 20000 | 20000 | 8522 | 11.12 | 1.0E-04 | 0.83545 | 0.00106 | 0.83756 | hciacyt12_20_2_3 | 0.83388 | 0.00099 | 0.83585 |
| nciacyt11_19_2_3 | 1.4 | 19000 | 19000 | 8575 | 11.78 | 1.0E-04 | 0.82051 | 0.00130 | 0.82311 | hciacyt12_19_2_3 | 0.82263 | 0.00109 | 0.82480 |
| nciacyt11_18_2_3 | 1.4 | 18000 | 18000 | 8628 | 12.51 | 1.0E-04 | 0.81105 | 0.00122 | 0.81350 | hciacyt12_18_2_3 | 0.81076 | 0.00113 | 0.81301 |
| nciacyt11_15_2_3 | 1.4 | 15000 | 15000 | 8787 | 15.29 | 1.0E-04 | 0.76734 | 0.00107 | 0.76948 | hciacyt12_15_2_3 | 0.76757 | 0.00102 | 0.76960 |
| nciacyt11_12_2_3 | 1.4 | 12000 | 12000 | 8947 | 19.46 | 1.0E-04 | 0.71377 | 0.00097 | 0.71571 | hciacyt12_12_2_3 | 0.71466 | 0.00102 | 0.71669 |
| nciacyt11_9_2_3 | 1.4 | 9000 | 9000 | 9106 | 26.41 | 1.0E-04 | 0.64515 | 0.00110 | 0.64734 | hciacyt12_9_2_3 | 0.64486 | 0.00103 | 0.64692 |
| nciacyt11_6_2_3 | 1.4 | 6000 | 6000 | 9265 | 40.30 | 1.0E-04 | 0.54772 | 0.00094 | 0.54960 | hciacyt12_6_2_3 | 0.54697 | 0.00098 | 0.54893 |
| nciacyt11_3_2_3 | 1.4 | 3000 | 3000 | 9424 | 81.99 | 1.0E-04 | 0.39773 | 0.00080 | 0.39933 | hciacyt12_3_2_3 | 0.39723 | 0.00087 | 0.39896 |

**Table 6.9.6-3b. Results for spacing of 3.24 in.-diameter cylinder HEU metal content in CV calculation model**

| case name | np (in.) | $^{235}U$ (g) | $H_2O$ (g) | h/x | separation (cm) | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| **content in flooded containment vessel, reflected** | | | | | | | | | |
| **NCT** | | | | | | | | | |
| **separation is the distance between the 3.24 in.-diameter cylinders (an additional 1.4 in. is provided by the can spacer)** | | | | | | | | | |
| cvcrcyat11_1_2 | 1.4 | 30000 | 7992 | 6.95 | 0.000 | 1.0E+00 | 0.85525 | 0.00117 | 0.85760 |
| cvcrcyat11_2_2 | 1.4 | 30000 | 7992 | 6.95 | 0.254 | 1.0E+00 | 0.85568 | 0.00100 | 0.85768 |

**Table 6.9.6-3b. Results for spacing of 3.24 in.-diameter cylinder HEU metal content in CV calculation model**

| case name | np (in.) | $^{235}U$ (g) | $H_2O$ (g) | h/x | separation (cm) | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| cvcrcyat11_3_2 | 1.4 | 30000 | 7992 | 6.95 | 0.762 | 1.0E+00 | 0.85058 | 0.00110 | 0.85278 |
| cvcrcyat11_4_2 | 1.4 | 30000 | 7992 | 6.95 | 1.270 | 1.0E+00 | 0.84834 | 0.00124 | 0.85082 |
| cvcrcyat11_5_2 | 1.4 | 30000 | 7992 | 6.95 | 1.778 | 1.0E+00 | 0.84241 | 0.00123 | 0.84488 |
| cvcrcyat11_6_2 | 1.4 | 30000 | 7992 | 6.95 | 2.286 | 1.0E+00 | 0.83866 | 0.00099 | 0.84063 |
| cvcrcyat11_7_2 | 1.4 | 30000 | 7992 | 6.95 | 2.794 | 1.0E+00 | 0.83549 | 0.00117 | 0.83782 |
| cvcrcyat11_8_2 | 1.4 | 30000 | 7992 | 6.95 | 3.302 | 1.0E+00 | 0.83213 | 0.00126 | 0.83465 |
| cvcrcyat11_9_2 | 1.4 | 30000 | 7992 | 6.95 | 3.810 | 1.0E+00 | 0.82984 | 0.00125 | 0.83233 |
| cvcrcyat11_10_2 | 1.4 | 30000 | 7992 | 6.95 | 4.318 | 1.0E+00 | 0.82777 | 0.00105 | 0.82986 |
| cvcrcyat11_11_2 | 1.4 | 30000 | 7992 | 6.95 | 4.826 | 1.0E+00 | 0.82499 | 0.00116 | 0.82731 |
| cvcrcyat11_12_2 | 1.4 | 30000 | 7992 | 6.95 | 12.230 | 1.0E+00 | 0.80870 | 0.00121 | 0.81113 |

**Table 6.9.6-3c. Results for spacing of 3.24 in.-diameter cylinder HEU metal content in packaging calculation model**

| case name | np (in.) | $^{235}U$ (g) | $H_2O$ (g) | h/x | separation (cm) | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| **content in flooded containment vessel, single package reflected** | | | | | | | | | |
| **NCT** | | | | | | | | | |
| **separation is the distance between the 3.24 in.-diameter cylinders (an additional 1.4 in. is provided by the canned spacer)** | | | | | | | | | |
| ncsrcyat11_1_2_15 | 1.4 | 30000 | 7992 | 6.95 | 0.000 | 1.0E+00 | 0.84343 | 0.00114 | 0.84572 |
| ncsrcyat11_2_2_15 | 1.4 | 30000 | 7992 | 6.95 | 0.254 | 1.0E+00 | 0.84249 | 0.00111 | 0.84472 |
| ncsrcyat11_3_2_15 | 1.4 | 30000 | 7992 | 6.95 | 0.762 | 1.0E+00 | 0.83638 | 0.00103 | 0.83845 |
| ncsrcyat11_4_2_15 | 1.4 | 30000 | 7992 | 6.95 | 1.270 | 1.0E+00 | 0.83416 | 0.00110 | 0.83636 |
| ncsrcyat11_5_2_15 | 1.4 | 30000 | 7992 | 6.95 | 1.778 | 1.0E+00 | 0.82786 | 0.00128 | 0.83043 |
| ncsrcyat11_6_2_15 | 1.4 | 30000 | 7992 | 6.95 | 2.286 | 1.0E+00 | 0.82516 | 0.00113 | 0.82743 |

**Table 6.9.6-3c. Results for spacing of 3.24 in.-diameter cylinder HEU metal content in packaging calculation model**

| case name | np (in.) | $^{235}U$ (g) | $H_2O$ (g) | h/x | separation (cm) | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| ncsrcyat11_7_2_15 | 1.4 | 30000 | 7992 | 6.95 | 2.794 | 1.0E+00 | 0.82161 | 0.00116 | 0.82393 |
| ncsrcyat11_8_2_15 | 1.4 | 30000 | 7992 | 6.95 | 3.302 | 1.0E+00 | 0.82004 | 0.00114 | 0.82232 |
| ncsrcyat11_9_2_15 | 1.4 | 30000 | 7992 | 6.95 | 3.810 | 1.0E+00 | 0.81641 | 0.00101 | 0.81843 |
| ncsrcyat11_10_2_15 | 1.4 | 30000 | 7992 | 6.95 | 4.318 | 1.0E+00 | 0.81362 | 0.00109 | 0.81581 |
| ncsrcyat11_11_2_15 | 1.4 | 30000 | 7992 | 6.95 | 4.826 | 1.0E+00 | 0.81218 | 0.00104 | 0.81426 |
| ncsrcyat11_12_2_15 | 1.4 | 30000 | 7992 | 6.95 | 12.230 | 1.0E+00 | 0.79592 | 0.00100 | 0.79793 |

**Table 6.9.6-4. Results for 2.29 in.-square bar HEU metal content in CV calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| **flooded containment vessel, reflected** | | | | | | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | |
| cvcrsqt11_36_1 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E+00 | 0.87614 | 0.00128 | 0.87869 |
| cvcrsqt11_35_1 | 0.0 | 35000 | 35000 | 8340 | 6.22 | 1.0E+00 | 0.87560 | 0.00111 | 0.87781 |
| cvcrsqt11_34_1 | 0.0 | 34000 | 34000 | 8393 | 6.44 | 1.0E+00 | 0.87541 | 0.00126 | 0.87794 |
| cvcrsqt11_33_1 | 0.0 | 33000 | 33000 | 8446 | 6.68 | 1.0E+00 | 0.87396 | 0.00108 | 0.87612 |
| cvcrsqt11_32_1 | 0.0 | 32000 | 32000 | 8499 | 6.93 | 1.0E+00 | 0.87319 | 0.00119 | 0.87556 |
| cvcrsqt11_31_1 | 0.0 | 31000 | 31000 | 8552 | 7.20 | 1.0E+00 | 0.86993 | 0.00116 | 0.87225 |
| cvcrsqt11_30_1 | 0.0 | 30000 | 30000 | 8605 | 7.49 | 1.0E+00 | 0.87046 | 0.00120 | 0.87286 |
| cvcrsqt11_29_1 | 0.0 | 29000 | 29000 | 8658 | 7.79 | 1.0E+00 | 0.86852 | 0.00107 | 0.87067 |
| cvcrsqt11_28_1 | 0.0 | 28000 | 28000 | 8711 | 8.12 | 1.0E+00 | 0.86740 | 0.00113 | 0.86966 |
| cvcrsqt11_27_1 | 0.0 | 27000 | 27000 | 8764 | 8.47 | 1.0E+00 | 0.86366 | 0.00116 | 0.86597 |
| cvcrsqt11_26_1 | 0.0 | 26000 | 26000 | 8817 | 8.85 | 1.0E+00 | 0.86498 | 0.00138 | 0.86773 |

**Table 6.9.6-4. Results for 2.29 in.-square bar HEU metal content in CV calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| cvcrsqt11_25_1 | 0.0 | 25000 | 25000 | 8870 | 9.26 | 1.0E+00 | 0.86077 | 0.00121 | 0.86319 |
| cvcrsqt11_24_1 | 0.0 | 24000 | 24000 | 8923 | 9.70 | 1.0E+00 | 0.85955 | 0.00138 | 0.86231 |
| cvcrsqt11_23_1 | 0.0 | 23000 | 23000 | 8977 | 10.19 | 1.0E+00 | 0.85604 | 0.00106 | 0.85816 |
| cvcrsqt11_22_1 | 0.0 | 22000 | 22000 | 9030 | 10.71 | 1.0E+00 | 0.85211 | 0.00103 | 0.85417 |
| cvcrsqt11_21_1 | 0.0 | 21000 | 21000 | 9083 | 11.29 | 1.0E+00 | 0.84970 | 0.00118 | 0.85206 |
| cvcrsqt11_20_1 | 0.0 | 20000 | 20000 | 9136 | 11.92 | 1.0E+00 | 0.84694 | 0.00119 | 0.84931 |
| cvcrsqt11_19_1 | 0.0 | 19000 | 19000 | 9189 | 12.62 | 1.0E+00 | 0.84285 | 0.00109 | 0.84503 |
| cvcrsqt11_18_1 | 0.0 | 18000 | 18000 | 9242 | 13.40 | 1.0E+00 | 0.83888 | 0.00115 | 0.84117 |
| **with can spacers (np thickness=1.4 in.)** | | | | | | | | | |
| cvcrsqt11_36_2 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E+00 | 0.82217 | 0.00098 | 0.82414 |
| cvcrsqt11_35_2 | 1.4 | 35000 | 35000 | 7726 | 5.76 | 1.0E+00 | 0.81622 | 0.00130 | 0.81881 |
| cvcrsqt11_34_2 | 1.4 | 34000 | 34000 | 7779 | 5.97 | 1.0E+00 | 0.81548 | 0.00103 | 0.81755 |
| cvcrsqt11_33_2 | 1.4 | 33000 | 33000 | 7832 | 6.19 | 1.0E+00 | 0.81272 | 0.00118 | 0.81508 |
| cvcrsqt11_32_2 | 1.4 | 32000 | 32000 | 7885 | 6.43 | 1.0E+00 | 0.80782 | 0.00120 | 0.81022 |
| cvcrsqt11_31_2 | 1.4 | 31000 | 31000 | 7938 | 6.68 | 1.0E+00 | 0.80495 | 0.00109 | 0.80712 |
| cvcrsqt11_30_2 | 1.4 | 30000 | 30000 | 7992 | 6.95 | 1.0E+00 | 0.80163 | 0.00117 | 0.80397 |

**Table 6.9.6-5. Results for 2.29 in.-square bar HEU metal content in packaging calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **content in flooded containment vessel, single package reflected** | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | **HAC** | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | |
| ncsrsqt11_36_1_1 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-20 | 0.82940 | 0.00124 | 0.83189 | hcsrsqt12_36_1_1 | 0.83133 | 0.00125 | 0.83384 |
| ncsrsqt11_36_1_2 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-05 | 0.83107 | 0.00107 | 0.83320 | hcsrsqt12_36_1_2 | 0.83168 | 0.00121 | 0.83409 |
| ncsrsqt11_36_1_3 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-04 | 0.83051 | 0.00120 | 0.83292 | hcsrsqt12_36_1_3 | 0.83088 | 0.00103 | 0.83293 |
| ncsrsqt11_36_1_4 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-03 | 0.82981 | 0.00116 | 0.83213 | hcsrsqt12_36_1_4 | 0.83030 | 0.00122 | 0.83273 |
| ncsrsqt11_36_1_5 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-02 | 0.82859 | 0.00123 | 0.83105 | hcsrsqt12_36_1_5 | 0.83244 | 0.00126 | 0.83496 |
| ncsrsqt11_36_1_6 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-01 | 0.83608 | 0.00123 | 0.83853 | hcsrsqt12_36_1_6 | 0.83502 | 0.00119 | 0.83739 |
| ncsrsqt11_36_1_8 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 3.0E-01 | 0.84146 | 0.00118 | 0.84382 | hcsrsqt12_36_1_8 | 0.84236 | 0.00115 | 0.84465 |
| ncsrsqt11_36_1_15 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E+00 | 0.86253 | 0.00131 | 0.86516 | hcsrsqt12_36_1_15 | 0.86198 | 0.00112 | 0.86422 |
| | | | | | | | | | | | | | |
| ncsrsqt11_36_1_15 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E+00 | 0.86253 | 0.00131 | 0.86516 | hcsrsqt12_36_1_15 | 0.86198 | 0.00112 | 0.86422 |
| ncsrsqt11_35_1_15 | 0.0 | 35000 | 35000 | 8340 | 6.22 | 1.0E+00 | 0.86041 | 0.00112 | 0.86265 | hcsrsqt12_35_1_15 | 0.86067 | 0.00121 | 0.86309 |
| ncsrsqt11_34_1_15 | 0.0 | 34000 | 34000 | 8393 | 6.44 | 1.0E+00 | 0.85820 | 0.00129 | 0.86078 | hcsrsqt12_34_1_15 | 0.85896 | 0.00102 | 0.86101 |
| ncsrsqt11_33_1_15 | 0.0 | 33000 | 33000 | 8446 | 6.68 | 1.0E+00 | 0.85708 | 0.00106 | 0.85920 | hcsrsqt12_33_1_15 | 0.86064 | 0.00110 | 0.86285 |
| ncsrsqt11_32_1_15 | 0.0 | 32000 | 32000 | 8499 | 6.93 | 1.0E+00 | 0.85769 | 0.00107 | 0.85983 | hcsrsqt12_32_1_15 | 0.85800 | 0.00110 | 0.86020 |
| ncsrsqt11_31_1_15 | 0.0 | 31000 | 31000 | 8552 | 7.20 | 1.0E+00 | 0.85495 | 0.00127 | 0.85749 | hcsrsqt12_31_1_15 | 0.85333 | 0.00123 | 0.85580 |
| ncsrsqt11_30_1_15 | 0.0 | 30000 | 30000 | 8605 | 7.49 | 1.0E+00 | 0.85270 | 0.00120 | 0.85510 | hcsrsqt12_30_1_15 | 0.85520 | 0.00132 | 0.85784 |
| ncsrsqt11_29_1_15 | 0.0 | 29000 | 29000 | 8658 | 7.79 | 1.0E+00 | 0.85067 | 0.00119 | 0.85305 | hcsrsqt12_29_1_15 | 0.85348 | 0.00114 | 0.85575 |
| ncsrsqt11_28_1_15 | 0.0 | 28000 | 28000 | 8711 | 8.12 | 1.0E+00 | 0.85223 | 0.00111 | 0.85446 | hcsrsqt12_28_1_15 | 0.85043 | 0.00101 | 0.85246 |
| ncsrsqt11_27_1_15 | 0.0 | 27000 | 27000 | 8764 | 8.47 | 1.0E+00 | 0.84973 | 0.00121 | 0.85214 | hcsrsqt12_27_1_15 | 0.85029 | 0.00111 | 0.85250 |
| ncsrsqt11_26_1_15 | 0.0 | 26000 | 26000 | 8817 | 8.85 | 1.0E+00 | 0.84838 | 0.00127 | 0.85091 | hcsrsqt12_26_1_15 | 0.84829 | 0.00115 | 0.85058 |
| ncsrsqt11_25_1_15 | 0.0 | 25000 | 25000 | 8870 | 9.26 | 1.0E+00 | 0.84598 | 0.00113 | 0.84824 | hcsrsqt12_25_1_15 | 0.84583 | 0.00105 | 0.84792 |
| ncsrsqt11_24_1_15 | 0.0 | 24000 | 24000 | 8923 | 9.70 | 1.0E+00 | 0.84390 | 0.00111 | 0.84611 | hcsrsqt12_24_1_15 | 0.84296 | 0.00112 | 0.84521 |

**Table 6.9.6-5. Results for 2.29 in.-square bar HEU metal content in packaging calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncsrsqt11_23_1_15 | 0.0 | 23000 | 23000 | 8977 | 10.19 | 1.0E+00 | 0.84101 | 0.00108 | 0.84317 | hcsrsqt12_23_1_15 | 0.84241 | 0.00129 | 0.84499 |
| ncsrsqt11_22_1_15 | 0.0 | 22000 | 22000 | 9030 | 10.71 | 1.0E+00 | 0.83888 | 0.00112 | 0.84111 | hcsrsqt12_22_1_15 | 0.83951 | 0.00107 | 0.84164 |
| ncsrsqt11_21_1_15 | 0.0 | 21000 | 21000 | 9083 | 11.29 | 1.0E+00 | 0.83473 | 0.00112 | 0.83696 | hcsrsqt12_21_1_15 | 0.83577 | 0.00128 | 0.83832 |
| ncsrsqt11_20_1_15 | 0.0 | 20000 | 20000 | 9136 | 11.92 | 1.0E+00 | 0.83029 | 0.00110 | 0.83250 | hcsrsqt12_20_1_15 | 0.83094 | 0.00103 | 0.83300 |
| ncsrsqt11_19_1_15 | 0.0 | 19000 | 19000 | 9189 | 12.62 | 1.0E+00 | 0.82676 | 0.00107 | 0.82889 | hcsrsqt12_19_1_15 | 0.82652 | 0.00113 | 0.82879 |
| ncsrsqt11_18_1_15 | 0.0 | 18000 | 18000 | 9242 | 13.40 | 1.0E+00 | 0.82247 | 0.00121 | 0.82489 | hcsrsqt12_18_1_15 | 0.82440 | 0.00112 | 0.82664 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | | |
| ncsrsqt11_36_2_1 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-20 | 0.78167 | 0.00104 | 0.78375 | hcsrsqt12_36_2_1 | 0.78308 | 0.00128 | 0.78563 |
| ncsrsqt11_36_2_2 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-05 | 0.78210 | 0.00112 | 0.78434 | hcsrsqt12_36_2_2 | 0.78549 | 0.00112 | 0.78772 |
| ncsrsqt11_36_2_3 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-04 | 0.78209 | 0.00104 | 0.78417 | hcsrsqt12_36_2_3 | 0.78508 | 0.00119 | 0.78746 |
| ncsrsqt11_36_2_4 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-03 | 0.78414 | 0.00111 | 0.78636 | hcsrsqt12_36_2_4 | 0.78484 | 0.00121 | 0.78727 |
| ncsrsqt11_36_2_5 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-02 | 0.78141 | 0.00137 | 0.78415 | hcsrsqt12_36_2_5 | 0.78362 | 0.00114 | 0.78591 |
| ncsrsqt11_36_2_6 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-01 | 0.78591 | 0.00113 | 0.78818 | hcsrsqt12_36_2_6 | 0.78757 | 0.00108 | 0.78972 |
| ncsrsqt11_36_2_8 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 3.0E-01 | 0.79206 | 0.00130 | 0.79466 | hcsrsqt12_36_2_8 | 0.79070 | 0.00128 | 0.79327 |
| ncsrsqt11_36_2_15 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E+00 | 0.80894 | 0.00103 | 0.81101 | hcsrsqt12_36_2_15 | 0.80856 | 0.00110 | 0.81077 |
| | | | | | | | | | | | | | |
| ncsrsqt11_36_2_15 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E+00 | 0.80894 | 0.00103 | 0.81101 | hcsrsqt12_36_2_15 | 0.80856 | 0.00110 | 0.81077 |
| ncsrsqt11_35_2_15 | 1.4 | 35000 | 35000 | 7726 | 5.76 | 1.0E+00 | 0.80583 | 0.00113 | 0.80808 | hcsrsqt12_35_2_15 | 0.80522 | 0.00112 | 0.80747 |
| ncsrsqt11_34_2_15 | 1.4 | 34000 | 34000 | 7779 | 5.97 | 1.0E+00 | 0.80341 | 0.00125 | 0.80591 | hcsrsqt12_34_2_15 | 0.80255 | 0.00107 | 0.80469 |
| ncsrsqt11_33_2_15 | 1.4 | 33000 | 33000 | 7832 | 6.19 | 1.0E+00 | 0.80213 | 0.00108 | 0.80429 | hcsrsqt12_33_2_15 | 0.79972 | 0.00096 | 0.80164 |
| ncsrsqt11_32_2_15 | 1.4 | 32000 | 32000 | 7885 | 6.43 | 1.0E+00 | 0.79784 | 0.00124 | 0.80032 | hcsrsqt12_32_2_15 | 0.79750 | 0.00118 | 0.79985 |
| ncsrsqt11_31_2_15 | 1.4 | 31000 | 31000 | 7938 | 6.68 | 1.0E+00 | 0.79226 | 0.00107 | 0.79440 | hcsrsqt12_31_2_15 | 0.79447 | 0.00099 | 0.79646 |
| ncsrsqt11_30_2_15 | 1.4 | 30000 | 30000 | 7992 | 6.95 | 1.0E+00 | 0.79192 | 0.00110 | 0.79412 | hcsrsqt12_30_2_15 | 0.79053 | 0.00108 | 0.79268 |

**Table 6.9.6-5. Results for 2.29 in.-square bar HEU metal content in packaging calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **content in flooded containment vessel, array packaging model for CSI=0.0** | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | **HAC** | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | |
| nciasqt11_36_1_3 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-04 | 0.93786 | 0.00112 | 0.94011 | hciasqt12_36_1_3 | 0.93760 | 0.00119 | 0.93998 |
| nciasqt11_35_1_3 | 0.0 | 35000 | 35000 | 8340 | 6.22 | 1.0E-04 | 0.93414 | 0.00107 | 0.93629 | hciasqt12_35_1_3 | 0.93524 | 0.00130 | 0.93785 |
| nciasqt11_34_1_3 | 0.0 | 34000 | 34000 | 8393 | 6.44 | 1.0E-04 | 0.93004 | 0.00116 | 0.93235 | hciasqt12_34_1_3 | 0.92962 | 0.00116 | 0.93195 |
| nciasqt11_33_1_3 | 0.0 | 33000 | 33000 | 8446 | 6.68 | 1.0E-04 | 0.92897 | 0.00121 | 0.93139 | hciasqt12_33_1_3 | 0.92744 | 0.00120 | 0.92984 |
| nciasqt11_32_1_3 | 0.0 | 32000 | 32000 | 8499 | 6.93 | 1.0E-04 | 0.92703 | 0.00119 | 0.92942 | hciasqt12_32_1_3 | 0.92854 | 0.00110 | 0.93073 |
| nciasqt11_31_1_3 | 0.0 | 31000 | 31000 | 8552 | 7.20 | 1.0E-04 | 0.92403 | 0.00109 | 0.92621 | hciasqt12_31_1_3 | 0.92290 | 0.00105 | 0.92499 |
| nciasqt11_30_1_3 | 0.0 | 30000 | 30000 | 8605 | 7.49 | 1.0E-04 | 0.91959 | 0.00114 | 0.92188 | hciasqt12_30_1_3 | 0.91960 | 0.00125 | 0.92211 |
| nciasqt11_29_1_3 | 0.0 | 29000 | 29000 | 8658 | 7.79 | 1.0E-04 | 0.91544 | 0.00122 | 0.91787 | hciasqt12_29_1_3 | 0.91645 | 0.00138 | 0.91922 |
| nciasqt11_28_1_3 | 0.0 | 28000 | 28000 | 8711 | 8.12 | 1.0E-04 | 0.91153 | 0.00123 | 0.91399 | hciasqt12_28_1_3 | 0.91477 | 0.00122 | 0.91722 |
| nciasqt11_27_1_3 | 0.0 | 27000 | 27000 | 8764 | 8.47 | 1.0E-04 | 0.90851 | 0.00099 | 0.91050 | hciasqt12_27_1_3 | 0.91066 | 0.00119 | 0.91305 |
| nciasqt11_26_1_3 | 0.0 | 26000 | 26000 | 8817 | 8.85 | 1.0E-04 | 0.90835 | 0.00125 | 0.91084 | hciasqt12_26_1_3 | 0.90452 | 0.00124 | 0.90699 |
| nciasqt11_25_1_3 | 0.0 | 25000 | 25000 | 8870 | 9.26 | 1.0E-04 | 0.90272 | 0.00115 | 0.90501 | hciasqt12_25_1_3 | 0.90142 | 0.00116 | 0.90374 |
| nciasqt11_24_1_3 | 0.0 | 24000 | 24000 | 8923 | 9.70 | 1.0E-04 | 0.89930 | 0.00123 | 0.90177 | hciasqt12_24_1_3 | 0.89640 | 0.00120 | 0.89881 |
| nciasqt11_23_1_3 | 0.0 | 23000 | 23000 | 8977 | 10.19 | 1.0E-04 | 0.89380 | 0.00120 | 0.89619 | hciasqt12_23_1_3 | 0.89613 | 0.00135 | 0.89882 |
| nciasqt11_22_1_3 | 0.0 | 22000 | 22000 | 9030 | 10.71 | 1.0E-04 | 0.88934 | 0.00105 | 0.89144 | hciasqt12_22_1_3 | 0.88839 | 0.00106 | 0.89051 |
| nciasqt11_21_1_3 | 0.0 | 21000 | 21000 | 9083 | 11.29 | 1.0E-04 | 0.88358 | 0.00109 | 0.88576 | hciasqt12_21_1_3 | 0.88413 | 0.00118 | 0.88649 |
| nciasqt11_20_1_3 | 0.0 | 20000 | 20000 | 9136 | 11.92 | 1.0E-04 | 0.87812 | 0.00123 | 0.88058 | hciasqt12_20_1_3 | 0.87811 | 0.00124 | 0.88058 |
| nciasqt11_19_1_3 | 0.0 | 19000 | 19000 | 9189 | 12.62 | 1.0E-04 | 0.87206 | 0.00108 | 0.87423 | hciasqt12_19_1_3 | 0.87171 | 0.00118 | 0.87408 |
| nciasqt11_18_1_3 | 0.0 | 18000 | 18000 | 9242 | 13.40 | 1.0E-04 | 0.86772 | 0.00140 | 0.87052 | hciasqt12_18_1_3 | 0.86555 | 0.00119 | 0.86794 |
| nciasqt11_15_1_3 | 0.0 | 15000 | 15000 | 9401 | 16.36 | 1.0E-04 | 0.84518 | 0.00119 | 0.84756 | hciasqt12_15_1_3 | 0.84416 | 0.00102 | 0.84620 |
| nciasqt11_12_1_3 | 0.0 | 12000 | 12000 | 9560 | 20.79 | 1.0E-04 | 0.81425 | 0.00113 | 0.81651 | hciasqt12_12_1_3 | 0.81332 | 0.00101 | 0.81534 |
| nciasqt11_9_1_3 | 0.0 | 9000 | 9000 | 9719 | 28.19 | 1.0E-04 | 0.76947 | 0.00115 | 0.77178 | hciasqt12_9_1_3 | 0.77066 | 0.00107 | 0.77280 |

**Table 6.9.6-5. Results for 2.29 in.-square bar HEU metal content in packaging calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| nciasqt11_6_1_3 | 0.0 | 6000 | 6000 | 9879 | 42.97 | 1.0E-04 | 0.69668 | 0.00099 | 0.69866 | hciasqt12_6_1_3 | 0.69648 | 0.00101 | 0.69850 |
| nciasqt11_3_1_3 | 0.0 | 3000 | 3000 | 10038 | 87.33 | 1.0E-04 | 0.55857 | 0.00089 | 0.56036 | hciasqt12_3_1_3 | 0.55806 | 0.00092 | 0.55989 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | | |
| nciasqt11_36_2_3 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-04 | 0.89382 | 0.00114 | 0.89610 | hciasqt12_36_2_3 | 0.89230 | 0.00114 | 0.89458 |
| nciasqt11_35_2_3 | 1.4 | 35000 | 35000 | 7726 | 5.76 | 1.0E-04 | 0.88604 | 0.00105 | 0.88813 | hciasqt12_35_2_3 | 0.88890 | 0.00130 | 0.89150 |
| nciasqt11_34_2_3 | 1.4 | 34000 | 34000 | 7779 | 5.97 | 1.0E-04 | 0.88480 | 0.00105 | 0.88690 | hciasqt12_34_2_3 | 0.88544 | 0.00139 | 0.88822 |
| nciasqt11_33_2_3 | 1.4 | 33000 | 33000 | 7832 | 6.19 | 1.0E-04 | 0.87854 | 0.00118 | 0.88090 | hciasqt12_33_2_3 | 0.87897 | 0.00106 | 0.88110 |
| nciasqt11_32_2_3 | 1.4 | 32000 | 32000 | 7885 | 6.43 | 1.0E-04 | 0.87561 | 0.00104 | 0.87768 | hciasqt12_32_2_3 | 0.87638 | 0.00121 | 0.87880 |
| nciasqt11_31_2_3 | 1.4 | 31000 | 31000 | 7938 | 6.68 | 1.0E-04 | 0.86867 | 0.00123 | 0.87114 | hciasqt12_31_2_3 | 0.87222 | 0.00105 | 0.87432 |
| nciasqt11_30_2_3 | 1.4 | 30000 | 30000 | 7992 | 6.95 | 1.0E-04 | 0.86347 | 0.00122 | 0.86590 | hciasqt12_30_2_3 | 0.86614 | 0.00121 | 0.86855 |
| nciasqt11_29_2_3 | 1.4 | 29000 | 29000 | 8045 | 7.24 | 1.0E-04 | 0.85781 | 0.00109 | 0.86000 | hciasqt12_29_2_3 | 0.85842 | 0.00113 | 0.86068 |
| nciasqt11_28_2_3 | 1.4 | 28000 | 28000 | 8098 | 7.55 | 1.0E-04 | 0.85401 | 0.00119 | 0.85640 | hciasqt12_28_2_3 | 0.85399 | 0.00116 | 0.85630 |
| nciasqt11_27_2_3 | 1.4 | 27000 | 27000 | 8151 | 7.88 | 1.0E-04 | 0.84755 | 0.00127 | 0.85009 | hciasqt12_27_2_3 | 0.84935 | 0.00125 | 0.85184 |
| nciasqt11_26_2_3 | 1.4 | 26000 | 26000 | 8204 | 8.24 | 1.0E-04 | 0.84285 | 0.00119 | 0.84522 | hciasqt12_26_2_3 | 0.84287 | 0.00106 | 0.84500 |
| nciasqt11_25_2_3 | 1.4 | 25000 | 25000 | 8257 | 8.62 | 1.0E-04 | 0.83719 | 0.00124 | 0.83967 | hciasqt12_25_2_3 | 0.83683 | 0.00113 | 0.83910 |
| nciasqt11_24_2_3 | 1.4 | 24000 | 24000 | 8310 | 9.04 | 1.0E-04 | 0.82927 | 0.00102 | 0.83132 | hciasqt12_24_2_3 | 0.83192 | 0.00111 | 0.83414 |
| nciasqt11_23_2_3 | 1.4 | 23000 | 23000 | 8363 | 9.49 | 1.0E-04 | 0.82375 | 0.00132 | 0.82638 | hciasqt12_23_2_3 | 0.82315 | 0.00124 | 0.82562 |
| nciasqt11_22_2_3 | 1.4 | 22000 | 22000 | 8416 | 9.98 | 1.0E-04 | 0.81735 | 0.00107 | 0.81950 | hciasqt12_22_2_3 | 0.81490 | 0.00105 | 0.81700 |
| nciasqt11_21_2_3 | 1.4 | 21000 | 21000 | 8469 | 10.53 | 1.0E-04 | 0.80580 | 0.00118 | 0.80817 | hciasqt12_21_2_3 | 0.81021 | 0.00121 | 0.81263 |
| nciasqt11_20_2_3 | 1.4 | 20000 | 20000 | 8522 | 11.12 | 1.0E-04 | 0.79977 | 0.00110 | 0.80197 | hciasqt12_20_2_3 | 0.80091 | 0.00116 | 0.80324 |
| nciasqt11_19_2_3 | 1.4 | 19000 | 19000 | 8575 | 11.78 | 1.0E-04 | 0.79125 | 0.00109 | 0.79343 | hciasqt12_19_2_3 | 0.79175 | 0.00113 | 0.79400 |
| nciasqt11_18_2_3 | 1.4 | 18000 | 18000 | 8628 | 12.51 | 1.0E-04 | 0.78165 | 0.00110 | 0.78386 | hciasqt12_18_2_3 | 0.78285 | 0.00110 | 0.78505 |
| nciasqt11_15_2_3 | 1.4 | 15000 | 15000 | 8787 | 15.29 | 1.0E-04 | 0.74822 | 0.00105 | 0.75032 | hciasqt12_15_2_3 | 0.74548 | 0.00107 | 0.74762 |
| nciasqt11_12_2_3 | 1.4 | 12000 | 12000 | 8947 | 19.46 | 1.0E-04 | 0.70519 | 0.00106 | 0.70732 | hciasqt12_12_2_3 | 0.70419 | 0.00105 | 0.70628 |
| nciasqt11_9_2_3 | 1.4 | 9000 | 9000 | 9106 | 26.41 | 1.0E-04 | 0.64473 | 0.00106 | 0.64685 | hciasqt12_9_2_3 | 0.64451 | 0.00101 | 0.64653 |

**Table 6.9.6-5. Results for 2.29 in.-square bar HEU metal content in packaging calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| nciasqt11_6_2_3 | 1.4 | 6000 | 6000 | 9265 | 40.30 | 1.0E-04 | 0.55778 | 0.00097 | 0.55972 | hciasqt12_6_2_3 | 0.55888 | 0.00098 | 0.56084 |
| nciasqt11_3_2_3 | 1.4 | 3000 | 3000 | 9424 | 81.99 | 1.0E-04 | 0.41347 | 0.00085 | 0.41517 | hciasqt12_3_2_3 | 0.41398 | 0.00074 | 0.41545 |

**Table 6.9.6-6. Results for 4.25 in.-diameter cylinder HEU metal content in CV calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| **flooded containment vessel, reflected** | | | | | | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | |
| cvcrcyct11_36_1 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E+00 | 1.06320 | 0.00115 | 1.06549 |
| cvcrcyct11_35_1 | 0.0 | 35000 | 35000 | 8340 | 6.22 | 1.0E+00 | 1.06114 | 0.00121 | 1.06356 |
| cvcrcyct11_34_1 | 0.0 | 34000 | 34000 | 8393 | 6.44 | 1.0E+00 | 1.05675 | 0.00122 | 1.05919 |
| cvcrcyct11_33_1 | 0.0 | 33000 | 33000 | 8446 | 6.68 | 1.0E+00 | 1.04990 | 0.00112 | 1.05214 |
| cvcrcyct11_32_1 | 0.0 | 32000 | 32000 | 8499 | 6.93 | 1.0E+00 | 1.04469 | 0.00123 | 1.04714 |
| cvcrcyct11_31_1 | 0.0 | 31000 | 31000 | 8552 | 7.20 | 1.0E+00 | 1.04101 | 0.00104 | 1.04310 |
| cvcrcyct11_30_1 | 0.0 | 30000 | 30000 | 8605 | 7.49 | 1.0E+00 | 1.03487 | 0.00117 | 1.03722 |
| cvcrcyct11_29_1 | 0.0 | 29000 | 29000 | 8658 | 7.79 | 1.0E+00 | 1.02817 | 0.00115 | 1.03046 |
| cvcrcyct11_28_1 | 0.0 | 28000 | 28000 | 8711 | 8.12 | 1.0E+00 | 1.02183 | 0.00125 | 1.02433 |
| cvcrcyct11_27_1 | 0.0 | 27000 | 27000 | 8764 | 8.47 | 1.0E+00 | 1.01524 | 0.00109 | 1.01742 |
| cvcrcyct11_26_1 | 0.0 | 26000 | 26000 | 8817 | 8.85 | 1.0E+00 | 1.00971 | 0.00116 | 1.01203 |
| cvcrcyct11_25_1 | 0.0 | 25000 | 25000 | 8870 | 9.26 | 1.0E+00 | 1.00149 | 0.00136 | 1.00420 |
| cvcrcyct11_24_1 | 0.0 | 24000 | 24000 | 8923 | 9.70 | 1.0E+00 | 0.99327 | 0.00137 | 0.99600 |
| cvcrcyct11_23_1 | 0.0 | 23000 | 23000 | 8977 | 10.19 | 1.0E+00 | 0.98432 | 0.00124 | 0.98680 |
| cvcrcyct11_22_1 | 0.0 | 22000 | 22000 | 9030 | 10.71 | 1.0E+00 | 0.97759 | 0.00112 | 0.97984 |

**Table 6.9.6-6. Results for 4.25 in.-diameter cylinder HEU metal content in CV calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| cvcrcyct11_21_1 | 0.0 | 21000 | 21000 | 9083 | 11.29 | 1.0E+00 | 0.96672 | 0.00116 | 0.96904 |
| cvcrcyct11_20_1 | 0.0 | 20000 | 20000 | 9136 | 11.92 | 1.0E+00 | 0.95743 | 0.00128 | 0.95999 |
| cvcrcyct11_19_1 | 0.0 | 19000 | 19000 | 9189 | 12.62 | 1.0E+00 | 0.94629 | 0.00118 | 0.94866 |
| cvcrcyct11_18_1 | 0.0 | 18000 | 18000 | 9242 | 13.40 | 1.0E+00 | 0.93349 | 0.00114 | 0.93576 |
| cvcrcyct11_17_1 | 0.0 | 17000 | 17000 | 9295 | 14.27 | 1.0E+00 | 0.91942 | 0.00105 | 0.92152 |
| cvcrcyct11_16_1 | 0.0 | 16000 | 16000 | 9348 | 15.25 | 1.0E+00 | 0.90458 | 0.00120 | 0.90699 |
| cvcrcyct11_15_1 | 0.0 | 15000 | 15000 | 9401 | 16.36 | 1.0E+00 | 0.88788 | 0.00107 | 0.89002 |
| | | | | | | | | | |
| **with can spacers (np thickness=1.4 in.)** | | | | | | | | | |
| cvcrcyct11_36_2 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E+00 | 0.94321 | 0.00111 | 0.94543 |
| cvcrcyct11_35_2 | 1.4 | 35000 | 35000 | 7726 | 5.76 | 1.0E+00 | 0.93828 | 0.00114 | 0.94056 |
| cvcrcyct11_34_2 | 1.4 | 34000 | 34000 | 7779 | 5.97 | 1.0E+00 | 0.93114 | 0.00129 | 0.93372 |
| cvcrcyct11_33_2 | 1.4 | 33000 | 33000 | 7832 | 6.19 | 1.0E+00 | 0.92558 | 0.00124 | 0.92805 |
| cvcrcyct11_32_2 | 1.4 | 32000 | 32000 | 7885 | 6.43 | 1.0E+00 | 0.91799 | 0.00111 | 0.92021 |
| cvcrcyct11_31_2 | 1.4 | 31000 | 31000 | 7938 | 6.68 | 1.0E+00 | 0.91146 | 0.00114 | 0.91375 |
| cvcrcyct11_30_2 | 1.4 | 30000 | 30000 | 7992 | 6.95 | 1.0E+00 | 0.90499 | 0.00117 | 0.90734 |

**Table 6.9.6-7. Results for 4.25 in.-diameter cylinder HEU metal content in packaging calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **content in flooded containment vessel, single package reflected** | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | **HAC** | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | |
| ncsrcyct11_36_1_1 | 0.0 | 36000 | 36000 | 8286.7 | 6.01 | 1.0E-20 | 0.98628 | 0.00107 | 0.98841 | hcsrcyct12_36_1_1 | 0.98723 | 0.00126 | 0.98975 |
| ncsrcyct11_36_1_2 | 0.0 | 36000 | 36000 | 8286.7 | 6.01 | 1.0E-05 | 0.98712 | 0.00138 | 0.98988 | hcsrcyct12_36_1_2 | 0.98582 | 0.00120 | 0.98823 |
| ncsrcyct11_36_1_3 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-04 | 0.98624 | 0.00119 | 0.98861 | hcsrcyct12_36_1_3 | 0.98691 | 0.00113 | 0.98917 |
| ncsrcyct11_36_1_4 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-03 | 0.98433 | 0.00102 | 0.98637 | hcsrcyct12_36_1_4 | 0.98537 | 0.00111 | 0.98759 |
| ncsrcyct11_36_1_5 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-02 | 0.98646 | 0.00103 | 0.98852 | hcsrcyct12_36_1_5 | 0.98809 | 0.00110 | 0.99028 |
| ncsrcyct11_36_1_6 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-01 | 0.99092 | 0.00127 | 0.99346 | hcsrcyct12_36_1_6 | 0.99096 | 0.00099 | 0.99295 |
| ncsrcyct11_36_1_8 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 3.0E-01 | 1.00000 | 0.00123 | 1.00246 | hcsrcyct12_36_1_8 | 1.00334 | 0.00119 | 1.00572 |
| ncsrcyct11_36_1_15 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E+00 | 1.03142 | 0.00144 | 1.03430 | hcsrcyct12_36_1_15 | 1.03141 | 0.00116 | 1.03374 |
| ncsrcyct11_36_1_15 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E+00 | 1.03142 | 0.00144 | 1.03430 | hcsrcyct12_36_1_15 | 1.03141 | 0.00116 | 1.03374 |
| ncsrcyct11_35_1_15 | 0.0 | 35000 | 35000 | 8340 | 6.22 | 1.0E+00 | 1.02816 | 0.00115 | 1.03045 | hcsrcyct12_35_1_15 | 1.03309 | 0.00126 | 1.03561 |
| ncsrcyct11_34_1_15 | 0.0 | 34000 | 34000 | 8393 | 6.44 | 1.0E+00 | 1.02658 | 0.00113 | 1.02884 | hcsrcyct12_34_1_15 | 1.02529 | 0.00124 | 1.02776 |
| ncsrcyct11_33_1_15 | 0.0 | 33000 | 33000 | 8446 | 6.68 | 1.0E+00 | 1.01975 | 0.00114 | 1.02203 | hcsrcyct12_33_1_15 | 1.02060 | 0.00124 | 1.02308 |
| ncsrcyct11_32_1_15 | 0.0 | 32000 | 32000 | 8499 | 6.93 | 1.0E+00 | 1.01647 | 0.00104 | 1.01854 | hcsrcyct12_32_1_15 | 1.01688 | 0.00114 | 1.01916 |
| ncsrcyct11_31_1_15 | 0.0 | 31000 | 31000 | 8552 | 7.20 | 1.0E+00 | 1.00952 | 0.00114 | 1.01179 | hcsrcyct12_31_1_15 | 1.01218 | 0.00144 | 1.01505 |
| ncsrcyct11_30_1_15 | 0.0 | 30000 | 30000 | 8605 | 7.49 | 1.0E+00 | 1.00434 | 0.00123 | 1.00679 | hcsrcyct12_30_1_15 | 1.00757 | 0.00117 | 1.00992 |
| ncsrcyct11_29_1_15 | 0.0 | 29000 | 29000 | 8658 | 7.79 | 1.0E+00 | 1.00074 | 0.00106 | 1.00287 | hcsrcyct12_29_1_15 | 1.00071 | 0.00139 | 1.00348 |
| ncsrcyct11_28_1_15 | 0.0 | 28000 | 28000 | 8711 | 8.12 | 1.0E+00 | 0.99381 | 0.00135 | 0.99652 | hcsrcyct12_28_1_15 | 0.99442 | 0.00129 | 0.99700 |
| ncsrcyct11_27_1_15 | 0.0 | 27000 | 27000 | 8764 | 8.47 | 1.0E+00 | 0.98595 | 0.00094 | 0.98782 | hcsrcyct12_27_1_15 | 0.99057 | 0.00119 | 0.99296 |
| ncsrcyct11_26_1_15 | 0.0 | 26000 | 26000 | 8817 | 8.85 | 1.0E+00 | 0.97783 | 0.00117 | 0.98017 | hcsrcyct12_26_1_15 | 0.98010 | 0.00135 | 0.98281 |
| ncsrcyct11_25_1_15 | 0.0 | 25000 | 25000 | 8870 | 9.26 | 1.0E+00 | 0.97189 | 0.00126 | 0.97440 | hcsrcyct12_25_1_15 | 0.97263 | 0.00118 | 0.97499 |
| ncsrcyct11_24_1_15 | 0.0 | 24000 | 24000 | 8923 | 9.70 | 1.0E+00 | 0.96439 | 0.00121 | 0.96681 | hcsrcyct12_24_1_15 | 0.96656 | 0.00113 | 0.96881 |
| ncsrcyct11_23_1_15 | 0.0 | 23000 | 23000 | 8977 | 10.19 | 1.0E+00 | 0.95375 | 0.00130 | 0.95635 | hcsrcyct12_23_1_15 | 0.95783 | 0.00118 | 0.96018 |

**Table 6.9.6-7. Results for 4.25 in.-diameter cylinder HEU metal content in packaging calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncsrcyct11_22_1_15 | 0.0 | 22000 | 22000 | 9030 | 10.71 | 1.0E+00 | 0.94744 | 0.00132 | 0.95008 | hcsrcyct12_22_1_15 | 0.94901 | 0.00143 | 0.95187 |
| ncsrcyct11_21_1_15 | 0.0 | 21000 | 21000 | 9083 | 11.29 | 1.0E+00 | 0.93842 | 0.00127 | 0.94095 | hcsrcyct12_21_1_15 | 0.93880 | 0.00126 | 0.94132 |
| ncsrcyct11_20_1_15 | 0.0 | 20000 | 20000 | 9136 | 11.92 | 1.0E+00 | 0.92684 | 0.00118 | 0.92920 | hcsrcyct12_20_1_15 | 0.92929 | 0.00124 | 0.93176 |
| ncsrcyct11_19_1_15 | 0.0 | 19000 | 19000 | 9189 | 12.62 | 1.0E+00 | 0.91527 | 0.00109 | 0.91745 | hcsrcyct12_19_1_15 | 0.91879 | 0.00101 | 0.92081 |
| ncsrcyct11_18_1_15 | 0.0 | 18000 | 18000 | 9242 | 13.40 | 1.0E+00 | 0.90374 | 0.00111 | 0.90597 | hcsrcyct12_18_1_15 | 0.90716 | 0.00105 | 0.90927 |
| ncsrcyct11_17_1_15 | 0.0 | 17000 | 17000 | 9295 | 14.27 | 1.0E+00 | 0.89147 | 0.00133 | 0.89412 | hcsrcyct12_17_1_15 | 0.89585 | 0.00104 | 0.89794 |
| ncsrcyct11_16_1_15 | 0.0 | 16000 | 16000 | 9348 | 15.25 | 1.0E+00 | 0.87788 | 0.00101 | 0.87990 | hcsrcyct12_16_1_15 | 0.87933 | 0.00118 | 0.88168 |
| ncsrcyct11_15_1_15 | 0.0 | 15000 | 15000 | 9401 | 16.36 | 1.0E+00 | 0.86209 | 0.00110 | 0.86429 | hcsrcyct12_15_1_15 | 0.86488 | 0.00110 | 0.86708 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | | |
| ncsrcyct11_36_2_1 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-20 | 0.87502 | 0.00112 | 0.87725 | hcsrcyct12_36_2_1 | 0.87543 | 0.00107 | 0.87757 |
| ncsrcyct11_36_2_2 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-05 | 0.87474 | 0.00108 | 0.87691 | hcsrcyct12_36_2_2 | 0.87795 | 0.00117 | 0.88029 |
| ncsrcyct11_36_2_3 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-04 | 0.87595 | 0.00126 | 0.87846 | hcsrcyct12_36_2_3 | 0.87675 | 0.00112 | 0.87899 |
| ncsrcyct11_36_2_4 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-03 | 0.87655 | 0.00100 | 0.87856 | hcsrcyct12_36_2_4 | 0.87798 | 0.00106 | 0.88011 |
| ncsrcyct11_36_2_5 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-02 | 0.87634 | 0.00104 | 0.87843 | hcsrcyct12_36_2_5 | 0.87876 | 0.00109 | 0.88094 |
| ncsrcyct11_36_2_6 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-01 | 0.87971 | 0.00102 | 0.88174 | hcsrcyct12_36_2_6 | 0.88317 | 0.00111 | 0.88539 |
| ncsrcyct11_36_2_8 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 3.0E-01 | 0.88865 | 0.00115 | 0.89094 | hcsrcyct12_36_2_8 | 0.89169 | 0.00103 | 0.89375 |
| ncsrcyct11_36_2_15 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E+00 | 0.91608 | 0.00120 | 0.91847 | hcsrcyct12_36_2_15 | 0.91815 | 0.00118 | 0.92050 |
| | | | | | | | | | | | | | |
| ncsrcyct11_36_2_15 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E+00 | 0.91608 | 0.00120 | 0.91847 | hcsrcyct12_36_2_15 | 0.91815 | 0.00118 | 0.92050 |
| ncsrcyct11_35_2_15 | 1.4 | 35000 | 35000 | 7726 | 5.76 | 1.0E+00 | 0.91190 | 0.00116 | 0.91422 | hcsrcyct12_35_2_15 | 0.91300 | 0.00117 | 0.91534 |
| ncsrcyct11_34_2_15 | 1.4 | 34000 | 34000 | 7779 | 5.97 | 1.0E+00 | 0.90497 | 0.00112 | 0.90721 | hcsrcyct12_34_2_15 | 0.90616 | 0.00116 | 0.90848 |
| ncsrcyct11_33_2_15 | 1.4 | 33000 | 33000 | 7832 | 6.19 | 1.0E+00 | 0.90032 | 0.00120 | 0.90272 | hcsrcyct12_33_2_15 | 0.90269 | 0.00118 | 0.90506 |
| ncsrcyct11_32_2_15 | 1.4 | 32000 | 32000 | 7885 | 6.43 | 1.0E+00 | 0.89251 | 0.00102 | 0.89455 | hcsrcyct12_32_2_15 | 0.89526 | 0.00120 | 0.89766 |
| ncsrcyct11_31_2_15 | 1.4 | 31000 | 31000 | 7938 | 6.68 | 1.0E+00 | 0.88531 | 0.00136 | 0.88803 | hcsrcyct12_31_2_15 | 0.88765 | 0.00108 | 0.88981 |
| ncsrcyct11_30_2_15 | 1.4 | 30000 | 30000 | 7992 | 6.95 | 1.0E+00 | 0.88012 | 0.00120 | 0.88252 | hcsrcyct12_30_2_15 | 0.88005 | 0.00120 | 0.88246 |

**Table 6.9.6-7. Results for 4.25 in.-diameter cylinder HEU metal content in packaging calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **content in flooded containment vessel, array packaging model for CSI=0.0** | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | **HAC** | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | |
| nciacyct11_36_1_3 | 0.0 | 36000 | 36000 | 8287 | 6.01 | 1.0E-04 | 1.10334 | 0.00135 | 1.10604 | hciacyct12_36_1_3 | 1.10722 | 0.00119 | 1.10961 |
| nciacyct11_35_1_3 | 0.0 | 35000 | 35000 | 8340 | 6.22 | 1.0E-04 | 1.10128 | 0.00116 | 1.10360 | hciacyct12_35_1_3 | 1.10067 | 0.00114 | 1.10295 |
| nciacyct11_34_1_3 | 0.0 | 34000 | 34000 | 8393 | 6.44 | 1.0E-04 | 1.09399 | 0.00125 | 1.09648 | hciacyct12_34_1_3 | 1.09477 | 0.00124 | 1.09726 |
| nciacyct11_33_1_3 | 0.0 | 33000 | 33000 | 8446 | 6.68 | 1.0E-04 | 1.08794 | 0.00127 | 1.09048 | hciacyct12_33_1_3 | 1.08942 | 0.00134 | 1.09210 |
| nciacyct11_32_1_3 | 0.0 | 32000 | 32000 | 8499 | 6.93 | 1.0E-04 | 1.08183 | 0.00131 | 1.08444 | hciacyct12_32_1_3 | 1.08089 | 0.00128 | 1.08346 |
| nciacyct11_31_1_3 | 0.0 | 31000 | 31000 | 8552 | 7.20 | 1.0E-04 | 1.07391 | 0.00114 | 1.07619 | hciacyct12_31_1_3 | 1.07627 | 0.00101 | 1.07829 |
| nciacyct11_30_1_3 | 0.0 | 30000 | 30000 | 8605 | 7.49 | 1.0E-04 | 1.06840 | 0.00131 | 1.07102 | hciacyct12_30_1_3 | 1.06781 | 0.00107 | 1.06994 |
| nciacyct11_29_1_3 | 0.0 | 29000 | 29000 | 8658 | 7.79 | 1.0E-04 | 1.06070 | 0.00108 | 1.06286 | hciacyct12_29_1_3 | 1.05946 | 0.00121 | 1.06188 |
| nciacyct11_28_1_3 | 0.0 | 28000 | 28000 | 8711 | 8.12 | 1.0E-04 | 1.05398 | 0.00116 | 1.05630 | hciacyct12_28_1_3 | 1.05253 | 0.00102 | 1.05457 |
| nciacyct11_27_1_3 | 0.0 | 27000 | 27000 | 8764 | 8.47 | 1.0E-04 | 1.04385 | 0.00142 | 1.04670 | hciacyct12_27_1_3 | 1.04481 | 0.00121 | 1.04723 |
| nciacyct11_26_1_3 | 0.0 | 26000 | 26000 | 8817 | 8.85 | 1.0E-04 | 1.03489 | 0.00124 | 1.03736 | hciacyct12_26_1_3 | 1.03688 | 0.00118 | 1.03923 |
| nciacyct11_25_1_3 | 0.0 | 25000 | 25000 | 8870 | 9.26 | 1.0E-04 | 1.02495 | 0.00128 | 1.02751 | hciacyct12_25_1_3 | 1.02706 | 0.00120 | 1.02946 |
| nciacyct11_24_1_3 | 0.0 | 24000 | 24000 | 8923 | 9.70 | 1.0E-04 | 1.01610 | 0.00120 | 1.01850 | hciacyct12_24_1_3 | 1.01634 | 0.00118 | 1.01870 |
| nciacyct11_23_1_3 | 0.0 | 23000 | 23000 | 8977 | 10.19 | 1.0E-04 | 1.00723 | 0.00108 | 1.00938 | hciacyct12_23_1_3 | 1.00427 | 0.00110 | 1.00648 |
| nciacyct11_22_1_3 | 0.0 | 22000 | 22000 | 9030 | 10.71 | 1.0E-04 | 0.99573 | 0.00122 | 0.99817 | hciacyct12_22_1_3 | 0.99481 | 0.00112 | 0.99705 |
| nciacyct11_21_1_3 | 0.0 | 21000 | 21000 | 9083 | 11.29 | 1.0E-04 | 0.98149 | 0.00122 | 0.98393 | hciacyct12_21_1_3 | 0.98514 | 0.00127 | 0.98768 |
| nciacyct11_20_1_3 | 0.0 | 20000 | 20000 | 9136 | 11.92 | 1.0E-04 | 0.97377 | 0.00104 | 0.97585 | hciacyct12_20_1_3 | 0.97210 | 0.00120 | 0.97450 |
| nciacyct11_19_1_3 | 0.0 | 19000 | 19000 | 9189 | 12.62 | 1.0E-04 | 0.95985 | 0.00127 | 0.96240 | hciacyct12_19_1_3 | 0.95807 | 0.00143 | 0.96092 |
| nciacyct11_18_1_3 | 0.0 | 18000 | 18000 | 9242 | 13.40 | 1.0E-04 | 0.94375 | 0.00137 | 0.94649 | hciacyct12_18_1_3 | 0.94639 | 0.00124 | 0.94887 |
| nciacyct11_15_1_3 | 0.0 | 15000 | 15000 | 9401 | 16.36 | 1.0E-04 | 0.89699 | 0.00109 | 0.89917 | hciacyct12_15_1_3 | 0.89646 | 0.00108 | 0.89862 |
| nciacyct11_12_1_3 | 0.0 | 12000 | 12000 | 9560 | 20.79 | 1.0E-04 | 0.83537 | 0.00118 | 0.83772 | hciacyct12_12_1_3 | 0.83858 | 0.00118 | 0.84093 |
| nciacyct11_9_1_3 | 0.0 | 9000 | 9000 | 9719 | 28.19 | 1.0E-04 | 0.76061 | 0.00121 | 0.76303 | hciacyct12_9_1_3 | 0.75657 | 0.00112 | 0.75882 |

**Table 6.9.6-7. Results for 4.25 in.-diameter cylinder HEU metal content in packaging calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| nciacyct11_6_1_3 | 0.0 | 6000 | 6000 | 9879 | 42.97 | 1.0E-04 | 0.64959 | 0.00106 | 0.65172 | hciacyct12_6_1_3 | 0.64940 | 0.00109 | 0.65157 |
| nciacyct11_3_1_3 | 0.0 | 3000 | 3000 | 10038 | 87.33 | 1.0E-04 | 0.48405 | 0.00103 | 0.48611 | hciacyct12_3_1_3 | 0.48552 | 0.00096 | 0.48745 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | | |
| nciacyct11_36_2_3 | 1.4 | 36000 | 36000 | 7673 | 5.56 | 1.0E-04 | 1.01018 | 0.00139 | 1.01297 | hciacyct12_36_2_3 | 1.01024 | 0.00120 | 1.01263 |
| nciacyct11_35_2_3 | 1.4 | 35000 | 35000 | 7726 | 5.76 | 1.0E-04 | 1.00029 | 0.00110 | 1.00249 | hciacyct12_35_2_3 | 1.00083 | 0.00105 | 1.00293 |
| nciacyct11_34_2_3 | 1.4 | 34000 | 34000 | 7779 | 5.97 | 1.0E-04 | 0.99523 | 0.00100 | 0.99723 | hciacyct12_34_2_3 | 0.99499 | 0.00116 | 0.99731 |
| nciacyct11_33_2_3 | 1.4 | 33000 | 33000 | 7832 | 6.19 | 1.0E-04 | 0.98713 | 0.00110 | 0.98932 | hciacyct12_33_2_3 | 0.98922 | 0.00108 | 0.99139 |
| nciacyct11_32_2_3 | 1.4 | 32000 | 32000 | 7885 | 6.43 | 1.0E-04 | 0.97809 | 0.00109 | 0.98028 | hciacyct12_32_2_3 | 0.98046 | 0.00098 | 0.98242 |
| nciacyct11_31_2_3 | 1.4 | 31000 | 31000 | 7938 | 6.68 | 1.0E-04 | 0.96968 | 0.00130 | 0.97227 | hciacyct12_31_2_3 | 0.96951 | 0.00147 | 0.97246 |
| nciacyct11_30_2_3 | 1.4 | 30000 | 30000 | 7992 | 6.95 | 1.0E-04 | 0.96031 | 0.00132 | 0.96295 | hciacyct12_30_2_3 | 0.96156 | 0.00107 | 0.96370 |
| nciacyct11_29_2_3 | 1.4 | 29000 | 29000 | 8045 | 7.24 | 1.0E-04 | 0.95128 | 0.00117 | 0.95362 | hciacyct12_29_2_3 | 0.95414 | 0.00120 | 0.95654 |
| nciacyct11_28_2_3 | 1.4 | 28000 | 28000 | 8098 | 7.55 | 1.0E-04 | 0.94378 | 0.00138 | 0.94654 | hciacyct12_28_2_3 | 0.94376 | 0.00138 | 0.94652 |
| nciacyct11_27_2_3 | 1.4 | 27000 | 27000 | 8151 | 7.88 | 1.0E-04 | 0.93234 | 0.00111 | 0.93456 | hciacyct12_27_2_3 | 0.93273 | 0.00132 | 0.93536 |
| nciacyct11_26_2_3 | 1.4 | 26000 | 26000 | 8204 | 8.24 | 1.0E-04 | 0.92078 | 0.00104 | 0.92287 | hciacyct12_26_2_3 | 0.92390 | 0.00128 | 0.92646 |
| nciacyct11_25_2_3 | 1.4 | 25000 | 25000 | 8257 | 8.62 | 1.0E-04 | 0.91264 | 0.00100 | 0.91465 | hciacyct12_25_2_3 | 0.91352 | 0.00105 | 0.91562 |
| nciacyct11_24_2_3 | 1.4 | 24000 | 24000 | 8310 | 9.04 | 1.0E-04 | 0.89955 | 0.00124 | 0.90203 | hciacyct12_24_2_3 | 0.90170 | 0.00109 | 0.90388 |
| nciacyct11_23_2_3 | 1.4 | 23000 | 23000 | 8363 | 9.49 | 1.0E-04 | 0.89118 | 0.00128 | 0.89374 | hciacyct12_23_2_3 | 0.89159 | 0.00128 | 0.89414 |
| nciacyct11_22_2_3 | 1.4 | 22000 | 22000 | 8416 | 9.98 | 1.0E-04 | 0.87715 | 0.00098 | 0.87910 | hciacyct12_22_2_3 | 0.87791 | 0.00103 | 0.87997 |
| nciacyct11_21_2_3 | 1.4 | 21000 | 21000 | 8469 | 10.53 | 1.0E-04 | 0.86679 | 0.00109 | 0.86898 | hciacyct12_21_2_3 | 0.86482 | 0.00106 | 0.86693 |
| nciacyct11_20_2_3 | 1.4 | 20000 | 20000 | 8522 | 11.12 | 1.0E-04 | 0.85029 | 0.00131 | 0.85292 | hciacyct12_20_2_3 | 0.85207 | 0.00119 | 0.85445 |
| nciacyct11_19_2_3 | 1.4 | 19000 | 19000 | 8575 | 11.78 | 1.0E-04 | 0.83585 | 0.00110 | 0.83805 | hciacyct12_19_2_3 | 0.83631 | 0.00101 | 0.83833 |
| nciacyct11_18_2_3 | 1.4 | 18000 | 18000 | 8628 | 12.51 | 1.0E-04 | 0.82112 | 0.00105 | 0.82323 | hciacyct12_18_2_3 | 0.82020 | 0.00108 | 0.82236 |
| nciacyct11_15_2_3 | 1.4 | 15000 | 15000 | 8787 | 15.29 | 1.0E-04 | 0.77012 | 0.00102 | 0.77216 | hciacyct12_15_2_3 | 0.77067 | 0.00099 | 0.77265 |
| nciacyct11_12_2_3 | 1.4 | 12000 | 12000 | 8947 | 19.46 | 1.0E-04 | 0.70996 | 0.00113 | 0.71222 | hciacyct12_12_2_3 | 0.70716 | 0.00100 | 0.70915 |
| nciacyct11_9_2_3 | 1.4 | 9000 | 9000 | 9106 | 26.41 | 1.0E-04 | 0.38338 | 0.00093 | 0.38524 | hciacyct12_9_2_3 | 0.62982 | 0.00097 | 0.63175 |

**Table 6.9.6-7. Results for 4.25 in.-diameter cylinder HEU metal content in packaging calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| nciacyct11_6_2_3 | 1.4 | 6000 | 6000 | 9265 | 40.30 | 1.0E-04 | 0.63066 | 0.00100 | 0.63267 | hciacyct12_6_2_3 | 0.52901 | 0.00100 | 0.53101 |
| nciacyct11_3_2_3 | 1.4 | 3000 | 3000 | 9424 | 81.99 | 1.0E-04 | 0.52971 | 0.00101 | 0.53173 | hciacyct12_3_2_3 | 0.38124 | 0.00075 | 0.38274 |

**Table 6.9.6-8. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in CV calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | content description |
|---|---|---|---|---|---|---|---|---|---|---|
| **flooded containment vessel, reflected** | | | | | | | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | |
| cvcr5st11_1_1 | 0.0 | 18277 | 18277 | 9227 | 13.18 | 1.0E+00 | 0.90734 | 0.00123 | 0.90980 | 5 slugs in a pentagonal ring |
| cvcr5est11_1_1 | 0.0 | 18277 | 18277 | 9227 | 13.18 | 1.0E+00 | 0.90718 | 0.00119 | 0.90955 | 5 slugs in a pentagonal ring, extended spacing |
| cvcr50st11_1 | 0.0 | 18277 | 18277 | 9227 | 13.18 | 1.0E+00 | 0.90671 | 0.00120 | 0.90911 | 5 slugs in cruciform pattern |
| cvcr5e0st11_1 | 0.0 | 18277 | 18277 | 9227 | 13.18 | 1.0E+00 | 0.90690 | 0.00124 | 0.90938 | 5 slugs in cruciform pattern, extended spacing |
| cvcr5u0st11_1 | 0.0 | 18277 | 18277 | 9227 | 13.18 | 1.0E+00 | 0.90690 | 0.00122 | 0.90935 | 5 slugs in four pointed star pattern |
| cvcr5l0st11_1 | 0.0 | 18277 | 18277 | 9227 | 13.18 | 1.0E+00 | 0.90660 | 0.00113 | 0.90885 | 5 slugs, filled hex. Ring with 2 slugs missing |
| cvcr6st11_1_1 | 0.0 | 21933 | 21933 | 9033 | 10.75 | 1.0E+00 | 0.95173 | 0.00118 | 0.95409 | 6 slugs in a hexagonal ring |
| cvcr6e0st11_1 | 0.0 | 21933 | 21933 | 9033 | 10.75 | 1.0E+00 | 0.95531 | 0.00106 | 0.95742 | 6 slugs in pentagonal ring with center slug |
| cvcr70st11_1 | 0.0 | 25588 | 25588 | 8839 | 9.02 | 1.0E+00 | 0.99827 | 0.00135 | 1.00097 | 7 slugs in hexagonal ring with center slug |
| cvcr5st11_1_2 | 0.0 | 36555 | 36555 | 8257 | 5.90 | 1.0E+00 | 0.99909 | 0.00125 | 1.00158 | 10 slugs in stacked pentagonal rings |
| cvcr5est11_1_2 | 0.0 | 36555 | 36555 | 8257 | 5.90 | 1.0E+00 | 1.00409 | 0.00136 | 1.00681 | 10 slugs in stacked pent. rings, extended spacing |
| cvcr6e4st11_1 | 0.0 | 36555 | 36555 | 8257 | 5.90 | 1.0E+00 | 1.00361 | 0.00134 | 1.00630 | 10 slugs, lower 6 slugs in hex ring, upper 4 in square |
| cvcr73st11_1 | 0.0 | 36555 | 36555 | 8257 | 5.90 | 1.0E+00 | 1.00523 | 0.00127 | 1.00776 | 10 slugs, lower 7 slugs in hex ring, upper 3 in triangle |
| cvcr6st11_1_2 | 0.0 | 43865 | 43865 | 7869 | 4.68 | 1.0E+00 | 1.05336 | 0.00130 | 1.05597 | 12 slugs in stacked hexagonal rings |

**Table 6.9.6-8. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in CV calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | content description |
|---|---|---|---|---|---|---|---|---|---|---|
| **with can spacers (np thickness=1.4 in.)** | | | | | | | | | | |
| cvcr5st11_2_1 | 1.4 | 18277 | 18277 | 8613 | 12.30 | 1.0E+00 | 0.76864 | 0.00113 | 0.77089 | 5 slugs in a pentagonal ring |
| cvcr5est11_2_1 | 1.4 | 18277 | 18277 | 8613 | 12.30 | 1.0E+00 | 0.76420 | 0.00102 | 0.76624 | 5 slugs in a pentagonal ring, extended spacing |
| cvcr50st11_2 | 1.4 | 18277 | 18277 | 8613 | 12.30 | 1.0E+00 | 0.76929 | 0.00117 | 0.77163 | 5 slugs in cruciform pattern |
| cvcr5e0st11_2 | 1.4 | 18277 | 18277 | 8613 | 12.30 | 1.0E+00 | 0.76532 | 0.00127 | 0.76785 | 5 slugs in cruciform pattern, extended spacing |
| cvcr5u0st11_2 | 1.4 | 18277 | 18277 | 8613 | 12.30 | 1.0E+00 | 0.76953 | 0.00108 | 0.77168 | 5 slugs in four pointed star pattern |
| cvcr5l0st11_2 | 1.4 | 18277 | 18277 | 8613 | 12.30 | 1.0E+00 | 0.77162 | 0.00102 | 0.77366 | 5 slugs, filled hex. Ring with 2 slugs missing |
| cvcr6st11_2_1 | 1.4 | 21933 | 21933 | 8419 | 10.02 | 1.0E+00 | 0.81300 | 0.00148 | 0.81596 | 6 slugs in a hexagonal ring |
| cvcr6e0st11_2 | 1.4 | 21933 | 21933 | 8419 | 10.02 | 1.0E+00 | 0.81943 | 0.00116 | 0.82176 | 6 slugs in pentagonal ring with center slug |
| cvcr70st11_2 | 1.4 | 25588 | 25588 | 8225 | 8.39 | 1.0E+00 | 0.86296 | 0.00104 | 0.86503 | 7 slugs in hexagonal ring with center slug |
| cvcr5st11_2_2 | 1.4 | 36555 | 36555 | 7643 | 5.46 | 1.0E+00 | 0.90058 | 0.00115 | 0.90287 | 10 slugs in stacked pentagonal rings |
| cvcr5est11_2_2 | 1.4 | 36555 | 36555 | 7643 | 5.46 | 1.0E+00 | 0.89862 | 0.00121 | 0.90104 | 10 slugs in stacked pent. rings, extended spacing |
| cvcr6e4st11_2 | 1.4 | 36555 | 36555 | 7643 | 5.46 | 1.0E+00 | 0.89991 | 0.00109 | 0.90209 | 10 slugs, lower 6 slugs in hex ring, upper 4 in square |
| cvcr73st11_2 | 1.4 | 36555 | 36555 | 7643 | 5.46 | 1.0E+00 | 0.89922 | 0.00109 | 0.90139 | 10 slugs, lower 7 slugs in hex ring, upper 3 in triangle |
| cvcr6st11_2_2 | 1.4 | 43865 | 43865 | 7256 | 4.32 | 1.0E+00 | 0.94962 | 0.00126 | 0.95213 | 12 slugs in stacked hexagonal rings |
| **evaluation of model approximations in no can spacer configurations (np thickness=0.0002 in.)** | | | | | | | | | | |
| cvcr6e0st11_1 | 0.0 | 21933 | 21933 | 9033 | 10.75 | 1.0E+00 | 0.95531 | 0.00106 | 0.95742 | 6 slugs in pentagonal ring with center slug |
| cv0r6e0s_1 | 0.0 | 21933 | 21933 | 9033 | 10.75 | 1.0E+00 | 0.95418 | 0.00135 | 0.95689 | 0.0002 cm thick spacers voided in above model |
| cvwr6e0s_1 | 0.0 | 21933 | 21933 | 9033 | 10.75 | 1.0E+00 | 0.95384 | 0.00117 | 0.95618 | 0.0002 cm thick spacers replaced with water in above |
| cvcr70st11_1 | 0.0 | 25588 | 25588 | 8839 | 9.02 | 1.0E+00 | 0.99827 | 0.00135 | 1.00097 | 7 slugs, hex ring with slug in center |
| cv0r70s_1 | 0.0 | 25588 | 25588 | 8839 | 9.02 | 1.0E+00 | 0.99814 | 0.00118 | 1.00051 | 0.0002 cm thick spacers voided in above model |
| cvwr70s_1 | 0.0 | 25588 | 25588 | 8839 | 9.02 | 1.0E+00 | 0.99847 | 0.00120 | 1.00088 | 0.0002 cm thick spacers flooded in above model |
| **evaluation of model approximations in configurations with can spacers (np thickness=1.4 in.)** | | | | | | | | | | |
| cvcr6e0st11_2 | 1.4 | 21933 | 21933 | 8419 | 10.02 | 1.0E+00 | 0.81943 | 0.00116 | 0.82176 | 6 slugs in pentagonal ring with center slug |
| cv0r6e0s_2 | 1.4 | 21933 | 21933 | 8419 | 10.02 | 1.0E+00 | 0.84682 | 0.00118 | 0.84918 | 1.4 in thick spacers voided in above model |

**Table 6.9.6-8. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in CV calculation model**

| case name | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | content description |
|---|---|---|---|---|---|---|---|---|---|---|
| cvcr6e0st11_1 | 0.0 | 21933 | 21933 | 9033 | 10.75 | 1.0E+00 | 0.95531 | 0.00106 | 0.95742 | 6 slugs in pentagonal ring with center slug |
| cvwr6e0s_2 | 1.4 | 21933 | 21933 | 9033 | 10.75 | 1.0E+00 | 0.89988 | 0.00138 | 0.90263 | 1.4 in thick spacers replace with water |
| | | | | | | | | | | |
| cvcr70st11_2 | 1.4 | 25588 | 25588 | 8225 | 8.39 | 1.0E+00 | 0.86296 | 0.00104 | 0.86503 | 7 slugs, hex ring with slug in center |
| cv0r70s_2 | 1.4 | 25588 | 25588 | 8225 | 8.39 | 1.0E+00 | 0.88250 | 0.00110 | 0.88470 | 1.4 in thick spacers voided in above model |
| cvcr70st11_1 | 0.0 | 25588 | 25588 | 8839 | 9.02 | 1.0E+00 | 0.99827 | 0.00135 | 1.00097 | 7 slugs, hex ring with slug in center |
| cvwr70s_2 | 1.4 | 25588 | 25588 | 8839 | 9.02 | 1.0E+00 | 0.93953 | 0.00111 | 0.94175 | 1.4 in thick spacers replace with water |

**Table 6.9.6-9. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in packaging calculation model**

| case name | enr | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **content in flooded containment vessel, single package reflected** | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | **HAC** | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | |
| ncsr5est11_1_1_15 | 100 | 18277 | 18277 | 9227 | 13.18 | 1.0E+00 | 0.86857 | 0.00128 | 0.87113 | hcsr5est12_1_1_15 | 0.87319 | 0.00116 | 0.87551 |
| ncsr5st11_1_1_15 | 100 | 18277 | 18277 | 9227 | 13.18 | 1.0E+00 | 0.88102 | 0.00119 | 0.88339 | hcsr5st12_1_1_15 | 0.88322 | 0.00142 | 0.88606 |
| ncsr6st11_1_1_15 | 100 | 21933 | 21933 | 9033 | 10.75 | 1.0E+00 | 0.91461 | 0.00110 | 0.91680 | | | | |
| | | | | | | | | | | | | | |
| ncsr5est11_1_2_15 | 100 | 36555 | 36555 | 8257 | 5.90 | 1.0E+00 | 0.96511 | 0.00123 | 0.96756 | hcsr5est12_1_2_15 | 0.96512 | 0.00128 | 0.96768 |
| ncsr5st11_1_2_15 | 100 | 36555 | 36555 | 8257 | 5.90 | 1.0E+00 | 0.96727 | 0.00116 | 0.96960 | hcsr5st12_1_2_15 | 0.97082 | 0.00124 | 0.97330 |
| | | | | | | | | | | | | | |
| ncsr6e4st11_1_1 | 100 | 36555 | 36555 | 8257 | 5.90 | 1.0E-20 | 0.92156 | 0.00105 | 0.92367 | | | | |
| ncsr6e4st11_1_2 | 100 | 36555 | 36555 | 8257 | 5.90 | 1.0E-05 | 0.92051 | 0.00114 | 0.92279 | | | | |

**Table 6.9.6-9. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in packaging calculation model**

| case name | enr | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncsr6e4st11_1_3 | 100 | 36555 | 36555 | 8257 | 5.90 | 1.0E-04 | 0.92239 | 0.00107 | 0.92453 | | | | |
| ncsr6e4st11_1_4 | 100 | 36555 | 36555 | 8257 | 5.90 | 1.0E-03 | 0.91834 | 0.00126 | 0.92086 | | | | |
| ncsr6e4st11_1_5 | 100 | 36555 | 36555 | 8257 | 5.90 | 1.0E-02 | 0.92233 | 0.00111 | 0.92455 | | | | |
| ncsr6e4st11_1_6 | 100 | 36555 | 36555 | 8257 | 5.90 | 1.0E-01 | 0.92584 | 0.00123 | 0.92830 | | | | |
| ncsr6e4st11_1_8 | 100 | 36555 | 36555 | 8257 | 5.90 | 3.0E-01 | 0.93741 | 0.00125 | 0.93990 | | | | |
| ncsr6e4st11_1_15 | 100 | 36555 | 36555 | 8257 | 5.90 | 1.0E+00 | 0.97010 | 0.00114 | 0.97238 | | | | |
| | | | | | | | | | | | | | |
| ncsr73st11_1_1 | 100 | 36555 | 36555 | 8257 | 5.90 | 1.0E-20 | 0.92144 | 0.00127 | 0.92399 | | | | |
| ncsr73st11_1_2 | 100 | 36555 | 36555 | 8257 | 5.90 | 1.0E-05 | 0.92591 | 0.00108 | 0.92808 | | | | |
| ncsr73st11_1_3 | 100 | 36555 | 36555 | 8257 | 5.90 | 1.0E-04 | 0.92106 | 0.00121 | 0.92348 | | | | |
| ncsr73st11_1_4 | 100 | 36555 | 36555 | 8257 | 5.90 | 1.0E-03 | 0.92326 | 0.00122 | 0.92570 | | | | |
| ncsr73st11_1_5 | 100 | 36555 | 36555 | 8257 | 5.90 | 1.0E-02 | 0.92213 | 0.00113 | 0.92439 | | | | |
| ncsr73st11_1_6 | 100 | 36555 | 36555 | 8257 | 5.90 | 1.0E-01 | 0.92784 | 0.00111 | 0.93007 | | | | |
| ncsr73st11_1_8 | 100 | 36555 | 36555 | 8257 | 5.90 | 3.0E-01 | 0.93898 | 0.00115 | 0.94128 | | | | |
| ncsr73st11_1_15 | 100 | 36555 | 36555 | 8257 | 5.90 | 1.0E+00 | 0.96854 | 0.00128 | 0.97110 | | | | |
| | | | | | | | | | | | | | |
| ncsr6st11_1_2_15 | 100 | 43865 | 43865 | 7869 | 4.68 | 1.0E+00 | 1.01197 | 0.00132 | 1.01461 | | | | |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | | |
| ncsr5est11_2_1_1 | 100 | 18277 | 18277 | 8613 | 12.30 | 1.0E-20 | 0.68597 | 0.00122 | 0.68841 | hcsr5est12_2_1_1 | 0.68926 | 0.00101 | 0.69128 |
| ncsr5est11_2_1_2 | 100 | 18277 | 18277 | 8613 | 12.30 | 1.0E-05 | 0.68486 | 0.00101 | 0.68688 | hcsr5est12_2_1_2 | 0.68645 | 0.00110 | 0.68866 |
| ncsr5est11_2_1_3 | 100 | 18277 | 18277 | 8613 | 12.30 | 1.0E-04 | 0.68766 | 0.00128 | 0.69022 | hcsr5est12_2_1_3 | 0.68796 | 0.00105 | 0.69007 |
| ncsr5est11_2_1_4 | 100 | 18277 | 18277 | 8613 | 12.30 | 1.0E-03 | 0.68729 | 0.00120 | 0.68969 | hcsr5est12_2_1_4 | 0.68815 | 0.00098 | 0.69010 |
| ncsr5est11_2_1_5 | 100 | 18277 | 18277 | 8613 | 12.30 | 1.0E-02 | 0.68465 | 0.00128 | 0.68720 | hcsr5est12_2_1_5 | 0.69008 | 0.00097 | 0.69201 |
| ncsr5est11_2_1_6 | 100 | 18277 | 18277 | 8613 | 12.30 | 1.0E-01 | 0.68906 | 0.00105 | 0.69117 | hcsr5est12_2_1_6 | 0.69613 | 0.00117 | 0.69847 |

**Table 6.9.6-9. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in packaging calculation model**

| case name | enr | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncsr5est11_2_1_8 | 100 | 18277 | 18277 | 8613 | 12.30 | 3.0E-01 | 0.70289 | 0.00101 | 0.70491 | hcsr5est12_2_1_8 | 0.70357 | 0.00107 | 0.70571 |
| ncsr5est11_2_1_15 | 100 | 18277 | 18277 | 8613 | 12.30 | 1.0E+00 | 0.73412 | 0.00109 | 0.73629 | hcsr5est12_2_1_15 | 0.73557 | 0.00101 | 0.73759 |
| | | | | | | | | | | | | | |
| ncsr5st11_2_1_1 | 100 | 18277 | 18277 | 8613 | 12.30 | 1.0E-20 | 0.70896 | 0.00096 | 0.71087 | | | | |
| ncsr5st11_2_1_2 | 100 | 18277 | 18277 | 8613 | 12.30 | 1.0E-05 | 0.70901 | 0.00095 | 0.71092 | | | | |
| ncsr5st11_2_1_3 | 100 | 18277 | 18277 | 8613 | 12.30 | 1.0E-04 | 0.71109 | 0.00096 | 0.71300 | | | | |
| ncsr5st11_2_1_4 | 100 | 18277 | 18277 | 8613 | 12.30 | 1.0E-03 | 0.70980 | 0.00102 | 0.71184 | | | | |
| ncsr5st11_2_1_5 | 100 | 18277 | 18277 | 8613 | 12.30 | 1.0E-02 | 0.71089 | 0.00103 | 0.71294 | | | | |
| ncsr5st11_2_1_6 | 100 | 18277 | 18277 | 8613 | 12.30 | 1.0E-01 | 0.71505 | 0.00112 | 0.71729 | | | | |
| ncsr5st11_2_1_8 | 100 | 18277 | 18277 | 8613 | 12.30 | 3.0E-01 | 0.72364 | 0.00121 | 0.72605 | | | | |
| ncsr5st11_2_1_15 | 100 | 18277 | 18277 | 8613 | 12.30 | 1.0E+00 | 0.74773 | 0.00114 | 0.75001 | hcsr5st12_2_1_15 | 0.74885 | 0.00101 | 0.75087 |
| | | | | | | | | | | | | | |
| ncsr6st11_2_1_1 | 100 | 21933 | 21933 | 8419 | 10.02 | 1.0E-20 | 0.73305 | 0.00104 | 0.73514 | | | | |
| ncsr6st11_2_1_2 | 100 | 21933 | 21933 | 8419 | 10.02 | 1.0E-05 | 0.73284 | 0.00105 | 0.73494 | | | | |
| ncsr6st11_2_1_3 | 100 | 21933 | 21933 | 8419 | 10.02 | 1.0E-04 | 0.73419 | 0.00111 | 0.73641 | | | | |
| ncsr6st11_2_1_4 | 100 | 21933 | 21933 | 8419 | 10.02 | 1.0E-03 | 0.73339 | 0.00106 | 0.73551 | | | | |
| ncsr6st11_2_1_5 | 100 | 21933 | 21933 | 8419 | 10.02 | 1.0E-02 | 0.73282 | 0.00101 | 0.73484 | | | | |
| ncsr6st11_2_1_6 | 100 | 21933 | 21933 | 8419 | 10.02 | 1.0E-01 | 0.73962 | 0.00104 | 0.74170 | | | | |
| ncsr6st11_2_1_8 | 100 | 21933 | 21933 | 8419 | 10.02 | 3.0E-01 | 0.74981 | 0.00112 | 0.75206 | | | | |
| ncsr6st11_2_1_15 | 100 | 21933 | 21933 | 8419 | 10.02 | 1.0E+00 | 0.78295 | 0.00118 | 0.78531 | | | | |
| | | | | | | | | | | | | | |
| ncsr5est11_2_2_1 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-20 | 0.81441 | 0.00102 | 0.81646 | hcsr5est12_2_2_1 | 0.81949 | 0.00126 | 0.82202 |
| ncsr5est11_2_2_2 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-05 | 0.81751 | 0.00107 | 0.81966 | hcsr5est12_2_2_2 | 0.81765 | 0.00108 | 0.81981 |
| ncsr5est11_2_2_3 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-04 | 0.81443 | 0.00110 | 0.81664 | hcsr5est12_2_2_3 | 0.81691 | 0.00115 | 0.81922 |
| ncsr5est11_2_2_4 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-03 | 0.81628 | 0.00124 | 0.81876 | hcsr5est12_2_2_4 | 0.81854 | 0.00123 | 0.82100 |

**Table 6.9.6-9. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in packaging calculation model**

| case name | enr | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncsr5est11_2_2_5 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-02 | 0.81513 | 0.00118 | 0.81749 | hcsr5est12_2_2_5 | 0.81898 | 0.00104 | 0.82106 |
| ncsr5est11_2_2_6 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-01 | 0.82099 | 0.00114 | 0.82326 | hcsr5est12_2_2_6 | 0.82414 | 0.00111 | 0.82636 |
| ncsr5est11_2_2_8 | 100 | 36555 | 36555 | 7643 | 5.46 | 3.0E-01 | 0.83205 | 0.00109 | 0.83424 | hcsr5est12_2_2_8 | 0.83469 | 0.00107 | 0.83683 |
| ncsr5est11_2_2_15 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E+00 | 0.86471 | 0.00124 | 0.86719 | hcsr5est12_2_2_15 | 0.86591 | 0.00115 | 0.86822 |
| | | | | | | | | | | | | | |
| ncsr5st11_2_2_1 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-20 | 0.83654 | 0.00109 | 0.83872 | | | | |
| ncsr5st11_2_2_2 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-05 | 0.83389 | 0.00104 | 0.83597 | | | | |
| ncsr5st11_2_2_3 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-04 | 0.83615 | 0.00113 | 0.83841 | | | | |
| ncsr5st11_2_2_4 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-03 | 0.83524 | 0.00141 | 0.83806 | | | | |
| ncsr5st11_2_2_5 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-02 | 0.83580 | 0.00109 | 0.83797 | | | | |
| ncsr5st11_2_2_6 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-01 | 0.84206 | 0.00110 | 0.84426 | | | | |
| ncsr5st11_2_2_8 | 100 | 36555 | 36555 | 7643 | 5.46 | 3.0E-01 | 0.85011 | 0.00135 | 0.85281 | | | | |
| ncsr5st11_2_2_15 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E+00 | 0.87549 | 0.00131 | 0.87810 | hcsr5st12_2_2_15 | 0.87483 | 0.00116 | 0.87715 |
| | | | | | | | | | | | | | |
| ncsr6e4st11_2_1 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-20 | 0.83636 | 0.00110 | 0.83857 | | | | |
| ncsr6e4st11_2_2 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-05 | 0.83532 | 0.00112 | 0.83757 | | | | |
| ncsr6e4st11_2_3 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-04 | 0.83689 | 0.00118 | 0.83924 | | | | |
| ncsr6e4st11_2_4 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-03 | 0.83744 | 0.00114 | 0.83972 | | | | |
| ncsr6e4st11_2_5 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-02 | 0.83615 | 0.00122 | 0.83858 | | | | |
| ncsr6e4st11_2_6 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-01 | 0.84173 | 0.00127 | 0.84426 | | | | |
| ncsr6e4st11_2_8 | 100 | 36555 | 36555 | 7643 | 5.46 | 3.0E-01 | 0.84987 | 0.00113 | 0.85213 | | | | |
| ncsr6e4st11_2_15 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E+00 | 0.87722 | 0.00131 | 0.87984 | | | | |
| | | | | | | | | | | | | | |
| ncsr73st11_2_1 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-20 | 0.83665 | 0.00111 | 0.83887 | | | | |
| ncsr73st11_2_2 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-05 | 0.83570 | 0.00116 | 0.83801 | | | | |

**Table 6.9.6-9. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in packaging calculation model**

| case name | enr | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncsr73st11_2_3 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-04 | 0.83716 | 0.00115 | 0.83946 | | | | |
| ncsr73st11_2_4 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-03 | 0.83728 | 0.00117 | 0.83961 | | | | |
| ncsr73st11_2_5 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-02 | 0.83790 | 0.00116 | 0.84023 | | | | |
| ncsr73st11_2_6 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-01 | 0.84068 | 0.00120 | 0.84309 | | | | |
| ncsr73st11_2_8 | 100 | 36555 | 36555 | 7643 | 5.46 | 3.0E-01 | 0.84928 | 0.00106 | 0.85139 | | | | |
| ncsr73st11_2_15 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E+00 | 0.87257 | 0.00099 | 0.87455 | | | | |
| | | | | | | | | | | | | | |
| ncsr6st11_2_2_1 | 100 | 43865 | 43865 | 7256 | 4.32 | 1.0E-20 | 0.86427 | 0.00104 | 0.86636 | | | | |
| ncsr6st11_2_2_2 | 100 | 43865 | 43865 | 7256 | 4.32 | 1.0E-05 | 0.86386 | 0.00108 | 0.86601 | | | | |
| ncsr6st11_2_2_3 | 100 | 43865 | 43865 | 7256 | 4.32 | 1.0E-04 | 0.86637 | 0.00117 | 0.86870 | | | | |
| ncsr6st11_2_2_4 | 100 | 43865 | 43865 | 7256 | 4.32 | 1.0E-03 | 0.86498 | 0.00125 | 0.86747 | | | | |
| ncsr6st11_2_2_5 | 100 | 43865 | 43865 | 7256 | 4.32 | 1.0E-02 | 0.86541 | 0.00116 | 0.86773 | | | | |
| ncsr6st11_2_2_6 | 100 | 43865 | 43865 | 7256 | 4.32 | 1.0E-01 | 0.87070 | 0.00111 | 0.87292 | | | | |
| ncsr6st11_2_2_8 | 100 | 43865 | 43865 | 7256 | 4.32 | 3.0E-01 | 0.88148 | 0.00122 | 0.88392 | | | | |
| ncsr6st11_2_2_15 | 100 | 43865 | 43865 | 7256 | 4.32 | 1.0E+00 | 0.91478 | 0.00118 | 0.91713 | | | | |
| **content in flooded containment vessel, array packaging model for CSI=0.0** | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | **HAC** | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | |
| ncia5est11_1_1_8_3 | 100 | 18277 | 18277 | 9227 | 13.18 | 1.0E-04 | 0.92163 | 0.00126 | 0.92414 | hcia5est12_1_1_8_3 | 0.91941 | 0.00126 | 0.92194 |
| ncia5est11_1_1_7_3 | 95 | 18289 | 17374 | 9227 | 13.86 | 1.0E-04 | 0.90412 | 0.00109 | 0.90630 | hcia5est12_1_1_7_3 | 0.90066 | 0.00110 | 0.90285 |
| ncia5est11_1_1_5_3 | 90 | 18324 | 14659 | 9227 | 16.43 | 1.0E-04 | 0.85207 | 0.00110 | 0.85427 | hcia5est12_1_1_6_3 | 0.88401 | 0.00108 | 0.88616 |
| ncia5est11_1_1_4_3 | 80 | 18347 | 12843 | 9227 | 18.75 | 1.0E-04 | 0.81402 | 0.00108 | 0.81617 | hcia5est12_1_1_5_3 | 0.84983 | 0.00117 | 0.85217 |
| ncia5est11_1_1_6_3 | 70 | 18300 | 16470 | 9227 | 14.62 | 1.0E-04 | 0.88510 | 0.00118 | 0.88746 | hcia5est12_1_1_4_3 | 0.81368 | 0.00111 | 0.81590 |
| ncia5est11_1_1_3_3 | 60 | 18370 | 11022 | 9227 | 21.85 | 1.0E-04 | 0.77131 | 0.00109 | 0.77349 | hcia5est12_1_1_3_3 | 0.77296 | 0.00113 | 0.77523 |

**Table 6.9.6-9. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in packaging calculation model**

| case name | enr | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncia5est11_1_1_2_3 | 40 | 18417 | 7367 | 9227 | 32.69 | 1.0E-04 | 0.67736 | 0.00103 | 0.67943 | hcia5est12_1_1_2_3 | 0.67968 | 0.00108 | 0.68184 |
| ncia5est11_1_1_1_3 | 19 | 18466 | 3509 | 9227 | 68.64 | 1.0E-04 | 0.54780 | 0.00092 | 0.54964 | hcia5est12_1_1_1_3 | 0.54586 | 0.00117 | 0.54819 |
| | | | | | | | | | | | | | |
| ncia5st11_1_1_8_3 | 100 | 18277 | 18277 | 9227 | 13.18 | 1.0E-04 | 0.92611 | 0.00127 | 0.92865 | hcia5st12_1_1_8_3 | 0.92609 | 0.00110 | 0.92829 |
| ncia5st11_1_1_7_3 | 95 | 18289 | 17374 | 9227 | 13.86 | 1.0E-04 | 0.90538 | 0.00116 | 0.90769 | hcia5st12_1_1_7_3 | 0.90683 | 0.00113 | 0.90909 |
| ncia5st11_1_1_5_3 | 90 | 18324 | 14659 | 9227 | 16.43 | 1.0E-04 | 0.88586 | 0.00112 | 0.88811 | hcia5st12_1_1_6_3 | 0.88827 | 0.00110 | 0.89046 |
| ncia5st11_1_1_4_3 | 80 | 18347 | 12843 | 9227 | 18.75 | 1.0E-04 | 0.84871 | 0.00124 | 0.85119 | hcia5st12_1_1_5_3 | 0.85050 | 0.00113 | 0.85276 |
| ncia5st11_1_1_6_3 | 70 | 18300 | 16470 | 9227 | 14.62 | 1.0E-04 | 0.80834 | 0.00102 | 0.81037 | hcia5st12_1_1_4_3 | 0.80870 | 0.00112 | 0.81094 |
| ncia5st11_1_1_3_3 | 60 | 18370 | 11022 | 9227 | 21.85 | 1.0E-04 | 0.76467 | 0.00098 | 0.76663 | hcia5st12_1_1_3_3 | 0.76245 | 0.00105 | 0.76454 |
| ncia5st11_1_1_2_3 | 40 | 18417 | 7367 | 9227 | 32.69 | 1.0E-04 | 0.66040 | 0.00106 | 0.66252 | hcia5st12_1_1_2_3 | 0.65955 | 0.00097 | 0.66149 |
| ncia5st11_1_1_1_3 | 19 | 18466 | 3509 | 9227 | 68.64 | 1.0E-04 | 0.51929 | 0.00090 | 0.52109 | hcia5st12_1_1_1_3 | 0.51805 | 0.00084 | 0.51973 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | | |
| ncia5est11_2_1_8_3 | 100 | 18277 | 18277 | 8613 | 12.30 | 1.0E-04 | 0.80353 | 0.00113 | 0.80580 | hcia5est12_2_1_8_3 | 0.80594 | 0.00121 | 0.80835 |
| ncia5est11_2_1_7_3 | 95 | 18289 | 17374 | 8613 | 12.94 | 1.0E-04 | 0.78741 | 0.00118 | 0.78977 | hcia5est12_2_1_7_3 | 0.78684 | 0.00107 | 0.78898 |
| ncia5est11_2_1_6_3 | 90 | 18300 | 16470 | 8613 | 13.65 | 1.0E-04 | 0.77061 | 0.00112 | 0.77285 | hcia5est12_2_1_6_3 | 0.77268 | 0.00114 | 0.77496 |
| ncia5est11_2_1_5_3 | 80 | 18324 | 14659 | 8613 | 15.34 | 1.0E-04 | 0.73732 | 0.00118 | 0.73969 | hcia5est12_2_1_5_3 | 0.73645 | 0.00094 | 0.73834 |
| ncia5est11_2_1_4_3 | 70 | 18347 | 12843 | 8613 | 17.51 | 1.0E-04 | 0.70261 | 0.00108 | 0.70477 | hcia5est12_2_1_4_3 | 0.70418 | 0.00107 | 0.70631 |
| ncia5est11_2_1_3_3 | 60 | 18370 | 11022 | 8613 | 20.40 | 1.0E-04 | 0.66332 | 0.00094 | 0.66520 | hcia5est12_2_1_3_3 | 0.66396 | 0.00114 | 0.66624 |
| ncia5est11_2_1_2_3 | 40 | 18417 | 7367 | 8613 | 30.52 | 1.0E-04 | 0.57466 | 0.00097 | 0.57660 | hcia5est12_2_1_2_3 | 0.57526 | 0.00080 | 0.57687 |
| ncia5est11_2_1_1_3 | 19 | 18466 | 3509 | 8613 | 64.08 | 1.0E-04 | 0.45117 | 0.00082 | 0.45280 | hcia5est12_2_1_1_3 | 0.45114 | 0.00084 | 0.45281 |
| | | | | | | | | | | | | | |
| ncia70st11_2_8_3 | 100 | 25588 | 25588 | 8225 | 8.39 | 1.0E-04 | 0.91300 | 0.00104 | 0.91507 | hcia70st12_2_8_3 | 0.91329 | 0.00111 | 0.91551 |
| ncia70st11_2_7_3 | 95 | 25604 | 24324 | 8225 | 8.83 | 1.0E-04 | 0.89143 | 0.00108 | 0.89360 | hcia70st12_2_7_3 | 0.89210 | 0.00124 | 0.89457 |
| ncia70st11_2_6_3 | 90 | 25621 | 23059 | 8225 | 9.31 | 1.0E-04 | 0.87368 | 0.00108 | 0.87585 | hcia70st12_2_6_3 | 0.87198 | 0.00113 | 0.87425 |
| ncia70st11_2_5_3 | 80 | 25653 | 20522 | 8225 | 10.46 | 1.0E-04 | 0.83357 | 0.00110 | 0.83577 | hcia70st12_2_5_3 | 0.83150 | 0.00106 | 0.83362 |

**Table 6.9.6-9. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in packaging calculation model**

| case name | enr | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncia70st11_2_4_3 | 70 | 25686 | 17980 | 8225 | 11.94 | 1.0E-04 | 0.78606 | 0.00105 | 0.78816 | hcia70st12_2_4_3 | 0.78783 | 0.00099 | 0.78981 |
| ncia70st11_2_3_3 | 60 | 25718 | 15431 | 8225 | 13.91 | 1.0E-04 | 0.73820 | 0.00099 | 0.74017 | hcia70st12_2_3_3 | 0.73745 | 0.00100 | 0.73944 |
| ncia70st11_2_2_3 | 40 | 25784 | 10313 | 8225 | 20.82 | 1.0E-04 | 0.62591 | 0.00090 | 0.62771 | hcia70st12_2_2_3 | 0.62664 | 0.00107 | 0.62878 |
| ncia70st11_2_1_3 | 19 | 25853 | 4912 | 8225 | 43.71 | 1.0E-04 | 0.47179 | 0.00077 | 0.47333 | hcia70st12_2_1_3 | 0.47178 | 0.00086 | 0.47349 |
| | | | | | | | | | | | | | |
| ncia5est11_2_2_8_3 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-04 | 0.98202 | 0.00112 | 0.98425 | hcia5est12_2_2_8_3 | 0.98033 | 0.00111 | 0.98254 |
| ncia5est11_2_2_7_3 | 95 | 36578 | 34749 | 7643 | 5.74 | 1.0E-04 | 0.96108 | 0.00119 | 0.96346 | hcia5est12_2_2_7_3 | 0.96166 | 0.00113 | 0.96392 |
| ncia5est11_2_2_6_3 | 90 | 36601 | 32941 | 7643 | 6.06 | 1.0E-04 | 0.94424 | 0.00134 | 0.94692 | hcia5est12_2_2_6_3 | 0.94560 | 0.00118 | 0.94796 |
| ncia5est11_2_2_5_3 | 80 | 36647 | 29318 | 7643 | 6.80 | 1.0E-04 | 0.90628 | 0.00109 | 0.90846 | hcia5est12_2_2_5_3 | 0.90763 | 0.00117 | 0.90997 |
| ncia5est11_2_2_4_3 | 70 | 36694 | 25686 | 7643 | 7.77 | 1.0E-04 | 0.86606 | 0.00104 | 0.86814 | hcia5est12_2_2_4_3 | 0.86855 | 0.00104 | 0.87064 |
| ncia5est11_2_2_3_3 | 60 | 36740 | 22044 | 7643 | 9.05 | 1.0E-04 | 0.82451 | 0.00098 | 0.82647 | hcia5est12_2_2_3_3 | 0.82536 | 0.00115 | 0.82767 |
| ncia5est11_2_2_2_3 | 40 | 36834 | 14734 | 7643 | 13.54 | 1.0E-04 | 0.72349 | 0.00093 | 0.72535 | hcia5est12_2_2_2_3 | 0.72285 | 0.00114 | 0.72513 |
| ncia5est11_2_2_1_3 | 19 | 36932 | 7017 | 7643 | 28.43 | 1.0E-04 | 0.58171 | 0.00100 | 0.58370 | hcia5est12_2_2_1_3 | 0.58235 | 0.00096 | 0.58427 |
| | | | | | | | | | | | | | |
| ncia5st11_2_2_8_3 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-04 | 0.97720 | 0.00133 | 0.97986 | hcia5st12_2_2_8_3 | 0.97562 | 0.00123 | 0.97807 |
| ncia5st11_2_2_7_3 | 95 | 36578 | 34749 | 7643 | 5.74 | 1.0E-04 | 0.95854 | 0.00105 | 0.96064 | hcia5st12_2_2_7_3 | 0.95594 | 0.00097 | 0.95789 |
| ncia5st11_2_2_6_3 | 90 | 36601 | 32941 | 7643 | 6.06 | 1.0E-04 | 0.93619 | 0.00132 | 0.93883 | hcia5st12_2_2_6_3 | 0.93579 | 0.00110 | 0.93800 |
| ncia5st11_2_2_5_3 | 80 | 36647 | 29318 | 7643 | 6.80 | 1.0E-04 | 0.90011 | 0.00117 | 0.90244 | hcia5st12_2_2_5_3 | 0.89786 | 0.00154 | 0.90095 |
| ncia5st11_2_2_4_3 | 70 | 36694 | 25686 | 7643 | 7.77 | 1.0E-04 | 0.85499 | 0.00102 | 0.85703 | hcia5st12_2_2_4_3 | 0.85363 | 0.00119 | 0.85601 |
| ncia5st11_2_2_3_3 | 60 | 36740 | 22044 | 7643 | 9.05 | 1.0E-04 | 0.80868 | 0.00116 | 0.81101 | hcia5st12_2_2_3_3 | 0.80882 | 0.00105 | 0.81091 |
| ncia5st11_2_2_2_3 | 40 | 36834 | 14734 | 7643 | 13.54 | 1.0E-04 | 0.70077 | 0.00098 | 0.70274 | hcia5st12_2_2_2_3 | 0.70205 | 0.00105 | 0.70415 |
| ncia5st11_2_2_1_3 | 19 | 36932 | 7017 | 7643 | 28.43 | 1.0E-04 | 0.55139 | 0.00095 | 0.55330 | hcia5st12_2_2_1_3 | 0.55187 | 0.00101 | 0.55389 |

**Table 6.9.6-9. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in packaging calculation model**

| case name | enr | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **content in flooded containment vessel, array packaging model for CSI=0.4** | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | **HAC** | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | |
| ncf15est11_1_1_8_3 | 100 | 18277 | 18277 | 9227 | 13.18 | 1.0E-04 | 0.87707 | 0.00119 | 0.87944 | hcf25est12_1_1_8_3 | 0.86992 | 0.00106 | 0.87204 |
| ncf15est11_1_1_7_3 | 95 | 18289 | 17374 | 9227 | 13.86 | 1.0E-04 | 0.86115 | 0.00120 | 0.86354 | hcf25est12_1_1_7_3 | 0.85401 | 0.00126 | 0.85652 |
| ncf15est11_1_1_6_3 | 90 | 18300 | 16470 | 9227 | 14.62 | 1.0E-04 | 0.84672 | 0.00112 | 0.84896 | hcf25est12_1_1_6_3 | 0.83451 | 0.00102 | 0.83656 |
| ncf15est11_1_1_5_3 | 80 | 18324 | 14659 | 9227 | 16.43 | 1.0E-04 | 0.81108 | 0.00109 | 0.81327 | hcf25est12_1_1_5_3 | 0.80144 | 0.00107 | 0.80358 |
| ncf15est11_1_1_4_3 | 70 | 18347 | 12843 | 9227 | 18.75 | 1.0E-04 | 0.77287 | 0.00112 | 0.77510 | hcf25est12_1_1_4_3 | 0.76516 | 0.00111 | 0.76739 |
| ncf15est11_1_1_3_3 | 60 | 18370 | 11022 | 9227 | 21.85 | 1.0E-04 | 0.73211 | 0.00114 | 0.73440 | hcf25est12_1_1_3_3 | 0.72484 | 0.00118 | 0.72719 |
| ncf15est11_1_1_2_3 | 40 | 18417 | 7367 | 9227 | 32.69 | 1.0E-04 | 0.64270 | 0.00105 | 0.64480 | hcf25est12_1_1_2_3 | 0.63366 | 0.00107 | 0.63580 |
| ncf15est11_1_1_1_3 | 19 | 18466 | 3509 | 9227 | 68.64 | 1.0E-04 | 0.51398 | 0.00088 | 0.51573 | hcf25est12_1_1_1_3 | 0.51052 | 0.00094 | 0.51241 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | | |
| ncf15est11_2_1_8_3 | 100 | 18277 | 18277 | 8613 | 12.30 | 1.0E-04 | 0.76015 | 0.00112 | 0.76239 | hcf25est12_2_1_8_3 | 0.75353 | 0.00102 | 0.75558 |
| ncf15est11_2_1_7_3 | 95 | 18289 | 17374 | 8613 | 12.94 | 1.0E-04 | 0.74428 | 0.00129 | 0.74686 | hcf25est12_2_1_7_3 | 0.73938 | 0.00109 | 0.74156 |
| ncf15est11_2_1_6_3 | 90 | 18300 | 16470 | 8613 | 13.65 | 1.0E-04 | 0.72783 | 0.00107 | 0.72998 | hcf25est12_2_1_6_3 | 0.72401 | 0.00105 | 0.72611 |
| ncf15est11_2_1_5_3 | 80 | 18324 | 14659 | 8613 | 15.34 | 1.0E-04 | 0.69813 | 0.00098 | 0.70009 | hcf25est12_2_1_5_3 | 0.69017 | 0.00089 | 0.69195 |
| ncf15est11_2_1_4_3 | 70 | 18347 | 12843 | 8613 | 17.51 | 1.0E-04 | 0.66593 | 0.00098 | 0.66789 | hcf25est12_2_1_4_3 | 0.65691 | 0.00113 | 0.65916 |
| ncf15est11_2_1_3_3 | 60 | 18370 | 11022 | 8613 | 20.40 | 1.0E-04 | 0.62541 | 0.00096 | 0.62733 | hcf25est12_2_1_3_3 | 0.61903 | 0.00111 | 0.62125 |
| ncf15est11_2_1_2_3 | 40 | 18417 | 7367 | 8613 | 30.52 | 1.0E-04 | 0.54139 | 0.00091 | 0.54320 | hcf25est12_2_1_2_3 | 0.53450 | 0.00087 | 0.53625 |
| ncf15est11_2_1_1_3 | 19 | 18466 | 3509 | 8613 | 64.08 | 1.0E-04 | 0.42329 | 0.00080 | 0.42489 | hcf25est12_2_1_1_3 | 0.41671 | 0.00077 | 0.41825 |
| | | | | | | | | | | | | | |
| ncf15est11_2_2_8_3 | 100 | 36555 | 36555 | 7643 | 5.46 | 1.0E-04 | 0.93621 | 0.00109 | 0.93839 | hcf25est12_2_2_8_3 | 0.92186 | 0.00104 | 0.92394 |
| ncf15est11_2_2_7_3 | 95 | 36578 | 34749 | 7643 | 5.74 | 1.0E-04 | 0.91732 | 0.00132 | 0.91995 | hcf25est12_2_2_7_3 | 0.90286 | 0.00137 | 0.90560 |
| ncf15est11_2_2_6_3 | 90 | 36601 | 32941 | 7643 | 6.06 | 1.0E-04 | 0.89754 | 0.00118 | 0.89990 | hcf25est12_2_2_6_3 | 0.88774 | 0.00119 | 0.89013 |
| ncf15est11_2_2_5_3 | 80 | 36647 | 29318 | 7643 | 6.80 | 1.0E-04 | 0.86210 | 0.00109 | 0.86428 | hcf25est12_2_2_5_3 | 0.85335 | 0.00111 | 0.85557 |

**Table 6.9.6-9. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in packaging calculation model**

| case name | enr | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncf15est11_2_2_4_3 | 70 | 36694 | 25686 | 7643 | 7.77 | 1.0E-04 | 0.82389 | 0.00121 | 0.82631 | hcf25est12_2_2_4_3 | 0.81165 | 0.00110 | 0.81386 |
| ncf15est11_2_2_3_3 | 60 | 36740 | 22044 | 7643 | 9.05 | 1.0E-04 | 0.78278 | 0.00120 | 0.78519 | hcf25est12_2_2_3_3 | 0.77147 | 0.00114 | 0.77375 |
| ncf15est11_2_2_2_3 | 40 | 36834 | 14734 | 7643 | 13.54 | 1.0E-04 | 0.68461 | 0.00116 | 0.68692 | hcf25est12_2_2_2_3 | 0.67454 | 0.00112 | 0.67679 |
| ncf15est11_2_2_1_3 | 19 | 36932 | 7017 | 7643 | 28.43 | 1.0E-04 | 0.54624 | 0.00099 | 0.54823 | hcf25est12_2_2_1_3 | 0.53779 | 0.00105 | 0.53989 |

**Table 6.9.6-10. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **metal as 1-in. cubes, flooded containment vessel, reflected** | | | | | | | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | |
| cvr3sqa_36_1_8_15 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E+00 | 0.93455 | 0.00107 | 0.93668 |
| cvr3sqa_36_1_7_15 | 0.0 | 95 | 35164 | 33406 | 8332 | 6.51 | 1.0E+00 | 0.91663 | 0.00128 | 0.91920 |
| cvr3sqa_36_1_6_15 | 0.0 | 90 | 35186 | 31667 | 8332 | 6.87 | 1.0E+00 | 0.90133 | 0.00123 | 0.90379 |
| cvr3sqa_36_1_5_15 | 0.0 | 80 | 35230 | 28184 | 8332 | 7.72 | 1.0E+00 | 0.87330 | 0.00119 | 0.87567 |
| cvr3sqa_36_1_4_15 | 0.0 | 70 | 35275 | 24693 | 8332 | 8.81 | 1.0E+00 | 0.84424 | 0.00113 | 0.84650 |
| cvr3sqa_36_1_3_15 | 0.0 | 60 | 35320 | 21192 | 8332 | 10.26 | 1.0E+00 | 0.81162 | 0.00124 | 0.81410 |
| cvr3sqa_36_1_2_15 | 0.0 | 40 | 35410 | 14164 | 8332 | 15.35 | 1.0E+00 | 0.73700 | 0.00098 | 0.73896 |
| cvr3sqa_36_1_1_15 | 0.0 | 19 | 35505 | 6746 | 8332 | 32.24 | 1.0E+00 | 0.63755 | 0.00119 | 0.63992 |
| | | | | | | | | | | |
| cvr3sqa_36_1_8_1 | 0.0 | 100 | 35142 | 35142 | 0 | 0.00 | 1.0E-20 | 0.78442 | 0.00112 | 0.78667 |
| cvr3sqa_36_1_8_6 | 0.0 | 100 | 35142 | 35142 | 833 | 0.62 | 1.0E-01 | 0.79134 | 0.00116 | 0.79366 |
| cvr3sqa_36_1_8_7 | 0.0 | 100 | 35142 | 35142 | 1666 | 1.24 | 2.0E-01 | 0.80350 | 0.00113 | 0.80577 |

**Table 6.9.6-10. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| cvr3sqa_36_1_8_8 | 0.0 | 100 | 35142 | 35142 | 2500 | 1.86 | 3.0E-01 | 0.81548 | 0.00107 | 0.81761 |
| cvr3sqa_36_1_8_9 | 0.0 | 100 | 35142 | 35142 | 3333 | 2.48 | 4.0E-01 | 0.83048 | 0.00122 | 0.83293 |
| cvr3sqa_36_1_8_10 | 0.0 | 100 | 35142 | 35142 | 4166 | 3.09 | 5.0E-01 | 0.84727 | 0.00122 | 0.84971 |
| cvr3sqa_36_1_8_11 | 0.0 | 100 | 35142 | 35142 | 4999 | 3.71 | 6.0E-01 | 0.86174 | 0.00123 | 0.86420 |
| cvr3sqa_36_1_8_12 | 0.0 | 100 | 35142 | 35142 | 5832 | 4.33 | 7.0E-01 | 0.87977 | 0.00118 | 0.88213 |
| cvr3sqa_36_1_8_13 | 0.0 | 100 | 35142 | 35142 | 6666 | 4.95 | 8.0E-01 | 0.89818 | 0.00110 | 0.90037 |
| cvr3sqa_36_1_8_14 | 0.0 | 100 | 35142 | 35142 | 7499 | 5.57 | 9.0E-01 | 0.91611 | 0.00118 | 0.91846 |
| cvr3sqa_36_1_8_15 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E+00 | 0.93455 | 0.00107 | 0.93668 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | |
| cvr3sqa_36_2_8_15 | 1.4 | 100 | 35142 | 35142 | 7719 | 5.73 | 1.0E+00 | 0.85151 | 0.00123 | 0.85397 |
| cvr3sqa_36_2_7_15 | 1.4 | 95 | 35164 | 33406 | 7719 | 6.03 | 1.0E+00 | 0.83521 | 0.00123 | 0.83766 |
| cvr3sqa_36_2_6_15 | 1.4 | 90 | 35186 | 31667 | 7719 | 6.36 | 1.0E+00 | 0.82166 | 0.00125 | 0.82415 |
| cvr3sqa_36_2_5_15 | 1.4 | 80 | 35230 | 28184 | 7719 | 7.15 | 1.0E+00 | 0.78928 | 0.00112 | 0.79152 |
| cvr3sqa_36_2_4_15 | 1.4 | 70 | 35275 | 24693 | 7719 | 8.16 | 1.0E+00 | 0.75994 | 0.00113 | 0.76220 |
| cvr3sqa_36_2_3_15 | 1.4 | 60 | 35320 | 21192 | 7719 | 9.51 | 1.0E+00 | 0.72673 | 0.00112 | 0.72898 |
| cvr3sqa_36_2_2_15 | 1.4 | 40 | 35410 | 14164 | 7719 | 14.22 | 1.0E+00 | 0.65008 | 0.00102 | 0.65213 |
| cvr3sqa_36_2_1_15 | 1.4 | 19 | 35505 | 6746 | 7719 | 29.86 | 1.0E+00 | 0.54677 | 0.00102 | 0.54881 |
| **metal as lattice homogenized 1-in. cubes, flooded containment vessel, reflected** | | | | | | | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | |
| cvr3lha_36_1_8_1 | 0.0 | 100 | 35142 | 35142 | 0 | 0.00 | 1.0E-20 | 0.74814 | 0.00123 | 0.75060 |
| cvr3lha_36_1_8_6 | 0.0 | 100 | 35142 | 35142 | 833 | 0.62 | 1.0E-01 | 0.76415 | 0.00125 | 0.76665 |
| cvr3lha_36_1_8_7 | 0.0 | 100 | 35142 | 35142 | 1666 | 1.24 | 2.0E-01 | 0.77899 | 0.00102 | 0.78103 |
| cvr3lha_36_1_8_8 | 0.0 | 100 | 35142 | 35142 | 2500 | 1.86 | 3.0E-01 | 0.79660 | 0.00143 | 0.79946 |
| cvr3lha_36_1_8_9 | 0.0 | 100 | 35142 | 35142 | 3333 | 2.48 | 4.0E-01 | 0.81635 | 0.00113 | 0.81861 |

**Table 6.9.6-10. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| cvr3lha_36_1_8_10 | 0.0 | 100 | 35142 | 35142 | 4166 | 3.09 | 5.0E-01 | 0.83767 | 0.00109 | 0.83986 |
| cvr3lha_36_1_8_11 | 0.0 | 100 | 35142 | 35142 | 4999 | 3.71 | 6.0E-01 | 0.85716 | 0.00116 | 0.85949 |
| cvr3lha_36_1_8_12 | 0.0 | 100 | 35142 | 35142 | 5832 | 4.33 | 7.0E-01 | 0.88187 | 0.00114 | 0.88415 |
| cvr3lha_36_1_8_13 | 0.0 | 100 | 35142 | 35142 | 6666 | 4.95 | 8.0E-01 | 0.90182 | 0.00109 | 0.90399 |
| cvr3lha_36_1_8_14 | 0.0 | 100 | 35142 | 35142 | 7499 | 5.57 | 9.0E-01 | 0.92553 | 0.00148 | 0.92849 |
| cvr3lha_36_1_8_15 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E+00 | 0.94654 | 0.00126 | 0.94906 |
| | | | | | | | | | | |
| cvr3lha_36_1_8_15 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E+00 | 0.94654 | 0.00126 | 0.94906 |
| cvr3lha_36_1_7_15 | 0.0 | 95 | 35164 | 33406 | 8332 | 6.51 | 1.0E+00 | 0.93172 | 0.00115 | 0.93403 |
| cvr3lha_36_1_6_15 | 0.0 | 90 | 35186 | 31667 | 8332 | 6.87 | 1.0E+00 | 0.91744 | 0.00126 | 0.91995 |
| cvr3lha_36_1_5_15 | 0.0 | 80 | 35230 | 28184 | 8332 | 7.72 | 1.0E+00 | 0.89049 | 0.00113 | 0.89274 |
| cvr3lha_36_1_4_15 | 0.0 | 70 | 35275 | 24693 | 8332 | 8.81 | 1.0E+00 | 0.85930 | 0.00133 | 0.86196 |
| cvr3lha_36_1_3_15 | 0.0 | 60 | 35320 | 21192 | 8332 | 10.26 | 1.0E+00 | 0.82623 | 0.00131 | 0.82886 |
| cvr3lha_36_1_2_15 | 0.0 | 40 | 35410 | 14164 | 8332 | 15.35 | 1.0E+00 | 0.75317 | 0.00110 | 0.75536 |
| cvr3lha_36_1_1_15 | 0.0 | 19 | 35505 | 6746 | 8332 | 32.24 | 1.0E+00 | 0.65522 | 0.00102 | 0.65726 |
| | | | | | | | | | | |
| cvr3lha_36_1_8_15 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E+00 | 0.94654 | 0.00126 | 0.94906 |
| cvr3lha_35_1_8_15 | 0.0 | 100 | 34217 | 34217 | 8381 | 6.39 | 1.0E+00 | 0.94183 | 0.00106 | 0.94396 |
| cvr3lha_34_1_8_15 | 0.0 | 100 | 33292 | 33292 | 8430 | 6.61 | 1.0E+00 | 0.93673 | 0.00125 | 0.93922 |
| cvr3lha_33_1_8_15 | 0.0 | 100 | 32367 | 32367 | 8479 | 6.84 | 1.0E+00 | 0.95706 | 0.00123 | 0.95952 |
| cvr3lha_32_1_8_15 | 0.0 | 100 | 31442 | 31442 | 8528 | 7.08 | 1.0E+00 | 0.94986 | 0.00142 | 0.95271 |
| cvr3lha_31_1_8_15 | 0.0 | 100 | 30518 | 30518 | 8578 | 7.34 | 1.0E+00 | 0.94716 | 0.00118 | 0.94953 |
| cvr3lha_30_1_8_15 | 0.0 | 100 | 29593 | 29593 | 8627 | 7.61 | 1.0E+00 | 0.93908 | 0.00127 | 0.94162 |
| cvr3lha_29_1_8_15 | 0.0 | 100 | 28668 | 28668 | 8676 | 7.90 | 1.0E+00 | 0.93306 | 0.00126 | 0.93557 |

**Table 6.9.6-10. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| cvr3lha_28_1_8_15 | 0.0 | 100 | 27743 | 27743 | 8725 | 8.21 | 1.0E+00 | 0.93059 | 0.00137 | 0.93333 |
| cvr3lha_27_1_8_15 | 0.0 | 100 | 26818 | 26818 | 8774 | 8.54 | 1.0E+00 | 0.92502 | 0.00139 | 0.92780 |
| cvr3lha_26_1_8_15 | 0.0 | 100 | 25894 | 25894 | 8823 | 8.89 | 1.0E+00 | 0.91519 | 0.00145 | 0.91810 |
| cvr3lha_25_1_8_15 | 0.0 | 100 | 24969 | 24969 | 8872 | 9.27 | 1.0E+00 | 0.91200 | 0.00125 | 0.91451 |
| cvr3lha_24_1_8_15 | 0.0 | 100 | 23119 | 23119 | 8970 | 10.13 | 1.0E+00 | 0.92028 | 0.00106 | 0.92241 |
| cvr3lha_23_1_8_15 | 0.0 | 100 | 22195 | 22195 | 9019 | 10.61 | 1.0E+00 | 0.91201 | 0.00115 | 0.91430 |
| cvr3lha_22_1_8_15 | 0.0 | 100 | 21270 | 21270 | 9068 | 11.13 | 1.0E+00 | 0.90500 | 0.00138 | 0.90777 |
| cvr3lha_21_1_8_15 | 0.0 | 100 | 20345 | 20345 | 9117 | 11.70 | 1.0E+00 | 0.89763 | 0.00133 | 0.90030 |
| | | | | | | | | | | |
| cvr3lha_31_1_7_15 | 0.0 | 95 | 30537 | 29010 | 8578 | 7.72 | 1.0E+00 | 0.92875 | 0.00129 | 0.93134 |
| cvr3lha_30_1_7_15 | 0.0 | 95 | 29612 | 28131 | 8627 | 8.00 | 1.0E+00 | 0.92618 | 0.00111 | 0.92840 |
| cvr3lha_29_1_7_15 | 0.0 | 95 | 28686 | 27252 | 8676 | 8.31 | 1.0E+00 | 0.91841 | 0.00107 | 0.92055 |
| cvr3lha_28_1_7_15 | 0.0 | 95 | 27761 | 26373 | 8725 | 8.63 | 1.0E+00 | 0.91075 | 0.00124 | 0.91322 |
| cvr3lha_27_1_7_15 | 0.0 | 95 | 26835 | 25494 | 8774 | 8.98 | 1.0E+00 | 0.90920 | 0.00117 | 0.91153 |
| | | | | | | | | | | |
| cvr3lha_33_1_6_15 | 0.0 | 90 | 32408 | 29167 | 8479 | 7.59 | 1.0E+00 | 0.92553 | 0.00126 | 0.92804 |
| cvr3lha_32_1_6_15 | 0.0 | 90 | 31482 | 28334 | 8528 | 7.86 | 1.0E+00 | 0.92000 | 0.00119 | 0.92238 |
| cvr3lha_31_1_6_15 | 0.0 | 90 | 30556 | 27501 | 8578 | 8.14 | 1.0E+00 | 0.91758 | 0.00132 | 0.92021 |
| | | | | | | | | | | |
| cvr3lha_36_1_5_15 | 0.0 | 80 | 35230 | 28184 | 8332 | 7.72 | 1.0E+00 | 0.89049 | 0.00113 | 0.89274 |
| cvr3lha_35_1_5_15 | 0.0 | 80 | 34303 | 27443 | 8381 | 7.97 | 1.0E+00 | 0.88496 | 0.00111 | 0.88719 |
| cvr3lha_34_1_5_15 | 0.0 | 80 | 33376 | 26701 | 8430 | 8.24 | 1.0E+00 | 0.88044 | 0.00106 | 0.88256 |
| cvr3lha_33_1_5_15 | 0.0 | 80 | 32449 | 25959 | 8479 | 8.53 | 1.0E+00 | 0.89355 | 0.00112 | 0.89579 |

**Table 6.9.6-10. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| cvr3lha_32_1_5_15 | 0.0 | 80 | 31522 | 25218 | 8528 | 8.83 | 1.0E+00 | 0.88961 | 0.00146 | 0.89253 |
| cvr3lha_31_1_5_15 | 0.0 | 80 | 30595 | 24476 | 8578 | 9.15 | 1.0E+00 | 0.88752 | 0.00141 | 0.89034 |
| | | | | | | | | | | |
| cvr3lha_36_1_4_15 | 0.0 | 70 | 35275 | 24693 | 8332 | 8.81 | 1.0E+00 | 0.85930 | 0.00133 | 0.86196 |
| cvr3lha_35_1_4_15 | 0.0 | 70 | 34347 | 24043 | 8381 | 9.10 | 1.0E+00 | 0.85473 | 0.00113 | 0.85698 |
| cvr3lha_34_1_4_15 | 0.0 | 70 | 33419 | 23393 | 8430 | 9.41 | 1.0E+00 | 0.85237 | 0.00129 | 0.85496 |
| cvr3lha_33_1_4_15 | 0.0 | 70 | 32490 | 22743 | 8479 | 9.73 | 1.0E+00 | 0.86299 | 0.00121 | 0.86542 |
| cvr3lha_32_1_4_15 | 0.0 | 70 | 31562 | 22093 | 8528 | 10.08 | 1.0E+00 | 0.85876 | 0.00132 | 0.86140 |
| cvr3lha_31_1_4_15 | 0.0 | 70 | 30634 | 21444 | 8578 | 10.44 | 1.0E+00 | 0.85471 | 0.00125 | 0.85720 |
| | | | | | | | | | | |
| cvr3lha_36_1_3_15 | 0.0 | 60 | 35320 | 21192 | 8332 | 10.26 | 1.0E+00 | 0.82623 | 0.00131 | 0.82886 |
| | | | | | | | | | | |
| cvr3lha_36_1_2_15 | 0.0 | 40 | 35410 | 14164 | 8332 | 15.35 | 1.0E+00 | 0.75317 | 0.00110 | 0.75536 |
| | | | | | | | | | | |
| cvr3lha_36_1_1_15 | 0.0 | 19 | 35505 | 6746 | 8332 | 32.24 | 1.0E+00 | 0.65522 | 0.00102 | 0.65726 |
| | | | | | | | | | | |
| cvr3lha_36_2_8_15 | 1.4 | 100 | 35142 | 35142 | 7719 | 5.73 | 1.0E+00 | 0.87286 | 0.00134 | 0.87554 |
| cvr3lha_36_2_7_15 | 1.4 | 95 | 35164 | 33406 | 7719 | 6.03 | 1.0E+00 | 0.85858 | 0.00109 | 0.86077 |
| cvr3lha_36_2_6_15 | 1.4 | 90 | 35186 | 31667 | 7719 | 6.36 | 1.0E+00 | 0.84459 | 0.00107 | 0.84672 |
| cvr3lha_36_2_5_15 | 1.4 | 80 | 35230 | 28184 | 7719 | 7.15 | 1.0E+00 | 0.81698 | 0.00127 | 0.81952 |
| cvr3lha_36_2_4_15 | 1.4 | 70 | 35275 | 24693 | 7719 | 8.16 | 1.0E+00 | 0.78484 | 0.00122 | 0.78727 |
| cvr3lha_36_2_3_15 | 1.4 | 60 | 35320 | 21192 | 7719 | 9.51 | 1.0E+00 | 0.75584 | 0.00105 | 0.75795 |
| cvr3lha_36_2_2_15 | 1.4 | 40 | 35410 | 14164 | 7719 | 14.22 | 1.0E+00 | 0.68360 | 0.00131 | 0.68623 |
| cvr3lha_36_2_1_15 | 1.4 | 19 | 35505 | 6746 | 7719 | 29.86 | 1.0E+00 | 0.58144 | 0.00104 | 0.58352 |

**Table 6.9.6-10. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| **metal as 1-in. cubes fully homogenized with water for flooded containment vessel, reflected** | | | | | | | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | |
| cvr3cha_36_1_8_1 | 0.0 | 100 | 35142 | 35142 | 0 | 0.00 | 1.0E-20 | 0.61068 | 0.00099 | 0.61266 |
| cvr3cha_36_1_8_6 | 0.0 | 100 | 35142 | 35142 | 833 | 0.62 | 1.0E-01 | 0.64671 | 0.00117 | 0.64905 |
| cvr3cha_36_1_8_7 | 0.0 | 100 | 35142 | 35142 | 1666 | 1.24 | 2.0E-01 | 0.68117 | 0.00106 | 0.68329 |
| cvr3cha_36_1_8_8 | 0.0 | 100 | 35142 | 35142 | 2500 | 1.86 | 3.0E-01 | 0.71931 | 0.00121 | 0.72174 |
| cvr3cha_36_1_8_9 | 0.0 | 100 | 35142 | 35142 | 3333 | 2.48 | 4.0E-01 | 0.75910 | 0.00125 | 0.76160 |
| cvr3cha_36_1_8_10 | 0.0 | 100 | 35142 | 35142 | 4166 | 3.09 | 5.0E-01 | 0.79344 | 0.00123 | 0.79589 |
| cvr3cha_36_1_8_11 | 0.0 | 100 | 35142 | 35142 | 4999 | 3.71 | 6.0E-01 | 0.83513 | 0.00132 | 0.83777 |
| cvr3cha_36_1_8_12 | 0.0 | 100 | 35142 | 35142 | 5833 | 4.33 | 7.0E-01 | 0.87270 | 0.00117 | 0.87504 |
| cvr3cha_36_1_8_13 | 0.0 | 100 | 35142 | 35142 | 6666 | 4.95 | 8.0E-01 | 0.90988 | 0.00115 | 0.91219 |
| cvr3cha_36_1_8_14 | 0.0 | 100 | 35142 | 35142 | 7499 | 5.57 | 9.0E-01 | 0.94696 | 0.00136 | 0.94968 |
| cvr3cha_36_1_8_15 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E+00 | 0.98062 | 0.00128 | 0.98318 |
| | | | | | | | | | | |
| cvr3cha_36_1_8_15 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E+00 | 0.98062 | 0.00128 | 0.98318 |
| cvr3cha_36_1_7_15 | 0.0 | 95 | 35164 | 33406 | 8332 | 6.51 | 1.0E+00 | 0.96729 | 0.00134 | 0.96997 |
| cvr3cha_36_1_6_15 | 0.0 | 90 | 35186 | 31667 | 8332 | 6.87 | 1.0E+00 | 0.95443 | 0.00144 | 0.95731 |
| cvr3cha_36_1_5_15 | 0.0 | 80 | 35231 | 28184 | 8332 | 7.72 | 1.0E+00 | 0.93639 | 0.00114 | 0.93867 |
| cvr3cha_36_1_4_15 | 0.0 | 70 | 35275 | 24693 | 8332 | 8.81 | 1.0E+00 | 0.91729 | 0.00125 | 0.91978 |
| cvr3cha_36_1_3_15 | 0.0 | 60 | 35320 | 21192 | 8332 | 10.26 | 1.0E+00 | 0.89768 | 0.00137 | 0.90042 |
| cvr3cha_36_1_2_15 | 0.0 | 40 | 35410 | 14164 | 8332 | 15.35 | 1.0E+00 | 0.85347 | 0.00132 | 0.85612 |
| cvr3cha_36_1_1_15 | 0.0 | 19 | 35505 | 6746 | 8332 | 32.24 | 1.0E+00 | 0.78799 | 0.00132 | 0.79064 |
| | | | | | | | | | | |

**Table 6.9.6-10. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| cvr3cha_9_1_8_15 | 0.0 | 100 | 8323 | 8323 | 9755 | 30.59 | 1.0E+00 | 0.92411 | 0.00165 | 0.92741 |
| cvr3cha_8_1_8_15 | 0.0 | 100 | 7398 | 7398 | 9804 | 34.59 | 1.0E+00 | 0.91970 | 0.00146 | 0.92263 |
| cvr3cha_7_1_8_15 | 0.0 | 100 | 6473 | 6473 | 9854 | 39.73 | 1.0E+00 | 0.91473 | 0.00144 | 0.91762 |
| cvr3cha_6_1_8_15 | 0.0 | 100 | 5549 | 5549 | 9903 | 46.58 | 1.0E+00 | 0.90826 | 0.00144 | 0.91114 |
| cvr3cha_5_1_8_15 | 0.0 | 100 | 4624 | 4624 | 9952 | 56.17 | 1.0E+00 | 0.89884 | 0.00156 | 0.90196 |
| cvr3cha_4_1_8_15 | 0.0 | 100 | 3699 | 3699 | 10001 | 70.56 | 1.0E+00 | 0.88830 | 0.00130 | 0.89090 |
| cvr3cha_3_1_8_15 | 0.0 | 100 | 2774 | 2774 | 10050 | 94.55 | 1.0E+00 | 0.86596 | 0.00144 | 0.86884 |
| cvr3cha_2_1_8_15 | 0.0 | 100 | 1850 | 1850 | 10099 | 142.5 | 1.0E+00 | 0.82987 | 0.00147 | 0.83281 |
| cvr3cha_1_1_8_15 | 0.0 | 100 | 925 | 925 | 10148 | 286.4 | 1.0E+00 | 0.73830 | 0.00123 | 0.74075 |
| | | | | | | | | | | |
| cvr3cha_13_1_7_15 | 0.0 | 95 | 12955 | 12307 | 9510 | 20.17 | 1.0E+00 | 0.92721 | 0.00146 | 0.93013 |
| cvr3cha_12_1_7_15 | 0.0 | 95 | 11104 | 10549 | 9608 | 23.77 | 1.0E+00 | 0.92145 | 0.00152 | 0.92449 |
| cvr3cha_11_1_7_15 | 0.0 | 95 | 10179 | 9670 | 9657 | 26.07 | 1.0E+00 | 0.92161 | 0.00139 | 0.92439 |
| cvr3cha_10_1_7_15 | 0.0 | 95 | 9254 | 8791 | 9706 | 28.82 | 1.0E+00 | 0.91850 | 0.00146 | 0.92142 |
| cvr3cha_9_1_7_15 | 0.0 | 95 | 8328 | 7912 | 9755 | 32.18 | 1.0E+00 | 0.91420 | 0.00139 | 0.91699 |
| cvr3cha_8_1_7_15 | 0.0 | 95 | 7403 | 7033 | 9804 | 36.39 | 1.0E+00 | 0.91089 | 0.00129 | 0.91347 |
| cvr3cha_7_1_7_15 | 0.0 | 95 | 6478 | 6154 | 9854 | 41.79 | 1.0E+00 | 0.90510 | 0.00141 | 0.90792 |
| cvr3cha_6_1_7_15 | 0.0 | 95 | 5552 | 5275 | 9903 | 49.00 | 1.0E+00 | 0.89876 | 0.00141 | 0.90158 |
| cvr3cha_5_1_7_15 | 0.0 | 95 | 4627 | 4396 | 9952 | 59.09 | 1.0E+00 | 0.89248 | 0.00137 | 0.89522 |
| cvr3cha_4_1_7_15 | 0.0 | 95 | 3701 | 3516 | 10001 | 74.23 | 1.0E+00 | 0.87921 | 0.00123 | 0.88166 |
| cvr3cha_3_1_7_15 | 0.0 | 95 | 2776 | 2637 | 10050 | 99.46 | 1.0E+00 | 0.85895 | 0.00143 | 0.86181 |
| cvr3cha_2_1_7_15 | 0.0 | 95 | 1851 | 1758 | 10099 | 149.92 | 1.0E+00 | 0.82077 | 0.00151 | 0.82380 |
| cvr3cha_1_1_7_15 | 0.0 | 95 | 925 | 879 | 10148 | 301.30 | 1.0E+00 | 0.72727 | 0.00130 | 0.72988 |
| | | | | | | | | | | |

**Table 6.9.6-10. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| cvr3cha_17_1_6_15 | 0.0 | 90 | 16667 | 15000 | 9314 | 16.21 | 1.0E+00 | 0.92297 | 0.00142 | 0.92580 |
| cvr3cha_16_1_6_15 | 0.0 | 90 | 15741 | 14167 | 9363 | 17.25 | 1.0E+00 | 0.92154 | 0.00140 | 0.92434 |
| cvr3cha_15_1_6_15 | 0.0 | 90 | 14815 | 13334 | 9412 | 18.42 | 1.0E+00 | 0.92402 | 0.00131 | 0.92664 |
| cvr3cha_14_1_6_15 | 0.0 | 90 | 13889 | 12500 | 9461 | 19.75 | 1.0E+00 | 0.91968 | 0.00162 | 0.92291 |
| cvr3cha_13_1_6_15 | 0.0 | 90 | 12963 | 11667 | 9510 | 21.28 | 1.0E+00 | 0.91675 | 0.00152 | 0.91979 |
| | | | | | | | | | | |
| cvr3cha_28_1_5_15 | 0.0 | 80 | 27814 | 22251 | 8725 | 10.23 | 1.0E+00 | 0.92438 | 0.00137 | 0.92712 |
| cvr3cha_27_1_5_15 | 0.0 | 80 | 26886 | 21509 | 8774 | 10.65 | 1.0E+00 | 0.92213 | 0.00147 | 0.92507 |
| cvr3cha_26_1_5_15 | 0.0 | 80 | 25959 | 20767 | 8823 | 11.09 | 1.0E+00 | 0.92209 | 0.00165 | 0.92540 |
| cvr3cha_25_1_5_15 | 0.0 | 80 | 24105 | 19284 | 8921 | 12.07 | 1.0E+00 | 0.91935 | 0.00157 | 0.92249 |
| cvr3cha_24_1_5_15 | 0.0 | 80 | 23178 | 18542 | 8970 | 12.63 | 1.0E+00 | 0.91637 | 0.00132 | 0.91900 |
| cvr3cha_23_1_5_15 | 0.0 | 80 | 22251 | 17801 | 9019 | 13.22 | 1.0E+00 | 0.91519 | 0.00139 | 0.91798 |
| | | | | | | | | | | |
| cvr3cha_36_1_4_15 | 0.0 | 70 | 35275 | 24693 | 8332 | 8.81 | 1.0E+00 | 0.91729 | 0.00125 | 0.91978 |
| cvr3cha_35_1_4_15 | 0.0 | 70 | 34347 | 24043 | 8381 | 9.10 | 1.0E+00 | 0.91586 | 0.00125 | 0.91835 |
| cvr3cha_34_1_4_15 | 0.0 | 70 | 33419 | 23393 | 8430 | 9.41 | 1.0E+00 | 0.91481 | 0.00139 | 0.91758 |
| cvr3cha_33_1_4_15 | 0.0 | 70 | 32490 | 22743 | 8479 | 9.73 | 1.0E+00 | 0.91228 | 0.00128 | 0.91484 |
| cvr3cha_32_1_4_15 | 0.0 | 70 | 31562 | 22093 | 8529 | 10.08 | 1.0E+00 | 0.91196 | 0.00129 | 0.91454 |
| cvr3cha_31_1_4_15 | 0.0 | 70 | 30634 | 21444 | 8578 | 10.44 | 1.0E+00 | 0.90865 | 0.00139 | 0.91143 |
| | | | | | | | | | | |
| cvr3cha_36_1_3_15 | 0.0 | 60 | 35320 | 21192 | 8332 | 10.26 | 1.0E+00 | 0.89768 | 0.00137 | 0.90042 |
| cvr3cha_35_1_3_15 | 0.0 | 60 | 34391 | 20634 | 8381 | 10.60 | 1.0E+00 | 0.89413 | 0.00135 | 0.89683 |
| cvr3cha_34_1_3_15 | 0.0 | 60 | 33461 | 20077 | 8430 | 10.96 | 1.0E+00 | 0.89574 | 0.00118 | 0.89810 |
| cvr3cha_33_1_3_15 | 0.0 | 60 | 32532 | 19519 | 8479 | 11.34 | 1.0E+00 | 0.89333 | 0.00129 | 0.89591 |

**Table 6.9.6-10. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| cvr3cha_32_1_3_15 | 0.0 | 60 | 31602 | 18961 | 8529 | 11.74 | 1.0E+00 | 0.89469 | 0.00121 | 0.89710 |
| cvr3cha_31_1_3_15 | 0.0 | 60 | 30673 | 18404 | 8578 | 12.17 | 1.0E+00 | 0.89268 | 0.00145 | 0.89558 |
| | | | | | | | | | | |
| cvr3cha_36_1_2_15 | 0.0 | 40 | 35410 | 14164 | 8332 | 15.35 | 1.0E+00 | 0.85347 | 0.00132 | 0.85612 |
| cvr3cha_35_1_2_15 | 0.0 | 40 | 34478 | 13791 | 8381 | 15.86 | 1.0E+00 | 0.85471 | 0.00109 | 0.85690 |
| cvr3cha_34_1_2_15 | 0.0 | 40 | 33546 | 13419 | 8430 | 16.40 | 1.0E+00 | 0.85466 | 0.00125 | 0.85716 |
| cvr3cha_33_1_2_15 | 0.0 | 40 | 32614 | 13046 | 8479 | 16.96 | 1.0E+00 | 0.85311 | 0.00132 | 0.85575 |
| cvr3cha_32_1_2_15 | 0.0 | 40 | 31683 | 12673 | 8529 | 17.57 | 1.0E+00 | 0.85294 | 0.00136 | 0.85566 |
| cvr3cha_31_1_2_15 | 0.0 | 40 | 30751 | 12300 | 8578 | 18.20 | 1.0E+00 | 0.85042 | 0.00127 | 0.85295 |
| | | | | | | | | | | |
| cvr3cha_36_1_1_15 | 0.0 | 19 | 35505 | 6746 | 8332 | 32.24 | 1.0E+00 | 0.78799 | 0.00132 | 0.79064 |
| cvr3cha_35_1_1_15 | 0.0 | 19 | 34570 | 6568 | 8381 | 33.30 | 1.0E+00 | 0.78798 | 0.00132 | 0.79062 |
| cvr3cha_34_1_1_15 | 0.0 | 19 | 33636 | 6391 | 8430 | 34.43 | 1.0E+00 | 0.78692 | 0.00142 | 0.78976 |
| cvr3cha_33_1_1_15 | 0.0 | 19 | 32702 | 6213 | 8479 | 35.62 | 1.0E+00 | 0.78967 | 0.00115 | 0.79198 |
| cvr3cha_32_1_1_15 | 0.0 | 19 | 31767 | 6036 | 8529 | 36.88 | 1.0E+00 | 0.78868 | 0.00135 | 0.79138 |
| cvr3cha_31_1_1_15 | 0.0 | 19 | 30833 | 5858 | 8578 | 38.22 | 1.0E+00 | 0.78919 | 0.00118 | 0.79155 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | |
| cvr3cha_36_2_8_15 | 1.4 | 100 | 35142 | 35142 | 7719 | 5.73 | 1.0E+00 | 0.96066 | 0.00128 | 0.96321 |
| cvr3cha_36_2_7_15 | 1.4 | 95 | 35164 | 33406 | 7719 | 6.03 | 1.0E+00 | 0.94267 | 0.00127 | 0.94521 |
| cvr3cha_36_2_6_15 | 1.4 | 90 | 35186 | 31667 | 7719 | 6.36 | 1.0E+00 | 0.93250 | 0.00117 | 0.93484 |
| cvr3cha_36_2_5_15 | 1.4 | 80 | 35231 | 28184 | 7719 | 7.15 | 1.0E+00 | 0.91364 | 0.00126 | 0.91615 |
| cvr3cha_36_2_4_15 | 1.4 | 70 | 35275 | 24693 | 7719 | 8.16 | 1.0E+00 | 0.89707 | 0.00125 | 0.89957 |
| cvr3cha_36_2_3_15 | 1.4 | 60 | 35320 | 21192 | 7719 | 9.51 | 1.0E+00 | 0.87509 | 0.00121 | 0.87751 |

**Table 6.9.6-10. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| cvr3cha_36_2_2_15 | 1.4 | 40 | 35410 | 14164 | 7719 | 14.22 | 1.0E+00 | 0.82672 | 0.00135 | 0.82943 |
| cvr3cha_36_2_1_15 | 1.4 | 19 | 35505 | 6746 | 7719 | 29.86 | 1.0E+00 | 0.76024 | 0.00148 | 0.76320 |
| | | | | | | | | | | |
| cvr3cha_11_2_8_15 | 1.4 | 100 | 10173 | 10173 | 9044 | 23.20 | 1.0E+00 | 0.92383 | 0.00148 | 0.92679 |
| cvr3cha_10_2_8_15 | 1.4 | 100 | 9248 | 9248 | 9093 | 25.66 | 1.0E+00 | 0.91980 | 0.00132 | 0.92244 |
| cvr3cha_09_2_8_15 | 1.4 | 100 | 8323 | 8323 | 9142 | 28.67 | 1.0E+00 | 0.91510 | 0.00129 | 0.91768 |
| | | | | | | | | | | |
| cvr3cha_16_2_7_15 | 1.4 | 95 | 15731 | 14945 | 8749 | 15.28 | 1.0E+00 | 0.92275 | 0.00162 | 0.92599 |
| cvr3cha_15_2_7_15 | 1.4 | 95 | 14806 | 14066 | 8798 | 16.33 | 1.0E+00 | 0.92071 | 0.00155 | 0.92380 |
| cvr3cha_14_2_7_15 | 1.4 | 95 | 13880 | 13186 | 8847 | 17.51 | 1.0E+00 | 0.92004 | 0.00132 | 0.92268 |
| | | | | | | | | | | |
| cvr3cha_25_2_6_15 | 1.4 | 90 | 24075 | 21667 | 8308 | 10.01 | 1.0E+00 | 0.92554 | 0.00129 | 0.92813 |
| cvr3cha_24_2_6_15 | 1.4 | 90 | 23149 | 20834 | 8357 | 10.47 | 1.0E+00 | 0.92042 | 0.00132 | 0.92306 |
| cvr3cha_23_2_6_15 | 1.4 | 90 | 22223 | 20000 | 8406 | 10.97 | 1.0E+00 | 0.92148 | 0.00135 | 0.92419 |
| cvr3cha_22_2_6_15 | 1.4 | 90 | 21297 | 19167 | 8455 | 11.51 | 1.0E+00 | 0.91898 | 0.00142 | 0.92181 |

**Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **content in flooded containment vessel, single package reflected** | | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | | **HAC** | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | | |
| ncsrbmt11_36_1_1 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E-20 | 0.81144 | 0.00127 | 0.81397 | hcsrbmt12_36_1_1 | 0.81597 | 0.00140 | 0.81877 |
| ncsrbmt11_36_1_2 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E-05 | 0.81278 | 0.00143 | 0.81563 | hcsrbmt12_36_1_2 | 0.81496 | 0.00123 | 0.81741 |
| ncsrbmt11_36_1_3 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E-04 | 0.81066 | 0.00124 | 0.81314 | hcsrbmt12_36_1_3 | 0.81490 | 0.00149 | 0.81787 |
| ncsrbmt11_36_1_4 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E-03 | 0.81064 | 0.00142 | 0.81347 | hcsrbmt12_36_1_4 | 0.81512 | 0.00157 | 0.81826 |
| ncsrbmt11_36_1_5 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E-02 | 0.81069 | 0.00138 | 0.81346 | hcsrbmt12_36_1_5 | 0.81594 | 0.00126 | 0.81846 |
| ncsrbmt11_36_1_6 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E-01 | 0.81880 | 0.00126 | 0.82132 | hcsrbmt12_36_1_6 | 0.82255 | 0.00126 | 0.82507 |
| ncsrbmt11_36_1_8 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 3.0E-01 | 0.83502 | 0.00115 | 0.83732 | hcsrbmt12_36_1_8 | 0.83846 | 0.00125 | 0.84095 |
| ncsrbmt11_36_1_15 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E+00 | 0.88830 | 0.00122 | 0.89075 | hcsrbmt12_36_1_15 | 0.88841 | 0.00140 | 0.89122 |
| | | | | | | | | | | | | | | |
| ncsrbmt11_36_1_15 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E+00 | 0.88830 | 0.00122 | 0.89075 | | | | |
| ncsrbmt11_35_1_15 | 0.0 | 100 | 34217 | 34217 | 8381 | 6.39 | 1.0E+00 | 0.88662 | 0.00129 | 0.88921 | | | | |
| ncsrbmt11_34_1_15 | 0.0 | 100 | 33292 | 33292 | 8430 | 6.61 | 1.0E+00 | 0.88622 | 0.00119 | 0.88860 | | | | |
| ncsrbmt11_33_1_15 | 0.0 | 100 | 32367 | 32367 | 8479 | 6.84 | 1.0E+00 | 0.88175 | 0.00127 | 0.88429 | | | | |
| ncsrbmt11_32_1_15 | 0.0 | 100 | 31442 | 31442 | 8529 | 7.08 | 1.0E+00 | 0.88109 | 0.00124 | 0.88357 | | | | |
| ncsrbmt11_31_1_15 | 0.0 | 100 | 30518 | 30518 | 8578 | 7.34 | 1.0E+00 | 0.87995 | 0.00126 | 0.88247 | | | | |
| ncsrbmt11_30_1_15 | 0.0 | 100 | 29593 | 29593 | 8627 | 7.61 | 1.0E+00 | 0.87410 | 0.00144 | 0.87697 | | | | |
| ncsrbmt11_29_1_15 | 0.0 | 100 | 28668 | 28668 | 8676 | 7.90 | 1.0E+00 | 0.87385 | 0.00118 | 0.87621 | | | | |
| ncsrbmt11_28_1_15 | 0.0 | 100 | 27743 | 27743 | 8725 | 8.21 | 1.0E+00 | 0.87237 | 0.00119 | 0.87474 | | | | |
| ncsrbmt11_27_1_15 | 0.0 | 100 | 26819 | 26819 | 8774 | 8.54 | 1.0E+00 | 0.86800 | 0.00126 | 0.87053 | | | | |
| ncsrbmt11_26_1_15 | 0.0 | 100 | 25894 | 25894 | 8823 | 8.89 | 1.0E+00 | 0.86869 | 0.00123 | 0.87115 | | | | |
| ncsrbmt11_25_1_15 | 0.0 | 100 | 24969 | 24969 | 8872 | 9.27 | 1.0E+00 | 0.86558 | 0.00152 | 0.86862 | | | | |

**Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncsrbmt11_24_1_15 | 0.0 | 100 | 23119 | 23119 | 8970 | 10.13 | 1.0E+00 | 0.85827 | 0.00123 | 0.86074 | | | | |
| ncsrbmt11_23_1_15 | 0.0 | 100 | 22195 | 22195 | 9019 | 10.61 | 1.0E+00 | 0.85657 | 0.00134 | 0.85924 | | | | |
| ncsrbmt11_22_1_15 | 0.0 | 100 | 21270 | 21270 | 9068 | 11.13 | 1.0E+00 | 0.85373 | 0.00156 | 0.85686 | | | | |
| ncsrbmt11_21_1_15 | 0.0 | 100 | 20345 | 20345 | 9117 | 11.70 | 1.0E+00 | 0.85521 | 0.00126 | 0.85774 | | | | |
| ncsrbmt11_20_1_15 | 0.0 | 100 | 19420 | 19420 | 9166 | 12.32 | 1.0E+00 | 0.84989 | 0.00157 | 0.85303 | | | | |
| ncsrbmt11_19_1_15 | 0.0 | 100 | 18496 | 18496 | 9216 | 13.00 | 1.0E+00 | 0.85069 | 0.00155 | 0.85378 | | | | |
| ncsrbmt11_18_1_15 | 0.0 | 100 | 17571 | 17571 | 9265 | 13.76 | 1.0E+00 | 0.84676 | 0.00182 | 0.85039 | | | | |
| ncsrbmt11_17_1_15 | 0.0 | 100 | 16646 | 16646 | 9314 | 14.60 | 1.0E+00 | 0.84566 | 0.00147 | 0.84859 | | | | |
| ncsrbmt11_16_1_15 | 0.0 | 100 | 15721 | 15721 | 9363 | 15.54 | 1.0E+00 | 0.84458 | 0.00125 | 0.84708 | | | | |
| ncsrbmt11_15_1_15 | 0.0 | 100 | 14796 | 14796 | 9412 | 16.60 | 1.0E+00 | 0.83932 | 0.00148 | 0.84229 | | | | |
| ncsrbmt11_14_1_15 | 0.0 | 100 | 13872 | 13872 | 9461 | 17.80 | 1.0E+00 | 0.83752 | 0.00133 | 0.84019 | | | | |
| ncsrbmt11_13_1_15 | 0.0 | 100 | 12947 | 12947 | 9510 | 19.17 | 1.0E+00 | 0.83532 | 0.00151 | 0.83834 | | | | |
| ncsrbmt11_12_1_15 | 0.0 | 100 | 11097 | 11097 | 9608 | 22.60 | 1.0E+00 | 0.82792 | 0.00133 | 0.83057 | | | | |
| ncsrbmt11_11_1_15 | 0.0 | 100 | 10173 | 10173 | 9657 | 24.78 | 1.0E+00 | 0.82643 | 0.00127 | 0.82898 | | | | |
| ncsrbmt11_10_1_15 | 0.0 | 100 | 9248 | 9248 | 9706 | 27.39 | 1.0E+00 | 0.82649 | 0.00160 | 0.82968 | | | | |
| ncsrbmt11_9_1_15 | 0.0 | 100 | 8323 | 8323 | 9755 | 30.59 | 1.0E+00 | 0.81840 | 0.00140 | 0.82119 | | | | |
| ncsrbmt11_8_1_15 | 0.0 | 100 | 7398 | 7398 | 9804 | 34.59 | 1.0E+00 | 0.81808 | 0.00170 | 0.82148 | | | | |
| ncsrbmt11_7_1_15 | 0.0 | 100 | 6473 | 6473 | 9854 | 39.73 | 1.0E+00 | 0.81130 | 0.00152 | 0.81434 | | | | |
| ncsrbmt11_6_1_15 | 0.0 | 100 | 5549 | 5549 | 9903 | 46.58 | 1.0E+00 | 0.80480 | 0.00140 | 0.80761 | | | | |
| ncsrbmt11_5_1_15 | 0.0 | 100 | 4624 | 4624 | 9952 | 56.17 | 1.0E+00 | 0.79723 | 0.00124 | 0.79971 | | | | |
| ncsrbmt11_4_1_15 | 0.0 | 100 | 3699 | 3699 | 10001 | 70.56 | 1.0E+00 | 0.78533 | 0.00133 | 0.78799 | | | | |
| ncsrbmt11_3_1_15 | 0.0 | 100 | 2774 | 2774 | 10050 | 94.55 | 1.0E+00 | 0.76796 | 0.00152 | 0.77099 | | | | |
| ncsrbmt11_2_1_15 | 0.0 | 100 | 1850 | 1850 | 10099 | 142.51 | 1.0E+00 | 0.73495 | 0.00142 | 0.73778 | | | | |
| ncsrbmt11_1_1_15 | 0.0 | 100 | 925 | 925 | 10148 | 286.41 | 1.0E+00 | 0.65230 | 0.00132 | 0.65494 | | | | |

**Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | | | |
| ncsrbmt11_36_2_1 | 1.4 | 100 | 35142 | 35142 | 7719 | 5.73 | 1.0E-20 | 0.79252 | 0.00122 | 0.79496 | hcsrbmt12_36_2_1 | 0.79368 | 0.00134 | 0.79636 |
| ncsrbmt11_36_2_2 | 1.4 | 100 | 35142 | 35142 | 7719 | 5.73 | 1.0E-05 | 0.79014 | 0.00147 | 0.79309 | hcsrbmt12_36_2_2 | 0.79487 | 0.00120 | 0.79727 |
| ncsrbmt11_36_2_3 | 1.4 | 100 | 35142 | 35142 | 7719 | 5.73 | 1.0E-04 | 0.79182 | 0.00134 | 0.79450 | hcsrbmt12_36_2_3 | 0.79667 | 0.00135 | 0.79938 |
| ncsrbmt11_36_2_4 | 1.4 | 100 | 35142 | 35142 | 7719 | 5.73 | 1.0E-03 | 0.79144 | 0.00116 | 0.79376 | hcsrbmt12_36_2_4 | 0.79705 | 0.00133 | 0.79971 |
| ncsrbmt11_36_2_5 | 1.4 | 100 | 35142 | 35142 | 7719 | 5.73 | 1.0E-02 | 0.78918 | 0.00111 | 0.79141 | hcsrbmt12_36_2_5 | 0.79627 | 0.00135 | 0.79898 |
| ncsrbmt11_36_2_6 | 1.4 | 100 | 35142 | 35142 | 7719 | 5.73 | 1.0E-01 | 0.80114 | 0.00117 | 0.80348 | hcsrbmt12_36_2_6 | 0.80431 | 0.00130 | 0.80691 |
| ncsrbmt11_36_2_8 | 1.4 | 100 | 35142 | 35142 | 7719 | 5.73 | 3.0E-01 | 0.81416 | 0.00141 | 0.81698 | hcsrbmt12_36_2_8 | 0.82035 | 0.00119 | 0.82273 |
| ncsrbmt11_36_2_15 | 1.4 | 100 | 35142 | 35142 | 7719 | 5.73 | 1.0E+00 | 0.86924 | 0.00119 | 0.87162 | hcsrbmt12_36_2_15 | 0.87124 | 0.00142 | 0.87408 |
| | | | | | | | | | | | | | | |
| ncsrbmt11_36_2_15 | 1.4 | 100 | 35142 | 35142 | 7719 | 5.73 | 1.0E+00 | 0.86924 | 0.00119 | 0.87162 | | | | |
| ncsrbmt11_35_2_15 | 1.4 | 100 | 34217 | 34217 | 7768 | 5.93 | 1.0E+00 | 0.86697 | 0.00130 | 0.86957 | | | | |
| ncsrbmt11_34_2_15 | 1.4 | 100 | 33292 | 33292 | 7817 | 6.13 | 1.0E+00 | 0.86435 | 0.00138 | 0.86712 | | | | |
| ncsrbmt11_33_2_15 | 1.4 | 100 | 32367 | 32367 | 7866 | 6.34 | 1.0E+00 | 0.86988 | 0.00130 | 0.87249 | | | | |
| ncsrbmt11_32_2_15 | 1.4 | 100 | 31442 | 31442 | 7915 | 6.57 | 1.0E+00 | 0.86598 | 0.00145 | 0.86889 | | | | |
| ncsrbmt11_31_2_15 | 1.4 | 100 | 30518 | 30518 | 7964 | 6.81 | 1.0E+00 | 0.86432 | 0.00153 | 0.86739 | | | | |
| ncsrbmt11_30_2_15 | 1.4 | 100 | 29593 | 29593 | 8013 | 7.07 | 1.0E+00 | 0.85951 | 0.00163 | 0.86277 | | | | |
| ncsrbmt11_29_2_15 | 1.4 | 100 | 28668 | 28668 | 8062 | 7.34 | 1.0E+00 | 0.85938 | 0.00134 | 0.86206 | | | | |
| ncsrbmt11_28_2_15 | 1.4 | 100 | 27743 | 27743 | 8111 | 7.63 | 1.0E+00 | 0.85890 | 0.00133 | 0.86157 | | | | |
| ncsrbmt11_27_2_15 | 1.4 | 100 | 26819 | 26819 | 8160 | 7.94 | 1.0E+00 | 0.85736 | 0.00143 | 0.86023 | | | | |
| ncsrbmt11_26_2_15 | 1.4 | 100 | 25894 | 25894 | 8209 | 8.28 | 1.0E+00 | 0.85189 | 0.00129 | 0.85447 | | | | |
| ncsrbmt11_25_2_15 | 1.4 | 100 | 24969 | 24969 | 8258 | 8.63 | 1.0E+00 | 0.84986 | 0.00148 | 0.85281 | | | | |
| ncsrbmt11_24_2_15 | 1.4 | 100 | 23119 | 23119 | 8357 | 9.43 | 1.0E+00 | 0.85225 | 0.00131 | 0.85488 | | | | |
| ncsrbmt11_23_2_15 | 1.4 | 100 | 22195 | 22195 | 8406 | 9.89 | 1.0E+00 | 0.84824 | 0.00142 | 0.85108 | | | | |

**Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncsrbmt11_22_2_15 | 1.4 | 100 | 21270 | 21270 | 8455 | 10.38 | 1.0E+00 | 0.84600 | 0.00135 | 0.84869 | | | | |
| ncsrbmt11_21_2_15 | 1.4 | 100 | 20345 | 20345 | 8504 | 10.91 | 1.0E+00 | 0.84406 | 0.00150 | 0.84706 | | | | |
| ncsrbmt11_20_2_15 | 1.4 | 100 | 19420 | 19420 | 8553 | 11.50 | 1.0E+00 | 0.83992 | 0.00126 | 0.84244 | | | | |
| ncsrbmt11_19_2_15 | 1.4 | 100 | 18496 | 18496 | 8602 | 12.14 | 1.0E+00 | 0.83869 | 0.00134 | 0.84138 | | | | |
| ncsrbmt11_18_2_15 | 1.4 | 100 | 17571 | 17571 | 8651 | 12.85 | 1.0E+00 | 0.83488 | 0.00152 | 0.83793 | | | | |
| ncsrbmt11_17_2_15 | 1.4 | 100 | 16646 | 16646 | 8700 | 13.64 | 1.0E+00 | 0.83409 | 0.00130 | 0.83669 | | | | |
| ncsrbmt11_16_2_15 | 1.4 | 100 | 15721 | 15721 | 8749 | 14.53 | 1.0E+00 | 0.83520 | 0.00135 | 0.83789 | | | | |
| ncsrbmt11_15_2_15 | 1.4 | 100 | 14796 | 14796 | 8798 | 15.52 | 1.0E+00 | 0.83427 | 0.00129 | 0.83686 | | | | |
| ncsrbmt11_14_2_15 | 1.4 | 100 | 13872 | 13872 | 8847 | 16.65 | 1.0E+00 | 0.83162 | 0.00157 | 0.83476 | | | | |
| ncsrbmt11_13_2_15 | 1.4 | 100 | 12947 | 12947 | 8896 | 17.94 | 1.0E+00 | 0.82907 | 0.00147 | 0.83201 | | | | |
| ncsrbmt11_12_2_15 | 1.4 | 100 | 11097 | 11097 | 8995 | 21.16 | 1.0E+00 | 0.82195 | 0.00149 | 0.82493 | | | | |
| ncsrbmt11_11_2_15 | 1.4 | 100 | 10173 | 10173 | 9044 | 23.20 | 1.0E+00 | 0.81845 | 0.00120 | 0.82084 | | | | |
| ncsrbmt11_10_2_15 | 1.4 | 100 | 9248 | 9248 | 9093 | 25.66 | 1.0E+00 | 0.81508 | 0.00142 | 0.81792 | | | | |
| ncsrbmt11_9_2_15 | 1.4 | 100 | 8323 | 8323 | 9142 | 28.67 | 1.0E+00 | 0.81075 | 0.00138 | 0.81351 | | | | |
| ncsrbmt11_8_2_15 | 1.4 | 100 | 7398 | 7398 | 9191 | 32.43 | 1.0E+00 | 0.81425 | 0.00169 | 0.81764 | | | | |
| ncsrbmt11_7_2_15 | 1.4 | 100 | 6473 | 6473 | 9240 | 37.26 | 1.0E+00 | 0.80774 | 0.00155 | 0.81084 | | | | |
| ncsrbmt11_6_2_15 | 1.4 | 100 | 5549 | 5549 | 9289 | 43.70 | 1.0E+00 | 0.80060 | 0.00138 | 0.80336 | | | | |
| ncsrbmt11_5_2_15 | 1.4 | 100 | 4624 | 4624 | 9338 | 52.71 | 1.0E+00 | 0.79537 | 0.00167 | 0.79870 | | | | |
| ncsrbmt11_4_2_15 | 1.4 | 100 | 3699 | 3699 | 9387 | 66.24 | 1.0E+00 | 0.78379 | 0.00136 | 0.78651 | | | | |
| ncsrbmt11_3_2_15 | 1.4 | 100 | 2774 | 2774 | 9436 | 88.78 | 1.0E+00 | 0.76586 | 0.00130 | 0.76846 | | | | |
| ncsrbmt11_2_2_15 | 1.4 | 100 | 1850 | 1850 | 9485 | 133.86 | 1.0E+00 | 0.73246 | 0.00135 | 0.73516 | | | | |
| ncsrbmt11_1_2_15 | 1.4 | 100 | 925 | 925 | 9534 | 269.10 | 1.0E+00 | 0.65664 | 0.00150 | 0.65963 | | | | |

**Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **content in flooded containment vessel, array packaging model for CSI=0.0** | | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | | **HAC** | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | | |
| nciabmt11_36_1_8_1 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E-20 | 1.13613 | 0.00121 | 1.13855 | hciabmt12_36_1_8_1 | 1.13721 | 0.00124 | 1.13969 |
| nciabmt11_36_1_8_2 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E-05 | 1.13830 | 0.00153 | 1.14135 | hciabmt12_36_1_8_2 | 1.13634 | 0.00114 | 1.13862 |
| nciabmt11_36_1_8_3 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E-04 | 1.13709 | 0.00121 | 1.13952 | hciabmt12_36_1_8_3 | 1.13700 | 0.00127 | 1.13954 |
| nciabmt11_36_1_8_4 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E-03 | 1.13450 | 0.00115 | 1.13679 | hciabmt12_36_1_8_4 | 1.13567 | 0.00121 | 1.13809 |
| nciabmt11_36_1_8_5 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E-02 | 1.11154 | 0.00120 | 1.11394 | hciabmt12_36_1_8_5 | 1.12232 | 0.00129 | 1.12490 |
| nciabmt11_36_1_8_6 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E-01 | 0.98653 | 0.00121 | 0.98894 | hciabmt12_36_1_8_6 | 1.03049 | 0.00115 | 1.03278 |
| nciabmt11_36_1_8_8 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 3.0E-01 | 0.91622 | 0.00135 | 0.91892 | hciabmt12_36_1_8_8 | 0.95566 | 0.00126 | 0.95818 |
| nciabmt11_36_1_8_15 | 0.0 | 100 | 35142 | 35142 | 8332 | 6.19 | 1.0E+00 | 0.91008 | 0.00124 | 0.91255 | hciabmt12_36_1_8_15 | 0.93645 | 0.00120 | 0.93884 |
| | | | | | | | | | | | | | | |
| nciabmt11_7_1_5_3 | 0.0 | 80 | 6490 | 5192 | 9854 | 49.54 | 1.0E-04 | 0.96163 | 0.00130 | 0.96423 | hciabmt12_7_1_5_3 | 0.96193 | 0.00149 | 0.96490 |
| nciabmt11_6_1_5_3 | 0.0 | 80 | 5563 | 4450 | 9903 | 58.08 | 1.0E-04 | 0.95210 | 0.00130 | 0.95471 | hciabmt12_6_1_5_3 | 0.95164 | 0.00139 | 0.95442 |
| nciabmt11_5_1_5_3 | 0.0 | 80 | 4636 | 3709 | 9952 | 70.04 | 1.0E-04 | 0.93892 | 0.00161 | 0.94215 | hciabmt12_5_1_5_3 | 0.93880 | 0.00141 | 0.94162 |
| nciabmt11_4_1_5_3 | 0.0 | 80 | 3709 | 2967 | 10001 | 87.98 | 1.0E-04 | 0.91835 | 0.00149 | 0.92133 | hciabmt12_4_1_5_3 | 0.92156 | 0.00160 | 0.92476 |
| nciabmt11_3_1_5_3 | 0.0 | 80 | 2781 | 2225 | 10050 | 117.89 | 1.0E-04 | 0.89262 | 0.00129 | 0.89520 | hciabmt12_3_1_5_3 | 0.89109 | 0.00160 | 0.89430 |
| | | | | | | | | | | | | | | |
| nciabmt11_9_1_4_3 | 0.0 | 70 | 8355 | 5848 | 9755 | 43.54 | 1.0E-04 | 0.95952 | 0.00130 | 0.96213 | hciabmt12_9_1_4_3 | 0.95495 | 0.00150 | 0.95795 |
| nciabmt11_8_1_4_3 | 0.0 | 70 | 7426 | 5198 | 9804 | 49.23 | 1.0E-04 | 0.94887 | 0.00152 | 0.95191 | hciabmt12_8_1_4_3 | 0.95267 | 0.00156 | 0.95578 |
| nciabmt11_7_1_4_3 | 0.0 | 70 | 6498 | 4549 | 9854 | 56.54 | 1.0E-04 | 0.94082 | 0.00132 | 0.94346 | hciabmt12_7_1_4_3 | 0.94409 | 0.00125 | 0.94659 |
| nciabmt11_6_1_4_3 | 0.0 | 70 | 5570 | 3899 | 9903 | 66.29 | 1.0E-04 | 0.92987 | 0.00119 | 0.93225 | hciabmt12_6_1_4_3 | 0.93280 | 0.00123 | 0.93526 |
| nciabmt11_5_1_4_3 | 0.0 | 70 | 4642 | 3249 | 9952 | 79.95 | 1.0E-04 | 0.91799 | 0.00136 | 0.92070 | hciabmt12_5_1_4_3 | 0.92053 | 0.00147 | 0.92347 |
| | | | | | | | | | | | | | | |

**Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| nciabmt11_10_1_3_3 | 0.0 | 60 | 9295 | 5577 | 9706 | 45.43 | 1.0E-04 | 0.94106 | 0.00152 | 0.94409 | hciabmt12_10_1_3_3 | 0.94167 | 0.00126 | 0.94419 |
| nciabmt11_9_1_3_3 | 0.0 | 60 | 8365 | 5019 | 9755 | 50.73 | 1.0E-04 | 0.93671 | 0.00123 | 0.93918 | hciabmt12_9_1_3_3 | 0.93973 | 0.00135 | 0.94242 |
| nciabmt11_8_1_3_3 | 0.0 | 60 | 7436 | 4462 | 9804 | 57.36 | 1.0E-04 | 0.92907 | 0.00129 | 0.93166 | hciabmt12_8_1_3_3 | 0.93016 | 0.00128 | 0.93273 |
| nciabmt11_7_1_3_3 | 0.0 | 60 | 6506 | 3904 | 9854 | 65.88 | 1.0E-04 | 0.92171 | 0.00118 | 0.92407 | hciabmt12_7_1_3_3 | 0.92300 | 0.00130 | 0.92560 |
| nciabmt11_6_1_3_3 | 0.0 | 60 | 5577 | 3346 | 9903 | 77.24 | 1.0E-04 | 0.91221 | 0.00147 | 0.91515 | hciabmt12_6_1_3_3 | 0.91017 | 0.00128 | 0.91274 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | | | |
| nciabmt11_36_2_8_1 | 1.4 | 100 | 35142 | 35142 | 7719 | 5.73 | 1.0E-20 | 1.11012 | 0.00118 | 1.11249 | hciabmt12_36_2_8_1 | 1.11021 | 0.00115 | 1.11250 |
| nciabmt11_36_2_8_2 | 1.4 | 100 | 35142 | 35142 | 7719 | 5.73 | 1.0E-05 | 1.10934 | 0.00103 | 1.11141 | hciabmt12_36_2_8_2 | 1.10929 | 0.00137 | 1.11202 |
| nciabmt11_36_2_8_3 | 1.4 | 100 | 35142 | 35142 | 7719 | 5.73 | 1.0E-04 | 1.10991 | 0.00131 | 1.11252 | hciabmt12_36_2_8_3 | 1.10922 | 0.00112 | 1.11145 |
| nciabmt11_36_2_8_4 | 1.4 | 100 | 35142 | 35142 | 7719 | 5.73 | 1.0E-03 | 1.10774 | 0.00123 | 1.11020 | hciabmt12_36_2_8_4 | 1.10732 | 0.00115 | 1.10963 |
| nciabmt11_36_2_8_5 | 1.4 | 100 | 35142 | 35142 | 7719 | 5.73 | 1.0E-02 | 1.08309 | 0.00140 | 1.08589 | hciabmt12_36_2_8_5 | 1.09559 | 0.00114 | 1.09786 |
| nciabmt11_36_2_8_6 | 1.4 | 100 | 35142 | 35142 | 7719 | 5.73 | 1.0E-01 | 0.95955 | 0.00128 | 0.96212 | hciabmt12_36_2_8_6 | 1.00216 | 0.00124 | 1.00463 |
| nciabmt11_36_2_8_8 | 1.4 | 100 | 35142 | 35142 | 7719 | 5.73 | 3.0E-01 | 0.88829 | 0.00112 | 0.89053 | hciabmt12_36_2_8_8 | 0.92859 | 0.00158 | 0.93175 |
| nciabmt11_36_2_8_15 | 1.4 | 100 | 35142 | 35142 | 7719 | 5.73 | 1.0E+00 | 0.88638 | 0.00158 | 0.88953 | hciabmt12_36_2_8_15 | 0.91405 | 0.00147 | 0.91698 |
| | | | | | | | | | | | | | | |
| nciabmt11_5_2_8_3 | 1.4 | 100 | 4624 | 4624 | 9338 | 52.71 | 1.0E-04 | 0.94785 | 0.00147 | 0.95079 | hciabmt12_5_2_8_3 | 0.95226 | 0.00143 | 0.95511 |
| nciabmt11_4_2_8_3 | 1.4 | 100 | 3699 | 3699 | 9387 | 66.24 | 1.0E-04 | 0.92504 | 0.00170 | 0.92845 | hciabmt12_4_2_8_3 | 0.93069 | 0.00142 | 0.93352 |
| nciabmt11_3_2_8_3 | 1.4 | 100 | 2774 | 2774 | 9436 | 88.78 | 1.0E-04 | 0.90131 | 0.00139 | 0.90409 | hciabmt12_3_2_8_3 | 0.90243 | 0.00127 | 0.90497 |
| nciabmt11_2_2_8_3 | 1.4 | 100 | 1850 | 1850 | 9485 | 133.86 | 1.0E-04 | 0.85414 | 0.00141 | 0.85696 | hciabmt12_2_2_8_3 | 0.85600 | 0.00123 | 0.85846 |
| nciabmt11_1_2_8_3 | 1.4 | 100 | 925 | 925 | 9534 | 269.10 | 1.0E-04 | 0.74985 | 0.00124 | 0.75232 | hciabmt12_1_2_8_3 | 0.75078 | 0.00135 | 0.75347 |
| | | | | | | | | | | | | | | |
| nciabmt11_6_2_7_3 | 1.4 | 95 | 5552 | 5275 | 9289 | 45.97 | 1.0E-04 | 0.95078 | 0.00124 | 0.95327 | hciabmt12_6_2_7_3 | 0.95399 | 0.00153 | 0.95704 |
| nciabmt11_5_2_7_3 | 1.4 | 95 | 4627 | 4396 | 9338 | 55.45 | 1.0E-04 | 0.93742 | 0.00130 | 0.94002 | hciabmt12_5_2_7_3 | 0.93696 | 0.00142 | 0.93981 |
| nciabmt11_4_2_7_3 | 1.4 | 95 | 3701 | 3516 | 9387 | 69.68 | 1.0E-04 | 0.91690 | 0.00149 | 0.91987 | hciabmt12_4_2_7_3 | 0.92094 | 0.00140 | 0.92374 |

**Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| nciabmt11_3_2_7_3 | 1.4 | 95 | 2776 | 2637 | 9436 | 93.39 | 1.0E-04 | 0.89089 | 0.00127 | 0.89343 | hciabmt12_3_2_7_3 | 0.89250 | 0.00144 | 0.89537 |
| nciabmt11_2_2_7_3 | 1.4 | 95 | 1851 | 1758 | 9485 | 140.81 | 1.0E-04 | 0.84225 | 0.00143 | 0.84510 | hciabmt12_2_2_7_3 | 0.84604 | 0.00135 | 0.84875 |
| | | | | | | | | | | | | | | |
| nciabmt11_6_2_6_3 | 1.4 | 90 | 5556 | 5000 | 9289 | 48.49 | 1.0E-04 | 0.93703 | 0.00127 | 0.93956 | hciabmt12_6_2_6_3 | 0.93967 | 0.00130 | 0.94227 |
| nciabmt11_5_2_6_3 | 1.4 | 90 | 4630 | 4167 | 9338 | 58.49 | 1.0E-04 | 0.92640 | 0.00142 | 0.92925 | hciabmt12_5_2_6_3 | 0.92390 | 0.00155 | 0.92700 |
| nciabmt11_4_2_6_3 | 1.4 | 90 | 3704 | 3333 | 9387 | 73.50 | 1.0E-04 | 0.90541 | 0.00147 | 0.90835 | hciabmt12_4_2_6_3 | 0.90643 | 0.00133 | 0.90909 |
| nciabmt11_3_2_6_3 | 1.4 | 90 | 2778 | 2500 | 9436 | 98.52 | 1.0E-04 | 0.87970 | 0.00157 | 0.88283 | hciabmt12_3_2_6_3 | 0.87916 | 0.00154 | 0.88224 |
| nciabmt11_2_2_6_3 | 1.4 | 90 | 1852 | 1667 | 9485 | 148.54 | 1.0E-04 | 0.83371 | 0.00129 | 0.83628 | hciabmt12_2_2_6_3 | 0.83414 | 0.00130 | 0.83674 |
| | | | | | | | | | | | | | | |
| nciabmt11_8_2_5_3 | 1.4 | 80 | 7417 | 5934 | 9191 | 40.43 | 1.0E-04 | 0.94131 | 0.00162 | 0.94455 | hciabmt12_8_2_5_3 | 0.93963 | 0.00149 | 0.94261 |
| nciabmt11_7_2_5_3 | 1.4 | 80 | 6490 | 5192 | 9240 | 46.45 | 1.0E-04 | 0.92939 | 0.00127 | 0.93193 | hciabmt12_7_2_5_3 | 0.93070 | 0.00160 | 0.93391 |
| nciabmt11_6_2_5_3 | 1.4 | 80 | 5563 | 4450 | 9289 | 54.48 | 1.0E-04 | 0.91981 | 0.00127 | 0.92235 | hciabmt12_6_2_5_3 | 0.91987 | 0.00157 | 0.92301 |
| nciabmt11_5_2_5_3 | 1.4 | 80 | 4636 | 3709 | 9338 | 65.72 | 1.0E-04 | 0.90533 | 0.00127 | 0.90787 | hciabmt12_5_2_5_3 | 0.90772 | 0.00136 | 0.91044 |
| nciabmt11_4_2_5_3 | 1.4 | 80 | 3709 | 2967 | 9387 | 82.59 | 1.0E-04 | 0.88537 | 0.00136 | 0.88808 | hciabmt12_4_2_5_3 | 0.88792 | 0.00150 | 0.89092 |
| | | | | | | | | | | | | | | |
| nciabmt11_11_2_4_3 | 1.4 | 70 | 10211 | 7148 | 9044 | 33.02 | 1.0E-04 | 0.93094 | 0.00141 | 0.93376 | hciabmt12_11_2_4_3 | 0.93119 | 0.00138 | 0.93395 |
| nciabmt11_10_2_4_3 | 1.4 | 70 | 9283 | 6498 | 9093 | 36.52 | 1.0E-04 | 0.92534 | 0.00139 | 0.92813 | hciabmt12_10_2_4_3 | 0.92795 | 0.00129 | 0.93052 |
| nciabmt11_9_2_4_3 | 1.4 | 70 | 8355 | 5848 | 9142 | 40.80 | 1.0E-04 | 0.91866 | 0.00122 | 0.92110 | hciabmt12_9_2_4_3 | 0.92290 | 0.00125 | 0.92540 |
| nciabmt11_8_2_4_3 | 1.4 | 70 | 7426 | 5198 | 9191 | 46.15 | 1.0E-04 | 0.91902 | 0.00137 | 0.92175 | hciabmt12_8_2_4_3 | 0.91835 | 0.00126 | 0.92086 |
| nciabmt11_7_2_4_3 | 1.4 | 70 | 6498 | 4549 | 9240 | 53.02 | 1.0E-04 | 0.90863 | 0.00152 | 0.91166 | hciabmt12_7_2_4_3 | 0.91042 | 0.00137 | 0.91316 |
| | | | | | | | | | | | | | | |
| nciabmt11_15_2_3_3 | 1.4 | 60 | 14872 | 8923 | 8798 | 25.74 | 1.0E-04 | 0.93047 | 0.00133 | 0.93313 | hciabmt12_15_2_3_3 | 0.93032 | 0.00114 | 0.93259 |
| nciabmt11_14_2_3_3 | 1.4 | 60 | 13942 | 8365 | 8847 | 27.61 | 1.0E-04 | 0.92560 | 0.00138 | 0.92837 | hciabmt12_14_2_3_3 | 0.92828 | 0.00143 | 0.93115 |
| nciabmt11_13_2_3_3 | 1.4 | 60 | 12083 | 7250 | 8946 | 32.21 | 1.0E-04 | 0.91963 | 0.00126 | 0.92214 | hciabmt12_13_2_3_3 | 0.92389 | 0.00124 | 0.92638 |

**Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| nciabmt11_12_2_3_3 | 1.4 | 60 | 11154 | 6692 | 8995 | 35.08 | 1.0E-04 | 0.91502 | 0.00155 | 0.91812 | hciabmt12_12_2_3_3 | 0.91776 | 0.00138 | 0.92053 |
| nciabmt11_11_2_3_3 | 1.4 | 60 | 10224 | 6135 | 9044 | 38.48 | 1.0E-04 | 0.90892 | 0.00140 | 0.91172 | hciabmt12_11_2_3_3 | 0.91237 | 0.00133 | 0.91503 |
| **content in flooded containment vessel, array packaging model for CSI=0.4** | | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | | **HAC** | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | | |
| | | | | | | | | | | | hcf2bmt12_11_1_5_3 | 0.91900 | 0.00131 | 0.92163 |
| | | | | | | | | | | | hcf2bmt12_10_1_5_3 | 0.91775 | 0.00161 | 0.92097 |
| | | | | | | | | | | | hcf2bmt12_9_1_5_3 | 0.91229 | 0.00127 | 0.91483 |
| ncf1bmt11_8_1_5_3 | 0.0 | 80 | 7417 | 5934 | 9804 | 43.13 | 1.0E-04 | 0.92824 | 0.00156 | 0.93135 | hcf2bmt12_8_1_5_3 | 0.90367 | 0.00138 | 0.90643 |
| ncf1bmt11_7_1_5_3 | 0.0 | 80 | 6490 | 5192 | 9854 | 49.54 | 1.0E-04 | 0.92088 | 0.00131 | 0.92349 | | | | |
| ncf1bmt11_6_1_5_3 | 0.0 | 80 | 5563 | 4450 | 9903 | 58.08 | 1.0E-04 | 0.91164 | 0.00153 | 0.91470 | | | | |
| ncf1bmt11_5_1_5_3 | 0.0 | 80 | 4636 | 3709 | 9952 | 70.04 | 1.0E-04 | 0.90130 | 0.00135 | 0.90400 | | | | |
| ncf1bmt11_4_1_5_3 | 0.0 | 80 | 3709 | 2967 | 10001 | 87.98 | 1.0E-04 | 0.88094 | 0.00128 | 0.88350 | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | hcf2bmt12_15_1_4_3 | 0.91711 | 0.00152 | 0.92016 |
| | | | | | | | | | | | hcf2bmt12_14_1_4_3 | 0.91432 | 0.00164 | 0.91760 |
| ncf1bmt11_13_1_4_3 | 0.0 | 70 | 12996 | 9097 | 9510 | 27.28 | 1.0E-04 | 0.93558 | 0.00138 | 0.93834 | hcf2bmt12_13_1_4_3 | 0.91429 | 0.00141 | 0.91711 |
| ncf1bmt11_12_1_4_3 | 0.0 | 70 | 11140 | 7798 | 9608 | 32.16 | 1.0E-04 | 0.92957 | 0.00130 | 0.93217 | hcf2bmt12_12_1_4_3 | 0.90853 | 0.00161 | 0.91175 |
| ncf1bmt11_11_1_4_3 | 0.0 | 70 | 10211 | 7148 | 9657 | 35.26 | 1.0E-04 | 0.92397 | 0.00139 | 0.92675 | | | | |
| ncf1bmt11_10_1_4_3 | 0.0 | 70 | 9283 | 6498 | 9706 | 38.99 | 1.0E-04 | 0.92240 | 0.00135 | 0.92510 | | | | |
| ncf1bmt11_9_1_4_3 | 0.0 | 70 | 8355 | 5848 | 9755 | 43.54 | 1.0E-04 | 0.91886 | 0.00139 | 0.92163 | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | hcf2bmt12_21_1_3_3 | 0.91091 | 0.00139 | 0.91369 |
| | | | | | | | | | | | hcf2bmt12_20_1_3_3 | 0.90915 | 0.00144 | 0.91203 |

**Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncf1bmt11_19_1_3_3 | 0.0 | 60 | 18589 | 11154 | 9216 | 21.57 | 1.0E-04 | 0.92771 | 0.00137 | 0.93044 | hcf2bmt12_19_1_3_3 | 0.90638 | 0.00160 | 0.90958 |
| ncf1bmt11_18_1_3_3 | 0.0 | 60 | 17660 | 10596 | 9265 | 22.82 | 1.0E-04 | 0.92867 | 0.00148 | 0.93164 | hcf2bmt12_18_1_3_3 | 0.90466 | 0.00124 | 0.90715 |
| ncf1bmt11_17_1_3_3 | 0.0 | 60 | 16731 | 10038 | 9314 | 24.22 | 1.0E-04 | 0.92948 | 0.00113 | 0.93173 | | | | |
| ncf1bmt11_16_1_3_3 | 0.0 | 60 | 15801 | 9481 | 9363 | 25.78 | 1.0E-04 | 0.92252 | 0.00158 | 0.92569 | | | | |
| ncf1bmt11_15_1_3_3 | 0.0 | 60 | 14872 | 8923 | 9412 | 27.53 | 1.0E-04 | 0.91999 | 0.00123 | 0.92246 | | | | |
| ncf1bmt11_14_1_3_3 | 0.0 | 60 | 13942 | 8365 | 9461 | 29.52 | 1.0E-04 | 0.91961 | 0.00144 | 0.92248 | | | | |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | | | |
| | | | | | | | | | | | hcf2bmt12_10_2_8_3 | 0.93154 | 0.00152 | 0.93458 |
| ncf1bmt11_9_2_8_3 | 1.4 | 100 | 8323 | 8323 | 9142 | 28.67 | 1.0E-04 | 0.94429 | 0.00138 | 0.94704 | hcf2bmt12_9_2_8_3 | 0.92329 | 0.00147 | 0.92622 |
| ncf1bmt11_8_2_8_3 | 1.4 | 100 | 7398 | 7398 | 9191 | 32.43 | 1.0E-04 | 0.94337 | 0.00169 | 0.94674 | hcf2bmt12_8_2_8_3 | 0.92153 | 0.00144 | 0.92442 |
| ncf1bmt11_7_2_8_3 | 1.4 | 100 | 6473 | 6473 | 9240 | 37.26 | 1.0E-04 | 0.93117 | 0.00172 | 0.93460 | | | | |
| ncf1bmt11_6_2_8_3 | 1.4 | 100 | 5549 | 5549 | 9289 | 43.70 | 1.0E-04 | 0.92119 | 0.00147 | 0.92412 | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | hcf2bmt12_13_2_7_3 | 0.93389 | 0.00167 | 0.93722 |
| | | | | | | | | | | | hcf2bmt12_12_2_7_3 | 0.92649 | 0.00146 | 0.92941 |
| ncf1bmt11_11_2_7_3 | 1.4 | 95 | 10179 | 9670 | 9044 | 24.41 | 1.0E-04 | 0.94326 | 0.00139 | 0.94604 | hcf2bmt12_11_2_7_3 | 0.92061 | 0.00130 | 0.92320 |
| ncf1bmt11_10_2_7_3 | 1.4 | 95 | 9254 | 8791 | 9093 | 27.00 | 1.0E-04 | 0.93829 | 0.00154 | 0.94138 | hcf2bmt12_10_2_7_3 | 0.91423 | 0.00145 | 0.91712 |
| ncf1bmt11_9_2_7_3 | 1.4 | 95 | 8328 | 7912 | 9142 | 30.16 | 1.0E-04 | 0.93239 | 0.00181 | 0.93600 | hcf2bmt12_9_2_7_3 | 0.90883 | 0.00137 | 0.91156 |
| ncf1bmt11_8_2_7_3 | 1.4 | 95 | 7403 | 7033 | 9191 | 34.11 | 1.0E-04 | 0.92812 | 0.00144 | 0.93100 | | | | |
| ncf1bmt11_7_2_7_3 | 1.4 | 95 | 6478 | 6154 | 9240 | 39.19 | 1.0E-04 | 0.91938 | 0.00130 | 0.92199 | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | hcf2bmt12_15_2_6_3 | 0.93106 | 0.00129 | 0.93364 |
| | | | | | | | | | | | hcf2bmt12_14_2_6_3 | 0.92492 | 0.00129 | 0.92749 |

**Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncf1bmt11_13_2_6_3 | 1.4 | 90 | 12963 | 11667 | 8896 | 19.90 | 1.0E-04 | 0.94806 | 0.00123 | 0.95052 | hcf2bmt12_13_2_6_3 | 0.92272 | 0.00138 | 0.92548 |
| ncf1bmt11_12_2_6_3 | 1.4 | 90 | 11111 | 10000 | 8995 | 23.48 | 1.0E-04 | 0.93464 | 0.00123 | 0.93710 | hcf2bmt12_12_2_6_3 | 0.91625 | 0.00149 | 0.91924 |
| ncf1bmt11_11_2_6_3 | 1.4 | 90 | 10185 | 9167 | 9044 | 25.75 | 1.0E-04 | 0.93068 | 0.00148 | 0.93363 | hcf2bmt12_11_2_6_3 | 0.91097 | 0.00136 | 0.91370 |
| ncf1bmt11_10_2_6_3 | 1.4 | 90 | 9260 | 8334 | 9093 | 28.48 | 1.0E-04 | 0.92732 | 0.00150 | 0.93032 | | | | |
| ncf1bmt11_9_2_6_3 | 1.4 | 90 | 8334 | 7500 | 9142 | 31.81 | 1.0E-04 | 0.91744 | 0.00145 | 0.92034 | | | | |
| ncf1bmt11_8_2_6_3 | 1.4 | 90 | 7408 | 6667 | 9191 | 35.98 | 1.0E-04 | 0.91952 | 0.00133 | 0.92218 | | | | |
| | | | | | | | | | | | | | | |
| ncf1bmt11_17_2_5_3 | 1.4 | 80 | 16688 | 13351 | 8700 | 17.01 | 1.0E-04 | 0.93531 | 0.00128 | 0.93787 | hcf2bmt12_17_2_5_3 | 0.91255 | 0.00114 | 0.91482 |
| ncf1bmt11_16_2_5_3 | 1.4 | 80 | 15761 | 12609 | 8749 | 18.11 | 1.0E-04 | 0.93511 | 0.00160 | 0.93832 | hcf2bmt12_16_2_5_3 | 0.91363 | 0.00123 | 0.91608 |
| ncf1bmt11_15_2_5_3 | 1.4 | 80 | 14834 | 11867 | 8798 | 19.35 | 1.0E-04 | 0.93431 | 0.00141 | 0.93713 | hcf2bmt12_15_2_5_3 | 0.91038 | 0.00115 | 0.91268 |
| ncf1bmt11_14_2_5_3 | 1.4 | 80 | 13907 | 11125 | 8847 | 20.76 | 1.0E-04 | 0.92939 | 0.00133 | 0.93205 | hcf2bmt12_14_2_5_3 | 0.90762 | 0.00139 | 0.91041 |
| ncf1bmt11_13_2_5_3 | 1.4 | 80 | 12980 | 10384 | 8896 | 22.36 | 1.0E-04 | 0.92453 | 0.00131 | 0.92715 | hcf2bmt12_13_2_5_3 | 0.90539 | 0.00137 | 0.90812 |
| ncf1bmt11_12_2_5_3 | 1.4 | 80 | 11125 | 8900 | 8995 | 26.38 | 1.0E-04 | 0.91584 | 0.00142 | 0.91868 | hcf2bmt12_12_2_5_3 | 0.89295 | 0.00174 | 0.89642 |
| | | | | | | | | | | | | | | |
| ncf1bmt11_24_2_4_3 | 1.4 | 70 | 23207 | 16245 | 8357 | 13.43 | 1.0E-04 | 0.93515 | 0.00143 | 0.93801 | hcf2bmt12_24_2_4_3 | 0.91356 | 0.00125 | 0.91606 |
| ncf1bmt11_23_2_4_3 | 1.4 | 70 | 22279 | 15595 | 8406 | 14.07 | 1.0E-04 | 0.93264 | 0.00113 | 0.93490 | hcf2bmt12_23_2_4_3 | 0.91116 | 0.00113 | 0.91342 |
| ncf1bmt11_22_2_4_3 | 1.4 | 70 | 21351 | 14946 | 8455 | 14.77 | 1.0E-04 | 0.93058 | 0.00128 | 0.93314 | hcf2bmt12_22_2_4_3 | 0.90737 | 0.00145 | 0.91027 |
| ncf1bmt11_21_2_4_3 | 1.4 | 70 | 20422 | 14296 | 8504 | 15.53 | 1.0E-04 | 0.92635 | 0.00112 | 0.92859 | hcf2bmt12_21_2_4_3 | 0.90516 | 0.00140 | 0.90796 |
| ncf1bmt11_20_2_4_3 | 1.4 | 70 | 19494 | 13646 | 8553 | 16.36 | 1.0E-04 | 0.92535 | 0.00141 | 0.92818 | hcf2bmt12_20_2_4_3 | 0.90283 | 0.00136 | 0.90555 |
| ncf1bmt11_19_2_4_3 | 1.4 | 70 | 18566 | 12996 | 8602 | 17.28 | 1.0E-04 | 0.92097 | 0.00177 | 0.92450 | hcf2bmt12_19_2_4_3 | 0.89757 | 0.00144 | 0.90046 |
| ncf1bmt11_18_2_4_3 | 1.4 | 70 | 17638 | 12346 | 8651 | 18.29 | 1.0E-04 | 0.91681 | 0.00140 | 0.91961 | hcf2bmt12_18_2_4_3 | 0.89367 | 0.00144 | 0.89656 |
| | | | | | | | | | | | | | | |
| ncf1bmt11_36_2_3_3 | 1.4 | 60 | 35320 | 21192 | 7719 | 9.51 | 1.0E-04 | 0.93212 | 0.00121 | 0.93455 | hcf2bmt12_36_2_3_3 | 0.90846 | 0.00137 | 0.91121 |
| ncf1bmt11_35_2_3_3 | 1.4 | 60 | 34391 | 20634 | 7768 | 9.83 | 1.0E-04 | 0.93168 | 0.00129 | 0.93426 | hcf2bmt12_35_2_3_3 | 0.90742 | 0.00118 | 0.90977 |

**Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncf1bmt11_34_2_3_3 | 1.4 | 60 | 33461 | 20077 | 7817 | 10.16 | 1.0E-04 | 0.93079 | 0.00145 | 0.93368 | hcf2bmt12_34_2_3_3 | 0.90657 | 0.00134 | 0.90925 |
| ncf1bmt11_33_2_3_3 | 1.4 | 60 | 32532 | 19519 | 7866 | 10.52 | 1.0E-04 | 0.92781 | 0.00131 | 0.93042 | hcf2bmt12_33_2_3_3 | 0.90603 | 0.00117 | 0.90837 |
| ncf1bmt11_32_2_3_3 | 1.4 | 60 | 31602 | 18961 | 7915 | 10.90 | 1.0E-04 | 0.92550 | 0.00131 | 0.92811 | hcf2bmt12_32_2_3_3 | 0.90015 | 0.00127 | 0.90270 |
| ncf1bmt11_31_2_3_3 | 1.4 | 60 | 30673 | 18404 | 7964 | 11.29 | 1.0E-04 | 0.92597 | 0.00128 | 0.92853 | hcf2bmt12_31_2_3_3 | 0.90333 | 0.00122 | 0.90577 |
| ncf1bmt11_30_2_3_3 | 1.4 | 60 | 29743 | 17846 | 8013 | 11.72 | 1.0E-04 | 0.92361 | 0.00120 | 0.92601 | hcf2bmt12_30_2_3_3 | 0.89683 | 0.00144 | 0.89971 |
| ncf1bmt11_29_2_3_3 | 1.4 | 60 | 28814 | 17288 | 8062 | 12.17 | 1.0E-04 | 0.92063 | 0.00143 | 0.92350 | | | | |
| **content in flooded containment vessel, array packaging model for CSI=0.8** | | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | | **HAC** | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | | |
| ncf2bmt11_17_1_5_3 | 0.0 | 80 | 16688 | 13351 | 9314 | 18.21 | 1.0E-04 | 0.93655 | 0.00144 | 0.93942 | hcf3bmt12_17_1_5_3 | 0.92003 | 0.00129 | 0.92262 |
| ncf2bmt11_16_1_5_3 | 0.0 | 80 | 15761 | 12609 | 9363 | 19.38 | 1.0E-04 | 0.93242 | 0.00143 | 0.93529 | hcf3bmt12_16_1_5_3 | 0.91399 | 0.00148 | 0.91694 |
| ncf2bmt11_15_1_5_3 | 0.0 | 80 | 14834 | 11867 | 9412 | 20.70 | 1.0E-04 | 0.92982 | 0.00135 | 0.93251 | hcf3bmt12_15_1_5_3 | 0.91169 | 0.00139 | 0.91448 |
| ncf2bmt11_14_1_5_3 | 0.0 | 80 | 13907 | 11125 | 9461 | 22.20 | 1.0E-04 | 0.92699 | 0.00137 | 0.92972 | hcf3bmt12_14_1_5_3 | 0.90943 | 0.00135 | 0.91213 |
| ncf2bmt11_13_1_5_3 | 0.0 | 80 | 12980 | 10384 | 9510 | 23.90 | 1.0E-04 | 0.92634 | 0.00138 | 0.92909 | hcf3bmt12_13_1_5_3 | 0.90348 | 0.00133 | 0.90615 |
| ncf2bmt11_12_1_5_3 | 0.0 | 80 | 11125 | 8900 | 9608 | 28.18 | 1.0E-04 | 0.91826 | 0.00166 | 0.92158 | hcf3bmt12_12_1_5_3 | 0.89805 | 0.00155 | 0.90115 |
| | | | | | | | | | | | | | | |
| ncf2bmt11_21_1_4_3 | 0.0 | 70 | 20422 | 14296 | 9117 | 16.65 | 1.0E-04 | 0.92723 | 0.00123 | 0.92968 | | | | |
| ncf2bmt11_20_1_4_3 | 0.0 | 70 | 19494 | 13646 | 9166 | 17.53 | 1.0E-04 | 0.92094 | 0.00124 | 0.92342 | hcf3bmt12_20_1_4_3 | 0.90398 | 0.00124 | 0.90646 |
| ncf2bmt11_19_1_4_3 | 0.0 | 70 | 18566 | 12996 | 9216 | 18.51 | 1.0E-04 | 0.92341 | 0.00144 | 0.92629 | hcf3bmt12_19_1_4_3 | 0.90150 | 0.00151 | 0.90452 |
| ncf2bmt11_18_1_4_3 | 0.0 | 70 | 17638 | 12346 | 9265 | 19.59 | 1.0E-04 | 0.91814 | 0.00135 | 0.92085 | hcf3bmt12_18_1_4_3 | 0.89955 | 0.00134 | 0.90222 |
| ncf2bmt11_17_1_4_3 | 0.0 | 70 | 16709 | 11697 | 9314 | 20.78 | 1.0E-04 | 0.91793 | 0.00133 | 0.92058 | hcf3bmt12_17_1_4_3 | 0.89730 | 0.00133 | 0.89996 |
| ncf2bmt11_16_1_4_3 | 0.0 | 70 | 15781 | 11047 | 9363 | 22.12 | 1.0E-04 | 0.91629 | 0.00133 | 0.91895 | hcf3bmt12_16_1_4_3 | 0.89458 | 0.00122 | 0.89702 |
| ncf2bmt11_15_1_4_3 | 0.0 | 70 | 14853 | 10397 | 9412 | 23.63 | 1.0E-04 | 0.91068 | 0.00125 | 0.91317 | hcf3bmt12_15_1_4_3 | 0.89088 | 0.00130 | 0.89347 |
| | | | | | | | | | | | | | | |

**Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncf2bmt11_36_1_3_3 | 0.0 | 60 | 35320 | 21192 | 8332 | 10.26 | 1.0E-04 | 0.93348 | 0.00105 | 0.93558 | hcf3bmt12_36_1_3_3 | 0.91223 | 0.00113 | 0.91450 |
| ncf2bmt11_35_1_3_3 | 0.0 | 60 | 34391 | 20634 | 8381 | 10.60 | 1.0E-04 | 0.93036 | 0.00127 | 0.93290 | hcf3bmt12_35_1_3_3 | 0.91033 | 0.00128 | 0.91288 |
| ncf2bmt11_34_1_3_3 | 0.0 | 60 | 33461 | 20077 | 8430 | 10.96 | 1.0E-04 | 0.92584 | 0.00127 | 0.92837 | hcf3bmt12_34_1_3_3 | 0.90950 | 0.00126 | 0.91202 |
| ncf2bmt11_33_1_3_3 | 0.0 | 60 | 32532 | 19519 | 8479 | 11.34 | 1.0E-04 | 0.92680 | 0.00142 | 0.92965 | hcf3bmt12_33_1_3_3 | 0.90720 | 0.00143 | 0.91007 |
| ncf2bmt11_32_1_3_3 | 0.0 | 60 | 31602 | 18961 | 8529 | 11.74 | 1.0E-04 | 0.92588 | 0.00144 | 0.92877 | hcf3bmt12_32_1_3_3 | 0.90425 | 0.00126 | 0.90678 |
| ncf2bmt11_31_1_3_3 | 0.0 | 60 | 30673 | 18404 | 8578 | 12.17 | 1.0E-04 | 0.92420 | 0.00123 | 0.92665 | hcf3bmt12_31_1_3_3 | 0.90271 | 0.00118 | 0.90506 |
| ncf2bmt11_30_1_3_3 | 0.0 | 60 | 29743 | 17846 | 8627 | 12.62 | 1.0E-04 | 0.92236 | 0.00165 | 0.92566 | hcf3bmt12_30_1_3_3 | 0.90323 | 0.00138 | 0.90599 |
| ncf2bmt11_29_1_3_3 | 0.0 | 60 | 28814 | 17288 | 8676 | 13.10 | 1.0E-04 | 0.91822 | 0.00113 | 0.92047 | hcf3bmt12_29_1_3_3 | 0.89982 | 0.00121 | 0.90224 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | | | |
| ncf2bmt11_12_2_8_3 | 1.4 | 100 | 11097 | 11097 | 8995 | 21.16 | 1.0E-04 | 0.93137 | 0.00124 | 0.93385 | hcf3bmt12_12_2_8_3 | 0.91417 | 0.00139 | 0.91696 |
| ncf2bmt11_11_2_8_3 | 1.4 | 100 | 10173 | 10173 | 9044 | 23.20 | 1.0E-04 | 0.92641 | 0.00144 | 0.92928 | hcf3bmt12_11_2_8_3 | 0.91315 | 0.00164 | 0.91642 |
| ncf2bmt11_10_2_8_3 | 1.4 | 100 | 9248 | 9248 | 9093 | 25.66 | 1.0E-04 | 0.92058 | 0.00138 | 0.92334 | hcf3bmt12_10_2_8_3 | 0.90570 | 0.00166 | 0.90902 |
| ncf2bmt11_9_2_8_3 | 1.4 | 100 | 8323 | 8323 | 9142 | 28.67 | 1.0E-04 | 0.91671 | 0.00138 | 0.91947 | hcf3bmt12_9_2_8_3 | 0.89648 | 0.00131 | 0.89911 |
| ncf2bmt11_8_2_8_3 | 1.4 | 100 | 7398 | 7398 | 9191 | 32.43 | 1.0E-04 | 0.91365 | 0.00171 | 0.91706 | hcf3bmt12_8_2_8_3 | 0.89682 | 0.00139 | 0.89960 |
| ncf2bmt11_7_2_8_3 | 1.4 | 100 | 6473 | 6473 | 9240 | 37.26 | 1.0E-04 | 0.90684 | 0.00166 | 0.91016 | hcf3bmt12_7_2_8_3 | 0.88907 | 0.00143 | 0.89192 |
| ncf2bmt11_6_2_8_3 | 1.4 | 100 | 5549 | 5549 | 9289 | 43.70 | 1.0E-04 | 0.89705 | 0.00145 | 0.89995 | hcf3bmt12_6_2_8_3 | 0.87797 | 0.00166 | 0.88130 |
| | | | | | | | | | | | | | | |
| ncf2bmt11_14_2_7_3 | 1.4 | 95 | 13880 | 13186 | 8847 | 17.51 | 1.0E-04 | 0.93174 | 0.00131 | 0.93437 | hcf3bmt12_14_2_7_3 | 0.91453 | 0.00162 | 0.91777 |
| ncf2bmt11_13_2_7_3 | 1.4 | 95 | 12955 | 12307 | 8896 | 18.87 | 1.0E-04 | 0.92685 | 0.00140 | 0.92965 | hcf3bmt12_13_2_7_3 | 0.91006 | 0.00135 | 0.91276 |
| ncf2bmt11_12_2_7_3 | 1.4 | 95 | 11104 | 10549 | 8995 | 22.25 | 1.0E-04 | 0.91939 | 0.00136 | 0.92210 | hcf3bmt12_12_2_7_3 | 0.89784 | 0.00132 | 0.90048 |
| ncf2bmt11_11_2_7_3 | 1.4 | 95 | 10179 | 9670 | 9044 | 24.41 | 1.0E-04 | 0.91215 | 0.00134 | 0.91483 | hcf3bmt12_11_2_7_3 | 0.89423 | 0.00146 | 0.89715 |
| ncf2bmt11_10_2_7_3 | 1.4 | 95 | 9254 | 8791 | 9093 | 27.00 | 1.0E-04 | 0.90898 | 0.00126 | 0.91151 | hcf3bmt12_10_2_7_3 | 0.89121 | 0.00159 | 0.89438 |
| ncf2bmt11_9_2_7_3 | 1.4 | 95 | 8328 | 7912 | 9142 | 30.16 | 1.0E-04 | 0.90123 | 0.00147 | 0.90416 | hcf3bmt12_9_2_7_3 | 0.88311 | 0.00145 | 0.88602 |
| | | | | | | | | | | | | | | |

**Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncf2bmt11_16_2_6_3 | 1.4 | 90 | 15741 | 14167 | 8749 | 16.12 | 1.0E-04 | 0.92855 | 0.00124 | 0.93103 | hcf3bmt12_16_2_6_3 | 0.91007 | 0.00134 | 0.91276 |
| ncf2bmt11_15_2_6_3 | 1.4 | 90 | 14815 | 13334 | 8798 | 17.22 | 1.0E-04 | 0.92599 | 0.00107 | 0.92813 | hcf3bmt12_15_2_6_3 | 0.90421 | 0.00136 | 0.90693 |
| ncf2bmt11_14_2_6_3 | 1.4 | 90 | 13889 | 12500 | 8847 | 18.47 | 1.0E-04 | 0.91938 | 0.00131 | 0.92200 | hcf3bmt12_14_2_6_3 | 0.90163 | 0.00129 | 0.90422 |
| ncf2bmt11_13_2_6_3 | 1.4 | 90 | 12963 | 11667 | 8896 | 19.90 | 1.0E-04 | 0.91387 | 0.00110 | 0.91607 | hcf3bmt12_13_2_6_3 | 0.89824 | 0.00123 | 0.90069 |
| ncf2bmt11_12_2_6_3 | 1.4 | 90 | 11111 | 10000 | 8995 | 23.48 | 1.0E-04 | 0.90989 | 0.00135 | 0.91258 | hcf3bmt12_12_2_6_3 | 0.88832 | 0.00136 | 0.89105 |
| ncf2bmt11_11_2_6_3 | 1.4 | 90 | 10185 | 9167 | 9044 | 25.75 | 1.0E-04 | 0.90334 | 0.00152 | 0.90637 | hcf3bmt12_11_2_6_3 | 0.88574 | 0.00168 | 0.88911 |
| ncf2bmt11_10_2_6_3 | 1.4 | 90 | 9260 | 8334 | 9093 | 28.48 | 1.0E-04 | 0.89868 | 0.00172 | 0.90212 | hcf3bmt12_10_2_6_3 | 0.87986 | 0.00134 | 0.88254 |
| ncf2bmt11_9_2_6_3 | 1.4 | 90 | 8334 | 7500 | 9142 | 31.81 | 1.0E-04 | 0.89190 | 0.00154 | 0.89499 | hcf3bmt12_9_2_6_3 | 0.87453 | 0.00140 | 0.87733 |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | hcf3bmt12_24_2_5_3 | 0.90790 | 0.00134 | 0.91058 |
| | | | | | | | | | | | hcf3bmt12_23_2_5_3 | 0.90282 | 0.00121 | 0.90523 |
| ncf2bmt11_22_2_5_3 | 1.4 | 80 | 21324 | 17059 | 8455 | 12.94 | 1.0E-04 | 0.92358 | 0.00131 | 0.92619 | hcf3bmt12_22_2_5_3 | 0.90006 | 0.00139 | 0.90284 |
| ncf2bmt11_21_2_5_3 | 1.4 | 80 | 20397 | 16317 | 8504 | 13.60 | 1.0E-04 | 0.91640 | 0.00145 | 0.91930 | hcf3bmt12_21_2_5_3 | 0.89948 | 0.00134 | 0.90216 |
| ncf2bmt11_20_2_5_3 | 1.4 | 80 | 19470 | 15576 | 8553 | 14.33 | 1.0E-04 | 0.91428 | 0.00133 | 0.91694 | hcf3bmt12_20_2_5_3 | 0.89698 | 0.00122 | 0.89941 |
| ncf2bmt11_19_2_5_3 | 1.4 | 80 | 18542 | 14834 | 8602 | 15.14 | 1.0E-04 | 0.91020 | 0.00130 | 0.91281 | hcf3bmt12_19_2_5_3 | 0.89282 | 0.00129 | 0.89541 |
| ncf2bmt11_18_2_5_3 | 1.4 | 80 | 17615 | 14092 | 8651 | 16.02 | 1.0E-04 | 0.90784 | 0.00135 | 0.91054 | hcf3bmt12_18_2_5_3 | 0.88897 | 0.00125 | 0.89148 |
| ncf2bmt11_17_2_5_3 | 1.4 | 80 | 16688 | 13351 | 8700 | 17.01 | 1.0E-04 | 0.90364 | 0.00123 | 0.90610 | hcf3bmt12_17_2_5_3 | 0.88452 | 0.00123 | 0.88697 |
| ncf2bmt11_16_2_5_3 | 1.4 | 80 | 15761 | 12609 | 8749 | 18.11 | 1.0E-04 | 0.90402 | 0.00132 | 0.90666 | hcf3bmt12_16_2_5_3 | 0.88688 | 0.00121 | 0.88929 |
| ncf2bmt11_15_2_5_3 | 1.4 | 80 | 14834 | 11867 | 8798 | 19.35 | 1.0E-04 | 0.90496 | 0.00145 | 0.90786 | hcf3bmt12_15_2_5_3 | 0.88496 | 0.00135 | 0.88765 |
| | | | | | | | | | | | | | | |
| ncf2bmt11_33_2_4_3 | 1.4 | 70 | 32490 | 22743 | 7866 | 9.03 | 1.0E-04 | 0.92631 | 0.00120 | 0.92871 | hcf3bmt12_33_2_4_3 | 0.90516 | 0.00118 | 0.90752 |
| ncf2bmt11_32_2_4_3 | 1.4 | 70 | 31562 | 22093 | 7915 | 9.35 | 1.0E-04 | 0.92304 | 0.00128 | 0.92560 | hcf3bmt12_32_2_4_3 | 0.90236 | 0.00135 | 0.90507 |
| ncf2bmt11_31_2_4_3 | 1.4 | 70 | 30634 | 21444 | 7964 | 9.69 | 1.0E-04 | 0.92250 | 0.00132 | 0.92514 | hcf3bmt12_31_2_4_3 | 0.90127 | 0.00111 | 0.90349 |
| ncf2bmt11_30_2_4_3 | 1.4 | 70 | 29705 | 20794 | 8013 | 10.06 | 1.0E-04 | 0.92048 | 0.00138 | 0.92325 | hcf3bmt12_30_2_4_3 | 0.89944 | 0.00124 | 0.90192 |

**Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncf2bmt11_29_2_4_3 | 1.4 | 70 | 28777 | 20144 | 8062 | 10.45 | 1.0E-04 | 0.91607 | 0.00135 | 0.91878 | hcf3bmt12_29_2_4_3 | 0.89544 | 0.00139 | 0.89823 |
| ncf2bmt11_28_2_4_3 | 1.4 | 70 | 27849 | 19494 | 8111 | 10.86 | 1.0E-04 | 0.91338 | 0.00129 | 0.91596 | hcf3bmt12_28_2_4_3 | 0.89451 | 0.00127 | 0.89706 |
| ncf2bmt11_27_2_4_3 | 1.4 | 70 | 26921 | 18844 | 8160 | 11.30 | 1.0E-04 | 0.91255 | 0.00127 | 0.91510 | hcf3bmt12_27_2_4_3 | 0.88990 | 0.00135 | 0.89261 |
| | | | | | | | | | | | | | | |
| ncf2bmt11_36_2_3_3 | 1.4 | 60 | 35320 | 21192 | 7719 | 9.51 | 1.0E-04 | 0.90382 | 0.00130 | 0.90642 | hcf3bmt12_36_2_3_3 | 0.88262 | 0.00120 | 0.88503 |
| ncf2bmt11_35_2_3_3 | 1.4 | 60 | 34391 | 20634 | 7768 | 9.83 | 1.0E-04 | 0.90020 | 0.00136 | 0.90291 | hcf3bmt12_35_2_3_3 | 0.87857 | 0.00132 | 0.88120 |
| ncf2bmt11_34_2_3_3 | 1.4 | 60 | 33461 | 20077 | 7817 | 10.16 | 1.0E-04 | 0.89689 | 0.00121 | 0.89932 | hcf3bmt12_34_2_3_3 | 0.87717 | 0.00111 | 0.87939 |
| ncf2bmt11_33_2_3_3 | 1.4 | 60 | 32532 | 19519 | 7866 | 10.52 | 1.0E-04 | 0.89834 | 0.00117 | 0.90069 | hcf3bmt12_33_2_3_3 | 0.87502 | 0.00127 | 0.87757 |
| ncf2bmt11_32_2_3_3 | 1.4 | 60 | 31602 | 18961 | 7915 | 10.90 | 1.0E-04 | 0.89483 | 0.00136 | 0.89755 | hcf3bmt12_32_2_3_3 | 0.87552 | 0.00129 | 0.87809 |
| ncf2bmt11_31_2_3_3 | 1.4 | 60 | 30673 | 18404 | 7964 | 11.29 | 1.0E-04 | 0.89450 | 0.00137 | 0.89723 | hcf3bmt12_31_2_3_3 | 0.87475 | 0.00139 | 0.87752 |
| ncf2bmt11_30_2_3_3 | 1.4 | 60 | 29743 | 17846 | 8013 | 11.72 | 1.0E-04 | 0.89227 | 0.00133 | 0.89493 | hcf3bmt12_30_2_3_3 | 0.87454 | 0.00121 | 0.87695 |
| **content in flooded containment vessel, array packaging model for CSI=2.0** | | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | | **HAC** | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | | |
| ncf3bmt11_24_1_5_3 | 0.0 | 80 | 23178 | 18542 | 8970 | 12.63 | 1.0E-04 | 0.92510 | 0.00131 | 0.92772 | hcf4bmt12_24_1_5_3 | 0.88778 | 0.00138 | 0.89054 |
| ncf3bmt11_23_1_5_3 | 0.0 | 80 | 22251 | 17801 | 9019 | 13.22 | 1.0E-04 | 0.92307 | 0.00144 | 0.92595 | hcf4bmt12_23_1_5_3 | 0.88545 | 0.00131 | 0.88806 |
| ncf3bmt11_22_1_5_3 | 0.0 | 80 | 21324 | 17059 | 9068 | 13.87 | 1.0E-04 | 0.91977 | 0.00125 | 0.92228 | hcf4bmt12_22_1_5_3 | 0.88238 | 0.00140 | 0.88519 |
| ncf3bmt11_21_1_5_3 | 0.0 | 80 | 20397 | 16317 | 9117 | 14.58 | 1.0E-04 | 0.91607 | 0.00134 | 0.91876 | hcf4bmt12_21_1_5_3 | 0.87917 | 0.00128 | 0.88173 |
| ncf3bmt11_20_1_5_3 | 0.0 | 80 | 19470 | 15576 | 9166 | 15.36 | 1.0E-04 | 0.91812 | 0.00123 | 0.92059 | hcf4bmt12_20_1_5_3 | 0.87731 | 0.00132 | 0.87995 |
| | | | | | | | | | | | | | | |
| ncf3bmt11_36_1_4_3 | 0.0 | 70 | 35275 | 24693 | 8332 | 8.81 | 1.0E-04 | 0.93179 | 0.00144 | 0.93467 | hcf4bmt12_36_1_4_3 | 0.89390 | 0.00117 | 0.89625 |
| ncf3bmt11_35_1_4_3 | 0.0 | 70 | 34347 | 24043 | 8381 | 9.10 | 1.0E-04 | 0.92998 | 0.00125 | 0.93248 | hcf4bmt12_35_1_4_3 | 0.89164 | 0.00140 | 0.89444 |
| ncf3bmt11_34_1_4_3 | 0.0 | 70 | 33419 | 23393 | 8430 | 9.41 | 1.0E-04 | 0.92792 | 0.00128 | 0.93049 | hcf4bmt12_34_1_4_3 | 0.88829 | 0.00123 | 0.89075 |
| ncf3bmt11_33_1_4_3 | 0.0 | 70 | 32490 | 22743 | 8479 | 9.73 | 1.0E-04 | 0.92421 | 0.00134 | 0.92690 | hcf4bmt12_33_1_4_3 | 0.88600 | 0.00117 | 0.88834 |

**Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncf3bmt11_32_1_4_3 | 0.0 | 70 | 31562 | 22093 | 8529 | 10.08 | 1.0E-04 | 0.92329 | 0.00131 | 0.92591 | hcf4bmt12_32_1_4_3 | 0.88581 | 0.00140 | 0.88861 |
| ncf3bmt11_31_1_4_3 | 0.0 | 70 | 30634 | 21444 | 8578 | 10.44 | 1.0E-04 | 0.91896 | 0.00132 | 0.92160 | hcf4bmt12_31_1_4_3 | 0.88314 | 0.00132 | 0.88577 |
| | | | | | | | | | | | | | | |
| ncf3bmt11_36_1_3_3 | 0.0 | 60 | 35320 | 21192 | 8332 | 10.26 | 1.0E-04 | 0.90201 | 0.00123 | 0.90447 | hcf4bmt12_36_1_3_3 | 0.86792 | 0.00130 | 0.87053 |
| ncf3bmt11_35_1_3_3 | 0.0 | 60 | 34391 | 20634 | 8381 | 10.60 | 1.0E-04 | 0.90103 | 0.00130 | 0.90363 | hcf4bmt12_35_1_3_3 | 0.86477 | 0.00150 | 0.86777 |
| ncf3bmt11_34_1_3_3 | 0.0 | 60 | 33461 | 20077 | 8430 | 10.96 | 1.0E-04 | 0.89984 | 0.00147 | 0.90278 | hcf4bmt12_34_1_3_3 | 0.86396 | 0.00137 | 0.86670 |
| ncf3bmt11_33_1_3_3 | 0.0 | 60 | 32532 | 19519 | 8479 | 11.34 | 1.0E-04 | 0.89745 | 0.00130 | 0.90004 | hcf4bmt12_33_1_3_3 | 0.86136 | 0.00134 | 0.86404 |
| ncf3bmt11_32_1_3_3 | 0.0 | 60 | 31602 | 18961 | 8529 | 11.74 | 1.0E-04 | 0.89310 | 0.00137 | 0.89585 | hcf4bmt12_32_1_3_3 | 0.86115 | 0.00124 | 0.86362 |
| ncf3bmt11_31_1_3_3 | 0.0 | 60 | 30673 | 18404 | 8578 | 12.17 | 1.0E-04 | 0.89440 | 0.00135 | 0.89711 | hcf4bmt12_31_1_3_3 | 0.85909 | 0.00151 | 0.86212 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | | | |
| ncf3bmt11_19_2_8_3 | 1.4 | 100 | 18496 | 18496 | 8602 | 12.14 | 1.0E-04 | 0.93577 | 0.00135 | 0.93847 | hcf4bmt12_19_2_8_3 | 0.89811 | 0.00149 | 0.90110 |
| ncf3bmt11_18_2_8_3 | 1.4 | 100 | 17571 | 17571 | 8651 | 12.85 | 1.0E-04 | 0.93186 | 0.00154 | 0.93494 | hcf4bmt12_18_2_8_3 | 0.89794 | 0.00151 | 0.90096 |
| ncf3bmt11_17_2_8_3 | 1.4 | 100 | 16646 | 16646 | 8700 | 13.64 | 1.0E-04 | 0.92731 | 0.00135 | 0.93002 | hcf4bmt12_17_2_8_3 | 0.89377 | 0.00134 | 0.89644 |
| ncf3bmt11_16_2_8_3 | 1.4 | 100 | 15721 | 15721 | 8749 | 14.53 | 1.0E-04 | 0.92992 | 0.00126 | 0.93244 | hcf4bmt12_16_2_8_3 | 0.89138 | 0.00121 | 0.89379 |
| ncf3bmt11_15_2_8_3 | 1.4 | 100 | 14796 | 14796 | 8798 | 15.52 | 1.0E-04 | 0.92597 | 0.00134 | 0.92865 | hcf4bmt12_15_2_8_3 | 0.89085 | 0.00130 | 0.89345 |
| ncf3bmt11_14_2_8_3 | 1.4 | 100 | 13872 | 13872 | 8847 | 16.65 | 1.0E-04 | 0.91788 | 0.00124 | 0.92037 | hcf4bmt12_14_2_8_3 | 0.88486 | 0.00143 | 0.88772 |
| ncf3bmt11_13_2_8_3 | 1.4 | 100 | 12947 | 12947 | 8896 | 17.94 | 1.0E-04 | 0.91410 | 0.00116 | 0.91642 | hcf4bmt12_13_2_8_3 | 0.88161 | 0.00147 | 0.88454 |
| ncf3bmt11_12_2_8_3 | 1.4 | 100 | 11097 | 11097 | 8995 | 21.16 | 1.0E-04 | 0.90586 | 0.00164 | 0.90915 | hcf4bmt12_12_2_8_3 | 0.87451 | 0.00129 | 0.87708 |
| ncf3bmt11_11_2_8_3 | 1.4 | 100 | 10173 | 10173 | 9044 | 23.20 | 1.0E-04 | 0.90034 | 0.00144 | 0.90322 | hcf4bmt12_11_2_8_3 | 0.86789 | 0.00129 | 0.87047 |
| | | | | | | | | | | | | | | |
| ncf3bmt11_24_2_7_3 | 1.4 | 95 | 23134 | 21977 | 8357 | 9.92 | 1.0E-04 | 0.93439 | 0.00143 | 0.93724 | hcf4bmt12_24_2_7_3 | 0.89896 | 0.00122 | 0.90141 |
| ncf3bmt11_23_2_7_3 | 1.4 | 95 | 22209 | 21098 | 8406 | 10.40 | 1.0E-04 | 0.93453 | 0.00131 | 0.93716 | hcf4bmt12_23_2_7_3 | 0.89761 | 0.00131 | 0.90024 |
| ncf3bmt11_22_2_7_3 | 1.4 | 95 | 21283 | 20219 | 8455 | 10.91 | 1.0E-04 | 0.92992 | 0.00130 | 0.93252 | hcf4bmt12_22_2_7_3 | 0.89290 | 0.00142 | 0.89574 |
| ncf3bmt11_21_2_7_3 | 1.4 | 95 | 20358 | 19340 | 8504 | 11.48 | 1.0E-04 | 0.92588 | 0.00136 | 0.92860 | hcf4bmt12_21_2_7_3 | 0.89171 | 0.00135 | 0.89441 |

**Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncf3bmt11_20_2_7_3 | 1.4 | 95 | 19433 | 18461 | 8553 | 12.09 | 1.0E-04 | 0.92140 | 0.00126 | 0.92392 | hcf4bmt12_20_2_7_3 | 0.88860 | 0.00138 | 0.89135 |
| ncf3bmt11_19_2_7_3 | 1.4 | 95 | 18507 | 17582 | 8602 | 12.77 | 1.0E-04 | 0.91794 | 0.00128 | 0.92049 | hcf4bmt12_19_2_7_3 | 0.88544 | 0.00131 | 0.88806 |
| ncf3bmt11_18_2_7_3 | 1.4 | 95 | 17582 | 16703 | 8651 | 13.52 | 1.0E-04 | 0.91432 | 0.00143 | 0.91717 | hcf4bmt12_18_2_7_3 | 0.87916 | 0.00119 | 0.88154 |
| | | | | | | | | | | | | | | |
| ncf3bmt11_28_2_6_3 | 1.4 | 90 | 27778 | 25001 | 8111 | 8.47 | 1.0E-04 | 0.93537 | 0.00113 | 0.93763 | hcf4bmt12_28_2_6_3 | 0.89885 | 0.00127 | 0.90138 |
| ncf3bmt11_27_2_6_3 | 1.4 | 90 | 26852 | 24167 | 8160 | 8.81 | 1.0E-04 | 0.93322 | 0.00129 | 0.93581 | hcf4bmt12_27_2_6_3 | 0.89628 | 0.00137 | 0.89902 |
| ncf3bmt11_26_2_6_3 | 1.4 | 90 | 25927 | 23334 | 8209 | 9.18 | 1.0E-04 | 0.92880 | 0.00119 | 0.93117 | hcf4bmt12_26_2_6_3 | 0.89189 | 0.00127 | 0.89443 |
| ncf3bmt11_25_2_6_3 | 1.4 | 90 | 24075 | 21667 | 8308 | 10.01 | 1.0E-04 | 0.92446 | 0.00149 | 0.92745 | hcf4bmt12_25_2_6_3 | 0.88877 | 0.00144 | 0.89165 |
| ncf3bmt11_24_2_6_3 | 1.4 | 90 | 23149 | 20834 | 8357 | 10.47 | 1.0E-04 | 0.92270 | 0.00138 | 0.92547 | hcf4bmt12_24_2_6_3 | 0.88731 | 0.00129 | 0.88990 |
| ncf3bmt11_23_2_6_3 | 1.4 | 90 | 22223 | 20000 | 8406 | 10.97 | 1.0E-04 | 0.91857 | 0.00138 | 0.92133 | hcf4bmt12_23_2_6_3 | 0.88245 | 0.00133 | 0.88512 |
| ncf3bmt11_22_2_6_3 | 1.4 | 90 | 21297 | 19167 | 8455 | 11.51 | 1.0E-04 | 0.91639 | 0.00145 | 0.91929 | hcf4bmt12_22_2_6_3 | 0.87838 | 0.00119 | 0.88076 |
| | | | | | | | | | | | | | | |
| ncf3bmt11_34_2_5_3 | 1.4 | 80 | 33376 | 26701 | 7817 | 7.64 | 1.0E-04 | 0.92540 | 0.00127 | 0.92795 | hcf4bmt12_34_2_5_3 | 0.88608 | 0.00131 | 0.88869 |
| ncf3bmt11_33_2_5_3 | 1.4 | 80 | 32449 | 25959 | 7866 | 7.91 | 1.0E-04 | 0.92436 | 0.00140 | 0.92716 | hcf4bmt12_33_2_5_3 | 0.88749 | 0.00156 | 0.89061 |
| ncf3bmt11_32_2_5_3 | 1.4 | 80 | 31522 | 25218 | 7915 | 8.19 | 1.0E-04 | 0.91919 | 0.00120 | 0.92159 | hcf4bmt12_32_2_5_3 | 0.88581 | 0.00130 | 0.88841 |
| ncf3bmt11_31_2_5_3 | 1.4 | 80 | 30595 | 24476 | 7964 | 8.49 | 1.0E-04 | 0.91747 | 0.00126 | 0.92000 | hcf4bmt12_31_2_5_3 | 0.88299 | 0.00141 | 0.88582 |
| | | | | | | | | | | | | | | |
| ncf3bmt11_36_2_4_3 | 1.4 | 70 | 35275 | 24693 | 7719 | 8.16 | 1.0E-04 | 0.90114 | 0.00120 | 0.90353 | hcf4bmt12_36_2_4_3 | 0.86624 | 0.00106 | 0.86835 |
| ncf3bmt11_35_2_4_3 | 1.4 | 70 | 34347 | 24043 | 7768 | 8.43 | 1.0E-04 | 0.89908 | 0.00131 | 0.90169 | hcf4bmt12_35_2_4_3 | 0.86262 | 0.00143 | 0.86549 |
| ncf3bmt11_34_2_4_3 | 1.4 | 70 | 33419 | 23393 | 7817 | 8.72 | 1.0E-04 | 0.89841 | 0.00115 | 0.90070 | hcf4bmt12_34_2_4_3 | 0.86008 | 0.00129 | 0.86265 |
| | | | | | | | | | | | | | | |
| ncf3bmt11_36_2_3_3 | 1.4 | 60 | 35320 | 21192 | 7719 | 9.51 | 1.0E-04 | 0.87206 | 0.00120 | 0.87446 | hcf4bmt12_36_2_3_3 | 0.83873 | 0.00122 | 0.84116 |
| ncf3bmt11_35_2_3_3 | 1.4 | 60 | 34391 | 20634 | 7768 | 9.83 | 1.0E-04 | 0.86988 | 0.00123 | 0.87235 | hcf4bmt12_35_2_3_3 | 0.83470 | 0.00130 | 0.83731 |
| ncf3bmt11_34_2_3_3 | 1.4 | 60 | 33461 | 20077 | 7817 | 10.16 | 1.0E-04 | 0.86818 | 0.00130 | 0.87078 | hcf4bmt12_34_2_3_3 | 0.83204 | 0.00117 | 0.83439 |

**Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **content in flooded containment vessel, array packaging model for CSI=3.1** | | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | | **HAC** | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | | |
| nctf5bmt11_36_1_5_3 | 0.0 | 80 | 35231 | 28184 | 8332 | 7.72 | 1.0E-04 | 0.92519 | 0.00130 | 0.92779 | hctf5bmt12_36_1_5_3 | 0.90361 | 0.00119 | 0.90600 |
| nctf5bmt11_35_1_5_3 | 0.0 | 80 | 34303 | 27443 | 8381 | 7.97 | 1.0E-04 | 0.91980 | 0.00138 | 0.92255 | hctf5bmt12_35_1_5_3 | 0.90246 | 0.00137 | 0.90520 |
| nctf5bmt11_34_1_5_3 | 0.0 | 80 | 33376 | 26701 | 8430 | 8.24 | 1.0E-04 | 0.92113 | 0.00138 | 0.92389 | hctf5bmt12_34_1_5_3 | 0.89974 | 0.00136 | 0.90246 |
| nctf5bmt11_33_1_5_3 | 0.0 | 80 | 32449 | 25959 | 8479 | 8.53 | 1.0E-04 | 0.91846 | 0.00117 | 0.92079 | hctf5bmt12_33_1_5_3 | 0.89587 | 0.00129 | 0.89845 |
| nctf5bmt11_32_1_5_3 | 0.0 | 80 | 31522 | 25218 | 8529 | 8.83 | 1.0E-04 | 0.91556 | 0.00119 | 0.91795 | hctf5bmt12_32_1_5_3 | 0.89459 | 0.00148 | 0.89755 |
| | | | | | | | | | | | | | | |
| nctf5bmt11_36_1_4_3 | 0.0 | 70 | 35275 | 24693 | 8332 | 8.81 | 1.0E-04 | 0.90020 | 0.00139 | 0.90299 | hctf5bmt12_36_1_4_3 | 0.87905 | 0.00142 | 0.88188 |
| nctf5bmt11_35_1_4_3 | 0.0 | 70 | 34347 | 24043 | 8381 | 9.10 | 1.0E-04 | 0.89748 | 0.00118 | 0.89984 | hctf5bmt12_35_1_4_3 | 0.87388 | 0.00126 | 0.87639 |
| nctf5bmt11_34_1_4_3 | 0.0 | 70 | 33419 | 23393 | 8430 | 9.41 | 1.0E-04 | 0.89206 | 0.00115 | 0.89437 | hctf5bmt12_34_1_4_3 | 0.87550 | 0.00150 | 0.87851 |
| | | | | | | | | | | | | | | |
| nctf5bmt11_36_1_3_3 | 0.0 | 60 | 35320 | 21192 | 8332 | 10.26 | 1.0E-04 | 0.87170 | 0.00131 | 0.87433 | hctf5bmt12_36_1_3_3 | 0.85181 | 0.00121 | 0.85423 |
| nctf5bmt11_35_1_3_3 | 0.0 | 60 | 34391 | 20634 | 8381 | 10.60 | 1.0E-04 | 0.87122 | 0.00146 | 0.87414 | hctf5bmt12_35_1_3_3 | 0.85100 | 0.00135 | 0.85369 |
| nctf5bmt11_26_2_8_3 | 1.4 | 100 | 25894 | 25894 | 8209 | 8.28 | 1.0E-04 | 0.92880 | 0.00114 | 0.93108 | hctf5bmt12_26_2_8_3 | 0.90779 | 0.00115 | 0.91009 |
| nctf5bmt11_25_2_8_3 | 1.4 | 100 | 24969 | 24969 | 8258 | 8.63 | 1.0E-04 | 0.92250 | 0.00118 | 0.92485 | hctf5bmt12_25_2_8_3 | 0.90619 | 0.00136 | 0.90890 |
| nctf5bmt11_24_2_8_3 | 1.4 | 100 | 23119 | 23119 | 8357 | 9.43 | 1.0E-04 | 0.92133 | 0.00137 | 0.92406 | hctf5bmt12_24_2_8_3 | 0.90163 | 0.00125 | 0.90413 |
| nctf5bmt11_23_2_8_3 | 1.4 | 100 | 22195 | 22195 | 8406 | 9.89 | 1.0E-04 | 0.92154 | 0.00124 | 0.92401 | hctf5bmt12_23_2_8_3 | 0.90028 | 0.00150 | 0.90329 |
| nctf5bmt11_22_2_8_3 | 1.4 | 100 | 21270 | 21270 | 8455 | 10.38 | 1.0E-04 | 0.91455 | 0.00141 | 0.91737 | hctf5bmt12_22_2_8_3 | 0.89693 | 0.00148 | 0.89990 |
| nctf5bmt11_21_2_8_3 | 1.4 | 100 | 20345 | 20345 | 8504 | 10.91 | 1.0E-04 | 0.91027 | 0.00140 | 0.91306 | hctf5bmt12_21_2_8_3 | 0.89420 | 0.00140 | 0.89700 |
| | | | | | | | | | | | | | | |
| nctf5bmt11_30_2_7_3 | 1.4 | 95 | 29612 | 28131 | 8013 | 7.43 | 1.0E-04 | 0.92409 | 0.00126 | 0.92660 | hctf5bmt12_30_2_7_3 | 0.90413 | 0.00129 | 0.90670 |
| nctf5bmt11_29_2_7_3 | 1.4 | 95 | 28686 | 27252 | 8062 | 7.72 | 1.0E-04 | 0.92175 | 0.00160 | 0.92495 | hctf5bmt12_29_2_7_3 | 0.90149 | 0.00125 | 0.90400 |

**Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model**

| case name | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| nctf5bmt11_28_2_7_3 | 1.4 | 95 | 27761 | 26373 | 8111 | 8.03 | 1.0E-04 | 0.91662 | 0.00149 | 0.91960 | hctf5bmt12_28_2_7_3 | 0.89554 | 0.00127 | 0.89809 |
| nctf5bmt11_27_2_7_3 | 1.4 | 95 | 26835 | 25494 | 8160 | 8.35 | 1.0E-04 | 0.91290 | 0.00112 | 0.91515 | hctf5bmt12_27_2_7_3 | 0.89349 | 0.00120 | 0.89588 |
| nctf5bmt11_26_2_7_3 | 1.4 | 95 | 25910 | 24615 | 8209 | 8.71 | 1.0E-04 | 0.90934 | 0.00124 | 0.91182 | hctf5bmt12_26_2_7_3 | 0.88954 | 0.00116 | 0.89187 |
| nctf5bmt11_25_2_7_3 | 1.4 | 95 | 24985 | 23736 | 8258 | 9.08 | 1.0E-04 | 0.90900 | 0.00116 | 0.91131 | hctf5bmt12_25_2_7_3 | 0.88811 | 0.00120 | 0.89051 |
| nctf5bmt11_24_2_7_3 | 1.4 | 95 | 23134 | 21977 | 8357 | 9.92 | 1.0E-04 | 0.90460 | 0.00146 | 0.90752 | hctf5bmt12_24_2_7_3 | 0.88850 | 0.00132 | 0.89113 |
| | | | | | | | | | | | | | | |
| nctf5bmt11_35_2_6_3 | 1.4 | 90 | 34260 | 30834 | 7768 | 6.58 | 1.0E-04 | 0.92200 | 0.00132 | 0.92464 | hctf5bmt12_35_2_6_3 | 0.90072 | 0.00123 | 0.90318 |
| nctf5bmt11_34_2_6_3 | 1.4 | 90 | 33334 | 30001 | 7817 | 6.80 | 1.0E-04 | 0.91799 | 0.00130 | 0.92059 | hctf5bmt12_34_2_6_3 | 0.89921 | 0.00112 | 0.90145 |
| nctf5bmt11_33_2_6_3 | 1.4 | 90 | 32408 | 29167 | 7866 | 7.04 | 1.0E-04 | 0.91789 | 0.00136 | 0.92061 | hctf5bmt12_33_2_6_3 | 0.89931 | 0.00137 | 0.90206 |
| nctf5bmt11_32_2_6_3 | 1.4 | 90 | 31482 | 28334 | 7915 | 7.29 | 1.0E-04 | 0.91514 | 0.00113 | 0.91740 | hctf5bmt12_32_2_6_3 | 0.89395 | 0.00118 | 0.89631 |
| | | | | | | | | | | | | | | |
| nctf5bmt11_36_2_5_3 | 1.4 | 80 | 35231 | 28184 | 7719 | 7.15 | 1.0E-04 | 0.89457 | 0.00141 | 0.89739 | hctf5bmt12_36_2_5_3 | 0.87726 | 0.00158 | 0.88041 |
| nctf5bmt11_35_2_5_3 | 1.4 | 80 | 34303 | 27443 | 7768 | 7.39 | 1.0E-04 | 0.89528 | 0.00129 | 0.89787 | hctf5bmt12_35_2_5_3 | 0.87420 | 0.00120 | 0.87660 |
| nctf5bmt11_34_2_5_3 | 1.4 | 80 | 33376 | 26701 | 7817 | 7.64 | 1.0E-04 | 0.89346 | 0.00115 | 0.89576 | hctf5bmt12_34_2_5_3 | 0.87530 | 0.00122 | 0.87775 |
| | | | | | | | | | | | | | | |
| nctf5bmt11_36_2_4_3 | 1.4 | 70 | 35275 | 24693 | 7719 | 8.16 | 1.0E-04 | 0.87119 | 0.00121 | 0.87361 | hctf5bmt12_36_2_4_3 | 0.85030 | 0.00147 | 0.85323 |
| nctf5bmt11_35_2_4_3 | 1.4 | 70 | 34347 | 24043 | 7768 | 8.43 | 1.0E-04 | 0.86740 | 0.00110 | 0.86959 | hctf5bmt12_35_2_4_3 | 0.84958 | 0.00107 | 0.85173 |
| | | | | | | | | | | | | | | |
| nctf5bmt11_36_2_3_3 | 1.4 | 60 | 35320 | 21192 | 7719 | 9.51 | 1.0E-04 | 0.84212 | 0.00121 | 0.84454 | hctf5bmt12_36_2_3_3 | 0.82413 | 0.00117 | 0.82647 |
| nctf5bmt11_35_2_3_3 | 1.4 | 60 | 34391 | 20634 | 7768 | 9.83 | 1.0E-04 | 0.83953 | 0.00135 | 0.84223 | hctf5bmt12_35_2_3_3 | 0.82142 | 0.00125 | 0.82393 |

**Table 6.9.6-11b. Comparison of NCT results for HEU broken metal content in ES-3100 NCT packaging calculation models.**

**Note:** Reference results for content homogenized over volume of containment vessel are highlighted. Results shown below the reference results are for modified cases where the HEU packaging fraction varies from 0.2 to 0.6 and the content is homogenized with 500 g polyethylene.

| nciabmt11 | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **nciapbmflt11** | **np (in.)** | **PF** | **U (g)** | **$^{235}U$ (g)** | **$H_2O$ (g)** | **h/x** | **moifr** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** | **nciapbmfdt11** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** |
| **content in flooded containment vessel, array packaging model for CSI=0.0** | | | | | | | | | | | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | | |
| _4_1_5_3 | 0.0 | 80.0 | 3709 | 2967 | 10001 | 87.98 | 1.0E-04 | 0.91835 | 0.00149 | 0.92133 | | | | |
| _1_2_4_5 | 0.0 | 0.2 | 4000 | 3200 | 9443 | 82.26 | 1.0E-04 | 0.68903 | 0.00121 | 0.69146 | _1_2_4_5 | 0.85247 | 0.00116 | 0.85479 |
| _1_3_4_5 | 0.0 | 0.3 | 4000 | 3200 | 9443 | 82.26 | 1.0E-04 | 0.65516 | 0.00136 | 0.65788 | _1_3_4_5 | 0.84236 | 0.00121 | 0.84477 |
| _1_4_4_5 | 0.0 | 0.4 | 4000 | 3200 | 9443 | 82.26 | 1.0E-04 | 0.63720 | 0.00123 | 0.63965 | _1_4_4_5 | 0.83993 | 0.00137 | 0.84267 |
| _1_5_4_5 | 0.0 | 0.5 | 4000 | 3200 | 9443 | 82.26 | 1.0E-04 | 0.62195 | 0.00105 | 0.62405 | _1_5_4_5 | 0.83701 | 0.00126 | 0.83953 |
| _1_6_4_5 | 0.0 | 0.6 | 4000 | 3200 | 9443 | 82.26 | 1.0E-04 | 0.61282 | 0.00101 | 0.61484 | _1_6_4_5 | 0.83523 | 0.00118 | 0.83758 |
| | | | | | | | | | | | | | | |
| _5_1_4_3 | 0.0 | 70.0 | 4642 | 3249 | 9952 | 79.95 | 1.0E-04 | 0.91799 | 0.00136 | 0.92070 | | | | |
| _1_2_5_4 | 0.0 | 0.2 | 5000 | 3500 | 9390 | 74.82 | 1.0E-04 | 0.70497 | 0.00140 | 0.70778 | _1_2_5_4 | 0.85830 | 0.00155 | 0.86140 |
| _1_3_5_4 | 0.0 | 0.3 | 5000 | 3500 | 9390 | 74.82 | 1.0E-04 | 0.66703 | 0.00120 | 0.66942 | _1_3_5_4 | 0.85296 | 0.00124 | 0.85545 |
| _1_4_5_4 | 0.0 | 0.4 | 5000 | 3500 | 9390 | 74.82 | 1.0E-04 | 0.64665 | 0.00120 | 0.64904 | _1_4_5_4 | 0.84681 | 0.00155 | 0.84991 |
| _1_5_5_4 | 0.0 | 0.5 | 5000 | 3500 | 9390 | 74.82 | 1.0E-04 | 0.63242 | 0.00127 | 0.63496 | _1_5_5_4 | 0.84544 | 0.00142 | 0.84827 |
| _1_6_5_4 | 0.0 | 0.6 | 5000 | 3500 | 9390 | 74.82 | 1.0E-04 | 0.62104 | 0.00129 | 0.62362 | _1_6_5_4 | 0.84411 | 0.00122 | 0.84656 |
| | | | | | | | | | | | | | | |
| _6_1_3_3 | 0.0 | 60.0 | 5577 | 3346 | 9903 | 77.24 | 1.0E-04 | 0.91221 | 0.00147 | 0.91515 | | | | |
| _1_2_6_3 | 0.0 | 0.2 | 6000 | 3600 | 9338 | 72.36 | 1.0E-04 | 0.71137 | 0.00124 | 0.71386 | _1_2_6_3 | 0.85681 | 0.00117 | 0.85916 |
| _1_3_6_3 | 0.0 | 0.3 | 6000 | 3600 | 9338 | 72.36 | 1.0E-04 | 0.67406 | 0.00124 | 0.67654 | _1_3_6_3 | 0.85226 | 0.00126 | 0.85478 |
| _1_4_6_3 | 0.0 | 0.4 | 6000 | 3600 | 9338 | 72.36 | 1.0E-04 | 0.65407 | 0.00115 | 0.65637 | _1_4_6_3 | 0.84813 | 0.00119 | 0.85052 |

**Table 6.9.6-11b. Comparison of NCT results for HEU broken metal content in ES-3100 NCT packaging calculation models.**

**Note:** Reference results for content homogenized over volume of containment vessel are highlighted. Results shown below the reference results are for modified cases where the HEU packaging fraction varies from 0.2 to 0.6 and the content is homogenized with 500 g polyethylene.

| nciabmt11 | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **nciapbmflt11** | **np (in.)** | **PF** | **U (g)** | **$^{235}U$ (g)** | **$H_2O$ (g)** | **h/x** | **moifr** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** | **nciapbmfdt11** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** |
| _1_5_6_3 | 0.0 | 0.5 | 6000 | 3600 | 9338 | 72.36 | 1.0E-04 | 0.63393 | 0.00117 | 0.63626 | _1_5_6_3 | 0.84385 | 0.00128 | 0.84642 |
| _1_6_6_3 | 0.0 | 0.6 | 6000 | 3600 | 9338 | 72.36 | 1.0E-04 | 0.62196 | 0.00126 | 0.62449 | _1_6_6_3 | 0.84286 | 0.00127 | 0.84541 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | | | |
| _3_2_8_3 | 1.4 | 100.0 | 2774 | 2774 | 9436 | 88.78 | 1.0E-04 | 0.90131 | 0.00139 | 0.90409 | | | | |
| _2_2_3_8 | 1.4 | 0.2 | 3000 | 3000 | 8882 | 82.86 | 1.0E-04 | 0.57463 | 0.00111 | 0.57684 | _2_2_3_8 | 0.81623 | 0.00130 | 0.81883 |
| _2_3_3_8 | 1.4 | 0.3 | 3000 | 3000 | 8882 | 82.86 | 1.0E-04 | 0.54703 | 0.00098 | 0.54900 | _2_3_3_8 | 0.81643 | 0.00134 | 0.81912 |
| _2_4_3_8 | 1.4 | 0.4 | 3000 | 3000 | 8882 | 82.86 | 1.0E-04 | 0.53274 | 0.00097 | 0.53467 | _2_4_3_8 | 0.81357 | 0.00122 | 0.81600 |
| _2_5_3_8 | 1.4 | 0.5 | 3000 | 3000 | 8882 | 82.86 | 1.0E-04 | 0.52613 | 0.00105 | 0.52822 | _2_5_3_8 | 0.81038 | 0.00125 | 0.81288 |
| _2_6_3_8 | 1.4 | 0.6 | 3000 | 3000 | 8882 | 82.86 | 1.0E-04 | 0.51882 | 0.00092 | 0.52065 | _2_6_3_8 | 0.81249 | 0.00116 | 0.81482 |
| | | | | | | | | | | | | | | |
| _4_2_7_3 | 1.4 | 95.0 | 3701 | 3516 | 9387 | 69.68 | 1.0E-04 | 0.91690 | 0.00149 | 0.91987 | | | | |
| _2_2_4_7 | 1.4 | 0.2 | 4000 | 3800 | 8829 | 65.05 | 1.0E-04 | 0.61562 | 0.00115 | 0.61792 | _2_2_4_7 | 0.85451 | 0.00154 | 0.85759 |
| _2_3_4_7 | 1.4 | 0.3 | 4000 | 3800 | 8829 | 65.05 | 1.0E-04 | 0.58602 | 0.00121 | 0.58843 | _2_3_4_7 | 0.84752 | 0.00128 | 0.85009 |
| _2_4_4_7 | 1.4 | 0.4 | 4000 | 3800 | 8829 | 65.05 | 1.0E-04 | 0.56904 | 0.00124 | 0.57153 | _2_4_4_7 | 0.84935 | 0.00118 | 0.85170 |
| _2_5_4_7 | 1.4 | 0.5 | 4000 | 3800 | 8829 | 65.05 | 1.0E-04 | 0.55712 | 0.00096 | 0.55904 | _2_5_4_7 | 0.84837 | 0.00138 | 0.85113 |
| _2_6_4_7 | 1.4 | 0.6 | 4000 | 3800 | 8829 | 65.05 | 1.0E-04 | 0.55125 | 0.00100 | 0.55326 | _2_6_4_7 | 0.84715 | 0.00114 | 0.84943 |
| | | | | | | | | | | | | | | |
| _4_2_6_3 | 1.4 | 90.0 | 3704 | 3333 | 9387 | 73.50 | 1.0E-04 | 0.90541 | 0.00147 | 0.90835 | | | | |
| _2_2_4_6 | 1.4 | 0.2 | 4000 | 3600 | 8829 | 68.67 | 1.0E-04 | 0.60511 | 0.00103 | 0.60717 | _2_2_4_6 | 0.84248 | 0.00138 | 0.84524 |
| _2_3_4_6 | 1.4 | 0.3 | 4000 | 3600 | 8829 | 68.67 | 1.0E-04 | 0.57445 | 0.00092 | 0.57628 | _2_3_4_6 | 0.83740 | 0.00119 | 0.83978 |
| _2_4_4_6 | 1.4 | 0.4 | 4000 | 3600 | 8829 | 68.67 | 1.0E-04 | 0.55835 | 0.00103 | 0.56041 | _2_4_4_6 | 0.83957 | 0.00113 | 0.84184 |

**Table 6.9.6-11b. Comparison of NCT results for HEU broken metal content in ES-3100 NCT packaging calculation models.**

**Note:** Reference results for content homogenized over volume of containment vessel are highlighted. Results shown below the reference results are for modified cases where the HEU packaging fraction varies from 0.2 to 0.6 and the content is homogenized with 500 g polyethylene.

| nciabmt11 | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **nciapbmflt11** | **np (in.)** | **PF** | **U (g)** | **$^{235}U$ (g)** | **$H_2O$ (g)** | **h/x** | **moifr** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** | **nciapbmfdt11** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** |
| _2_5_4_6 | 1.4 | 0.5 | 4000 | 3600 | 8829 | 68.67 | 1.0E-04 | 0.54727 | 0.00106 | 0.54939 | _2_5_4_6 | 0.83601 | 0.00137 | 0.83875 |
| _2_6_4_6 | 1.4 | 0.6 | 4000 | 3600 | 8829 | 68.67 | 1.0E-04 | 0.53974 | 0.00107 | 0.54189 | _2_6_4_6 | 0.83732 | 0.00140 | 0.84011 |
| | | | | | | | | | | | | | | |
| _6_2_5_3 | 1.4 | 80.0 | 5563 | 4450 | 9289 | 54.48 | 1.0E-04 | 0.91981 | 0.00127 | 0.92235 | | | | |
| _2_2_6_5 | 1.4 | 0.2 | 6000 | 4800 | 8723 | 50.93 | 1.0E-04 | 0.66266 | 0.00117 | 0.66500 | _2_2_6_5 | 0.87671 | 0.00141 | 0.87952 |
| _2_3_6_5 | 1.4 | 0.3 | 6000 | 4800 | 8723 | 50.93 | 1.0E-04 | 0.62900 | 0.00108 | 0.63116 | _2_3_6_5 | 0.87268 | 0.00141 | 0.87551 |
| _2_4_6_5 | 1.4 | 0.4 | 6000 | 4800 | 8723 | 50.93 | 1.0E-04 | 0.60636 | 0.00106 | 0.60848 | _2_4_6_5 | 0.87070 | 0.00137 | 0.87344 |
| _2_5_6_5 | 1.4 | 0.5 | 6000 | 4800 | 8723 | 50.93 | 1.0E-04 | 0.59549 | 0.00110 | 0.59769 | _2_5_6_5 | 0.87064 | 0.00126 | 0.87316 |
| _2_6_6_5 | 1.4 | 0.6 | 6000 | 4800 | 8723 | 50.93 | 1.0E-04 | 0.58580 | 0.00104 | 0.58789 | _2_6_6_5 | 0.86937 | 0.00136 | 0.87209 |
| | | | | | | | | | | | | | | |
| _8_2_4_3 | 1.4 | 70.0 | 7426 | 5198 | 9191 | 46.15 | 1.0E-04 | 0.91902 | 0.00137 | 0.92175 | | | | |
| _2_2_8_4 | 1.4 | 0.2 | 8000 | 5600 | 8618 | 43.16 | 1.0E-04 | 0.69894 | 0.00117 | 0.70128 | _2_2_8_4 | 0.88757 | 0.00154 | 0.89065 |
| _2_3_8_4 | 1.4 | 0.3 | 8000 | 5600 | 8618 | 43.16 | 1.0E-04 | 0.65861 | 0.00101 | 0.66064 | _2_3_8_4 | 0.88142 | 0.00149 | 0.88440 |
| _2_4_8_4 | 1.4 | 0.4 | 8000 | 5600 | 8618 | 43.16 | 1.0E-04 | 0.63538 | 0.00119 | 0.63775 | _2_4_8_4 | 0.88292 | 0.00164 | 0.88621 |
| _2_5_8_4 | 1.4 | 0.5 | 8000 | 5600 | 8618 | 43.16 | 1.0E-04 | 0.62021 | 0.00120 | 0.62260 | _2_5_8_4 | 0.88202 | 0.00141 | 0.88484 |
| _2_6_8_4 | 1.4 | 0.6 | 8000 | 5600 | 8618 | 43.16 | 1.0E-04 | 0.61023 | 0.00116 | 0.61255 | _2_6_8_4 | 0.88175 | 0.00132 | 0.88439 |
| | | | | | | | | | | | | | | |
| _12_2_3_3 | 1.4 | 60.0 | 11154 | 6692 | 8995 | 35.08 | 1.0E-04 | 0.91502 | 0.00155 | 0.91812 | | | | |
| _2_2_12_3 | 1.4 | 0.2 | 12000 | 7200 | 8407 | 32.81 | 1.0E-04 | 0.75340 | 0.00124 | 0.75588 | _2_2_12_3 | 0.90142 | 0.00133 | 0.90409 |
| _2_3_12_3 | 1.4 | 0.3 | 12000 | 7200 | 8407 | 32.81 | 1.0E-04 | 0.71017 | 0.00101 | 0.71220 | _2_3_12_3 | 0.90203 | 0.00119 | 0.90441 |
| _2_4_12_3 | 1.4 | 0.4 | 12000 | 7200 | 8407 | 32.81 | 1.0E-04 | 0.68355 | 0.00103 | 0.68561 | _2_4_12_3 | 0.89718 | 0.00145 | 0.90009 |

**Table 6.9.6-11b. Comparison of NCT results for HEU broken metal content in ES-3100 NCT packaging calculation models.**

**Note:** Reference results for content homogenized over volume of containment vessel are highlighted. Results shown below the reference results are for modified cases where the HEU packaging fraction varies from 0.2 to 0.6 and the content is homogenized with 500 g polyethylene.

| nciabmt11 | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **nciapbmflt11** | **np (in.)** | **PF** | **U (g)** | **$^{235}U$ (g)** | **$H_2O$ (g)** | **h/x** | **moifr** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** | **nciapbmfdt11** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** |
| _2_5_12_3 | 1.4 | 0.5 | 12000 | 7200 | 8407 | 32.81 | 1.0E-04 | 0.66830 | 0.00090 | 0.67011 | _2_5_12_3 | 0.90008 | 0.00114 | 0.90237 |
| _2_6_12_3 | 1.4 | 0.6 | 12000 | 7200 | 8407 | 32.81 | 1.0E-04 | 0.65711 | 0.00100 | 0.65912 | _2_6_12_3 | 0.89900 | 0.00120 | 0.90140 |

**Table 6.9.6-11c. Comparison of HAC results for HEU broken metal content in ES-3100 HAC packaging calculation models.**

**Note:** Reference results for content homogenized over volume of containment vessel are highlighted. Results are for modified cases where the HEU packaging fraction varies from 0.2 to 0.6 and the content is homogenized with 500 g polyethylene.

| hciabmt12 | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **hciapbmflt12** | **np (in.)** | **PF** | **U (g)** | **$^{235}U$ (g)** | **$H_2O$ (g)** | **h/x** | **moifr** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** | **hciapbmfdt12** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** |
| **content in flooded containment vessel, array packaging model for CSI=0.0** | | | | | | | | | | | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | | |
| _4_1_5_3 | 0.0 | 80.0 | 3709 | 2967 | 10001 | 87.98 | 1.0E-04 | 0.92156 | 0.00160 | 0.92476 | | | | |
| _1_2_4_5 | 0.0 | 0.2 | 4000 | 3200 | 9443 | 82.26 | 1.0E-04 | 0.69676 | 0.00134 | 0.69944 | _1_2_4_5 | 0.85244 | 0.00119 | 0.85481 |
| _1_3_4_5 | 0.0 | 0.3 | 4000 | 3200 | 9443 | 82.26 | 1.0E-04 | 0.66231 | 0.00119 | 0.66469 | _1_3_4_5 | 0.84158 | 0.00146 | 0.84451 |
| _1_4_4_5 | 0.0 | 0.4 | 4000 | 3200 | 9443 | 82.26 | 1.0E-04 | 0.64127 | 0.00133 | 0.64392 | _1_4_4_5 | 0.84036 | 0.00120 | 0.84276 |
| _1_5_4_5 | 0.0 | 0.5 | 4000 | 3200 | 9443 | 82.26 | 1.0E-04 | 0.62704 | 0.00115 | 0.62934 | _1_5_4_5 | 0.83647 | 0.00127 | 0.83901 |
| _1_6_4_5 | 0.0 | 0.6 | 4000 | 3200 | 9443 | 82.26 | 1.0E-04 | 0.61943 | 0.00110 | 0.62164 | _1_6_4_5 | 0.83721 | 0.00128 | 0.83977 |
| | | | | | | | | | | | | | | |

**Table 6.9.6-11c. Comparison of HAC results for HEU broken metal content in ES-3100 HAC packaging calculation models.**

**Note:** Reference results for content homogenized over volume of containment vessel are highlighted. Results are for modified cases where the HEU packaging fraction varies from 0.2 to 0.6 and the content is homogenized with 500 g polyethylene.

| hciabmt12 | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **hciapbmflt12** | **np (in.)** | **PF** | **U (g)** | **$^{235}U$ (g)** | **$H_2O$ (g)** | **h/x** | **moifr** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** | **hciapbmfdt12** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** |
| _5_1_4_3 | 0.0 | 70.0 | 4642 | 3249 | 9952 | 79.95 | 1.0E-04 | 0.92053 | 0.00147 | 0.92347 | | | | |
| _1_2_5_4 | 0.0 | 0.2 | 5000 | 3500 | 9390 | 74.82 | 1.0E-04 | 0.71271 | 0.00111 | 0.71494 | _1_2_5_4 | 0.86056 | 0.00125 | 0.86305 |
| _1_3_5_4 | 0.0 | 0.3 | 5000 | 3500 | 9390 | 74.82 | 1.0E-04 | 0.67372 | 0.00145 | 0.67662 | _1_3_5_4 | 0.85614 | 0.00119 | 0.85851 |
| _1_4_5_4 | 0.0 | 0.4 | 5000 | 3500 | 9390 | 74.82 | 1.0E-04 | 0.65481 | 0.00129 | 0.65738 | _1_4_5_4 | 0.84829 | 0.00144 | 0.85117 |
| _1_5_5_4 | 0.0 | 0.5 | 5000 | 3500 | 9390 | 74.82 | 1.0E-04 | 0.63822 | 0.00113 | 0.64047 | _1_5_5_4 | 0.84683 | 0.00118 | 0.84919 |
| _1_6_5_4 | 0.0 | 0.6 | 5000 | 3500 | 9390 | 74.82 | 1.0E-04 | 0.62688 | 0.00106 | 0.62899 | _1_6_5_4 | 0.84497 | 0.00128 | 0.84754 |
| | | | | | | | | | | | | | | |
| _6_1_3_3 | 0.0 | 60.0 | 5577 | 3346 | 9903 | 77.24 | 1.0E-04 | 0.91017 | 0.00128 | 0.91274 | | | | |
| _1_2_6_3 | 0.0 | 0.2 | 6000 | 3600 | 9338 | 72.36 | 1.0E-04 | 0.71739 | 0.00119 | 0.71977 | _1_2_6_3 | 0.85989 | 0.00142 | 0.86273 |
| _1_3_6_3 | 0.0 | 0.3 | 6000 | 3600 | 9338 | 72.36 | 1.0E-04 | 0.68131 | 0.00126 | 0.68383 | _1_3_6_3 | 0.85119 | 0.00113 | 0.85345 |
| _1_4_6_3 | 0.0 | 0.4 | 6000 | 3600 | 9338 | 72.36 | 1.0E-04 | 0.65662 | 0.00118 | 0.65898 | _1_4_6_3 | 0.84466 | 0.00126 | 0.84718 |
| _1_5_6_3 | 0.0 | 0.5 | 6000 | 3600 | 9338 | 72.36 | 1.0E-04 | 0.63993 | 0.00109 | 0.64211 | _1_5_6_3 | 0.84460 | 0.00144 | 0.84749 |
| _1_6_6_3 | 0.0 | 0.6 | 6000 | 3600 | 9338 | 72.36 | 1.0E-04 | 0.62949 | 0.00119 | 0.63187 | _1_6_6_3 | 0.84243 | 0.00125 | 0.84493 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | | | |
| _3_2_8_3 | 1.4 | 100.0 | 2774 | 2774 | 9436 | 88.78 | 1.0E-04 | 0.90243 | 0.00127 | 0.90497 | | | | |
| _2_2_3_8 | 1.4 | 0.2 | 3000 | 3000 | 8882 | 82.86 | 1.0E-04 | 0.57951 | 0.00103 | 0.58157 | _2_2_3_8 | 0.81782 | 0.00115 | 0.82012 |
| _2_3_3_8 | 1.4 | 0.3 | 3000 | 3000 | 8882 | 82.86 | 1.0E-04 | 0.55359 | 0.00094 | 0.55547 | _2_3_3_8 | 0.81514 | 0.00148 | 0.81810 |
| _2_4_3_8 | 1.4 | 0.4 | 3000 | 3000 | 8882 | 82.86 | 1.0E-04 | 0.53870 | 0.00102 | 0.54075 | _2_4_3_8 | 0.81423 | 0.00122 | 0.81666 |
| _2_5_3_8 | 1.4 | 0.5 | 3000 | 3000 | 8882 | 82.86 | 1.0E-04 | 0.52950 | 0.00097 | 0.53143 | _2_5_3_8 | 0.81351 | 0.00131 | 0.81613 |
| _2_6_3_8 | 1.4 | 0.6 | 3000 | 3000 | 8882 | 82.86 | 1.0E-04 | 0.52360 | 0.00120 | 0.52599 | _2_6_3_8 | 0.81065 | 0.00127 | 0.81320 |
| | | | | | | | | | | | | | | |

**Table 6.9.6-11c. Comparison of HAC results for HEU broken metal content in ES-3100 HAC packaging calculation models.**

**Note:** Reference results for content homogenized over volume of containment vessel are highlighted. Results are for modified cases where the HEU packaging fraction varies from 0.2 to 0.6 and the content is homogenized with 500 g polyethylene.

| hciabmt12 | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **hciapbmflt12** | **np (in.)** | **PF** | **U (g)** | **$^{235}U$ (g)** | **$H_2O$ (g)** | **h/x** | **moifr** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** | **hciapbmfdt12** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** |
| _4_2_7_3 | 1.4 | 95.0 | 3701 | 3516 | 9387 | 69.68 | 1.0E-04 | 0.92094 | 0.00140 | 0.92374 | | | | |
| _2_2_4_7 | 1.4 | 0.2 | 4000 | 3800 | 8829 | 65.05 | 1.0E-04 | 0.62129 | 0.00113 | 0.62355 | _2_2_4_7 | 0.85574 | 0.00150 | 0.85874 |
| _2_3_4_7 | 1.4 | 0.3 | 4000 | 3800 | 8829 | 65.05 | 1.0E-04 | 0.59045 | 0.00106 | 0.59256 | _2_3_4_7 | 0.85080 | 0.00142 | 0.85364 |
| _2_4_4_7 | 1.4 | 0.4 | 4000 | 3800 | 8829 | 65.05 | 1.0E-04 | 0.57686 | 0.00095 | 0.57875 | _2_4_4_7 | 0.84954 | 0.00126 | 0.85205 |
| _2_5_4_7 | 1.4 | 0.5 | 4000 | 3800 | 8829 | 65.05 | 1.0E-04 | 0.56383 | 0.00096 | 0.56576 | _2_5_4_7 | 0.84837 | 0.00159 | 0.85155 |
| _2_6_4_7 | 1.4 | 0.6 | 4000 | 3800 | 8829 | 65.05 | 1.0E-04 | 0.55861 | 0.00120 | 0.56100 | _2_6_4_7 | 0.85112 | 0.00127 | 0.85366 |
| | | | | | | | | | | | | | | |
| _4_2_6_3 | 1.4 | 90.0 | 3704 | 3333 | 9387 | 73.50 | 1.0E-04 | 0.90643 | 0.00133 | 0.90909 | | | | |
| _2_2_4_6 | 1.4 | 0.2 | 4000 | 3600 | 8829 | 68.67 | 1.0E-04 | 0.61197 | 0.00116 | 0.61429 | _2_2_4_6 | 0.84318 | 0.00154 | 0.84626 |
| _2_3_4_6 | 1.4 | 0.3 | 4000 | 3600 | 8829 | 68.67 | 1.0E-04 | 0.58023 | 0.00112 | 0.58248 | _2_3_4_6 | 0.83944 | 0.00123 | 0.84190 |
| _2_4_4_6 | 1.4 | 0.4 | 4000 | 3600 | 8829 | 68.67 | 1.0E-04 | 0.56418 | 0.00111 | 0.56641 | _2_4_4_6 | 0.83754 | 0.00123 | 0.84000 |
| _2_5_4_6 | 1.4 | 0.5 | 4000 | 3600 | 8829 | 68.67 | 1.0E-04 | 0.55222 | 0.00100 | 0.55423 | _2_5_4_6 | 0.83876 | 0.00144 | 0.84163 |
| _2_6_4_6 | 1.4 | 0.6 | 4000 | 3600 | 8829 | 68.67 | 1.0E-04 | 0.54866 | 0.00099 | 0.55063 | _2_6_4_6 | 0.83719 | 0.00119 | 0.83958 |
| | | | | | | | | | | | | | | |
| _6_2_5_3 | 1.4 | 80.0 | 5563 | 4450 | 9289 | 54.48 | 1.0E-04 | 0.91987 | 0.00157 | 0.92301 | | | | |
| _2_2_6_5 | 1.4 | 0.2 | 6000 | 4800 | 8723 | 50.93 | 1.0E-04 | 0.67004 | 0.00099 | 0.67203 | _2_2_6_5 | 0.87714 | 0.00150 | 0.88015 |
| _2_3_6_5 | 1.4 | 0.3 | 6000 | 4800 | 8723 | 50.93 | 1.0E-04 | 0.63588 | 0.00098 | 0.63783 | _2_3_6_5 | 0.87335 | 0.00149 | 0.87633 |
| _2_4_6_5 | 1.4 | 0.4 | 6000 | 4800 | 8723 | 50.93 | 1.0E-04 | 0.61580 | 0.00114 | 0.61809 | _2_4_6_5 | 0.87067 | 0.00120 | 0.87306 |
| _2_5_6_5 | 1.4 | 0.5 | 6000 | 4800 | 8723 | 50.93 | 1.0E-04 | 0.60063 | 0.00111 | 0.60284 | _2_5_6_5 | 0.87386 | 0.00137 | 0.87660 |
| _2_6_6_5 | 1.4 | 0.6 | 6000 | 4800 | 8723 | 50.93 | 1.0E-04 | 0.59340 | 0.00097 | 0.59534 | _2_6_6_5 | 0.87070 | 0.00141 | 0.87353 |
| | | | | | | | | | | | | | | |

**Table 6.9.6-11c. Comparison of HAC results for HEU broken metal content in ES-3100 HAC packaging calculation models.**

**Note:** Reference results for content homogenized over volume of containment vessel are highlighted. Results are for modified cases where the HEU packaging fraction varies from 0.2 to 0.6 and the content is homogenized with 500 g polyethylene.

| hciabmt12 | np (in.) | enr. (wt %) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **hciapbmflt12** | **np (in.)** | **PF** | **U (g)** | **$^{235}U$ (g)** | **$H_2O$ (g)** | **h/x** | **moifr** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** | **hciapbmfdt12** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** |
| _8_2_4_3 | 1.4 | 70.0 | 7426 | 5198 | 9191 | 46.15 | 1.0E-04 | 0.91835 | 0.00126 | 0.92086 | | | | |
| _2_2_8_4 | 1.4 | 0.2 | 8000 | 5600 | 8618 | 43.16 | 1.0E-04 | 0.70405 | 0.00125 | 0.70655 | _2_2_8_4 | 0.88804 | 0.00136 | 0.89077 |
| _2_3_8_4 | 1.4 | 0.3 | 8000 | 5600 | 8618 | 43.16 | 1.0E-04 | 0.66628 | 0.00114 | 0.66856 | _2_3_8_4 | 0.88503 | 0.00118 | 0.88740 |
| _2_4_8_4 | 1.4 | 0.4 | 8000 | 5600 | 8618 | 43.16 | 1.0E-04 | 0.64431 | 0.00125 | 0.64681 | _2_4_8_4 | 0.88186 | 0.00141 | 0.88467 |
| _2_5_8_4 | 1.4 | 0.5 | 8000 | 5600 | 8618 | 43.16 | 1.0E-04 | 0.62989 | 0.00106 | 0.63201 | _2_5_8_4 | 0.88416 | 0.00142 | 0.88701 |
| _2_6_8_4 | 1.4 | 0.6 | 8000 | 5600 | 8618 | 43.16 | 1.0E-04 | 0.61934 | 0.00096 | 0.62126 | _2_6_8_4 | 0.88358 | 0.00130 | 0.88618 |
| | | | | | | | | | | | | | | |
| _12_2_3_3 | 1.4 | 60.0 | 11154 | 6692 | 8995 | 35.08 | 1.0E-04 | 0.91776 | 0.00138 | 0.92053 | | | | |
| _2_2_12_3 | 1.4 | 0.2 | 12000 | 7200 | 8407 | 32.81 | 1.0E-04 | 0.75872 | 0.00115 | 0.76102 | _2_2_12_3 | 0.90576 | 0.00134 | 0.90845 |
| _2_3_12_3 | 1.4 | 0.3 | 12000 | 7200 | 8407 | 32.81 | 1.0E-04 | 0.71743 | 0.00106 | 0.71954 | _2_3_12_3 | 0.90165 | 0.00138 | 0.90440 |
| _2_4_12_3 | 1.4 | 0.4 | 12000 | 7200 | 8407 | 32.81 | 1.0E-04 | 0.69072 | 0.00115 | 0.69301 | _2_4_12_3 | 0.90012 | 0.00124 | 0.90260 |
| _2_5_12_3 | 1.4 | 0.5 | 12000 | 7200 | 8407 | 32.81 | 1.0E-04 | 0.67462 | 0.00099 | 0.67660 | _2_5_12_3 | 0.89870 | 0.00124 | 0.90118 |
| _2_6_12_3 | 1.4 | 0.6 | 12000 | 7200 | 8407 | 32.81 | 1.0E-04 | 0.66490 | 0.00106 | 0.66702 | _2_6_12_3 | 0.90032 | 0.00117 | 0.90267 |

**Table 6.9.6-11d. Comparison of results for the 277-4 canned spacer under the nominal and minimal acceptance criteria for HEU broken metal content in ES-3100 HAC packaging calculation models.**

**Note:** Reference Cases **hciabmt12** selected from Table 6.9.6-11 are based for the nominal 277-4 canned spacer. These cases which establish loading limits were rerun with SCALE5, indicated as Cases **5hciabmt12** where case results are highlighted in yellow. The results for the corresponding Cases **5_401by131** for the 277-4 canned spacer sized per the minimal acceptance criteria are presented on the lines below. An absolute value of the quantity " **$(\Delta k_{eff}+2\sigma)/\sigma$** " >3 indicates that a statistically significant difference occurs between the case results.

| 5hciabmt12 | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **5_401by131** | **np (in.)** | **U (g)** | **$^{235}U$ (g)** | **$H_2O$ (g)** | **h/x** | **moifr** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** | **$\Delta k_{eff}+2\sigma$** | **$(\Delta k_{eff}+2\sigma)/\sigma$** |
| **content in flooded containment vessel, array packaging model for CSI=0.0** | | | | | | | | | | | |
| **with can spacers** | | | | | | | | | | | |
| _3_2_8_3 | 1.40 | 2774 | 2774 | 9436 | 88.78 | 1.0E-04 | 0.90362 | 0.00128 | 0.90619 | | |
| _3_2_8_3 | 1.31 | 2774 | 2774 | 9507 | 89.44 | 1.0E-04 | 0.90271 | 0.00146 | 0.90563 | 0.00056 | 0.38 |
| | | | | | | | | | | | |
| _4_2_7_3 | 1.40 | 3701 | 3516 | 9387 | 69.68 | 1.0E-04 | 0.91873 | 0.00154 | 0.92182 | | |
| _4_2_7_3 | 1.31 | 3701 | 3516 | 9458 | 70.20 | 1.0E-04 | 0.91848 | 0.00149 | 0.92145 | 0.00037 | 0.25 |
| | | | | | | | | | | | |
| _4_2_6_3 | 1.40 | 3704 | 3333 | 9387 | 73.50 | 1.0E-04 | 0.90865 | 0.00143 | 0.91151 | | |
| _4_2_6_3 | 1.31 | 3704 | 3333 | 9458 | 74.06 | 1.0E-04 | 0.90937 | 0.00139 | 0.91216 | -0.00065 | -0.47 |
| | | | | | | | | | | | |
| _6_2_5_3 | 1.40 | 5563 | 4450 | 9289 | 54.48 | 1.0E-04 | 0.92059 | 0.00142 | 0.92344 | | |
| _6_2_5_3 | 1.31 | 5563 | 4450 | 9360 | 54.90 | 1.0E-04 | 0.92273 | 0.00125 | 0.92524 | -0.00180 | -1.44 |
| | | | | | | | | | | | |
| _8_2_4_3 | 1.40 | 7426 | 5198 | 9191 | 46.15 | 1.0E-04 | 0.91790 | 0.00124 | 0.92039 | | |
| _8_2_4_3 | 1.31 | 7426 | 5198 | 9262 | 46.50 | 1.0E-04 | 0.92080 | 0.00183 | 0.92445 | -0.00406 | -2.22 |
| | | | | | | | | | | | |

**Table 6.9.6-11d. Comparison of results for the 277-4 canned spacer under the nominal and minimal acceptance criteria for HEU broken metal content in ES-3100 HAC packaging calculation models.**

**Note:** Reference Cases **hciabmt12** selected from Table 6.9.6-11 are based for the nominal 277-4 canned spacer. These cases which establish loading limits were rerun with SCALE5, indicated as Cases **5hciabmt12** where case results are highlighted in yellow. The results for the corresponding Cases **5_401by131** for the 277-4 canned spacer sized per the minimal acceptance criteria are presented on the lines below. An absolute value of the quantity " **($\Delta k_{eff}+2\sigma)/\sigma$** " >3 indicates that a statistically significant difference occurs between the case results.

| 5hciabmt12 | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5_401by131 | np (in.) | U (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | $\Delta k_{eff}+2\sigma$ | $(\Delta k_{eff}+2\sigma)/\sigma$ |
| _12_2_3_3 | 1.40 | 11154 | 6692 | 8995 | 35.08 | 1.0E-04 | 0.91638 | 0.00127 | 0.91892 | | |
| _12_2_3_3 | 1.31 | 11154 | 6692 | 9065 | 35.36 | 1.0E-04 | 0.91711 | 0.00133 | 0.91978 | -0.00086 | -0.65 |

**Table 6.9.6-12. Results for HEU oxide content in CV calculation model**

| case name (cvcrpdoxt11) | Ox (g) | $^{235}U$ (g) | Ox density ($g/cm^3$) | Ox volume ($cm^3$) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **$UO_2$ content, 500 g polyethylene, flooded containment vessel, reflected** | | | | | | | | | | | |
| _1_3_24_15 | 24000 | 21125 | 4.00 | 6000 | 3803 | 3665 | 10.02 | 1.0E+00 | 0.91157 | 0.00138 | 0.91434 |
| _1_4_24_15 | 24000 | 21125 | 5.00 | 4800 | 2606 | 4863 | 10.02 | 1.0E+00 | 0.90264 | 0.00139 | 0.90541 |
| _1_5_24_15 | 24000 | 21125 | 6.54 | 5000 | 1477 | 5991 | 10.02 | 1.0E+00 | 0.89152 | 0.00115 | 0.89382 |
| _1_2_20_15 | 20000 | 17604 | 3.00 | 6667 | 4833 | 3000 | 12.57 | 1.0E+00 | 0.90943 | 0.00117 | 0.91177 |
| _1_3_20_15 | 20000 | 17604 | 4.00 | 5000 | 3170 | 4663 | 12.57 | 1.0E+00 | 0.89797 | 0.00129 | 0.90055 |
| _1_4_20_15 | 20000 | 17604 | 5.00 | 4000 | 2171 | 5662 | 12.57 | 1.0E+00 | 0.89035 | 0.00121 | 0.89278 |
| _1_5_20_15 | 20000 | 17604 | 6.54 | 3058 | 1231 | 6602 | 12.57 | 1.0E+00 | 0.87565 | 0.00112 | 0.87789 |
| _1_2_15_15 | 15000 | 13203 | 3.00 | 5000 | 3625 | 4664 | 17.66 | 1.0E+00 | 0.89891 | 0.00138 | 0.90166 |

**Table 6.9.6-12. Results for HEU oxide content in CV calculation model**

| case name (cvcrpdoxt11) | Ox (g) | $^{235}U$ (g) | Ox density ($g/cm^3$) | Ox volume ($cm^3$) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| _1_3_15_15 | 15000 | 13203 | 4.00 | 3750 | 2377 | 5911 | 17.66 | 1.0E+00 | 0.87963 | 0.00116 | 0.88195 |
| _1_4_15_15 | 15000 | 13203 | 5.00 | 3000 | 1629 | 6660 | 17.66 | 1.0E+00 | 0.86309 | 0.00134 | 0.86578 |
| _1_5_15_15 | 15000 | 13203 | 6.54 | 2294 | 923 | 7365 | 17.66 | 1.0E+00 | 0.84270 | 0.00121 | 0.84513 |
| **14,000 g $UO_2$ content, 500 g polyethylene, flooded containment vessel, reflected** | | | | | | | | | | | |
| _1_1_14_15 | 14000 | 12323 | 2.00 | 7000 | 5712 | 2667 | 19.11 | 1.0E+00 | 0.90801 | 0.00154 | 0.91110 |
| _1_2_14_15 | 14000 | 12323 | 3.00 | 4667 | 3383 | 4996 | 19.11 | 1.0E+00 | 0.89261 | 0.00124 | 0.89510 |
| _1_3_14_15 | 14000 | 12323 | 4.00 | 3500 | 2219 | 6161 | 19.11 | 1.0E+00 | 0.87604 | 0.00119 | 0.87842 |
| _1_4_14_15 | 14000 | 12323 | 5.00 | 2800 | 1520 | 6860 | 19.11 | 1.0E+00 | 0.85585 | 0.00139 | 0.85863 |
| _1_5_14_15 | 14000 | 12323 | 6.54 | 2141 | 862 | 7518 | 19.11 | 1.0E+00 | 0.83530 | 0.00112 | 0.83755 |
| **14,000 g $U_3O_8$ content, 500 g polyethylene, flooded containment vessel, reflected** | | | | | | | | | | | |
| _2_1_14_15 | 14000 | 11850 | 2.00 | 7000 | 5304 | 2667 | 18.97 | 1.0E+00 | 0.88331 | 0.00144 | 0.88620 |
| _2_2_14_15 | 14000 | 11850 | 3.00 | 4667 | 2975 | 4996 | 18.97 | 1.0E+00 | 0.85075 | 0.00129 | 0.85333 |
| _2_3_14_15 | 14000 | 11850 | 4.00 | 3500 | 1810 | 6161 | 18.97 | 1.0E+00 | 0.82386 | 0.00123 | 0.82632 |
| _2_4_14_15 | 14000 | 11850 | 5.00 | 2800 | 1111 | 6860 | 18.97 | 1.0E+00 | 0.79922 | 0.00143 | 0.80209 |
| _2_5_14_15 | 14000 | 11850 | 6.54 | 2141 | 453 | 7518 | 18.97 | 1.0E+00 | 0.76510 | 0.00114 | 0.76738 |
| **14,000 g $UO_3$ content, 500 g polyethylene, flooded containment vessel, reflected** | | | | | | | | | | | |
| _3_1_14_15 | 14000 | 11627 | 2.00 | 7000 | 5071 | 2667 | 18.81 | 1.0E+00 | 0.86835 | 0.00122 | 0.87079 |
| _3_2_14_15 | 14000 | 11627 | 3.00 | 4667 | 2741 | 4996 | 18.81 | 1.0E+00 | 0.83069 | 0.00119 | 0.83307 |
| _3_3_14_15 | 14000 | 11627 | 4.00 | 3500 | 1577 | 6161 | 18.81 | 1.0E+00 | 0.79457 | 0.00132 | 0.79720 |
| _3_4_14_15 | 14000 | 11627 | 5.00 | 2800 | 878 | 6860 | 18.81 | 1.0E+00 | 0.76399 | 0.00140 | 0.76679 |
| _3_5_14_15 | 14000 | 11627 | 6.54 | 2141 | 220 | 7518 | 18.81 | 1.0E+00 | 0.72235 | 0.00127 | 0.72490 |

**Table 6.9.6-12. Results for HEU oxide content in CV calculation model**

| case name (cvcrpdoxt11) | Ox (g) | $^{235}U$ (g) | Ox density ($g/cm^3$) | Ox volume ($cm^3$) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **14,000 g $UO_2$ content, 500 g polyethylene, dry containment vessel, reflected** | | | | | | | | | | | |
| _1_1_14_1 | 14000 | 12323 | 2.00 | 7000 | 5712 | 0 | 13.46 | 1.0E-20 | 0.90869 | 0.00156 | 0.91180 |
| _1_2_14_1 | 14000 | 12323 | 3.00 | 4667 | 3383 | 0 | 8.53 | 1.0E-20 | 0.88628 | 0.00144 | 0.88916 |
| _1_3_14_1 | 14000 | 12323 | 4.00 | 3500 | 2219 | 0 | 6.06 | 1.0E-20 | 0.86750 | 0.00131 | 0.87012 |
| _1_4_14_1 | 14000 | 12323 | 5.00 | 2800 | 1520 | 0 | 4.58 | 1.0E-20 | 0.84555 | 0.00151 | 0.84857 |
| _1_5_14_1 | 14000 | 12323 | 6.54 | 2141 | 862 | 0 | 3.19 | 1.0E-20 | 0.82157 | 0.00109 | 0.82375 |
| **$UO_2$ content, 2.0 $g/cm^3$ oxide density, 500 g polyethylene, flooded containment vessel, reflected** | | | | | | | | | | | |
| _1_1_14_15 | 14000 | 12323 | 2.00 | 7000 | 5712 | 2667 | 19.11 | 1.0E+00 | 0.90801 | 0.00154 | 0.91110 |
| _1_1_13_15 | 13000 | 11443 | 2.00 | 6500 | 5304 | 3166 | 20.79 | 1.0E+00 | 0.91011 | 0.00123 | 0.91258 |
| _1_1_12_15 | 12000 | 10562 | 2.00 | 6000 | 4896 | 3665 | 22.74 | 1.0E+00 | 0.90176 | 0.00141 | 0.90457 |
| _1_1_11_15 | 11000 | 9682 | 2.00 | 5500 | 4488 | 4164 | 25.06 | 1.0E+00 | 0.89737 | 0.00154 | 0.90044 |
| _1_1_10_15 | 10000 | 8802 | 2.00 | 5000 | 4080 | 4663 | 27.83 | 1.0E+00 | 0.89620 | 0.00130 | 0.89880 |
| _1_1_9_15 | 9000 | 7922 | 2.00 | 4500 | 3672 | 5163 | 31.23 | 1.0E+00 | 0.88551 | 0.00161 | 0.88872 |
| _1_1_8_15 | 8000 | 7042 | 2.00 | 4000 | 3264 | 5662 | 35.47 | 1.0E+00 | 0.87598 | 0.00157 | 0.87912 |
| _1_1_7_15 | 7000 | 6162 | 2.00 | 3500 | 2856 | 6161 | 40.92 | 1.0E+00 | 0.86765 | 0.00148 | 0.87061 |
| _1_1_6_15 | 6000 | 5281 | 2.00 | 3000 | 2448 | 6660 | 48.19 | 1.0E+00 | 0.85412 | 0.00120 | 0.85652 |
| _1_1_5_15 | 5000 | 4401 | 2.00 | 2500 | 2040 | 7159 | 58.37 | 1.0E+00 | 0.83022 | 0.00138 | 0.83298 |
| _1_1_4_15 | 4000 | 3521 | 2.00 | 2000 | 1632 | 7658 | 73.63 | 1.0E+00 | 0.80856 | 0.00156 | 0.81168 |
| _1_1_3_15 | 3000 | 2641 | 2.00 | 1500 | 1224 | 8157 | 99.08 | 1.0E+00 | 0.77245 | 0.00147 | 0.77539 |
| _1_1_2_15 | 2000 | 1761 | 2.00 | 1000 | 816 | 8656 | 149.96 | 1.0E+00 | 0.72062 | 0.00132 | 0.72326 |
| _1_1_1_15 | 1000 | 880 | 2.00 | 500 | 408 | 9155 | 302.58 | 1.0E+00 | 0.63401 | 0.00126 | 0.63653 |

**Table 6.9.6-13. Results for HEU product oxide content at 6.54 g/cm3 in single-unit packaging calculation model**

| case name | Ox (g) | $^{235}U$ (g) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$UO_2$ content and 500 g polyethylene in flooded containment vessel, single package reflected** | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | **HAC** | | | |
| ncsrpoxt11_1_24_1 | 24000 | 21125 | 1477 | 5991 | 10.02 | 1.0E-20 | 0.72148 | 0.00120 | 0.72388 | | | | |
| ncsrpoxt11_1_24_2 | 24000 | 21125 | 1477 | 5991 | 10.02 | 1.0E-05 | 0.71942 | 0.00107 | 0.72156 | | | | |
| ncsrpoxt11_1_24_3 | 24000 | 21125 | 1477 | 5991 | 10.02 | 0.0E+00 | 0.71790 | 0.00122 | 0.72035 | | | | |
| ncsrpoxt11_1_24_4 | 24000 | 21125 | 1477 | 5991 | 10.02 | 1.0E-03 | 0.72072 | 0.00154 | 0.72380 | | | | |
| ncsrpoxt11_1_24_5 | 24000 | 21125 | 1477 | 5991 | 10.02 | 1.0E-02 | 0.71999 | 0.00123 | 0.72244 | | | | |
| ncsrpoxt11_1_24_6 | 24000 | 21125 | 1477 | 5991 | 10.02 | 1.0E-01 | 0.72828 | 0.00103 | 0.73035 | | | | |
| ncsrpoxt11_1_24_8 | 24000 | 21125 | 1477 | 5991 | 10.02 | 3.0E-01 | 0.74362 | 0.00123 | 0.74607 | | | | |
| ncsrpoxt11_1_24_15 | 24000 | 21125 | 1477 | 5991 | 10.02 | 1.0E+00 | 0.80222 | 0.00108 | 0.80438 | | | | |

**Table 6.9.6-13a. Results for HEU oxide content in single-unit packaging calculation model**

| case name (ncsrpdoxt11) | Ox (g) | $^{235}U$ (g) | Ox den. ($g/cm^3$) | Ox vol. ($cm^3$) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name (hcsrpdoxt12) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **NCT** | | | | | | | | | | | **HAC** | | | |
| **$UO_2$ content and 500 g polyethylene in flooded containment vessel, flooded package** | | | | | | | | | | | | | | |
| _1_3_24 | 24000 | 21125 | 4.00 | 6000 | 3803 | 3665 | 10.02 | 0.81371 | 0.00144 | 0.81659 | _1_3_24 | 0.81599 | 0.00133 | 0.81865 |
| _1_4_24 | 24000 | 21125 | 5.00 | 4800 | 2606 | 4863 | 10.02 | 0.80666 | 0.00111 | 0.80887 | _1_4_24 | 0.81112 | 0.00119 | 0.81350 |
| _1_5_24 | 24000 | 21125 | 6.54 | 3670 | 1477 | 5991 | 10.02 | 0.80222 | 0.00108 | 0.80438 | _1_5_24 | 0.80624 | 0.00114 | 0.80852 |
| _1_2_20 | 20000 | 17604 | 3.00 | 6667 | 4833 | 3000 | 12.57 | 0.81352 | 0.00155 | 0.81662 | _1_2_20 | 0.81200 | 0.00136 | 0.81472 |
| _1_3_20 | 20000 | 17604 | 4.00 | 5000 | 3170 | 4663 | 12.57 | 0.80451 | 0.00124 | 0.80698 | _1_3_20 | 0.80524 | 0.00118 | 0.80760 |

**Table 6.9.6-13a. Results for HEU oxide content in single-unit packaging calculation model**

| case name (ncsrpdoxt11) | Ox (g) | $^{235}U$ (g) | Ox den. ($g/cm^3$) | Ox vol. ($cm^3$) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name (hcsrpdoxt12) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| _1_4_20 | 20000 | 17604 | 5.00 | 4000 | 2171 | 5662 | 12.57 | 0.79655 | 0.00129 | 0.79914 | _1_4_20 | 0.79813 | 0.00137 | 0.80087 |
| _1_5_20 | 20000 | 17604 | 6.54 | 3058 | 1231 | 6602 | 12.57 | 0.78510 | 0.00133 | 0.78775 | _1_5_20 | 0.78801 | 0.00121 | 0.79043 |
| _1_2_15 | 15000 | 13203 | 3.00 | 5000 | 3625 | 4664 | 17.66 | 0.79666 | 0.00133 | 0.79933 | _1_2_15 | 0.79891 | 0.00149 | 0.80189 |
| _1_3_15 | 15000 | 13203 | 4.00 | 3750 | 2377 | 5911 | 17.66 | 0.78374 | 0.00123 | 0.78619 | _1_3_15 | 0.78801 | 0.00130 | 0.79061 |
| _1_4_15 | 15000 | 13203 | 5.00 | 3000 | 1629 | 6660 | 17.66 | 0.77585 | 0.00104 | 0.77794 | _1_4_15 | 0.77767 | 0.00131 | 0.78028 |
| _1_5_15 | 15000 | 13203 | 6.54 | 2294 | 923 | 7365 | 17.66 | 0.75988 | 0.00120 | 0.76228 | _1_5_15 | 0.76047 | 0.00122 | 0.76291 |
| **$UO_2$, content and 500 g polyethylene in flooded containment vessel, flooded package** | | | | | | | | | | | | | | |
| _1_1_14 | 14000 | 12323 | 2.00 | 7000 | 5712 | 2667 | 19.11 | 0.81144 | 0.00130 | 0.81403 | _1_1_14 | 0.80983 | 0.00147 | 0.81276 |
| _1_2_14 | 14000 | 12323 | 3.00 | 4667 | 3383 | 4996 | 19.11 | 0.79632 | 0.00134 | 0.79900 | _1_2_14 | 0.79412 | 0.00155 | 0.79722 |
| _1_3_14 | 14000 | 12323 | 4.00 | 3500 | 2219 | 6161 | 19.11 | 0.78024 | 0.00138 | 0.78300 | _1_3_14 | 0.78251 | 0.00141 | 0.78533 |
| _1_4_14 | 14000 | 12323 | 5.00 | 2800 | 1520 | 6860 | 19.11 | 0.76867 | 0.00119 | 0.77106 | _1_4_14 | 0.77186 | 0.00130 | 0.77446 |
| _1_5_14 | 14000 | 12323 | 6.54 | 2141 | 862 | 7518 | 19.11 | 0.75106 | 0.00143 | 0.75393 | _1_5_14 | 0.75712 | 0.00132 | 0.75975 |
| **$UO_3$ content and 500 g polyethylene in flooded containment vessel, flooded package** | | | | | | | | | | | | | | |
| _2_1_14 | 14000 | 11850 | 2.00 | 7000 | 5304 | 2667 | 18.97 | 0.77449 | 0.00162 | 0.77772 | _2_1_14 | 0.77571 | 0.00138 | 0.77847 |
| _2_2_14 | 14000 | 11850 | 3.00 | 4667 | 2975 | 4996 | 18.97 | 0.75132 | 0.00141 | 0.75415 | _2_2_14 | 0.74985 | 0.00135 | 0.75256 |
| _2_3_14 | 14000 | 11850 | 4.00 | 3500 | 1810 | 6161 | 18.97 | 0.72213 | 0.00119 | 0.72452 | _2_3_14 | 0.72485 | 0.00112 | 0.72708 |
| _2_4_14 | 14000 | 11850 | 5.00 | 2800 | 1111 | 6860 | 18.97 | 0.70025 | 0.00132 | 0.70289 | _2_4_14 | 0.70229 | 0.00135 | 0.70498 |
| _2_5_14 | 14000 | 11850 | 6.54 | 2141 | 453 | 7518 | 18.97 | 0.66897 | 0.00140 | 0.67177 | _2_5_14 | 0.67431 | 0.00107 | 0.67645 |
| **$U_3O_8$ content and 500 g polyethylene in flooded containment vessel, flooded package** | | | | | | | | | | | | | | |
| _3_1_14 | 14000 | 11627 | 2.00 | 7000 | 5071 | 2667 | 18.81 | 0.75704 | 0.00138 | 0.75980 | _3_1_14 | 0.75676 | 0.00139 | 0.75954 |
| _3_2_14 | 14000 | 11627 | 3.00 | 4667 | 2741 | 4996 | 18.81 | 0.72097 | 0.00124 | 0.72345 | _3_2_14 | 0.72300 | 0.00121 | 0.72542 |
| _3_3_14 | 14000 | 11627 | 4.00 | 3500 | 1577 | 6161 | 18.81 | 0.69035 | 0.00114 | 0.69263 | _3_3_14 | 0.69274 | 0.00112 | 0.69498 |
| _3_4_14 | 14000 | 11627 | 5.00 | 2800 | 878 | 6860 | 18.81 | 0.66080 | 0.00123 | 0.66326 | _3_4_14 | 0.66443 | 0.00115 | 0.66674 |
| _3_5_14 | 14000 | 11627 | 6.54 | 2141 | 220 | 7518 | 18.81 | 0.62168 | 0.00129 | 0.62427 | _3_5_14 | 0.62544 | 0.00118 | 0.62780 |

**Table 6.9.6-13b. Results for HEU oxide content in array packaging calculation model**

| case name (nciapdoxt11) | Ox (g) | $^{235}U$ (g) | Ox den. ($g/cm^3$) | Ox vol. ($cm^3$) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name (hciapdoxt12) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$UO_2$ content and 500 g polyethylene in flooded containment vessel, array packaging model for CSI=0.0** | | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | | **HAC** | | | |
| _1_3_24_3 | 24000 | 21125 | 4.00 | 6000 | 3803 | 3665 | 10.02 | 0.96758 | 0.00121 | 0.97000 | _1_3_24_3 | 0.96822 | 0.00124 | 0.97070 |
| _1_4_24_3 | 24000 | 21125 | 5.00 | 4800 | 2606 | 4863 | 10.02 | 0.94340 | 0.00119 | 0.94578 | _1_4_24_3 | 0.94131 | 0.00115 | 0.94360 |
| _1_5_24_3 | 24000 | 21125 | 6.54 | 3670 | 1477 | 5991 | 10.02 | 0.91495 | 0.00134 | 0.91764 | _1_5_24_3 | 0.91666 | 0.00106 | 0.91878 |
| _1_2_20_3 | 20000 | 17604 | 3.00 | 6667 | 4833 | 3000 | 12.57 | 0.97118 | 0.00122 | 0.97363 | _1_2_20_3 | 0.97255 | 0.00139 | 0.97532 |
| _1_3_20_3 | 20000 | 17604 | 4.00 | 5000 | 3170 | 4663 | 12.57 | 0.93543 | 0.00122 | 0.93786 | _1_3_20_3 | 0.93616 | 0.00141 | 0.93897 |
| _1_4_20_3 | 20000 | 17604 | 5.00 | 4000 | 2171 | 5662 | 12.57 | 0.91167 | 0.00117 | 0.91401 | _1_4_20_3 | 0.91202 | 0.00126 | 0.91453 |
| _1_5_20_3 | 20000 | 17604 | 6.54 | 3058 | 1231 | 6602 | 12.57 | 0.88413 | 0.00124 | 0.88661 | _1_5_20_3 | 0.88426 | 0.00137 | 0.88700 |
| _1_2_15_3 | 15000 | 13203 | 3.00 | 5000 | 3625 | 4664 | 17.66 | 0.92181 | 0.00128 | 0.92438 | _1_2_15_3 | 0.92129 | 0.00139 | 0.92407 |
| _1_3_15_3 | 15000 | 13203 | 4.00 | 3750 | 2377 | 5911 | 17.66 | 0.88533 | 0.00117 | 0.88767 | _1_3_15_3 | 0.88414 | 0.00125 | 0.88663 |
| _1_4_15_3 | 15000 | 13203 | 5.00 | 3000 | 1628 | 6660 | 17.66 | 0.86168 | 0.00116 | 0.86400 | _1_4_15_3 | 0.86039 | 0.00117 | 0.86273 |
| _1_5_15_3 | 15000 | 13203 | 6.54 | 2294 | 923 | 7365 | 17.66 | 0.83434 | 0.00122 | 0.83678 | _1_5_15_3 | 0.83140 | 0.00111 | 0.83363 |
| _1_1_12_3 | 12000 | 10562 | 2.00 | 6000 | 4896 | 3665 | 22.74 | 0.93409 | 0.00140 | 0.93688 | _1_1_12_3 | 0.93732 | 0.00137 | 0.94006 |
| _1_2_12_3 | 12000 | 10562 | 3.00 | 4000 | 2900 | 5662 | 22.74 | 0.88391 | 0.00131 | 0.88652 | _1_2_12_3 | 0.88387 | 0.00121 | 0.88630 |
| _1_3_12_3 | 12000 | 10562 | 4.00 | 3000 | 1902 | 6660 | 22.74 | 0.85157 | 0.00111 | 0.85379 | _1_3_12_3 | 0.84658 | 0.00133 | 0.84925 |
| _1_4_12_3 | 12000 | 10562 | 5.00 | 2400 | 1303 | 7259 | 22.74 | 0.82574 | 0.00128 | 0.82831 | _1_4_12_3 | 0.82349 | 0.00119 | 0.82587 |
| _1_5_12_3 | 12000 | 10562 | 6.54 | 1835 | 739 | 7823 | 22.74 | 0.79328 | 0.00110 | 0.79548 | _1_5_12_3 | 0.79233 | 0.00121 | 0.79475 |
| _1_1_11_3 | 11000 | 9682 | 2.00 | 5500 | 4488 | 4164 | 25.06 | 0.91822 | 0.00129 | 0.92079 | _1_1_11_3 | 0.92203 | 0.00134 | 0.92471 |
| _1_2_11_3 | 11000 | 9682 | 3.00 | 3667 | 2658 | 5994 | 25.06 | 0.86689 | 0.00129 | 0.86946 | _1_2_11_3 | 0.87093 | 0.00135 | 0.87364 |
| _1_3_11_3 | 11000 | 9682 | 4.00 | 2750 | 1743 | 6909 | 25.06 | 0.83492 | 0.00133 | 0.83757 | _1_3_11_3 | 0.83515 | 0.00124 | 0.83763 |

**Table 6.9.6-13b. Results for HEU oxide content in array packaging calculation model**

| case name (nciapdoxt11) | Ox (g) | $^{235}U$ (g) | Ox den. ($g/cm^3$) | Ox vol. ($cm^3$) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name (hciapdoxt12) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| _1_4_11_3 | 11000 | 9682 | 5.00 | 2200 | 1194 | 7458 | 25.06 | 0.80930 | 0.00149 | 0.81227 | _1_4_11_3 | 0.80948 | 0.00129 | 0.81205 |
| _1_5_11_3 | 11000 | 9682 | 6.54 | 1682 | 677 | 7976 | 25.06 | 0.77906 | 0.00100 | 0.78106 | _1_5_11_3 | 0.77935 | 0.00118 | 0.78171 |
| _1_1_10_3 | 10000 | 8802 | 2.00 | 5000 | 4080 | 4663 | 27.83 | 0.90471 | 0.00131 | 0.90733 | _1_1_10_3 | 0.90600 | 0.00128 | 0.90856 |
| _1_1_9_3 | 9000 | 7922 | 2.00 | 4500 | 3672 | 5163 | 31.23 | 0.88936 | 0.00137 | 0.89210 | _1_1_9_3 | 0.88714 | 0.00123 | 0.88960 |
| _1_1_8_3 | 8000 | 7042 | 2.00 | 4000 | 3264 | 5662 | 35.47 | 0.86854 | 0.00144 | 0.87141 | _1_1_8_3 | 0.86980 | 0.00145 | 0.87270 |
| _1_1_7_3 | 7000 | 6162 | 2.00 | 3500 | 2856 | 6161 | 40.92 | 0.84876 | 0.00125 | 0.85126 | _1_1_7_3 | 0.84926 | 0.00133 | 0.85192 |
| _1_1_6_3 | 6000 | 5281 | 2.00 | 3000 | 2448 | 6660 | 48.19 | 0.82546 | 0.00127 | 0.82800 | _1_1_6_3 | 0.82275 | 0.00135 | 0.82544 |
| **$UO_2$, $UO_3$, or $U_3O_8$ content and 500 g polyethylene in flooded containment vessel, array packaging model for CSI=0.0** | | | | | | | | | | | | | | |
| _1_1_7_3 | 7000 | 6162 | 2.00 | 3500 | 2856 | 6161 | 40.92 | 0.84876 | 0.00125 | 0.85126 | _1_1_7_3 | 0.84926 | 0.00133 | 0.85192 |
| _2_1_7_3 | 7000 | 5925 | 2.00 | 3500 | 2652 | 6161 | 41.65 | 0.81721 | 0.00130 | 0.81980 | _2_1_7_3 | 0.81943 | 0.00125 | 0.82194 |
| _3_1_7_3 | 7000 | 5813 | 2.00 | 3500 | 2535 | 6161 | 41.93 | 0.80044 | 0.00129 | 0.80302 | _3_1_7_3 | 0.80086 | 0.00134 | 0.80355 |

**Table 6.9.6-14. Results for UNX crystal content in CV calculation model**

| case name | unh (g) | $^{235}U$ (g) | unh $H_2O$ (g) | CV $H_2O$ (g) | h/x | gU/l | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **UNH crystal content, 0 g polyethylene, flooded containment vessel, reflected** | | | | | | | | | | |
| cvcrunhct11_24_1 | 24000 | 11303 | 5197 | 1620 | 15.74 | 1106 | 1.0E+00 | 0.82007 | 0.00128 | 0.82262 |
| cvcrunhct11_23_1 | 23000 | 10832 | 4980 | 1978 | 16.77 | 1060 | 1.0E+00 | 0.82120 | 0.00129 | 0.82378 |
| cvcrunhct11_22_1 | 22000 | 10361 | 4764 | 2335 | 17.88 | 1014 | 1.0E+00 | 0.82675 | 0.00122 | 0.82919 |
| cvcrunhct11_21_1 | 21000 | 9890 | 4547 | 2693 | 19.11 | 968 | 1.0E+00 | 0.82938 | 0.00118 | 0.83174 |
| cvcrunhct11_20_1 | 20000 | 9419 | 4331 | 3050 | 20.45 | 922 | 1.0E+00 | 0.83221 | 0.00129 | 0.83480 |

**Table 6.9.6-14. Results for UNX crystal content in CV calculation model**

| case name | unh (g) | $^{235}U$ (g) | unh $H_2O$ (g) | CV $H_2O$ (g) | h/x | gU/l | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| cvcrunhct11_19_1 | 19000 | 8948 | 4114 | 3407 | 21.94 | 876 | 1.0E+00 | 0.83423 | 0.00152 | 0.83728 |
| cvcrunhct11_18_1 | 18000 | 8477 | 3898 | 3765 | 23.59 | 830 | 1.0E+00 | 0.83622 | 0.00128 | 0.83878 |
| cvcrunhct11_17_1 | 17000 | 8006 | 3681 | 4122 | 25.44 | 784 | 1.0E+00 | 0.84032 | 0.00167 | 0.84365 |
| cvcrunhct11_16_1 | 16000 | 7536 | 3464 | 4479 | 27.51 | 738 | 1.0E+00 | 0.84509 | 0.00151 | 0.84811 |
| cvcrunhct11_15_1 | 15000 | 7064 | 3248 | 4837 | 29.87 | 692 | 1.0E+00 | 0.84402 | 0.00133 | 0.84667 |
| cvcrunhct11_14_1 | 14000 | 6594 | 3031 | 5194 | 32.56 | 645 | 1.0E+00 | 0.84915 | 0.00130 | 0.85175 |
| cvcrunhct11_13_1 | 13000 | 6123 | 2815 | 5551 | 35.67 | 599 | 1.0E+00 | 0.84986 | 0.00127 | 0.85241 |
| cvcrunhct11_12_1 | 12000 | 5652 | 2598 | 5909 | 39.29 | 553 | 1.0E+00 | 0.85138 | 0.00159 | 0.85456 |
| cvcrunhct11_11_1 | 11000 | 5181 | 2382 | 6266 | 43.57 | 507 | 1.0E+00 | 0.85137 | 0.00136 | 0.85408 |
| cvcrunhct11_10_1 | 10000 | 4710 | 2165 | 6623 | 48.71 | 461 | 1.0E+00 | 0.85062 | 0.00149 | 0.85359 |
| cvcrunhct11_9_1 | 9000 | 4239 | 1949 | 6981 | 54.99 | 415 | 1.0E+00 | 0.85423 | 0.00147 | 0.85718 |
| cvcrunhct11_8_1 | 8000 | 3768 | 1732 | 7338 | 62.83 | 369 | 1.0E+00 | 0.84783 | 0.00152 | 0.85088 |
| cvcrunhct11_7_1 | 7000 | 3297 | 1516 | 7695 | 72.92 | 323 | 1.0E+00 | 0.84713 | 0.00166 | 0.85044 |
| cvcrunhct11_6_1 | 6000 | 2826 | 1299 | 8053 | 86.38 | 277 | 1.0E+00 | 0.83915 | 0.00151 | 0.84218 |
| cvcrunhct11_5_1 | 5000 | 2355 | 1083 | 8410 | 105.2 | 231 | 1.0E+00 | 0.82865 | 0.00177 | 0.83220 |
| cvcrunhct11_4_1 | 4000 | 1884 | 866 | 8768 | 133.5 | 184 | 1.0E+00 | 0.81158 | 0.00162 | 0.81483 |
| cvcrunhct11_3_1 | 3000 | 1413 | 650 | 9125 | 180.6 | 138 | 1.0E+00 | 0.78282 | 0.00120 | 0.78522 |
| cvcrunhct11_2_1 | 2000 | 942 | 433 | 9482 | 274.7 | 92 | 1.0E+00 | 0.73150 | 0.00114 | 0.73377 |
| cvcrunhct11_1_1 | 1000 | 471 | 217 | 9840 | 557.2 | 46 | 1.0E+00 | 0.60716 | 0.00106 | 0.60927 |
| **UNH crystal content, 500 g polyethylene, flooded containment vessel, reflected** | | | | | | | | | | |
| cvcrpunhct11_24_15 | 24000 | 11303 | 5197 | 1078 | 15.97 | 1106 | 1.0E+00 | 0.82422 | 0.00129 | 0.82681 |
| cvcrpunhct11_23_15 | 23000 | 10832 | 4980 | 1435 | 17.01 | 1060 | 1.0E+00 | 0.82842 | 0.00146 | 0.83134 |
| cvcrpunhct11_22_15 | 22000 | 10361 | 4764 | 1793 | 18.13 | 1014 | 1.0E+00 | 0.83462 | 0.00156 | 0.83773 |
| cvcrpunhct11_21_15 | 21000 | 9890 | 4547 | 2150 | 19.37 | 968 | 1.0E+00 | 0.83608 | 0.00149 | 0.83906 |

**Table 6.9.6-14. Results for UNX crystal content in CV calculation model**

| case name | unh (g) | $^{235}U$ (g) | unh $H_2O$ (g) | CV $H_2O$ (g) | h/x | gU/l | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| cvcrpunhct11_20_15 | 20000 | 9419 | 4331 | 2507 | 20.73 | 922 | 1.0E+00 | 0.84111 | 0.00143 | 0.84397 |
| cvcrpunhct11_19_15 | 19000 | 8948 | 4114 | 2865 | 22.23 | 876 | 1.0E+00 | 0.84084 | 0.00135 | 0.84355 |
| cvcrpunhct11_18_15 | 18000 | 8477 | 3898 | 3222 | 23.90 | 830 | 1.0E+00 | 0.84379 | 0.00138 | 0.84654 |
| cvcrpunhct11_17_15 | 17000 | 8006 | 3681 | 3579 | 25.76 | 784 | 1.0E+00 | 0.84513 | 0.00147 | 0.84807 |
| cvcrpunhct11_16_15 | 16000 | 7536 | 3464 | 3937 | 27.86 | 738 | 1.0E+00 | 0.84809 | 0.00132 | 0.85072 |
| cvcrpunhct11_15_15 | 15000 | 7064 | 3248 | 4294 | 30.24 | 692 | 1.0E+00 | 0.85178 | 0.00146 | 0.85470 |
| cvcrpunhct11_14_15 | 14000 | 6594 | 3031 | 4652 | 32.96 | 645 | 1.0E+00 | 0.85473 | 0.00134 | 0.85741 |
| cvcrpunhct11_13_15 | 13000 | 6123 | 2815 | 5009 | 36.09 | 599 | 1.0E+00 | 0.85544 | 0.00134 | 0.85812 |
| cvcrpunhct11_12_15 | 12000 | 5652 | 2598 | 5366 | 39.75 | 553 | 1.0E+00 | 0.85658 | 0.00142 | 0.85941 |
| cvcrpunhct11_11_15 | 11000 | 5181 | 2382 | 5724 | 44.07 | 507 | 1.0E+00 | 0.85830 | 0.00152 | 0.86133 |
| cvcrpunhct11_10_15 | 10000 | 4710 | 2165 | 6081 | 49.26 | 461 | 1.0E+00 | 0.85943 | 0.00176 | 0.86296 |
| cvcrpunhct11_9_15 | 9000 | 4239 | 1949 | 6438 | 55.60 | 415 | 1.0E+00 | 0.85882 | 0.00139 | 0.86161 |
| cvcrpunhct11_8_15 | 8000 | 3768 | 1732 | 6796 | 63.53 | 369 | 1.0E+00 | 0.85472 | 0.00116 | 0.85705 |
| cvcrpunhct11_7_15 | 7000 | 3297 | 1516 | 7153 | 73.72 | 323 | 1.0E+00 | 0.84975 | 0.00143 | 0.85261 |
| cvcrpunhct11_6_15 | 6000 | 2826 | 1299 | 7510 | 87.31 | 277 | 1.0E+00 | 0.84484 | 0.00132 | 0.84748 |
| cvcrpunhct11_5_15 | 5000 | 2355 | 1083 | 7868 | 106.33 | 231 | 1.0E+00 | 0.83459 | 0.00167 | 0.83793 |
| cvcrpunhct11_4_15 | 4000 | 1884 | 866 | 8225 | 134.85 | 184 | 1.0E+00 | 0.82093 | 0.00142 | 0.82378 |
| cvcrpunhct11_3_15 | 3000 | 1413 | 650 | 8582 | 182.42 | 138 | 1.0E+00 | 0.78968 | 0.00130 | 0.79228 |
| cvcrpunhct11_2_15 | 2000 | 942 | 433 | 8940 | 277.51 | 92 | 1.0E+00 | 0.73500 | 0.00145 | 0.73791 |
| cvcrpunhct11_1_15 | 1000 | 471 | 217 | 9297 | 562.74 | 46 | 1.0E+00 | 0.61053 | 0.00118 | 0.61289 |
| **UNH crystal content, 500 g polyethylene, dry containment vessel, reflected** | | | | | | | | | | |
| cvcrpunhct11_24_1 | 24000 | 11303 | 5197 | 0 | 13.48 | 1106.5 | 1.0E-20 | 0.76603 | 0.00145 | 0.76893 |
| cvcrpunhct11_23_1 | 23000 | 10832 | 4980 | 0 | 13.55 | 1060.4 | 1.0E-20 | 0.75118 | 0.00132 | 0.75382 |
| cvcrpunhct11_22_1 | 22000 | 10361 | 4764 | 0 | 13.62 | 1014.3 | 1.0E-20 | 0.73265 | 0.00133 | 0.73531 |

**Table 6.9.6-14. Results for UNX crystal content in CV calculation model**

| case name | unh (g) | $^{235}U$ (g) | unh $H_2O$ (g) | CV $H_2O$ (g) | h/x | gU/l | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| cvcrpunhct11_21_1 | 21000 | 9890 | 4547 | 0 | 13.70 | 968.2 | 1.0E-20 | 0.71276 | 0.00125 | 0.71527 |
| cvcrpunhct11_20_1 | 20000 | 9419 | 4331 | 0 | 13.78 | 922.1 | 1.0E-20 | 0.69662 | 0.00146 | 0.69955 |
| cvcrpunhct11_19_1 | 19000 | 8948 | 4114 | 0 | 13.87 | 876.0 | 1.0E-20 | 0.67992 | 0.00144 | 0.68279 |
| cvcrpunhct11_18_1 | 18000 | 8477 | 3898 | 0 | 13.98 | 829.9 | 1.0E-20 | 0.66144 | 0.00115 | 0.66374 |
| cvcrpunhct11_17_1 | 17000 | 8006 | 3681 | 0 | 14.09 | 783.8 | 1.0E-20 | 0.64482 | 0.00128 | 0.64738 |
| cvcrpunhct11_16_1 | 16000 | 7536 | 3464 | 0 | 14.23 | 737.7 | 1.0E-20 | 0.62404 | 0.00110 | 0.62624 |
| cvcrpunhct11_15_1 | 15000 | 7064 | 3248 | 0 | 14.37 | 691.5 | 1.0E-20 | 0.60835 | 0.00125 | 0.61085 |
| cvcrpunhct11_14_1 | 14000 | 6594 | 3031 | 0 | 14.54 | 645.5 | 1.0E-20 | 0.58778 | 0.00113 | 0.59003 |
| cvcrpunhct11_13_1 | 13000 | 6123 | 2815 | 0 | 14.74 | 599.4 | 1.0E-20 | 0.56892 | 0.00115 | 0.57123 |
| cvcrpunhct11_12_1 | 12000 | 5652 | 2598 | 0 | 14.97 | 553.2 | 1.0E-20 | 0.55059 | 0.00129 | 0.55317 |
| cvcrpunhct11_11_1 | 11000 | 5181 | 2382 | 0 | 15.24 | 507.1 | 1.0E-20 | 0.53268 | 0.00108 | 0.53485 |
| cvcrpunhct11_10_1 | 10000 | 4710 | 2165 | 0 | 15.56 | 461.0 | 1.0E-20 | 0.51381 | 0.00135 | 0.51650 |
| cvcrpunhct11_9_1 | 9000 | 4239 | 1949 | 0 | 15.96 | 414.9 | 1.0E-20 | 0.49374 | 0.00111 | 0.49596 |
| cvcrpunhct11_8_1 | 8000 | 3768 | 1732 | 0 | 16.45 | 368.8 | 1.0E-20 | 0.47312 | 0.00106 | 0.47524 |
| cvcrpunhct11_7_1 | 7000 | 3297 | 1516 | 0 | 17.09 | 322.7 | 1.0E-20 | 0.45221 | 0.00108 | 0.45437 |
| cvcrpunhct11_6_1 | 6000 | 2826 | 1299 | 0 | 17.93 | 276.6 | 1.0E-20 | 0.43063 | 0.00114 | 0.43290 |
| cvcrpunhct11_5_1 | 5000 | 2355 | 1083 | 0 | 19.12 | 230.5 | 1.0E-20 | 0.40936 | 0.00103 | 0.41141 |
| cvcrpunhct11_4_1 | 4000 | 1884 | 866 | 0 | 20.90 | 184.4 | 1.0E-20 | 0.38394 | 0.00105 | 0.38603 |
| cvcrpunhct11_3_1 | 3000 | 1413 | 650 | 0 | 23.87 | 138.3 | 1.0E-20 | 0.35655 | 0.00096 | 0.35846 |
| cvcrpunhct11_2_1 | 2000 | 942 | 433 | 0 | 29.80 | 92.2 | 1.0E-20 | 0.31381 | 0.00093 | 0.31566 |
| cvcrpunhct11_1_1 | 1000 | 471 | 217 | 0 | 47.60 | 46.1 | 1.0E-20 | 0.24974 | 0.00079 | 0.25132 |
| **500 g polyethylene and undissolved UNH crystals, flooded containment vessel, reflected** | | | | | | | | | | |
| cvcrbpunhct11_24_15 | 24000 | 11303 | 5197 | 1078 | 15.97 | NA | 1.0E+00 | 0.81439 | 0.00135 | 0.81710 |
| cvcrbpunhct11_23_15 | 23000 | 10832 | 4980 | 1435 | 17.01 | NA | 1.0E+00 | 0.81243 | 0.00128 | 0.81498 |

**Table 6.9.6-14. Results for UNX crystal content in CV calculation model**

| case name | unh (g) | $^{235}U$ (g) | unh $H_2O$ (g) | CV $H_2O$ (g) | h/x | gU/l | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| cvcrbpunhct11_22_15 | 22000 | 10361 | 4764 | 1793 | 18.13 | NA | 1.0E+00 | 0.81092 | 0.00139 | 0.81369 |
| cvcrbpunhct11_21_15 | 21000 | 9890 | 4547 | 2150 | 19.37 | NA | 1.0E+00 | 0.80901 | 0.00135 | 0.81172 |
| cvcrbpunhct11_20_15 | 20000 | 9419 | 4331 | 2507 | 20.73 | NA | 1.0E+00 | 0.80864 | 0.00168 | 0.81200 |
| cvcrbpunhct11_19_15 | 19000 | 8948 | 4114 | 2865 | 22.23 | NA | 1.0E+00 | 0.80344 | 0.00145 | 0.80635 |
| cvcrbpunhct11_18_15 | 18000 | 8477 | 3898 | 3222 | 23.90 | NA | 1.0E+00 | 0.80646 | 0.00132 | 0.80911 |
| cvcrbpunhct11_17_15 | 17000 | 8006 | 3681 | 3579 | 25.76 | NA | 1.0E+00 | 0.80294 | 0.00134 | 0.80563 |
| cvcrbpunhct11_16_15 | 16000 | 7536 | 3465 | 3937 | 27.86 | NA | 1.0E+00 | 0.79909 | 0.00115 | 0.80139 |
| cvcrbpunhct11_15_15 | 15000 | 7064 | 3248 | 4294 | 30.24 | NA | 1.0E+00 | 0.79593 | 0.00133 | 0.79858 |
| cvcrbpunhct11_14_15 | 14000 | 6594 | 3031 | 4652 | 32.96 | NA | 1.0E+00 | 0.79487 | 0.00109 | 0.79705 |
| cvcrbpunhct11_13_15 | 13000 | 6123 | 2815 | 5009 | 36.09 | NA | 1.0E+00 | 0.78728 | 0.00118 | 0.78964 |
| cvcrbpunhct11_12_15 | 12000 | 5652 | 2598 | 5366 | 39.75 | NA | 1.0E+00 | 0.78337 | 0.00127 | 0.78592 |
| cvcrbpunhct11_11_15 | 11000 | 5181 | 2382 | 5724 | 44.07 | NA | 1.0E+00 | 0.77773 | 0.00122 | 0.78017 |
| cvcrbpunhct11_10_15 | 10000 | 4710 | 2165 | 6081 | 49.26 | NA | 1.0E+00 | 0.77009 | 0.00154 | 0.77317 |
| cvcrbpunhct11_9_15 | 9000 | 4239 | 1949 | 6438 | 55.60 | NA | 1.0E+00 | 0.76494 | 0.00133 | 0.76760 |
| cvcrbpunhct11_8_15 | 8000 | 3768 | 1732 | 6796 | 63.53 | NA | 1.0E+00 | 0.75339 | 0.00148 | 0.75635 |
| cvcrbpunhct11_7_15 | 7000 | 3297 | 1516 | 7153 | 73.72 | NA | 1.0E+00 | 0.74139 | 0.00149 | 0.74437 |
| cvcrbpunhct11_6_15 | 6000 | 2826 | 1299 | 7510 | 87.31 | NA | 1.0E+00 | 0.72740 | 0.00134 | 0.73009 |
| cvcrbpunhct11_5_15 | 5000 | 2355 | 1083 | 7868 | 6.33 | NA | 1.0E+00 | 0.70988 | 0.00128 | 0.71244 |
| cvcrbpunhct11_4_15 | 4000 | 1884 | 866 | 8225 | 34.85 | NA | 1.0E+00 | 0.68707 | 0.00137 | 0.68981 |
| cvcrbpunhct11_3_15 | 3000 | 1413 | 650 | 8582 | 82.42 | NA | 1.0E+00 | 0.65613 | 0.00136 | 0.65885 |
| cvcrbpunhct11_2_15 | 2000 | 942 | 433 | 8940 | 77.51 | NA | 1.0E+00 | 0.61167 | 0.00117 | 0.61402 |
| cvcrbpunhct11_1_15 | 1000 | 471 | 217 | 9297 | 62.74 | NA | 1.0E+00 | 0.55043 | 0.00140 | 0.55324 |

**Table 6.9.6-14. Results for UNX crystal content in CV calculation model**

| case name | unh (g) | $^{235}U$ (g) | unh $H_2O$ (g) | CV $H_2O$ (g) | h/x | gU/l | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **500 g polyethylene and undissolved UNH crystals, dry containment vessel, reflected** | | | | | | | | | | |
| cvcrbpunhct11_24_1 | 24000 | 11303 | 5197 | 0 | 13.48 | NA | 1.0E-20 | 0.81264 | 0.00142 | 0.81548 |
| cvcrbpunhct11_23_1 | 23000 | 10832 | 4980 | 0 | 13.55 | NA | 1.0E-20 | 0.81127 | 0.00129 | 0.81384 |
| cvcrbpunhct11_22_1 | 22000 | 10361 | 4764 | 0 | 13.62 | NA | 1.0E-20 | 0.80828 | 0.00121 | 0.81069 |
| cvcrbpunhct11_21_1 | 21000 | 9890 | 4547 | 0 | 13.70 | NA | 1.0E-20 | 0.80873 | 0.00122 | 0.81117 |
| cvcrbpunhct11_20_1 | 20000 | 9419 | 4331 | 0 | 13.78 | NA | 1.0E-20 | 0.80508 | 0.00132 | 0.80773 |
| cvcrbpunhct11_19_1 | 19000 | 8948 | 4114 | 0 | 13.87 | NA | 1.0E-20 | 0.80364 | 0.00150 | 0.80664 |
| cvcrbpunhct11_18_1 | 18000 | 8477 | 3898 | 0 | 13.98 | NA | 1.0E-20 | 0.80002 | 0.00170 | 0.80343 |
| cvcrbpunhct11_17_1 | 17000 | 8006 | 3681 | 0 | 14.09 | NA | 1.0E-20 | 0.79969 | 0.00165 | 0.80298 |
| cvcrbpunhct11_16_1 | 16000 | 7536 | 3465 | 0 | 14.23 | NA | 1.0E-20 | 0.79458 | 0.00144 | 0.79746 |
| cvcrbpunhct11_15_1 | 15000 | 7064 | 3248 | 0 | 14.37 | NA | 1.0E-20 | 0.79130 | 0.00141 | 0.79411 |
| cvcrbpunhct11_14_1 | 14000 | 6594 | 3031 | 0 | 14.54 | NA | 1.0E-20 | 0.78794 | 0.00127 | 0.79048 |
| cvcrbpunhct11_13_1 | 13000 | 6123 | 2815 | 0 | 14.74 | NA | 1.0E-20 | 0.78506 | 0.00137 | 0.78781 |
| cvcrbpunhct11_12_1 | 12000 | 5652 | 2598 | 0 | 14.97 | NA | 1.0E-20 | 0.78061 | 0.00121 | 0.78303 |
| cvcrbpunhct11_11_1 | 11000 | 5181 | 2382 | 0 | 15.24 | NA | 1.0E-20 | 0.77102 | 0.00125 | 0.77352 |
| cvcrbpunhct11_10_1 | 10000 | 4710 | 2165 | 0 | 15.56 | NA | 1.0E-20 | 0.76415 | 0.00129 | 0.76673 |
| cvcrbpunhct11_9_1 | 9000 | 4239 | 1949 | 0 | 15.96 | NA | 1.0E-20 | 0.75589 | 0.00141 | 0.75872 |
| cvcrbpunhct11_8_1 | 8000 | 3768 | 1732 | 0 | 16.45 | NA | 1.0E-20 | 0.74147 | 0.00151 | 0.74449 |
| cvcrbpunhct11_7_1 | 7000 | 3297 | 1516 | 0 | 17.09 | NA | 1.0E-20 | 0.72828 | 0.00125 | 0.73077 |
| cvcrbpunhct11_6_1 | 6000 | 2826 | 1299 | 0 | 17.93 | NA | 1.0E-20 | 0.71077 | 0.00122 | 0.71321 |
| cvcrbpunhct11_5_1 | 5000 | 2355 | 1083 | 0 | 19.12 | NA | 1.0E-20 | 0.68823 | 0.00137 | 0.69096 |
| cvcrbpunhct11_4_1 | 4000 | 1884 | 866 | 0 | 20.90 | NA | 1.0E-20 | 0.66016 | 0.00146 | 0.66309 |
| cvcrbpunhct11_3_1 | 3000 | 1413 | 650 | 0 | 23.87 | NA | 1.0E-20 | 0.61922 | 0.00144 | 0.62211 |

**Table 6.9.6-14. Results for UNX crystal content in CV calculation model**

| case name | unh (g) | $^{235}U$ (g) | unh $H_2O$ (g) | CV $H_2O$ (g) | h/x | gU/l | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| cvcrbpunhct11_2_1 | 2000 | 942 | 433 | 0 | 29.80 | NA | 1.0E-20 | 0.56205 | 0.00129 | 0.56462 |
| cvcrbpunhct11_1_1 | 1000 | 471 | 217 | 0 | 47.60 | NA | 1.0E-20 | 0.47544 | 0.00110 | 0.47765 |

**Table 6.9.6-15. Results for UNX crystal content in packaging calculation model**

| case name | unh (g) | $^{235}U$ (g) | unh $H_2O$ (g) | CV $H_2O$ (g) | h/x | gU/l | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UNH crystal content, 0 g polyethylene in flooded containment vessel, single package reflected** | | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | | **HAC** | | | |
| ncsrunhct11_24_1_1 | 24000 | 11303 | 5197 | 1620 | 15.74 | 1106 | 1.0E-20 | 0.60250 | 0.00130 | 0.60510 | hcsrunhct12_24_1_1 | 0.60528 | 0.00129 | 0.60786 |
| ncsrunhct11_24_1_2 | 24000 | 11303 | 5197 | 1620 | 15.74 | 1106 | 1.0E-05 | 0.59895 | 0.00119 | 0.60134 | hcsrunhct12_24_1_2 | 0.60289 | 0.00142 | 0.60574 |
| ncsrunhct11_24_1_3 | 24000 | 11303 | 5197 | 1620 | 15.74 | 1106 | 1.0E-04 | 0.59947 | 0.00124 | 0.60194 | hcsrunhct12_24_1_3 | 0.60552 | 0.00130 | 0.60812 |
| ncsrunhct11_24_1_4 | 24000 | 11303 | 5197 | 1620 | 15.74 | 1106 | 1.0E-03 | 0.60331 | 0.00132 | 0.60595 | hcsrunhct12_24_1_4 | 0.60265 | 0.00112 | 0.60489 |
| ncsrunhct11_24_1_5 | 24000 | 11303 | 5197 | 1620 | 15.74 | 1106 | 1.0E-02 | 0.60398 | 0.00118 | 0.60635 | hcsrunhct12_24_1_5 | 0.60426 | 0.00152 | 0.60731 |
| ncsrunhct11_24_1_6 | 24000 | 11303 | 5197 | 1620 | 15.74 | 1106 | 1.0E-01 | 0.61004 | 0.00142 | 0.61287 | hcsrunhct12_24_1_6 | 0.61378 | 0.00127 | 0.61632 |
| ncsrunhct11_24_1_8 | 24000 | 11303 | 5197 | 1620 | 15.74 | 1106 | 3.0E-01 | 0.63238 | 0.00143 | 0.63524 | hcsrunhct12_24_1_8 | 0.63556 | 0.00128 | 0.63813 |
| ncsrunhct11_24_1_15 | 24000 | 11303 | 5197 | 1620 | 15.74 | 1106 | 1.0E+00 | 0.69882 | 0.00142 | 0.70166 | hcsrunhct12_24_1_15 | 0.70190 | 0.00129 | 0.70448 |
| | | | | | | | | | | | | | | |
| ncsrunhct11_24_1_15 | 24000 | 11303 | 5197 | 1620 | 15.74 | 1106 | 1.0E+00 | 0.69882 | 0.00142 | 0.70166 | hcsrunhct12_24_1_15 | 0.70190 | 0.00129 | 0.70448 |
| ncsrunhct11_23_1_15 | 23000 | 10832 | 4980 | 1978 | 16.77 | 1060 | 1.0E+00 | 0.70360 | 0.00134 | 0.70628 | hcsrunhct12_23_1_15 | 0.70555 | 0.00129 | 0.70813 |
| ncsrunhct11_22_1_15 | 22000 | 10361 | 4764 | 2335 | 17.88 | 1014 | 1.0E+00 | 0.70899 | 0.00132 | 0.71163 | hcsrunhct12_22_1_15 | 0.70899 | 0.00136 | 0.71171 |
| ncsrunhct11_21_1_15 | 21000 | 9890 | 4547 | 2693 | 19.11 | 968 | 1.0E+00 | 0.71172 | 0.00133 | 0.71438 | hcsrunhct12_21_1_15 | 0.71348 | 0.00158 | 0.71664 |

**Table 6.9.6-15. Results for UNX crystal content in packaging calculation model**

| case name | unh (g) | $^{235}U$ (g) | unh $H_2O$ (g) | CV $H_2O$ (g) | h/x | gU/l | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncsrunhct11_20_1_15 | 20000 | 9419 | 4331 | 3050 | 20.45 | 922 | 1.0E+00 | 0.71256 | 0.00123 | 0.71501 | hcsrunhct12_20_1_15 | 0.71623 | 0.00117 | 0.71858 |
| ncsrunhct11_19_1_15 | 19000 | 8948 | 4114 | 3407 | 21.94 | 876 | 1.0E+00 | 0.71780 | 0.00132 | 0.72045 | hcsrunhct12_19_1_15 | 0.71798 | 0.00132 | 0.72063 |
| ncsrunhct11_18_1_15 | 18000 | 8477 | 3898 | 3765 | 23.59 | 830 | 1.0E+00 | 0.72130 | 0.00139 | 0.72407 | hcsrunhct12_18_1_15 | 0.72545 | 0.00149 | 0.72843 |
| ncsrunhct11_17_1_15 | 17000 | 8006 | 3681 | 4122 | 25.44 | 784 | 1.0E+00 | 0.72340 | 0.00161 | 0.72663 | hcsrunhct12_17_1_15 | 0.72589 | 0.00134 | 0.72856 |
| ncsrunhct11_16_1_15 | 16000 | 7536 | 3464 | 4479 | 27.51 | 738 | 1.0E+00 | 0.72816 | 0.00141 | 0.73098 | hcsrunhct12_16_1_15 | 0.73042 | 0.00147 | 0.73336 |
| ncsrunhct11_15_1_15 | 15000 | 7064 | 3248 | 4837 | 29.87 | 692 | 1.0E+00 | 0.73150 | 0.00149 | 0.73449 | hcsrunhct12_15_1_15 | 0.73525 | 0.00151 | 0.73827 |
| ncsrunhct11_14_1_15 | 14000 | 6594 | 3031 | 5194 | 32.56 | 645 | 1.0E+00 | 0.73255 | 0.00135 | 0.73524 | hcsrunhct12_14_1_15 | 0.73405 | 0.00150 | 0.73704 |
| ncsrunhct11_13_1_15 | 13000 | 6123 | 2815 | 5551 | 35.67 | 599 | 1.0E+00 | 0.73488 | 0.00128 | 0.73745 | hcsrunhct12_13_1_15 | 0.73722 | 0.00159 | 0.74040 |
| ncsrunhct11_12_1_15 | 12000 | 5652 | 2598 | 5909 | 39.29 | 553 | 1.0E+00 | 0.73982 | 0.00146 | 0.74274 | hcsrunhct12_12_1_15 | 0.74114 | 0.00126 | 0.74366 |
| ncsrunhct11_11_1_15 | 11000 | 5181 | 2382 | 6266 | 43.57 | 507 | 1.0E+00 | 0.74059 | 0.00156 | 0.74370 | hcsrunhct12_11_1_15 | 0.74104 | 0.00187 | 0.74477 |
| ncsrunhct11_10_1_15 | 10000 | 4710 | 2165 | 6623 | 48.71 | 461 | 1.0E+00 | 0.74238 | 0.00148 | 0.74533 | hcsrunhct12_10_1_15 | 0.74247 | 0.00134 | 0.74514 |
| ncsrunhct11_9_1_15 | 9000 | 4239 | 1949 | 6981 | 54.99 | 415 | 1.0E+00 | 0.74214 | 0.00135 | 0.74484 | hcsrunhct12_9_1_15 | 0.74537 | 0.00150 | 0.74836 |
| ncsrunhct11_8_1_15 | 8000 | 3768 | 1732 | 7338 | 62.83 | 369 | 1.0E+00 | 0.74436 | 0.00146 | 0.74728 | hcsrunhct12_8_1_15 | 0.74169 | 0.00176 | 0.74521 |
| ncsrunhct11_7_1_15 | 7000 | 3297 | 1516 | 7695 | 72.92 | 323 | 1.0E+00 | 0.73972 | 0.00146 | 0.74265 | hcsrunhct12_7_1_15 | 0.74201 | 0.00129 | 0.74459 |
| ncsrunhct11_6_1_15 | 6000 | 2826 | 1299 | 8053 | 86.38 | 277 | 1.0E+00 | 0.73458 | 0.00147 | 0.73752 | hcsrunhct12_6_1_15 | 0.73491 | 0.00155 | 0.73802 |
| ncsrunhct11_5_1_15 | 5000 | 2355 | 1083 | 8410 | 105.22 | 231 | 1.0E+00 | 0.72880 | 0.00143 | 0.73166 | hcsrunhct12_5_1_15 | 0.72804 | 0.00151 | 0.73107 |
| ncsrunhct11_4_1_15 | 4000 | 1884 | 866 | 8768 | 133.47 | 184 | 1.0E+00 | 0.71269 | 0.00158 | 0.71585 | hcsrunhct12_4_1_15 | 0.71463 | 0.00147 | 0.71758 |
| ncsrunhct11_3_1_15 | 3000 | 1413 | 650 | 9125 | 180.57 | 138 | 1.0E+00 | 0.68768 | 0.00137 | 0.69042 | hcsrunhct12_3_1_15 | 0.69065 | 0.00121 | 0.69306 |
| ncsrunhct11_2_1_15 | 2000 | 942 | 433 | 9482 | 274.74 | 92 | 1.0E+00 | 0.64383 | 0.00118 | 0.64619 | hcsrunhct12_2_1_15 | 0.64813 | 0.00131 | 0.65076 |
| **UNH crystal content, 500 g polyethylene in flooded containment vessel, single package reflected** | | | | | | | | | | | | | | |
| ncsrpunhct11_24_1 | 24000 | 11303 | 5197 | 1078 | 15.97 | 1106 | 1E-20 | 0.60653 | 0.00140 | 0.60932 | hcsrpunhct12_24_1 | 0.60988 | 0.00142 | 0.61273 |
| ncsrpunhct11_24_15 | 24000 | 11303 | 5197 | 1078 | 15.97 | 1106 | 1E+00 | 0.70571 | 0.00135 | 0.70841 | hcsrpunhct12_24_15 | 0.70886 | 0.00133 | 0.71152 |
| | | | | | | | | | | | | | | |

**Table 6.9.6-15. Results for UNX crystal content in packaging calculation model**

| case name | unh (g) | $^{235}U$ (g) | unh $H_2O$ (g) | CV $H_2O$ (g) | h/x | gU/l | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncsrpunhct11_24_15 | 24000 | 11303 | 5197 | 1078 | 15.97 | 1106 | 1E+00 | 0.70571 | 0.00135 | 0.70841 | hcsrpunhct12_24_15 | 0.70886 | 0.00133 | 0.71152 |
| ncsrpunhct11_23_15 | 23000 | 10832 | 4980 | 1435 | 17.01 | 1060 | 1E+00 | 0.71244 | 0.00130 | 0.71504 | hcsrpunhct12_23_15 | 0.71209 | 0.00121 | 0.71452 |
| ncsrpunhct11_22_15 | 22000 | 10361 | 4764 | 1793 | 18.13 | 1014 | 1E+00 | 0.71524 | 0.00158 | 0.71841 | hcsrpunhct12_22_15 | 0.71753 | 0.00126 | 0.72006 |
| ncsrpunhct11_21_15 | 21000 | 9890 | 4547 | 2150 | 19.37 | 968 | 1E+00 | 0.71747 | 0.00154 | 0.72055 | hcsrpunhct12_21_15 | 0.71997 | 0.00137 | 0.72270 |
| ncsrpunhct11_20_15 | 20000 | 9419 | 4331 | 2507 | 20.73 | 922 | 1E+00 | 0.72176 | 0.00151 | 0.72479 | hcsrpunhct12_20_15 | 0.72403 | 0.00130 | 0.72663 |
| ncsrpunhct11_19_15 | 19000 | 8948 | 4114 | 2865 | 22.23 | 876 | 1E+00 | 0.72616 | 0.00138 | 0.72891 | hcsrpunhct12_19_15 | 0.72647 | 0.00141 | 0.72929 |
| ncsrpunhct11_18_15 | 18000 | 8477 | 3898 | 3222 | 23.90 | 830 | 1E+00 | 0.72901 | 0.00163 | 0.73227 | hcsrpunhct12_18_15 | 0.73343 | 0.00131 | 0.73606 |
| ncsrpunhct11_17_15 | 17000 | 8006 | 3681 | 3579 | 25.76 | 784 | 1E+00 | 0.73255 | 0.00127 | 0.73508 | hcsrpunhct12_17_15 | 0.73387 | 0.00128 | 0.73643 |
| ncsrpunhct11_16_15 | 16000 | 7536 | 3465 | 3937 | 27.86 | 738 | 1E+00 | 0.73515 | 0.00152 | 0.73818 | hcsrpunhct12_16_15 | 0.73768 | 0.00152 | 0.74073 |
| ncsrpunhct11_15_15 | 15000 | 7064 | 3248 | 4294 | 30.24 | 692 | 1E+00 | 0.74097 | 0.00126 | 0.74349 | hcsrpunhct12_15_15 | 0.74006 | 0.00132 | 0.74270 |
| ncsrpunhct11_14_15 | 14000 | 6594 | 3031 | 4652 | 32.96 | 645 | 1E+00 | 0.74169 | 0.00135 | 0.74438 | hcsrpunhct12_14_15 | 0.74240 | 0.00141 | 0.74522 |
| ncsrpunhct11_13_15 | 13000 | 6123 | 2815 | 5009 | 36.09 | 599 | 1E+00 | 0.74466 | 0.00139 | 0.74744 | hcsrpunhct12_13_15 | 0.74534 | 0.00141 | 0.74815 |
| ncsrpunhct11_12_15 | 12000 | 5652 | 2598 | 5366 | 39.75 | 553 | 1E+00 | 0.74381 | 0.00142 | 0.74666 | hcsrpunhct12_12_15 | 0.74529 | 0.00132 | 0.74794 |
| ncsrpunhct11_11_15 | 11000 | 5181 | 2382 | 5724 | 44.07 | 507 | 1E+00 | 0.74858 | 0.00146 | 0.75151 | hcsrpunhct12_11_15 | 0.74980 | 0.00139 | 0.75259 |
| ncsrpunhct11_10_15 | 10000 | 4710 | 2165 | 6081 | 49.26 | 461 | 1E+00 | 0.74595 | 0.00140 | 0.74875 | hcsrpunhct12_10_15 | 0.74967 | 0.00141 | 0.75249 |
| ncsrpunhct11_9_15 | 9000 | 4239 | 1949 | 6438 | 55.60 | 415 | 1E+00 | 0.74868 | 0.00167 | 0.75202 | hcsrpunhct12_9_15 | 0.75260 | 0.00164 | 0.75587 |
| ncsrpunhct11_8_15 | 8000 | 3768 | 1732 | 6796 | 63.53 | 369 | 1E+00 | 0.74978 | 0.00139 | 0.75255 | hcsrpunhct12_8_15 | 0.74914 | 0.00120 | 0.75155 |
| ncsrpunhct11_7_15 | 7000 | 3297 | 1516 | 7153 | 73.72 | 323 | 1E+00 | 0.74628 | 0.00147 | 0.74922 | hcsrpunhct12_7_15 | 0.74708 | 0.00155 | 0.75018 |
| ncsrpunhct11_6_15 | 6000 | 2826 | 1299 | 7510 | 87.31 | 277 | 1E+00 | 0.74259 | 0.00122 | 0.74503 | hcsrpunhct12_6_15 | 0.74481 | 0.00150 | 0.74781 |
| ncsrpunhct11_5_15 | 5000 | 2355 | 1083 | 7868 | 106.33 | 231 | 1E+00 | 0.73226 | 0.00133 | 0.73492 | hcsrpunhct12_5_15 | 0.73303 | 0.00153 | 0.73609 |
| ncsrpunhct11_4_15 | 4000 | 1884 | 866 | 8225 | 134.85 | 184 | 1E+00 | 0.72045 | 0.00145 | 0.72334 | hcsrpunhct12_4_15 | 0.71942 | 0.00168 | 0.72279 |
| ncsrpunhct11_3_15 | 3000 | 1413 | 650 | 8582 | 182.42 | 138 | 1E+00 | 0.69669 | 0.00167 | 0.70003 | hcsrpunhct12_3_15 | 0.69613 | 0.00139 | 0.69891 |
| ncsrpunhct11_2_15 | 2000 | 942 | 433 | 8940 | 277.51 | 92 | 1E+00 | 0.65100 | 0.00112 | 0.65324 | hcsrpunhct12_2_15 | 0.65137 | 0.00149 | 0.65436 |
| ncsrpunhct11_1_15 | 1000 | 471 | 217 | 9297 | 562.74 | 46 | 1E+00 | 0.54270 | 0.00116 | 0.54501 | hcsrpunhct12_1_15 | 0.54296 | 0.00099 | 0.54494 |

**Table 6.9.6-15. Results for UNX crystal content in packaging calculation model**

| case name | unh (g) | $^{235}U$ (g) | unh $H_2O$ (g) | CV $H_2O$ (g) | h/x | gU/l | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UNH crystal content, 0 g polyethylene in flooded containment vessel, array packaging calculation model for CSI=0.0** | | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | | **HAC** | | | |
| nciaunhct11_8_24_1_1 | 24000 | 11303 | 5197 | 1620 | 15.74 | 1106 | 1.0E-20 | 0.91485 | 0.00136 | 0.91756 | hciaunhct12_8_24_1_1 | 0.91665 | 0.00134 | 0.91933 |
| nciaunhct11_8_24_1_2 | 24000 | 11303 | 5197 | 1620 | 15.74 | 1106 | 1.0E-05 | 0.91420 | 0.00120 | 0.91659 | hciaunhct12_8_24_1_2 | 0.91708 | 0.00131 | 0.91969 |
| nciaunhct11_8_24_1_3 | 24000 | 11303 | 5197 | 1620 | 15.74 | 1106 | 1.0E-04 | 0.91426 | 0.00123 | 0.91672 | hciaunhct12_8_24_1_3 | 0.91632 | 0.00112 | 0.91856 |
| nciaunhct11_8_24_1_4 | 24000 | 11303 | 5197 | 1620 | 15.74 | 1106 | 1.0E-03 | 0.91095 | 0.00119 | 0.91333 | hciaunhct12_8_24_1_4 | 0.91159 | 0.00120 | 0.91399 |
| nciaunhct11_8_24_1_5 | 24000 | 11303 | 5197 | 1620 | 15.74 | 1106 | 1.0E-02 | 0.88904 | 0.00117 | 0.89138 | hciaunhct12_8_24_1_5 | 0.89357 | 0.00127 | 0.89610 |
| nciaunhct11_8_24_1_6 | 24000 | 11303 | 5197 | 1620 | 15.74 | 1106 | 1.0E-01 | 0.77132 | 0.00109 | 0.77350 | hciaunhct12_8_24_1_6 | 0.78417 | 0.00129 | 0.78676 |
| nciaunhct11_8_24_1_8 | 24000 | 11303 | 5197 | 1620 | 15.74 | 1106 | 3.0E-01 | 0.71012 | 0.00130 | 0.71272 | hciaunhct12_8_24_1_8 | 0.71917 | 0.00135 | 0.72188 |
| nciaunhct11_8_24_1_15 | 24000 | 11303 | 5197 | 1620 | 15.74 | 1106 | 1.0E+00 | 0.71873 | 0.00134 | 0.72140 | hciaunhct12_8_24_1_15 | 0.72598 | 0.00147 | 0.72892 |
| | | | | | | | | | | | | | | |
| nciaunhct11_8_24_1_3 | 24000 | 11303 | 5197 | 1620 | 15.74 | 1106 | 1.0E-04 | 0.91426 | 0.00123 | 0.91672 | hciaunhct12_8_24_1_3 | 0.91632 | 0.00112 | 0.91856 |
| nciaunhct11_8_12_1_3 | 12000 | 5652 | 2598 | 5909 | 39.29 | 553 | 1.0E-04 | 0.93016 | 0.00130 | 0.93277 | hciaunhct12_8_12_1_3 | 0.92942 | 0.00157 | 0.93256 |
| nciaunhct11_8_11_1_3 | 11000 | 5181 | 2382 | 6266 | 43.57 | 507 | 1.0E-04 | 0.92825 | 0.00132 | 0.93090 | hciaunhct12_8_11_1_3 | 0.92834 | 0.00152 | 0.93138 |
| nciaunhct11_8_10_1_3 | 10000 | 4710 | 2165 | 6623 | 48.71 | 461 | 1.0E-04 | 0.92490 | 0.00152 | 0.92794 | hciaunhct12_8_10_1_3 | 0.92555 | 0.00137 | 0.92828 |
| nciaunhct11_8_9_1_3 | 9000 | 4239 | 1949 | 6981 | 54.99 | 415 | 1.0E-04 | 0.92044 | 0.00124 | 0.92293 | hciaunhct12_8_9_1_3 | 0.92360 | 0.00136 | 0.92631 |
| nciaunhct11_8_8_1_3 | 8000 | 3768 | 1732 | 7338 | 62.83 | 369 | 1.0E-04 | 0.91662 | 0.00121 | 0.91905 | hciaunhct12_8_8_1_3 | 0.91875 | 0.00144 | 0.92163 |
| nciaunhct11_8_7_1_3 | 7000 | 3297 | 1516 | 7695 | 72.92 | 323 | 1.0E-04 | 0.91132 | 0.00140 | 0.91411 | hciaunhct12_8_7_1_3 | 0.90978 | 0.00135 | 0.91247 |
| nciaunhct11_8_6_1_3 | 6000 | 2826 | 1299 | 8053 | 86.38 | 277 | 1.0E-04 | 0.90036 | 0.00128 | 0.90293 | hciaunhct12_8_6_1_3 | 0.89938 | 0.00150 | 0.90238 |
| nciaunhct11_8_5_1_3 | 5000 | 2355 | 1083 | 8410 | 105.22 | 231 | 1.0E-04 | 0.88578 | 0.00141 | 0.88860 | hciaunhct12_8_5_1_3 | 0.88489 | 0.00149 | 0.88788 |
| nciaunhct11_8_4_1_3 | 4000 | 1884 | 866 | 8768 | 133.47 | 184 | 1.0E-04 | 0.86530 | 0.00119 | 0.86769 | hciaunhct12_8_4_1_3 | 0.86326 | 0.00139 | 0.86604 |
| nciaunhct11_8_3_1_3 | 3000 | 1413 | 650 | 9125 | 180.57 | 138 | 1.0E-04 | 0.82655 | 0.00120 | 0.82895 | hciaunhct12_8_3_1_3 | 0.83005 | 0.00118 | 0.83242 |
| nciaunhct11_8_2_1_3 | 2000 | 942 | 433 | 9482 | 274.74 | 92 | 1.0E-04 | 0.76783 | 0.00123 | 0.77029 | hciaunhct12_8_2_1_3 | 0.76545 | 0.00129 | 0.76804 |
| nciaunhct11_8_1_1_3 | 1000 | 471 | 217 | 9840 | 557.20 | 46 | 1.0E-04 | 0.62610 | 0.00112 | 0.62834 | hciaunhct12_8_1_1_3 | 0.62341 | 0.00104 | 0.62549 |

**Table 6.9.6-15. Results for UNX crystal content in packaging calculation model**

| case name | unh (g) | $^{235}U$ (g) | unh $H_2O$ (g) | CV $H_2O$ (g) | h/x | gU/l | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UNH crystal content, 500 g polyethylene in flooded containment vessel, array packaging calculation model for CSI=0.0** | | | | | | | | | | | | | | |
| nciapunhct11_24_1 | 24000 | 11303 | 5197 | 1078 | 15.97 | 1106 | 1E-20 | 0.92205 | 0.00118 | 0.92442 | hciapunhct12_24_1 | 0.92136 | 0.00123 | 0.92383 |
| nciapunhct11_24_15 | 24000 | 11303 | 5197 | 1078 | 15.97 | 1106 | 1E+00 | 0.72649 | 0.00128 | 0.72905 | hciapunhct12_24_15 | 0.73087 | 0.00128 | 0.73343 |
| | | | | | | | | | | | | | | |
| nciapunhct11_24_3 | 24000 | 11303 | 5197 | 1078 | 15.97 | 1106 | 1E-04 | 0.92258 | 0.00141 | 0.92539 | hciapunhct12_24_3 | 0.92172 | 0.00124 | 0.92419 |
| nciapunhct11_16_3 | 16000 | 7536 | 3465 | 3937 | 27.86 | 738 | 1E-04 | 0.93498 | 0.00131 | 0.93759 | hciapunhct12_16_3 | 0.93544 | 0.00130 | 0.93804 |
| nciapunhct11_15_3 | 15000 | 7064 | 3248 | 4294 | 30.24 | 692 | 1E-04 | 0.93400 | 0.00139 | 0.93678 | hciapunhct12_15_3 | 0.93500 | 0.00136 | 0.93771 |
| nciapunhct11_14_3 | 14000 | 6594 | 3031 | 4652 | 32.96 | 645 | 1E-04 | 0.93374 | 0.00153 | 0.93680 | hciapunhct12_14_3 | 0.93539 | 0.00135 | 0.93810 |
| nciapunhct11_8_3 | 8000 | 3768 | 1732 | 6796 | 63.53 | 369 | 1E-04 | 0.92190 | 0.00144 | 0.92478 | hciapunhct12_8_3 | 0.92270 | 0.00159 | 0.92589 |
| nciapunhct11_7_3 | 7000 | 3297 | 1516 | 7153 | 73.72 | 323 | 1E-04 | 0.91677 | 0.00157 | 0.91991 | hciapunhct12_7_3 | 0.91538 | 0.00132 | 0.91803 |
| nciapunhct11_1_3 | 1000 | 471 | 217 | 9297 | 562.74 | 46 | 1E-04 | 0.62819 | 0.00115 | 0.63049 | hciapunhct12_1_3 | 0.62885 | 0.00109 | 0.63103 |
| **UNH crystal content, 0 g polyethylene in flooded containment vessel, array packaging calculation model for CSI=0.4** | | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | | **HAC** | | | |
| ncf1unhct11_8_24_1_3 | 24000 | 11303 | 5197 | 1620 | 15.74 | 1106 | 1.0E-04 | 0.86774 | 0.00127 | 0.87027 | hcf2unhct12_8_24_1_3 | 0.82915 | 0.00145 | 0.83205 |
| ncf1unhct11_8_12_1_3 | 12000 | 5652 | 2598 | 5909 | 39.29 | 553 | 1.0E-04 | 0.88287 | 0.00133 | 0.88554 | hcf2unhct12_8_12_1_3 | 0.85267 | 0.00165 | 0.85597 |
| ncf1unhct11_8_11_1_3 | 11000 | 5181 | 2382 | 6266 | 43.57 | 507 | 1.0E-04 | 0.88535 | 0.00133 | 0.88802 | hcf2unhct12_8_11_1_3 | 0.85565 | 0.00134 | 0.85833 |
| ncf1unhct11_8_10_1_3 | 10000 | 4710 | 2165 | 6623 | 48.71 | 461 | 1.0E-04 | 0.88182 | 0.00140 | 0.88461 | hcf2unhct12_8_10_1_3 | 0.85153 | 0.00132 | 0.85416 |
| ncf1unhct11_8_1_1_3 | 1000 | 471 | 217 | 9840 | 557.20 | 46 | 1.0E-04 | 0.60011 | 0.00143 | 0.60297 | hcf2unhct12_8_1_1_3 | 0.58199 | 0.00107 | 0.58414 |
| **UNH crystal content, 500 g polyethylene in flooded containment vessel, array packaging calculation model for CSI=0.4** | | | | | | | | | | | | | | |
| ncf1punhct11_24_3 | 24000 | 11303 | 5197 | 1078 | 15.97 | 1106 | 1E-04 | 0.87035 | 0.00135 | 0.87304 | hcf2punhct12_24_3 | 0.83958 | 0.00135 | 0.84227 |
| ncf1punhct11_15_3 | 15000 | 7064 | 3248 | 4294 | 30.24 | 692 | 1E-04 | 0.89208 | 0.00154 | 0.89516 | hcf2punhct12_15_3 | 0.86102 | 0.00149 | 0.86400 |
| ncf1punhct11_14_3 | 14000 | 6594 | 3031 | 4652 | 32.96 | 645 | 1E-04 | 0.89354 | 0.00152 | 0.89658 | hcf2punhct12_14_3 | 0.85954 | 0.00131 | 0.86216 |
| ncf1punhct11_1_3 | 1000 | 471 | 217 | 9297 | 562.74 | 46 | 1E-04 | 0.60481 | 0.00118 | 0.60718 | hcf2punhct12_1_3 | 0.58731 | 0.00119 | 0.58968 |

**Table 6.9.6-16. Results for leakage of UNX crystal content out of containment vessel**

| case name | U (g) | $^{235}U$ (g) | unh $H_2O$ (g) | CV $H_2O$ (g) | h/x | CV gU/l | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **UNH crystal content, 0 g polyethylene in flooded containment vessel, out leakage, single package reflected** | | | | | | | | | | |
| **HAC** | | | | | | | | | | |
| icsrunhct12_24_1_1 | 24000 | 11303 | 5197 | 4875 | 30.14 | 687 | 1.0E-20 | 0.78331 | 0.00139 | 0.78609 |
| icsrunhct12_24_1_2 | 24000 | 11303 | 5197 | 4875 | 30.14 | 687 | 1.0E-05 | 0.78291 | 0.00159 | 0.78610 |
| icsrunhct12_24_1_3 | 24000 | 11303 | 5197 | 4875 | 30.14 | 687 | 1.0E-04 | 0.78197 | 0.00153 | 0.78503 |
| icsrunhct12_24_1_4 | 24000 | 11303 | 5197 | 4875 | 30.14 | 687 | 1.0E-03 | 0.78003 | 0.00145 | 0.78294 |
| icsrunhct12_24_1_5 | 24000 | 11303 | 5197 | 4875 | 30.14 | 687 | 1.0E-02 | 0.78443 | 0.00140 | 0.78723 |
| icsrunhct12_24_1_6 | 24000 | 11303 | 5197 | 4875 | 30.14 | 687 | 1.0E-01 | 0.78426 | 0.00151 | 0.78729 |
| icsrunhct12_24_1_8 | 24000 | 11303 | 5197 | 4875 | 30.14 | 687 | 3.0E-01 | 0.78841 | 0.00153 | 0.79146 |
| icsrunhct12_24_1_15 | 24000 | 11303 | 5197 | 4875 | 30.14 | 687 | 1.0E+00 | 0.79193 | 0.00164 | 0.79521 |
| | | | | | | | | | | |
| icsrunhct12_24_1_15 | 24000 | 11303 | 5197 | 4875 | 30.14 | 687 | 1.0E+00 | 0.79193 | 0.00164 | 0.79521 |
| icsrunhct12_23_1_15 | 23000 | 10832 | 4980 | 5097 | 31.79 | 658 | 1.0E+00 | 0.79465 | 0.00130 | 0.79724 |
| icsrunhct12_22_1_15 | 22000 | 10361 | 4764 | 5318 | 33.59 | 629 | 1.0E+00 | 0.79665 | 0.00145 | 0.79956 |
| icsrunhct12_21_1_15 | 21000 | 9890 | 4547 | 5540 | 35.56 | 601 | 1.0E+00 | 0.79533 | 0.00156 | 0.79845 |
| icsrunhct12_20_1_15 | 20000 | 9419 | 4331 | 5762 | 37.73 | 572 | 1.0E+00 | 0.79937 | 0.00179 | 0.80295 |
| icsrunhct12_19_1_15 | 19000 | 8948 | 4114 | 5984 | 40.13 | 544 | 1.0E+00 | 0.80059 | 0.00135 | 0.80329 |
| icsrunhct12_18_1_15 | 18000 | 8477 | 3898 | 6205 | 42.79 | 515 | 1.0E+00 | 0.79930 | 0.00144 | 0.80219 |
| icsrunhct12_17_1_15 | 17000 | 8006 | 3681 | 6427 | 45.77 | 486 | 1.0E+00 | 0.80320 | 0.00153 | 0.80626 |
| icsrunhct12_16_1_15 | 16000 | 7536 | 3464 | 6649 | 49.11 | 458 | 1.0E+00 | 0.80113 | 0.00142 | 0.80396 |
| icsrunhct12_15_1_15 | 15000 | 7064 | 3248 | 6871 | 52.91 | 429 | 1.0E+00 | 0.80445 | 0.00148 | 0.80740 |
| icsrunhct12_14_1_15 | 14000 | 6594 | 3031 | 7092 | 57.24 | 401 | 1.0E+00 | 0.79995 | 0.00124 | 0.80243 |
| icsrunhct12_13_1_15 | 13000 | 6123 | 2815 | 7314 | 62.25 | 372 | 1.0E+00 | 0.80425 | 0.00139 | 0.80703 |

**Table 6.9.6-16. Results for leakage of UNX crystal content out of containment vessel**

| case name | U (g) | $^{235}U$ (g) | unh $H_2O$ (g) | CV $H_2O$ (g) | h/x | CV gU/l | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| icsrunhct12_12_1_15 | 12000 | 5652 | 2598 | 7536 | 68.09 | 343 | 1.0E+00 | 0.79843 | 0.00129 | 0.80100 |
| icsrunhct12_11_1_15 | 11000 | 5181 | 2382 | 7758 | 74.98 | 315 | 1.0E+00 | 0.80002 | 0.00147 | 0.80297 |
| icsrunhct12_10_1_15 | 10000 | 4710 | 2165 | 7979 | 83.26 | 286 | 1.0E+00 | 0.79540 | 0.00162 | 0.79864 |
| icsrunhct12_9_1_15 | 9000 | 4239 | 1949 | 8201 | 93.38 | 257 | 1.0E+00 | 0.79147 | 0.00156 | 0.79459 |
| icsrunhct12_8_1_15 | 8000 | 3768 | 1732 | 8423 | 106.03 | 229 | 1.0E+00 | 0.78224 | 0.00165 | 0.78553 |
| icsrunhct12_7_1_15 | 7000 | 3297 | 1516 | 8645 | 122.29 | 200 | 1.0E+00 | 0.77559 | 0.00131 | 0.77821 |
| icsrunhct12_6_1_15 | 6000 | 2826 | 1299 | 8866 | 143.98 | 172 | 1.0E+00 | 0.76261 | 0.00136 | 0.76532 |
| icsrunhct12_5_1_15 | 5000 | 2355 | 1083 | 9088 | 174.33 | 143 | 1.0E+00 | 0.74504 | 0.00138 | 0.74781 |
| icsrunhct12_4_1_15 | 4000 | 1884 | 866 | 9310 | 219.86 | 114 | 1.0E+00 | 0.72070 | 0.00131 | 0.72333 |
| icsrunhct12_3_1_15 | 3000 | 1413 | 650 | 9532 | 295.76 | 86 | 1.0E+00 | 0.68185 | 0.00131 | 0.68447 |
| icsrunhct12_2_1_15 | 2000 | 942 | 433 | 9753 | 447.52 | 57 | 1.0E+00 | 0.61401 | 0.00117 | 0.61635 |
| icsrunhct12_1_1_15 | 1000 | 471 | 217 | 9975 | 902.71 | 29 | 1.0E+00 | 0.47625 | 0.00103 | 0.47831 |
| **UNH crystal content, 500 g polyethylene in flooded containment vessel, out leakage, single package reflected** | | | | | | | | | | |
| icsrpunhct12_24_1 | 24000 | 11303 | 5197 | 4444 | 30.37 | 710 | 1E-20 | 0.79145 | 0.00146 | 0.79436 |
| icsrpunhct12_24_15 | 24000 | 11303 | 5197 | 4444 | 30.37 | 710 | 1E+00 | 0.80433 | 0.00145 | 0.80723 |
| | | | | | | | | | | |
| icsrpunhct12_24_15 | 24000 | 11303 | 5197 | 4444 | 30.37 | 710 | 1E+00 | 0.80433 | 0.00145 | 0.80723 |
| icsrpunhct12_23_15 | 23000 | 10832 | 4980 | 4661 | 32.03 | 680 | 1E+00 | 0.80343 | 0.00127 | 0.80597 |
| icsrpunhct12_22_15 | 22000 | 10361 | 4764 | 4878 | 33.84 | 651 | 1E+00 | 0.80375 | 0.00125 | 0.80625 |
| icsrpunhct12_21_15 | 21000 | 9890 | 4547 | 5095 | 35.83 | 621 | 1E+00 | 0.80639 | 0.00161 | 0.80961 |
| icsrpunhct12_20_15 | 20000 | 9419 | 4331 | 5312 | 38.01 | 592 | 1E+00 | 0.80696 | 0.00144 | 0.80984 |
| icsrpunhct12_19_15 | 19000 | 8948 | 4114 | 5529 | 40.42 | 562 | 1E+00 | 0.80928 | 0.00157 | 0.81242 |
| icsrpunhct12_18_15 | 18000 | 8477 | 3898 | 5746 | 43.10 | 533 | 1E+00 | 0.80687 | 0.00138 | 0.80963 |
| icsrpunhct12_17_15 | 17000 | 8006 | 3681 | 5963 | 46.09 | 503 | 1E+00 | 0.80989 | 0.00164 | 0.81317 |

**Table 6.9.6-16. Results for leakage of UNX crystal content out of containment vessel**

| case name | U (g) | $^{235}U$ (g) | unh $H_2O$ (g) | CV $H_2O$ (g) | h/x | CV gU/l | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| icsrpunhct12_16_15 | 16000 | 7536 | 3464 | 6180 | 49.46 | 473 | 1E+00 | 0.80777 | 0.00162 | 0.81101 |
| icsrpunhct12_15_15 | 15000 | 7064 | 3248 | 6398 | 53.28 | 444 | 1E+00 | 0.81131 | 0.00154 | 0.81439 |
| icsrpunhct12_14_15 | 14000 | 6594 | 3031 | 6615 | 57.64 | 414 | 1E+00 | 0.80815 | 0.00162 | 0.81139 |
| icsrpunhct12_13_15 | 13000 | 6123 | 2815 | 6832 | 62.67 | 385 | 1E+00 | 0.80680 | 0.00133 | 0.80947 |
| icsrpunhct12_12_15 | 12000 | 5652 | 2598 | 7049 | 68.55 | 355 | 1E+00 | 0.80665 | 0.00151 | 0.80967 |
| icsrpunhct12_11_15 | 11000 | 5181 | 2382 | 7266 | 75.49 | 325 | 1E+00 | 0.80422 | 0.00157 | 0.80736 |
| icsrpunhct12_10_15 | 10000 | 4710 | 2165 | 7483 | 83.82 | 296 | 1E+00 | 0.80093 | 0.00148 | 0.80388 |
| icsrpunhct12_9_15 | 9000 | 4239 | 1949 | 7700 | 94.00 | 266 | 1E+00 | 0.79650 | 0.00144 | 0.79937 |
| icsrpunhct12_8_15 | 8000 | 3768 | 1732 | 7918 | 106.72 | 237 | 1E+00 | 0.79302 | 0.00182 | 0.79667 |
| icsrpunhct12_7_15 | 7000 | 3297 | 1516 | 8135 | 123.08 | 207 | 1E+00 | 0.78234 | 0.00156 | 0.78546 |
| icsrpunhct12_6_15 | 6000 | 2826 | 1299 | 8352 | 144.90 | 178 | 1E+00 | 0.76957 | 0.00175 | 0.77308 |
| icsrpunhct12_5_15 | 5000 | 2355 | 1083 | 8569 | 175.44 | 148 | 1E+00 | 0.75295 | 0.00147 | 0.75588 |
| icsrpunhct12_4_15 | 4000 | 1884 | 866 | 8786 | 221.24 | 118 | 1E+00 | 0.72610 | 0.00127 | 0.72864 |
| icsrpunhct12_3_15 | 3000 | 1413 | 650 | 9003 | 297.61 | 89 | 1E+00 | 0.68788 | 0.00134 | 0.69055 |
| icsrpunhct12_2_15 | 2000 | 942 | 433 | 9220 | 450.29 | 59 | 1E+00 | 0.61943 | 0.00119 | 0.62182 |
| icsrpunhct12_1_15 | 1000 | 471 | 217 | 9437 | 908.25 | 30 | 1E+00 | 0.47924 | 0.00105 | 0.48134 |

**Table 6.9.6-17. Results for skull oxide (SO) content in CV calculation model**

| case name | SO (g) | $U_3O_8$ (g) | Sat. $H_2O$ (g) | SO h/x | U (g) | $^{235}U$ (g) | C (g) | mg C/ g $^{235}U$ | CV $H_2O$ (g) | CV h/x | Unident. (g) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **flooded containment vessel, reflected** | | | | | | | | | | | | | | |
| **513 g polyethylene, no can spacers** | | | | | | | | | | | | | | |
| cvcrsk3cc_1_15_17 | 11589 | 8063 | 4468 | 28.09 | 6828 | 4765 | 417 | 87518 | 4105 | 50.58 | 2596 | 0.82806 | 0.00135 | 0.83075 |
| cvcrsk3cc_2_15_17 | 14934 | 11665 | 4015 | 17.79 | 9879 | 6858 | 504 | 73492 | 4105 | 33.41 | 2252 | 0.81716 | 0.00136 | 0.81989 |
| cvcrsk3cc_3_15_17 | 13821 | 11876 | 4893 | 20.62 | 10058 | 7028 | 372 | 52930 | 3233 | 32.62 | 1060 | 0.82909 | 0.00144 | 0.83197 |
| cvcrsk3cc_4_15_17 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 60 | 6786 | 3235 | 25.07 | -227 | 0.82622 | 0.00154 | 0.82930 |
| cvcrsk3cc_5_15_17 | 21216 | 21036 | 3869 | 9.49 | 17815 | 12455 | 27 | 2168 | 3235 | 16.27 | -360 | 0.81061 | 0.00116 | 0.81293 |
| cvcrsk3cc_6_15_17 | 15111 | 12933 | 3765 | 28.02 | 10960 | 4122 | 921 | 223432 | 4105 | 54.01 | 744 | 0.75711 | 0.00110 | 0.75932 |
| cvcrsk3cc_7_15_17 | 13155 | 11666 | 3989 | 32.68 | 9886 | 3712 | 609 | 164054 | 4106 | 61.55 | 367 | 0.76196 | 0.00136 | 0.76469 |
| cvcrsk3cc_8_15_17 | 13650 | 11689 | 4068 | 33.01 | 9906 | 3737 | 261 | 69834 | 4106 | 61.69 | 1187 | 0.76713 | 0.00137 | 0.76988 |
| cvcrsk3cc_9_15_17 | 21300 | 19865 | 3801 | 7.43 | 16816 | 15673 | 921 | 58764 | 3235 | 12.82 | 1 | 0.84737 | 0.00114 | 0.84965 |
| cvcrsk3cc_10_15_17 | 21300 | 20786 | 3905 | 7.27 | 17596 | 16399 | 0 | 0 | 3235 | 12.41 | 1 | 0.85155 | 0.00148 | 0.85451 |
| | | | | | | | | | | | | | | |
| cvcrsk3cc_4_1_1 | 15246 | 14900 | 0 | 1.95 | 12619 | 8842 | 0.00 | 0 | 0 | 1.95 | -227 | 0.49030 | 0.00095 | 0.49220 |
| cvcrsk3cc_4_1_2 | 15246 | 14900 | 0 | 1.95 | 12619 | 8842 | 3.75 | 424 | 0 | 1.95 | -227 | 0.49148 | 0.00090 | 0.49328 |
| cvcrsk3cc_4_1_3 | 15246 | 14900 | 0 | 1.95 | 12619 | 8842 | 7.50 | 848 | 0 | 1.95 | -227 | 0.49081 | 0.00095 | 0.49270 |
| cvcrsk3cc_4_1_4 | 15246 | 14900 | 0 | 1.95 | 12619 | 8842 | 11.25 | 1272 | 0 | 1.95 | -227 | 0.49337 | 0.00123 | 0.49584 |
| cvcrsk3cc_4_1_5 | 15246 | 14900 | 0 | 1.95 | 12619 | 8842 | 15.00 | 1696 | 0 | 1.95 | -227 | 0.49100 | 0.00105 | 0.49309 |
| cvcrsk3cc_4_1_6 | 15246 | 14900 | 0 | 1.95 | 12619 | 8842 | 18.75 | 2120 | 0 | 1.95 | -227 | 0.49125 | 0.00112 | 0.49348 |
| cvcrsk3cc_4_1_7 | 15246 | 14900 | 0 | 1.95 | 12619 | 8842 | 22.50 | 2545 | 0 | 1.95 | -227 | 0.49155 | 0.00104 | 0.49363 |
| cvcrsk3cc_4_1_8 | 15246 | 14900 | 0 | 1.95 | 12619 | 8842 | 26.25 | 2969 | 0 | 1.95 | -227 | 0.49300 | 0.00105 | 0.49510 |
| cvcrsk3cc_4_1_9 | 15246 | 14900 | 0 | 1.95 | 12619 | 8842 | 30.00 | 3393 | 0 | 1.95 | -227 | 0.49295 | 0.00117 | 0.49530 |
| cvcrsk3cc_4_1_10 | 15246 | 14900 | 0 | 1.95 | 12619 | 8842 | 33.75 | 3817 | 0 | 1.95 | -227 | 0.49206 | 0.00092 | 0.49391 |
| cvcrsk3cc_4_1_11 | 15246 | 14900 | 0 | 1.95 | 12619 | 8842 | 37.50 | 4241 | 0 | 1.95 | -227 | 0.49004 | 0.00115 | 0.49233 |
| cvcrsk3cc_4_1_12 | 15246 | 14900 | 0 | 1.95 | 12619 | 8842 | 41.25 | 4665 | 0 | 1.95 | -227 | 0.49325 | 0.00116 | 0.49558 |

**Table 6.9.6-17. Results for skull oxide (SO) content in CV calculation model**

| case name | SO (g) | $U_3O_8$ (g) | Sat. $H_2O$ (g) | SO h/x | U (g) | $^{235}U$ (g) | C (g) | mg C/ g $^{235}U$ | CV $H_2O$ (g) | CV h/x | Unident. (g) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| cvcrsk3cc_4_1_13 | 15246 | 14900 | 0 | 1.95 | 12619 | 8842 | 45.00 | 5089 | 0 | 1.95 | -227 | 0.49242 | 0.00093 | 0.49429 |
| cvcrsk3cc_4_1_14 | 15246 | 14900 | 0 | 1.95 | 12619 | 8842 | 48.75 | 5513 | 0 | 1.95 | -227 | 0.49328 | 0.00119 | 0.49566 |
| cvcrsk3cc_4_1_15 | 15246 | 14900 | 0 | 1.95 | 12619 | 8842 | 52.50 | 5937 | 0 | 1.95 | -227 | 0.49139 | 0.00117 | 0.49373 |
| cvcrsk3cc_4_1_16 | 15246 | 14900 | 0 | 1.95 | 12619 | 8842 | 56.25 | 6362 | 0 | 1.95 | -227 | 0.49068 | 0.00105 | 0.49278 |
| cvcrsk3cc_4_1_17 | 15246 | 14900 | 0 | 1.95 | 12619 | 8842 | 60.00 | 6786 | 0 | 1.95 | -227 | 0.49303 | 0.00100 | 0.49502 |
| | | | | | | | | | | | | | | |
| cvcrsk3cc_4_6_1 | 15246 | 14900 | 460 | 3.3 | 12619 | 8842 | 0.00 | 0 | 323.51 | 4.26 | -227 | 0.52088 | 0.00109 | 0.52306 |
| cvcrsk3cc_4_6_2 | 15246 | 14900 | 460 | 3.3 | 12619 | 8842 | 3.75 | 424 | 323.51 | 4.26 | -227 | 0.52247 | 0.00114 | 0.52474 |
| cvcrsk3cc_4_6_3 | 15246 | 14900 | 460 | 3.3 | 12619 | 8842 | 7.50 | 848 | 323.51 | 4.26 | -227 | 0.52250 | 0.00116 | 0.52482 |
| cvcrsk3cc_4_6_4 | 15246 | 14900 | 460 | 3.3 | 12619 | 8842 | 11.25 | 1272 | 323.51 | 4.26 | -227 | 0.52325 | 0.00103 | 0.52531 |
| cvcrsk3cc_4_6_5 | 15246 | 14900 | 460 | 3.3 | 12619 | 8842 | 15.00 | 1696 | 323.51 | 4.26 | -227 | 0.52252 | 0.00116 | 0.52485 |
| cvcrsk3cc_4_6_6 | 15246 | 14900 | 460 | 3.3 | 12619 | 8842 | 18.75 | 2120 | 323.51 | 4.26 | -227 | 0.52123 | 0.00113 | 0.52348 |
| cvcrsk3cc_4_6_7 | 15246 | 14900 | 460 | 3.3 | 12619 | 8842 | 22.50 | 2545 | 323.51 | 4.26 | -227 | 0.52156 | 0.00098 | 0.52353 |
| cvcrsk3cc_4_6_8 | 15246 | 14900 | 460 | 3.3 | 12619 | 8842 | 26.25 | 2969 | 323.51 | 4.26 | -227 | 0.52048 | 0.00106 | 0.52260 |
| cvcrsk3cc_4_6_9 | 15246 | 14900 | 460 | 3.3 | 12619 | 8842 | 30.00 | 3393 | 323.51 | 4.26 | -227 | 0.52115 | 0.00100 | 0.52315 |
| cvcrsk3cc_4_6_10 | 15246 | 14900 | 460 | 3.3 | 12619 | 8842 | 33.75 | 3817 | 323.51 | 4.26 | -227 | 0.52271 | 0.00114 | 0.52500 |
| cvcrsk3cc_4_6_11 | 15246 | 14900 | 460 | 3.3 | 12619 | 8842 | 37.50 | 4241 | 323.51 | 4.26 | -227 | 0.52221 | 0.00127 | 0.52474 |
| cvcrsk3cc_4_6_12 | 15246 | 14900 | 460 | 3.3 | 12619 | 8842 | 41.25 | 4665 | 323.51 | 4.26 | -227 | 0.52079 | 0.00104 | 0.52287 |
| cvcrsk3cc_4_6_13 | 15246 | 14900 | 460 | 3.3 | 12619 | 8842 | 45.00 | 5089 | 323.51 | 4.26 | -227 | 0.52323 | 0.00110 | 0.52543 |
| cvcrsk3cc_4_6_14 | 15246 | 14900 | 460 | 3.3 | 12619 | 8842 | 48.75 | 5513 | 323.51 | 4.26 | -227 | 0.52202 | 0.00129 | 0.52459 |
| cvcrsk3cc_4_6_15 | 15246 | 14900 | 460 | 3.3 | 12619 | 8842 | 52.50 | 5937 | 323.51 | 4.26 | -227 | 0.52288 | 0.00094 | 0.52476 |
| cvcrsk3cc_4_6_16 | 15246 | 14900 | 460 | 3.3 | 12619 | 8842 | 56.25 | 6362 | 323.51 | 4.26 | -227 | 0.52179 | 0.00106 | 0.52391 |
| cvcrsk3cc_4_6_17 | 15246 | 14900 | 460 | 3.3 | 12619 | 8842 | 60.00 | 6786 | 323.51 | 4.26 | -227 | 0.52265 | 0.00108 | 0.52481 |
| | | | | | | | | | | | | | | |
| cvcrsk3cc_4_7_1 | 15246 | 14900 | 920 | 4.66 | 12619 | 8842 | 0.00 | 0 | 647.03 | 6.57 | -227 | 0.55466 | 0.00117 | 0.55699 |
| cvcrsk3cc_4_7_2 | 15246 | 14900 | 920 | 4.66 | 12619 | 8842 | 3.75 | 424 | 647.03 | 6.57 | -227 | 0.55192 | 0.00105 | 0.55402 |

**Table 6.9.6-17. Results for skull oxide (SO) content in CV calculation model**

| case name | SO (g) | $U_3O_8$ (g) | Sat. $H_2O$ (g) | SO h/x | U (g) | $^{235}U$ (g) | C (g) | mg C/ g $^{235}U$ | CV $H_2O$ (g) | CV h/x | Unident. (g) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| cvcrsk3cc_4_7_3 | 15246 | 14900 | 920 | 4.66 | 12619 | 8842 | 7.50 | 848 | 647.03 | 6.57 | -227 | 0.55432 | 0.00118 | 0.55668 |
| cvcrsk3cc_4_7_4 | 15246 | 14900 | 920 | 4.66 | 12619 | 8842 | 11.25 | 1272 | 647.03 | 6.57 | -227 | 0.55387 | 0.00107 | 0.55600 |
| cvcrsk3cc_4_7_5 | 15246 | 14900 | 920 | 4.66 | 12619 | 8842 | 15.00 | 1696 | 647.03 | 6.57 | -227 | 0.55390 | 0.00102 | 0.55595 |
| cvcrsk3cc_4_7_6 | 15246 | 14900 | 920 | 4.66 | 12619 | 8842 | 18.75 | 2120 | 647.03 | 6.57 | -227 | 0.55272 | 0.00112 | 0.55496 |
| cvcrsk3cc_4_7_7 | 15246 | 14900 | 920 | 4.66 | 12619 | 8842 | 22.50 | 2545 | 647.03 | 6.57 | -227 | 0.55292 | 0.00118 | 0.55529 |
| cvcrsk3cc_4_7_8 | 15246 | 14900 | 920 | 4.66 | 12619 | 8842 | 26.25 | 2969 | 647.03 | 6.57 | -227 | 0.55262 | 0.00111 | 0.55484 |
| cvcrsk3cc_4_7_9 | 15246 | 14900 | 920 | 4.66 | 12619 | 8842 | 30.00 | 3393 | 647.03 | 6.57 | -227 | 0.55242 | 0.00108 | 0.55457 |
| cvcrsk3cc_4_7_10 | 15246 | 14900 | 920 | 4.66 | 12619 | 8842 | 33.75 | 3817 | 647.03 | 6.57 | -227 | 0.55457 | 0.00137 | 0.55732 |
| cvcrsk3cc_4_7_11 | 15246 | 14900 | 920 | 4.66 | 12619 | 8842 | 37.50 | 4241 | 647.03 | 6.57 | -227 | 0.55376 | 0.00117 | 0.55610 |
| cvcrsk3cc_4_7_12 | 15246 | 14900 | 920 | 4.66 | 12619 | 8842 | 41.25 | 4665 | 647.03 | 6.57 | -227 | 0.55283 | 0.00131 | 0.55545 |
| cvcrsk3cc_4_7_13 | 15246 | 14900 | 920 | 4.66 | 12619 | 8842 | 45.00 | 5089 | 647.03 | 6.57 | -227 | 0.55393 | 0.00118 | 0.55630 |
| cvcrsk3cc_4_7_14 | 15246 | 14900 | 920 | 4.66 | 12619 | 8842 | 48.75 | 5513 | 647.03 | 6.57 | -227 | 0.55181 | 0.00107 | 0.55395 |
| cvcrsk3cc_4_7_15 | 15246 | 14900 | 920 | 4.66 | 12619 | 8842 | 52.50 | 5937 | 647.03 | 6.57 | -227 | 0.55425 | 0.00107 | 0.55640 |
| cvcrsk3cc_4_7_16 | 15246 | 14900 | 920 | 4.66 | 12619 | 8842 | 56.25 | 6362 | 647.03 | 6.57 | -227 | 0.55377 | 0.00105 | 0.55587 |
| cvcrsk3cc_4_7_17 | 15246 | 14900 | 920 | 4.66 | 12619 | 8842 | 60.00 | 6786 | 647.03 | 6.57 | -227 | 0.55425 | 0.00101 | 0.55628 |
| | | | | | | | | | | | | | | |
| cvcrsk3cc_4_8_1 | 15246 | 14900 | 1380 | 6.02 | 12619 | 8842 | 0.00 | 0 | 970.54 | 8.88 | -227 | 0.58801 | 0.00133 | 0.59068 |
| cvcrsk3cc_4_8_2 | 15246 | 14900 | 1380 | 6.02 | 12619 | 8842 | 3.75 | 424 | 970.54 | 8.88 | -227 | 0.58867 | 0.00114 | 0.59095 |
| cvcrsk3cc_4_8_3 | 15246 | 14900 | 1380 | 6.02 | 12619 | 8842 | 7.50 | 848 | 970.54 | 8.88 | -227 | 0.58712 | 0.00112 | 0.58936 |
| cvcrsk3cc_4_8_4 | 15246 | 14900 | 1380 | 6.02 | 12619 | 8842 | 11.25 | 1272 | 970.54 | 8.88 | -227 | 0.58657 | 0.00115 | 0.58887 |
| cvcrsk3cc_4_8_5 | 15246 | 14900 | 1380 | 6.02 | 12619 | 8842 | 15.00 | 1696 | 970.54 | 8.88 | -227 | 0.58720 | 0.00105 | 0.58930 |
| cvcrsk3cc_4_8_6 | 15246 | 14900 | 1380 | 6.02 | 12619 | 8842 | 18.75 | 2120 | 970.54 | 8.88 | -227 | 0.58418 | 0.00122 | 0.58663 |
| cvcrsk3cc_4_8_7 | 15246 | 14900 | 1380 | 6.02 | 12619 | 8842 | 22.50 | 2545 | 970.54 | 8.88 | -227 | 0.58706 | 0.00118 | 0.58943 |
| cvcrsk3cc_4_8_8 | 15246 | 14900 | 1380 | 6.02 | 12619 | 8842 | 26.25 | 2969 | 970.54 | 8.88 | -227 | 0.58528 | 0.00110 | 0.58748 |
| cvcrsk3cc_4_8_9 | 15246 | 14900 | 1380 | 6.02 | 12619 | 8842 | 30.00 | 3393 | 970.54 | 8.88 | -227 | 0.58452 | 0.00119 | 0.58689 |
| cvcrsk3cc_4_8_10 | 15246 | 14900 | 1380 | 6.02 | 12619 | 8842 | 33.75 | 3817 | 970.54 | 8.88 | -227 | 0.58645 | 0.00113 | 0.58870 |

**Table 6.9.6-17. Results for skull oxide (SO) content in CV calculation model**

| case name | SO (g) | $U_3O_8$ (g) | Sat. $H_2O$ (g) | SO h/x | U (g) | $^{235}U$ (g) | C (g) | mg C/ g $^{235}U$ | CV $H_2O$ (g) | CV h/x | Unident. (g) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| cvcrsk3cc_4_8_11 | 15246 | 14900 | 1380 | 6.02 | 12619 | 8842 | 37.50 | 4241 | 970.54 | 8.88 | -227 | 0.58475 | 0.00109 | 0.58694 |
| cvcrsk3cc_4_8_12 | 15246 | 14900 | 1380 | 6.02 | 12619 | 8842 | 41.25 | 4665 | 970.54 | 8.88 | -227 | 0.58633 | 0.00110 | 0.58853 |
| cvcrsk3cc_4_8_13 | 15246 | 14900 | 1380 | 6.02 | 12619 | 8842 | 45.00 | 5089 | 970.54 | 8.88 | -227 | 0.58553 | 0.00107 | 0.58766 |
| cvcrsk3cc_4_8_14 | 15246 | 14900 | 1380 | 6.02 | 12619 | 8842 | 48.75 | 5513 | 970.54 | 8.88 | -227 | 0.58632 | 0.00118 | 0.58869 |
| cvcrsk3cc_4_8_15 | 15246 | 14900 | 1380 | 6.02 | 12619 | 8842 | 52.50 | 5937 | 970.54 | 8.88 | -227 | 0.58543 | 0.00106 | 0.58756 |
| cvcrsk3cc_4_8_16 | 15246 | 14900 | 1380 | 6.02 | 12619 | 8842 | 56.25 | 6362 | 970.54 | 8.88 | -227 | 0.58716 | 0.00123 | 0.58962 |
| cvcrsk3cc_4_8_17 | 15246 | 14900 | 1380 | 6.02 | 12619 | 8842 | 60.00 | 6786 | 970.54 | 8.88 | -227 | 0.58845 | 0.00113 | 0.59071 |
| | | | | | | | | | | | | | | |
| cvcrsk3cc_4_9_1 | 15246 | 14900 | 1840 | 7.38 | 12619 | 8842 | 0.00 | 0 | 1294.06 | 11.2 | -227 | 0.62013 | 0.00104 | 0.62220 |
| cvcrsk3cc_4_9_2 | 15246 | 14900 | 1840 | 7.38 | 12619 | 8842 | 3.75 | 424 | 1294.06 | 11.2 | -227 | 0.61947 | 0.00123 | 0.62193 |
| cvcrsk3cc_4_9_3 | 15246 | 14900 | 1840 | 7.38 | 12619 | 8842 | 7.50 | 848 | 1294.06 | 11.2 | -227 | 0.62178 | 0.00112 | 0.62402 |
| cvcrsk3cc_4_9_4 | 15246 | 14900 | 1840 | 7.38 | 12619 | 8842 | 11.25 | 1272 | 1294.06 | 11.2 | -227 | 0.62009 | 0.00108 | 0.62225 |
| cvcrsk3cc_4_9_5 | 15246 | 14900 | 1840 | 7.38 | 12619 | 8842 | 15.00 | 1696 | 1294.06 | 11.2 | -227 | 0.61950 | 0.00114 | 0.62178 |
| cvcrsk3cc_4_9_6 | 15246 | 14900 | 1840 | 7.38 | 12619 | 8842 | 18.75 | 2120 | 1294.06 | 11.2 | -227 | 0.62035 | 0.00102 | 0.62240 |
| cvcrsk3cc_4_9_7 | 15246 | 14900 | 1840 | 7.38 | 12619 | 8842 | 22.50 | 2545 | 1294.06 | 11.2 | -227 | 0.61820 | 0.00111 | 0.62042 |
| cvcrsk3cc_4_9_8 | 15246 | 14900 | 1840 | 7.38 | 12619 | 8842 | 26.25 | 2969 | 1294.06 | 11.2 | -227 | 0.62037 | 0.00127 | 0.62290 |
| cvcrsk3cc_4_9_9 | 15246 | 14900 | 1840 | 7.38 | 12619 | 8842 | 30.00 | 3393 | 1294.06 | 11.2 | -227 | 0.62084 | 0.00111 | 0.62306 |
| cvcrsk3cc_4_9_10 | 15246 | 14900 | 1840 | 7.38 | 12619 | 8842 | 33.75 | 3817 | 1294.06 | 11.2 | -227 | 0.61977 | 0.00114 | 0.62205 |
| cvcrsk3cc_4_9_11 | 15246 | 14900 | 1840 | 7.38 | 12619 | 8842 | 37.50 | 4241 | 1294.06 | 11.2 | -227 | 0.61997 | 0.00123 | 0.62243 |
| cvcrsk3cc_4_9_12 | 15246 | 14900 | 1840 | 7.38 | 12619 | 8842 | 41.25 | 4665 | 1294.06 | 11.2 | -227 | 0.62097 | 0.00112 | 0.62320 |
| cvcrsk3cc_4_9_13 | 15246 | 14900 | 1840 | 7.38 | 12619 | 8842 | 45.00 | 5089 | 1294.06 | 11.2 | -227 | 0.62013 | 0.00126 | 0.62266 |
| cvcrsk3cc_4_9_14 | 15246 | 14900 | 1840 | 7.38 | 12619 | 8842 | 48.75 | 5513 | 1294.06 | 11.2 | -227 | 0.62028 | 0.00109 | 0.62245 |
| cvcrsk3cc_4_9_15 | 15246 | 14900 | 1840 | 7.38 | 12619 | 8842 | 52.50 | 5937 | 1294.06 | 11.2 | -227 | 0.62003 | 0.00107 | 0.62216 |
| cvcrsk3cc_4_9_16 | 15246 | 14900 | 1840 | 7.38 | 12619 | 8842 | 56.25 | 6362 | 1294.06 | 11.2 | -227 | 0.62193 | 0.00107 | 0.62408 |
| cvcrsk3cc_4_9_17 | 15246 | 14900 | 1840 | 7.38 | 12619 | 8842 | 60.00 | 6786 | 1294.06 | 11.2 | -227 | 0.62122 | 0.00117 | 0.62356 |
| | | | | | | | | | | | | | | |

**Table 6.9.6-17. Results for skull oxide (SO) content in CV calculation model**

| case name | SO (g) | $U_3O_8$ (g) | Sat. $H_2O$ (g) | SO h/x | U (g) | $^{235}U$ (g) | C (g) | mg C/ g $^{235}U$ | CV $H_2O$ (g) | CV h/x | Unident. (g) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| cvcrsk3cc_4_10_1 | 15246 | 14900 | 2300 | 8.73 | 12619 | 8842 | 0.00 | 0 | 1617.57 | 13.51 | -227 | 0.65504 | 0.00131 | 0.65766 |
| cvcrsk3cc_4_10_2 | 15246 | 14900 | 2300 | 8.73 | 12619 | 8842 | 3.75 | 424 | 1617.57 | 13.51 | -227 | 0.65421 | 0.00099 | 0.65618 |
| cvcrsk3cc_4_10_3 | 15246 | 14900 | 2300 | 8.73 | 12619 | 8842 | 7.50 | 848 | 1617.57 | 13.51 | -227 | 0.65445 | 0.00123 | 0.65692 |
| cvcrsk3cc_4_10_4 | 15246 | 14900 | 2300 | 8.73 | 12619 | 8842 | 11.25 | 1272 | 1617.57 | 13.51 | -227 | 0.65392 | 0.00127 | 0.65646 |
| cvcrsk3cc_4_10_5 | 15246 | 14900 | 2300 | 8.73 | 12619 | 8842 | 15.00 | 1696 | 1617.57 | 13.51 | -227 | 0.65599 | 0.00134 | 0.65868 |
| cvcrsk3cc_4_10_6 | 15246 | 14900 | 2300 | 8.73 | 12619 | 8842 | 18.75 | 2120 | 1617.57 | 13.51 | -227 | 0.65239 | 0.00107 | 0.65454 |
| cvcrsk3cc_4_10_7 | 15246 | 14900 | 2300 | 8.73 | 12619 | 8842 | 22.50 | 2545 | 1617.57 | 13.51 | -227 | 0.65356 | 0.00101 | 0.65558 |
| cvcrsk3cc_4_10_8 | 15246 | 14900 | 2300 | 8.73 | 12619 | 8842 | 26.25 | 2969 | 1617.57 | 13.51 | -227 | 0.65451 | 0.00134 | 0.65719 |
| cvcrsk3cc_4_10_9 | 15246 | 14900 | 2300 | 8.73 | 12619 | 8842 | 30.00 | 3393 | 1617.57 | 13.51 | -227 | 0.65576 | 0.00140 | 0.65855 |
| cvcrsk3cc_4_10_10 | 15246 | 14900 | 2300 | 8.73 | 12619 | 8842 | 33.75 | 3817 | 1617.57 | 13.51 | -227 | 0.65386 | 0.00121 | 0.65629 |
| cvcrsk3cc_4_10_11 | 15246 | 14900 | 2300 | 8.73 | 12619 | 8842 | 37.50 | 4241 | 1617.57 | 13.51 | -227 | 0.65645 | 0.00113 | 0.65871 |
| cvcrsk3cc_4_10_12 | 15246 | 14900 | 2300 | 8.73 | 12619 | 8842 | 41.25 | 4665 | 1617.57 | 13.51 | -227 | 0.65406 | 0.00130 | 0.65666 |
| cvcrsk3cc_4_10_13 | 15246 | 14900 | 2300 | 8.73 | 12619 | 8842 | 45.00 | 5089 | 1617.57 | 13.51 | -227 | 0.65406 | 0.00120 | 0.65646 |
| cvcrsk3cc_4_10_14 | 15246 | 14900 | 2300 | 8.73 | 12619 | 8842 | 48.75 | 5513 | 1617.57 | 13.51 | -227 | 0.65484 | 0.00126 | 0.65736 |
| cvcrsk3cc_4_10_15 | 15246 | 14900 | 2300 | 8.73 | 12619 | 8842 | 52.50 | 5937 | 1617.57 | 13.51 | -227 | 0.65420 | 0.00128 | 0.65675 |
| cvcrsk3cc_4_10_16 | 15246 | 14900 | 2300 | 8.73 | 12619 | 8842 | 56.25 | 6362 | 1617.57 | 13.51 | -227 | 0.65433 | 0.00123 | 0.65679 |
| cvcrsk3cc_4_10_17 | 15246 | 14900 | 2300 | 8.73 | 12619 | 8842 | 60.00 | 6786 | 1617.57 | 13.51 | -227 | 0.65399 | 0.00123 | 0.65646 |
| | | | | | | | | | | | | | | |
| cvcrsk3cc_4_11_1 | 15246 | 14900 | 2760 | 10.09 | 12619 | 8842 | 0.00 | 0 | 1941.09 | 15.82 | -227 | 0.68728 | 0.00114 | 0.68956 |
| cvcrsk3cc_4_11_2 | 15246 | 14900 | 2760 | 10.09 | 12619 | 8842 | 3.75 | 424 | 1941.09 | 15.82 | -227 | 0.68899 | 0.00121 | 0.69141 |
| cvcrsk3cc_4_11_3 | 15246 | 14900 | 2760 | 10.09 | 12619 | 8842 | 7.50 | 848 | 1941.09 | 15.82 | -227 | 0.68815 | 0.00113 | 0.69041 |
| cvcrsk3cc_4_11_4 | 15246 | 14900 | 2760 | 10.09 | 12619 | 8842 | 11.25 | 1272 | 1941.09 | 15.82 | -227 | 0.68967 | 0.00117 | 0.69200 |
| cvcrsk3cc_4_11_5 | 15246 | 14900 | 2760 | 10.09 | 12619 | 8842 | 15.00 | 1696 | 1941.09 | 15.82 | -227 | 0.68936 | 0.00133 | 0.69201 |
| cvcrsk3cc_4_11_6 | 15246 | 14900 | 2760 | 10.09 | 12619 | 8842 | 18.75 | 2120 | 1941.09 | 15.82 | -227 | 0.68713 | 0.00127 | 0.68966 |
| cvcrsk3cc_4_11_7 | 15246 | 14900 | 2760 | 10.09 | 12619 | 8842 | 22.50 | 2545 | 1941.09 | 15.82 | -227 | 0.68933 | 0.00141 | 0.69216 |
| cvcrsk3cc_4_11_8 | 15246 | 14900 | 2760 | 10.09 | 12619 | 8842 | 26.25 | 2969 | 1941.09 | 15.82 | -227 | 0.68808 | 0.00130 | 0.69068 |

**Table 6.9.6-17. Results for skull oxide (SO) content in CV calculation model**

| case name | SO (g) | $U_3O_8$ (g) | Sat. $H_2O$ (g) | SO h/x | U (g) | $^{235}U$ (g) | C (g) | mg C/ g $^{235}U$ | CV $H_2O$ (g) | CV h/x | Unident. (g) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| cvcrsk3cc_4_11_9 | 15246 | 14900 | 2760 | 10.09 | 12619 | 8842 | 30.00 | 3393 | 1941.09 | 15.82 | -227 | 0.69012 | 0.00114 | 0.69239 |
| cvcrsk3cc_4_11_10 | 15246 | 14900 | 2760 | 10.09 | 12619 | 8842 | 33.75 | 3817 | 1941.09 | 15.82 | -227 | 0.68913 | 0.00148 | 0.69208 |
| cvcrsk3cc_4_11_11 | 15246 | 14900 | 2760 | 10.09 | 12619 | 8842 | 37.50 | 4241 | 1941.09 | 15.82 | -227 | 0.68961 | 0.00139 | 0.69239 |
| cvcrsk3cc_4_11_12 | 15246 | 14900 | 2760 | 10.09 | 12619 | 8842 | 41.25 | 4665 | 1941.09 | 15.82 | -227 | 0.68779 | 0.00113 | 0.69005 |
| cvcrsk3cc_4_11_13 | 15246 | 14900 | 2760 | 10.09 | 12619 | 8842 | 45.00 | 5089 | 1941.09 | 15.82 | -227 | 0.69197 | 0.00114 | 0.69425 |
| cvcrsk3cc_4_11_14 | 15246 | 14900 | 2760 | 10.09 | 12619 | 8842 | 48.75 | 5513 | 1941.09 | 15.82 | -227 | 0.68861 | 0.00114 | 0.69090 |
| cvcrsk3cc_4_11_15 | 15246 | 14900 | 2760 | 10.09 | 12619 | 8842 | 52.50 | 5937 | 1941.09 | 15.82 | -227 | 0.68815 | 0.00127 | 0.69069 |
| cvcrsk3cc_4_11_16 | 15246 | 14900 | 2760 | 10.09 | 12619 | 8842 | 56.25 | 6362 | 1941.09 | 15.82 | -227 | 0.69041 | 0.00131 | 0.69303 |
| cvcrsk3cc_4_11_17 | 15246 | 14900 | 2760 | 10.09 | 12619 | 8842 | 60.00 | 6786 | 1941.09 | 15.82 | -227 | 0.68744 | 0.00129 | 0.69003 |
| | | | | | | | | | | | | | | |
| cvcrsk3cc_4_12_1 | 15246 | 14900 | 3220 | 11.45 | 12619 | 8842 | 0.00 | 0 | 2264.6 | 18.13 | -227 | 0.72168 | 0.00119 | 0.72405 |
| cvcrsk3cc_4_12_2 | 15246 | 14900 | 3220 | 11.45 | 12619 | 8842 | 3.75 | 424 | 2264.6 | 18.13 | -227 | 0.72398 | 0.00131 | 0.72660 |
| cvcrsk3cc_4_12_3 | 15246 | 14900 | 3220 | 11.45 | 12619 | 8842 | 7.50 | 848 | 2264.6 | 18.13 | -227 | 0.72501 | 0.00142 | 0.72786 |
| cvcrsk3cc_4_12_4 | 15246 | 14900 | 3220 | 11.45 | 12619 | 8842 | 11.25 | 1272 | 2264.6 | 18.13 | -227 | 0.72327 | 0.00132 | 0.72592 |
| cvcrsk3cc_4_12_5 | 15246 | 14900 | 3220 | 11.45 | 12619 | 8842 | 15.00 | 1696 | 2264.6 | 18.13 | -227 | 0.72278 | 0.00124 | 0.72526 |
| cvcrsk3cc_4_12_6 | 15246 | 14900 | 3220 | 11.45 | 12619 | 8842 | 18.75 | 2120 | 2264.6 | 18.13 | -227 | 0.72081 | 0.00142 | 0.72364 |
| cvcrsk3cc_4_12_7 | 15246 | 14900 | 3220 | 11.45 | 12619 | 8842 | 22.50 | 2545 | 2264.6 | 18.13 | -227 | 0.72286 | 0.00141 | 0.72568 |
| cvcrsk3cc_4_12_8 | 15246 | 14900 | 3220 | 11.45 | 12619 | 8842 | 26.25 | 2969 | 2264.6 | 18.13 | -227 | 0.72457 | 0.00118 | 0.72693 |
| cvcrsk3cc_4_12_9 | 15246 | 14900 | 3220 | 11.45 | 12619 | 8842 | 30.00 | 3393 | 2264.6 | 18.13 | -227 | 0.72295 | 0.00126 | 0.72547 |
| cvcrsk3cc_4_12_10 | 15246 | 14900 | 3220 | 11.45 | 12619 | 8842 | 33.75 | 3817 | 2264.6 | 18.13 | -227 | 0.71959 | 0.00131 | 0.72221 |
| cvcrsk3cc_4_12_11 | 15246 | 14900 | 3220 | 11.45 | 12619 | 8842 | 37.50 | 4241 | 2264.6 | 18.13 | -227 | 0.72351 | 0.00106 | 0.72563 |
| cvcrsk3cc_4_12_12 | 15246 | 14900 | 3220 | 11.45 | 12619 | 8842 | 41.25 | 4665 | 2264.6 | 18.13 | -227 | 0.72291 | 0.00139 | 0.72570 |
| cvcrsk3cc_4_12_13 | 15246 | 14900 | 3220 | 11.45 | 12619 | 8842 | 45.00 | 5089 | 2264.6 | 18.13 | -227 | 0.72324 | 0.00125 | 0.72574 |
| cvcrsk3cc_4_12_14 | 15246 | 14900 | 3220 | 11.45 | 12619 | 8842 | 48.75 | 5513 | 2264.6 | 18.13 | -227 | 0.72395 | 0.00143 | 0.72680 |
| cvcrsk3cc_4_12_15 | 15246 | 14900 | 3220 | 11.45 | 12619 | 8842 | 52.50 | 5937 | 2264.6 | 18.13 | -227 | 0.72591 | 0.00111 | 0.72814 |

**Table 6.9.6-17. Results for skull oxide (SO) content in CV calculation model**

| case name | SO (g) | $U_3O_8$ (g) | Sat. $H_2O$ (g) | SO h/x | U (g) | $^{235}U$ (g) | C (g) | mg C/ g $^{235}U$ | CV $H_2O$ (g) | CV h/x | Unident. (g) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| cvcrsk3cc_4_12_16 | 15246 | 14900 | 3220 | 11.45 | 12619 | 8842 | 56.25 | 6362 | 2264.6 | 18.13 | -227 | 0.72242 | 0.00146 | 0.72535 |
| cvcrsk3cc_4_12_17 | 15246 | 14900 | 3220 | 11.45 | 12619 | 8842 | 60.00 | 6786 | 2264.6 | 18.13 | -227 | 0.72398 | 0.00117 | 0.72631 |
| | | | | | | | | | | | | | | |
| cvcrsk3cc_4_13_1 | 15246 | 14900 | 3679 | 12.81 | 12619 | 8842 | 0.00 | 0 | 2588.12 | 20.45 | -227 | 0.75630 | 0.00133 | 0.75896 |
| cvcrsk3cc_4_13_2 | 15246 | 14900 | 3679 | 12.81 | 12619 | 8842 | 3.75 | 424 | 2588.12 | 20.45 | -227 | 0.75574 | 0.00132 | 0.75838 |
| cvcrsk3cc_4_13_3 | 15246 | 14900 | 3679 | 12.81 | 12619 | 8842 | 7.50 | 848 | 2588.12 | 20.45 | -227 | 0.75761 | 0.00136 | 0.76032 |
| cvcrsk3cc_4_13_4 | 15246 | 14900 | 3679 | 12.81 | 12619 | 8842 | 11.25 | 1272 | 2588.12 | 20.45 | -227 | 0.75747 | 0.00147 | 0.76042 |
| cvcrsk3cc_4_13_5 | 15246 | 14900 | 3679 | 12.81 | 12619 | 8842 | 15.00 | 1696 | 2588.12 | 20.45 | -227 | 0.75674 | 0.00120 | 0.75914 |
| cvcrsk3cc_4_13_6 | 15246 | 14900 | 3679 | 12.81 | 12619 | 8842 | 18.75 | 2120 | 2588.12 | 20.45 | -227 | 0.75883 | 0.00137 | 0.76157 |
| cvcrsk3cc_4_13_7 | 15246 | 14900 | 3679 | 12.81 | 12619 | 8842 | 22.50 | 2545 | 2588.12 | 20.45 | -227 | 0.75912 | 0.00125 | 0.76162 |
| cvcrsk3cc_4_13_8 | 15246 | 14900 | 3679 | 12.81 | 12619 | 8842 | 26.25 | 2969 | 2588.12 | 20.45 | -227 | 0.75690 | 0.00131 | 0.75952 |
| cvcrsk3cc_4_13_9 | 15246 | 14900 | 3679 | 12.81 | 12619 | 8842 | 30.00 | 3393 | 2588.12 | 20.45 | -227 | 0.75692 | 0.00123 | 0.75938 |
| cvcrsk3cc_4_13_10 | 15246 | 14900 | 3679 | 12.81 | 12619 | 8842 | 33.75 | 3817 | 2588.12 | 20.45 | -227 | 0.75676 | 0.00123 | 0.75923 |
| cvcrsk3cc_4_13_11 | 15246 | 14900 | 3679 | 12.81 | 12619 | 8842 | 37.50 | 4241 | 2588.12 | 20.45 | -227 | 0.75541 | 0.00134 | 0.75808 |
| cvcrsk3cc_4_13_12 | 15246 | 14900 | 3679 | 12.81 | 12619 | 8842 | 41.25 | 4665 | 2588.12 | 20.45 | -227 | 0.75894 | 0.00141 | 0.76176 |
| cvcrsk3cc_4_13_13 | 15246 | 14900 | 3679 | 12.81 | 12619 | 8842 | 45.00 | 5089 | 2588.12 | 20.45 | -227 | 0.75688 | 0.00137 | 0.75963 |
| cvcrsk3cc_4_13_14 | 15246 | 14900 | 3679 | 12.81 | 12619 | 8842 | 48.75 | 5513 | 2588.12 | 20.45 | -227 | 0.75618 | 0.00140 | 0.75898 |
| cvcrsk3cc_4_13_15 | 15246 | 14900 | 3679 | 12.81 | 12619 | 8842 | 52.50 | 5937 | 2588.12 | 20.45 | -227 | 0.75806 | 0.00143 | 0.76092 |
| cvcrsk3cc_4_13_16 | 15246 | 14900 | 3679 | 12.81 | 12619 | 8842 | 56.25 | 6362 | 2588.12 | 20.45 | -227 | 0.75838 | 0.00131 | 0.76100 |
| cvcrsk3cc_4_13_17 | 15246 | 14900 | 3679 | 12.81 | 12619 | 8842 | 60.00 | 6786 | 2588.12 | 20.45 | -227 | 0.75890 | 0.00130 | 0.76150 |
| | | | | | | | | | | | | | | |
| cvcrsk3cc_4_14_1 | 15246 | 14900 | 4139 | 14.16 | 12619 | 8842 | 0.00 | 0 | 2911.63 | 22.76 | -227 | 0.78934 | 0.00142 | 0.79219 |
| cvcrsk3cc_4_14_2 | 15246 | 14900 | 4139 | 14.16 | 12619 | 8842 | 3.75 | 424 | 2911.63 | 22.76 | -227 | 0.79102 | 0.00153 | 0.79408 |
| cvcrsk3cc_4_14_3 | 15246 | 14900 | 4139 | 14.16 | 12619 | 8842 | 7.50 | 848 | 2911.63 | 22.76 | -227 | 0.78792 | 0.00140 | 0.79073 |
| cvcrsk3cc_4_14_4 | 15246 | 14900 | 4139 | 14.16 | 12619 | 8842 | 11.25 | 1272 | 2911.63 | 22.76 | -227 | 0.78817 | 0.00122 | 0.79061 |
| cvcrsk3cc_4_14_5 | 15246 | 14900 | 4139 | 14.16 | 12619 | 8842 | 15.00 | 1696 | 2911.63 | 22.76 | -227 | 0.79185 | 0.00133 | 0.79451 |

**Table 6.9.6-17. Results for skull oxide (SO) content in CV calculation model**

| case name | SO (g) | $U_3O_8$ (g) | Sat. $H_2O$ (g) | SO h/x | U (g) | $^{235}U$ (g) | C (g) | mg C/ g $^{235}U$ | CV $H_2O$ (g) | CV h/x | Unident. (g) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| cvcrsk3cc_4_14_6 | 15246 | 14900 | 4139 | 14.16 | 12619 | 8842 | 18.75 | 2120 | 2911.63 | 22.76 | -227 | 0.78935 | 0.00155 | 0.79244 |
| cvcrsk3cc_4_14_7 | 15246 | 14900 | 4139 | 14.16 | 12619 | 8842 | 22.50 | 2545 | 2911.63 | 22.76 | -227 | 0.79031 | 0.00139 | 0.79310 |
| cvcrsk3cc_4_14_8 | 15246 | 14900 | 4139 | 14.16 | 12619 | 8842 | 26.25 | 2969 | 2911.63 | 22.76 | -227 | 0.79032 | 0.00119 | 0.79269 |
| cvcrsk3cc_4_14_9 | 15246 | 14900 | 4139 | 14.16 | 12619 | 8842 | 30.00 | 3393 | 2911.63 | 22.76 | -227 | 0.79075 | 0.00125 | 0.79326 |
| cvcrsk3cc_4_14_10 | 15246 | 14900 | 4139 | 14.16 | 12619 | 8842 | 33.75 | 3817 | 2911.63 | 22.76 | -227 | 0.78950 | 0.00127 | 0.79203 |
| cvcrsk3cc_4_14_11 | 15246 | 14900 | 4139 | 14.16 | 12619 | 8842 | 37.50 | 4241 | 2911.63 | 22.76 | -227 | 0.79226 | 0.00132 | 0.79490 |
| cvcrsk3cc_4_14_12 | 15246 | 14900 | 4139 | 14.16 | 12619 | 8842 | 41.25 | 4665 | 2911.63 | 22.76 | -227 | 0.79141 | 0.00129 | 0.79400 |
| cvcrsk3cc_4_14_13 | 15246 | 14900 | 4139 | 14.16 | 12619 | 8842 | 45.00 | 5089 | 2911.63 | 22.76 | -227 | 0.79226 | 0.00131 | 0.79488 |
| cvcrsk3cc_4_14_14 | 15246 | 14900 | 4139 | 14.16 | 12619 | 8842 | 48.75 | 5513 | 2911.63 | 22.76 | -227 | 0.79139 | 0.00140 | 0.79418 |
| cvcrsk3cc_4_14_15 | 15246 | 14900 | 4139 | 14.16 | 12619 | 8842 | 52.50 | 5937 | 2911.63 | 22.76 | -227 | 0.79157 | 0.00136 | 0.79429 |
| cvcrsk3cc_4_14_16 | 15246 | 14900 | 4139 | 14.16 | 12619 | 8842 | 56.25 | 6362 | 2911.63 | 22.76 | -227 | 0.78883 | 0.00118 | 0.79119 |
| cvcrsk3cc_4_14_17 | 15246 | 14900 | 4139 | 14.16 | 12619 | 8842 | 60.00 | 6786 | 2911.63 | 22.76 | -227 | 0.79251 | 0.00163 | 0.79576 |
| | | | | | | | | | | | | | | |
| cvcrsk3cc_4_15_1 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 0.00 | 0 | 3235.15 | 25.07 | -227 | 0.82370 | 0.00143 | 0.82655 |
| cvcrsk3cc_4_15_2 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 3.75 | 424 | 3235.15 | 25.07 | -227 | 0.82249 | 0.00121 | 0.82491 |
| cvcrsk3cc_4_15_3 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 7.50 | 848 | 3235.15 | 25.07 | -227 | 0.82289 | 0.00125 | 0.82539 |
| cvcrsk3cc_4_15_4 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 11.25 | 1272 | 3235.15 | 25.07 | -227 | 0.82409 | 0.00117 | 0.82643 |
| cvcrsk3cc_4_15_5 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 15.00 | 1696 | 3235.15 | 25.07 | -227 | 0.82541 | 0.00127 | 0.82794 |
| cvcrsk3cc_4_15_6 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 18.75 | 2120 | 3235.15 | 25.07 | -227 | 0.82424 | 0.00123 | 0.82669 |
| cvcrsk3cc_4_15_7 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 22.50 | 2545 | 3235.15 | 25.07 | -227 | 0.82476 | 0.00182 | 0.82841 |
| cvcrsk3cc_4_15_8 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 26.25 | 2969 | 3235.15 | 25.07 | -227 | 0.82419 | 0.00142 | 0.82702 |
| cvcrsk3cc_4_15_9 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 30.00 | 3393 | 3235.15 | 25.07 | -227 | 0.82530 | 0.00145 | 0.82820 |
| cvcrsk3cc_4_15_10 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 33.75 | 3817 | 3235.15 | 25.07 | -227 | 0.82433 | 0.00155 | 0.82742 |
| cvcrsk3cc_4_15_11 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 37.50 | 4241 | 3235.15 | 25.07 | -227 | 0.82379 | 0.00142 | 0.82663 |
| cvcrsk3cc_4_15_12 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 41.25 | 4665 | 3235.15 | 25.07 | -227 | 0.82450 | 0.00146 | 0.82742 |
| cvcrsk3cc_4_15_13 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 45.00 | 5089 | 3235.15 | 25.07 | -227 | 0.82666 | 0.00109 | 0.82883 |

**Table 6.9.6-17. Results for skull oxide (SO) content in CV calculation model**

| case name | SO (g) | $U_3O_8$ (g) | Sat. $H_2O$ (g) | SO h/x | U (g) | $^{235}U$ (g) | C (g) | mg C/ g $^{235}U$ | CV $H_2O$ (g) | CV h/x | Unident. (g) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| cvcrsk3cc_4_15_14 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 48.75 | 5513 | 3235.15 | 25.07 | -227 | 0.82521 | 0.00125 | 0.82772 |
| cvcrsk3cc_4_15_15 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 52.50 | 5937 | 3235.15 | 25.07 | -227 | 0.82544 | 0.00120 | 0.82784 |
| cvcrsk3cc_4_15_16 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 56.25 | 6362 | 3235.15 | 25.07 | -227 | 0.82578 | 0.00133 | 0.82844 |
| cvcrsk3cc_4_15_17 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 60.00 | 6786 | 3235.15 | 25.07 | -227 | 0.82622 | 0.00154 | 0.82930 |
| | | | | | | | | | | | | | | |
| cvcrsk3cc_6_1_17 | 15111 | 12933 | 0 | 4.17 | 10960 | 4122 | 921 | 223432 | 0 | 4.17 | 744 | 0.44158 | 0.00098 | 0.44355 |
| cvcrsk3cc_6_6_17 | 15111 | 12933 | 377 | 6.56 | 10960 | 4122 | 921 | 223432 | 410 | 9.16 | 744 | 0.46812 | 0.00103 | 0.47018 |
| cvcrsk3cc_6_7_17 | 15111 | 12933 | 753 | 8.94 | 10960 | 4122 | 921 | 223432 | 821 | 14.14 | 744 | 0.49580 | 0.00108 | 0.49797 |
| cvcrsk3cc_6_8_17 | 15111 | 12933 | 1130 | 11.33 | 10960 | 4122 | 921 | 223432 | 1231 | 19.12 | 744 | 0.52824 | 0.00111 | 0.53046 |
| cvcrsk3cc_6_9_17 | 15111 | 12933 | 1506 | 13.71 | 10960 | 4122 | 921 | 223432 | 1642 | 24.11 | 744 | 0.55880 | 0.00129 | 0.56139 |
| cvcrsk3cc_6_10_17 | 15111 | 12933 | 1883 | 16.09 | 10960 | 4122 | 921 | 223432 | 2052 | 29.09 | 744 | 0.58946 | 0.00103 | 0.59153 |
| cvcrsk3cc_6_11_17 | 15111 | 12933 | 2259 | 18.48 | 10960 | 4122 | 921 | 223432 | 2463 | 34.07 | 744 | 0.62334 | 0.00130 | 0.62593 |
| cvcrsk3cc_6_12_17 | 15111 | 12933 | 2636 | 20.86 | 10960 | 4122 | 921 | 223432 | 2873 | 39.06 | 744 | 0.65813 | 0.00115 | 0.66044 |
| cvcrsk3cc_6_13_17 | 15111 | 12933 | 3012 | 23.25 | 10960 | 4122 | 921 | 223432 | 3284 | 44.04 | 744 | 0.69032 | 0.00104 | 0.69240 |
| cvcrsk3cc_6_14_17 | 15111 | 12933 | 3389 | 25.63 | 10960 | 4122 | 921 | 223432 | 3694 | 49.02 | 744 | 0.72104 | 0.00142 | 0.72388 |
| cvcrsk3cc_6_15_17 | 15111 | 12933 | 3765 | 28.02 | 10960 | 4122 | 921 | 223432 | 4105 | 54.01 | 744 | 0.75711 | 0.00110 | 0.75932 |

**Table 6.9.6-18a. NCT results for skull oxide (SO) content in packaging calculation model**

| case name | SO (g) | $U_3O_8$ (g) | Sat. $H_2O$ (g) | SO h/x | U (g) | $^{235}U$ (g) | C (g) | mg C/ g $^{235}U$ | CV $H_2O$ (g) | CV h/x | Unident. (g) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **content in flooded CV, NCT single package, reflected** | | | | | | | | | | | | | | |
| **513 g polyethylene, no can spacers** | | | | | | | | | | | | | | |
| ncsrsk_1_15 | 11589 | 8063 | 4468 | 28.09 | 6828 | 4765 | 417 | 87518 | 4105 | 50.58 | 2596 | 0.71933 | 0.00154 | 0.72241 |
| ncsrsk_2_15 | 14934 | 11665 | 4015 | 17.79 | 9879 | 6858 | 504 | 73492 | 4105 | 33.41 | 2252 | 0.70319 | 0.00144 | 0.70606 |
| ncsrsk_3_15 | 13821 | 11876 | 4893 | 20.62 | 10058 | 7028 | 372 | 52930 | 3233 | 32.62 | 1060 | 0.71916 | 0.00128 | 0.72172 |
| ncsrsk_4_15 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 60 | 6786 | 3235 | 25.07 | -227 | 0.71123 | 0.00145 | 0.71413 |
| ncsrsk_5_15 | 21216 | 21036 | 3869 | 9.49 | 17815 | 12455 | 27 | 2168 | 3235 | 16.27 | -360 | 0.69577 | 0.00139 | 0.69855 |
| ncsrsk_6_15 | 15111 | 12933 | 3765 | 28.02 | 10960 | 4122 | 921 | 223432 | 4105 | 54.01 | 744 | 0.63803 | 0.00171 | 0.64146 |
| ncsrsk_7_15 | 13155 | 11666 | 3989 | 32.68 | 9886 | 3712 | 609 | 164054 | 4106 | 61.55 | 367 | 0.65018 | 0.00127 | 0.65271 |
| ncsrsk_8_15 | 13650 | 11689 | 4068 | 33.01 | 9906 | 3737 | 261 | 69834 | 4106 | 61.69 | 1187 | 0.65349 | 0.00128 | 0.65604 |
| ncsrsk_9_15 | 21300 | 19865 | 3801 | 7.43 | 16816 | 15673 | 921 | 58764 | 3235 | 12.82 | 1 | 0.73837 | 0.00130 | 0.74096 |
| ncsrsk_10_15 | 21300 | 20786 | 3905 | 7.27 | 17596 | 16399 | 0 | 0 | 3235 | 12.41 | 1 | 0.74201 | 0.00149 | 0.74499 |
| | | | | | | | | | | | | | | |
| ncsrsk_9_1 | 21300 | 19865 | 0 | 1.10 | 16816 | 15673 | 921 | 58764 | 0 | 1.10 | 1 | 0.40142 | 0.00078 | 0.40297 |
| ncsrsk_9_6 | 21300 | 19865 | 380 | 1.73 | 16816 | 15673 | 921 | 58764 | 324 | 2.27 | 1 | 0.43142 | 0.00096 | 0.43334 |
| ncsrsk_9_7 | 21300 | 19865 | 760 | 2.36 | 16816 | 15673 | 921 | 58764 | 647 | 3.44 | 1 | 0.46578 | 0.00099 | 0.46776 |
| ncsrsk_9_8 | 21300 | 19865 | 1140 | 3.00 | 16816 | 15673 | 921 | 58764 | 971 | 4.61 | 1 | 0.49839 | 0.00107 | 0.50053 |
| ncsrsk_9_9 | 21300 | 19865 | 1521 | 3.63 | 16816 | 15673 | 921 | 58764 | 1294 | 5.79 | 1 | 0.53148 | 0.00124 | 0.53397 |
| ncsrsk_9_10 | 21300 | 19865 | 1901 | 4.26 | 16816 | 15673 | 921 | 58764 | 1618 | 6.96 | 1 | 0.56633 | 0.00122 | 0.56877 |
| ncsrsk_9_11 | 21300 | 19865 | 2281 | 4.90 | 16816 | 15673 | 921 | 58764 | 1941 | 8.13 | 1 | 0.60204 | 0.00118 | 0.60441 |
| ncsrsk_9_12 | 21300 | 19865 | 2661 | 5.53 | 16816 | 15673 | 921 | 58764 | 2265 | 9.30 | 1 | 0.63600 | 0.00119 | 0.63839 |
| ncsrsk_9_13 | 21300 | 19865 | 3041 | 6.16 | 16816 | 15673 | 921 | 58764 | 2588 | 10.47 | 1 | 0.67128 | 0.00130 | 0.67389 |
| ncsrsk_9_14 | 21300 | 19865 | 3421 | 6.80 | 16816 | 15673 | 921 | 58764 | 2912 | 11.64 | 1 | 0.70363 | 0.00130 | 0.70623 |
| ncsrsk_9_15 | 21300 | 19865 | 3801 | 7.43 | 16816 | 15673 | 921 | 58764 | 3235 | 12.82 | 1 | 0.73837 | 0.00130 | 0.74096 |
| | | | | | | | | | | | | | | |

**Table 6.9.6-18a. NCT results for skull oxide (SO) content in packaging calculation model**

| case name | SO (g) | $U_3O_8$ (g) | Sat. $H_2O$ (g) | SO h/x | U (g) | $^{235}U$ (g) | C (g) | mg C/ g $^{235}U$ | CV $H_2O$ (g) | CV h/x | Unident. (g) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncsrsk_10_1 | 21300 | 20786 | 0 | 1.05 | 17596 | 16399 | 0 | 0 | 0 | 1.05 | 1 | 0.40278 | 0.00079 | 0.40436 |
| ncsrsk_10_6 | 21300 | 20786 | 391 | 1.67 | 17596 | 16399 | 0 | 0 | 324 | 2.19 | 1 | 0.43497 | 0.00093 | 0.43683 |
| ncsrsk_10_7 | 21300 | 20786 | 781 | 2.29 | 17596 | 16399 | 0 | 0 | 647 | 3.32 | 1 | 0.46764 | 0.00104 | 0.46971 |
| ncsrsk_10_8 | 21300 | 20786 | 1172 | 2.91 | 17596 | 16399 | 0 | 0 | 971 | 4.46 | 1 | 0.50067 | 0.00103 | 0.50274 |
| ncsrsk_10_9 | 21300 | 20786 | 1562 | 3.54 | 17596 | 16399 | 0 | 0 | 1294 | 5.60 | 1 | 0.53570 | 0.00129 | 0.53828 |
| ncsrsk_10_10 | 21300 | 20786 | 1953 | 4.16 | 17596 | 16399 | 0 | 0 | 1618 | 6.73 | 1 | 0.57116 | 0.00119 | 0.57355 |
| ncsrsk_10_11 | 21300 | 20786 | 2343 | 4.78 | 17596 | 16399 | 0 | 0 | 1941 | 7.87 | 1 | 0.60642 | 0.00131 | 0.60904 |
| ncsrsk_10_12 | 21300 | 20786 | 2734 | 5.40 | 17596 | 16399 | 0 | 0 | 2265 | 9.00 | 1 | 0.63938 | 0.00118 | 0.64175 |
| ncsrsk_10_13 | 21300 | 20786 | 3124 | 6.02 | 17596 | 16399 | 0 | 0 | 2588 | 10.14 | 1 | 0.67610 | 0.00123 | 0.67856 |
| ncsrsk_10_14 | 21300 | 20786 | 3515 | 6.64 | 17596 | 16399 | 0 | 0 | 2912 | 11.28 | 1 | 0.70857 | 0.00115 | 0.71087 |
| ncsrsk_10_15 | 21300 | 20786 | 3905 | 7.27 | 17596 | 16399 | 0 | 0 | 3235 | 12.41 | 1 | 0.74201 | 0.00149 | 0.74499 |
| **content in flooded containment vessel, NCT array packaging calculation model for CSI=0.0** | | | | | | | | | | | | | | |
| **513 g polyethylene, no can spacers** | | | | | | | | | | | | | | |
| nciask_1_15 | 11589 | 8063 | 4468 | 28.09 | 6828 | 4765 | 417 | 87518 | 4105 | 50.58 | 2596 | 0.73555 | 0.00130 | 0.73814 |
| nciask_2_15 | 14934 | 11665 | 4015 | 17.79 | 9879 | 6858 | 504 | 73492 | 4105 | 33.41 | 2252 | 0.72258 | 0.00122 | 0.72503 |
| nciask_3_15 | 13821 | 11876 | 4893 | 20.62 | 10058 | 7028 | 372 | 52930 | 3233 | 32.62 | 1060 | 0.73483 | 0.00120 | 0.73724 |
| nciask_4_15 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 60 | 6786 | 3235 | 25.07 | -227 | 0.72783 | 0.00122 | 0.73027 |
| nciask_5_15 | 21216 | 21036 | 3869 | 9.49 | 17815 | 12455 | 27 | 2168 | 3235 | 16.27 | -360 | 0.71163 | 0.00123 | 0.71409 |
| nciask_6_15 | 15111 | 12933 | 3765 | 28.02 | 10960 | 4122 | 921 | 223432 | 4105 | 54.01 | 744 | 0.65333 | 0.00109 | 0.65551 |
| nciask_7_15 | 13155 | 11666 | 3989 | 32.68 | 9886 | 3712 | 609 | 164054 | 4106 | 61.55 | 367 | 0.66124 | 0.00107 | 0.66339 |
| nciask_8_15 | 13650 | 11689 | 4068 | 33.01 | 9906 | 3737 | 261 | 69834 | 4106 | 61.69 | 1187 | 0.66664 | 0.00124 | 0.66912 |
| nciask_9_15 | 21300 | 19865 | 3801 | 7.43 | 16816 | 15673 | 921 | 58764 | 3235 | 12.82 | 1 | 0.75365 | 0.00127 | 0.75620 |
| nciask_10_15 | 21300 | 20786 | 3905 | 7.27 | 17596 | 16399 | 0 | 0 | 3235 | 12.41 | 1 | 0.76141 | 0.00140 | 0.76422 |
| | | | | | | | | | | | | | | |

**Table 6.9.6-18a. NCT results for skull oxide (SO) content in packaging calculation model**

| case name | SO (g) | $U_3O_8$ (g) | Sat. $H_2O$ (g) | SO h/x | U (g) | $^{235}U$ (g) | C (g) | mg C/ g $^{235}U$ | CV $H_2O$ (g) | CV h/x | Unident. (g) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| nciask_6_1 | 15111 | 12933 | 0 | 4.17 | 10960 | 4122 | 921 | 223432 | 0 | 4.17 | 744 | 0.26223 | 0.00069 | 0.26361 |
| nciask_6_6 | 15111 | 12933 | 377 | 6.56 | 10960 | 4122 | 921 | 223432 | 410 | 9.16 | 744 | 0.29333 | 0.00078 | 0.29489 |
| nciask_6_7 | 15111 | 12933 | 753 | 8.94 | 10960 | 4122 | 921 | 223432 | 821 | 14.14 | 744 | 0.32968 | 0.00084 | 0.33136 |
| nciask_6_8 | 15111 | 12933 | 1130 | 11.33 | 10960 | 4122 | 921 | 223432 | 1231 | 19.12 | 744 | 0.36777 | 0.00088 | 0.36953 |
| nciask_6_9 | 15111 | 12933 | 1506 | 13.71 | 10960 | 4122 | 921 | 223432 | 1642 | 24.11 | 744 | 0.40621 | 0.00127 | 0.40874 |
| nciask_6_10 | 15111 | 12933 | 1883 | 16.09 | 10960 | 4122 | 921 | 223432 | 2052 | 29.09 | 744 | 0.44807 | 0.00116 | 0.45039 |
| nciask_6_11 | 15111 | 12933 | 2259 | 18.48 | 10960 | 4122 | 921 | 223432 | 2463 | 34.07 | 744 | 0.49212 | 0.00111 | 0.49435 |
| nciask_6_12 | 15111 | 12933 | 2636 | 20.86 | 10960 | 4122 | 921 | 223432 | 2873 | 39.06 | 744 | 0.53233 | 0.00122 | 0.53477 |
| nciask_6_13 | 15111 | 12933 | 3012 | 23.25 | 10960 | 4122 | 921 | 223432 | 3284 | 44.04 | 744 | 0.57192 | 0.00123 | 0.57439 |
| nciask_6_14 | 15111 | 12933 | 3389 | 25.63 | 10960 | 4122 | 921 | 223432 | 3694 | 49.02 | 744 | 0.61188 | 0.00136 | 0.61460 |
| nciask_6_15 | 15111 | 12933 | 3765 | 28.02 | 10960 | 4122 | 921 | 223432 | 4105 | 54.01 | 744 | 0.65333 | 0.00109 | 0.65551 |
| | | | | | | | | | | | | | | |
| nciask_9_1 | 21300 | 19865 | 0 | 1.1 | 16816 | 15673 | 921 | 58764 | 0 | 1.10 | 1 | 0.41949 | 0.00093 | 0.42134 |
| nciask_9_6 | 21300 | 19865 | 380 | 1.73 | 16816 | 15673 | 921 | 58764 | 324 | 2.27 | 1 | 0.45272 | 0.00092 | 0.45456 |
| nciask_9_7 | 21300 | 19865 | 760 | 2.36 | 16816 | 15673 | 921 | 58764 | 647 | 3.44 | 1 | 0.48472 | 0.00116 | 0.48704 |
| nciask_9_8 | 21300 | 19865 | 1140 | 3 | 16816 | 15673 | 921 | 58764 | 971 | 4.61 | 1 | 0.51805 | 0.00111 | 0.52027 |
| nciask_9_9 | 21300 | 19865 | 1521 | 3.63 | 16816 | 15673 | 921 | 58764 | 1294 | 5.79 | 1 | 0.55105 | 0.00116 | 0.55336 |
| nciask_9_10 | 21300 | 19865 | 1901 | 4.26 | 16816 | 15673 | 921 | 58764 | 1618 | 6.96 | 1 | 0.58571 | 0.00105 | 0.58780 |
| nciask_9_11 | 21300 | 19865 | 2281 | 4.9 | 16816 | 15673 | 921 | 58764 | 1941 | 8.13 | 1 | 0.62158 | 0.00114 | 0.62386 |
| nciask_9_12 | 21300 | 19865 | 2661 | 5.53 | 16816 | 15673 | 921 | 58764 | 2265 | 9.30 | 1 | 0.65700 | 0.00141 | 0.65983 |
| nciask_9_13 | 21300 | 19865 | 3041 | 6.16 | 16816 | 15673 | 921 | 58764 | 2588 | 10.47 | 1 | 0.68964 | 0.00125 | 0.69214 |
| nciask_9_14 | 21300 | 19865 | 3421 | 6.8 | 16816 | 15673 | 921 | 58764 | 2912 | 11.64 | 1 | 0.72169 | 0.00141 | 0.72451 |
| nciask_9_15 | 21300 | 19865 | 3801 | 7.43 | 16816 | 15673 | 921 | 58764 | 3235 | 12.82 | 1 | 0.75365 | 0.00127 | 0.75620 |
| | | | | | | | | | | | | | | |
| nciask_10_1 | 21300 | 20786 | 0 | 1.05 | 17596 | 16399 | 0 | 0 | 0 | 1.05 | 1 | 0.42530 | 0.00082 | 0.42693 |
| nciask_10_6 | 21300 | 20786 | 391 | 1.67 | 17596 | 16399 | 0 | 0 | 324 | 2.19 | 1 | 0.45517 | 0.00080 | 0.45677 |

**Table 6.9.6-18a. NCT results for skull oxide (SO) content in packaging calculation model**

| case name | SO (g) | $U_3O_8$ (g) | Sat. $H_2O$ (g) | SO h/x | U (g) | $^{235}U$ (g) | C (g) | mg C/ g $^{235}U$ | CV $H_2O$ (g) | CV h/x | Unident. (g) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| nciask_10_7 | 21300 | 20786 | 781 | 2.29 | 17596 | 16399 | 0 | 0 | 647 | 3.32 | 1 | 0.48754 | 0.00099 | 0.48952 |
| nciask_10_8 | 21300 | 20786 | 1172 | 2.91 | 17596 | 16399 | 0 | 0 | 971 | 4.46 | 1 | 0.52247 | 0.00101 | 0.52448 |
| nciask_10_9 | 21300 | 20786 | 1562 | 3.54 | 17596 | 16399 | 0 | 0 | 1294 | 5.60 | 1 | 0.55799 | 0.00107 | 0.56013 |
| nciask_10_10 | 21300 | 20786 | 1953 | 4.16 | 17596 | 16399 | 0 | 0 | 1618 | 6.73 | 1 | 0.59209 | 0.00104 | 0.59416 |
| nciask_10_11 | 21300 | 20786 | 2343 | 4.78 | 17596 | 16399 | 0 | 0 | 1941 | 7.87 | 1 | 0.62721 | 0.00107 | 0.62935 |
| nciask_10_12 | 21300 | 20786 | 2734 | 5.4 | 17596 | 16399 | 0 | 0 | 2265 | 9.00 | 1 | 0.65769 | 0.00115 | 0.65999 |
| nciask_10_13 | 21300 | 20786 | 3124 | 6.02 | 17596 | 16399 | 0 | 0 | 2588 | 10.14 | 1 | 0.69394 | 0.00131 | 0.69655 |
| nciask_10_14 | 21300 | 20786 | 3515 | 6.64 | 17596 | 16399 | 0 | 0 | 2912 | 11.28 | 1 | 0.72808 | 0.00150 | 0.73109 |
| nciask_10_15 | 21300 | 20786 | 3905 | 7.27 | 17596 | 16399 | 0 | 0 | 3235 | 12.41 | 1 | 0.76141 | 0.00140 | 0.76422 |

**Table 6.9.6-18b. HAC results for skull oxide (SO) content in packaging calculation model**

| case name | SO (g) | $U_3O_8$ (g) | Sat. $H_2O$ (g) | SO h/x | U (g) | $^{235}U$ (g) | C (g) | mg C/ g $^{235}U$ | CV $H_2O$ (g) | CV h/x | Unident. (g) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **content in flooded CV, HAC single package, reflected** | | | | | | | | | | | | | | |
| **513 g polyethylene, no can spacers** | | | | | | | | | | | | | | |
| hcsrsk_1_15 | 11589 | 8063 | 4468 | 28.09 | 6828 | 4765 | 417 | 87518 | 4105 | 50.58 | 2596 | 0.72049 | 0.00145 | 0.72339 |
| hcsrsk_2_15 | 14934 | 11665 | 4015 | 17.79 | 9879 | 6858 | 504 | 73492 | 4105 | 33.41 | 2252 | 0.70717 | 0.00140 | 0.70997 |
| hcsrsk_3_15 | 13821 | 11876 | 4893 | 20.62 | 10058 | 7028 | 372 | 52930 | 3233 | 32.62 | 1060 | 0.72081 | 0.00136 | 0.72353 |
| hcsrsk_4_15 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 60 | 6786 | 3235 | 25.07 | -227 | 0.71449 | 0.00128 | 0.71706 |
| hcsrsk_5_15 | 21216 | 21036 | 3869 | 9.49 | 17815 | 12455 | 27 | 2168 | 3235 | 16.27 | -360 | 0.69845 | 0.00134 | 0.70113 |
| hcsrsk_6_15 | 15111 | 12933 | 3765 | 28.02 | 10960 | 4122 | 921 | 223432 | 4105 | 54.01 | 744 | 0.63787 | 0.00140 | 0.64066 |
| hcsrsk_7_15 | 13155 | 11666 | 3989 | 32.68 | 9886 | 3712 | 609 | 164054 | 4106 | 61.55 | 367 | 0.64910 | 0.00150 | 0.65210 |
| hcsrsk_8_15 | 13650 | 11689 | 4068 | 33.01 | 9906 | 3737 | 261 | 69834 | 4106 | 61.69 | 1187 | 0.65332 | 0.00140 | 0.65613 |

**Table 6.9.6-18b. HAC results for skull oxide (SO) content in packaging calculation model**

| case name | SO (g) | $U_3O_8$ (g) | Sat. $H_2O$ (g) | SO h/x | U (g) | $^{235}U$ (g) | C (g) | mg C/ g $^{235}U$ | CV $H_2O$ (g) | CV h/x | Unident. (g) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| hcsrsk_9_15 | 21300 | 19865 | 3801 | 7.43 | 16816 | 15673 | 921 | 58764 | 3235 | 12.82 | 1 | 0.73855 | 0.00121 | 0.74096 |
| hcsrsk_10_15 | 21300 | 20786 | 3905 | 7.27 | 17596 | 16399 | 0 | 0 | 3235 | 12.41 | 1 | 0.74359 | 0.00118 | 0.74595 |
| | | | | | | | | | | | | | | |
| hcsrsk_9_1 | 21300 | 19865 | 0 | 1.10 | 16816 | 15673 | 921 | 58764 | 0 | 1.10 | 1 | 0.40344 | 0.00080 | 0.40505 |
| hcsrsk_9_6 | 21300 | 19865 | 380 | 1.73 | 16816 | 15673 | 921 | 58764 | 324 | 2.27 | 1 | 0.43432 | 0.00091 | 0.43614 |
| hcsrsk_9_7 | 21300 | 19865 | 760 | 2.36 | 16816 | 15673 | 921 | 58764 | 647 | 3.44 | 1 | 0.46617 | 0.00090 | 0.46796 |
| hcsrsk_9_8 | 21300 | 19865 | 1140 | 3.00 | 16816 | 15673 | 921 | 58764 | 971 | 4.61 | 1 | 0.49951 | 0.00104 | 0.50160 |
| hcsrsk_9_9 | 21300 | 19865 | 1521 | 3.63 | 16816 | 15673 | 921 | 58764 | 1294 | 5.79 | 1 | 0.53428 | 0.00114 | 0.53656 |
| hcsrsk_9_10 | 21300 | 19865 | 1901 | 4.26 | 16816 | 15673 | 921 | 58764 | 1618 | 6.96 | 1 | 0.57081 | 0.00102 | 0.57286 |
| hcsrsk_9_11 | 21300 | 19865 | 2281 | 4.90 | 16816 | 15673 | 921 | 58764 | 1941 | 8.13 | 1 | 0.60569 | 0.00111 | 0.60792 |
| hcsrsk_9_12 | 21300 | 19865 | 2661 | 5.53 | 16816 | 15673 | 921 | 58764 | 2265 | 9.30 | 1 | 0.63704 | 0.00125 | 0.63955 |
| hcsrsk_9_13 | 21300 | 19865 | 3041 | 6.16 | 16816 | 15673 | 921 | 58764 | 2588 | 10.47 | 1 | 0.67153 | 0.00139 | 0.67431 |
| hcsrsk_9_14 | 21300 | 19865 | 3421 | 6.80 | 16816 | 15673 | 921 | 58764 | 2912 | 11.64 | 1 | 0.70545 | 0.00113 | 0.70770 |
| hcsrsk_9_15 | 21300 | 19865 | 3801 | 7.43 | 16816 | 15673 | 921 | 58764 | 3235 | 12.82 | 1 | 0.73855 | 0.00121 | 0.74096 |
| | | | | | | | | | | | | | | |
| hcsrsk_10_1 | 21300 | 20786 | 0 | 1.05 | 17596 | 16399 | 0 | 0 | 0 | 1.05 | 1 | 0.40569 | 0.00088 | 0.40745 |
| hcsrsk_10_6 | 21300 | 20786 | 391 | 1.67 | 17596 | 16399 | 0 | 0 | 324 | 2.19 | 1 | 0.43659 | 0.00086 | 0.43832 |
| hcsrsk_10_7 | 21300 | 20786 | 781 | 2.29 | 17596 | 16399 | 0 | 0 | 647 | 3.32 | 1 | 0.47008 | 0.00095 | 0.47198 |
| hcsrsk_10_8 | 21300 | 20786 | 1172 | 2.91 | 17596 | 16399 | 0 | 0 | 971 | 4.46 | 1 | 0.50524 | 0.00097 | 0.50717 |
| hcsrsk_10_9 | 21300 | 20786 | 1562 | 3.54 | 17596 | 16399 | 0 | 0 | 1294 | 5.60 | 1 | 0.53928 | 0.00102 | 0.54133 |
| hcsrsk_10_10 | 21300 | 20786 | 1953 | 4.16 | 17596 | 16399 | 0 | 0 | 1618 | 6.73 | 1 | 0.57494 | 0.00115 | 0.57724 |
| hcsrsk_10_11 | 21300 | 20786 | 2343 | 4.78 | 17596 | 16399 | 0 | 0 | 1941 | 7.87 | 1 | 0.60702 | 0.00111 | 0.60924 |
| hcsrsk_10_12 | 21300 | 20786 | 2734 | 5.40 | 17596 | 16399 | 0 | 0 | 2265 | 9.00 | 1 | 0.64205 | 0.00132 | 0.64469 |
| hcsrsk_10_13 | 21300 | 20786 | 3124 | 6.02 | 17596 | 16399 | 0 | 0 | 2588 | 10.14 | 1 | 0.67634 | 0.00138 | 0.67911 |
| hcsrsk_10_14 | 21300 | 20786 | 3515 | 6.64 | 17596 | 16399 | 0 | 0 | 2912 | 11.28 | 1 | 0.71259 | 0.00144 | 0.71547 |
| hcsrsk_10_15 | 21300 | 20786 | 3905 | 7.27 | 17596 | 16399 | 0 | 0 | 3235 | 12.41 | 1 | 0.74359 | 0.00118 | 0.74595 |

**Table 6.9.6-18b. HAC results for skull oxide (SO) content in packaging calculation model**

| case name | SO (g) | $U_3O_8$ (g) | Sat. $H_2O$ (g) | SO h/x | U (g) | $^{235}U$ (g) | C (g) | mg C/ g $^{235}U$ | CV $H_2O$ (g) | CV h/x | Unident. (g) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **content in flooded containment vessel, HAC array packaging calculation model for CSI=0.0** | | | | | | | | | | | | | | |
| **513 g polyethylene, no can spacers** | | | | | | | | | | | | | | |
| hciask_1_15 | 11589 | 8063 | 4468 | 28.09 | 6828 | 4765 | 417 | 87518 | 4105 | 50.58 | 2596 | 0.73896 | 0.00132 | 0.74159 |
| hciask_2_15 | 14934 | 11665 | 4015 | 17.79 | 9879 | 6858 | 504 | 73492 | 4105 | 33.41 | 2252 | 0.72435 | 0.00127 | 0.72689 |
| hciask_3_15 | 13821 | 11876 | 4893 | 20.62 | 10058 | 7028 | 372 | 52930 | 3233 | 32.62 | 1060 | 0.73900 | 0.00130 | 0.74160 |
| hciask_4_15 | 15246 | 14900 | 4599 | 15.52 | 12619 | 8842 | 60 | 6786 | 3235 | 25.07 | -227 | 0.73199 | 0.00123 | 0.73445 |
| hciask_5_15 | 21216 | 21036 | 3869 | 9.49 | 17815 | 12455 | 27 | 2168 | 3235 | 16.27 | -360 | 0.71601 | 0.00117 | 0.71835 |
| hciask_6_15 | 15111 | 12933 | 3765 | 28.02 | 10960 | 4122 | 921 | 223432 | 4105 | 54.01 | 744 | 0.65587 | 0.00125 | 0.65837 |
| hciask_7_15 | 13155 | 11666 | 3989 | 32.68 | 9886 | 3712 | 609 | 164054 | 4106 | 61.55 | 367 | 0.66608 | 0.00159 | 0.66925 |
| hciask_8_15 | 13650 | 11689 | 4068 | 33.01 | 9906 | 3737 | 261 | 69834 | 4106 | 61.69 | 1187 | 0.66948 | 0.00153 | 0.67255 |
| hciask_9_15 | 21300 | 19865 | 3801 | 7.43 | 16816 | 15673 | 921 | 58764 | 3235 | 12.82 | 1 | 0.75757 | 0.00116 | 0.75989 |
| hciask_10_15 | 21300 | 20786 | 3905 | 7.27 | 17596 | 16399 | 0 | 0 | 3235 | 12.41 | 1 | 0.76462 | 0.00131 | 0.76725 |
| | | | | | | | | | | | | | | |
| hciask_6_1 | 15111 | 12933 | 0 | 4.17 | 10960 | 4122 | 921 | 223432 | 0 | 4.17 | 744 | 0.26620 | 0.00075 | 0.26769 |
| hciask_6_6 | 15111 | 12933 | 377 | 6.56 | 10960 | 4122 | 921 | 223432 | 411 | 9.16 | 744 | 0.29787 | 0.00085 | 0.29957 |
| hciask_6_7 | 15111 | 12933 | 753 | 8.94 | 10960 | 4122 | 921 | 223432 | 821 | 14.14 | 744 | 0.33370 | 0.00085 | 0.33539 |
| hciask_6_8 | 15111 | 12933 | 1130 | 11.33 | 10960 | 4122 | 921 | 223432 | 1231 | 19.12 | 744 | 0.37226 | 0.00098 | 0.37422 |
| hciask_6_9 | 15111 | 12933 | 1506 | 13.71 | 10960 | 4122 | 921 | 223432 | 1642 | 24.11 | 744 | 0.41300 | 0.00083 | 0.41465 |
| hciask_6_10 | 15111 | 12933 | 1883 | 16.09 | 10960 | 4122 | 921 | 223432 | 2052 | 29.09 | 744 | 0.45192 | 0.00106 | 0.45403 |
| hciask_6_11 | 15111 | 12933 | 2259 | 18.48 | 10960 | 4122 | 921 | 223432 | 2463 | 34.07 | 744 | 0.49341 | 0.00113 | 0.49566 |
| hciask_6_12 | 15111 | 12933 | 2636 | 20.86 | 10960 | 4122 | 921 | 223432 | 2873 | 39.06 | 744 | 0.53469 | 0.00111 | 0.53691 |
| hciask_6_13 | 15111 | 12933 | 3012 | 23.25 | 10960 | 4122 | 921 | 223432 | 3284 | 44.04 | 744 | 0.57324 | 0.00123 | 0.57571 |
| hciask_6_14 | 15111 | 12933 | 3389 | 25.63 | 10960 | 4122 | 921 | 223432 | 3694 | 49.02 | 744 | 0.61596 | 0.00125 | 0.61847 |
| hciask_6_15 | 15111 | 12933 | 3765 | 28.02 | 10960 | 4122 | 921 | 223432 | 4105 | 54.01 | 744 | 0.65587 | 0.00125 | 0.65837 |
| | | | | | | | | | | | | | | |

**Table 6.9.6-18b. HAC results for skull oxide (SO) content in packaging calculation model**

| case name | SO (g) | $U_3O_8$ (g) | Sat. $H_2O$ (g) | SO h/x | U (g) | $^{235}U$ (g) | C (g) | mg C/ g $^{235}U$ | CV $H_2O$ (g) | CV h/x | Unident. (g) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| hciask_9_1 | 21300 | 19865 | 0 | 1.10 | 16816 | 15673 | 921 | 58764 | 0 | 1.10 | 1 | 0.42753 | 0.00091 | 0.42935 |
| hciask_9_6 | 21300 | 19865 | 380 | 1.73 | 16816 | 15673 | 921 | 58764 | 324 | 2.27 | 1 | 0.45603 | 0.00103 | 0.45808 |
| hciask_9_7 | 21300 | 19865 | 760 | 2.36 | 16816 | 15673 | 921 | 58764 | 647 | 3.44 | 1 | 0.48912 | 0.00101 | 0.49114 |
| hciask_9_8 | 21300 | 19865 | 1140 | 3.00 | 16816 | 15673 | 921 | 58764 | 971 | 4.61 | 1 | 0.52104 | 0.00109 | 0.52322 |
| hciask_9_9 | 21300 | 19865 | 1521 | 3.63 | 16816 | 15673 | 921 | 58764 | 1294 | 5.79 | 1 | 0.55643 | 0.00104 | 0.55851 |
| hciask_9_10 | 21300 | 19865 | 1901 | 4.26 | 16816 | 15673 | 921 | 58764 | 1618 | 6.96 | 1 | 0.59193 | 0.00105 | 0.59403 |
| hciask_9_11 | 21300 | 19865 | 2281 | 4.90 | 16816 | 15673 | 921 | 58764 | 1941 | 8.13 | 1 | 0.62726 | 0.00109 | 0.62945 |
| hciask_9_12 | 21300 | 19865 | 2661 | 5.53 | 16816 | 15673 | 921 | 58764 | 2265 | 9.30 | 1 | 0.65952 | 0.00106 | 0.66163 |
| hciask_9_13 | 21300 | 19865 | 3041 | 6.16 | 16816 | 15673 | 921 | 58764 | 2588 | 10.47 | 1 | 0.69094 | 0.00127 | 0.69348 |
| hciask_9_14 | 21300 | 19865 | 3421 | 6.80 | 16816 | 15673 | 921 | 58764 | 2912 | 11.64 | 1 | 0.72863 | 0.00116 | 0.73095 |
| hciask_9_15 | 21300 | 19865 | 3801 | 7.43 | 16816 | 15673 | 921 | 58764 | 3235 | 12.82 | 1 | 0.75757 | 0.00116 | 0.75989 |
| | | | | | | | | | | | | | | |
| hciask_10_1 | 21300 | 20786 | 0 | 1.05 | 17596 | 16399 | 0 | 0 | 0 | 1.05 | 1 | 0.43087 | 0.00111 | 0.43308 |
| hciask_10_6 | 21300 | 20786 | 391 | 1.67 | 17596 | 16399 | 0 | 0 | 324 | 2.19 | 1 | 0.46066 | 0.00092 | 0.46250 |
| hciask_10_7 | 21300 | 20786 | 781 | 2.29 | 17596 | 16399 | 0 | 0 | 647 | 3.32 | 1 | 0.49381 | 0.00097 | 0.49574 |
| hciask_10_8 | 21300 | 20786 | 1172 | 2.91 | 17596 | 16399 | 0 | 0 | 971 | 4.46 | 1 | 0.52679 | 0.00113 | 0.52906 |
| hciask_10_9 | 21300 | 20786 | 1562 | 3.54 | 17596 | 16399 | 0 | 0 | 1294 | 5.60 | 1 | 0.56200 | 0.00121 | 0.56442 |
| hciask_10_10 | 21300 | 20786 | 1953 | 4.16 | 17596 | 16399 | 0 | 0 | 1618 | 6.73 | 1 | 0.59673 | 0.00118 | 0.59908 |
| hciask_10_11 | 21300 | 20786 | 2343 | 4.78 | 17596 | 16399 | 0 | 0 | 1941 | 7.87 | 1 | 0.63042 | 0.00109 | 0.63260 |
| hciask_10_12 | 21300 | 20786 | 2734 | 5.40 | 17596 | 16399 | 0 | 0 | 2265 | 9.00 | 1 | 0.66502 | 0.00116 | 0.66735 |
| hciask_10_13 | 21300 | 20786 | 3124 | 6.02 | 17596 | 16399 | 0 | 0 | 2588 | 10.14 | 1 | 0.69780 | 0.00108 | 0.69997 |
| hciask_10_14 | 21300 | 20786 | 3515 | 6.64 | 17596 | 16399 | 0 | 0 | 2912 | 11.28 | 1 | 0.73223 | 0.00123 | 0.73470 |
| hciask_10_15 | 21300 | 20786 | 3905 | 7.27 | 17596 | 16399 | 0 | 0 | 3235 | 12.41 | 1 | 0.76462 | 0.00131 | 0.76725 |
| nciask_10_14 | 21300 | 20786 | 3515 | 6.64 | 17596 | 16399 | 0 | 0 | 2912 | 11.28 | 1 | 0.72808 | 0.00150 | 0.73109 |
| nciask_10_15 | 21300 | 20786 | 3905 | 7.27 | 17596 | 16399 | 0 | 0 | 3235 | 12.41 | 1 | 0.76141 | 0.00140 | 0.76422 |

**Table 6.9.6-19a. Results for $UZrH_x$ content in CV calculation model**

| case name | np | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| **TRIGA ($UZrH_x$) fuel content at 19.7 wt % $^{235}U$, 500 g $CH_2$, containment vessel, reflected** | | | | | | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | |
| cvcrtriga_1_1 | 0.0 | 10,400 | 921 | 0 | 0.00 | 1.0E-20 | 0.34219 | 0.00107 | 0.34432 |
| cvcrtriga_1_6 | 0.0 | 10,400 | 921 | 900 | 25.50 | 1.0E-01 | 0.34704 | 0.00101 | 0.34905 |
| cvcrtriga_1_7 | 0.0 | 10,400 | 921 | 1,800 | 51.00 | 2.0E-01 | 0.35869 | 0.00094 | 0.36057 |
| cvcrtriga_1_8 | 0.0 | 10,400 | 921 | 2,700 | 76.50 | 3.0E-01 | 0.37291 | 0.00103 | 0.37496 |
| cvcrtriga_1_9 | 0.0 | 10,400 | 921 | 3,599 | 102.00 | 4.0E-01 | 0.38978 | 0.00115 | 0.39209 |
| cvcrtriga_1_10 | 0.0 | 10,400 | 921 | 4,499 | 127.50 | 5.0E-01 | 0.41521 | 0.00099 | 0.41719 |
| cvcrtriga_1_11 | 0.0 | 10,400 | 921 | 5,399 | 153.00 | 6.0E-01 | 0.43399 | 0.00108 | 0.43616 |
| cvcrtriga_1_12 | 0.0 | 10,400 | 921 | 6,299 | 178.50 | 7.0E-01 | 0.45681 | 0.00116 | 0.45914 |
| cvcrtriga_1_13 | 0.0 | 10,400 | 921 | 7,199 | 204.00 | 8.0E-01 | 0.48121 | 0.00136 | 0.48393 |
| cvcrtriga_1_14 | 0.0 | 10,400 | 921 | 8,098 | 229.51 | 9.0E-01 | 0.50284 | 0.00114 | 0.50511 |
| cvcrtriga_1_15 | 0.0 | 10,400 | 921 | 8,998 | 255.01 | 1.0E+00 | 0.52494 | 0.00120 | 0.52735 |
| **can spacers (np thickness = 1.4 in.)** | | | | | | | | | |
| cvcrtriga_2_15 | 1.4 | 10,400 | 921 | 8,385 | 237.62 | 1.0E+00 | 0.42157 | 0.00099 | 0.42354 |
| **TRIGA ($UZrH_x$) fuel content at 70.1 wt % $^{235}U$, 500 g $CH_2$, containment vessel, reflected** | | | | | | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | |
| cvcrtriga_70_1_1 | 0.0 | 6,847 | 408 | 0 | 0.00 | 1.0E+00 | 0.29196 | 0.00097 | 0.29391 |
| cvcrtriga_70_1_6 | 0.0 | 6,847 | 408 | 900 | 57.56 | 1.0E+00 | 0.30096 | 0.00102 | 0.30300 |
| cvcrtriga_70_1_7 | 0.0 | 6,847 | 408 | 1,800 | 115.13 | 1.0E+00 | 0.31496 | 0.00089 | 0.31674 |
| cvcrtriga_70_1_8 | 0.0 | 6,847 | 408 | 2,700 | 172.69 | 1.0E+00 | 0.33376 | 0.00106 | 0.33588 |
| cvcrtriga_70_1_9 | 0.0 | 6,847 | 408 | 3,599 | 230.26 | 1.0E+00 | 0.35363 | 0.00100 | 0.35564 |
| cvcrtriga_70_1_10 | 0.0 | 6,847 | 408 | 4,499 | 287.82 | 1.0E+00 | 0.37761 | 0.00098 | 0.37956 |
| cvcrtriga_70_1_11 | 0.0 | 6,847 | 408 | 5,399 | 345.38 | 1.0E+00 | 0.40017 | 0.00120 | 0.40257 |

**Table 6.9.6-19a. Results for $UZrH_x$ content in CV calculation model**

| case name | np | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| cvcrtriga_70_1_12 | 0.0 | 6,847 | 408 | 6,299 | 402.95 | 1.0E+00 | 0.42263 | 0.00109 | 0.42481 |
| cvcrtriga_70_1_13 | 0.0 | 6,847 | 408 | 7,199 | 460.51 | 1.0E+00 | 0.44607 | 0.00120 | 0.44848 |
| cvcrtriga_70_1_14 | 0.0 | 6,847 | 408 | 8,098 | 518.07 | 1.0E+00 | 0.46618 | 0.00104 | 0.46827 |
| cvcrtriga_70_1_15 | 0.0 | 6,847 | 408 | 8,998 | 575.64 | 1.0E+00 | 0.48847 | 0.00130 | 0.49107 |
| **can spacers (np thickness = 1.4 in.)** | | | | | | | | | |
| cvcrtriga_70_2_15 | 1.4 | 6,847 | 408 | 8,385 | 536.39 | 1.0E+00 | 0.38372 | 0.00112 | 0.38596 |

**Table 6.9.6-19b. Results for $UZrH_x$ content spacing in CV calculation model**

| case name | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | pitch (cm) | pitch (in.) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| **TRIGA ($UZrH_x$) fuel content at 19.7 wt % $^{235}U$, triangular pitch spacing from touching sections to sections touching convenience can** | | | | | | | | | |
| **500 g $CH_2$ in cc, no can spacers (np thickness = 0.0 in.), containment vessel, reflected** | | | | | | | | | |
| **mocfr=1.0** | | | | | | | | | |
| cvT20ptch_1_15_1 | 10,400 | 921 | 8,998 | 255.01 | 2.11201 | 1.440 | 0.48176 | 0.00106 | 0.48387 |
| cvT20ptch_1_15_2 | 10,400 | 921 | 8,998 | 255.01 | 2.25466 | 1.537 | 0.49373 | 0.00119 | 0.49612 |
| cvT20ptch_1_15_3 | 10,400 | 921 | 8,998 | 255.01 | 2.39731 | 1.635 | 0.50012 | 0.00131 | 0.50274 |
| cvT20ptch_1_15_4 | 10,400 | 921 | 8,998 | 255.01 | 2.53996 | 1.732 | 0.50823 | 0.00110 | 0.51044 |
| cvT20ptch_1_15_5 | 10,400 | 921 | 8,998 | 255.01 | 2.68261 | 1.829 | 0.51676 | 0.00126 | 0.51928 |
| cvT20ptch_1_15_6 | 10,400 | 921 | 8,998 | 255.01 | 2.82526 | 1.927 | 0.52300 | 0.00115 | 0.52530 |
| cvT20ptch_1_15_7 | 10,400 | 921 | 8,998 | 255.01 | 2.96791 | 2.024 | 0.52511 | 0.00127 | 0.52766 |
| cvT20ptch_1_15_8 | 10,400 | 921 | 8,998 | 255.01 | 3.11056 | 2.121 | 0.52789 | 0.00116 | 0.53022 |
| cvT20ptch_1_15_9 | 10,400 | 921 | 8,998 | 255.01 | 3.25321 | 2.218 | 0.52959 | 0.00109 | 0.53177 |

**Table 6.9.6-19b. Results for $UZrH_x$ content spacing in CV calculation model**

| case name | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | pitch (cm) | pitch (in.) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| cvT20ptch_1_15_10 | 10,400 | 921 | 8,998 | 255.01 | 3.39586 | 2.316 | 0.52841 | 0.00115 | 0.53072 |
| cvT20ptch_1_15_11 | 10,400 | 921 | 8,998 | 255.01 | 3.53851 | 2.413 | 0.52767 | 0.00109 | 0.52985 |
| **mocfr=0.9** | | | | | | | | | |
| cvT20ptch_1_14_1 | 10,400 | 921 | 8,098 | 229.51 | 2.11201 | 1.440 | 0.46727 | 0.00112 | 0.46951 |
| cvT20ptch_1_14_6 | 10,400 | 921 | 8,098 | 229.51 | 2.82526 | 1.927 | 0.50042 | 0.00110 | 0.50263 |
| cvT20ptch_1_14_11 | 10,400 | 921 | 8,098 | 229.51 | 3.53851 | 2.413 | 0.51015 | 0.00114 | 0.51244 |
| **mocfr=0.8** | | | | | | | | | |
| cvT20ptch_1_13_1 | 10,400 | 921 | 7,199 | 204.00 | 2.11201 | 1.440 | 0.44680 | 0.00107 | 0.44894 |
| cvT20ptch_1_13_6 | 10,400 | 921 | 7,199 | 204.00 | 2.82526 | 1.927 | 0.47920 | 0.00102 | 0.48124 |
| cvT20ptch_1_13_11 | 10,400 | 921 | 7,199 | 204.00 | 3.53851 | 2.413 | 0.49183 | 0.00115 | 0.49413 |
| **mocfr=0.7** | | | | | | | | | |
| cvT20ptch_1_12_1 | 10,400 | 921 | 6,299 | 178.50 | 2.11201 | 1.440 | 0.43179 | 0.00117 | 0.43413 |
| cvT20ptch_1_12_6 | 10,400 | 921 | 6,299 | 178.50 | 2.82526 | 1.927 | 0.45630 | 0.00123 | 0.45875 |
| cvT20ptch_1_12_11 | 10,400 | 921 | 6,299 | 178.50 | 3.53851 | 2.413 | 0.46790 | 0.00112 | 0.47014 |
| **mocfr=0.6** | | | | | | | | | |
| cvT20ptch_1_11_1 | 10,400 | 921 | 5,399 | 153.00 | 2.11201 | 1.440 | 0.41313 | 0.00109 | 0.41531 |
| cvT20ptch_1_11_6 | 10,400 | 921 | 5,399 | 153.00 | 2.82526 | 1.927 | 0.43561 | 0.00115 | 0.43792 |
| cvT20ptch_1_11_11 | 10,400 | 921 | 5,399 | 153.00 | 3.53851 | 2.413 | 0.44764 | 0.00100 | 0.44964 |
| **mocfr=0.5** | | | | | | | | | |
| cvT20ptch_1_10_1 | 10,400 | 921 | 4,499 | 127.50 | 2.11201 | 1.440 | 0.39451 | 0.00106 | 0.39664 |
| cvT20ptch_1_10_6 | 10,400 | 921 | 4,499 | 127.50 | 2.82526 | 1.927 | 0.41120 | 0.00128 | 0.41376 |
| cvT20ptch_1_10_11 | 10,400 | 921 | 4,499 | 127.50 | 3.53851 | 2.413 | 0.42438 | 0.00120 | 0.42678 |

**Table 6.9.6-19b. Results for $UZrH_x$ content spacing in CV calculation model**

| case name | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | pitch (cm) | pitch (in.) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| **mocfr=0.4** | | | | | | | | | |
| cvT20ptch_1_9_1 | 10,400 | 921 | 3,599 | 102.00 | 2.11201 | 1.440 | 0.38008 | 0.00097 | 0.38203 |
| cvT20ptch_1_9_6 | 10,400 | 921 | 3,599 | 102.00 | 2.82526 | 1.927 | 0.39106 | 0.00098 | 0.39303 |
| cvT20ptch_1_9_11 | 10,400 | 921 | 3,599 | 102.00 | 3.53851 | 2.413 | 0.40267 | 0.00126 | 0.40519 |
| **mocfr=0.3** | | | | | | | | | |
| cvT20ptch_1_8_1 | 10,400 | 921 | 2,700 | 76.50 | 2.11201 | 1.440 | 0.36348 | 0.00091 | 0.36531 |
| cvT20ptch_1_8_6 | 10,400 | 921 | 2,700 | 76.50 | 2.82526 | 1.927 | 0.37106 | 0.00102 | 0.37309 |
| cvT20ptch_1_8_11 | 10,400 | 921 | 2,700 | 76.50 | 3.53851 | 2.413 | 0.38210 | 0.00098 | 0.38406 |
| **mocfr=0.2** | | | | | | | | | |
| cvT20ptch_1_7_1 | 10,400 | 921 | 1,800 | 51.00 | 2.11201 | 1.440 | 0.35255 | 0.00094 | 0.35443 |
| cvT20ptch_1_7_6 | 10,400 | 921 | 1,800 | 51.00 | 2.82526 | 1.927 | 0.35542 | 0.00089 | 0.35721 |
| cvT20ptch_1_7_11 | 10,400 | 921 | 1,800 | 51.00 | 3.53851 | 2.413 | 0.36444 | 0.00091 | 0.36627 |
| **mocfr=0.1** | | | | | | | | | |
| cvT20ptch_1_6_1 | 10,400 | 921 | 900 | 25.50 | 2.11201 | 1.440 | 0.34383 | 0.00115 | 0.34612 |
| cvT20ptch_1_6_6 | 10,400 | 921 | 900 | 25.50 | 2.82526 | 1.927 | 0.34516 | 0.00093 | 0.34703 |
| cvT20ptch_1_6_11 | 10,400 | 921 | 900 | 25.50 | 3.53851 | 2.413 | 0.35189 | 0.00102 | 0.35394 |
| **mocfr=1.0E-20** | | | | | | | | | |
| cvT20ptch_1_1_1 | 10,400 | 921 | 0 | 0.00 | 2.11201 | 1.440 | 0.34314 | 0.00084 | 0.34482 |
| cvT20ptch_1_1_6 | 10,400 | 921 | 0 | 0.00 | 2.82526 | 1.927 | 0.34273 | 0.00089 | 0.34452 |
| cvT20ptch_1_1_11 | 10,400 | 921 | 0 | 0.00 | 3.53851 | 2.413 | 0.34291 | 0.00087 | 0.34466 |

**Table 6.9.6-19c. Results for $UZrH_x$ content uranium weight fraction in CV calculation model**

| case name | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|
| **TRIGA ($UZrH_x$) fuel content at 19.7 wt % $^{235}U$, variation of uranium weight fraction in content** | | | | | | | | |
| **500 g $CH_2$ in cc, no can spacers (np thickness = 0.0 in.), containment vessel, reflected** | | | | | | | | |
| **45 wt % U** | | | | | | | | |
| cvTE20U45_1_15 | 10,400 | 921 | 8,998 | 255.01 | 1.0E+00 | 0.52494 | 0.00120 | 0.52735 |
| cvTE20U45_1_14 | 10,400 | 921 | 8,098 | 229.51 | 9.0E-01 | 0.50284 | 0.00114 | 0.50511 |
| cvTE20U45_1_13 | 10,400 | 921 | 7,199 | 204.00 | 8.0E-01 | 0.48121 | 0.00136 | 0.48393 |
| cvTE20U45_1_12 | 10,400 | 921 | 6,299 | 178.50 | 7.0E-01 | 0.45681 | 0.00116 | 0.45914 |
| cvTE20U45_1_11 | 10,400 | 921 | 5,399 | 153.00 | 6.0E-01 | 0.43399 | 0.00108 | 0.43616 |
| cvTE20U45_1_10 | 10,400 | 921 | 4,499 | 127.50 | 5.0E-01 | 0.41521 | 0.00099 | 0.41719 |
| cvTE20U45_1_9 | 10,400 | 921 | 3,599 | 102.00 | 4.0E-01 | 0.38978 | 0.00115 | 0.39209 |
| cvTE20U45_1_8 | 10,400 | 921 | 2,700 | 76.50 | 3.0E-01 | 0.37291 | 0.00103 | 0.37496 |
| cvTE20U45_1_7 | 10,400 | 921 | 1,800 | 51.00 | 2.0E-01 | 0.35869 | 0.00094 | 0.36057 |
| cvTE20U45_1_6 | 10,400 | 921 | 900 | 25.50 | 1.0E-01 | 0.34704 | 0.00101 | 0.34905 |
| cvTE20U45_1_1 | 10,400 | 921 | 0 | 0.00 | 1.0E-20 | 0.34219 | 0.00107 | 0.34432 |
| **30 wt % U** | | | | | | | | |
| cvTE20U30_1_15 | 8,250 | 489 | 8,998 | 480.29 | 1.0E+00 | 0.47671 | 0.00135 | 0.47942 |
| cvTE20U30_1_14 | 8,250 | 489 | 8,098 | 432.26 | 9.0E-01 | 0.45562 | 0.00105 | 0.45772 |
| cvTE20U30_1_13 | 8,250 | 489 | 7,199 | 384.23 | 8.0E-01 | 0.43218 | 0.00113 | 0.43445 |
| cvTE20U30_1_12 | 8,250 | 489 | 6,299 | 336.20 | 7.0E-01 | 0.41165 | 0.00096 | 0.41356 |
| cvTE20U30_1_11 | 8,250 | 489 | 5,399 | 288.17 | 6.0E-01 | 0.38706 | 0.00099 | 0.38903 |
| cvTE20U30_1_10 | 8,250 | 489 | 4,499 | 240.14 | 5.0E-01 | 0.36759 | 0.00092 | 0.36944 |
| cvTE20U30_1_9 | 8,250 | 489 | 3,599 | 192.11 | 4.0E-01 | 0.34766 | 0.00094 | 0.34954 |
| cvTE20U30_1_8 | 8,250 | 489 | 2,700 | 144.09 | 3.0E-01 | 0.33073 | 0.00086 | 0.33245 |
| cvTE20U30_1_7 | 8,250 | 489 | 1,800 | 96.06 | 2.0E-01 | 0.31555 | 0.00082 | 0.31720 |

**Table 6.9.6-19c. Results for $UZrH_x$ content uranium weight fraction in CV calculation model**

| case name | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|
| cvTE20U30_1_6 | 8,250 | 489 | 900 | 48.03 | 1.0E-01 | 0.31018 | 0.00092 | 0.31202 |
| cvTE20U30_1_01 | 8,250 | 489 | 0 | 0.00 | 1.0E-20 | 0.30488 | 0.00083 | 0.30654 |
| **20 wt % U** | | | | | | | | |
| cvTE20U20_1_15 | 7,545 | 297 | 8,998 | 790.78 | 1.0E+00 | 0.46046 | 0.00121 | 0.46289 |
| cvTE20U20_1_14 | 7,545 | 297 | 8,098 | 711.70 | 9.0E-01 | 0.43928 | 0.00114 | 0.44156 |
| cvTE20U20_1_13 | 7,545 | 297 | 7,199 | 632.62 | 8.0E-01 | 0.41486 | 0.00108 | 0.41702 |
| cvTE20U20_1_12 | 7,545 | 297 | 6,299 | 553.54 | 7.0E-01 | 0.39584 | 0.00113 | 0.39809 |
| cvTE20U20_1_11 | 7,545 | 297 | 5,399 | 474.47 | 6.0E-01 | 0.37399 | 0.00106 | 0.37612 |
| cvTE20U20_1_10 | 7,545 | 297 | 4,499 | 395.39 | 5.0E-01 | 0.35345 | 0.00100 | 0.35545 |
| cvTE20U20_1_9 | 7,545 | 297 | 3,599 | 316.31 | 4.0E-01 | 0.33290 | 0.00098 | 0.33486 |
| cvTE20U20_1_8 | 7,545 | 297 | 2,700 | 237.23 | 3.0E-01 | 0.31513 | 0.00103 | 0.31719 |
| cvTE20U20_1_7 | 7,545 | 297 | 1,800 | 158.16 | 2.0E-01 | 0.30148 | 0.00101 | 0.30350 |
| cvTE20U20_1_6 | 7,545 | 297 | 900 | 79.08 | 1.0E-01 | 0.29354 | 0.00089 | 0.29532 |
| cvTE20U20_1_1 | 7,545 | 297 | 0 | 0.00 | 1.0E-20 | 0.29227 | 0.00083 | 0.29392 |
| **12 wt % U** | | | | | | | | |
| cvTE20U12_1_15 | 7,125 | 168 | 8,998 | 1397.90 | 1.0E+00 | 0.44948 | 0.00108 | 0.45163 |
| cvTE20U12_1_14 | 7,125 | 168 | 8,098 | 1258.10 | 9.0E-01 | 0.43067 | 0.00106 | 0.43280 |
| cvTE20U12_1_13 | 7,125 | 168 | 7,199 | 1118.30 | 8.0E-01 | 0.40699 | 0.00098 | 0.40894 |
| cvTE20U12_1_12 | 7,125 | 168 | 6,299 | 978.59 | 7.0E-01 | 0.38549 | 0.00098 | 0.38744 |
| cvTE20U12_1_11 | 7,125 | 168 | 5,399 | 838.79 | 6.0E-01 | 0.36416 | 0.00089 | 0.36595 |
| cvTE20U12_1_10 | 7,125 | 168 | 4,499 | 698.99 | 5.0E-01 | 0.34375 | 0.00106 | 0.34586 |
| cvTE20U12_1_9 | 7,125 | 168 | 3,599 | 559.19 | 4.0E-01 | 0.32505 | 0.00108 | 0.32721 |
| cvTE20U12_1_8 | 7,125 | 168 | 2,700 | 419.40 | 3.0E-01 | 0.30767 | 0.00087 | 0.30940 |
| cvTE20U12_1_7 | 7,125 | 168 | 1,800 | 279.60 | 2.0E-01 | 0.29545 | 0.00076 | 0.29698 |

**Table 6.9.6-19c. Results for $UZrH_x$ content uranium weight fraction in CV calculation model**

| case name | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|
| cvTE20U12_1_6 | 7,125 | 168 | 900 | 139.80 | 1.0E-01 | 0.28602 | 0.00086 | 0.28774 |
| cvTE20U12_1_1 | 7,125 | 168 | 0 | 0.00 | 1.0E-20 | 0.28442 | 0.00079 | 0.28601 |
| **8.5 wt % U** | | | | | | | | |
| cvTE20U8p5_1_15 | 6,953 | 117 | 8,998 | 2007.30 | 1.0E+00 | 0.44412 | 0.00115 | 0.44643 |
| cvTE20U8p5_1_14 | 6,953 | 117 | 8,098 | 1806.60 | 9.0E-01 | 0.42328 | 0.00110 | 0.42549 |
| cvTE20U8p5_1_13 | 6,953 | 117 | 7,199 | 1605.80 | 8.0E-01 | 0.40452 | 0.00100 | 0.40652 |
| cvTE20U8p5_1_12 | 6,953 | 117 | 6,299 | 1405.10 | 7.0E-01 | 0.38253 | 0.00122 | 0.38496 |
| cvTE20U8p5_1_11 | 6,953 | 117 | 5,399 | 1204.40 | 6.0E-01 | 0.35988 | 0.00111 | 0.36209 |
| cvTE20U8p5_1_10 | 6,953 | 117 | 4,499 | 1003.60 | 5.0E-01 | 0.33974 | 0.00099 | 0.34173 |
| cvTE20U8p5_1_9 | 6,953 | 117 | 3,599 | 802.94 | 4.0E-01 | 0.31938 | 0.00090 | 0.32118 |
| cvTE20U8p5_1_8 | 6,953 | 117 | 2,700 | 602.20 | 3.0E-01 | 0.30560 | 0.00084 | 0.30729 |
| cvTE20U8p5_1_7 | 6,953 | 117 | 1,800 | 401.47 | 2.0E-01 | 0.29237 | 0.00085 | 0.29407 |
| cvTE20U8p5_1_6 | 6,953 | 117 | 900 | 200.73 | 1.0E-01 | 0.28287 | 0.00104 | 0.28495 |
| cvTE20U8p5_1_1 | 6,953 | 117 | 0 | 0.00 | 1.0E-20 | 0.28060 | 0.00080 | 0.28219 |
| **500 g $CH_2$ in cc, can spacers (np thickness = 1.4 in.), containment vessel, reflected** | | | | | | | | |
| cvTE20U45_02_15 | 10,400 | 921 | 8,385 | 237.62 | 1.0E+00 | 0.42157 | 0.00099 | 0.42354 |
| cvTE20U30_02_15 | 8,250 | 489 | 8,385 | 447.54 | 1.0E+00 | 0.37862 | 0.00092 | 0.38046 |
| cvTE20U20_02_15 | 7,545 | 297 | 8,385 | 736.86 | 1.0E+00 | 0.36052 | 0.00089 | 0.36229 |
| cvTE20U12_02_15 | 7,125 | 168 | 8,385 | 1302.60 | 1.0E+00 | 0.35193 | 0.00100 | 0.35392 |
| cvTE20U8p5_02_15 | 6,953 | 117 | 8,385 | 1870.40 | 1.0E+00 | 0.34847 | 0.00108 | 0.35064 |

**Table 6.9.6-20a. Results for $UZrH_x$ content at 19.7 wt % $^{235}U$ in packaging calculation model**

| case name | np (in.) | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr/ moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **content in flooded containment vessel, single package reflected** | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | **HAC** | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | |
| | | | | | | **mocfr** | | | | | | | |
| ncsrtriga_1_1_15 | 0.0 | 10,400 | 921 | 0 | 0.00 | 1.0E-20 | 0.19699 | 0.00072 | 0.19844 | hcsrtriga_1_1_15 | 0.19912 | 0.00071 | 0.20055 |
| ncsrtriga_1_6_15 | 0.0 | 10,400 | 921 | 900 | 25.50 | 1.0E-01 | 0.22100 | 0.00077 | 0.22253 | hcsrtriga_1_6_15 | 0.22405 | 0.00077 | 0.22559 |
| ncsrtriga_1_7_15 | 0.0 | 10,400 | 921 | 1,800 | 51.00 | 2.0E-02 | 0.25006 | 0.00081 | 0.25167 | hcsrtriga_1_7_15 | 0.25119 | 0.00075 | 0.25268 |
| ncsrtriga_1_8_15 | 0.0 | 10,400 | 921 | 2,700 | 76.50 | 3.0E-01 | 0.27901 | 0.00083 | 0.28067 | hcsrtriga_1_8_15 | 0.28071 | 0.00086 | 0.28243 |
| ncsrtriga_1_9_15 | 0.0 | 10,400 | 921 | 3,599 | 102.00 | 4.0E-01 | 0.31206 | 0.00097 | 0.31399 | hcsrtriga_1_9_15 | 0.31333 | 0.00093 | 0.31520 |
| ncsrtriga_1_10_15 | 0.0 | 10,400 | 921 | 4,499 | 127.50 | 5.0E-01 | 0.34408 | 0.00096 | 0.34601 | hcsrtriga_1_10_15 | 0.34576 | 0.00103 | 0.34781 |
| ncsrtriga_1_11_15 | 0.0 | 10,400 | 921 | 5,399 | 153.00 | 6.0E-01 | 0.37488 | 0.00093 | 0.37674 | hcsrtriga_1_11_15 | 0.37800 | 0.00111 | 0.38023 |
| ncsrtriga_1_12_15 | 0.0 | 10,400 | 921 | 6,299 | 178.50 | 7.0E-01 | 0.40792 | 0.00107 | 0.41006 | hcsrtriga_1_12_15 | 0.40683 | 0.00105 | 0.40893 |
| ncsrtriga_1_13_15 | 0.0 | 10,400 | 921 | 7,199 | 204.00 | 8.0E-01 | 0.43782 | 0.00116 | 0.44013 | hcsrtriga_1_13_15 | 0.43867 | 0.00123 | 0.44113 |
| ncsrtriga_1_14_15 | 0.0 | 10,400 | 921 | 8,098 | 229.51 | 9.0E-01 | 0.46460 | 0.00106 | 0.46672 | hcsrtriga_1_14_15 | 0.46627 | 0.00120 | 0.46867 |
| ncsrtriga_1_15_15 | 0.0 | 10,400 | 921 | 8,998 | 255.01 | 1.0E+00 | 0.49295 | 0.00104 | 0.49503 | hcsrtriga_1_15_15 | 0.49247 | 0.00103 | 0.49454 |
| | | | | | | **moifr** | | | | | | | |
| ncsrtriga_1_15_1 | 0.0 | 10,400 | 921 | 8,998 | 255.01 | 1.0E-20 | 0.44499 | 0.00100 | 0.44700 | hcsrtriga_1_15_1 | 0.44706 | 0.00104 | 0.44914 |
| ncsrtriga_1_15_2 | 0.0 | 10,400 | 921 | 8,998 | 255.01 | 1.0E-05 | 0.44282 | 0.00109 | 0.44500 | hcsrtriga_1_15_2 | 0.44626 | 0.00100 | 0.44825 |
| ncsrtriga_1_15_3 | 0.0 | 10,400 | 921 | 8,998 | 255.01 | 1.0E-04 | 0.44454 | 0.00120 | 0.44693 | hcsrtriga_1_15_3 | 0.44469 | 0.00125 | 0.44719 |
| ncsrtriga_1_15_4 | 0.0 | 10,400 | 921 | 8,998 | 255.01 | 1.0E-03 | 0.44553 | 0.00111 | 0.44774 | hcsrtriga_1_15_4 | 0.44692 | 0.00113 | 0.44918 |
| ncsrtriga_1_15_5 | 0.0 | 10,400 | 921 | 8,998 | 255.01 | 1.0E-02 | 0.44389 | 0.00121 | 0.44631 | hcsrtriga_1_15_5 | 0.44565 | 0.00104 | 0.44773 |
| ncsrtriga_1_15_6 | 0.0 | 10,400 | 921 | 8,998 | 255.01 | 1.0E-01 | 0.44801 | 0.00104 | 0.45008 | hcsrtriga_1_15_6 | 0.45115 | 0.00120 | 0.45356 |
| ncsrtriga_1_15_8 | 0.0 | 10,400 | 921 | 8,998 | 255.01 | 3.0E-01 | 0.45921 | 0.00143 | 0.46207 | hcsrtriga_1_15_8 | 0.46090 | 0.00112 | 0.46314 |
| ncsrtriga_1_15_15 | 0.0 | 10,400 | 921 | 8,998 | 255.01 | 1.0E+00 | 0.49295 | 0.00104 | 0.49503 | hcsrtriga_1_15_15 | 0.49247 | 0.00103 | 0.49454 |

**Table 6.9.6-20a. Results for $UZrH_x$ content at 19.7 wt % $^{235}U$ in packaging calculation model**

| case name | np (in.) | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr/ moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | | |
| | | | | | | **mocfr** | | | | | | | |
| ncsrtriga_2_1_15 | 1.4 | 10,400 | 921 | 0 | 0.00 | 1.0E-20 | 0.16519 | 0.00060 | 0.16640 | hcsrtriga_2_1_15 | 0.16449 | 0.00062 | 0.16573 |
| ncsrtriga_2_6_15 | 1.4 | 10,400 | 921 | 839 | 23.76 | 1.0E-01 | 0.18078 | 0.00063 | 0.18204 | hcsrtriga_2_6_15 | 0.18163 | 0.00061 | 0.18284 |
| ncsrtriga_2_7_15 | 1.4 | 10,400 | 921 | 1,677 | 47.52 | 2.0E-01 | 0.20001 | 0.00066 | 0.20133 | hcsrtriga_2_7_15 | 0.20112 | 0.00072 | 0.20256 |
| ncsrtriga_2_8_15 | 1.4 | 10,400 | 921 | 2,515 | 71.29 | 3.0E-01 | 0.22235 | 0.00085 | 0.22405 | hcsrtriga_2_8_15 | 0.22446 | 0.00079 | 0.22603 |
| ncsrtriga_2_9_15 | 1.4 | 10,400 | 921 | 3,354 | 95.05 | 4.0E-01 | 0.24785 | 0.00076 | 0.24936 | hcsrtriga_2_9_15 | 0.24932 | 0.00079 | 0.25090 |
| ncsrtriga_2_10_15 | 1.4 | 10,400 | 921 | 4,192 | 118.81 | 5.0E-01 | 0.27336 | 0.00091 | 0.27517 | hcsrtriga_2_10_15 | 0.27427 | 0.00084 | 0.27595 |
| ncsrtriga_2_11_15 | 1.4 | 10,400 | 921 | 5,031 | 142.57 | 6.0E-01 | 0.29864 | 0.00105 | 0.30075 | hcsrtriga_2_11_15 | 0.30007 | 0.00090 | 0.30188 |
| ncsrtriga_2_12_15 | 1.4 | 10,400 | 921 | 5,869 | 166.33 | 7.0E-01 | 0.32492 | 0.00094 | 0.32680 | hcsrtriga_2_12_15 | 0.32594 | 0.00113 | 0.32820 |
| ncsrtriga_2_13_15 | 1.4 | 10,400 | 921 | 6,708 | 190.09 | 8.0E-01 | 0.35137 | 0.00101 | 0.35339 | hcsrtriga_2_13_15 | 0.35174 | 0.00101 | 0.35375 |
| ncsrtriga_2_14_15 | 1.4 | 10,400 | 921 | 7,546 | 213.86 | 9.0E-01 | 0.37602 | 0.00105 | 0.37812 | hcsrtriga_2_14_15 | 0.37666 | 0.00093 | 0.37852 |
| ncsrtriga_2_15_15 | 1.4 | 10,400 | 921 | 8,385 | 237.62 | 1.0E+00 | 0.40040 | 0.00106 | 0.40252 | hcsrtriga_2_15_15 | 0.40020 | 0.00112 | 0.40244 |
| | | | | | | **moifr** | | | | | | | |
| ncsrtriga_2_15_1 | 1.4 | 10,400 | 921 | 8,385 | 237.62 | 1.0E-20 | 0.36082 | 0.00102 | 0.36286 | hcsrtriga_2_15_1 | 0.36370 | 0.00103 | 0.36576 |
| ncsrtriga_2_15_2 | 1.4 | 10,400 | 921 | 8,385 | 237.62 | 1.0E-05 | 0.36163 | 0.00105 | 0.36373 | hcsrtriga_2_15_2 | 0.36457 | 0.00097 | 0.36651 |
| ncsrtriga_2_15_3 | 1.4 | 10,400 | 921 | 8,385 | 237.62 | 1.0E-04 | 0.36349 | 0.00115 | 0.36579 | hcsrtriga_2_15_3 | 0.36369 | 0.00107 | 0.36584 |
| ncsrtriga_2_15_4 | 1.4 | 10,400 | 921 | 8,385 | 237.62 | 1.0E-03 | 0.36368 | 0.00093 | 0.36554 | hcsrtriga_2_15_4 | 0.36290 | 0.00107 | 0.36503 |
| ncsrtriga_2_15_5 | 1.4 | 10,400 | 921 | 8,385 | 237.62 | 1.0E-02 | 0.36298 | 0.00111 | 0.36520 | hcsrtriga_2_15_5 | 0.36275 | 0.00112 | 0.36498 |
| ncsrtriga_2_15_6 | 1.4 | 10,400 | 921 | 8,385 | 237.62 | 1.0E-01 | 0.36587 | 0.00090 | 0.36766 | hcsrtriga_2_15_6 | 0.37015 | 0.00095 | 0.37205 |
| ncsrtriga_2_15_8 | 1.4 | 10,400 | 921 | 8,385 | 237.62 | 3.0E-01 | 0.37454 | 0.00104 | 0.37662 | hcsrtriga_2_15_8 | 0.37482 | 0.00099 | 0.37680 |
| ncsrtriga_2_15_15 | 1.4 | 10,400 | 921 | 8,385 | 237.62 | 1.0E+00 | 0.40040 | 0.00106 | 0.40252 | hcsrtriga_2_15_15 | 0.40020 | 0.00112 | 0.40244 |

**Table 6.9.6-20a. Results for $UZrH_x$ content at 19.7 wt % $^{235}U$ in packaging calculation model**

| case name | np (in.) | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr/ moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **content in flooded containment vessel, array packaging model for CSI=0.0** | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | **HAC** | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | |
| | | | | | | **moifr** | | | | | | | |
| nciatriga_1_1_3 | 0.0 | 10,400 | 921 | 0 | 0.00 | 1.0E-04 | 0.21653 | 0.00055 | 0.21763 | hciatriga_1_1_3 | 0.21640 | 0.00062 | 0.21763 |
| nciatriga_1_6_3 | 0.0 | 10,400 | 921 | 900 | 25.50 | 1.0E-04 | 0.24325 | 0.00064 | 0.24453 | hciatriga_1_6_3 | 0.24355 | 0.00069 | 0.24493 |
| nciatriga_1_7_3 | 0.0 | 10,400 | 921 | 1,800 | 51.00 | 1.0E-04 | 0.27402 | 0.00079 | 0.27561 | hciatriga_1_7_3 | 0.27398 | 0.00073 | 0.27544 |
| nciatriga_1_8_3 | 0.0 | 10,400 | 921 | 2,700 | 76.50 | 1.0E-04 | 0.30790 | 0.00105 | 0.30999 | hciatriga_1_8_3 | 0.30795 | 0.00081 | 0.30958 |
| nciatriga_1_9_3 | 0.0 | 10,400 | 921 | 3,599 | 102.00 | 1.0E-04 | 0.34171 | 0.00109 | 0.34390 | hciatriga_1_9_3 | 0.34285 | 0.00108 | 0.34500 |
| nciatriga_1_10_3 | 0.0 | 10,400 | 921 | 4,499 | 127.50 | 1.0E-04 | 0.37614 | 0.00108 | 0.37830 | hciatriga_1_10_3 | 0.37487 | 0.00101 | 0.37689 |
| nciatriga_1_11_3 | 0.0 | 10,400 | 921 | 5,399 | 153.00 | 1.0E-04 | 0.40944 | 0.00101 | 0.41146 | hciatriga_1_11_3 | 0.40922 | 0.00099 | 0.41120 |
| nciatriga_1_12_3 | 0.0 | 10,400 | 921 | 6,299 | 178.50 | 1.0E-04 | 0.44034 | 0.00116 | 0.44267 | hciatriga_1_12_3 | 0.44217 | 0.00104 | 0.44426 |
| nciatriga_1_13_3 | 0.0 | 10,400 | 921 | 7,199 | 204.00 | 1.0E-04 | 0.46949 | 0.00102 | 0.47153 | hciatriga_1_13_3 | 0.46841 | 0.00104 | 0.47049 |
| nciatriga_1_14_3 | 0.0 | 10,400 | 921 | 8,098 | 229.51 | 1.0E-04 | 0.49678 | 0.00102 | 0.49881 | hciatriga_1_14_3 | 0.49952 | 0.00113 | 0.50179 |
| nciatriga_1_15_3 | 0.0 | 10,400 | 921 | 8,998 | 255.01 | 1.0E-04 | 0.52325 | 0.00109 | 0.52543 | hciatriga_1_15_3 | 0.52373 | 0.00117 | 0.52606 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | | |
| nciatriga_2_1_3 | 1.4 | 10,400 | 921 | 0 | 0.00 | 1.0E-04 | 0.19663 | 0.00056 | 0.19775 | hciatriga_2_1_3 | 0.19533 | 0.00058 | 0.19648 |
| nciatriga_2_6_3 | 1.4 | 10,400 | 921 | 839 | 23.76 | 1.0E-04 | 0.21458 | 0.00063 | 0.21583 | hciatriga_2_6_3 | 0.21404 | 0.00062 | 0.21528 |
| nciatriga_2_7_3 | 1.4 | 10,400 | 921 | 1,677 | 47.52 | 1.0E-04 | 0.23878 | 0.00069 | 0.24017 | hciatriga_2_7_3 | 0.23939 | 0.00065 | 0.24068 |
| nciatriga_2_8_3 | 1.4 | 10,400 | 921 | 2,515 | 71.29 | 1.0E-04 | 0.26268 | 0.00095 | 0.26458 | hciatriga_2_8_3 | 0.26265 | 0.00073 | 0.26410 |
| nciatriga_2_9_3 | 1.4 | 10,400 | 921 | 3,354 | 95.05 | 1.0E-04 | 0.28930 | 0.00075 | 0.29081 | hciatriga_2_9_3 | 0.29016 | 0.00077 | 0.29169 |
| nciatriga_2_10_3 | 1.4 | 10,400 | 921 | 4,192 | 118.81 | 1.0E-04 | 0.31695 | 0.00092 | 0.31879 | hciatriga_2_10_3 | 0.31775 | 0.00088 | 0.31951 |
| nciatriga_2_11_3 | 1.4 | 10,400 | 921 | 5,031 | 142.57 | 1.0E-04 | 0.34183 | 0.00090 | 0.34364 | hciatriga_2_11_3 | 0.34164 | 0.00096 | 0.34355 |
| nciatriga_2_12_3 | 1.4 | 10,400 | 921 | 5,869 | 166.33 | 1.0E-04 | 0.36766 | 0.00092 | 0.36949 | hciatriga_2_12_3 | 0.36733 | 0.00102 | 0.36937 |
| nciatriga_2_13_3 | 1.4 | 10,400 | 921 | 6,708 | 190.09 | 1.0E-04 | 0.39176 | 0.00122 | 0.39420 | hciatriga_2_13_3 | 0.39342 | 0.00103 | 0.39547 |

**Table 6.9.6-20a. Results for $UZrH_x$ content at 19.7 wt % $^{235}U$ in packaging calculation model**

| case name | np (in.) | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr/ moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| nciatriga_2_14_3 | 1.4 | 10,400 | 921 | 7,546 | 213.86 | 1.0E-04 | 0.41783 | 0.00101 | 0.41986 | hciatriga_2_14_3 | 0.41760 | 0.00108 | 0.41976 |
| nciatriga_2_15_3 | 1.4 | 10,400 | 921 | 8,385 | 237.62 | 1.0E-04 | 0.43993 | 0.00109 | 0.44211 | hciatriga_2_15_3 | 0.44034 | 0.00119 | 0.44271 |

**Table 6.9.6-20b. Results for $UZrH_x$ content at 70.1 wt % $^{235}U$ in packaging calculation model**

| case name | np (in.) | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr/ moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **content in flooded containment vessel, single package reflected** | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | **HAC** | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | |
| | | | | | | **moifr** | | | | | | | |
| ncsrtriga70_1_1_15 | 0.0 | 6,847 | 408 | 0 | 0.00 | 1.0E+00 | 0.15814 | 0.00073 | 0.15960 | hcsrtriga70_1_1_15 | 0.15823 | 0.00062 | 0.15947 |
| ncsrtriga70_1_6_15 | 0.0 | 6,847 | 408 | 900 | 57.56 | 1.0E+00 | 0.18268 | 0.00068 | 0.18403 | hcsrtriga70_1_6_15 | 0.18526 | 0.00075 | 0.18676 |
| ncsrtriga70_1_7_15 | 0.0 | 6,847 | 408 | 1,800 | 115.13 | 1.0E+00 | 0.21248 | 0.00074 | 0.21396 | hcsrtriga70_1_7_15 | 0.21376 | 0.00082 | 0.21540 |
| ncsrtriga70_1_8_15 | 0.0 | 6,847 | 408 | 2,700 | 172.69 | 1.0E+00 | 0.24596 | 0.00086 | 0.24769 | hcsrtriga70_1_8_15 | 0.24666 | 0.00081 | 0.24829 |
| ncsrtriga70_1_9_15 | 0.0 | 6,847 | 408 | 3,599 | 230.26 | 1.0E+00 | 0.27756 | 0.00103 | 0.27963 | hcsrtriga70_1_9_15 | 0.27837 | 0.00085 | 0.28007 |
| ncsrtriga70_1_10_15 | 0.0 | 6,847 | 408 | 4,499 | 287.82 | 1.0E+00 | 0.30903 | 0.00102 | 0.31107 | hcsrtriga70_1_10_15 | 0.31172 | 0.00101 | 0.31374 |
| ncsrtriga70_1_11_15 | 0.0 | 6,847 | 408 | 5,399 | 345.38 | 1.0E+00 | 0.34331 | 0.00121 | 0.34573 | hcsrtriga70_1_11_15 | 0.34406 | 0.00110 | 0.34626 |
| ncsrtriga70_1_12_15 | 0.0 | 6,847 | 408 | 6,299 | 402.95 | 1.0E+00 | 0.37320 | 0.00129 | 0.37578 | hcsrtriga70_1_12_15 | 0.37419 | 0.00109 | 0.37637 |
| ncsrtriga70_1_13_15 | 0.0 | 6,847 | 408 | 7,199 | 460.51 | 1.0E+00 | 0.40369 | 0.00106 | 0.40581 | hcsrtriga70_1_13_15 | 0.40592 | 0.00110 | 0.40811 |
| ncsrtriga70_1_14_15 | 0.0 | 6,847 | 408 | 8,098 | 518.07 | 1.0E+00 | 0.43096 | 0.00129 | 0.43353 | hcsrtriga70_1_14_15 | 0.42993 | 0.00109 | 0.43212 |
| ncsrtriga70_1_15_15 | 0.0 | 6,847 | 408 | 8,998 | 575.64 | 1.0E+00 | 0.45846 | 0.00117 | 0.46080 | hcsrtriga70_1_15_15 | 0.45656 | 0.00108 | 0.45872 |

**Table 6.9.6-20b. Results for $UZrH_x$ content at 70.1 wt % $^{235}U$ in packaging calculation model**

| case name | np (in.) | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr/ moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **moifr** | | | | | | | |
| ncsrtriga70_1_15_1 | 0.0 | 6,847 | 408 | 8,998 | 575.64 | 1.0E-20 | 0.40894 | 0.00119 | 0.41131 | hcsrtriga70_1_15_1_ | 0.41076 | 0.00122 | 0.41320 |
| ncsrtriga70_1_15_2 | 0.0 | 6,847 | 408 | 8,998 | 575.64 | 1.0E-05 | 0.40806 | 0.00115 | 0.41036 | hcsrtriga70_1_15_2 | 0.41073 | 0.00130 | 0.41332 |
| ncsrtriga70_1_15_3 | 0.0 | 6,847 | 408 | 8,998 | 575.64 | 1.0E-04 | 0.40992 | 0.00118 | 0.41228 | hcsrtriga70_1_15_3 | 0.41080 | 0.00120 | 0.41319 |
| ncsrtriga70_1_15_4 | 0.0 | 6,847 | 408 | 8,998 | 575.64 | 1.0E-03 | 0.41084 | 0.00110 | 0.41304 | hcsrtriga70_1_15_4 | 0.41181 | 0.00115 | 0.41412 |
| ncsrtriga70_1_15_5 | 0.0 | 6,847 | 408 | 8,998 | 575.64 | 1.0E-02 | 0.41069 | 0.00116 | 0.41300 | hcsrtriga70_1_15_5 | 0.41159 | 0.00124 | 0.41407 |
| ncsrtriga70_1_15_6 | 0.0 | 6,847 | 408 | 8,998 | 575.64 | 1.0E-01 | 0.41431 | 0.00107 | 0.41644 | hcsrtriga70_1_15_6 | 0.41621 | 0.00123 | 0.41868 |
| ncsrtriga70_1_15_8 | 0.0 | 6,847 | 408 | 8,998 | 575.64 | 3.0E-01 | 0.42523 | 0.00129 | 0.42780 | hcsrtriga70_1_15_8 | 0.42893 | 0.00120 | 0.43133 |
| ncsrtriga70_1_15_15 | 0.0 | 6,847 | 408 | 8,998 | 575.64 | 1.0E+00 | 0.45846 | 0.00117 | 0.46080 | hcsrtriga70_1_15_15 | 0.45656 | 0.00108 | 0.45872 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | | |
| | | | | | | **moifr** | | | | | | | |
| ncsrtriga70_2_1_15 | 1.4 | 6,847 | 408 | 0 | 0.00 | 1.0E+00 | 0.12174 | 0.00059 | 0.12291 | hcsrtriga70_2_1_15 | 0.12413 | 0.00057 | 0.12528 |
| ncsrtriga70_2_6_15 | 1.4 | 6,847 | 408 | 839 | 53.64 | 1.0E+00 | 0.14017 | 0.00063 | 0.14143 | hcsrtriga70_2_6_15 | 0.14097 | 0.00061 | 0.14220 |
| ncsrtriga70_2_7_15 | 1.4 | 6,847 | 408 | 1,677 | 107.28 | 1.0E+00 | 0.16109 | 0.00066 | 0.16241 | hcsrtriga70_2_7_15 | 0.16260 | 0.00068 | 0.16396 |
| ncsrtriga70_2_8_15 | 1.4 | 6,847 | 408 | 2,515 | 160.92 | 1.0E+00 | 0.18174 | 0.00080 | 0.18335 | hcsrtriga70_2_8_15 | 0.18552 | 0.00067 | 0.18686 |
| ncsrtriga70_2_9_15 | 1.4 | 6,847 | 408 | 3,354 | 214.55 | 1.0E+00 | 0.20707 | 0.00076 | 0.20859 | hcsrtriga70_2_9_15 | 0.20911 | 0.00077 | 0.21064 |
| ncsrtriga70_2_10_15 | 1.4 | 6,847 | 408 | 4,192 | 268.19 | 1.0E+00 | 0.23324 | 0.00089 | 0.23503 | hcsrtriga70_2_10_15 | 0.23447 | 0.00074 | 0.23595 |
| ncsrtriga70_2_11_15 | 1.4 | 6,847 | 408 | 5,031 | 321.83 | 1.0E+00 | 0.26093 | 0.00080 | 0.26254 | hcsrtriga70_2_11_15 | 0.26039 | 0.00085 | 0.26209 |
| ncsrtriga70_2_12_15 | 1.4 | 6,847 | 408 | 5,869 | 375.47 | 1.0E+00 | 0.28710 | 0.00084 | 0.28878 | hcsrtriga70_2_12_15 | 0.28784 | 0.00093 | 0.28970 |
| ncsrtriga70_2_13_15 | 1.4 | 6,847 | 408 | 6,708 | 429.11 | 1.0E+00 | 0.30929 | 0.00098 | 0.31124 | hcsrtriga70_2_13_15 | 0.31105 | 0.00093 | 0.31291 |
| ncsrtriga70_2_14_15 | 1.4 | 6,847 | 408 | 7,546 | 482.75 | 1.0E+00 | 0.33473 | 0.00114 | 0.33702 | hcsrtriga70_2_14_15 | 0.33634 | 0.00094 | 0.33822 |
| ncsrtriga70_2_15_15 | 1.4 | 6,847 | 408 | 8,385 | 536.39 | 1.0E+00 | 0.35776 | 0.00116 | 0.36008 | hcsrtriga70_2_15_15 | 0.35922 | 0.00110 | 0.36142 |
| | | | | | | **moifr** | | | | | | | |
| ncsrtriga70_2_15_1 | 1.4 | 6,847 | 408 | 8,385 | 536.39 | 1.0E-20 | 0.32321 | 0.00094 | 0.32508 | hcsrtriga70_2_15_1 | 0.32561 | 0.00106 | 0.32774 |
| ncsrtriga70_2_15_2 | 1.4 | 6,847 | 408 | 8,385 | 536.39 | 1.0E-05 | 0.32283 | 0.00092 | 0.32467 | hcsrtriga70_2_15_2 | 0.32441 | 0.00099 | 0.32639 |

**Table 6.9.6-20b. Results for $UZrH_x$ content at 70.1 wt % $^{235}U$ in packaging calculation model**

| case name | np (in.) | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr/ moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ncsrtriga70_2_15_3 | 1.4 | 6,847 | 408 | 8,385 | 536.39 | 1.0E-04 | 0.32432 | 0.00088 | 0.32608 | hcsrtriga70_2_15_3 | 0.32423 | 0.00102 | 0.32628 |
| ncsrtriga70_2_15_4 | 1.4 | 6,847 | 408 | 8,385 | 536.39 | 1.0E-03 | 0.32279 | 0.00104 | 0.32488 | hcsrtriga70_2_15_4 | 0.32600 | 0.00111 | 0.32822 |
| ncsrtriga70_2_15_5 | 1.4 | 6,847 | 408 | 8,385 | 536.39 | 1.0E-02 | 0.32448 | 0.00105 | 0.32658 | hcsrtriga70_2_15_5 | 0.32622 | 0.00093 | 0.32808 |
| ncsrtriga70_2_15_6 | 1.4 | 6,847 | 408 | 8,385 | 536.39 | 1.0E-01 | 0.32871 | 0.00097 | 0.33065 | hcsrtriga70_2_15_6 | 0.32929 | 0.00110 | 0.33150 |
| ncsrtriga70_2_15_8 | 1.4 | 6,847 | 408 | 8,385 | 536.39 | 3.0E-01 | 0.33627 | 0.00091 | 0.33809 | hcsrtriga70_2_15_8 | 0.33709 | 0.00106 | 0.33920 |
| ncsrtriga70_2_15_15 | 1.4 | 6,847 | 408 | 8,385 | 536.39 | 1.0E+00 | 0.35776 | 0.00116 | 0.36008 | hcsrtriga70_2_15_15 | 0.35922 | 0.00110 | 0.36142 |
| **content in flooded containment vessel, array packaging model for CSI=0.0** | | | | | | | | | | | | | |
| **NCT** | | | | | | | | | | **HAC** | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | | |
| | | | | | | **moifr** | | | | | | | |
| nciatriga70_1_1_3 | 0.0 | 6,847 | 408 | 0 | 0.00 | 1.0E-04 | 0.16525 | 0.00063 | 0.16651 | hciatriga70_1_1_3 | 0.16514 | 0.00067 | 0.16648 |
| nciatriga70_1_6_3 | 0.0 | 6,847 | 408 | 900 | 57.56 | 1.0E-04 | 0.19360 | 0.00070 | 0.19500 | hciatriga70_1_6_3 | 0.19280 | 0.00066 | 0.19411 |
| nciatriga70_1_7_3 | 0.0 | 6,847 | 408 | 1,800 | 115.13 | 1.0E-04 | 0.22946 | 0.00076 | 0.23099 | hciatriga70_1_7_3 | 0.23027 | 0.00076 | 0.23179 |
| nciatriga70_1_8_3 | 0.0 | 6,847 | 408 | 2,700 | 172.69 | 1.0E-04 | 0.26461 | 0.00087 | 0.26635 | hciatriga70_1_8_3 | 0.26463 | 0.00074 | 0.26612 |
| nciatriga70_1_9_3 | 0.0 | 6,847 | 408 | 3,599 | 230.26 | 1.0E-04 | 0.30186 | 0.00095 | 0.30375 | hciatriga70_1_9_3 | 0.30020 | 0.00084 | 0.30187 |
| nciatriga70_1_10_3 | 0.0 | 6,847 | 408 | 4,499 | 287.82 | 1.0E-04 | 0.33608 | 0.00095 | 0.33798 | hciatriga70_1_10_3 | 0.33776 | 0.00089 | 0.33954 |
| nciatriga70_1_11_3 | 0.0 | 6,847 | 408 | 5,399 | 345.38 | 1.0E-04 | 0.37069 | 0.00105 | 0.37279 | hciatriga70_1_11_3 | 0.37191 | 0.00104 | 0.37400 |
| nciatriga70_1_12_3 | 0.0 | 6,847 | 408 | 6,299 | 402.95 | 1.0E-04 | 0.40431 | 0.00110 | 0.40651 | hciatriga70_1_12_3 | 0.40368 | 0.00099 | 0.40567 |
| nciatriga70_1_13_3 | 0.0 | 6,847 | 408 | 7,199 | 460.51 | 1.0E-04 | 0.43185 | 0.00143 | 0.43472 | hciatriga70_1_13_3 | 0.43386 | 0.00141 | 0.43668 |
| nciatriga70_1_14_3 | 0.0 | 6,847 | 408 | 8,098 | 518.07 | 1.0E-04 | 0.46029 | 0.00122 | 0.46272 | hciatriga70_1_14_3 | 0.46036 | 0.00120 | 0.46277 |
| nciatriga70_1_15_3 | 0.0 | 6,847 | 408 | 8,998 | 575.64 | 1.0E-04 | 0.48628 | 0.00123 | 0.48875 | hciatriga70_1_15_3 | 0.48653 | 0.00107 | 0.48868 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | | |
| nciatriga70_2_1_3 | 1.4 | 6,847 | 408 | 0 | 0.00 | 1.0E-04 | 0.14342 | 0.00054 | 0.14450 | hciatriga70_2_1_3 | 0.14299 | 0.00055 | 0.14410 |
| nciatriga70_2_6_3 | 1.4 | 6,847 | 408 | 839 | 53.64 | 1.0E-04 | 0.16333 | 0.00057 | 0.16446 | hciatriga70_2_6_3 | 0.16444 | 0.00071 | 0.16586 |
| nciatriga70_2_7_3 | 1.4 | 6,847 | 408 | 1,677 | 107.28 | 1.0E-04 | 0.18886 | 0.00069 | 0.19024 | hciatriga70_2_7_3 | 0.18870 | 0.00075 | 0.19020 |

**Table 6.9.6-20b. Results for $UZrH_x$ content at 70.1 wt % $^{235}U$ in packaging calculation model**

| case name | np (in.) | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr/ moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| nciatriga70_2_8_3 | 1.4 | 6,847 | 408 | 2,515 | 160.92 | 1.0E-04 | 0.21548 | 0.00077 | 0.21703 | hciatriga70_2_8_3 | 0.21709 | 0.00079 | 0.21867 |
| nciatriga70_2_9_3 | 1.4 | 6,847 | 408 | 3,354 | 214.55 | 1.0E-04 | 0.24403 | 0.00092 | 0.24587 | hciatriga70_2_9_3 | 0.24443 | 0.00082 | 0.24606 |
| nciatriga70_2_10_3 | 1.4 | 6,847 | 408 | 4,192 | 268.19 | 1.0E-04 | 0.27230 | 0.00090 | 0.27410 | hciatriga70_2_10_3 | 0.27167 | 0.00077 | 0.27321 |
| nciatriga70_2_11_3 | 1.4 | 6,847 | 408 | 5,031 | 321.83 | 1.0E-04 | 0.29818 | 0.00092 | 0.30003 | hciatriga70_2_11_3 | 0.29902 | 0.00096 | 0.30093 |
| nciatriga70_2_12_3 | 1.4 | 6,847 | 408 | 5,869 | 375.47 | 1.0E-04 | 0.32583 | 0.00081 | 0.32745 | hciatriga70_2_12_3 | 0.32607 | 0.00087 | 0.32781 |
| nciatriga70_2_13_3 | 1.4 | 6,847 | 408 | 6,708 | 429.11 | 1.0E-04 | 0.35008 | 0.00102 | 0.35212 | hciatriga70_2_13_3 | 0.34964 | 0.00088 | 0.35140 |
| nciatriga70_2_14_3 | 1.4 | 6,847 | 408 | 7,546 | 482.75 | 1.0E-04 | 0.37201 | 0.00116 | 0.37434 | hciatriga70_2_14_3 | 0.37167 | 0.00099 | 0.37364 |
| nciatriga70_2_15_3 | 1.4 | 6,847 | 408 | 8,385 | 536.39 | 1.0E-04 | 0.39529 | 0.00120 | 0.39769 | hciatriga70_2_15_3 | 0.39403 | 0.00109 | 0.39622 |

**Table 6.9.6-20c. Results for 1.31 in. smaller diameter $UZrH_x$ content at 70.1 wt % $^{235}U$ in packaging calculation model**

| case name | np (in.) | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr/ moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| **1.31 in. diameter content in flooded containment vessel, single package reflected** | | | | | | | | | |
| **NCT** | | | | | | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | |
| | | | | | | **mocfr** | | | |
| ncsrT70_131_1_1_15 | 0.0 | 5,667 | 338 | 0 | 0.00 | 1.0E+00 | 0.12864 | 0.00055 | 0.12974 |
| ncsrT70_131_1_6_15 | 0.0 | 5,667 | 338 | 920 | 71.15 | 1.0E+00 | 0.15144 | 0.00066 | 0.15276 |
| ncsrT70_131_1_7_15 | 0.0 | 5,667 | 338 | 1,841 | 142.31 | 1.0E+00 | 0.18245 | 0.00065 | 0.18375 |
| ncsrT70_131_1_8_15 | 0.0 | 5,667 | 338 | 2,762 | 213.46 | 1.0E+00 | 0.21360 | 0.00085 | 0.21530 |
| ncsrT70_131_1_9_15 | 0.0 | 5,667 | 338 | 3,682 | 284.61 | 1.0E+00 | 0.24688 | 0.00096 | 0.24880 |
| ncsrT70_131_1_10_15 | 0.0 | 5,667 | 338 | 4,602 | 355.77 | 1.0E+00 | 0.28138 | 0.00101 | 0.28340 |
| ncsrT70_131_1_11_15 | 0.0 | 5,667 | 338 | 5,523 | 426.92 | 1.0E+00 | 0.31377 | 0.00098 | 0.31574 |

**Table 6.9.6-20c. Results for 1.31 in. smaller diameter $UZrH_x$ content at 70.1 wt % $^{235}U$ in packaging calculation model**

| case name | np (in.) | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr/ moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| ncsrT70_131_1_12_15 | 0.0 | 5,667 | 338 | 6,443 | 498.07 | 1.0E+00 | 0.34582 | 0.00107 | 0.34797 |
| ncsrT70_131_1_13_15 | 0.0 | 5,667 | 338 | 7,364 | 569.23 | 1.0E+00 | 0.37661 | 0.00103 | 0.37867 |
| ncsrT70_131_1_14_15 | 0.0 | 5,667 | 338 | 8,284 | 640.38 | 1.0E+00 | 0.40376 | 0.00110 | 0.40597 |
| ncsrT70_131_1_15_15 | 0.0 | 5,667 | 338 | 9,205 | 711.53 | 1.0E+00 | 0.43000 | 0.00103 | 0.43206 |
| | | | | | | **moifr** | | | |
| ncsrT70_131_1_15_1 | 0.0 | 5,667 | 338 | 9,205 | 711.53 | 1.0E-20 | 0.38521 | 0.00136 | 0.38793 |
| ncsrT70_131_1_15_2 | 0.0 | 5,667 | 338 | 9,205 | 711.53 | 1.0E-05 | 0.38339 | 0.00098 | 0.38536 |
| ncsrT70_131_1_15_3 | 0.0 | 5,667 | 338 | 9,205 | 711.53 | 1.0E-04 | 0.38633 | 0.00100 | 0.38834 |
| ncsrT70_131_1_15_4 | 0.0 | 5,667 | 338 | 9,205 | 711.53 | 1.0E-03 | 0.38417 | 0.00096 | 0.38610 |
| ncsrT70_131_1_15_5 | 0.0 | 5,667 | 338 | 9,205 | 711.53 | 1.0E-02 | 0.38613 | 0.00108 | 0.38829 |
| ncsrT70_131_1_15_6 | 0.0 | 5,667 | 338 | 9,205 | 711.53 | 1.0E-01 | 0.39026 | 0.00098 | 0.39222 |
| ncsrT70_131_1_15_8 | 0.0 | 5,667 | 338 | 9,205 | 711.53 | 3.0E-01 | 0.40187 | 0.00122 | 0.40430 |
| ncsrT70_131_1_15_15 | 0.0 | 5,667 | 338 | 9,205 | 711.53 | 1.0E+00 | 0.43000 | 0.00103 | 0.43206 |
| **1.31 in. diameter content content in flooded containment vessel, array packaging model for CSI=0.0** | | | | | | | | | |
| **NCT** | | | | | | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | |
| | | | | | | **moifr** | | | |
| nciaT70_131_1_1_3 | 0.0 | 5,667 | 338 | 0 | 0.00 | 1.0E-04 | 0.12954 | 0.00047 | 0.13048 |
| nciaT70_131_1_6_3 | 0.0 | 5,667 | 338 | 920 | 71.15 | 1.0E-04 | 0.15804 | 0.00057 | 0.15918 |
| nciaT70_131_1_7_3 | 0.0 | 5,667 | 338 | 1,841 | 142.31 | 1.0E-04 | 0.19290 | 0.00064 | 0.19417 |
| nciaT70_131_1_8_3 | 0.0 | 5,667 | 338 | 2,762 | 213.46 | 1.0E-04 | 0.22844 | 0.00085 | 0.23015 |
| nciaT70_131_1_9_3 | 0.0 | 5,667 | 338 | 3,682 | 284.61 | 1.0E-04 | 0.26752 | 0.00081 | 0.26914 |
| nciaT70_131_1_10_3 | 0.0 | 5,667 | 338 | 4,602 | 355.77 | 1.0E-04 | 0.30500 | 0.00096 | 0.30692 |
| nciaT70_131_1_11_3 | 0.0 | 5,667 | 338 | 5,523 | 426.92 | 1.0E-04 | 0.33850 | 0.00107 | 0.34064 |
| nciaT70_131_1_12_3 | 0.0 | 5,667 | 338 | 6,443 | 498.07 | 1.0E-04 | 0.37139 | 0.00102 | 0.37342 |

**Table 6.9.6-20c. Results for 1.31 in. smaller diameter $UZrH_x$ content at 70.1 wt % $^{235}U$ in packaging calculation model**

| case name | np (in.) | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr/ moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| nciaT70_131_1_13_3 | 0.0 | 5,667 | 338 | 7,364 | 569.23 | 1.0E-04 | 0.40245 | 0.00098 | 0.40441 |
| nciaT70_131_1_14_3 | 0.0 | 5,667 | 338 | 8,284 | 640.38 | 1.0E-04 | 0.43010 | 0.00115 | 0.43241 |
| nciaT70_131_1_15_3 | 0.0 | 5,667 | 338 | 9,205 | 711.53 | 1.0E-04 | 0.45804 | 0.00122 | 0.46047 |

**Table 6.9.6-20d. Results for $UZrH_x$ content at 19.7 wt % $^{235}U$ in packaging calculation model**

| case name | np (in.) | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr/ moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| **homogenized content in flooded containment vessel, single package reflected [10 CFR 71.55(d)(2)]** | | | | | | | | | |
| **NCT** | | | | | | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | |
| | | | | | | **mocfr** | | | |
| ncsrt55d2_1_1_15 | 0.0 | 10,400 | 921 | 0 | 0.00 | 1.0E+00 | 0.11370 | 0.00054 | 0.11477 |
| ncsrt55d2_1_6_15 | 0.0 | 10,400 | 921 | 900 | 25.50 | 1.0E+00 | 0.15074 | 0.00061 | 0.15196 |
| ncsrt55d2_1_7_15 | 0.0 | 10,400 | 921 | 1,800 | 51.00 | 1.0E+00 | 0.19298 | 0.00070 | 0.19439 |
| ncsrt55d2_1_8_15 | 0.0 | 10,400 | 921 | 2,700 | 76.50 | 1.0E+00 | 0.24182 | 0.00082 | 0.24346 |
| ncsrt55d2_1_9_15 | 0.0 | 10,400 | 921 | 3,599 | 102.00 | 1.0E+00 | 0.29424 | 0.00084 | 0.29591 |
| ncsrt55d2_1_10_15 | 0.0 | 10,400 | 921 | 4,499 | 127.50 | 1.0E+00 | 0.34858 | 0.00100 | 0.35059 |
| ncsrt55d2_1_11_15 | 0.0 | 10,400 | 921 | 5,399 | 153.00 | 1.0E+00 | 0.40341 | 0.00119 | 0.40579 |
| ncsrt55d2_1_12_15 | 0.0 | 10,400 | 921 | 6,299 | 178.50 | 1.0E+00 | 0.45802 | 0.00109 | 0.46020 |
| ncsrt55d2_1_13_15 | 0.0 | 10,400 | 921 | 7,199 | 204.00 | 1.0E+00 | 0.51163 | 0.00121 | 0.51404 |
| ncsrt55d2_1_14_15 | 0.0 | 10,400 | 921 | 8,098 | 229.51 | 1.0E+00 | 0.56264 | 0.00129 | 0.56521 |
| ncsrt55d2_1_15_15 | 0.0 | 10,400 | 921 | 8,998 | 255.01 | 1.0E+00 | 0.60824 | 0.00136 | 0.61095 |
| | | | | | | **moifr** | | | |
| ncsrt55d2_1_15_15 | 0.0 | 10,400 | 921 | 8,998 | 255.01 | 1.0E+00 | 0.60824 | 0.00136 | 0.61095 |
| ncsrt55d2_1_15_8 | 0.0 | 10,400 | 921 | 8,998 | 255.01 | 3.0E-01 | 0.55284 | 0.00122 | 0.55528 |

**Table 6.9.6-20d. Results for $UZrH_x$ content at 19.7 wt % $^{235}U$ in packaging calculation model**

| case name | np (in.) | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr/ moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| ncsrt55d2_1_15_6 | 0.0 | 10,400 | 921 | 8,998 | 255.01 | 1.0E-01 | 0.53397 | 0.00114 | 0.53626 |
| ncsrt55d2_1_15_5 | 0.0 | 10,400 | 921 | 8,998 | 255.01 | 1.0E-02 | 0.52373 | 0.00115 | 0.52604 |
| ncsrt55d2_1_15_4 | 0.0 | 10,400 | 921 | 8,998 | 255.01 | 1.0E-03 | 0.52361 | 0.00124 | 0.52609 |
| ncsrt55d2_1_15_3 | 0.0 | 10,400 | 921 | 8,998 | 255.01 | 1.0E-04 | 0.52050 | 0.00116 | 0.52283 |
| ncsrt55d2_1_15_2 | 0.0 | 10,400 | 921 | 8,998 | 255.01 | 1.0E-05 | 0.52366 | 0.00123 | 0.52611 |
| ncsrt55d2_1_15_1 | 0.0 | 10,400 | 921 | 8,998 | 255.01 | 1.0E-20 | 0.52390 | 0.00120 | 0.52631 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | |
| | | | | | | **mocfr** | | | |
| ncsrt55d2_2_1_15 | 1.4 | 10,400 | 921 | 0 | 0.00 | 1.0E+00 | 0.10877 | 0.00048 | 0.10972 |
| ncsrt55d2_2_6_15 | 1.4 | 10,400 | 921 | 839 | 23.76 | 1.0E+00 | 0.14519 | 0.00062 | 0.14643 |
| ncsrt55d2_2_7_15 | 1.4 | 10,400 | 921 | 1,677 | 47.52 | 1.0E+00 | 0.18564 | 0.00082 | 0.18729 |
| ncsrt55d2_2_8_15 | 1.4 | 10,400 | 921 | 2,515 | 71.29 | 1.0E+00 | 0.23269 | 0.00095 | 0.23459 |
| ncsrt55d2_2_9_15 | 1.4 | 10,400 | 921 | 3,354 | 95.05 | 1.0E+00 | 0.28305 | 0.00082 | 0.28469 |
| ncsrt55d2_2_10_15 | 1.4 | 10,400 | 921 | 4,192 | 118.81 | 1.0E+00 | 0.33734 | 0.00105 | 0.33944 |
| ncsrt55d2_2_11_15 | 1.4 | 10,400 | 921 | 5,031 | 142.57 | 1.0E+00 | 0.39111 | 0.00128 | 0.39367 |
| ncsrt55d2_2_12_15 | 1.4 | 10,400 | 921 | 5,869 | 166.33 | 1.0E+00 | 0.44324 | 0.00114 | 0.44553 |
| ncsrt55d2_2_13_15 | 1.4 | 10,400 | 921 | 6,708 | 190.09 | 1.0E+00 | 0.49696 | 0.00128 | 0.49951 |
| ncsrt55d2_2_14_15 | 1.4 | 10,400 | 921 | 7,546 | 213.86 | 1.0E+00 | 0.54756 | 0.00093 | 0.54942 |
| ncsrt55d2_2_15_15 | 1.4 | 10,400 | 921 | 8,385 | 237.62 | 1.0E+00 | 0.59538 | 0.00144 | 0.59825 |
| | | | | | | **moifr** | | | |
| ncsrt55d2_2_15_15 | 1.4 | 10,400 | 921 | 8,385 | 237.62 | 1.0E+00 | 0.59538 | 0.00144 | 0.59825 |
| ncsrt55d2_2_15_8 | 1.4 | 10,400 | 921 | 8,385 | 237.62 | 3.0E-01 | 0.53671 | 0.00112 | 0.53895 |
| ncsrt55d2_2_15_6 | 1.4 | 10,400 | 921 | 8,385 | 237.62 | 1.0E-01 | 0.52002 | 0.00107 | 0.52217 |
| ncsrt55d2_2_15_5 | 1.4 | 10,400 | 921 | 8,385 | 237.62 | 1.0E-02 | 0.50958 | 0.00123 | 0.51204 |
| ncsrt55d2_2_15_4 | 1.4 | 10,400 | 921 | 8,385 | 237.62 | 1.0E-03 | 0.50803 | 0.00111 | 0.51024 |

**Table 6.9.6-20d. Results for $UZrH_x$ content at 19.7 wt % $^{235}U$ in packaging calculation model**

| case name | np (in.) | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr/ moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| ncsrt55d2_2_15_3 | 1.4 | 10,400 | 921 | 8,385 | 237.62 | 1.0E-04 | 0.50785 | 0.00116 | 0.51018 |
| ncsrt55d2_2_15_2 | 1.4 | 10,400 | 921 | 8,385 | 237.62 | 1.0E-05 | 0.50851 | 0.00117 | 0.51086 |
| ncsrt55d2_2_15_1 | 1.4 | 10,400 | 921 | 8,385 | 237.62 | 1.0E-20 | 0.50763 | 0.00113 | 0.50989 |
| **homogenized content in flooded containment vessel, array packaging model for CSI=0.0 [10 CFR 71.55(d)(2)]** | | | | | | | | | |
| **NCT** | | | | | | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | |
| | | | | | | **moifr** | | | |
| nciat55d2_1_1_3 | 0.0 | 10400 | 921 | 0 | 0.00 | 1.0E-04 | 0.13090 | 0.00039 | 0.13168 |
| nciat55d2_1_6_3 | 0.0 | 10400 | 921 | 900 | 25.50 | 1.0E-04 | 0.18600 | 0.00056 | 0.18713 |
| nciat55d2_1_7_3 | 0.0 | 10400 | 921 | 1,800 | 51.00 | 1.0E-04 | 0.24841 | 0.00078 | 0.24997 |
| nciat55d2_1_8_3 | 0.0 | 10400 | 921 | 2,700 | 76.50 | 1.0E-04 | 0.31679 | 0.00074 | 0.31826 |
| nciat55d2_1_9_3 | 0.0 | 10400 | 921 | 3,599 | 102.00 | 1.0E-04 | 0.38338 | 0.00097 | 0.38531 |
| nciat55d2_1_10_3 | 0.0 | 10400 | 921 | 4,499 | 127.50 | 1.0E-04 | 0.44808 | 0.00093 | 0.44993 |
| nciat55d2_1_11_3 | 0.0 | 10400 | 921 | 5,399 | 153.00 | 1.0E-04 | 0.51062 | 0.00096 | 0.51254 |
| nciat55d2_1_12_3 | 0.0 | 10400 | 921 | 6,299 | 178.50 | 1.0E-04 | 0.56869 | 0.00104 | 0.57076 |
| nciat55d2_1_13_3 | 0.0 | 10400 | 921 | 7,198 | 204.00 | 1.0E-04 | 0.62259 | 0.00112 | 0.62484 |
| nciat55d2_1_14_3 | 0.0 | 10400 | 921 | 8,098 | 229.51 | 1.0E-04 | 0.67077 | 0.00100 | 0.67276 |
| nciat55d2_1_15_3 | 0.0 | 10400 | 921 | 8,998 | 255.01 | 1.0E-04 | 0.71379 | 0.00131 | 0.71641 |
| **with can spacers (np thickness = 1.4 in.)** | | | | | | | | | |
| nciat55d2_02_1_3 | 1.4 | 10400 | 921 | 0 | 0.00 | 1.0E-04 | 0.12620 | 0.00039 | 0.12697 |
| nciat55d2_02_6_3 | 1.4 | 10400 | 921 | 838 | 23.76 | 1.0E-04 | 0.17224 | 0.00043 | 0.17310 |
| nciat55d2_02_7_3 | 1.4 | 10400 | 921 | 1,677 | 47.52 | 1.0E-04 | 0.22779 | 0.00057 | 0.22894 |
| nciat55d2_02_8_3 | 1.4 | 10400 | 921 | 2,515 | 71.29 | 1.0E-04 | 0.28723 | 0.00081 | 0.28884 |
| nciat55d2_02_9_3 | 1.4 | 10400 | 921 | 3,354 | 95.05 | 1.0E-04 | 0.34934 | 0.00079 | 0.35091 |
| nciat55d2_02_10_3 | 1.4 | 10400 | 921 | 4,192 | 118.81 | 1.0E-04 | 0.40899 | 0.00097 | 0.41094 |

**Table 6.9.6-20d. Results for $UZrH_x$ content at 19.7 wt % $^{235}U$ in packaging calculation model**

| case name | np (in.) | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr/ moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| nciat55d2_02_11_3 | 1.4 | 10400 | 921 | 5,031 | 142.57 | 1.0E-04 | 0.46775 | 0.00101 | 0.46977 |
| nciat55d2_02_12_3 | 1.4 | 10400 | 921 | 5,869 | 166.33 | 1.0E-04 | 0.52454 | 0.00105 | 0.52664 |
| nciat55d2_02_13_3 | 1.4 | 10400 | 921 | 6,708 | 190.09 | 1.0E-04 | 0.57561 | 0.00105 | 0.57771 |
| nciat55d2_02_14_3 | 1.4 | 10400 | 921 | 7,546 | 213.86 | 1.0E-04 | 0.62437 | 0.00100 | 0.62637 |
| nciat55d2_02_15_3 | 1.4 | 10400 | 921 | 8,385 | 237.62 | 1.0E-04 | 0.66968 | 0.00118 | 0.67203 |

**Table 6.9.6-21. Results for solid HEU metal content for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | Kaolite (g) | $H_2O$ (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| **compromised package, HEU-poly core in spherical configuration, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| **10,000 g HEU** | | | | | | | | | | | | | | |
| atdmr_10_8 | 10,000 | 500 | na | na | 1.68 | 6.3550 | na | na | na | na | 0.0703 | 0.84682 | 0.00132 | 0.84946 |
| atdmr_10_7 | 9,500 | 500 | na | na | 1.77 | 6.3544 | na | na | na | na | 0.0708 | 0.82979 | 0.00121 | 0.83220 |
| atdmr_10_6 | 9,000 | 500 | na | na | 1.86 | 6.3537 | na | na | na | na | 0.0704 | 0.81840 | 0.00105 | 0.82051 |
| atdmr_10_5 | 8,000 | 500 | na | na | 2.10 | 6.3524 | na | na | na | na | 0.0705 | 0.79201 | 0.00116 | 0.79433 |
| atdmr_10_4 | 7,000 | 500 | na | na | 2.40 | 6.3511 | na | na | na | na | 0.0706 | 0.76698 | 0.00108 | 0.76915 |
| atdmr_10_3 | 6,000 | 500 | na | na | 2.80 | 6.3497 | na | na | na | na | 0.0713 | 0.73619 | 0.00111 | 0.73841 |
| atdmr_10_2 | 4,000 | 500 | na | na | 4.19 | 6.3471 | na | na | na | na | 0.0715 | 0.67188 | 0.00126 | 0.67440 |
| atdmr_10_1 | 1,900 | 500 | na | na | 8.83 | 6.3443 | na | na | na | na | 0.0718 | 0.58417 | 0.00103 | 0.58623 |
| **9,000 g HEU** | | | | | | | | | | | | | | |
| atdmr_9_8 | 9,000 | 500 | na | na | 1.86 | 6.2485 | na | na | na | na | 0.0710 | 0.82672 | 0.00113 | 0.82898 |
| atdmr_9_7 | 8,550 | 500 | na | na | 1.96 | 6.2479 | na | na | na | na | 0.0716 | 0.81253 | 0.00143 | 0.81540 |

**Table 6.9.6-21. Results for solid HEU metal content for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | Kaolite (g) | $H_2O$ (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| atdmr_9_6 | 8,100 | 500 | na | na | 2.07 | 6.2473 | na | na | na | na | 0.0712 | 0.80165 | 0.00110 | 0.80385 |
| atdmr_9_5 | 7,200 | 500 | na | na | 2.33 | 6.2460 | na | na | na | na | 0.0710 | 0.77728 | 0.00120 | 0.77967 |
| atdmr_9_4 | 6,300 | 500 | na | na | 2.66 | 6.2448 | na | na | na | na | 0.0716 | 0.75139 | 0.00124 | 0.75387 |
| atdmr_9_3 | 5,400 | 500 | na | na | 3.11 | 6.2436 | na | na | na | na | 0.0724 | 0.72346 | 0.00126 | 0.72598 |
| atdmr_9_2 | 3,600 | 500 | na | na | 4.66 | 6.2411 | na | na | na | na | 0.0724 | 0.65951 | 0.00101 | 0.66152 |
| atdmr_9_1 | 1,710 | 500 | na | na | 9.81 | 6.2385 | na | na | na | na | 0.0734 | 0.57813 | 0.00106 | 0.58024 |
| **8,000 g HEU** | | | | | | | | | | | | | | |
| atdmr_8_8 | 8,000 | 500 | na | na | 2.10 | 6.1382 | na | na | na | na | 0.0718 | 0.80824 | 0.00110 | 0.81045 |
| atdmr_8_7 | 7,600 | 500 | na | na | 2.21 | 6.1377 | na | na | na | na | 0.0724 | 0.79414 | 0.00125 | 0.79663 |
| atdmr_8_6 | 7,200 | 500 | na | na | 2.33 | 6.1371 | na | na | na | na | 0.0722 | 0.78358 | 0.00124 | 0.78606 |
| atdmr_8_5 | 6,400 | 500 | na | na | 2.62 | 6.1360 | na | na | na | na | 0.0723 | 0.76006 | 0.00119 | 0.76244 |
| atdmr_8_4 | 5,600 | 500 | na | na | 2.99 | 6.1348 | na | na | na | na | 0.0719 | 0.73542 | 0.00116 | 0.73773 |
| atdmr_8_3 | 4,800 | 500 | na | na | 3.49 | 6.1337 | na | na | na | na | 0.0726 | 0.70911 | 0.00113 | 0.71138 |
| atdmr_8_2 | 3,200 | 500 | na | na | 5.24 | 6.1314 | na | na | na | na | 0.0733 | 0.65087 | 0.00120 | 0.65326 |
| atdmr_8_1 | 1,520 | 500 | na | na | 11.03 | 6.1290 | na | na | na | na | 0.0731 | 0.57072 | 0.00116 | 0.57304 |
| **7,000 g HEU** | | | | | | | | | | | | | | |
| atdmr_7_8 | 7,000 | 500 | na | na | 2.40 | 6.0238 | na | na | na | na | 0.0732 | 0.78837 | 0.00130 | 0.79098 |
| atdmr_7_7 | 6,650 | 500 | na | na | 2.52 | 6.0233 | na | na | na | na | 0.0727 | 0.77467 | 0.00108 | 0.77683 |
| atdmr_7_6 | 6,300 | 500 | na | na | 2.66 | 6.0228 | na | na | na | na | 0.0735 | 0.76362 | 0.00120 | 0.76603 |
| atdmr_7_5 | 5,600 | 500 | na | na | 2.99 | 6.0218 | na | na | na | na | 0.0735 | 0.74073 | 0.00115 | 0.74302 |
| atdmr_7_4 | 4,900 | 500 | na | na | 3.42 | 6.0207 | na | na | na | na | 0.0731 | 0.71741 | 0.00120 | 0.71982 |
| atdmr_7_3 | 4,200 | 500 | na | na | 3.99 | 6.0197 | na | na | na | na | 0.0740 | 0.69409 | 0.00108 | 0.69624 |
| atdmr_7_2 | 2,800 | 500 | na | na | 5.99 | 6.0176 | na | na | na | na | 0.0735 | 0.63885 | 0.00113 | 0.64111 |
| atdmr_7_1 | 1,330 | 500 | na | na | 12.61 | 6.0155 | na | na | na | na | 0.0745 | 0.56445 | 0.00108 | 0.56660 |

**Table 6.9.6-21. Results for solid HEU metal content for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | Kaolite (g) | $H_2O$ (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| **compromised package, HEU-poly core in spherical configuration, stainless steel shell, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| **7,000 g HEU 100% enrichment** | | | | | | | | | | | | | | |
| atdmsr_7_8_11 | 7,000 | 500 | na | na | 2.40 | 6.0238 | na | na | 66,133.1 | 13.0198 | 0.0297 | 0.76607 | 0.00120 | 0.76847 |
| atdmsr_7_8_10 | 7,000 | 500 | na | na | 2.40 | 6.0238 | na | na | 59,519.8 | 12.6164 | 0.0313 | 0.76407 | 0.00104 | 0.76615 |
| atdmsr_7_8_9 | 7,000 | 500 | na | na | 2.40 | 6.0238 | na | na | 52,906.5 | 12.1855 | 0.0329 | 0.76034 | 0.00112 | 0.76259 |
| atdmsr_7_8_8 | 7,000 | 500 | na | na | 2.40 | 6.0238 | na | na | 46,293.2 | 11.7217 | 0.0348 | 0.75468 | 0.00126 | 0.75720 |
| atdmsr_7_8_7 | 7,000 | 500 | na | na | 2.40 | 6.0238 | na | na | 39,679.9 | 11.2179 | 0.0370 | 0.75125 | 0.00130 | 0.75384 |
| atdmsr_7_8_6 | 7,000 | 500 | na | na | 2.40 | 6.0238 | na | na | 33,066.6 | 10.6643 | 0.0396 | 0.74580 | 0.00123 | 0.74827 |
| atdmsr_7_8_5 | 7,000 | 500 | na | na | 2.40 | 6.0238 | na | na | 26,453.3 | 10.0464 | 0.0428 | 0.73992 | 0.00122 | 0.74235 |
| atdmsr_7_8_4 | 7,000 | 500 | na | na | 2.40 | 6.0238 | na | na | 19,839.9 | 9.3414 | 0.0464 | 0.73585 | 0.00164 | 0.73913 |
| atdmsr_7_8_3 | 7,000 | 500 | na | na | 2.40 | 6.0238 | na | na | 13,226.6 | 8.5100 | 0.0517 | 0.73131 | 0.00121 | 0.73373 |
| atdmsr_7_8_2 | 7,000 | 500 | na | na | 2.40 | 6.0238 | na | na | 6,613.3 | 7.4736 | 0.0594 | 0.73612 | 0.00125 | 0.73863 |
| atdmsr_7_8_1 | 7,000 | 500 | na | na | 2.40 | 6.0238 | na | na | 0.0 | 6.0239 | 0.0730 | 0.78843 | 0.00113 | 0.79069 |
| **7,000 g HEU 95% enrichment** | | | | | | | | | | | | | | |
| atdmsr_7_7_11 | 6,650 | 500 | na | na | 2.52 | 6.0233 | na | na | 66,133.1 | 13.0197 | 0.0297 | 0.75217 | 0.00105 | 0.75427 |
| atdmsr_7_7_10 | 6,650 | 500 | na | na | 2.52 | 6.0233 | na | na | 59,519.8 | 12.6163 | 0.0311 | 0.74832 | 0.00120 | 0.75072 |
| atdmsr_7_7_9 | 6,650 | 500 | na | na | 2.52 | 6.0233 | na | na | 52,906.5 | 12.1854 | 0.0330 | 0.74504 | 0.00122 | 0.74749 |
| atdmsr_7_7_8 | 6,650 | 500 | na | na | 2.52 | 6.0233 | na | na | 46,293.2 | 11.7215 | 0.0350 | 0.74113 | 0.00139 | 0.74391 |
| atdmsr_7_7_7 | 6,650 | 500 | na | na | 2.52 | 6.0233 | na | na | 39,679.9 | 11.2178 | 0.0367 | 0.73518 | 0.00113 | 0.73745 |
| atdmsr_7_7_6 | 6,650 | 500 | na | na | 2.52 | 6.0233 | na | na | 33,066.6 | 10.6642 | 0.0398 | 0.73061 | 0.00114 | 0.73289 |
| atdmsr_7_7_5 | 6,650 | 500 | na | na | 2.52 | 6.0233 | na | na | 26,453.3 | 10.0462 | 0.0424 | 0.72581 | 0.00115 | 0.72811 |
| atdmsr_7_7_4 | 6,650 | 500 | na | na | 2.52 | 6.0233 | na | na | 19,839.9 | 9.3412 | 0.0465 | 0.72114 | 0.00114 | 0.72341 |
| atdmsr_7_7_3 | 6,650 | 500 | na | na | 2.52 | 6.0233 | na | na | 13,226.6 | 8.5097 | 0.0513 | 0.71750 | 0.00128 | 0.72006 |
| atdmsr_7_7_2 | 6,650 | 500 | na | na | 2.52 | 6.0233 | na | na | 6,613.3 | 7.4733 | 0.0595 | 0.72179 | 0.00125 | 0.72429 |
| atdmsr_7_7_1 | 6,650 | 500 | na | na | 2.52 | 6.0233 | na | na | 0.0 | 6.0234 | 0.0731 | 0.77710 | 0.00130 | 0.77970 |

**Table 6.9.6-21. Results for solid HEU metal content for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | Kaolite (g) | $H_2O$ (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| **7,000 g HEU 90% enrichment** | | | | | | | | | | | | | | |
| atdmsr_7_6_11 | 6,300 | 500 | na | na | 2.66 | 6.0228 | na | na | 66,133.1 | 13.0196 | 0.0300 | 0.73788 | 0.00105 | 0.73999 |
| atdmsr_7_6_10 | 6,300 | 500 | na | na | 2.66 | 6.0228 | na | na | 59,519.8 | 12.6162 | 0.0308 | 0.73548 | 0.00108 | 0.73763 |
| atdmsr_7_6_9 | 6,300 | 500 | na | na | 2.66 | 6.0228 | na | na | 52,906.5 | 12.1852 | 0.0327 | 0.73014 | 0.00125 | 0.73263 |
| atdmsr_7_6_8 | 6,300 | 500 | na | na | 2.66 | 6.0228 | na | na | 46,293.2 | 11.7214 | 0.0349 | 0.72624 | 0.00124 | 0.72873 |
| atdmsr_7_6_7 | 6,300 | 500 | na | na | 2.66 | 6.0228 | na | na | 39,679.9 | 11.2176 | 0.0371 | 0.72341 | 0.00126 | 0.72594 |
| atdmsr_7_6_6 | 6,300 | 500 | na | na | 2.66 | 6.0228 | na | na | 33,066.6 | 10.6640 | 0.0393 | 0.71807 | 0.00109 | 0.72025 |
| atdmsr_7_6_5 | 6,300 | 500 | na | na | 2.66 | 6.0228 | na | na | 26,453.3 | 10.0460 | 0.0423 | 0.71292 | 0.00108 | 0.71507 |
| atdmsr_7_6_4 | 6,300 | 500 | na | na | 2.66 | 6.0228 | na | na | 19,839.9 | 9.3409 | 0.0462 | 0.70851 | 0.00126 | 0.71103 |
| atdmsr_7_6_3 | 6,300 | 500 | na | na | 2.66 | 6.0228 | na | na | 13,226.6 | 8.5095 | 0.0515 | 0.70125 | 0.00118 | 0.70361 |
| atdmsr_7_6_2 | 6,300 | 500 | na | na | 2.66 | 6.0228 | na | na | 6,613.3 | 7.4730 | 0.0595 | 0.70829 | 0.00122 | 0.71074 |
| atdmsr_7_6_1 | 6,300 | 500 | na | na | 2.66 | 6.0228 | na | na | 0.0 | 6.0229 | 0.0731 | 0.76522 | 0.00130 | 0.76782 |
| **7,000 g HEU 80% enrichment** | | | | | | | | | | | | | | |
| atdmsr_7_5_11 | 5,600 | 500 | na | na | 2.99 | 6.0218 | na | na | 66,133.1 | 13.0194 | 0.0300 | 0.70826 | 0.00130 | 0.71086 |
| atdmsr_7_5_10 | 5,600 | 500 | na | na | 2.99 | 6.0218 | na | na | 59,519.8 | 12.6160 | 0.0313 | 0.70615 | 0.00122 | 0.70860 |
| atdmsr_7_5_9 | 5,600 | 500 | na | na | 2.99 | 6.0218 | na | na | 52,906.5 | 12.1850 | 0.0332 | 0.70259 | 0.00104 | 0.70468 |
| atdmsr_7_5_8 | 5,600 | 500 | na | na | 2.99 | 6.0218 | na | na | 46,293.2 | 11.7211 | 0.0351 | 0.69758 | 0.00113 | 0.69985 |
| atdmsr_7_5_7 | 5,600 | 500 | na | na | 2.99 | 6.0218 | na | na | 39,679.9 | 11.2173 | 0.0371 | 0.69312 | 0.00126 | 0.69564 |
| atdmsr_7_5_6 | 5,600 | 500 | na | na | 2.99 | 6.0218 | na | na | 33,066.6 | 10.6637 | 0.0394 | 0.69094 | 0.00100 | 0.69295 |
| atdmsr_7_5_5 | 5,600 | 500 | na | na | 2.99 | 6.0218 | na | na | 26,453.3 | 10.0457 | 0.0430 | 0.68484 | 0.00109 | 0.68701 |
| atdmsr_7_5_4 | 5,600 | 500 | na | na | 2.99 | 6.0218 | na | na | 19,839.9 | 9.3405 | 0.0467 | 0.67851 | 0.00126 | 0.68102 |
| atdmsr_7_5_3 | 5,600 | 500 | na | na | 2.99 | 6.0218 | na | na | 13,226.6 | 8.5089 | 0.0520 | 0.67622 | 0.00128 | 0.67878 |
| atdmsr_7_5_2 | 5,600 | 500 | na | na | 2.99 | 6.0218 | na | na | 6,613.3 | 7.4723 | 0.0596 | 0.68260 | 0.00122 | 0.68505 |
| atdmsr_7_5_1 | 5,600 | 500 | na | na | 2.99 | 6.0218 | na | na | 0.0 | 6.0219 | 0.0729 | 0.74067 | 0.00120 | 0.74307 |

**Table 6.9.6-21. Results for solid HEU metal content for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | Kaolite (g) | $H_2O$ (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| **7,000 g HEU 70% enrichment** | | | | | | | | | | | | | | |
| atdmsr_7_4_11 | 4,900 | 500 | na | na | 3.42 | 6.0207 | na | na | 66,133.1 | 13.0192 | 0.0298 | 0.67942 | 0.00111 | 0.68164 |
| atdmsr_7_4_10 | 4,900 | 500 | na | na | 3.42 | 6.0207 | na | na | 59,519.8 | 12.6157 | 0.0315 | 0.67468 | 0.00108 | 0.67683 |
| atdmsr_7_4_9 | 4,900 | 500 | na | na | 3.42 | 6.0207 | na | na | 52,906.5 | 12.1847 | 0.0329 | 0.67332 | 0.00107 | 0.67547 |
| atdmsr_7_4_8 | 4,900 | 500 | na | na | 3.42 | 6.0207 | na | na | 46,293.2 | 11.7208 | 0.0344 | 0.66696 | 0.00109 | 0.66915 |
| atdmsr_7_4_7 | 4,900 | 500 | na | na | 3.42 | 6.0207 | na | na | 39,679.9 | 11.2170 | 0.0371 | 0.66405 | 0.00102 | 0.66610 |
| atdmsr_7_4_6 | 4,900 | 500 | na | na | 3.42 | 6.0207 | na | na | 33,066.6 | 10.6633 | 0.0396 | 0.65978 | 0.00133 | 0.66244 |
| atdmsr_7_4_5 | 4,900 | 500 | na | na | 3.42 | 6.0207 | na | na | 26,453.3 | 10.0453 | 0.0430 | 0.65491 | 0.00111 | 0.65714 |
| atdmsr_7_4_4 | 4,900 | 500 | na | na | 3.42 | 6.0207 | na | na | 19,839.9 | 9.3401 | 0.0461 | 0.65283 | 0.00115 | 0.65513 |
| atdmsr_7_4_3 | 4,900 | 500 | na | na | 3.42 | 6.0207 | na | na | 13,226.6 | 8.5084 | 0.0519 | 0.64816 | 0.00119 | 0.65053 |
| atdmsr_7_4_2 | 4,900 | 500 | na | na | 3.42 | 6.0207 | na | na | 6,613.3 | 7.4716 | 0.0592 | 0.65866 | 0.00129 | 0.66124 |
| atdmsr_7_4_1 | 4,900 | 500 | na | na | 3.42 | 6.0207 | na | na | 0.0 | 6.0208 | 0.0735 | 0.71618 | 0.00119 | 0.71855 |
| **7,000 g HEU 60% enrichment** | | | | | | | | | | | | | | |
| atdmsr_7_3_11 | 4,200 | 500 | na | na | 3.99 | 6.0197 | na | na | 66,133.1 | 13.0189 | 0.0301 | 0.64937 | 0.00120 | 0.65177 |
| atdmsr_7_3_10 | 4,200 | 500 | na | na | 3.99 | 6.0197 | na | na | 59,519.8 | 12.6155 | 0.0314 | 0.64512 | 0.00109 | 0.64731 |
| atdmsr_7_3_9 | 4,200 | 500 | na | na | 3.99 | 6.0197 | na | na | 52,906.5 | 12.1845 | 0.0331 | 0.64112 | 0.00108 | 0.64328 |
| atdmsr_7_3_8 | 4,200 | 500 | na | na | 3.99 | 6.0197 | na | na | 46,293.2 | 11.7206 | 0.0347 | 0.63750 | 0.00100 | 0.63951 |
| atdmsr_7_3_7 | 4,200 | 500 | na | na | 3.99 | 6.0197 | na | na | 39,679.9 | 11.2167 | 0.0378 | 0.63266 | 0.00109 | 0.63483 |
| atdmsr_7_3_6 | 4,200 | 500 | na | na | 3.99 | 6.0197 | na | na | 33,066.6 | 10.6630 | 0.0400 | 0.62892 | 0.00118 | 0.63129 |
| atdmsr_7_3_5 | 4,200 | 500 | na | na | 3.99 | 6.0197 | na | na | 26,453.3 | 10.0449 | 0.0432 | 0.62395 | 0.00111 | 0.62617 |
| atdmsr_7_3_4 | 4,200 | 500 | na | na | 3.99 | 6.0197 | na | na | 19,839.9 | 9.3397 | 0.0468 | 0.62020 | 0.00121 | 0.62262 |
| atdmsr_7_3_3 | 4,200 | 500 | na | na | 3.99 | 6.0197 | na | na | 13,226.6 | 8.5079 | 0.0521 | 0.61780 | 0.00100 | 0.61980 |
| atdmsr_7_3_2 | 4,200 | 500 | na | na | 3.99 | 6.0197 | na | na | 6,613.3 | 7.4710 | 0.0597 | 0.62719 | 0.00106 | 0.62931 |
| atdmsr_7_3_1 | 4,200 | 500 | na | na | 3.99 | 6.0197 | na | na | 0.0 | 6.0198 | 0.0734 | 0.69368 | 0.00104 | 0.69575 |

**Table 6.9.6-21. Results for solid HEU metal content for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | Kaolite (g) | $H_2O$ (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| **7,000 g HEU 40% enrichment** | | | | | | | | | | | | | | |
| atdmsr_7_2_11 | 2,800 | 500 | na | na | 5.99 | 6.0176 | na | na | 66,133.1 | 13.0185 | 0.0298 | 0.57617 | 0.00095 | 0.57807 |
| atdmsr_7_2_10 | 2,800 | 500 | na | na | 5.99 | 6.0176 | na | na | 59,519.8 | 12.6150 | 0.0319 | 0.57141 | 0.00113 | 0.57367 |
| atdmsr_7_2_9 | 2,800 | 500 | na | na | 5.99 | 6.0176 | na | na | 52,906.5 | 12.1840 | 0.0329 | 0.56944 | 0.00094 | 0.57132 |
| atdmsr_7_2_8 | 2,800 | 500 | na | na | 5.99 | 6.0176 | na | na | 46,293.2 | 11.7200 | 0.0351 | 0.56671 | 0.00107 | 0.56885 |
| atdmsr_7_2_7 | 2,800 | 500 | na | na | 5.99 | 6.0176 | na | na | 39,679.9 | 11.2161 | 0.0373 | 0.56408 | 0.00108 | 0.56623 |
| atdmsr_7_2_6 | 2,800 | 500 | na | na | 5.99 | 6.0176 | na | na | 33,066.6 | 10.6624 | 0.0400 | 0.56030 | 0.00098 | 0.56225 |
| atdmsr_7_2_5 | 2,800 | 500 | na | na | 5.99 | 6.0176 | na | na | 26,453.3 | 10.0442 | 0.0427 | 0.55427 | 0.00096 | 0.55618 |
| atdmsr_7_2_4 | 2,800 | 500 | na | na | 5.99 | 6.0176 | na | na | 19,839.9 | 9.3388 | 0.0468 | 0.55088 | 0.00103 | 0.55294 |
| atdmsr_7_2_3 | 2,800 | 500 | na | na | 5.99 | 6.0176 | na | na | 13,226.6 | 8.5069 | 0.0518 | 0.55147 | 0.00094 | 0.55335 |
| atdmsr_7_2_2 | 2,800 | 500 | na | na | 5.99 | 6.0176 | na | na | 6,613.3 | 7.4696 | 0.0598 | 0.56246 | 0.00099 | 0.56444 |
| atdmsr_7_2_1 | 2,800 | 500 | na | na | 5.99 | 6.0176 | na | na | 0.0 | 6.0177 | 0.0741 | 0.63782 | 0.00112 | 0.64006 |
| **7,000 g HEU 19% enrichment** | | | | | | | | | | | | | | |
| atdmsr_7_1_11 | 1,330 | 500 | na | na | 12.61 | 6.0155 | na | na | 66,133.1 | 13.0180 | 0.0303 | 0.47486 | 0.00104 | 0.47693 |
| atdmsr_7_1_10 | 1,330 | 500 | na | na | 12.61 | 6.0155 | na | na | 59,519.8 | 12.6145 | 0.0319 | 0.47397 | 0.00122 | 0.47641 |
| atdmsr_7_1_9 | 1,330 | 500 | na | na | 12.61 | 6.0155 | na | na | 52,906.5 | 12.1834 | 0.0332 | 0.47151 | 0.00104 | 0.47360 |
| atdmsr_7_1_8 | 1,330 | 500 | na | na | 12.61 | 6.0155 | na | na | 46,293.2 | 11.7195 | 0.0349 | 0.46786 | 0.00095 | 0.46975 |
| atdmsr_7_1_7 | 1,330 | 500 | na | na | 12.61 | 6.0155 | na | na | 39,679.9 | 11.2155 | 0.0376 | 0.46514 | 0.00108 | 0.46730 |
| atdmsr_7_1_6 | 1,330 | 500 | na | na | 12.61 | 6.0155 | na | na | 33,066.6 | 10.6617 | 0.0398 | 0.46144 | 0.00102 | 0.46347 |
| atdmsr_7_1_5 | 1,330 | 500 | na | na | 12.61 | 6.0155 | na | na | 26,453.3 | 10.0434 | 0.0428 | 0.45904 | 0.00094 | 0.46093 |
| atdmsr_7_1_4 | 1,330 | 500 | na | na | 12.61 | 6.0155 | na | na | 19,839.9 | 9.3379 | 0.0465 | 0.45553 | 0.00100 | 0.45753 |
| atdmsr_7_1_3 | 1,330 | 500 | na | na | 12.61 | 6.0155 | na | na | 13,226.6 | 8.5058 | 0.0528 | 0.45536 | 0.00100 | 0.45737 |
| atdmsr_7_1_2 | 1,330 | 500 | na | na | 12.61 | 6.0155 | na | na | 6,613.3 | 7.4682 | 0.0598 | 0.46993 | 0.00112 | 0.47216 |
| atdmsr_7_1_1 | 1,330 | 500 | na | na | 12.61 | 6.0155 | na | na | 0.0 | 6.0156 | 0.0742 | 0.56352 | 0.00123 | 0.56598 |

**Table 6.9.6-21. Results for solid HEU metal content for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | Kaolite (g) | $H_2O$ (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| **compromised package, HEU-poly core in spherical configuration, dry (bound water) Kaolite shell, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| **7,000 g HEU 100% enrichment** | | | | | | | | | | | | | | |
| atdmdkr_7_8_6 | 7,000 | 500 | na | na | 2.40 | 6.0238 | 51,214.9 | 2,204.2 | 53,419.1 | 31.0802 | 0.0493 | 0.58882 | 0.00117 | 0.59116 |
| atdmdkr_7_8_5 | 7,000 | 500 | na | na | 2.40 | 6.0238 | 40,971.9 | 1,763.4 | 42,735.3 | 28.8698 | 0.0508 | 0.59271 | 0.00122 | 0.59516 |
| atdmdkr_7_8_4 | 7,000 | 500 | na | na | 2.40 | 6.0238 | 30,729.0 | 1,322.5 | 32,051.5 | 26.2565 | 0.0530 | 0.59911 | 0.00118 | 0.60147 |
| atdmdkr_7_8_3 | 7,000 | 500 | na | na | 2.40 | 6.0238 | 20,485.9 | 881.7 | 21,367.6 | 22.9832 | 0.0559 | 0.60599 | 0.00101 | 0.60801 |
| atdmdkr_7_8_2 | 7,000 | 500 | na | na | 2.40 | 6.0238 | 10,243.0 | 440.8 | 10,683.8 | 18.3506 | 0.0604 | 0.62729 | 0.00116 | 0.62962 |
| atdmdkr_7_8_1 | 7,000 | 500 | na | na | 2.40 | 6.0238 | 0.0 | 0.0 | 0.0 | 6.0239 | 0.0733 | 0.78590 | 0.00118 | 0.78826 |
| **compromised package, HEU-poly core in spherical configuration, wet (bound plus 15 lb free water) Kaolite shell, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| **7,000 g HEU 100% enrichment** | | | | | | | | | | | | | | |
| atdm15kr_7_8_6 | 7,000 | 500 | na | na | 2.40 | 6.0238 | 51,214.9 | 9,008.1 | 60,223.0 | 31.0802 | 0.0402 | 0.59780 | 0.00113 | 0.60006 |
| atdm15kr_7_8_5 | 7,000 | 500 | na | na | 2.40 | 6.0238 | 40,971.9 | 7,206.5 | 48,178.4 | 28.8698 | 0.0425 | 0.60257 | 0.00108 | 0.60473 |
| atdm15kr_7_8_4 | 7,000 | 500 | na | na | 2.40 | 6.0238 | 30,728.9 | 5,404.9 | 36,133.8 | 26.2565 | 0.0452 | 0.60526 | 0.00112 | 0.60750 |
| atdm15kr_7_8_3 | 7,000 | 500 | na | na | 2.40 | 6.0238 | 20,486.0 | 3,603.2 | 24,089.2 | 22.9832 | 0.0487 | 0.61255 | 0.00103 | 0.61461 |
| atdm15kr_7_8_2 | 7,000 | 500 | na | na | 2.40 | 6.0238 | 10,243.0 | 1,801.6 | 12,044.6 | 18.3506 | 0.0546 | 0.63083 | 0.00104 | 0.63292 |
| atdm15kr_7_8_1 | 7,000 | 500 | na | na | 2.40 | 6.0238 | 0.0 | 0.0 | 0.0 | 6.0239 | 0.0735 | 0.78760 | 0.00130 | 0.79020 |
| **7,000 g HEU 95% enrichment** | | | | | | | | | | | | | | |
| atdm15kr_7_7_6 | 6,650 | 500 | na | na | 2.52 | 6.0233 | 51,214.9 | 9,008.1 | 60,223.0 | 31.0802 | 0.0405 | 0.58499 | 0.00117 | 0.58733 |
| atdm15kr_7_7_5 | 6,650 | 500 | na | na | 2.52 | 6.0233 | 40,971.8 | 7,206.6 | 48,178.4 | 28.8698 | 0.0427 | 0.58888 | 0.00102 | 0.59093 |
| atdm15kr_7_7_4 | 6,650 | 500 | na | na | 2.52 | 6.0233 | 30,728.9 | 5,404.9 | 36,133.8 | 26.2564 | 0.0451 | 0.59189 | 0.00101 | 0.59391 |
| atdm15kr_7_7_3 | 6,650 | 500 | na | na | 2.52 | 6.0233 | 20,485.9 | 3,603.3 | 24,089.2 | 22.9832 | 0.0490 | 0.59837 | 0.00098 | 0.60034 |
| atdm15kr_7_7_2 | 6,650 | 500 | na | na | 2.52 | 6.0233 | 10,243.0 | 1,801.6 | 12,044.6 | 18.3506 | 0.0553 | 0.61938 | 0.00126 | 0.62190 |
| atdm15kr_7_7_1 | 6,650 | 500 | na | na | 2.52 | 6.0233 | 0.0 | 0.0 | 0.0 | 6.0234 | 0.0727 | 0.77397 | 0.00119 | 0.77636 |

**Table 6.9.6-21. Results for solid HEU metal content for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | Kaolite (g) | $H_2O$ (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| **7,000 g HEU 90% enrichment** | | | | | | | | | | | | | | |
| atdm15kr_7_6_6 | 6,300 | 500 | na | na | 2.66 | 6.0228 | 51,214.9 | 9,008.1 | 60,223.0 | 31.0802 | 0.0404 | 0.57465 | 0.00119 | 0.57703 |
| atdm15kr_7_6_5 | 6,300 | 500 | na | na | 2.66 | 6.0228 | 40,971.8 | 7,206.6 | 48,178.4 | 28.8698 | 0.0425 | 0.57735 | 0.00128 | 0.57991 |
| atdm15kr_7_6_4 | 6,300 | 500 | na | na | 2.66 | 6.0228 | 30,728.9 | 5,404.9 | 36,133.8 | 26.2564 | 0.0450 | 0.57926 | 0.00117 | 0.58159 |
| atdm15kr_7_6_3 | 6,300 | 500 | na | na | 2.66 | 6.0228 | 20,485.9 | 3,603.3 | 24,089.2 | 22.9831 | 0.0487 | 0.58806 | 0.00114 | 0.59034 |
| atdm15kr_7_6_2 | 6,300 | 500 | na | na | 2.66 | 6.0228 | 10,243.0 | 1,801.6 | 12,044.6 | 18.3505 | 0.0554 | 0.60486 | 0.00116 | 0.60718 |
| atdm15kr_7_6_1 | 6,300 | 500 | na | na | 2.66 | 6.0228 | 0.0 | 0.0 | 0.0 | 6.0229 | 0.0730 | 0.76331 | 0.00116 | 0.76563 |
| **7,000 g HEU 80% enrichment** | | | | | | | | | | | | | | |
| atdm15kr_7_5_6 | 5,600 | 500 | na | na | 2.99 | 6.0218 | 51,214.9 | 9,008.1 | 60,223.0 | 31.0802 | 0.0408 | 0.54645 | 0.00099 | 0.54842 |
| atdm15kr_7_5_5 | 5,600 | 500 | na | na | 2.99 | 6.0218 | 40,971.8 | 7,206.6 | 48,178.4 | 28.8698 | 0.0423 | 0.54984 | 0.00093 | 0.55170 |
| atdm15kr_7_5_4 | 5,600 | 500 | na | na | 2.99 | 6.0218 | 30,728.9 | 5,404.9 | 36,133.8 | 26.2563 | 0.0446 | 0.55606 | 0.00114 | 0.55834 |
| atdm15kr_7_5_3 | 5,600 | 500 | na | na | 2.99 | 6.0218 | 20,485.9 | 3,603.3 | 24,089.2 | 22.9831 | 0.0487 | 0.56202 | 0.00110 | 0.56422 |
| atdm15kr_7_5_2 | 5,600 | 500 | na | na | 2.99 | 6.0218 | 10,243.0 | 1,801.6 | 12,044.6 | 18.3504 | 0.0552 | 0.58092 | 0.00102 | 0.58295 |
| atdm15kr_7_5_1 | 5,600 | 500 | na | na | 2.99 | 6.0218 | 0.0 | 0.0 | 0.0 | 6.0219 | 0.0730 | 0.74103 | 0.00130 | 0.74363 |
| **7,000 g HEU 70% enrichment** | | | | | | | | | | | | | | |
| atdm15kr_7_4_6 | 4,900 | 500 | na | na | 3.42 | 6.0207 | 51,214.9 | 9,008.1 | 60,223.0 | 31.0801 | 0.0409 | 0.52118 | 0.00095 | 0.52308 |
| atdm15kr_7_4_5 | 4,900 | 500 | na | na | 3.42 | 6.0207 | 40,971.8 | 7,206.6 | 48,178.4 | 28.8697 | 0.0426 | 0.52194 | 0.00095 | 0.52385 |
| atdm15kr_7_4_4 | 4,900 | 500 | na | na | 3.42 | 6.0207 | 30,728.9 | 5,404.9 | 36,133.8 | 26.2563 | 0.0452 | 0.52781 | 0.00096 | 0.52973 |
| atdm15kr_7_4_3 | 4,900 | 500 | na | na | 3.42 | 6.0207 | 20,485.9 | 3,603.3 | 24,089.2 | 22.9830 | 0.0487 | 0.53753 | 0.00090 | 0.53933 |
| atdm15kr_7_4_2 | 4,900 | 500 | na | na | 3.42 | 6.0207 | 10,243.0 | 1,801.6 | 12,044.6 | 18.3503 | 0.0550 | 0.55570 | 0.00095 | 0.55760 |
| atdm15kr_7_4_1 | 4,900 | 500 | na | na | 3.42 | 6.0207 | 0.0 | 0.0 | 0.0 | 6.0208 | 0.0732 | 0.71662 | 0.00127 | 0.71916 |

**Table 6.9.6-21. Results for solid HEU metal content for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | Kaolite (g) | $H_2O$ (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| **7,000 g HEU 60% enrichment** | | | | | | | | | | | | | | |
| atdm15kr_7_3_6 | 4,200 | 500 | na | na | 3.99 | 6.0197 | 51,214.9 | 9,008.1 | 60,223.0 | 31.0801 | 0.0403 | 0.49438 | 0.00093 | 0.49623 |
| atdm15kr_7_3_5 | 4,200 | 500 | na | na | 3.99 | 6.0197 | 40,971.8 | 7,206.6 | 48,178.4 | 28.8697 | 0.0424 | 0.49599 | 0.00119 | 0.49837 |
| atdm15kr_7_3_4 | 4,200 | 500 | na | na | 3.99 | 6.0197 | 30,728.9 | 5,404.9 | 36,133.8 | 26.2562 | 0.0455 | 0.50053 | 0.00097 | 0.50248 |
| atdm15kr_7_3_3 | 4,200 | 500 | na | na | 3.99 | 6.0197 | 20,485.9 | 3,603.3 | 24,089.2 | 22.9829 | 0.0495 | 0.50936 | 0.00114 | 0.51163 |
| atdm15kr_7_3_2 | 4,200 | 500 | na | na | 3.99 | 6.0197 | 10,243.0 | 1,801.6 | 12,044.6 | 18.3502 | 0.0557 | 0.52826 | 0.00099 | 0.53024 |
| atdm15kr_7_3_1 | 4,200 | 500 | na | na | 3.99 | 6.0197 | 0.0 | 0.0 | 0.0 | 6.0198 | 0.0735 | 0.69521 | 0.00106 | 0.69734 |
| **7,000 g HEU 40% enrichment** | | | | | | | | | | | | | | |
| atdm15kr_7_2_6 | 2,800 | 500 | na | na | 5.99 | 6.0176 | 51,214.9 | 9,008.1 | 60,223.0 | 31.0800 | 0.0409 | 0.43125 | 0.00093 | 0.43312 |
| atdm15kr_7_2_5 | 2,800 | 500 | na | na | 5.99 | 6.0176 | 40,971.8 | 7,206.6 | 48,178.4 | 28.8696 | 0.0430 | 0.43173 | 0.00091 | 0.43356 |
| atdm15kr_7_2_4 | 2,800 | 500 | na | na | 5.99 | 6.0176 | 30,728.9 | 5,404.9 | 36,133.8 | 26.2561 | 0.0454 | 0.43686 | 0.00096 | 0.43879 |
| atdm15kr_7_2_3 | 2,800 | 500 | na | na | 5.99 | 6.0176 | 20,485.9 | 3,603.3 | 24,089.2 | 22.9828 | 0.0498 | 0.44558 | 0.00085 | 0.44727 |
| atdm15kr_7_2_2 | 2,800 | 500 | na | na | 5.99 | 6.0176 | 10,243.0 | 1,801.6 | 12,044.6 | 18.3500 | 0.0559 | 0.46589 | 0.00105 | 0.46800 |
| atdm15kr_7_2_1 | 2,800 | 500 | na | na | 5.99 | 6.0176 | 0.0 | 0.0 | 0.0 | 6.0177 | 0.0738 | 0.63718 | 0.00107 | 0.63932 |
| **7,000 g HEU 19% enrichment** | | | | | | | | | | | | | | |
| atdm15kr_7_1_6 | 1,330 | 500 | na | na | 12.61 | 6.0155 | 51,214.9 | 9,008.1 | 60,223.0 | 31.0799 | 0.0410 | 0.34386 | 0.00104 | 0.34594 |
| atdm15kr_7_1_5 | 1,330 | 500 | na | na | 12.61 | 6.0155 | 40,971.8 | 7,206.6 | 48,178.4 | 28.8695 | 0.0430 | 0.34663 | 0.00078 | 0.34819 |
| atdm15kr_7_1_4 | 1,330 | 500 | na | na | 12.61 | 6.0155 | 30,728.9 | 5,404.9 | 36,133.8 | 26.2560 | 0.0458 | 0.35247 | 0.00090 | 0.35428 |
| atdm15kr_7_1_3 | 1,330 | 500 | na | na | 12.61 | 6.0155 | 20,485.9 | 3,603.3 | 24,089.2 | 22.9826 | 0.0495 | 0.36066 | 0.00085 | 0.36236 |
| atdm15kr_7_1_2 | 1,330 | 500 | na | na | 12.61 | 6.0155 | 10,243.0 | 1,801.6 | 12,044.6 | 18.3497 | 0.0559 | 0.38250 | 0.00092 | 0.38433 |
| atdm15kr_7_1_1 | 1,330 | 500 | na | na | 12.61 | 6.0155 | 0.0 | 0.0 | 0.0 | 6.0156 | 0.0743 | 0.56556 | 0.00123 | 0.56802 |

**Table 6.9.6-22a. Results for TRIGA ($UZrH_x$) fuel element content at 19.7 wt % $^{235}U$ for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | Kaolite (g) | $H_2O$ (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| **compromised package, 10,400 g $UZrH_x$ plus poly in spherical configuration, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| atdzr | 921 | 500 | na | na | 43.37 | 7.4677 | na | na | na | na | 0.0617 | 0.67633 | 0.00116 | 0.67906 |
| **compromised package, spherical core (10,400 g $UZrH_x$ plus poly), stainless steel shell, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| atdzsr_11 | 921 | 500 | na | na | 43.37 | 7.4677 | na | na | 66,133.0 | 13.3978 | 0.0271 | 0.61692 | 0.00121 | 0.61933 |
| atdzsr_10 | 921 | 500 | na | na | 43.37 | 7.4677 | na | na | 59,520.0 | 13.0179 | 0.0285 | 0.61377 | 0.00109 | 0.61595 |
| atdzsr_9 | 921 | 500 | na | na | 43.37 | 7.4677 | na | na | 52,907.0 | 12.6144 | 0.0301 | 0.60931 | 0.00156 | 0.61243 |
| atdzsr_8 | 921 | 500 | na | na | 43.37 | 7.4677 | na | na | 46,293.0 | 12.1833 | 0.0315 | 0.60602 | 0.00132 | 0.60867 |
| atdzsr_7 | 921 | 500 | na | na | 43.37 | 7.4677 | na | na | 39,680.0 | 11.7193 | 0.0332 | 0.60256 | 0.00138 | 0.60533 |
| atdzsr_6 | 921 | 500 | na | na | 43.37 | 7.4677 | na | na | 33,067.0 | 11.2153 | 0.0356 | 0.59752 | 0.00129 | 0.60010 |
| atdzsr_5 | 921 | 500 | na | na | 43.37 | 7.4677 | na | na | 26,453.0 | 10.6615 | 0.0379 | 0.59162 | 0.00109 | 0.59381 |
| atdzsr_4 | 921 | 500 | na | na | 43.37 | 7.4677 | na | na | 19,840.0 | 10.0432 | 0.0407 | 0.59012 | 0.00116 | 0.59243 |
| atdzsr_3 | 921 | 500 | na | na | 43.37 | 7.4677 | na | na | 13,227.0 | 9.3377 | 0.0458 | 0.58978 | 0.00116 | 0.59210 |
| atdzsr_2 | 921 | 500 | na | na | 43.37 | 7.4677 | na | na | 6,613.0 | 8.5055 | 0.0515 | 0.60131 | 0.00135 | 0.60401 |
| atdzsr_1 | 921 | 500 | na | na | 43.37 | 7.4677 | na | na | 0.0 | 7.4677 | 0.0614 | 0.67521 | 0.00128 | 0.67777 |
| **compromised package, spherical core (10,400 g $UZrH_x$ plus poly), wet (bound plus 15 lb free water) Kaolite shell, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| atdz15kr_6 | 921 | 500 | na | na | 43.37 | 7.4677 | 51214.9 | 9008.1 | 60,223.0 | 31.1484 | 0.0352 | 0.46526 | 0.00113 | 0.46752 |
| atdz15kr_5 | 921 | 500 | na | na | 43.37 | 7.4677 | 40971.9 | 7206.5 | 48,178.4 | 28.9488 | 0.0369 | 0.47017 | 0.00113 | 0.47243 |
| atdz15kr_4 | 921 | 500 | na | na | 43.37 | 7.4677 | 30728.9 | 5404.9 | 36,133.8 | 26.3518 | 0.0393 | 0.47656 | 0.00109 | 0.47875 |
| atdz15kr_3 | 921 | 500 | na | na | 43.37 | 7.4677 | 20486.0 | 3603.2 | 24,089.2 | 23.1074 | 0.0424 | 0.48601 | 0.00119 | 0.48839 |
| atdz15kr_2 | 921 | 500 | na | na | 43.37 | 7.4677 | 10243.0 | 1801.6 | 12,044.6 | 18.5444 | 0.0476 | 0.50839 | 0.00112 | 0.51063 |
| atdz15kr_1 | 921 | 500 | na | na | 43.37 | 7.4677 | 0.0 | 0.0 | 0.0 | 7.4678 | 0.0610 | 0.67612 | 0.00136 | 0.67885 |
| **compromised package, homogenous core (10,400 g $UZrH_x$, poly, and wet Kaolite) in spherical configuration, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| athzp15kr_5 | 921 | 500 | 9,008.5 | 51,214.9 | 298.60 | 31.1484 | na | na | na | na | 0.0583 | 0.35614 | 0.00079 | 0.35772 |
| athzp15kr_4 | 921 | 500 | 7,307.6 | 51,214.9 | 250.40 | 31.1484 | na | na | na | na | 0.0600 | 0.34337 | 0.00084 | 0.34504 |
| athzp15kr_3 | 921 | 500 | 5,606.6 | 51,214.9 | 202.20 | 31.1484 | na | na | na | na | 0.0619 | 0.33243 | 0.00085 | 0.33414 |

**Table 6.9.6-22a. Results for TRIGA ($UZrH_x$) fuel element content at 19.7 wt % $^{235}U$ for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | Kaolite (g) | $H_2O$ (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| athzp15kr_2 | 921 | 500 | 3,905.7 | 51,214.9 | 154.00 | 31.1484 | na | na | na | na | 0.0646 | 0.31864 | 0.00079 | 0.32022 |
| athzp15kr_1 | 921 | 500 | 2,204.7 | 51,214.9 | 105.80 | 31.1484 | na | na | na | na | 0.0666 | 0.30842 | 0.00079 | 0.31000 |
| **compromised package, homogenous core ($UZrH_x$, poly, and water from wet Kaolite shell), wet Kaolite shell, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| **9 fuel segments (10,400 g $UZrH_x$)** | | | | | | | | | | | | | | |
| athzpw15kr_5 | 921 | 500 | 6,803.8 | na | 236.10 | 12.6903 | 2,204.7 | 51,214.9 | 53,419.6 | 31.6977 | 0.0308 | 0.80474 | 0.00154 | 0.80781 |
| athzpw15kr_4 | 921 | 500 | 5,102.9 | na | 187.90 | 11.7852 | 3,905.7 | 51,214.9 | 55,120.5 | 31.5622 | 0.0316 | 0.76177 | 0.00142 | 0.76460 |
| athzpw15kr_3 | 921 | 500 | 3,401.9 | na | 139.70 | 10.7146 | 5,606.6 | 51,214.9 | 56,821.5 | 31.4254 | 0.0325 | 0.70349 | 0.00145 | 0.70638 |
| athzpw15kr_2 | 921 | 500 | 1,701.0 | na | 91.57 | 9.3723 | 7,307.6 | 51,214.9 | 58,522.4 | 31.2875 | 0.0334 | 0.61344 | 0.00132 | 0.61608 |
| athzpw15kr_1 | 921 | 500 | 0.0 | na | 43.37 | 7.4677 | 9,008.5 | 51,214.9 | 60,223.4 | 31.1484 | 0.0351 | 0.46733 | 0.00103 | 0.46938 |

**Table 6.9.6-22b. Results for TRIGA ($UZrH_x$) fuel element content at 70.1 wt % $^{235}U$ for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | $H_2O$ (g) | Kaolite (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| **compromised package, 6847 g $UZrH_x$ plus poly in spherical configuration, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| atdzr_70 | 408 | 500 | na | na | 103.30 | 7.4677 | na | na | na | na | 0.0624 | 0.67908 | 0.00139 | 0.68187 |
| **compromised package, spherical core (6,847 g $UZrH_x$ plus poly), stainless steel shell, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| atdzsr_70_11 | 408 | 500 | na | na | 103.30 | 7.4677 | na | na | 66,133.1 | 13.3978 | 0.0280 | 0.62618 | 0.00125 | 0.62868 |
| atdzsr_70_10 | 408 | 500 | na | na | 103.30 | 7.4677 | na | na | 59,519.8 | 13.0179 | 0.0296 | 0.62153 | 0.00132 | 0.62417 |
| atdzsr_70_9 | 408 | 500 | na | na | 103.30 | 7.4677 | na | na | 52,906.5 | 12.6144 | 0.0306 | 0.61874 | 0.00131 | 0.62135 |
| atdzsr_70_8 | 408 | 500 | na | na | 103.30 | 7.4677 | na | na | 46,293.2 | 12.1833 | 0.0323 | 0.61302 | 0.00159 | 0.61619 |
| atdzsr_70_7 | 408 | 500 | na | na | 103.30 | 7.4677 | na | na | 39,679.9 | 11.7193 | 0.0343 | 0.60579 | 0.00123 | 0.60825 |

**Table 6.9.6-22b. Results for TRIGA ($UZrH_x$) fuel element content at 70.1 wt % $^{235}U$ for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | $H_2O$ (g) | Kaolite (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| atdzsr_70_6 | 408 | 500 | na | na | 103.30 | 7.4677 | na | na | 33,066.6 | 11.2153 | 0.0368 | 0.60315 | 0.00128 | 0.60571 |
| atdzsr_70_5 | 408 | 500 | na | na | 103.30 | 7.4677 | na | na | 26,453.3 | 10.6615 | 0.0392 | 0.59802 | 0.00120 | 0.60043 |
| atdzsr_70_4 | 408 | 500 | na | na | 103.30 | 7.4677 | na | na | 19,839.9 | 10.0432 | 0.0427 | 0.58654 | 0.00123 | 0.58900 |
| atdzsr_70_3 | 408 | 500 | na | na | 103.30 | 7.4677 | na | na | 13,226.6 | 9.3377 | 0.0470 | 0.58790 | 0.00125 | 0.59040 |
| atdzsr_70_2 | 408 | 500 | na | na | 103.30 | 7.4677 | na | na | 6,613.3 | 8.5055 | 0.0529 | 0.59739 | 0.00132 | 0.60003 |
| atdzsr_70_1 | 408 | 500 | na | na | 103.30 | 7.4677 | na | na | 0.0 | 7.4677 | 0.0627 | 0.67646 | 0.00125 | 0.67896 |
| **compromised package, spherical core (6,847 g $UZrH_x$ plus poly), wet (bound plus 15 lb free water) Kaolite shell, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| atdz15kr70_6 | 408 | 500 | na | na | 103.30 | 7.4677 | na | na | 60,223.0 | 31.1484 | 0.0362 | 0.45220 | 0.00122 | 0.45465 |
| atdz15kr70_5 | 408 | 500 | na | na | 103.30 | 7.4677 | na | na | 48,178.4 | 28.9488 | 0.0381 | 0.45455 | 0.00142 | 0.45740 |
| atdz15kr70_4 | 408 | 500 | na | na | 103.30 | 7.4677 | na | na | 36,133.8 | 26.3518 | 0.0404 | 0.46170 | 0.00131 | 0.46431 |
| atdz15kr70_3 | 408 | 500 | na | na | 103.30 | 7.4677 | na | na | 24,089.2 | 23.1074 | 0.0437 | 0.47236 | 0.00111 | 0.47459 |
| atdz15kr70_2 | 408 | 500 | na | na | 103.30 | 7.4677 | na | na | 12,044.6 | 18.5444 | 0.0490 | 0.49052 | 0.00132 | 0.49316 |
| atdz15kr70_1 | 408 | 500 | na | na | 103.30 | 7.4677 | na | na | 0.0 | 7.4678 | 0.0626 | 0.67525 | 0.00131 | 0.67787 |
| **compromised package, homogenous core (6,847 g $UZrH_x$, poly, and wet Kaolite) in spherical configuration, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| athzp15kr70_5 | 408 | 500 | 9,008.5 | 51,214.9 | 679.60 | 31.1484 | na | na | na | na | 0.0581 | 0.24018 | 0.00055 | 0.24128 |
| athzp15kr70_4 | 408 | 500 | 7,307.6 | 51,214.9 | 570.80 | 31.1484 | na | na | na | na | 0.0598 | 0.23208 | 0.00050 | 0.23308 |
| athzp15kr70_3 | 408 | 500 | 5,606.6 | 51,214.9 | 461.90 | 31.1484 | na | na | na | na | 0.0623 | 0.22392 | 0.00052 | 0.22495 |
| athzp15kr70_2 | 408 | 500 | 3,905.7 | 51,214.9 | 353.10 | 31.1484 | na | na | na | na | 0.0650 | 0.21594 | 0.00064 | 0.21722 |
| athzp15kr70_1 | 408 | 500 | 2,204.7 | 51,214.9 | 244.30 | 31.1484 | na | na | na | na | 0.0672 | 0.20933 | 0.00057 | 0.21047 |
| **compromised package, homogenous core (6,847 g $UZrH_x$, poly, and water from wet Kaolite), wet Kaolite shell, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| **9 fuel segments (6,847 g $UZrH_x$)** | | | | | | | | | | | | | | |
| athzpw15kr70_5 | 408 | 500 | 6,803.8 | na | 538.50 | 12.6903 | 2,204.7 | 51,214.9 | 53,419.6 | 31.6977 | 0.0310 | 0.71851 | 0.00148 | 0.72147 |
| athzpw15kr70_4 | 408 | 500 | 5,102.9 | na | 429.70 | 11.7852 | 3,905.7 | 51,214.9 | 55,120.5 | 31.5622 | 0.0317 | 0.69647 | 0.00123 | 0.69894 |
| athzpw15kr70_3 | 408 | 500 | 3,401.9 | na | 320.90 | 10.7146 | 5,606.6 | 51,214.9 | 56,821.5 | 31.4254 | 0.0326 | 0.66072 | 0.00122 | 0.66315 |

**Table 6.9.6-22b. Results for TRIGA ($UZrH_x$) fuel element content at 70.1 wt % $^{235}U$ for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | $H_2O$ (g) | Kaolite (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| athzpw15kr70_2 | 408 | 500 | 1,701.0 | na | 212.10 | 9.3723 | 7,307.6 | 51,214.9 | 58,522.4 | 31.2875 | 0.0341 | 0.59094 | 0.00118 | 0.59330 |
| athzpw15kr70_1 | 408 | 500 | 0.0 | na | 103.30 | 7.4677 | 9,008.5 | 51,214.9 | 60,223.4 | 31.1484 | 0.0354 | 0.45119 | 0.00118 | 0.45355 |

**Table 6.9.6-22c. Results for research reactor fuel ($U_3O_8$-Al) content for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | $H_2O$ (g) | Kaolite (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| **compromised package, homogenous core ($UZrH_x$, poly, and water from wet Kaolite shell), wet Kaolite shell, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| **TRIGA content, 10,400 g $UZrH_x$ at 19.7 wt % $^{235}U$ (Reference Table 6.9.6-22a)** | | | | | | | | | | | | | | |
| athzpw15kr_5 | 921 | 500 | 6,803.8 | na | 236.10 | 12.6903 | 2,204.7 | 51,214.9 | 53,419.6 | 31.6977 | 0.0308 | 0.80474 | 0.00154 | 0.80781 |
| athzpw15kr_4 | 921 | 500 | 5,102.9 | na | 187.90 | 11.7852 | 3,905.7 | 51,214.9 | 55,120.5 | 31.5622 | 0.0316 | 0.76177 | 0.00142 | 0.76460 |
| athzpw15kr_3 | 921 | 500 | 3,401.9 | na | 139.70 | 10.7146 | 5,606.6 | 51,214.9 | 56,821.5 | 31.4254 | 0.0325 | 0.70349 | 0.00145 | 0.70638 |
| athzpw15kr_2 | 921 | 500 | 1,701.0 | na | 91.57 | 9.3723 | 7,307.6 | 51,214.9 | 58,522.4 | 31.2875 | 0.0334 | 0.61344 | 0.00132 | 0.61608 |
| athzpw15kr_1 | 921 | 500 | 0.0 | na | 43.37 | 7.4677 | 9,008.5 | 51,214.9 | 60,223.4 | 31.1484 | 0.0351 | 0.46733 | 0.00103 | 0.46938 |
| **compromised package, homogenous core ($UZrH_x$, poly, and water from wet Kaolite shell), wet Kaolite shell, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| **TRIGA content, 6,847 g $UZrH_x$ at 70.1 wt % $^{235}U$ (Reference Table 6.9.6-22b)** | | | | | | | | | | | | | | |
| athzpw15kr70_5 | 408 | 500 | 6,803.8 | na | 538.50 | 12.6903 | 2,204.7 | 51,214.9 | 53,419.6 | 31.6977 | 0.0310 | 0.71851 | 0.00148 | 0.72147 |
| athzpw15kr70_4 | 408 | 500 | 5,102.9 | na | 429.70 | 11.7852 | 3,905.7 | 51,214.9 | 55,120.5 | 31.5622 | 0.0317 | 0.69647 | 0.00123 | 0.69894 |
| athzpw15kr70_3 | 408 | 500 | 3,401.9 | na | 320.90 | 10.7146 | 5,606.6 | 51,214.9 | 56,821.5 | 31.4254 | 0.0326 | 0.66072 | 0.00122 | 0.66315 |
| athzpw15kr70_2 | 408 | 500 | 1,701.0 | na | 212.10 | 9.3723 | 7,307.6 | 51,214.9 | 58,522.4 | 31.2875 | 0.0341 | 0.59094 | 0.00118 | 0.59330 |
| athzpw15kr70_1 | 408 | 500 | 0.0 | na | 103.30 | 7.4677 | 9,008.5 | 51,214.9 | 60,223.4 | 31.1484 | 0.0354 | 0.45119 | 0.00118 | 0.45355 |

**Table 6.9.6-22c. Results for research reactor fuel ($U_3O_8$-Al) content for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | $H_2O$ (g) | Kaolite (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| **compromised package, homogenous core ($U_3O_8$-Al, poly, and water from wet Kaolite shell), wet Kaolite shell, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| **THAR content, 15,763 g $U_3O_8$-Al at 20 wt % $^{235}U$** | | | | | | | | | | | | | | |
| athopw15kr20_5 | 921 | 500 | 6,803.8 | na | 211.00 | 14.1381 | 2,204.7 | 51,214.9 | 53,419.6 | 31.9552 | 0.0370 | 0.62212 | 0.00133 | 0.62478 |
| athopw15kr20_4 | 921 | 500 | 5,102.9 | na | 162.80 | 13.4243 | 3,905.7 | 51,214.9 | 55,120.5 | 31.8218 | 0.0386 | 0.54443 | 0.00136 | 0.54715 |
| athopw15kr20_3 | 921 | 500 | 3,401.9 | na | 114.60 | 12.6252 | 5,606.6 | 51,214.9 | 56,821.5 | 31.6873 | 0.0412 | 0.43966 | 0.00106 | 0.44178 |
| athopw15kr20_2 | 921 | 500 | 1,701.0 | na | 66.42 | 11.7097 | 7,307.6 | 51,214.9 | 58,522.4 | 31.5517 | 0.0453 | 0.29892 | 0.00105 | 0.30102 |
| athopw15kr20_1 | 921 | 500 | 0.0 | na | 18.21 | 10.6230 | 9,008.5 | 51,214.9 | 60,223.4 | 31.4149 | 0.0515 | 0.16214 | 0.00052 | 0.16317 |
| **THAR content, 1,996 g $U_3O_8$-Al at 70 wt % $^{235}U$** | | | | | | | | | | | | | | |
| athopw15kr70_5 | 408 | 500 | 6,803.8 | na | 476.30 | 12.3688 | 2,204.7 | 51,214.9 | 53,419.6 | 31.6474 | 0.0340 | 0.67791 | 0.00146 | 0.68084 |
| athopw15kr70_4 | 408 | 500 | 5,102.9 | na | 367.50 | 11.4101 | 3,905.7 | 51,214.9 | 55,120.5 | 31.5114 | 0.0348 | 0.64009 | 0.00130 | 0.64269 |
| athopw15kr70_3 | 408 | 500 | 3,401.9 | na | 258.70 | 10.2557 | 5,606.6 | 51,214.9 | 56,821.5 | 31.3743 | 0.0369 | 0.57400 | 0.00118 | 0.57635 |
| athopw15kr70_2 | 408 | 500 | 1,701.0 | na | 149.90 | 8.7585 | 7,307.6 | 51,214.9 | 58,522.4 | 31.2359 | 0.0400 | 0.44909 | 0.00120 | 0.45150 |
| athopw15kr70_1 | 408 | 500 | 0.0 | na | 41.10 | 6.4237 | 9,008.5 | 51,214.9 | 60,223.4 | 31.0963 | 0.0479 | 0.18508 | 0.00083 | 0.18674 |
| **THAR content, 1,505 g $U_3O_8$-Al at 93 wt % $^{235}U$** | | | | | | | | | | | | | | |
| athopw15kr93_5 | 408 | 500 | 6,803.8 | na | 476.30 | 12.2959 | 2,204.7 | 51,214.9 | 53,419.6 | 31.6363 | 0.0338 | 0.69183 | 0.00144 | 0.69471 |
| athopw15kr93_4 | 408 | 500 | 5,102.9 | na | 367.50 | 11.3242 | 3,905.7 | 51,214.9 | 55,120.5 | 31.5002 | 0.0348 | 0.65724 | 0.00123 | 0.65970 |
| athopw15kr93_3 | 408 | 500 | 3,401.9 | na | 258.70 | 10.1491 | 5,606.6 | 51,214.9 | 56,821.5 | 31.3630 | 0.0365 | 0.59543 | 0.00147 | 0.59838 |
| athopw15kr93_2 | 408 | 500 | 1,701.0 | na | 149.90 | 8.6114 | 7,307.6 | 51,214.9 | 58,522.4 | 31.2245 | 0.0395 | 0.47503 | 0.00134 | 0.47771 |
| athopw15kr93_1 | 408 | 500 | 0.0 | na | 41.10 | 6.1427 | 9,008.5 | 51,214.9 | 60,223.4 | 31.0848 | 0.0471 | 0.20615 | 0.00083 | 0.20780 |

**Table 6.9.6-22d. Results for research reactor fuel ($UO_2$-Mg) content for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | $H_2O$ (g) | Kaolite (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| **compromised package, homogenous core ($UZrH_x$, poly, and water from wet Kaolite shell), wet Kaolite shell, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| **TRIGA content, 10,400 g $UZrH_x$ at 19.7 wt % $^{235}U$ (Reference Table 6.9.6-22a)** | | | | | | | | | | | | | | |
| athzpw15kr_5 | 921 | 500 | 6,803.8 | na | 236.10 | 12.6903 | 2,204.7 | 51,214.9 | 53,419.6 | 31.6977 | 0.0308 | 0.80474 | 0.00154 | 0.80781 |
| **compromised package, homogenous core (6,847 g $UZrH_x$, poly, and water from wet Kaolite shell), wet Kaolite shell, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| **TRIGA content, 6,847 g $UZrH_x$ at 70.1 wt % $^{235}U$ (Reference Table 6.9.6-22b)** | | | | | | | | | | | | | | |
| athzpw15kr70_5 | 408 | 500 | 6,803.8 | na | 538.50 | 12.6903 | 2,204.7 | 51,214.9 | 53,419.6 | 31.6977 | 0.0310 | 0.71851 | 0.00148 | 0.72147 |
| **compromised package, homogenous core ($UO_2$-Mg Al clad, poly, and water from wet Kaolite shell), wet Kaolite shell, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| **EK10 content, 19,592 g $UO_2$-Mg Al clad at 9.89 wt % $^{235}U$** | | | | | | | | | | | | | | |
| athupw15kr09_5 | 921 | 500 | 6,803.8 | na | 210.70 | 14.3227 | 2,204.7 | 51,214.9 | 53,419.6 | 31.9917 | 0.0370 | 0.59466 | 0.00133 | 0.59731 |
| athupw15kr09_4 | 921 | 500 | 5,102.9 | na | 162.60 | 13.6286 | 3,905.7 | 51,214.9 | 55,120.5 | 31.8587 | 0.0382 | 0.51941 | 0.00125 | 0.52191 |
| athupw15kr09_3 | 921 | 500 | 3,401.9 | na | 114.40 | 12.8555 | 5,606.6 | 51,214.9 | 56,821.5 | 31.7245 | 0.0413 | 0.41977 | 0.00109 | 0.42195 |
| athupw15kr09_2 | 921 | 500 | 1,701.0 | na | 66.34 | 11.9762 | 7,307.6 | 51,214.9 | 58,522.4 | 31.5892 | 0.0452 | 0.29437 | 0.00087 | 0.29611 |
| athupw15kr09_1 | 921 | 500 | 0.0 | na | 18.19 | 10.9444 | 9,008.5 | 51,214.9 | 60,223.4 | 31.4527 | 0.0512 | 0.17226 | 0.00061 | 0.17348 |
| **EK10 content, 9,678 g $UO_2$-Mg Al clad at 20 wt % $^{235}U$** | | | | | | | | | | | | | | |
| athupw15kr20_5 | 921 | 500 | 6,803.8 | na | 211.00 | 13.2769 | 2,204.7 | 51,214.9 | 53,419.6 | 31.7958 | 0.0356 | 0.68552 | 0.00138 | 0.68828 |
| athupw15kr20_4 | 921 | 500 | 5,102.9 | na | 162.80 | 12.4581 | 3,905.7 | 51,214.9 | 55,120.5 | 31.6611 | 0.0371 | 0.61477 | 0.00137 | 0.61752 |
| athupw15kr20_3 | 921 | 500 | 3,401.9 | na | 114.60 | 11.5148 | 5,606.6 | 51,214.9 | 56,821.5 | 31.5253 | 0.0394 | 0.51363 | 0.00128 | 0.51620 |
| athupw15kr20_2 | 921 | 500 | 1,701.0 | na | 66.41 | 10.3849 | 7,307.6 | 51,214.9 | 58,522.4 | 31.3882 | 0.0435 | 0.36126 | 0.00110 | 0.36346 |
| athupw15kr20_1 | 921 | 500 | 0.0 | na | 18.21 | 8.9343 | 9,008.5 | 51,214.9 | 60,223.4 | 31.2500 | 0.0514 | 0.16764 | 0.00069 | 0.16901 |
| **EK10 content, 921 g $UO_2$-Mg Al clad at 93.2 wt % $^{235}U$** | | | | | | | | | | | | | | |
| athupw15kr93_5 | 408 | 500 | 6,803.8 | na | 476.30 | 12.2567 | 2,204.7 | 51,214.9 | 53,419.6 | 31.6304 | 0.0338 | 0.69466 | 0.00138 | 0.69741 |
| athupw15kr93_4 | 408 | 500 | 5,102.9 | na | 367.50 | 11.2780 | 3,905.7 | 51,214.9 | 55,120.5 | 31.4943 | 0.0348 | 0.65939 | 0.00125 | 0.66189 |
| athupw15kr93_3 | 408 | 500 | 3,401.9 | na | 258.70 | 10.0914 | 5,606.6 | 51,214.9 | 56,821.5 | 31.3570 | 0.0365 | 0.59641 | 0.00153 | 0.59947 |

**Table 6.9.6-22d. Results for research reactor fuel ($UO_2$-Mg) content for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | $H_2O$ (g) | Kaolite (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| athupw15kr93_2 | 408 | 500 | 1,701.0 | na | 149.90 | 8.5310 | 7,307.6 | 51,214.9 | 58,522.4 | 31.2185 | 0.0395 | 0.47695 | 0.00113 | 0.47921 |
| athupw15kr93_1 | 408 | 500 | 0.0 | na | 41.10 | 5.9820 | 9,008.5 | 51,214.9 | 60,223.4 | 31.0787 | 0.0471 | 0.21220 | 0.00082 | 0.21384 |
| **497 g $UO_2$ at 93.2 wt % $^{235}U$** | | | | | | | | | | | | | | |
| athbpw15kr93_5 | 408 | 500 | 6,803.8 | na | 476.30 | 12.1057 | 2,204.7 | 51,214.9 | 53,419.6 | 31.6080 | 0.0329 | 0.70973 | 0.00139 | 0.71252 |
| athbpw15kr93_4 | 408 | 500 | 5,102.9 | na | 367.50 | 11.0990 | 3,905.7 | 51,214.9 | 55,120.5 | 31.4717 | 0.0341 | 0.67992 | 0.00137 | 0.68266 |
| athbpw15kr93_3 | 408 | 500 | 3,401.9 | na | 258.70 | 9.8664 | 5,606.6 | 51,214.9 | 56,821.5 | 31.3342 | 0.0360 | 0.62656 | 0.00139 | 0.62935 |
| athbpw15kr93_2 | 408 | 500 | 1,701.0 | na | 149.90 | 8.2112 | 7,307.6 | 51,214.9 | 58,522.4 | 31.1954 | 0.0384 | 0.52289 | 0.00131 | 0.52550 |
| athbpw15kr93_1 | 408 | 500 | 0.0 | na | 41.10 | 5.2756 | 9,008.5 | 51,214.9 | 60,223.4 | 31.0555 | 0.0437 | 0.30087 | 0.00123 | 0.30334 |

**Table 6.9.6-23. Results for HEU broken metal content for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | $H_2O$ (g) | Kaolite (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| **compromised package, HEU in spherical configuration, 20.0 cm water reflector (See Table 6.9.6-21)** | | | | | | | | | | | | | | |
| **compromised package, HEU in spherical configuration, stainless steel, 20.0 cm water reflector (See Table 6.9.6-21)** | | | | | | | | | | | | | | |
| **compromised package, HEU in spherical configuration, Kaolite shell, 20.0 cm water reflector (See Table 6.9.6-21)** | | | | | | | | | | | | | | |
| **compromised package, homogenous core (HEU broken metal, poly, and wet Kaolite) in spherical configuration, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| **7,000 g HEU 100% enrichment** | | | | | | | | | | | | | | |
| athmp15kr_12_8_5 | 7,000 | 500 | 9008.5 | 51,214.9 | 35.99 | 31.0803 | na | na | na | na | 0.0579 | 0.58855 | 0.00115 | 0.59085 |
| athmp15kr_12_8_4 | 7,000 | 500 | 7307.6 | 51,214.9 | 29.64 | 31.0803 | na | na | na | na | 0.0600 | 0.56644 | 0.00118 | 0.56880 |
| athmp15kr_12_8_3 | 7,000 | 500 | 5606.6 | 51,214.9 | 23.30 | 31.0803 | na | na | na | na | 0.0617 | 0.54431 | 0.00107 | 0.54644 |

**Table 6.9.6-23. Results for HEU broken metal content for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | $H_2O$ (g) | Kaolite (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| athmp15kr_12_8_2 | 7,000 | 500 | 3905.7 | 51,214.9 | 16.96 | 31.0803 | na | na | na | na | 0.0640 | 0.51987 | 0.00112 | 0.52211 |
| athmp15kr_12_8_1 | 7,000 | 500 | 2204.7 | 51,214.9 | 10.62 | 31.0803 | na | na | na | na | 0.0658 | 0.50016 | 0.00111 | 0.50238 |
| **35,000 g HEU 20% enrichment** | | | | | | | | | | | | | | |
| athmp15kr_12_1_5 | 7,000 | 500 | 9008.5 | 51,214.9 | 7.20 | 31.2009 | na | na | na | na | 0.0558 | 0.56801 | 0.00109 | 0.57020 |
| athmp15kr_12_1_4 | 7,000 | 500 | 7307.6 | 51,214.9 | 5.93 | 31.2009 | na | na | na | na | 0.0579 | 0.54764 | 0.00104 | 0.54972 |
| athmp15kr_12_1_3 | 7,000 | 500 | 5606.6 | 51,214.9 | 4.66 | 31.2009 | na | na | na | na | 0.0603 | 0.52686 | 0.00109 | 0.52904 |
| athmp15kr_12_1_2 | 7,000 | 500 | 3905.7 | 51,214.9 | 3.39 | 31.2009 | na | na | na | na | 0.0621 | 0.50549 | 0.00104 | 0.50757 |
| athmp15kr_12_1_1 | 7,000 | 500 | 2204.7 | 51,214.9 | 2.12 | 31.2009 | na | na | na | na | 0.0645 | 0.48986 | 0.00121 | 0.49227 |
| **compromised package, homogenous core (HEU broken metal, poly, and water from wet Kaolite shell), wet Kaolite shell, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| **free water limited to 15 lb** | | | | | | | | | | | | | | |
| athmpw15kr_12_8_5 | 7,000 | 500 | 6803.8 | na | 27.77 | 12.2667 | 2,204.7 | 51,214.9 | 53,419.6 | 31.6319 | 0.0344 | 0.95651 | 0.00153 | 0.95956 |
| athmpw15kr_12_8_4 | 7,000 | 500 | 5102.9 | na | 21.42 | 11.2898 | 3,905.7 | 51,214.9 | 55,120.5 | 31.4958 | 0.0345 | 0.89106 | 0.00148 | 0.89402 |
| athmpw15kr_12_8_3 | 7,000 | 500 | 3401.9 | na | 15.08 | 10.1062 | 5,606.6 | 51,214.9 | 56,821.5 | 31.3585 | 0.0358 | 0.81175 | 0.00129 | 0.81433 |
| athmpw15kr_12_8_2 | 7,000 | 500 | 1701.0 | na | 8.74 | 8.5517 | 7,307.6 | 51,214.9 | 58,522.4 | 31.2200 | 0.0377 | 0.70771 | 0.00118 | 0.71008 |
| athmpw15kr_12_8_1 | 7,000 | 500 | 0.0 | na | 2.40 | 6.0238 | 9,008.5 | 51,214.9 | 60,223.4 | 31.0802 | 0.0401 | 0.60135 | 0.00123 | 0.60381 |
| **free water limited to 13 lb** | | | | | | | | | | | | | | |
| athmpw13kr_12_8_5 | 7,000 | 500 | 5896.7 | na | 24.38 | 11.7659 | 2,204.7 | 51,214.9 | 53,419.6 | 31.5595 | 0.0353 | 0.92418 | 0.00152 | 0.92721 |
| athmpw13kr_12_8_4 | 7,000 | 500 | 4422.5 | na | 18.89 | 10.8471 | 3,678.9 | 51,214.9 | 54,893.7 | 31.4410 | 0.0359 | 0.85851 | 0.00141 | 0.86133 |
| athmpw13kr_12_8_3 | 7,000 | 500 | 2948.3 | na | 13.39 | 9.7390 | 5,153.0 | 51,214.9 | 56,367.9 | 31.3217 | 0.0371 | 0.78403 | 0.00138 | 0.78680 |
| athmpw13kr_12_8_2 | 7,000 | 500 | 1474.2 | na | 7.89 | 8.2969 | 6,627.2 | 51,214.9 | 57,842.0 | 31.2014 | 0.0388 | 0.69268 | 0.00133 | 0.69535 |
| athmpw13kr_12_8_1 | 7,000 | 500 | 0.0 | na | 2.40 | 6.0238 | 8,101.3 | 51,214.9 | 59,316.2 | 31.0802 | 0.0413 | 0.59728 | 0.00111 | 0.59950 |
| **free water limited to 12 lb** | | | | | | | | | | | | | | |
| athmpw12kr_12_8_5 | 7,000 | 500 | 5443.1 | na | 22.69 | 11.4987 | 2,204.7 | 51,214.9 | 53,419.6 | 31.5231 | 0.0358 | 0.90261 | 0.00179 | 0.90618 |
| athmpw12kr_12_8_4 | 7,000 | 500 | 4082.3 | na | 17.62 | 10.6116 | 3,565.5 | 51,214.9 | 54,780.3 | 31.4136 | 0.0363 | 0.84275 | 0.00146 | 0.84568 |
| athmpw12kr_12_8_3 | 7,000 | 500 | 2721.5 | na | 12.54 | 9.5445 | 4,926.2 | 51,214.9 | 56,141.1 | 31.3033 | 0.0377 | 0.77003 | 0.00157 | 0.77317 |

**Table 6.9.6-23. Results for HEU broken metal content for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | $H_2O$ (g) | Kaolite (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| athmpw12kr_12_8_2 | 7,000 | 500 | 1360.8 | na | 7.47 | 8.1635 | 6,287.0 | 51,214.9 | 57,501.8 | 31.1921 | 0.0397 | 0.68336 | 0.00123 | 0.68583 |
| athmpw12kr_12_8_1 | 7,000 | 500 | 0.0 | na | 2.40 | 6.0238 | 7,647.8 | 51,214.9 | 58,862.6 | 31.0802 | 0.0420 | 0.59769 | 0.00093 | 0.59955 |
| **5,000 g HEU 100% enrichment** | | | | | | | | | | | | | | |
| **compromised package, homogenous core (HEU broken metal, poly, and wet Kaolite), HEU shell, 20.0 cm water reflector** | | | | | | | | | | | | | | |
| **7,000 g HEU total at 100% enrichment** | | | | | | | | | | | | | | |
| athmp15kmr_ | | | | | | | | | | | | | | |
| 13_1_8_5 | 6,500 | 500 | 9,008.5 | 51,214.9 | 38.75 | 31.0781 | na | na | 500 | 31.0804 | 0.0574 | 0.60317 | 0.00119 | 0.60556 |
| 13_1_8_4 | 6,500 | 500 | 7,307.6 | 51,214.9 | 31.92 | 31.0781 | na | na | 500 | 31.0804 | 0.0591 | 0.57747 | 0.00116 | 0.57980 |
| 13_1_8_3 | 6,500 | 500 | 5,606.6 | 51,214.9 | 25.09 | 31.0781 | na | na | 500 | 31.0804 | 0.0599 | 0.55460 | 0.00118 | 0.55695 |
| 13_1_8_2 | 6,500 | 500 | 3,905.7 | 51,214.9 | 18.26 | 31.0781 | na | na | 500 | 31.0804 | 0.0628 | 0.52945 | 0.00111 | 0.53166 |
| 13_1_8_1 | 6,500 | 500 | 2,204.7 | 51,214.9 | 11.43 | 31.0781 | na | na | 500 | 31.0804 | 0.0653 | 0.50475 | 0.00103 | 0.50680 |
| athmp15kmr_ | | | | | | | | | | | | | | |
| 12_2_8_5 | 6,000 | 500 | 9,008.5 | 51,214.9 | 41.98 | 31.0759 | na | na | 1,000 | 31.0804 | 0.0570 | 0.61042 | 0.00108 | 0.61259 |
| 12_2_8_4 | 6,000 | 500 | 7,307.6 | 51,214.9 | 34.58 | 31.0759 | na | na | 1,000 | 31.0804 | 0.0584 | 0.58402 | 0.00116 | 0.58635 |
| 12_2_8_3 | 6,000 | 500 | 5,606.6 | 51,214.9 | 27.18 | 31.0759 | na | na | 1,000 | 31.0804 | 0.0597 | 0.56023 | 0.00112 | 0.56247 |
| 12_2_8_2 | 6,000 | 500 | 3,905.7 | 51,214.9 | 19.79 | 31.0759 | na | na | 1,000 | 31.0804 | 0.0622 | 0.53546 | 0.00120 | 0.53785 |
| 12_2_8_1 | 6,000 | 500 | 2,204.7 | 51,214.9 | 12.39 | 31.0759 | na | na | 1,000 | 31.0804 | 0.0641 | 0.51198 | 0.00121 | 0.51440 |
| athmp15kmr_ | | | | | | | | | | | | | | |
| 11_3_8_5 | 5,500 | 500 | 9,008.5 | 51,214.9 | 45.80 | 31.0737 | na | na | 1,500 | 31.0804 | 0.0562 | 0.61411 | 0.00105 | 0.61622 |
| 11_3_8_4 | 5,500 | 500 | 7,307.6 | 51,214.9 | 37.73 | 31.0737 | na | na | 1,500 | 31.0804 | 0.0580 | 0.58816 | 0.00119 | 0.59055 |
| 11_3_8_3 | 5,500 | 500 | 5,606.6 | 51,214.9 | 29.66 | 31.0737 | na | na | 1,500 | 31.0804 | 0.0596 | 0.56400 | 0.00110 | 0.56619 |
| 11_3_8_2 | 5,500 | 500 | 3,905.7 | 51,214.9 | 21.58 | 31.0737 | na | na | 1,500 | 31.0804 | 0.0620 | 0.53899 | 0.00140 | 0.54180 |
| 11_3_8_1 | 5,500 | 500 | 2,204.7 | 51,214.9 | 13.51 | 31.0737 | na | na | 1,500 | 31.0804 | 0.0643 | 0.51766 | 0.00116 | 0.51999 |

**Table 6.9.6-23. Results for HEU broken metal content for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | $H_2O$ (g) | Kaolite (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| athmp15kmr_ | | | | | | | | | | | | | | |
| 10_4_8_5 | 5,000 | 500 | 9,008.5 | 51,214.9 | 50.38 | 31.0715 | na | na | 2,000 | 31.0804 | 0.0561 | 0.61900 | 0.00118 | 0.62136 |
| 10_4_8_4 | 5,000 | 500 | 7,307.6 | 51,214.9 | 41.50 | 31.0715 | na | na | 2,000 | 31.0804 | 0.0575 | 0.59390 | 0.00121 | 0.59633 |
| 10_4_8_3 | 5,000 | 500 | 5,606.6 | 51,214.9 | 32.62 | 31.0715 | na | na | 2,000 | 31.0804 | 0.0594 | 0.57154 | 0.00119 | 0.57393 |
| 10_4_8_2 | 5,000 | 500 | 3,905.7 | 51,214.9 | 23.74 | 31.0715 | na | na | 2,000 | 31.0804 | 0.0609 | 0.54282 | 0.00127 | 0.54536 |
| 10_4_8_1 | 5,000 | 500 | 2,204.7 | 51,214.9 | 14.86 | 31.0715 | na | na | 2,000 | 31.0804 | 0.0634 | 0.52061 | 0.00121 | 0.52302 |
| athmp15kmr_ | | | | | | | | | | | | | | |
| 9_5_8_5 | 4,500 | 500 | 9,008.5 | 51,214.9 | 55.98 | 31.0693 | na | na | 2,500 | 31.0804 | 0.0554 | 0.62058 | 0.00116 | 0.62290 |
| 9_5_8_4 | 4,500 | 500 | 7,307.6 | 51,214.9 | 46.11 | 31.0693 | na | na | 2,500 | 31.0804 | 0.0575 | 0.59711 | 0.00124 | 0.59959 |
| 9_5_8_3 | 4,500 | 500 | 5,606.6 | 51,214.9 | 36.25 | 31.0693 | na | na | 2,500 | 31.0804 | 0.0590 | 0.57410 | 0.00120 | 0.57651 |
| 9_5_8_2 | 4,500 | 500 | 3,905.7 | 51,214.9 | 26.38 | 31.0693 | na | na | 2,500 | 31.0804 | 0.0602 | 0.54863 | 0.00137 | 0.55137 |
| 9_5_8_1 | 4,500 | 500 | 2,204.7 | 51,214.9 | 16.51 | 31.0693 | na | na | 2,500 | 31.0804 | 0.0626 | 0.52393 | 0.00109 | 0.52612 |
| athmp15kmr_ | | | | | | | | | | | | | | |
| 8_6_8_5 | 4,000 | 500 | 9,008.5 | 51,214.9 | 62.98 | 31.0671 | na | na | 3,000 | 31.0804 | 0.0550 | 0.62552 | 0.00127 | 0.62807 |
| 8_6_8_4 | 4,000 | 500 | 7,307.6 | 51,214.9 | 51.88 | 31.0671 | na | na | 3,000 | 31.0804 | 0.0567 | 0.59946 | 0.00102 | 0.60150 |
| 8_6_8_3 | 4,000 | 500 | 5,606.6 | 51,214.9 | 40.78 | 31.0671 | na | na | 3,000 | 31.0804 | 0.0586 | 0.57673 | 0.00115 | 0.57902 |
| 8_6_8_2 | 4,000 | 500 | 3,905.7 | 51,214.9 | 29.68 | 31.0671 | na | na | 3,000 | 31.0804 | 0.0600 | 0.54941 | 0.00110 | 0.55162 |
| 8_6_8_1 | 4,000 | 500 | 2,204.7 | 51,214.9 | 18.58 | 31.0671 | na | na | 3,000 | 31.0804 | 0.0618 | 0.52536 | 0.00112 | 0.52759 |
| athmp15kmr_ | | | | | | | | | | | | | | |
| 7_7_8_5 | 3,500 | 500 | 9,008.5 | 51,214.9 | 71.97 | 31.0649 | na | na | 3,500 | 31.0804 | 0.0549 | 0.62911 | 0.00118 | 0.63147 |
| 7_7_8_4 | 3,500 | 500 | 7,307.6 | 51,214.9 | 59.29 | 31.0649 | na | na | 3,500 | 31.0804 | 0.0559 | 0.60301 | 0.00111 | 0.60524 |
| 7_7_8_3 | 3,500 | 500 | 5,606.6 | 51,214.9 | 46.60 | 31.0649 | na | na | 3,500 | 31.0804 | 0.0585 | 0.58073 | 0.00114 | 0.58300 |
| 7_7_8_2 | 3,500 | 500 | 3,905.7 | 51,214.9 | 33.92 | 31.0649 | na | na | 3,500 | 31.0804 | 0.0595 | 0.55359 | 0.00105 | 0.55569 |
| 7_7_8_1 | 3,500 | 500 | 2,204.7 | 51,214.9 | 21.23 | 31.0649 | na | na | 3,500 | 31.0804 | 0.0616 | 0.52699 | 0.00109 | 0.52917 |

**Table 6.9.6-23. Results for HEU broken metal content for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | $H_2O$ (g) | Kaolite (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| athmp15kmr_ | | | | | | | | | | | | | | |
| 6_8_8_5 | 3,000 | 500 | 9,008.5 | 51,214.9 | 83.97 | 31.0627 | na | na | 4,000 | 31.0804 | 0.0546 | 0.62838 | 0.00151 | 0.63139 |
| 6_8_8_4 | 3,000 | 500 | 7,307.6 | 51,214.9 | 69.17 | 31.0627 | na | na | 4,000 | 31.0804 | 0.0555 | 0.60625 | 0.00125 | 0.60875 |
| 6_8_8_3 | 3,000 | 500 | 5,606.6 | 51,214.9 | 54.37 | 31.0627 | na | na | 4,000 | 31.0804 | 0.0578 | 0.58134 | 0.00125 | 0.58383 |
| 6_8_8_2 | 3,000 | 500 | 3,905.7 | 51,214.9 | 39.57 | 31.0627 | na | na | 4,000 | 31.0804 | 0.0594 | 0.55515 | 0.00127 | 0.55768 |
| 6_8_8_1 | 3,000 | 500 | 2,204.7 | 51,214.9 | 24.77 | 31.0627 | na | na | 4,000 | 31.0804 | 0.0610 | 0.53102 | 0.00108 | 0.53319 |
| athmp15kmr_ | | | | | | | | | | | | | | |
| 5_9_8_5 | 2,500 | 500 | 9,008.5 | 51,214.9 | 100.76 | 31.0605 | na | na | 4,500 | 31.0804 | 0.0538 | 0.63099 | 0.00114 | 0.63327 |
| 5_9_8_4 | 2,500 | 500 | 7,307.6 | 51,214.9 | 83.00 | 31.0605 | na | na | 4,500 | 31.0804 | 0.0558 | 0.60575 | 0.00136 | 0.60847 |
| 5_9_8_3 | 2,500 | 500 | 5,606.6 | 51,214.9 | 65.24 | 31.0605 | na | na | 4,500 | 31.0804 | 0.0567 | 0.58348 | 0.00109 | 0.58565 |
| 5_9_8_2 | 2,500 | 500 | 3,905.7 | 51,214.9 | 47.48 | 31.0605 | na | na | 4,500 | 31.0804 | 0.0589 | 0.55833 | 0.00117 | 0.56068 |
| 5_9_8_1 | 2,500 | 500 | 2,204.7 | 51,214.9 | 29.73 | 31.0605 | na | na | 4,500 | 31.0804 | 0.0603 | 0.53262 | 0.00106 | 0.53475 |
| athmp15kmr_ | | | | | | | | | | | | | | |
| 4_10_8_5 | 2,000 | 500 | 9,008.5 | 51,214.9 | 125.95 | 31.0583 | na | na | 5,000 | 31.0804 | 0.0543 | 0.62891 | 0.00114 | 0.63120 |
| 4_10_8_4 | 2,000 | 500 | 7,307.6 | 51,214.9 | 103.75 | 31.0583 | na | na | 5,000 | 31.0804 | 0.0550 | 0.60731 | 0.00134 | 0.60999 |
| 4_10_8_3 | 2,000 | 500 | 5,606.6 | 51,214.9 | 81.55 | 31.0583 | na | na | 5,000 | 31.0804 | 0.0571 | 0.58296 | 0.00114 | 0.58524 |
| 4_10_8_2 | 2,000 | 500 | 3,905.7 | 51,214.9 | 59.36 | 31.0583 | na | na | 5,000 | 31.0804 | 0.0585 | 0.55876 | 0.00107 | 0.56090 |
| 4_10_8_1 | 2,000 | 500 | 2,204.7 | 51,214.9 | 37.16 | 31.0583 | na | na | 5,000 | 31.0804 | 0.0595 | 0.53467 | 0.00107 | 0.53680 |
| athmp15kmr_ | | | | | | | | | | | | | | |
| 3_11_8_5 | 1,500 | 500 | 9,008.5 | 51,214.9 | 167.93 | 31.0562 | na | na | 5,500 | 31.0804 | 0.0537 | 0.62987 | 0.00112 | 0.63211 |
| 3_11_8_4 | 1,500 | 500 | 7,307.6 | 51,214.9 | 138.34 | 31.0562 | na | na | 5,500 | 31.0804 | 0.0548 | 0.60668 | 0.00123 | 0.60914 |
| 3_11_8_3 | 1,500 | 500 | 5,606.6 | 51,214.9 | 108.74 | 31.0562 | na | na | 5,500 | 31.0804 | 0.0562 | 0.58487 | 0.00114 | 0.58715 |
| 3_11_8_2 | 1,500 | 500 | 3,905.7 | 51,214.9 | 79.14 | 31.0562 | na | na | 5,500 | 31.0804 | 0.0576 | 0.56087 | 0.00115 | 0.56318 |
| 3_11_8_1 | 1,500 | 500 | 2,204.7 | 51,214.9 | 49.54 | 31.0562 | na | na | 5,500 | 31.0804 | 0.0591 | 0.53887 | 0.00135 | 0.54156 |

**Table 6.9.6-23. Results for HEU broken metal content for air transportation**

| case name | $^{235}U$ (g) | $CH_2$ (g) | $H_2O$ (g) | Kaolite (g) | h/x | Rc (cm) | $H_2O$ (g) | Kaolite (g) | Shell (g) | Rs (cm) | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | core | | | | | | shell | | | | | | | |
| athmp15kmr_ | | | | | | | | | | | | | | |
| 2_12_8_5 | 1,000 | 500 | 9,008.5 | 51,214.9 | 251.90 | 31.0540 | na | na | 6,000 | 31.0804 | 0.0533 | 0.62727 | 0.00121 | 0.62970 |
| 2_12_8_4 | 1,000 | 500 | 7,307.6 | 51,214.9 | 207.50 | 31.0540 | na | na | 6,000 | 31.0804 | 0.0544 | 0.60687 | 0.00128 | 0.60942 |
| 2_12_8_3 | 1,000 | 500 | 5,606.6 | 51,214.9 | 163.11 | 31.0540 | na | na | 6,000 | 31.0804 | 0.0559 | 0.58520 | 0.00134 | 0.58788 |
| 2_12_8_2 | 1,000 | 500 | 3,905.7 | 51,214.9 | 118.71 | 31.0540 | na | na | 6,000 | 31.0804 | 0.0571 | 0.56092 | 0.00109 | 0.56310 |
| 2_12_8_1 | 1,000 | 500 | 2,204.7 | 51,214.9 | 74.32 | 31.0540 | na | na | 6,000 | 31.0804 | 0.0587 | 0.54206 | 0.00105 | 0.54415 |
| athmp15kmr_ | | | | | | | | | | | | | | |
| 1_13_8_5 | 500 | 500 | 9,008.5 | 51,214.9 | 503.80 | 31.0518 | na | na | 6,500 | 31.0804 | 0.0526 | 0.62145 | 0.00093 | 0.62332 |
| 1_13_8_4 | 500 | 500 | 7,307.6 | 51,214.9 | 415.01 | 31.0518 | na | na | 6,500 | 31.0804 | 0.0534 | 0.60274 | 0.00132 | 0.60537 |
| 1_13_8_3 | 500 | 500 | 5,606.6 | 51,214.9 | 326.22 | 31.0518 | na | na | 6,500 | 31.0804 | 0.0552 | 0.58252 | 0.00115 | 0.58482 |
| 1_13_8_2 | 500 | 500 | 3,905.7 | 51,214.9 | 237.42 | 31.0518 | na | na | 6,500 | 31.0804 | 0.0567 | 0.56327 | 0.00121 | 0.56570 |
| 1_13_8_1 | 500 | 500 | 2,204.7 | 51,214.9 | 148.63 | 31.0518 | na | na | 6,500 | 31.0804 | 0.0579 | 0.54039 | 0.00112 | 0.54263 |

## Appendix 6.9.7

## Input Listings of ES-3100 Calculation Models for Select Cases

This appendix contains selected input listing for calculations identified Tables 6.1a-f and Sects. 6.4, 6.5, and 6.6 of this document, and Sect. 6.7 on air transport.

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## ES-3100 Input file - Results table crosswalk

| Section | Case | Description | Results table |
|---|---|---|---|
| 6.9.7.1 | cvcrcyt11_21_1 | 3 cyl, 0.0 in. np, 21000 g U (21000 g $^{235}U$, 9082.6 g $H_2O$, h/x=11.29) | 6.9.6-1 |
| 6.9.7.2 | cvcrcyt11_36_2 | 3 cyl, 1.4 in. np, 36000 g U (36000 g $^{235}U$, 7673.1 g $H_2O$, h/x=5.56) | 6.9.6-1 |
| 6.9.7.3 | cvcrsqt11_36_1 | 3 bar, 0.0 in. np, 36000 g U (36000 g $^{235}U$, 8286.7 g $H_2O$, h/x=6.01) | 6.9.6-4 |
| 6.9.7.4 | cvcrcyct11_17_1 | 3 cyl, 0.0 in. np, 17000 gU (17000 g $^{235}U$, 9294.9 g $H_2O$, h/x=14.27) | 6.9.6-6 |
| 6.9.7.5 | cvcrcyct11_32_2 | 3 cyl, 1.4 in. np, 32000 g U (32000 g $^{235}U$, 7885.3 g $H_2O$, h/x= 6.43) | 6.9.6-6 |
| 6.9.7.6 | cvcr5est11_1_1 | 0.0 in. np, 18286.5 g U (18286.5 g $^{235}U$, 9226.6 g $H_2O$, h/x=13.75) | 6.9.6-8 |
| 6.9.7.7 | cvcr6e4st11_1 | 1.4 in. np, 36573.0 g U (36573.0 g $^{235}U$, 7642.7 g $H_2O$, h/x= 5.45) | 6.9.6-8 |
| 6.9.7.8 | cvcr70st11_2 | 1.4 in. np, 25588.2 g U (25588.2 g $^{235}U$, 8225.3 g $H_2O$, h/x= 8.39) | 6.9.6-8 |
| 6.9.7.9 | cvr3sqa_26_1_8_15 | 0.0 in. np, 25893.7 g U (25893.7 g $^{235}U$, 8822.9 g $H_2O$, h/x= 8.89) | N/A[a] |
| 6.9.7.10 | cvr3lha_26_1_8_15 | 0.0 in. np, 25893.7 g U (25893.7 g $^{235}U$, 8822.9 g $H_2O$, h/x= 8.89) | 6.9.6-10 |
| 6.9.7.11 | cvr3cha_26_1_8_15 | 0.0 in. np, 25893.7 g U (25893.7 g $^{235}U$, 8822.9 g $H_2O$, h/x= 8.89) | N/A[a] |
| 6.9.7.12 | cvcrpdoxt11_1_5_24_15 | 0.0 in. np, disp. 24,000 g $UO_2$ (21,124.9 g $^{235}U$, 1,477.3 g Sat.$H_2O$), 4 g $H_2O$ CV, h/x= 10.02) | 6.9.6-12 |
| 6.9.7.13 | cvcrsk3cc_9_15_17 | 0.0 in. np, 21300 g SOC (19865.3 g UOx, 15672.8 g $^{235}U$, 921.0 g C, h/x=12.82) | 6.9.6-17 |
| 6.9.7.14 | cvcrunhct11_9_1 | 0.0 in. np, disp. 9000 g UNHc (4238.7 g $^{235}U$, 6980.8 g $H_2O$, h/x=54.99) | 6.9.6-14 |
| 6.9.7.15 | cvcrtriga_1_15 | 0.0 in. np, 10400.0 g UZrHx (921.0 g $^{235}U$, 8998.2 g $H_2O$, h/x=255.01) | 6.9.6-19a |
| 6.9.7.16 | ncsrcyt11_21_1_15 | 3 cyl, 0.0 in. np, 21000 g U (21000 g $^{235}U$, 9082.6 g $H_2O$, h/x=11.29) | 6.9.6-2 |
| 6.9.7.17 | nciacyct11_25_2_3 | 3 cyl, 1.4 in. np, 25000 g U (25000 g $^{235}U$, 8256.8 g $H_2O$, h/x= 8.62) | 6.9.6-7 |
| 6.9.7.18 | hciacyct12_25_2_3 | 3 cyl, 1.4 in. np, 25000 g U (25000 g $^{235}U$, 8256.8 g $H_2O$, h/x= 8.62) | 6.9.6-7 |
| 6.9.7.19 | ncia70st11_2_8_3 | 1.4 in. np, 25588.2 g U (25588.2 g $^{235}U$, 8224.9 g $H_2O$, h/x= 8.39) | 6.9.6-9 |
| 6.9.7.20 | ncia5est11_2_2_5_3 | 1.4 in. np, 36647 g U (29318 g $^{235}U$, 7642.7 g $H_2O$, h/x= 6.80) | 6.9.6-9 |
| 6.9.7.21 | nciabmt11_4_1_5_3 | 0.0 in. np, 3708.5 g U (2966.8 g $^{235}U$, 10000.7 g $H_2O$, h/x=87.98) | 6.9.6-11 |
| 6.9.7.22 | hctf5bmt12_25_2_8_3 | 1.4 in. np, 24968.9 g U (24968.9 g $^{235}U$, 8258.4 g $H_2O$, h/x= 8.63) | 6.9.6-11 |
| 6.9.7.23 | nciaoxt11_1_24_1_3 | 0.0 in. np, disp. 24000 g $UO_2$ (21124.9 g $^{235}U$, 6533.9 g $H_2O$, h/x= 9.90) | N/A[a] |
| 6.9.7.24 | nciask_9_15 | 0.0 in. np, 21300 g SOC (19865.3 g UOx, 15672.8 g $^{235}U$, 921.0 g C, h/x=12.82) | 6.9.6-18a |
| 6.9.7.25 | ncsrunhct11_9_1_15 | 0.0 in. np, disp. 9000 g UNHc (4238.7 g $^{235}U$, 6980.8 g $H_2O$, h/x=54.99) | 6.9.6-15 |
| 6.9.7.26 | icsrunhct12_15_1_15 | 0.0 in.. np, disp. 15,000.0 g UNHc (7064.4 g $^{235}U$, 6870.7 g $H_2O$, h/x=52.91) | 6.9.6-16 |

## ES-3100 Input file - Results table crosswalk

| Section | Case | Description | Results table |
|---|---|---|---|
| 6.9.7.27 | ncsrtriga_1_15_15 | 0.0 in. np, 10400.0 g UZrHx (921.0 g $^{235}$U, 8998.2 g $H_2O$, h/x=255.01) | 6.9.6-20a |
| 6.9.7.28 | nciatriga_1_15_3 | 0.0 in. np, 10400.0 g UZrHx (921.0 g $^{235}$U, 8998.2 g $H_2O$, h/x=255.01) | 6.9.6-20a |
| 6.9.7.29 | atdmr_7_8 | 7000 g U, 7000 g $^{235}$U, 500.0 g $CH_2$, h/x=2.40, Rc=6.02382 cm | 6.9.6-21 |
| 6.9.7.30 | atdmsr_7_8_11 | 7000 g U, 7000 g $^{235}$U, 500.0 g $CH_2$, h/x=2.40, Rc=6.02382 cm, 66133.1 g SS, Rs=13.0198 cm | 6.9.6-21 |
| 6.9.7.31 | atdmdkr_7_8_6 | 7000 g U, 7000 g $^{235}$U, 500.0 g $CH_2$, h/x=2.40, Rc=6.02382 cm, 53419.1 g Kao, Rk=31.0802 cm | 6.9.6-21 |
| 6.9.7.32 | atdzr | 10400.0 g $UZrH_x$ (921.0 g $^{235}$U, 500.0 g $CH_2$, h/x=43.37), Rc=7.4677 cm | 6.9.6-22a |
| 6.9.7.33 | athzp15kr_5 | 10400.0 g $UZrH_x$ (921.0 g $^{235}$U, 500.0 g $CH_2$, 9008.5 g $H_2O$, h/x=298.6), Rc=31.14838 cm | 6.9.6-22a |
| 6.9.7.34 | athzpw15kr_5 | 10400 g $UZrH_x$, 921.0 g $^{235}$U, 500.0 g $CH_2$, 6803.8 g $H_2O$, h/x=236.1, Rc=12.69027 cm, Rs=31.69769 cm | 6.9.6-22a |
| 6.9.7.35 | athmp15kr_12_8_5 | 7000 g U, 7000 g $^{235}$U, 500.0 g $CH_2$, 9008.3 g $H_2O$, h/x=35.99, Rc=31.08025 cm | 6.9.6-23 |
| 6.9.7.36 | athmpw15kr_12_8_5 | 7000 g U, 7000 g $^{235}$U, 500.0 g $CH_2$, 6803.8 g $H_2O$, h/x=27.77, Rc=12.26673 cm, 53419.6 g Kao, Rs=31.63191 cm | 6.9.6-23 |
| 6.9.7.37 | athmpw13kr_12_8_5 | 7000 g U, 7000 g $^{235}$U, 500.0 g $CH_2$, 5896.6 g $H_2O$, h/x=24.38, Rc=11.76592 cm, 53419.6 g Kao, Rs=31.55946 cm | 6.9.6-23 |
| 6.9.7.38 | athmp15kmr_7_7_8_5 | 7000 g U,(3500 g $^{235}$U, 500 g $CH_2$, 9008.5 g $H_2O$, h/x=71.97, Rc=31.06492 cm, 3500 g $^{235}$U, Rs=31.08035 cm | 6.9.6-23 |
| 6.9.7.39 | cvcrtriga_1_1 | 0.0 in. np, 10400.0 g $UZrH_x$ (921.0 g $^{235}$U, 0.0 g $H_2O$, hx = 0.00) | 6.9.6-19a |
| 6.9.7.40 | cvcrtriga_1_15 | 0.0 in. np, 10400.0 g $UZrH_x$ (921.0 g $^{235}$U, 8998.2 g $H_2O$, hx = 255.01) | 6.9.6-19a |
| 6.9.7.41 | cvcrtriga_2_15 | 1.4 in. np, 10400.0 g $UZrH_x$ (921.0 g $^{235}$U, 8384.6 g $H_2O$, h/x = 237.62) | 6.9.6-19a |
| 6.9.7.42 | cvcrtriga_70_1_1 | 0.0 in. np, 6847.1 g $UZrH_x$ (408.0 g $^{235}$U, 0.0 g $H_2O$, h/x = 0.0) | 6.9.6-19a |
| 6.9.7.43 | cvcrtriga_70_1_15 | 0.0 in. np, 6847.1 g $UZrH_x$ (408.0 g $^{235}$U, 8998.2 g $H_2O$, h/x = 575.64) | 6.9.6-19a |
| 6.9.7.44 | cvcrtriga_70_2_15 | 1.4 in. np, 6847.1 g $UZrH_x$ (408.0 g $^{235}$U, 8384.6 g $H_2O$, h/x = 536.39) | 6.9.6-19a |
| 6.9.7.45 | ncsrtriga_1_15_15 | 0.0 in. np, 10400.0 g $UZrH_x$ (921.0 g $^{235}$U, 8998.2 g $H_2O$, h/x = 255.01) | 6.9.6-20a |
| 6.9.7.46 | ncsrtriga70_1_15_15 | 0.0 in. np, 6847.1 g UZrHx (408.0 g $^{235}$U, 8998.2 g $H_2O$, h/x = 575.64) | 6.9.6-20b |
| 6.9.7.47 | ncsrt55d2_1_15_15 | 0.0 in. np, 10400.0 g $UZrH_x$ (921.0 g $^{235}$U, 8998.2 g $H_2O$, h/x = 255.01) | 6.9.6-20d |
| 6.9.7.48 | hcsrtriga_1_15_15 | 0.0 in. np, 10400.0 g $UZrH_x$ (921.0 g $^{235}$U, 8998.2 g $H_2O$, h/x = 255.01) | 6.9.6-20a |
| 6.9.7.49 | hcsrtriga70_1_15_15 | 0.0 in. np, 6847.1 g $UZrH_x$ (408.0 g $^{235}$U, 8998.2 g $H_2O$, h/x = 575.64) | 6.9.6-20b |
| 6.9.7.50 | nciatriga_1_15_3 | 0.0 in. np, 10400.0 g $UZrH_x$ (921.0 g $^{235}$U, 8998.2 g $H_2O$, h/x = 255.01) | 6.9.6-20a |
| 6.9.7.51 | nciatriga70_1_15_3 | 0.0 in. np, 6847.1 g $UZrH_x$ (408.0 g $^{235}$U, 8998.2 g $H_2O$, h/x = 575.64) | 6.9.6-20b |
| 6.9.7.52 | hciatriga_1_15_3 | 0.0 in. np, 10400.0 g $UZrH_x$ (921.0 g $^{235}$U, 8998.2 g $H_2O$, h/x = 255.01) | 6.9.6-20a |

**ES-3100 Input file - Results table crosswalk**

| Section | Case | Description | Results table |
|---|---|---|---|
| 6.9.7.53 | hciatriga70_1_15_3 | 0.0 in. np, 6847.1 g $UZrH_x$ (408.0 g $^{235}U$, 8998.2 g $H_2O$, h/x = 575.64) | 6.9.6-20b |
| 6.9.7.54 | ncsrT70_131_1_15_15 | 0.0in. np, 5666.6 g $UZrH_x$ (337.7 g $^{235}U$, 9204.9 g $H_2O$, hx = 711.53), fr=1.0E+00 | 6.9.6-20c |
| 6.9.7.55 | nciaT70_131_1_15_3 | 0.0in. np, 5666.6 g $UZrH_x$ (337.7 g $^{235}U$, 9204.9 g $H_2O$, hx = 711.53), fr=1.0E-04 | 6.9.6-20c |
| 6.9.7.56 | athopw15kr20_5 | 15763.0 g $U_3O_8$-Al (921.0 g $^{235}U$, 500.0 g $CH_2$, 6803.8 g $H_2O$, h/x = 211.0, Rc=14.13813 cm, 53419.6 g Kao, Rs=31.95515 cm | 6.9.6-22c |
| 6.9.7.57 | athopw15kr70_5 | 1995.7 g $U_3O_8$-Al (408.0 g $^{235}U$, 500.0 g $CH_2$, 6803.8 g $H_2O$, h/x = 476.3, Rc=12.36884 cm, 53419.6 g Kao, Rs=31.64738 cm | 6.9.6-22c |
| 6.9.7.58 | athopw15kr93_5 | 1505.0 g $U_3O_8$-Al (408.0 g $^{235}U$, 500.0 g $CH_2$, 6803.8 g $H_2O$, h/x=476.3, Rc=12.29589 cm, 53419.6 g Kao, Rs=31.63630 cm | 6.9.6-22c |
| 6.9.7.59 | athupw15kr93_5 | 920.5 g $UO_2$ Mg-Al (408.0 g $^{235}U$, 500.0 g $CH_2$, 6803.8 g $H_2O$, g htox=476.3, Rc=12.25670 cm, 53419.6 g Kao, Rs=31.63040 cm | 6.9.6-22d |
| 6.9.7.60 | athupw15kr20_5 | 9677.7 g UO Mg-Al (921.0 g $^{235}U$, 500.0 g $CH_2$, 6803.8 g $H_2O$, g htox=211.0, Rc=13.27685 cm, 53419.6 g Kao, Rs=31.79582 cm | 6.9.6-22d |
| 6.9.7.61 | athupw15kr09_5 | 19592.0 g $UO_2$ Mg-Al (921.0 g $^{235}U$, 500.0 g $CH_2$, 6803.8 g $H_2O$, g htox=210.7, Rc=14.32268 cm, 53419.6 g Kao, Rs=31.99170 cm | 6.9.6-22d |
| 6.9.7.62 | athbpw15kr93_5 | 497.30 g $UO_2$ (408.0 g $^{235}U$, 500.0 g $CH_2$, 6803.8 g $H_2O$, htox=476.3, Rc=12.10567 cm, 53419.6 g Kao, Rs=31.60798 cm | 6.9.6-22d |
| 6.9.7.63 | cvcrcyat11_2_2 | 3 cyl, 1.4 in. np, 30,000 g U (30,000 g $^{235}U$, 7,991.5 g $H_2O$, hx=6.95), sep=0.254 | 6.9.6-3b |
| 6.9.7.64 | cvcrcyat11_11_2 | 3 cyl, 1.4 in. np, 30,000 g U (30,000 g $^{235}U$, 7,991.5 g $H_2O$, hx=6.95), sep=4.826 | 6.9.6-3b |
| 6.9.7.65 | cvcrpunhct11_10_15 | 10,000.2 g UNHc (4,709.7 g $^{235}U$, 2,165.3 g $H_2O$) 6,081 g $H_2O$ CV, hx=49.26 | 6.9.6-14 |
| 6.9.7.66 | cvcrbpunhct11_24_15 | 24,000.0 g UNHc (11,303.1 g $^{235}U$, 5,196.7 g $H_2O$) 1,077.9 g $H_2O$ CV, hx=15.97 | 6.9.6-14 |
| 6.9.7.67 | nciapbmflt11_1_6_4_5 | 0.0 in. np, 4,000.2 g U (3,200.2 g $^{235}U$), 9,442.7 g $H_2O$ CV, hx=82.26, fr=0.0001 | 6.9.6-11b |
| 6.9.7.68 | nciapbmfdt11_1_6_4_5 | 0.0 in. np, 4,000.2 g U (3,200.2 g $^{235}U$), 9,442.7 g $H_2O$ CV, hx=82.26, fr=0.0001 | 6.9.6-11b |
| 6.9.7.69 | ncsrpunhct11_8_15 | 8,000.1 g UNHc (3,767.7 g $^{235}U$, 1,732.2 g $H_2O$) 6,795.6 g $H_2O$ CV, hx= 63.53 | 6.9.6-15 |
| 6.9.7.70 | icsrpunhct12_15_15 | 15,000.0 g UNHc (7,064.4 g $^{235}U$, 3,247.9 g $H_2O$) 6,397.6 g $H_2O$ CV, hx=53.28 | 6.9.6-16 |

[a] N/A = not applicable. Input files included in appendix for comparison with bounding model but not recorded in results tables.

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### 6.9.7.1 Case cvcrcyt11_21_1

```
=csas25    parm=size=3000000
cvcrcyt11 3cyl,0.0in thk np,21000.0gU(21000.0g235, 9082.6gH2O hx= 11.29),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1116.36286, SPACER volume    0.00000'
'HEU wrapped dry content can hx=0.80, CV void volume 9098.99908'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrcyt11 3cyl,0.0in thk np,21000.0gU(21000.0g235, 9082.6gH2O,hx= 11.29),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1006
'content (collapsed) [Elev= 7.675 in.]'
 cylinder  1  1    4.114800     6.99579   0.0     com='cylindrical content'
 cylinder  3  1    6.426200    6.99629  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200    6.99629  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200    6.99629  -0.0005  com='drum chine outer radius'
```

```
unit 1007
'np277_4 spacer [Elev= 7.675 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'20.99097             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   56.09803   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   56.09803   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   56.09803   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
```

```
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.2 Case cvcrcyt11_36_2

```
=csas25    parm=size=3000000
cvcrcyt11 3cyl,1.4in thk np,36000.0gU(36000.0g235, 7673.1gH2O hx=  5.56),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1913.76490, SPACER volume  614.68012'
'HEU wrapped dry content can hx=0.47, CV void volume 7686.91692'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrcyt11 3cyl,1.4in thk np,36000.0gU(36000.0g235, 7673.1gH2O,hx=  5.56),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
```

```
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1006
'content (collapsed) [Elev= 9.642 in.]'
 cylinder  1  1    4.114800    11.99278   0.0     com='cylindrical content'
 cylinder  3  1    6.426200   11.99328  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200   11.99328  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   11.99328  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev=11.042 in.]'
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    3.55620  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'43.09395             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   33.99505   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   33.99505   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   33.99505   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
```

```
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.3 Case cvcrsqt11_36_1

```
=csas25    parm=size=3000000
cvcrsqt11 3bar,0.0in thk np,36000.0gU(36000.0g235, 8286.7gH2O hx=  6.01),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1913.76490, SPACER volume    0.00000'
'HEU wrapped dry content can hx=0.47, CV void volume 8301.59704'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                          8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                          9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                         10  0.94348 293  end
'reflective water'
```

```
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   21  1.0     293  end
end comp
cvcrsqt11 3bar,0.0in thk np,36000.0gU(36000.0g235, 8286.7gH2O,hx=  6.01),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1006
'content (collapsed) [Elev=12.337 in.]'
 cuboid    1  1  4p2.909600    18.83826   0.0     com='block content'
 cylinder  3  1    6.426200   18.83876  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200   18.83876  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   18.83876  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev=12.337 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'56.51838             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   20.57062   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   20.57062   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   20.57062   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
```

```
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.4 Case cvcrcyct11_17_1

```
=csas25    parm=size=3000000
cvcrcyct11 3cyl,0.0in thk np,17000.1gU(17000.1g235, 9294.9gH2O hx= 14.27),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume = 903.72763, SPACER volume    0.00000'
'HEU wrapped dry content can hx=0.99, CV void volume 9311.63431'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
```

```
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                  8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                                  8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                              8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                              9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                             10  0.94348 293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                                  8016   88.8087   21  1.0     293  end
end comp
cvcrcyct11 3cyl,0.0in thk np,17000.1gU(17000.1g235, 9294.9gH2O,hx= 14.27),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                           end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1006
'content (collapsed) [Elev= 6.216 in.]'
 cylinder  1  1    5.397500     3.29140   0.0     com='cylindrical content'
 cylinder  3  1    6.426200    3.29190  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200    3.29190  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200    3.29190  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 6.216 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
' 9.87781             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   67.21119   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   67.21119   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   67.21119   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
```

```
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.5 Case cvcrcyct11_32_2

```
=csas25    parm=size=3000000
cvcrcyct11 3cyl,1.4in thk np,32000.1gU(32000.1g235, 7885.3gH2O hx=  6.43),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1701.12968, SPACER volume  614.68012'
'HEU wrapped dry content can hx=0.52, CV void volume 7899.55215'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
```

```
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                  5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                  7014    0.0141
                                  8016   43.4251
                                 11023    0.1174
                                 12000    0.3378
                                 13027   39.0479
                                 14000    2.4672
                                 16000    0.3083
                                 20000   11.8336
                                 26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                  8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrcyct11 3cyl,1.4in thk np,32000.1gU(32000.1g235, 7885.3gH2O,hx=  6.43),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1006
'content (collapsed) [Elev= 7.360 in.]'
 cylinder  1  1    5.397500     6.19557   0.0     com='cylindrical content'
 cylinder  3  1    6.426200    6.19607  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200    6.19607  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200    6.19607  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 8.760 in.]'
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    3.55620  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'25.70230             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   51.38670   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   51.38670   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   51.38670   0.0     com='drum chine outer radius'
unit 1010
```

```
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.6 Case cvcr5est11_1_1

```
=csas25    parm=size=3000000
cvcr5est11,0.0in np,18277.3gU(18277.3g235, 9226.9gH2O hx= 13.18),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume = 971.62217, SPACER volume    0.01729'
'HEU wrapped dry content can hx=0.92, CV void volume 9243.50194'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
```

```
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                              8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                              8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                              8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                              8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                              8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                              8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                              8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                              8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
```

```
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                              8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcr5est11,0.0in np,18277.3gU(18277.3g235, 9226.9gH2O,hx= 13.18),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                          end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'1st content can (collapsed) [Elev= 6.983 in.]'
'Reference CRC 29 Ed. pg 105'
'side of pentagon denoted spent'
'radius of inscribed circle in pentagon denoted icrpent'
'radius of circumscribed circle outside pentagon denoted ccrpent'
'ccrpent equals 0.85065 times spent'
'icrpent equals 0.68819 times spent'
'side of pentagon equals diameter of a cylinder fit into cc'
'radius of cc equals ccrpent plus radius of cylinder fit into cc'
'radius of ccrpent equal diamater of slug'
' 3.96875 radius of circumscribed circle'
' 2.33277 half of side of pentagon'
' 3.21078 radius of inscribed circle'
' 3.77452 x axis location of 2nd cyl in cc'
' 1.22642 y axis location of 2nd cyl in cc'
 cylinder  3  1    6.426200    5.23925  -0.0005  com='cv well cavity'
 hole  1020    0.0       3.96875 0.0        com='cy1 (0,ccrpent)'
 hole  1020    3.77452   1.22642 0.0        com='cy2 (xtwo,ytwo)'
 hole  1020    2.33277  -3.21078 0.0        com='cy3 (hspent,-icrpent)'
 hole  1020   -2.33277  -3.21078 0.0        com='cy4 (-hspent,-icrpent)'
 hole  1020   -3.77452   1.22642 0.0        com='cy5 (-xtwo,ytwo)'
 cylinder  8  1    6.680200    5.23925  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200    5.23925  -0.0005  com='drum chine outer radius'
unit 1005
'np277_4 spacer [Elev= 6.983 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1006
'2nd content can (collapsed) [Elev= 9.046 in.]'
 cylinder  3  1    6.426200    5.23925  -0.0005  com='cv well cavity'
 hole  1021    0.0       3.96875 0.0        com='cy1 (0,ccrpent)'
 hole  1021    3.77452   1.22642 0.0        com='cy2 (xtwo,ytwo)'
 hole  1021    2.33277  -3.21078 0.0        com='cy3 (hspent,-icrpent)'
 hole  1021   -2.33277  -3.21078 0.0        com='cy4 (-hspent,-icrpent)'
 hole  1021   -3.77452   1.22642 0.0        com='cy5 (-xtwo,ytwo)'
 cylinder  8  1    6.680200    5.23925  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200    5.23925  -0.0005  com='drum chine outer radius'
```

```
unit 1007
'np277_4 spacer [Elev= 9.046 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'3rd content can (collapsed) [Elev= 9.046 in.]'
 cylinder  3  1    6.426200    5.23925  -0.0005  com='cv well cavity'
 hole  1022    0.0       3.96875 0.0        com='cy1 (0,ccrpent)'
 hole  1022    3.77452   1.22642 0.0        com='cy2 (xtwo,ytwo)'
 hole  1022    2.33277  -3.21078 0.0        com='cy3 (hspent,-icrpent)'
 hole  1022   -2.33277  -3.21078 0.0        com='cy4 (-hspent,-icrpent)'
 hole  1022   -3.77452   1.22642 0.0        com='cy5 (-xtwo,ytwo)'
 cylinder  8  1    6.680200    5.23925  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200    5.23925  -0.0005  com='drum chine outer radius'
unit 1009
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'15.72155             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   61.36745   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   61.36745   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   61.36745   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
unit 1020
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
```

```
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
unit 1021
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
unit 1022
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
global
unit 1023
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1025
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1004 1005 1006 1007 1008 1009 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1023               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.7 Case cvcr6e4st11_1

```
=csas25    parm=size=3000000
cvcr6e4st11,0.0in np,36554.5gU(36554.5g235, 8257.0gH2O hx=  5.90),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1943.24434, SPACER volume    0.01729'
'HEU wrapped dry content can hx=0.46, CV void volume 8271.87977'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
```

```
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                               5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                               7014    0.0141
                               8016   43.4251
                              11023    0.1174
                              12000    0.3378
                              13027   39.0479
                              14000    2.4672
                              16000    0.3083
                              20000   11.8336
                              26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                               8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                              8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                              8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                              8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                              8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                              8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                              8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                              8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                              8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430   13  0.367   293  end
```

```
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcr6e4st11,0.0in np,36554.5gU(36554.5g235, 8257.0gH2O,hx=  5.90),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'1st content can (collapsed) [Elev= 9.045 in.]'
'Reference CRC 29 Ed. pg 105'
'side of pentagon denoted spent'
'radius of inscribed circle in pentagon denoted icrpent'
'radius of circumscribed circle outside pentagon denoted ccrpent'
```

```
'ccrpent equals 0.85065 times spent'
'icrpent equals 0.68819 times spent'
'side of pentagon equals diameter of a cylinder fit into cc'
'radius of cc equals ccrpent plus radius of cylinder fit into cc'
'radius of ccrpent equal diamater of slug'
' 3.96925 radius of circumscribed circle'
' 2.33307 half of side of pentagon'
' 3.21119 radius of inscribed circle'
' 3.77499 x axis location of 2nd cyl in cc'
' 1.22658 y axis location of 2nd cyl in cc'
 cylinder  3  1    6.426200   10.47800  -0.0005  com='cv well cavity'
 hole  1020    0.0       3.96925 0.0        com='cy1 (0,ccrpent)'
 hole  1020    3.77499   1.22658 0.0        com='cy2 (xtwo,ytwo)'
 hole  1020    2.33307  -3.21119 0.0        com='cy3 (hspent,-icrpent)'
 hole  1020   -2.33307  -3.21119 0.0        com='cy4 (-hspent,-icrpent)'
 hole  1020   -3.77499   1.22658 0.0        com='cy5 (-xtwo,ytwo)'
 hole  1020    0.0       0.0    0.0        com='cy6 (0,0)'
 hole  1020    2.80704   0.0 5.23875      com='cy7'
 hole  1020   -2.80704   0.0 5.23875      com='cy8'
 hole  1020    0.0     2.80704 5.23875      com='cy9'
 hole  1020    0.0    -2.80704 5.23875      com='cy10'
 cylinder  8  1    6.680200   10.47800  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   10.47800  -0.0005  com='drum chine outer radius'
unit 1005
'np277_4 spacer [Elev= 9.046 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1006
'2nd content can (collapsed) [Elev=13.171 in.]'
 cylinder  3  1    6.426200   10.47800  -0.0005  com='cv well cavity'
 hole  1021    0.0       3.96925 0.0        com='cy1 (0,ccrpent)'
 hole  1021    3.77499   1.22658 0.0        com='cy2 (xtwo,ytwo)'
 hole  1021    2.33307  -3.21119 0.0        com='cy3 (hspent,-icrpent)'
 hole  1021   -2.33307  -3.21119 0.0        com='cy4 (-hspent,-icrpent)'
 hole  1021   -3.77499   1.22658 0.0        com='cy5 (-xtwo,ytwo)'
 hole  1021    0.0       0.0    0.0        com='cy6 (0,0)'
 hole  1021    2.80704   0.0 5.23875      com='cy7'
 hole  1021   -2.80704   0.0 5.23875      com='cy8'
 hole  1021    0.0     2.80704 5.23875      com='cy9'
 hole  1021    0.0    -2.80704 5.23875      com='cy10'
 cylinder  8  1    6.680200   10.47800  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   10.47800  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev=13.171 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'3rd content can (collapsed) [Elev=13.171 in.]'
 cylinder  3  1    6.426200   10.47800  -0.0005  com='cv well cavity'
 hole  1022    0.0       3.96925 0.0        com='cy1 (0,ccrpent)'
 hole  1022    3.77499   1.22658 0.0        com='cy2 (xtwo,ytwo)'
 hole  1022    2.33307  -3.21119 0.0        com='cy3 (hspent,-icrpent)'
 hole  1022   -2.33307  -3.21119 0.0        com='cy4 (-hspent,-icrpent)'
 hole  1022   -3.77499   1.22658 0.0        com='cy5 (-xtwo,ytwo)'
 hole  1022    0.0       0.0    0.0        com='cy6 (0,0)'
 hole  1022    2.80704   0.0 5.23875      com='cy7'
 hole  1022   -2.80704   0.0 5.23875      com='cy8'
```

```
 hole  1022    0.0     2.80704 5.23875      com='cy9'
 hole  1022    0.0    -2.80704 5.23875      com='cy10'
 cylinder  8  1    6.680200   10.47800  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   10.47800  -0.0005  com='drum chine outer radius'
unit 1009
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'31.43780             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   45.65120   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   45.65120   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   45.65120   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
unit 1020
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
unit 1021
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
unit 1022
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
global
unit 1023
```

```
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1025
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1004 1005 1006 1007 1008 1009 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1023               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.8 Case cvcr70st11_2

```
=csas25    parm=size=3000000
cvcr70st11,1.4in np,25588.2gU(25588.2g235, 8225.3gH2O hx=  8.39),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1360.27104, SPACER volume  614.69740'
'HEU wrapped dry content can hx=0.66, CV void volume 8240.17295'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                          8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                          9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                         10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
```

```
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
```

```
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  1       293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   21  1.0     293  end
end comp
cvcr70st11,1.4in np,25588.2gU(25588.2g235, 8225.3gH2O,hx=  8.39),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'1st content can (collapsed) [Elev= 6.983 in.]'
'3.437212   plus-y location cylinders'
'-3.437212  minus-y location cylinders'
'1.984375   plus-x location cylinders'
'-1.984375  minus-x location cylinders'
 cylinder  3  1    6.426200    5.23925  -0.0005  com='cv well cavity'
 hole  1020   -3.968750   0.0       0.0     com='cy1 (2cymx,0)'
 hole  1020   -1.984375   3.437212  0.0     com='cy2 (cymx,cypy)'
 hole  1020    1.984375   3.437212  0.0     com='cy3 (cypx,cypy)'
 hole  1020    3.968750   0.0       0.0     com='cy4 (2cypx,0)'
 hole  1020    1.984375  -3.437212  0.0     com='cy5 (cypx,cymx)'
 hole  1020   -1.984375  -3.437212  0.0     com='cy6 (cymx,cymy)'
 hole  1020    0.0        0.0       0.0     com='cy7 (0,0)'
 cylinder  8  1    6.680200    5.23925  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200    5.23925  -0.0005  com='drum chine outer radius'
unit 1005
'np277_4 spacer [Elev= 8.383 in.]'
```

```
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    3.55620  -0.0001  com='drum chine outer radius'
unit 1006
'2nd content can (collapsed) [Elev=10.446 in.]'
 cylinder  3  1    6.426200    5.23925  -0.0005  com='cv well cavity'
 hole  1021   -3.968750   0.0       0.0     com='cy1 (2cymx,0)'
 hole  1021   -1.984375   3.437212  0.0     com='cy2 (cymx,cypy)'
 hole  1021    1.984375   3.437212  0.0     com='cy3 (cypx,cypy)'
 hole  1021    3.968750   0.0       0.0     com='cy4 (2cypx,0)'
 hole  1021    1.984375  -3.437212  0.0     com='cy5 (cypx,cymx)'
 hole  1021   -1.984375  -3.437212  0.0     com='cy6 (cymx,cymy)'
 hole  1021    0.0        0.0       0.0     com='cy7 (0,0)'
 cylinder  8  1    6.680200    5.23925  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200    5.23925  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev=11.846 in.]'
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    3.55620  -0.0001  com='drum chine outer radius'
unit 1008
'3rd content can (collapsed) [Elev=10.446 in.]'
 cylinder  3  1    6.426200    5.23925  -0.0005  com='cv well cavity'
 hole  1022   -3.968750   0.0       0.0     com='cy1 (2cymx,0)'
 hole  1022   -1.984375   3.437212  0.0     com='cy2 (cymx,cypy)'
 hole  1022    1.984375   3.437212  0.0     com='cy3 (cypx,cypy)'
 hole  1022    3.968750   0.0       0.0     com='cy4 (2cypx,0)'
 hole  1022    1.984375  -3.437212  0.0     com='cy5 (cypx,cymx)'
 hole  1022   -1.984375  -3.437212  0.0     com='cy6 (cymx,cymy)'
 hole  1022    0.0        0.0       0.0     com='cy7 (0,0)'
 cylinder  8  1    6.680200    5.23925  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200    5.23925  -0.0005  com='drum chine outer radius'
unit 1009
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'22.83355             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   54.25545   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   54.25545   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   54.25545   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
```

```
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
unit 1020
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
unit 1021
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
unit 1022
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
global
unit 1023
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1025
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1004 1005 1006 1007 1008 1009 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1023               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.9 Case cvr3sqa_26_1_8_15

```
=csas25    parm=size=3000000
cvr 3x3sqa,0.0in thk np,25893.7gU(25893.7g235, 8822.9gH2O hx=  8.89),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1376.51338, SPACER volume    0.00000'
'HEU wrapped dry content can hx=0.65, CV void volume 8838.84856'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
```

```
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07072e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4264
                                11023    0.1174
                                12000    0.3378
                                13027   39.0470
                                14000    2.4671
                                16000    0.3083
                                20000   11.8333
                                26000    0.5297    2  1.0000  293  end
arbmnph2o 3.84144e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'void space internal to containmment vessel -- including content cans'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvr 3x3sqa,0.0in thk np,25893.7gU(25893.7g235, 8822.9gH2O,hx=  8.89),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'cubical content, stacked per cc'
'    9.08802     3.57796 lattice width-depth'
'    2.54000     1.00000 cube dimension'
'    1.27000     0.50000 cube half-dimension'
'   16.38706     1.00000 volume of HEU cube in unit cell'
'  308.25850             HEU mass one cube'
'   28                   number of HEU cubes per can'
' 8631.23808             HEU mass of cubes in cc'
'    3           3       number of cubes in -x direction'
'    3           3       number of cubes in -y direction'
'    9           9       number of HEU cubes in a layer'
'    4    VARIABLE       number of HEU layers in z-axis'
'    1    VARIABLE       number of HEU cubes in top layer modulus(Z%N)'
'    8    VARIABLE       number of HEU voids in top layer'
'    ara=1 nux=3 nuy=3 nuz=4   fill 28r1004  8r1005      end fill'
```

```
'    0.48924     0.19261 gap dimension                        CALCULATED
'    3.02924     1.19261 unit cell dimension                  CALCULATED
'    1.51462     0.59631 unit cell half-dimension             CALCULATED
'   27.79719     1.69629 volume of unit cell                  CALCULATED
'   11.41013     0.69629 volume of water gap in unit cell     CALCULATED
 cuboid    1  1  6p1.26990                       com='content cube'
 cuboid    3  1  6p1.51452                       com='unit cell'
unit 1005
'cubical void, filler for layers'
 cuboid    3  1  6p1.51452                       com='unit cell'
unit 1006
'content (collapsed) [Elev= 9.691 in.]'
' 4.54386     1.78892 half width-depth lattice            CALCULATED'
'12.11696             height lattice                      CALCULATED'
 array 1         2r-4.54386      0.0
 cuboid    3  1  4p4.54386     12.1169   0.0     com='content-array'
 cylinder  3  1    6.426200   12.11746  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200   12.11746  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   12.11746  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.691 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'36.35448             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   40.73452   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   40.73452   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   40.73452   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
```

```
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
 array 3   2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=1 nux=3 nuy=3 nuz=4   fill 28r1004  8r1005      end fill
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.10Case cvr3lha_26_1_8_15

```
=csas25    parm=size=3000000
cvr 3x3lha,0.0in thk np,25893.7gU(25893.7g235, 8822.9gH2O hx=  8.89),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1376.51338, SPACER volume    0.00000'
'HEU wrapped dry content can hx=0.65, CV void volume 8838.84856'
uranium  1 den=18.81109 0.45852 293      92235  100.00
                                      92238   0.000               end
arbmh20i   0.54051  2 0 0 0    1001   11.1913
                                8016   88.8087    1  1       293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07072e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4264
                                11023    0.1174
                                12000    0.3378
                                13027   39.0470
                                14000    2.4671
                                16000    0.3083
                                20000   11.8333
                                26000    0.5297    2  1.0000  293  end
arbmnph2o 3.84144e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
```

```
'void space internal to containmment vessel -- including content cans'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvr 3x3lha,0.0in thk np,25893.7gU(25893.7g235, 8822.9gH2O,hx=  8.89),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'cubical content, stacked per cc'
'    9.08802     3.57796 lattice width-depth'
'    2.54000     1.00000 cube dimension'
'    1.27000     0.50000 cube half-dimension'
'   16.38706     1.00000 volume of HEU cube in unit cell'
'  308.25850             HEU mass one cube'
'   28                   number of HEU cubes per can'
' 8631.23808             HEU mass of cubes in cc'
'    3           3       number of cubes in -x direction'
'    3           3       number of cubes in -y direction'
'    9           9       number of HEU cubes in a layer'
'    4    VARIABLE       number of HEU layers in z-axis'
'    1    VARIABLE       number of HEU cubes in top layer modulus(Z%N)'
'    8    VARIABLE       number of HEU voids in top layer'
'    ara=1 nux=3 nuy=3 nuz=4   fill 28r1004  8r1005      end fill'
'    0.48924     0.19261 gap dimension                       CALCULATED
'    3.02924     1.19261 unit cell dimension                 CALCULATED
'    1.51462     0.59631 unit cell half-dimension            CALCULATED
'   27.79719     1.69629 volume of unit cell                 CALCULATED
'   11.41013     0.69629 volume of water gap in unit cell    CALCULATED
' 1000.69893             lattice volume in cc                CALCULATED
'  541.86113             moderator volume in lattice in cc   CALCULATED
'  458.83779             HEU volume in lattice in cc         CALCULATED
'    0.45852             volume fraction of HEU in lattice'  CALCULATED
'    0.54051             bulk dens of water in lattice in cc CALCULATED
 cuboid    1  1  6p1.51452                      com='unit cell'
unit 1005
'cubical void, filler for layers'
 cuboid    1  1  6p1.51452                      com='unit cell'
unit 1006
'content (collapsed) [Elev= 9.691 in.]'
' 4.54386     1.78892 half width-depth lattice            CALCULATED'
'12.11696             height lattice                      CALCULATED'
```

```
'array 1         2r-4.54386      0.0'
 cuboid    1  1  4p4.54386     12.1169   0.0     com='homog. content-array'
 cylinder  3  1    6.426200   12.11746  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200   12.11746  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   12.11746  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.691 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'36.35448             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   40.73452   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   40.73452   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   40.73452   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
 array 3   2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
```

```
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=1 nux=3 nuy=3 nuz=4   fill 28r1004  8r1005      end fill
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.11Case cvr3cha_26_1_8_15

```
=csas25    parm=size=3000000
cvr 3x3cha,0.0in thk np,25893.7gU(25893.7g235, 8822.9gH2O hx=  8.89),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1376.51338, SPACER volume    0.00000'
'HEU wrapped dry content can hx=0.65, CV void volume 8838.84856'
uranium  1 den=18.81109 0.13475 293      92235  100.00
                                      92238   0.000               end
arbmh20i   0.86369  2 0 0 0    1001   11.1913
                               8016   88.8087    1  1       293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07072e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4264
                                11023    0.1174
                                12000    0.3378
                                13027   39.0470
                                14000    2.4671
                                16000    0.3083
                                20000   11.8333
                                26000    0.5297    2  1.0000  293  end
arbmnph2o 3.84144e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'void space internal to containmment vessel -- including content cans'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvr 3x3cha,0.0in thk np,25893.7gU(25893.7g235, 8822.9gH2O,hx=  8.89),fr=1.0e+00
```

```
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                          end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'cubical content, stacked per cc'
'    9.08802     3.57796 lattice width-depth'
'    2.54000     1.00000 cube dimension'
'    1.27000     0.50000 cube half-dimension'
'   16.38706     1.00000 volume of HEU cube in unit cell'
'  308.25850             HEU mass one cube'
'   28                   number of HEU cubes per can'
' 8631.23808             HEU mass of cubes in cc'
'    3           3       number of cubes in -x direction'
'    3           3       number of cubes in -y direction'
'    9           9       number of HEU cubes in a layer'
'    4    VARIABLE       number of HEU layers in z-axis'
'    1    VARIABLE       number of HEU cubes in top layer modulus(Z%N)'
'    8    VARIABLE       number of HEU voids in top layer'
'    ara=1 nux=3 nuy=3 nuz=4   fill 28r1004  8r1005      end fill'
'    0.48924     0.19261 gap dimension                        CALCULATED
'    3.02924     1.19261 unit cell dimension                  CALCULATED
'    1.51462     0.59631 unit cell half-dimension             CALCULATED
'   27.79719     1.69629 volume of unit cell                  CALCULATED
'   11.41013     0.69629 volume of water gap in unit cell     CALCULATED
' 1000.69893             lattice volume in cc                 CALCULATED
'  541.86113             moderator volume in lattice in cc    CALCULATED
'  458.83779             HEU volume in lattice in cc          CALCULATED
'    0.13475             volume fraction of HEU in CV         CALCULATED
'    0.86369             bulk dens of water in CV             CALCULATED
 cuboid    1  1  6p1.51452                       com='unit cell'
unit 1005
'cubical void, filler for layers'
 cuboid    1  1  6p1.51452                       com='unit cell'
unit 1006
'content (collapsed) [Elev= 9.691 in.]'
' 4.54386     1.78892 half width-depth lattice            CALCULATED'
'12.11696             height lattice                      CALCULATED'
'array 1         2r-4.54386      0.0'
 cuboid    1  1  4p4.54386     12.1169   0.0     com='homog. content-array'
 cylinder  1  1    6.426200   12.11746  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200   12.11746  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   12.11746  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.691 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  1  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'36.35448             stack height (content spacers)       CALCULATED
```

```
 cylinder  1  1    6.426200   40.73452   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   40.73452   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   40.73452   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  1  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  1  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  1  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
 array 3   2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=1 nux=3 nuy=3 nuz=4   fill 28r1004  8r1005      end fill
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
```

```
end start
end data
end
```

### 6.9.7.12Case cvcrpdoxt11_1_5_24_15

```
(This case name is actually cvcrpdoxt11_1_5_24_15.)
=csas25    parm=size=3000000
cvcrpoxt11,24000.0gUO2 (21124.9g235)1477.3gSH2O 5991.4gH2Ocv hx= 10.02 fr=1
238groupndf5 infhommedium
'HEU volume =3669.72477 HEU oxide, bulk density of oxide in cans=  6.54000 g/cm3'
'oxide= 24000.0 g, sat.h2o in HEU oxide=1477.3 g, oxide h/x= 1.83'
'poly (packed or wrapped) dry content h/x=0.79, CV void volume 6002.15891'
arbmuox    5.69638   2 0 0 0  92235   88.0203
                              8016   11.9797    1  1.0000  293  end
arbmastm  3.5063e-01  2 0 0 0  1001   11.1913
                              8016   88.8087    1  1.0000  293  end
arbmpoly  1.1867e-01  2 0 0 0  1001   14.3798
                              6012   85.6202    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0   1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
```

```
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                                8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                                8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                                8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                                8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                                8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                                8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                                8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                1001    8.1573
                                8016   21.5782
                               14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087   15  1       293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
steel: angle iron (ai) for single units'
ss304                                          18  1.0     293  end
```

```
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrpoxt11,24000.0gUO2 (21124.9g235)1477.3gSH2O 5991.4gH2Ocv,hx= 10.02 fr=1
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
 cylinder  3  1    6.426200   77.72400  33.11036 com='cavity abv HEU'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
```

```
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.13Case cvcrsk3cc_9_15_17

```
csas25    parm=size=3000000
cvcrsk3cc,0.0,21300.0g soc(19865.3uox,15672.8u235,  921.0c),hx= 12.82,fr=1.0e+00
238groupndf5 infhommedium
'  cm3: Skull oxide content 6974.5, SPACER    0.0, CV void 3240.9; CV htox=12.82'
'g/cm3: Skull oxide content  3.05400'
'U3O8   (19865.33gUOX,16816.3gU,15672.8g235U, 3801.4g.sat.H2O, HX=  7.43)'
'Carbon (  921.00gC,   58764.1mgC/g235U)'
'Poly   (  513.00gCH2)'
'Other  (    0.67gUnident (assumed H2O)'
''
'Increm (  921.0gC,15672.8g235U,   58764.1mgC/g235U)'
'GREP1:21300.00 19865.33 3.8014e+03    7.43 16816.35 15672.84   921.00  58764.1
'GREP2: 3235.07   513.00      12.82    0.67  1.0e+00
''
arbmuox    2.84830    3 0 0 0  92235   78.8954
                               92238    5.7563
                                8016   15.3483    1  1.0000  293  end
arbmc     1.3205e-01  1 0 0 0   6012  100.0000    1  1.0000  293  end
arbmastm  5.4505e-01  2 0 0 0   1001   11.1913
                                8016   88.8087    1  1.0000  293  end
arbmpoly   0.07355    2 0 0 0   1001   14.3798
                                6012   85.6202    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
```

```
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0   1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrsk3cc,0.0,21300.0g soc(19865.3uox,15672.8u235,  921.0c),hx= 12.82 fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
 cylinder  3  1    6.426200   77.72400  54.39413 com='cavity abv HEU'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.00000 com='cavity abv HEU'
```

```
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.14Case cvcrunhct11_9_1

```
=csas25    parm=size=3000000
cvcrunhct11 0.0innp,disp. 9000.0gUNHc( 4238.7g235, 6980.8gH2O hx= 54.99),fr=1.0e+00
238groupndf5 infhommedium
'U(enr)O2(NO3)2+6H2O [2.81 g/cc for U(nat)], gU/L= 414.9296'
'UNH crystals in cans  2.79329 g/cm3. wrapped dry content can hx=3.96'
arbmunh    2.79329  5 0 0 0   92235   47.0962
                              92238    0.0000
                               1001    2.4232
                               7014    5.6116
                               8016   44.8690    1  0.31541 293  end
```

```
arbmh2oc  6.8336e-01  2 0 0 0  1001   11.1913
                               8016   88.8087    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  6.8336e-01  2 0 0 0   1001   11.1913
                                8016   88.8087     3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                             8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                             9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                            10  0.94348 293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrunhct11 0.0innp,disp. 9000.0gUNHc( 4238.7g235, 6980.8gH2O,hx= 54.99),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                          end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
```

```
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.15Case cvcrtriga_1_15

```
=csas25    parm=size=3000000
cvcrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O hx=255.01),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=18.2, CV void volume 9014.40198'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
```

```
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O,hx=255.01),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
```

```
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
```

```
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.16Case ncsrcyt11_21_1_15

```
=csas25    parm=size=3000000
ncsrcyt11 3cyl,0.0in thk np,21000.0gU(21000.0g235, 9082.6gH2O hx= 11.29),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1116.36286, SPACER volume    0.00000'
'HEU wrapped dry content can hx=0.80, CV void volume 9098.99908'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
```

```
                              16000    0.3083
                              20000   11.8336
                              26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                               8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
```

```
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
ncsrcyt11 3cyl,0.0in thk np,21000.0gU(21000.0g235, 9082.6gH2O,hx= 11.29),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   23.329900    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   23.177500   11.59510   0.0     com='kaolite'
 cylinder  19 1   23.329900   11.59510   0.0     com='drum'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   23.177500    0.63500   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1006
'content (collapsed) [Elev= 7.675 in.]'
 cylinder  1  1    4.114800     6.99579   0.0     com='cylindrical content'
 cylinder  3  1    6.426200    6.99629  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200    6.99629  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800    6.99629  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200    6.99629  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000    6.99629  -0.0005  com='np277_4'
 cylinder  16 1   11.074400    6.99629  -0.0005  com='kaolite liner'
 cylinder  12 1   23.177500    6.99629  -0.0005  com='kaolite'
 cylinder  19 1   23.329900    6.99629  -0.0005  com='drum'
 cuboid    21 1 4p24.587200    6.99629  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 7.675 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
```

```
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   23.177500    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   23.329900    0.00020  -0.0001  com='drum'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'20.99097             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   56.09803   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   56.09803   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   56.09803   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   56.09803   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   56.09803   0.0     com='np277_4'
 cylinder  16 1   11.074400   56.09803   0.0     com='kaolite liner'
 cylinder  12 1   23.177500   56.09803   0.0     com='kaolite'
 cylinder  19 1   23.329900   56.09803   0.0     com='drum'
 cuboid    21 1 4p24.587200   56.09803   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   23.177500    0.22860   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.22860   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.27000   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.27000   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   23.177500    2.92100   0.0     com='kaolite'
 cylinder  19 1   23.329900    2.92100   0.0     com='drum'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
```

```
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.01600   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.01600   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   23.177500    8.17880   0.0     com='kaolite'
 cylinder  19 1   23.329900    8.17880   0.0     com='drum'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   23.177500    4.44500   0.0     com='kaolite'
 cylinder  19 1   23.329900    4.44500   0.0     com='drum'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   23.177500    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   22.961600    1.90500   0.15240 com='void above lid'
 cylinder  19 1   23.114000    1.90500   0.0     com='drum lid'
 cylinder  21 1   23.177500    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   23.329900    1.90500   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
```

```
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.17Case nciacyct11_25_2_3

```
=csas25    parm=size=3000000
nciacyct11 3cyl,1.4in thk np,25000.2gU(25000.2g235, 8256.8gH2O hx=  8.62),fr=1.0e-04
238groupndf5 infhommedium
'HEU volume =1329.01404, SPACER volume  614.68012'
'HEU wrapped dry content can hx=0.67, CV void volume 8271.66778'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
```

```
                              14000    2.4672
                              16000    0.3083
                              20000   11.8336
                              26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                               8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
```

```
'steel: angle iron (ai) for single units'
'ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
nciacyct11 3cyl,1.4in thk np,25000.2gU(25000.2g235, 8256.8gH2O,hx=  8.62),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                   end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.926 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1006
'content (collapsed) [Elev= 6.832 in.]'
 cylinder  1  1    5.397500     4.84031   0.0     com='cylindrical content'
 cylinder  3  1    6.426200    4.84081  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200    4.84081  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800    4.84081  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200    4.84081  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000    4.84081  -0.0005  com='np277_4'
 cylinder  16 1   11.074400    4.84081  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075    4.84081  -0.0005  com='kaolite'
 cylinder  19 1   21.722275    4.84081  -0.0005  com='drum'
 cuboid    20 1 4p22.866096    4.84081  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 8.232 in.]'
```

```
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    3.55620  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    3.55620  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    3.55620  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    3.55620  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    3.55620  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    3.55620  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    3.55620  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.276 in.]'
'21.63653             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   55.45247   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   55.45247   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   55.45247   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   55.45247   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   55.45247   0.0     com='np277_4'
 cylinder  16 1   11.074400   55.45247   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   55.45247   0.0     com='kaolite'
 cylinder  19 1   21.722275   55.45247   0.0     com='drum'
 cuboid    20 1 4p22.866096   55.45247   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
```

```
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    110.4900  0.0    com='bare package'
'cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
```

```
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.18Case hciacyct12_25_2_3

```
=csas25    parm=size=3000000
hciacyct12 3cyl,1.4in thk np,25000.2gU(25000.2g235, 8256.8gH2O hx=  8.62),fr=1.0e-04
238groupndf5 infhommedium
'HEU wrapped dry content can hx=0.67, CV void volume 8271.66778'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (HAC_MD&H)'
'HAC min.den.(95.3157 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07071e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.82995e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (HAC_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.476265 = (den.mult)(np277-4 min.den.) = 0.9668933*1.526803'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
```

```
                              13027   39.0477
                              14000    2.4671
                              16000    0.3083
                              20000   11.8335
                              26000    0.5298   11  1.0000  293  end
arbmnph2o 3.70316e-1  2 0 0 0    1001   11.1913
                               8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
```

```
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for HAC'
'nct density is multiplied by volume fraction 7.08030/5.74516'
ss304                                          18  1.23239 293  end
'steel: drum steel for HAC'
'nct density is multiplied by volume fraction 3.20482/2.95645'
ss304                                          19  1.08401 293  end
'void space external to drum'
'array density is assumed not reduced by hac'
arbmwed    0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                              8016   88.8087   21  1.0     293  end
end comp
hciacyct12 3cyl,1.4in thk np,25000.2gU(25000.2g235, 8256.8gH2O,hx=  8.62),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                   end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   21.838092    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   21.838092    0.26670   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p21.838092    0.26670   0.0     com='drum(chine)outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.685692   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.838092   11.59510   0.0     com='drum'
 cuboid    20 1 4p21.838092   11.59510   0.0     com='drum(chine)outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.685692    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1006
'content (collapsed) [Elev= 6.826 in.]'
 cylinder  1  1    5.397500     4.84031   0.0     com='cylindrical content'
 cylinder  3  1    6.426200    4.84081  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200    4.84081  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800    4.84081  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200    4.84081  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000    4.84081  -0.0005  com='np277_4'
 cylinder  16 1   11.074400    4.84081  -0.0005  com='kaolite liner'
 cylinder  12 1   21.685692    4.84081  -0.0005  com='kaolite'
 cylinder  19 1   21.838092    4.84081  -0.0005  com='drum'
 cuboid    20 1 4p21.838092    4.84081  -0.0005  com='drum(chine)outer radius'
unit 1007
'np277_4 spacer [Elev= 8.226 in.]'
```

```
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    3.55620  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    3.55620  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    3.55620  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    3.55620  -0.0001  com='kaolite liner'
 cylinder  12 1   21.685692    3.55620  -0.0001  com='kaolite'
 cylinder  19 1   21.838092    3.55620  -0.0001  com='drum'
 cuboid    20 1 4p21.838092    3.55620  -0.0001  com='drum(chine)outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'21.63653             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   55.45247   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   55.45247   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   55.45247   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   55.45247   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   55.45247   0.0     com='np277_4'
 cylinder  16 1   11.074400   55.45247   0.0     com='kaolite liner'
 cylinder  12 1   21.685692   55.45247   0.0     com='kaolite'
 cylinder  19 1   21.838092   55.45247   0.0     com='drum'
 cuboid    20 1 4p21.838092   55.45247   0.0     com='drum(chine)outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.685692    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.22860   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.22860   0.0     com='drum(chine)outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.27000   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.27000   0.0     com='drum(chine)outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.685692    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.838092    2.92100   0.0     com='drum'
 cuboid    20 1 4p21.838092    2.92100   0.0     com='drum(chine)outer radius'
```

```
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.01600   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.01600   0.0     com='drum(chine)outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.685692    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.838092    8.17880   0.0     com='drum'
 cuboid    20 1 4p21.838092    8.17880   0.0     com='drum(chine)outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.685692    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.838092    4.44500   0.0     com='drum'
 cuboid    20 1 4p21.838092    4.44500   0.0     com='drum(chine)outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.685692    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  20 1   21.469792    1.90500   0.15240 com='void above lid'
 cylinder  19 1   21.622192    1.90500   0.0     com='drum lid'
 cylinder  20 1   21.685692    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.838092    1.90500   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.90500   0.0     com='drum(chine)outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-21.838092     0.0
'cuboid     0  1 4p21.838092    110.4905  0.0    com='bare package'
'cuboid    21  1 4p52.318092   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
```

```
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.19Case ncia70st11_2_8_3

```
=csas25    parm=size=3000000
ncia70st11,1.4in np,25588.2gU(25588.2g235, 8225.3gH2O hx=  8.39),fr=1.0e-04
238groupndf5 infhommedium
'HEU volume =1360.27104, SPACER volume  614.69740'
'HEU wrapped dry content can hx=0.66, CV void volume 8240.17295'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
```

```
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
```

```
ss304                                              17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                              18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                              18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                              19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                              19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
ncia70st11,1.4in np,25588.2gU(25588.2g235, 8225.3gH2O,hx=  8.39),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                       end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.926 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1004
'1st content can (collapsed) [Elev= 6.989 in.]'
'3.437212   plus-y location cylinders'
'-3.437212  minus-y location cylinders'
'1.984375   plus-x location cylinders'
'-1.984375  minus-x location cylinders'
 cylinder  3  1    6.426200    5.23925  -0.0005  com='cv well cavity'
 hole  1020   -3.968750   0.0       0.0     com='cy1 (2cymx,0)'
 hole  1020   -1.984375   3.437212  0.0     com='cy2 (cymx,cypy)'
 hole  1020    1.984375   3.437212  0.0     com='cy3 (cypx,cypy)'
 hole  1020    3.968750   0.0       0.0     com='cy4 (2cypx,0)'
 hole  1020    1.984375  -3.437212  0.0     com='cy5 (cypx,cymx)'
 hole  1020   -1.984375  -3.437212  0.0     com='cy6 (cymx,cymy)'
```

```
 hole  1020    0.0        0.0       0.0     com='cy7 (0,0)'
 cylinder  8  1    6.680200    5.23925  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800    5.23925  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200    5.23925  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000    5.23925  -0.0005  com='np277_4'
 cylinder  16 1   11.074400    5.23925  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075    5.23925  -0.0005  com='kaolite'
 cylinder  19 1   21.722275    5.23925  -0.0005  com='drum'
 cuboid    20 1 4p22.866096    5.23925  -0.0005  com='drum chine outer radius'
unit 1005
'np277_4 spacer [Elev= 8.389 in.]'
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    3.55620  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    3.55620  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    3.55620  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    3.55620  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    3.55620  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    3.55620  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    3.55620  -0.0001  com='drum chine outer radius'
unit 1006
'2nd content can (collapsed) [Elev=10.452 in.]'
 cylinder  3  1    6.426200    5.23925  -0.0005  com='cv well cavity'
 hole  1021   -3.968750   0.0       0.0     com='cy1 (2cymx,0)'
 hole  1021   -1.984375   3.437212  0.0     com='cy2 (cymx,cypy)'
 hole  1021    1.984375   3.437212  0.0     com='cy3 (cypx,cypy)'
 hole  1021    3.968750   0.0       0.0     com='cy4 (2cypx,0)'
 hole  1021    1.984375  -3.437212  0.0     com='cy5 (cypx,cymx)'
 hole  1021   -1.984375  -3.437212  0.0     com='cy6 (cymx,cymy)'
 hole  1021    0.0        0.0       0.0     com='cy7 (0,0)'
 cylinder  8  1    6.680200    5.23925  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800    5.23925  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200    5.23925  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000    5.23925  -0.0005  com='np277_4'
 cylinder  16 1   11.074400    5.23925  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075    5.23925  -0.0005  com='kaolite'
 cylinder  19 1   21.722275    5.23925  -0.0005  com='drum'
 cuboid    20 1 4p22.866096    5.23925  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev=11.852 in.]'
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    3.55620  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    3.55620  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    3.55620  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    3.55620  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    3.55620  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    3.55620  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    3.55620  -0.0001  com='drum chine outer radius'
unit 1008
'3rd content can (collapsed) [Elev=10.452 in.]'
 cylinder  3  1    6.426200    5.23925  -0.0005  com='cv well cavity'
 hole  1022   -3.968750   0.0       0.0     com='cy1 (2cymx,0)'
 hole  1022   -1.984375   3.437212  0.0     com='cy2 (cymx,cypy)'
 hole  1022    1.984375   3.437212  0.0     com='cy3 (cypx,cypy)'
 hole  1022    3.968750   0.0       0.0     com='cy4 (2cypx,0)'
 hole  1022    1.984375  -3.437212  0.0     com='cy5 (cypx,cymx)'
 hole  1022   -1.984375  -3.437212  0.0     com='cy6 (cymx,cymy)'
 hole  1022    0.0        0.0       0.0     com='cy7 (0,0)'
```

```
 cylinder  8  1    6.680200    5.23925  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800    5.23925  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200    5.23925  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000    5.23925  -0.0005  com='np277_4'
 cylinder  16 1   11.074400    5.23925  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075    5.23925  -0.0005  com='kaolite'
 cylinder  19 1   21.722275    5.23925  -0.0005  com='drum'
 cuboid    20 1 4p22.866096    5.23925  -0.0005  com='drum chine outer radius'
unit 1009
'top of content stack to bottom of 1st step [Elev=35.276 in.]'
'22.83355             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   54.25545   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   54.25545   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   54.25545   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   54.25545   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   54.25545   0.0     com='np277_4'
 cylinder  16 1   11.074400   54.25545   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   54.25545   0.0     com='kaolite'
 cylinder  19 1   21.722275   54.25545   0.0     com='drum'
 cuboid    20 1 4p22.866096   54.25545   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
```

```
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
unit 1020
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
unit 1021
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
unit 1022
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
global
```

```
unit 1023
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    110.4900  0.0    com='bare package'
'cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1025
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1004 1005 1006 1007 1008 1009 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1023               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.20Case ncia5est11_2_2_5_3

*(This case name is actually **ncia5est11_2_2_5_3**.)*

```
=csas25    parm=size=3000000
ncia5est11,0.0in np,73294.2gU(58635.4g235, 6317.2gH2O hx=  2.81),fr=1.0e-04
238groupndf5 infhommedium
'HEU volume =3886.48867, SPACER volume    0.01729'
'HEU wrapped dry content can hx=0.57, CV void volume 6328.63543'
uranium  1 den=18.85873 1.0 293      92235  80.000
                                     92238  20.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                          8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                          9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                         10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
```

```
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
```

```
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                              8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                              8016   88.8087   21  1.0     293  end
end comp
ncia5est11,0.0in np,73294.2gU(58635.4g235, 6317.2gH2O,hx=  2.81),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                   end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.926 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1004
'1st content can (collapsed) [Elev= 9.051 in.]'
```

```
'Reference CRC 29 Ed. pg 105'
'side of pentagon denoted spent'
'radius of inscribed circle in pentagon denoted icrpent'
'radius of circumscribed circle outside pentagon denoted ccrpent'
'ccrpent equals 0.85065 times spent'
'icrpent equals 0.68819 times spent'
'side of pentagon equals diameter of a cylinder fit into cc'
'radius of cc equals ccrpent plus radius of cylinder fit into cc'
'radius of ccrpent equal diamater of slug'
' 3.96875 radius of circumscribed circle'
' 2.33277 half of side of pentagon'
' 3.21078 radius of inscribed circle'
' 3.77452 x axis location of 2nd cyl in cc'
' 1.22642 y axis location of 2nd cyl in cc'
 cylinder  3  1    6.426200   10.47800  -0.0005  com='cv well cavity'
 hole  1020    0.0       3.96875 0.0        com='cy1 (0,ccrpent)'
 hole  1020    3.77452   1.22642 0.0        com='cy2 (xtwo,ytwo)'
 hole  1020    2.33277  -3.21078 0.0        com='cy3 (hspent,-icrpent)'
 hole  1020   -2.33277  -3.21078 0.0        com='cy4 (-hspent,-icrpent)'
 hole  1020   -3.77452   1.22642 0.0        com='cy5 (-xtwo,ytwo)'
 cylinder  8  1    6.680200   10.47800  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   10.47800  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   10.47800  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   10.47800  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   10.47800  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075   10.47800  -0.0005  com='kaolite'
 cylinder  19 1   21.722275   10.47800  -0.0005  com='drum'
 cuboid    20 1 4p22.866096   10.47800  -0.0005  com='drum chine outer radius'
unit 1005
'np277_4 spacer [Elev= 9.051 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1006
'2nd content can (collapsed) [Elev=13.177 in.]'
 cylinder  3  1    6.426200   10.47800  -0.0005  com='cv well cavity'
 hole  1021    0.0       3.96875 0.0        com='cy1 (0,ccrpent)'
 hole  1021    3.77452   1.22642 0.0        com='cy2 (xtwo,ytwo)'
 hole  1021    2.33277  -3.21078 0.0        com='cy3 (hspent,-icrpent)'
 hole  1021   -2.33277  -3.21078 0.0        com='cy4 (-hspent,-icrpent)'
 hole  1021   -3.77452   1.22642 0.0        com='cy5 (-xtwo,ytwo)'
 cylinder  8  1    6.680200   10.47800  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   10.47800  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   10.47800  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   10.47800  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   10.47800  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075   10.47800  -0.0005  com='kaolite'
 cylinder  19 1   21.722275   10.47800  -0.0005  com='drum'
 cuboid    20 1 4p22.866096   10.47800  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev=13.177 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
```

```
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'3rd content can (collapsed) [Elev=13.177 in.]'
 cylinder  3  1    6.426200   10.47800  -0.0005  com='cv well cavity'
 hole  1022    0.0       3.96875 0.0        com='cy1 (0,ccrpent)'
 hole  1022    3.77452   1.22642 0.0        com='cy2 (xtwo,ytwo)'
 hole  1022    2.33277  -3.21078 0.0        com='cy3 (hspent,-icrpent)'
 hole  1022   -2.33277  -3.21078 0.0        com='cy4 (-hspent,-icrpent)'
 hole  1022   -3.77452   1.22642 0.0        com='cy5 (-xtwo,ytwo)'
 cylinder  8  1    6.680200   10.47800  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   10.47800  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   10.47800  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   10.47800  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   10.47800  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075   10.47800  -0.0005  com='kaolite'
 cylinder  19 1   21.722275   10.47800  -0.0005  com='drum'
 cuboid    20 1 4p22.866096   10.47800  -0.0005  com='drum chine outer radius'
unit 1009
'top of content stack to bottom of 1st step [Elev=35.276 in.]'
'31.43780             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   45.65120   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   45.65120   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   45.65120   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   45.65120   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   45.65120   0.0     com='np277_4'
 cylinder  16 1   11.074400   45.65120   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   45.65120   0.0     com='kaolite'
 cylinder  19 1   21.722275   45.65120   0.0     com='drum'
 cuboid    20 1 4p22.866096   45.65120   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
```

```
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
```

```
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
unit 1020
'HEU cylinder content, 3.96875cm diameter by 10.47750cm height'
' 129.54962cm3 single slug volume'
 cylinder  1  1    1.983875  10.4775   0.0       com='cyl'
unit 1021
'HEU cylinder content, 3.96875cm diameter by 10.47750cm height'
' 129.54962cm3 single slug volume'
 cylinder  1  1    1.983875  10.4775   0.0       com='cyl'
unit 1022
'HEU cylinder content, 3.96875cm diameter by 10.47750cm height'
' 129.54962cm3 single slug volume'
 cylinder  1  1    1.983875  10.4775   0.0       com='cyl'
global
unit 1023
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    110.4900  0.0    com='bare package'
'cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1025
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1004 1005 1006 1007 1008 1009 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1023               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.21Case nciabmt11_4_1_5_3

```
=csas25    parm=size=3000000
nciabmt11,0.0in thk np, 3708.5gU( 2966.8g235,10000.7gH2O hx= 87.98),fr=1.0e-04
238groupndf5 infhommedium
'HEU volume = 196.64477, SPACER volume    0.00000'
'HEU wrapped dry content can hx=5.65, CV void volume 10018.7171'
uranium  1 den=18.85873 0.01925 293      92235  80.000
                                      92238  20.000               end
arbmh20i   0.97898  2 0 0 0    1001   11.1913
                               8016   88.8087    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
```

```
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
```

```
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
nciabmt11,0.0in thk np, 3708.5gU( 2966.8g235,10000.7gH2O,hx= 87.98),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                  end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
```

```
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.926 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1004
'cubical content, stacked per cc'
'    9.08802     3.57796 lattice width-depth'
'    2.54000     1.00000 cube dimension'
'    1.27000     0.50000 cube half-dimension'
'   16.38706     1.00000 volume of HEU cube in unit cell'
'  309.03922             HEU mass one cube'
'   4                    number of HEU cubes per can'
' 1236.15687             HEU mass of cubes in cc'
'    3           3       number of cubes in -x direction'
'    3           3       number of cubes in -y direction'
'    9           9       number of HEU cubes in a layer'
'    1    VARIABLE       number of HEU layers in z-axis'
'    4    VARIABLE       number of HEU cubes in top layer modulus(Z%N)'
'    5    VARIABLE       number of HEU voids in top layer'
'    ara=1 nux=3 nuy=3 nuz=1   fill  4r1004  5r1005      end fill'
'    0.48924     0.19261 gap dimension                        CALCULATED
'    3.02924     1.19261 unit cell dimension                  CALCULATED
'    1.51462     0.59631 unit cell half-dimension             CALCULATED
'   27.79719     1.69629 volume of unit cell                  CALCULATED
'   11.41013     0.69629 volume of water gap in unit cell     CALCULATED
'  250.17473             lattice volume in cc                 CALCULATED
'  184.62648             moderator volume in lattice in cc    CALCULATED
'   65.54826             HEU volume in lattice in cc          CALCULATED
'    0.01925             volume fraction of HEU in CV         CALCULATED
'    0.97898             bulk dens of water in CV             CALCULATED
 cuboid    1  1  6p1.51452                      com='unit cell'
unit 1005
'cubical void, filler for layers'
 cuboid    1  1  6p1.51452                      com='unit cell'
unit 1006
'content (collapsed) [Elev= 6.119 in.]'
' 4.54386     1.78892 half width-depth lattice            CALCULATED'
' 3.02924             height lattice                      CALCULATED'
'array 1         2r-4.54386      0.0'
 cuboid    1  1  4p4.54386     3.02924   0.0     com='homog. content-array'
 cylinder  1  1    6.426200    3.02974  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200    3.02974  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800    3.02974  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200    3.02974  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000    3.02974  -0.0005  com='np277_4'
 cylinder  16 1   11.074400    3.02974  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075    3.02974  -0.0005  com='kaolite'
 cylinder  19 1   21.722275    3.02974  -0.0005  com='drum'
 cuboid    20 1 4p22.866096    3.02974  -0.0005  com='drum chine outer radius'
unit 1007
```

```
'np277_4 spacer [Elev= 6.119 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  1  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.276 in.]'
' 9.09132             stack height (content spacers)       CALCULATED
 cylinder  1  1    6.426200   67.99768   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   67.99768   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   67.99768   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   67.99768   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   67.99768   0.0     com='np277_4'
 cylinder  16 1   11.074400   67.99768   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   67.99768   0.0     com='kaolite'
 cylinder  19 1   21.722275   67.99768   0.0     com='drum'
 cuboid    20 1 4p22.866096   67.99768   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  1  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  1  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  1  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
```

```
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    110.4900  0.0    com='bare package'
'cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
```

```
'reflector  21 2  6r3.0  10
end geometry
read array
ara=1 nux=3 nuy=3 nuz=1   fill  4r1004  5r1005      end fill
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.22Case hctf5bmt12_25_2_8_3

```
=csas25    parm=size=4000000
hctf5bmt12,1.4in thk np,24968.9gU(24968.9g235, 8258.4gH2O hx=  8.63),fr=1.0e-04
238groupndf5 infhommedium
'HEU wrapped dry content can hx=0.67, CV void volume 8273.32964'
uranium  1 den=18.81109 0.13826 293      92235  100.00
                                      92238   0.000               end
arbmh20i   0.86019  2 0 0 0    1001   11.1913
                               8016   88.8087    1  1.0000  293  end
'np277-4: spacer (HAC_MD&H)'
'HAC min.den.(95.3157 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07071e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.82995e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                          8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                          9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                         10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (HAC_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.476265 = (den.mult)(np277-4 min.den.) = 0.9668933*1.526803'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9188
```

```
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.70316e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                                 8016   88.8087   12  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                                 8016   47.0610   12  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                                 8016   53.2430   12  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                                 8016   30.0460   12  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                                 8016   40.0465   12  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                                 8016   28.5185   12  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                                 8016   39.6831   12  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                                 8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                 8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                 8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                 8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                 8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                 8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                 8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                 8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                 8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                 1001    8.1573
                                 8016   21.5782
```

```
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for HAC'
'nct density is multiplied by volume fraction 7.08030/5.74516 for HAC'
ss304                                          18  1.23239 293  end
'steel: drum steel for HAC'
'nct density is multiplied by volume fraction 3.20482/2.95645 for HAC'
ss304                                          19  1.08401 293  end
'void space external to drum'
arbmwed    0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
more data dab=400 end
hctf5bmt12,1.4in thk np,24968.9gU(24968.9g235, 8258.4gH2O,hx=  8.63),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 nb8=400 end parameters
read boun       all=specular                   end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'zhemicyl-y  19 1   21.838092    0.26620   0.00050 com='extend radius not used'
 zhemicyl-y  19 1   21.838092    0.26620   0.00050 com='drum bottom flat cover'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 zhemicyl-y  15 1    3.175000   11.59460  11.16330 com='void in pad-1'
 zhemicyl-y  14 1    7.924800   11.59460  11.16330 com='pad-1'
 zhemicyl-y  16 1    8.077200   11.59460  11.16330 com='np277_4 liner'
 zhemicyl-y  11 1   10.922000   11.59460  11.16330 com='np277_4'
 zhemicyl-y  16 1   11.074400   11.59460  10.85850 com='kaolite liner bottom'
 zhemicyl-y  12 1   21.685692   11.59460   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092   11.59460   0.00050 com='drum'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 zhemicyl-y  8  1    6.680200    0.63450   0.00050 com='cv bottom'
 zhemicyl-y  15 1    7.924800    0.63450   0.00050 com='void btw cv-np liner'
 zhemicyl-y  16 1    8.077200    0.63450   0.00050 com='np277_4 liner'
 zhemicyl-y  11 1   10.922000    0.63450   0.00050 com='np277_4'
 zhemicyl-y  16 1   11.074400    0.63450   0.00050 com='kaolite liner'
 zhemicyl-y  12 1   21.685692    0.63450   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092    0.63450   0.00050 com='drum'
unit 1004
'cubical content, stacked per cc'
'    9.08802     3.57796 lattice width-depth'
'    2.54000     1.00000 cube dimension'
'    1.27000     0.50000 cube half-dimension'
'   16.38706     1.00000 volume of HEU cube in unit cell'
'  308.25850             HEU mass one cube'
'   27                   number of HEU cubes per can'
' 8322.97957             HEU mass of cubes in cc'
'    3           3       number of cubes in -x direction'
'    3           3       number of cubes in -y direction'
'    9           9       number of HEU cubes in a layer'
'    4    VARIABLE       number of HEU layers in z-axis'
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'    0    VARIABLE       number of HEU cubes in top layer modulus(Z%N)'
'    9    VARIABLE       number of HEU voids in top layer'
'    ara=1 nux=3 nuy=3 nuz=4   fill 27r1004  9r1005      end fill'
'    0.48924     0.19261 gap dimension                        CALCULATED
'    3.02924     1.19261 unit cell dimension                  CALCULATED
'    1.51462     0.59631 unit cell half-dimension             CALCULATED
'   27.79719     1.69629 volume of unit cell                  CALCULATED
'   11.41013     0.69629 volume of water gap in unit cell     CALCULATED
' 1000.69893             lattice volume in cc                 CALCULATED
'  558.24820             moderator volume in lattice in cc    CALCULATED
'  442.45073             HEU volume in lattice in cc          CALCULATED
'    0.13826             volume fraction of HEU in CV         CALCULATED
'    0.86019             bulk dens of water in CV             CALCULATED
 cuboid    1  1  6p1.51452                       com='unit cell'
unit 1005
'cubical void, filler for layers'
 cuboid    1  1  6p1.51452                       com='unit cell'
unit 1006
'content (collapsed) [Elev= 9.691 in.]'
' 4.54386     1.78892 half width-depth lattice             CALCULATED'
'12.11696             height lattice                       CALCULATED'
'array 1         2r-4.54386      0.0'
 cuboid  1  1  2p4.54386 0.0 -4.54386 12.1169 0.0005 com='homog. content-array'
 zhemicyl-y  1  1    6.426200   12.11696   0.00050 com='cv well cavity'
 zhemicyl-y  8  1    6.680200   12.11696   0.00050 com='cv below 1st step'
 zhemicyl-y  15 1    7.924800   12.11696   0.00050 com='void btw cv-np liner'
 zhemicyl-y  16 1    8.077200   12.11696   0.00050 com='np277_4 liner'
 zhemicyl-y  11 1   10.922000   12.11696   0.00050 com='np277_4'
 zhemicyl-y  16 1   11.074400   12.11696   0.00050 com='kaolite liner'
 zhemicyl-y  12 1   21.685692   12.11696   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092   12.11696   0.00050 com='drum'
unit 1007
'np277_4 spacer [Elev=11.091 in.]'
 zhemicyl-y  2  1    5.24510     3.55660   0.00050 com='np spacer'
 zhemicyl-y  1  1    6.426200    3.55660   0.00050 com='cv well cavity'
 zhemicyl-y  8  1    6.680200    3.55660   0.00050 com='cv below 1st step'
 zhemicyl-y  15 1    7.924800    3.55660   0.00050 com='void btw cv-np liner'
 zhemicyl-y  16 1    8.077200    3.55660   0.00050 com='np277_4 liner'
 zhemicyl-y  11 1   10.922000    3.55660   0.00050 com='np277_4'
 zhemicyl-y  16 1   11.074400    3.55660   0.00050 com='kaolite liner'
 zhemicyl-y  12 1   21.685692    3.55660   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092    3.55660   0.00050 com='drum'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'43.46828             stack height (content spacers)       CALCULATED
 zhemicyl-y  1  1    6.426200   33.62022   0.00050 com='cv well cavity'
 zhemicyl-y  8  1    6.680200   33.62022   0.00050 com='cv below 1st step'
 zhemicyl-y  15 1    7.924800   33.62022   0.00050 com='void btw cv-np liner'
 zhemicyl-y  16 1    8.077200   33.62022   0.00050 com='np277_4 liner'
 zhemicyl-y  11 1   10.922000   33.62022   0.00050 com='np277_4'
 zhemicyl-y  16 1   11.074400   33.62022   0.00050 com='kaolite liner'
 zhemicyl-y  12 1   21.685692   33.62022   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092   33.62022   0.00050 com='drum'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 zhemicyl-y  1  1    6.426200    0.15190   0.00050 com='cv well cavity'
 zhemicyl-y  8  1    6.680200    0.15190   0.00050 com='cv at 1st step'
 zhemicyl-y  15 1    7.924800    0.15190   0.00050 com='void btw cv and liner'
 zhemicyl-y  16 1   11.074400    0.15190   0.00050 com='liner 1st step'
 zhemicyl-y  12 1   21.685692    0.15190   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092    0.15190   0.00050 com='drum'
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unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 zhemicyl-y  1  1    6.426200    0.22810   0.00050 com='cv well cavity'
 zhemicyl-y  8  1    6.680200    0.22810   0.00050 com='cv gap btw step-flng'
 zhemicyl-y  15 1   10.922000    0.22810   0.00050 com='void btw cv and liner'
 zhemicyl-y  16 1   11.074400    0.22810   0.00050 com='liner wall'
 zhemicyl-y  12 1   21.685692    0.22810   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092    0.22810   0.00050 com='drum'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 zhemicyl-y  1  1    6.426200    1.26950   0.00050 com='cavity'
 zhemicyl-y  9  1    9.525000    1.26950   0.00050 com='flange to top of well'
 zhemicyl-y  15 1    9.525000    1.26950   0.00050 com='void btw cv and pad-2'
 zhemicyl-y  14 1   10.033000    1.26950   0.00050 com='pad-2'
 zhemicyl-y  15 1   10.922000    1.26950   0.00050 com='void btw cv and liner'
 zhemicyl-y  16 1   11.074400    1.26950   0.00050 com='liner wall'
 zhemicyl-y  12 1   21.685692    1.26950   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092    1.26950   0.00050 com='drum'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 zhemicyl-y  10 1    9.525000    2.92050   0.00050 com='flange above cv well'
 zhemicyl-y  15 1    9.525000    2.92050   0.00050 com='void btw cv and pad-2'
 zhemicyl-y  14 1   10.033000    2.92050   0.00050 com='pad-2'
 zhemicyl-y  15 1   10.922000    2.92050   0.00050 com='void btw pad2-liner'
 zhemicyl-y  16 1   11.074400    2.92050   0.00050 com='liner wall'
 zhemicyl-y  12 1   21.685692    2.92050   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092    2.92050   0.00050 com='drum'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 zhemicyl-y  14 1   10.033000    0.76150   0.00050 com='pad-2'
 zhemicyl-y  15 1   10.922000    1.01550   0.00050 com='void btw pad2-liner'
 zhemicyl-y  16 1   11.074400    1.01550   0.00050 com='liner wall'
 zhemicyl-y  12 1   21.685692    1.01550   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092    1.01550   0.00050 com='drum'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 zhemicyl-y  15 1   10.922000    0.15190   0.00050 com='void abv pad2'
 zhemicyl-y  16 1   18.757900    0.15190   0.00050 com='liner 2nd step'
 zhemicyl-y  12 1   21.685692    0.15190   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092    0.15190   0.00050 com='drum'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 zhemicyl-y  13 1   18.097500    8.17830   0.49276 com='plug kaolite'
 zhemicyl-y  17 1   18.249900    8.17830   0.34036 com='sides of plug case'
 zhemicyl-y  15 1   18.605500    8.17830   0.00050 com='void: plug to liner'
 zhemicyl-y  16 1   18.757900    8.17830   0.00050 com='liner wall'
 zhemicyl-y  12 1   21.685692    8.17830   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092    8.17830   0.00050 com='drum'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 zhemicyl-y  13 1   18.097500    4.44450   0.00050 com='plug kaolite'
 zhemicyl-y  17 1   18.249900    4.44450   0.00050 com='sides of plug case'
 zhemicyl-y  15 1   18.605500    4.44450   0.00050 com='void: plug to liner'
 zhemicyl-y  16 1   18.757900    4.44450   0.00050 com='liner wall'
 zhemicyl-y  18 1   19.392900    4.44450   0.00050 com='lower angle iron'
 zhemicyl-y  12 1   21.685692    4.44450   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092    4.44450   0.00050 com='drum'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 zhemicyl-y  13 1   18.097500    0.11126   0.00050 com='plug kaolite'
 zhemicyl-y  17 1   18.249900    0.26366   0.00050 com='sides of plug case'
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 zhemicyl-y  15 1   18.605500    0.63450   0.00050 com='void: plug to liner'
 zhemicyl-y  16 1   18.757900    0.63450   0.00050 com='liner wall'
 zhemicyl-y  18 1   21.685692    0.63450   0.00050 com='bend section of ai'
 zhemicyl-y  19 1   21.838092    0.63450   0.00050 com='drum'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 zhemicyl-y  20 1   21.469792    1.90450   0.15240 com='void above lid'
 zhemicyl-y  19 1   21.622192    1.90450   0.00050 com='drum lid'
 zhemicyl-y  20 1   21.685692    1.90450   0.00050 com='void btw lid-drumwall'
 zhemicyl-y  19 1   21.838092    1.90450   0.00050 com='drum'
unit 2001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'zhemicyl+y  19 1   21.838092    0.26620   0.00050 com='extended radius not used'
 zhemicyl+y  19 1   21.838092    0.26620   0.00050 com='drum bottom flat cover'
unit 2002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 zhemicyl+y  15 1    3.175000   11.59460  11.16330 com='void in pad-1'
 zhemicyl+y  14 1    7.924800   11.59460  11.16330 com='pad-1'
 zhemicyl+y  16 1    8.077200   11.59460  11.16330 com='np277_4 liner'
 zhemicyl+y  11 1   10.922000   11.59460  11.16330 com='np277_4'
 zhemicyl+y  16 1   11.074400   11.59460  10.85850 com='kaolite liner bottom'
 zhemicyl+y  12 1   21.685692   11.59460   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092   11.59460   0.00050 com='drum'
unit 2003
'cv bottom [Elev= 4.920 in.]'
 zhemicyl+y  8  1    6.680200    0.63450   0.00050 com='cv bottom'
 zhemicyl+y  15 1    7.924800    0.63450   0.00050 com='void btw cv-np liner'
 zhemicyl+y  16 1    8.077200    0.63450   0.00050 com='np277_4 liner'
 zhemicyl+y  11 1   10.922000    0.63450   0.00050 com='np277_4'
 zhemicyl+y  16 1   11.074400    0.63450   0.00050 com='kaolite liner'
 zhemicyl+y  12 1   21.685692    0.63450   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092    0.63450   0.00050 com='drum'
unit 2006
'content (collapsed) [Elev= 9.691 in.]'
 zhemicyl+y  1  1    6.426200   12.11696   0.00050 com='cv well cavity'
 zhemicyl+y  8  1    6.680200   12.11696   0.00050 com='cv below 1st step'
 zhemicyl+y  15 1    7.924800   12.11696   0.00050 com='void btw cv-np liner'
 zhemicyl+y  16 1    8.077200   12.11696   0.00050 com='np277_4 liner'
 zhemicyl+y  11 1   10.922000   12.11696   0.00050 com='np277_4'
 zhemicyl+y  16 1   11.074400   12.11696   0.00050 com='kaolite liner'
 zhemicyl+y  12 1   21.685692   12.11696   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092   12.11696   0.00050 com='drum'
unit 2007
'np277_4 spacer [Elev=11.091 in.]'
 zhemicyl+y  2  1    5.24510     3.55660   0.00050 com='np spacer'
 zhemicyl+y  1  1    6.426200    3.55660   0.00050 com='cv well cavity'
 zhemicyl+y  8  1    6.680200    3.55660   0.00050 com='cv below 1st step'
 zhemicyl+y  15 1    7.924800    3.55660   0.00050 com='void btw cv-np liner'
 zhemicyl+y  16 1    8.077200    3.55660   0.00050 com='np277_4 liner'
 zhemicyl+y  11 1   10.922000    3.55660   0.00050 com='np277_4'
 zhemicyl+y  16 1   11.074400    3.55660   0.00050 com='kaolite liner'
 zhemicyl+y  12 1   21.685692    3.55660   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092    3.55660   0.00050 com='drum'
unit 2008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
 zhemicyl+y  1  1    6.426200   33.62022   0.00050 com='cv well cavity'
 zhemicyl+y  8  1    6.680200   33.62022   0.00050 com='cv below 1st step'
 zhemicyl+y  15 1    7.924800   33.62022   0.00050 com='void btw cv-np liner'
 zhemicyl+y  16 1    8.077200   33.62022   0.00050 com='np277_4 liner'
 zhemicyl+y  11 1   10.922000   33.62022   0.00050 com='np277_4'
 zhemicyl+y  16 1   11.074400   33.62022   0.00050 com='kaolite liner'
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 zhemicyl+y  12 1   21.685692   33.62022   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092   33.62022   0.00050 com='drum'
unit 2010
'cv at 1st step in liner [Elev=35.330 in.]'
 zhemicyl+y  1  1    6.426200    0.15190   0.00050 com='cv well cavity'
 zhemicyl+y  8  1    6.680200    0.15190   0.00050 com='cv at 1st step'
 zhemicyl+y  15 1    7.924800    0.15190   0.00050 com='void btw cv and liner'
 zhemicyl+y  16 1   11.074400    0.15190   0.00050 com='liner 1st step'
 zhemicyl+y  12 1   21.685692    0.15190   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092    0.15190   0.00050 com='drum'
unit 2011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 zhemicyl+y  1  1    6.426200    0.22810   0.00050 com='cv well cavity'
 zhemicyl+y  8  1    6.680200    0.22810   0.00050 com='cv gap btw step-flng'
 zhemicyl+y  15 1   10.922000    0.22810   0.00050 com='void btw cv and liner'
 zhemicyl+y  16 1   11.074400    0.22810   0.00050 com='liner wall'
 zhemicyl+y  12 1   21.685692    0.22810   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092    0.22810   0.00050 com='drum'
unit 2012
'cv flange to top of cv well [Elev=35.920 in.]'
 zhemicyl+y  1  1    6.426200    1.26950   0.00050 com='cavity'
 zhemicyl+y  9  1    9.525000    1.26950   0.00050 com='flange to top of well'
 zhemicyl+y  15 1    9.525000    1.26950   0.00050 com='void btw cv and pad-2'
 zhemicyl+y  14 1   10.033000    1.26950   0.00050 com='pad-2'
 zhemicyl+y  15 1   10.922000    1.26950   0.00050 com='void btw cv and liner'
 zhemicyl+y  16 1   11.074400    1.26950   0.00050 com='liner wall'
 zhemicyl+y  12 1   21.685692    1.26950   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092    1.26950   0.00050 com='drum'
unit 2013
'cv flange above cv well [Elev=37.070 in.]'
 zhemicyl+y  10 1    9.525000    2.92050   0.00050 com='flange above cv well'
 zhemicyl+y  15 1    9.525000    2.92050   0.00050 com='void btw cv and pad-2'
 zhemicyl+y  14 1   10.033000    2.92050   0.00050 com='pad-2'
 zhemicyl+y  15 1   10.922000    2.92050   0.00050 com='void btw pad2-liner'
 zhemicyl+y  16 1   11.074400    2.92050   0.00050 com='liner wall'
 zhemicyl+y  12 1   21.685692    2.92050   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092    2.92050   0.00050 com='drum'
unit 2014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 zhemicyl+y  14 1   10.033000    0.76150   0.00050 com='pad-2'
 zhemicyl+y  15 1   10.922000    1.01550   0.00050 com='void btw pad2-liner'
 zhemicyl+y  16 1   11.074400    1.01550   0.00050 com='liner wall'
 zhemicyl+y  12 1   21.685692    1.01550   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092    1.01550   0.00050 com='drum'
unit 2015
'2nd step in liner [Elev=37.530 in.]'
 zhemicyl+y  15 1   10.922000    0.15190   0.00050 com='void abv pad2'
 zhemicyl+y  16 1   18.757900    0.15190   0.00050 com='liner 2nd step'
 zhemicyl+y  12 1   21.685692    0.15190   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092    0.15190   0.00050 com='drum'
unit 2016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 zhemicyl+y  13 1   18.097500    8.17830   0.49276 com='plug kaolite'
 zhemicyl+y  17 1   18.249900    8.17830   0.34036 com='sides of plug case'
 zhemicyl+y  15 1   18.605500    8.17830   0.00050 com='void: plug to liner'
 zhemicyl+y  16 1   18.757900    8.17830   0.00050 com='liner wall'
 zhemicyl+y  12 1   21.685692    8.17830   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092    8.17830   0.00050 com='drum'
unit 2017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 zhemicyl+y  13 1   18.097500    4.44450   0.00050 com='plug kaolite'
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 zhemicyl+y  17 1   18.249900    4.44450   0.00050 com='sides of plug case'
 zhemicyl+y  15 1   18.605500    4.44450   0.00050 com='void: plug to liner'
 zhemicyl+y  16 1   18.757900    4.44450   0.00050 com='liner wall'
 zhemicyl+y  18 1   19.392900    4.44450   0.00050 com='lower angle iron'
 zhemicyl+y  12 1   21.685692    4.44450   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092    4.44450   0.00050 com='drum'
unit 2018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 zhemicyl+y  13 1   18.097500    0.11126   0.00050 com='plug kaolite'
 zhemicyl+y  17 1   18.249900    0.26366   0.00050 com='sides of plug case'
 zhemicyl+y  15 1   18.605500    0.63450   0.00050 com='void: plug to liner'
 zhemicyl+y  16 1   18.757900    0.63450   0.00050 com='liner wall'
 zhemicyl+y  18 1   21.685692    0.63450   0.00050 com='bend section of ai'
 zhemicyl+y  19 1   21.838092    0.63450   0.00050 com='drum'
unit 2019
'drum lid and lip [Elev=43.500 in.]'
 zhemicyl+y  20 1   21.469792    1.90450   0.15240 com='void above lid'
 zhemicyl+y  19 1   21.622192    1.90450   0.00050 com='drum lid'
 zhemicyl+y  20 1   21.685692    1.90450   0.00050 com='void btw lid-drumwall'
 zhemicyl+y  19 1   21.838092    1.90450   0.00050 com='drum'
unit 3001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'zhemicyl-x  19 1   21.838092    0.26620   0.00050 com='extended radius not used'
 zhemicyl-x  19 1   21.838092    0.26620   0.00050 com='drum bottom flat cover'
unit 3002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 zhemicyl-x  15 1    3.175000   11.59460  11.16330 com='void in pad-1'
 zhemicyl-x  14 1    7.924800   11.59460  11.16330 com='pad-1'
 zhemicyl-x  16 1    8.077200   11.59460  11.16330 com='np277_4 liner'
 zhemicyl-x  11 1   10.922000   11.59460  11.16330 com='np277_4'
 zhemicyl-x  16 1   11.074400   11.59460  10.85850 com='kaolite liner bottom'
 zhemicyl-x  12 1   21.685692   11.59460   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092   11.59460   0.00050 com='drum'
unit 3003
'cv bottom [Elev= 4.920 in.]'
 zhemicyl-x  8  1    6.680200    0.63450   0.00050 com='cv bottom'
 zhemicyl-x  15 1    7.924800    0.63450   0.00050 com='void btw cv-np liner'
 zhemicyl-x  16 1    8.077200    0.63450   0.00050 com='np277_4 liner'
 zhemicyl-x  11 1   10.922000    0.63450   0.00050 com='np277_4'
 zhemicyl-x  16 1   11.074400    0.63450   0.00050 com='kaolite liner'
 zhemicyl-x  12 1   21.685692    0.63450   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092    0.63450   0.00050 com='drum'
unit 3006
'content (collapsed) [Elev= 9.691 in.]'
 zhemicyl-x  1  1    6.426200   12.11696   0.00050 com='cv well cavity'
 zhemicyl-x  8  1    6.680200   12.11696   0.00050 com='cv below 1st step'
 zhemicyl-x  15 1    7.924800   12.11696   0.00050 com='void btw cv-np liner'
 zhemicyl-x  16 1    8.077200   12.11696   0.00050 com='np277_4 liner'
 zhemicyl-x  11 1   10.922000   12.11696   0.00050 com='np277_4'
 zhemicyl-x  16 1   11.074400   12.11696   0.00050 com='kaolite liner'
 zhemicyl-x  12 1   21.685692   12.11696   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092   12.11696   0.00050 com='drum'
unit 3007
'np277_4 spacer [Elev=11.091 in.]'
 zhemicyl-x  2  1    5.24510     3.55660   0.00050 com='np spacer'
 zhemicyl-x  1  1    6.426200    3.55660   0.00050 com='cv well cavity'
 zhemicyl-x  8  1    6.680200    3.55660   0.00050 com='cv below 1st step'
 zhemicyl-x  15 1    7.924800    3.55660   0.00050 com='void btw cv-np liner'
 zhemicyl-x  16 1    8.077200    3.55660   0.00050 com='np277_4 liner'
 zhemicyl-x  11 1   10.922000    3.55660   0.00050 com='np277_4'
 zhemicyl-x  16 1   11.074400    3.55660   0.00050 com='kaolite liner'
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 zhemicyl-x  12 1   21.685692    3.55660   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092    3.55660   0.00050 com='drum'
unit 3008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
 zhemicyl-x  1  1    6.426200   33.62022   0.00050 com='cv well cavity'
 zhemicyl-x  8  1    6.680200   33.62022   0.00050 com='cv below 1st step'
 zhemicyl-x  15 1    7.924800   33.62022   0.00050 com='void btw cv-np liner'
 zhemicyl-x  16 1    8.077200   33.62022   0.00050 com='np277_4 liner'
 zhemicyl-x  11 1   10.922000   33.62022   0.00050 com='np277_4'
 zhemicyl-x  16 1   11.074400   33.62022   0.00050 com='kaolite liner'
 zhemicyl-x  12 1   21.685692   33.62022   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092   33.62022   0.00050 com='drum'
unit 3010
'cv at 1st step in liner [Elev=35.330 in.]'
 zhemicyl-x  1  1    6.426200    0.15190   0.00050 com='cv well cavity'
 zhemicyl-x  8  1    6.680200    0.15190   0.00050 com='cv at 1st step'
 zhemicyl-x  15 1    7.924800    0.15190   0.00050 com='void btw cv and liner'
 zhemicyl-x  16 1   11.074400    0.15190   0.00050 com='liner 1st step'
 zhemicyl-x  12 1   21.685692    0.15190   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092    0.15190   0.00050 com='drum'
unit 3011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 zhemicyl-x  1  1    6.426200    0.22810   0.00050 com='cv well cavity'
 zhemicyl-x  8  1    6.680200    0.22810   0.00050 com='cv gap btw step-flng'
 zhemicyl-x  15 1   10.922000    0.22810   0.00050 com='void btw cv and liner'
 zhemicyl-x  16 1   11.074400    0.22810   0.00050 com='liner wall'
 zhemicyl-x  12 1   21.685692    0.22810   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092    0.22810   0.00050 com='drum'
unit 3012
'cv flange to top of cv well [Elev=35.920 in.]'
 zhemicyl-x  1  1    6.426200    1.26950   0.00050 com='cavity'
 zhemicyl-x  9  1    9.525000    1.26950   0.00050 com='flange to top of well'
 zhemicyl-x  15 1    9.525000    1.26950   0.00050 com='void btw cv and pad-2'
 zhemicyl-x  14 1   10.033000    1.26950   0.00050 com='pad-2'
 zhemicyl-x  15 1   10.922000    1.26950   0.00050 com='void btw cv and liner'
 zhemicyl-x  16 1   11.074400    1.26950   0.00050 com='liner wall'
 zhemicyl-x  12 1   21.685692    1.26950   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092    1.26950   0.00050 com='drum'
unit 3013
'cv flange above cv well [Elev=37.070 in.]'
 zhemicyl-x  10 1    9.525000    2.92050   0.00050 com='flange above cv well'
 zhemicyl-x  15 1    9.525000    2.92050   0.00050 com='void btw cv and pad-2'
 zhemicyl-x  14 1   10.033000    2.92050   0.00050 com='pad-2'
 zhemicyl-x  15 1   10.922000    2.92050   0.00050 com='void btw pad2-liner'
 zhemicyl-x  16 1   11.074400    2.92050   0.00050 com='liner wall'
 zhemicyl-x  12 1   21.685692    2.92050   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092    2.92050   0.00050 com='drum'
unit 3014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 zhemicyl-x  14 1   10.033000    0.76150   0.00050 com='pad-2'
 zhemicyl-x  15 1   10.922000    1.01550   0.00050 com='void btw pad2-liner'
 zhemicyl-x  16 1   11.074400    1.01550   0.00050 com='liner wall'
 zhemicyl-x  12 1   21.685692    1.01550   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092    1.01550   0.00050 com='drum'
unit 3015
'2nd step in liner [Elev=37.530 in.]'
 zhemicyl-x  15 1   10.922000    0.15190   0.00050 com='void abv pad2'
 zhemicyl-x  16 1   18.757900    0.15190   0.00050 com='liner 2nd step'
 zhemicyl-x  12 1   21.685692    0.15190   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092    0.15190   0.00050 com='drum'
unit 3016
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'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 zhemicyl-x  13 1   18.097500    8.17830   0.49276 com='plug kaolite'
 zhemicyl-x  17 1   18.249900    8.17830   0.34036 com='sides of plug case'
 zhemicyl-x  15 1   18.605500    8.17830   0.00050 com='void: plug to liner'
 zhemicyl-x  16 1   18.757900    8.17830   0.00050 com='liner wall'
 zhemicyl-x  12 1   21.685692    8.17830   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092    8.17830   0.00050 com='drum'
unit 3017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 zhemicyl-x  13 1   18.097500    4.44450   0.00050 com='plug kaolite'
 zhemicyl-x  17 1   18.249900    4.44450   0.00050 com='sides of plug case'
 zhemicyl-x  15 1   18.605500    4.44450   0.00050 com='void: plug to liner'
 zhemicyl-x  16 1   18.757900    4.44450   0.00050 com='liner wall'
 zhemicyl-x  18 1   19.392900    4.44450   0.00050 com='lower angle iron'
 zhemicyl-x  12 1   21.685692    4.44450   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092    4.44450   0.00050 com='drum'
unit 3018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 zhemicyl-x  13 1   18.097500    0.11126   0.00050 com='plug kaolite'
 zhemicyl-x  17 1   18.249900    0.26366   0.00050 com='sides of plug case'
 zhemicyl-x  15 1   18.605500    0.63450   0.00050 com='void: plug to liner'
 zhemicyl-x  16 1   18.757900    0.63450   0.00050 com='liner wall'
 zhemicyl-x  18 1   21.685692    0.63450   0.00050 com='bend section of ai'
 zhemicyl-x  19 1   21.838092    0.63450   0.00050 com='drum'
unit 3019
'drum lid and lip [Elev=43.500 in.]'
 zhemicyl-x  20 1   21.469792    1.90450   0.15240 com='void above lid'
 zhemicyl-x  19 1   21.622192    1.90450   0.00050 com='drum lid'
 zhemicyl-x  20 1   21.685692    1.90450   0.00050 com='void btw lid-drumwall'
 zhemicyl-x  19 1   21.838092    1.90450   0.00050 com='drum'
unit 4001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'zhemicyl+x  19 1   21.838092    0.26620   0.00050 com='extended radius not used'
 zhemicyl+x  19 1   21.838092    0.26620   0.00050 com='drum bottom flat cover'
unit 4002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 zhemicyl+x  15 1    3.175000   11.59460  11.16330 com='void in pad-1'
 zhemicyl+x  14 1    7.924800   11.59460  11.16330 com='pad-1'
 zhemicyl+x  16 1    8.077200   11.59460  11.16330 com='np277_4 liner'
 zhemicyl+x  11 1   10.922000   11.59460  11.16330 com='np277_4'
 zhemicyl+x  16 1   11.074400   11.59460  10.85850 com='kaolite liner bottom'
 zhemicyl+x  12 1   21.685692   11.59460   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092   11.59460   0.00050 com='drum'
unit 4003
'cv bottom [Elev= 4.920 in.]'
 zhemicyl+x  8  1    6.680200    0.63450   0.00050 com='cv bottom'
 zhemicyl+x  15 1    7.924800    0.63450   0.00050 com='void btw cv-np liner'
 zhemicyl+x  16 1    8.077200    0.63450   0.00050 com='np277_4 liner'
 zhemicyl+x  11 1   10.922000    0.63450   0.00050 com='np277_4'
 zhemicyl+x  16 1   11.074400    0.63450   0.00050 com='kaolite liner'
 zhemicyl+x  12 1   21.685692    0.63450   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092    0.63450   0.00050 com='drum'
unit 4006
'content (collapsed) [Elev= 9.691 in.]'
 zhemicyl+x  1  1    6.426200   12.11696   0.00050 com='cv well cavity'
 zhemicyl+x  8  1    6.680200   12.11696   0.00050 com='cv below 1st step'
 zhemicyl+x  15 1    7.924800   12.11696   0.00050 com='void btw cv-np liner'
 zhemicyl+x  16 1    8.077200   12.11696   0.00050 com='np277_4 liner'
 zhemicyl+x  11 1   10.922000   12.11696   0.00050 com='np277_4'
 zhemicyl+x  16 1   11.074400   12.11696   0.00050 com='kaolite liner'
 zhemicyl+x  12 1   21.685692   12.11696   0.00050 com='kaolite'
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 zhemicyl+x  19 1   21.838092   12.11696   0.00050 com='drum'
unit 4007
'np277_4 spacer [Elev=11.091 in.]'
 zhemicyl+x  2  1    5.24510     3.55660   0.00050 com='np spacer'
 zhemicyl+x  1  1    6.426200    3.55660   0.00050 com='cv well cavity'
 zhemicyl+x  8  1    6.680200    3.55660   0.00050 com='cv below 1st step'
 zhemicyl+x  15 1    7.924800    3.55660   0.00050 com='void btw cv-np liner'
 zhemicyl+x  16 1    8.077200    3.55660   0.00050 com='np277_4 liner'
 zhemicyl+x  11 1   10.922000    3.55660   0.00050 com='np277_4'
 zhemicyl+x  16 1   11.074400    3.55660   0.00050 com='kaolite liner'
 zhemicyl+x  12 1   21.685692    3.55660   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092    3.55660   0.00050 com='drum'
unit 4008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
 zhemicyl+x  1  1    6.426200   33.62022   0.00050 com='cv well cavity'
 zhemicyl+x  8  1    6.680200   33.62022   0.00050 com='cv below 1st step'
 zhemicyl+x  15 1    7.924800   33.62022   0.00050 com='void btw cv-np liner'
 zhemicyl+x  16 1    8.077200   33.62022   0.00050 com='np277_4 liner'
 zhemicyl+x  11 1   10.922000   33.62022   0.00050 com='np277_4'
 zhemicyl+x  16 1   11.074400   33.62022   0.00050 com='kaolite liner'
 zhemicyl+x  12 1   21.685692   33.62022   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092   33.62022   0.00050 com='drum'
unit 4010
'cv at 1st step in liner [Elev=35.330 in.]'
 zhemicyl+x  1  1    6.426200    0.15190   0.00050 com='cv well cavity'
 zhemicyl+x  8  1    6.680200    0.15190   0.00050 com='cv at 1st step'
 zhemicyl+x  15 1    7.924800    0.15190   0.00050 com='void btw cv and liner'
 zhemicyl+x  16 1   11.074400    0.15190   0.00050 com='liner 1st step'
 zhemicyl+x  12 1   21.685692    0.15190   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092    0.15190   0.00050 com='drum'
unit 4011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 zhemicyl+x  1  1    6.426200    0.22810   0.00050 com='cv well cavity'
 zhemicyl+x  8  1    6.680200    0.22810   0.00050 com='cv gap btw step-flng'
 zhemicyl+x  15 1   10.922000    0.22810   0.00050 com='void btw cv and liner'
 zhemicyl+x  16 1   11.074400    0.22810   0.00050 com='liner wall'
 zhemicyl+x  12 1   21.685692    0.22810   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092    0.22810   0.00050 com='drum'
unit 4012
'cv flange to top of cv well [Elev=35.920 in.]'
 zhemicyl+x  1  1    6.426200    1.26950   0.00050 com='cavity'
 zhemicyl+x  9  1    9.525000    1.26950   0.00050 com='flange to top of well'
 zhemicyl+x  15 1    9.525000    1.26950   0.00050 com='void btw cv and pad-2'
 zhemicyl+x  14 1   10.033000    1.26950   0.00050 com='pad-2'
 zhemicyl+x  15 1   10.922000    1.26950   0.00050 com='void btw cv and liner'
 zhemicyl+x  16 1   11.074400    1.26950   0.00050 com='liner wall'
 zhemicyl+x  12 1   21.685692    1.26950   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092    1.26950   0.00050 com='drum'
unit 4013
'cv flange above cv well [Elev=37.070 in.]'
 zhemicyl+x  10 1    9.525000    2.92050   0.00050 com='flange above cv well'
 zhemicyl+x  15 1    9.525000    2.92050   0.00050 com='void btw cv and pad-2'
 zhemicyl+x  14 1   10.033000    2.92050   0.00050 com='pad-2'
 zhemicyl+x  15 1   10.922000    2.92050   0.00050 com='void btw pad2-liner'
 zhemicyl+x  16 1   11.074400    2.92050   0.00050 com='liner wall'
 zhemicyl+x  12 1   21.685692    2.92050   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092    2.92050   0.00050 com='drum'
unit 4014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 zhemicyl+x  14 1   10.033000    0.76150   0.00050 com='pad-2'
 zhemicyl+x  15 1   10.922000    1.01550   0.00050 com='void btw pad2-liner'
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 zhemicyl+x  16 1   11.074400    1.01550   0.00050 com='liner wall'
 zhemicyl+x  12 1   21.685692    1.01550   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092    1.01550   0.00050 com='drum'
unit 4015
'2nd step in liner [Elev=37.530 in.]'
 zhemicyl+x  15 1   10.922000    0.15190   0.00050 com='void abv pad2'
 zhemicyl+x  16 1   18.757900    0.15190   0.00050 com='liner 2nd step'
 zhemicyl+x  12 1   21.685692    0.15190   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092    0.15190   0.00050 com='drum'
unit 4016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 zhemicyl+x  13 1   18.097500    8.17830   0.49276 com='plug kaolite'
 zhemicyl+x  17 1   18.249900    8.17830   0.34036 com='sides of plug case'
 zhemicyl+x  15 1   18.605500    8.17830   0.00050 com='void: plug to liner'
 zhemicyl+x  16 1   18.757900    8.17830   0.00050 com='liner wall'
 zhemicyl+x  12 1   21.685692    8.17830   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092    8.17830   0.00050 com='drum'
unit 4017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 zhemicyl+x  13 1   18.097500    4.44450   0.00050 com='plug kaolite'
 zhemicyl+x  17 1   18.249900    4.44450   0.00050 com='sides of plug case'
 zhemicyl+x  15 1   18.605500    4.44450   0.00050 com='void: plug to liner'
 zhemicyl+x  16 1   18.757900    4.44450   0.00050 com='liner wall'
 zhemicyl+x  18 1   19.392900    4.44450   0.00050 com='lower angle iron'
 zhemicyl+x  12 1   21.685692    4.44450   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092    4.44450   0.00050 com='drum'
unit 4018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 zhemicyl+x  13 1   18.097500    0.11126   0.00050 com='plug kaolite'
 zhemicyl+x  17 1   18.249900    0.26366   0.00050 com='sides of plug case'
 zhemicyl+x  15 1   18.605500    0.63450   0.00050 com='void: plug to liner'
 zhemicyl+x  16 1   18.757900    0.63450   0.00050 com='liner wall'
 zhemicyl+x  18 1   21.685692    0.63450   0.00050 com='bend section of ai'
 zhemicyl+x  19 1   21.838092    0.63450   0.00050 com='drum'
unit 4019
'drum lid and lip [Elev=43.500 in.]'
 zhemicyl+x  20 1   21.469792    1.90450   0.15240 com='void above lid'
 zhemicyl+x  19 1   21.622192    1.90450   0.00050 com='drum lid'
 zhemicyl+x  20 1   21.685692    1.90450   0.00050 com='void btw lid-drumwall'
 zhemicyl+x  19 1   21.838092    1.90450   0.00050 com='drum'
unit 5001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    20 1 2p21.839092  2p37.826417   0.26670   0.0
 hole 1001 0.0   37.826417   0.0
 hole 2001 0.0  -37.826417   0.0
 hole 3001  21.839092   0.0   0.0
 hole 4001 -21.839092   0.0   0.0
unit 5002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    20 1 2p21.839092  2p37.826417  11.59510   0.0
 hole 1002 0.0   37.826417   0.0
 hole 2002 0.0  -37.826417   0.0
 hole 3002  21.839092   0.0   0.0
 hole 4002 -21.839092   0.0   0.0
unit 5003
'cv bottom [Elev= 4.920 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   0.63500   0.0
 hole 1003 0.0   37.826417   0.0
 hole 2003 0.0  -37.826417   0.0
 hole 3003  21.839092   0.0   0.0
 hole 4003 -21.839092   0.0   0.0
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unit 5006
'content (collapsed) [Elev= 9.691 in.]'
 cuboid    20 1 2p21.839092  2p37.826417  12.11746   0.0
 hole 1006 0.0   37.826417   0.0
 hole 2006 0.0  -37.826417   0.0
 hole 3006  21.839092   0.0   0.0
 hole 4006 -21.839092   0.0   0.0
unit 5007
'np277_4 spacer [Elev=11.091 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   3.55710   0.0
 hole 1007 0.0   37.826417   0.0
 hole 2007 0.0  -37.826417   0.0
 hole 3007  21.839092   0.0   0.0
 hole 4007 -21.839092   0.0   0.0
unit 5008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
 cuboid    20 1 2p21.839092  2p37.826417  33.62072   0.0
 hole 1008 0.0   37.826417   0.0
 hole 2008 0.0  -37.826417   0.0
 hole 3008  21.839092   0.0   0.0
 hole 4008 -21.839092   0.0   0.0
unit 5010
'cv at 1st step in liner [Elev=35.330 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   0.15240   0.0
 hole 1010 0.0   37.826417   0.0
 hole 2010 0.0  -37.826417   0.0
 hole 3010  21.839092   0.0   0.0
 hole 4010 -21.839092   0.0   0.0
unit 5011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   0.22860   0.0
 hole 1011 0.0   37.826417   0.0
 hole 2011 0.0  -37.826417   0.0
 hole 3011  21.839092   0.0   0.0
 hole 4011 -21.839092   0.0   0.0
unit 5012
'cv flange to top of cv well [Elev=35.920 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   1.27000   0.0
 hole 1012 0.0   37.826417   0.0
 hole 2012 0.0  -37.826417   0.0
 hole 3012  21.839092   0.0   0.0
 hole 4012 -21.839092   0.0   0.0
unit 5013
'cv flange above cv well [Elev=37.070 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   2.92100   0.0
 hole 1013 0.0   37.826417   0.0
 hole 2013 0.0  -37.826417   0.0
 hole 3013  21.839092   0.0   0.0
 hole 4013 -21.839092   0.0   0.0
unit 5014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   1.01600   0.0
 hole 1014 0.0   37.826417   0.0
 hole 2014 0.0  -37.826417   0.0
 hole 3014  21.839092   0.0   0.0
 hole 4014 -21.839092   0.0   0.0
unit 5015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   0.15240   0.0
 hole 1015 0.0   37.826417   0.0
 hole 2015 0.0  -37.826417   0.0
```

```
 hole 3015  21.839092   0.0   0.0
 hole 4015 -21.839092   0.0   0.0
unit 5016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   8.17880   0.0
 hole 1016 0.0   37.826417   0.0
 hole 2016 0.0  -37.826417   0.0
 hole 3016  21.839092   0.0   0.0
 hole 4016 -21.839092   0.0   0.0
unit 5017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   4.44500   0.0
 hole 1017 0.0   37.826417   0.0
 hole 2017 0.0  -37.826417   0.0
 hole 3017  21.839092   0.0   0.0
 hole 4017 -21.839092   0.0   0.0
unit 5018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   0.63500   0.0
 hole 1018 0.0   37.826417   0.0
 hole 2018 0.0  -37.826417   0.0
 hole 3018  21.839092   0.0   0.0
 hole 4018 -21.839092   0.0   0.0
unit 5019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   1.90500   0.0
 hole 1019 0.0   37.826417   0.0
 hole 2019 0.0  -37.826417   0.0
 hole 3019  21.839092   0.0   0.0
 hole 4019 -21.839092   0.0   0.0
unit 5020
'es3100 drum [Elev=43.500 in.]'
array 3         -21.839092   -37.826417    0.0
 cuboid    20  1 2p21.839592 2p37.826917 110.4905 0.0 com='interst. array space'
unit 6001
'drum bottom flat cover'
 cuboid    20  1 2p21.839092 0.0 -21.839092  0.26670 0.0
 hole 1001 0.0   0.0   0.0
unit 6002
'above drum bottom flat cover and below containment vessel'
 cuboid    20  1 2p21.839092 0.0 -21.839092 11.59510 0.0
 hole 1002 0.0   0.0   0.0
unit 6003
'cv bottom'
 cuboid    20  1 2p21.839092 0.0 -21.839092  0.63500 0.0
 hole 1003 0.0   0.0   0.0
unit 6006
'drum stand'
'content (collapsed)'
 cuboid    20  1 2p21.839092 0.0 -21.839092 12.11746 0.0
 hole 1006 0.0   0.0   0.0
unit 6007
'np277_4 spacer'
 cuboid    20  1 2p21.839092 0.0 -21.839092  3.55710 0.0
 hole 1007 0.0   0.0   0.0
unit 6008
'top of content stack to bottom of 1st step'
 cuboid    20  1 2p21.839092 0.0 -21.839092 33.62072 0.0
 hole 1008 0.0   0.0   0.0
unit 6010
'cv at 1st step in liner'
```

```
 cuboid    20  1 2p21.839092 0.0 -21.839092  0.15240 0.0
 hole 1010 0.0   0.0   0.0
unit 6011
'vertical gap between 1st step in liner and cv flange'
 cuboid    20  1 2p21.839092 0.0 -21.839092  0.22860 0.0
 hole 1011 0.0   0.0   0.0
unit 6012
'cv flange to top of cv well'
 cuboid    20  1 2p21.839092 0.0 -21.839092  1.27000 0.0
 hole 1012 0.0   0.0   0.0
unit 6013
'cv flange above cv well'
 cuboid    20  1 2p21.839092 0.0 -21.839092  2.92100 0.0
 hole 1013 0.0   0.0   0.0
unit 6014
'plugpad2 below liner 2nd step'
 cuboid    20  1 2p21.839092 0.0 -21.839092  1.01600 0.0
 hole 1014 0.0   0.0   0.0
unit 6015
'2nd step in liner'
 cuboid    20  1 2p21.839092 0.0 -21.839092  0.15240 0.0
 hole 1015 0.0   0.0   0.0
unit 6016
'abv 2nd step in liner to bottom of angle iron'
 cuboid    20  1 2p21.839092 0.0 -21.839092  8.17880 0.0
 hole 1016 0.0   0.0   0.0
unit 6017
'bottom of angle iron to bend in angle iron'
 cuboid    20  1 2p21.839092 0.0 -21.839092  4.44500 0.0
 hole 1017 0.0   0.0   0.0
unit 6018
'bend in angle iron to top of angle iron'
 cuboid    20  1 2p21.839092 0.0 -21.839092  0.63500 0.0
 hole 1018 0.0   0.0   0.0
unit 6019
'drum lid and lip'
 cuboid    20  1 2p21.839092 0.0 -21.839092  1.90500 0.0
 hole 1019 0.0   0.0   0.0
unit 6020
'es3100 drum'
array 4         2r-21.839092     0.0
 cuboid    20  1 2p21.839592 0.0005 -21.839592 110.4905 0.0
unit 7001
 cuboid    20  1 2p21.839092 21.839092 0.0  0.26670 0.0
 hole 2001 0.0   0.0   0.0
unit 7002
 cuboid    20  1 2p21.839092 21.839092 0.0 11.59510 0.0
 hole 2002 0.0   0.0   0.0
unit 7003
 cuboid    20  1 2p21.839092 21.839092 0.0  0.63500 0.0
 hole 2003 0.0   0.0   0.0
unit 7006
 cuboid    20  1 2p21.839092 21.839092 0.0 12.11746 0.0
 hole 2006 0.0   0.0   0.0
unit 7007
 cuboid    20  1 2p21.839092 21.839092 0.0  3.55710 0.0
 hole 2007 0.0   0.0   0.0
unit 7008
 cuboid    20  1 2p21.839092 21.839092 0.0 33.62072 0.0
 hole 2008 0.0   0.0   0.0
unit 7010
```

```
 cuboid    20  1 2p21.839092 21.839092 0.0  0.15240 0.0
 hole 2010 0.0   0.0   0.0
unit 7011
 cuboid    20  1 2p21.839092 21.839092 0.0  0.22860 0.0
 hole 2011 0.0   0.0   0.0
unit 7012
 cuboid    20  1 2p21.839092 21.839092 0.0  1.27000 0.0
 hole 2012 0.0   0.0   0.0
unit 7013
 cuboid    20  1 2p21.839092 21.839092 0.0  2.92100 0.0
 hole 2013 0.0   0.0   0.0
unit 7014
 cuboid    20  1 2p21.839092 21.839092 0.0  1.01600 0.0
 hole 2014 0.0   0.0   0.0
unit 7015
 cuboid    20  1 2p21.839092 21.839092 0.0  0.15240 0.0
 hole 2015 0.0   0.0   0.0
unit 7016
 cuboid    20  1 2p21.839092 21.839092 0.0  8.17880 0.0
 hole 2016 0.0   0.0   0.0
unit 7017
 cuboid    20  1 2p21.839092 21.839092 0.0  4.44500 0.0
 hole 2017 0.0   0.0   0.0
unit 7018
 cuboid    20  1 2p21.839092 21.839092 0.0  0.63500 0.0
 hole 2018 0.0   0.0   0.0
unit 7019
 cuboid    20  1 2p21.839092 21.839092 0.0  1.90500 0.0
 hole 2019 0.0   0.0   0.0
unit 7020
'es3100 drum'
array 5         -21.839092     0.0     0.0
 cuboid    20  1 2p21.839592 21.839592 -0.0005 110.4905 0.0
unit 8001
 cuboid    20  1 0.0 -21.839092 2p37.826417  0.26670 0.0
 hole 3001 0.0   0.0   0.0
unit 8002
 cuboid    20  1 0.0 -21.839092 2p37.826417 11.59510 0.0
 hole 3002 0.0   0.0   0.0
unit 8003
 cuboid    20  1 0.0 -21.839092 2p37.826417  0.63500 0.0
 hole 3003 0.0   0.0   0.0
unit 8006
 cuboid    20  1 0.0 -21.839092 2p37.826417 12.11746 0.0
 hole 3006 0.0   0.0   0.0
unit 8007
 cuboid    20  1 0.0 -21.839092 2p37.826417  3.55710 0.0
 hole 3007 0.0   0.0   0.0
unit 8008
 cuboid    20  1 0.0 -21.839092 2p37.826417 33.62072 0.0
 hole 3008 0.0   0.0   0.0
unit 8010
 cuboid    20  1 0.0 -21.839092 2p37.826417  0.15240 0.0
 hole 3010 0.0   0.0   0.0
unit 8011
 cuboid    20  1 0.0 -21.839092 2p37.826417  0.22860 0.0
 hole 3011 0.0   0.0   0.0
unit 8012
 cuboid    20  1 0.0 -21.839092 2p37.826417  1.27000 0.0
 hole 3012 0.0   0.0   0.0
unit 8013
```

```
 cuboid    20  1 0.0 -21.839092 2p37.826417  2.92100 0.0
 hole 3013 0.0   0.0   0.0
unit 8014
 cuboid    20  1 0.0 -21.839092 2p37.826417  1.01600 0.0
 hole 3014 0.0   0.0   0.0
unit 8015
 cuboid    20  1 0.0 -21.839092 2p37.826417  0.15240 0.0
 hole 3015 0.0   0.0   0.0
unit 8016
 cuboid    20  1 0.0 -21.839092 2p37.826417  8.17880 0.0
 hole 3016 0.0   0.0   0.0
unit 8017
 cuboid    20  1 0.0 -21.839092 2p37.826417  4.44500 0.0
 hole 3017 0.0   0.0   0.0
unit 8018
 cuboid    20  1 0.0 -21.839092 2p37.826417  0.63500 0.0
 hole 3018 0.0   0.0   0.0
unit 8019
 cuboid    20  1 0.0 -21.839092 2p37.826417  1.90500 0.0
 hole 3019 0.0   0.0   0.0
unit 8020
'es3100 drum'
array 6         -21.839092    -37.826417    0.0
 cuboid    20  1 0.0005 -21.839592 2p37.826917 110.4905 0.0
unit 9001
 cuboid    20  1 21.839092 0.0 2p37.826417  0.26670 0.0
 hole 4001 0.0   0.0   0.0
unit 9002
 cuboid    20  1 21.839092 0.0 2p37.826417 11.59510 0.0
 hole 4002 0.0   0.0   0.0
unit 9003
 cuboid    20  1 21.839092 0.0 2p37.826417  0.63500 0.0
 hole 4003 0.0   0.0   0.0
unit 9006
 cuboid    20  1 21.839092 0.0 2p37.826417 12.11746 0.0
 hole 4006 0.0   0.0   0.0
unit 9007
 cuboid    20  1 21.839092 0.0 2p37.826417  3.55710 0.0
 hole 4007 0.0   0.0   0.0
unit 9008
 cuboid    20  1 21.839092 0.0 2p37.826417 33.62072 0.0
 hole 4008 0.0   0.0   0.0
unit 9010
 cuboid    20  1 21.839092 0.0 2p37.826417  0.15240 0.0
 hole 4010 0.0   0.0   0.0
unit 9011
 cuboid    20  1 21.839092 0.0 2p37.826417  0.22860 0.0
 hole 4011 0.0   0.0   0.0
unit 9012
 cuboid    20  1 21.839092 0.0 2p37.826417  1.27000 0.0
 hole 4012 0.0   0.0   0.0
unit 9013
 cuboid    20  1 21.839092 0.0 2p37.826417  2.92100 0.0
 hole 4013 0.0   0.0   0.0
unit 9014
 cuboid    20  1 21.839092 0.0 2p37.826417  1.01600 0.0
 hole 4014 0.0   0.0   0.0
unit 9015
 cuboid    20  1 21.839092 0.0 2p37.826417  0.15240 0.0
 hole 4015 0.0   0.0   0.0
unit 9016
```

```
 cuboid    20  1 21.839092 0.0 2p37.826417  8.17880 0.0
 hole 4016 0.0   0.0   0.0
unit 9017
 cuboid    20  1 21.839092 0.0 2p37.826417  4.44500 0.0
 hole 4017 0.0   0.0   0.0
unit 9018
 cuboid    20  1 21.839092 0.0 2p37.826417  0.63500 0.0
 hole 4018 0.0   0.0   0.0
unit 9019
 cuboid    20  1 21.839092 0.0 2p37.826417  1.90500 0.0
 hole 4019 0.0   0.0   0.0
unit 9020
'es3100 drum'
array 7         0.0    -37.826417    0.0
 cuboid    20  1 21.839592 -0.0005 2p37.826917 110.4905 0.0
unit 9021
 cuboid    20  1 21.839092 0.0 21.839092 0.0  0.26670 0.0
unit 9022
 cuboid    20  1 21.839092 0.0 21.839092 0.0 11.59510 0.0
unit 9023
 cuboid    20  1 21.839092 0.0 21.839092 0.0  0.63500 0.0
unit 9026
 cuboid    20  1 21.839092 0.0 21.839092 0.0 12.11746 0.0
unit 9027
 cuboid    20  1 21.839092 0.0 21.839092 0.0  3.55710 0.0
unit 9028
 cuboid    20  1 21.839092 0.0 21.839092 0.0 33.62072 0.0
unit 9030
 cuboid    20  1 21.839092 0.0 21.839092 0.0  0.15240 0.0
unit 9031
 cuboid    20  1 21.839092 0.0 21.839092 0.0  0.22860 0.0
unit 9032
 cuboid    20  1 21.839092 0.0 21.839092 0.0  1.27000 0.0
unit 9033
 cuboid    20  1 21.839092 0.0 21.839092 0.0  2.92100 0.0
unit 9034
 cuboid    20  1 21.839092 0.0 21.839092 0.0  1.01600 0.0
unit 9035
 cuboid    20  1 21.839092 0.0 21.839092 0.0  0.15240 0.0
unit 9036
 cuboid    20  1 21.839092 0.0 21.839092 0.0  8.17880 0.0
unit 9037
 cuboid    20  1 21.839092 0.0 21.839092 0.0  4.44500 0.0
unit 9038
 cuboid    20  1 21.839092 0.0 21.839092 0.0  0.63500 0.0
unit 9039
 cuboid    20  1 21.839092 0.0 21.839092 0.0  1.90500 0.0
unit 9040
'array end space'
array 8         0.0    0.0    0.0
 cuboid    20  1 21.839592 -0.0005 21.839592 -0.0005 110.4905 0.0
global
unit 9050
array 9    3r0.0
reflector  21 2  6r3.0  10
end geometry
read array
ara=1 nux=3 nuy=3 nuz=4   fill 27r1004  9r1005      end fill
ara=3 nux=1 nuy=1 nuz=19 fill
5001 5002 5003 5006 5007 5006 5007 5006 5008 5010
5011 5012 5013 5014 5015 5016 5017 5018 5019       end fill
```

```
ara=4 nux=1 nuy=1 nuz=19                                fill
6001 6002 6003 6006 6007 6006 6007 6006 6008 6010
6011 6012 6013 6014 6015 6016 6017 6018 6019       end fill
ara=5 nux=1 nuy=1 nuz=19                                fill
7001 7002 7003 7006 7007 7006 7007 7006 7008 7010
7011 7012 7013 7014 7015 7016 7017 7018 7019       end fill
ara=6 nux=1 nuy=1 nuz=19                                fill
8001 8002 8003 8006 8007 8006 8007 8006 8008 8010
8011 8012 8013 8014 8015 8016 8017 8018 8019       end fill
ara=7 nux=1 nuy=1 nuz=19                                fill
9001 9002 9003 9006 9007 9006 9007 9006 9008 9010
9011 9012 9013 9014 9015 9016 9017 9018 9019       end fill
ara=8 nux=1 nuy=1 nuz=19                                fill
9021 9022 9023 9026 9027 9026 9027 9026 9028 9030
9031 9032 9033 9034 9035 9036 9037 9038 9039       end fill
ara=9 nux=7 nuy=3 nuz=3                                 fill
9040 5r6020 9040 8020 5r5020 9020 9040 5r7020 9040 2q21 end fill
end array
read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.23Case nciaoxt11_1_24_1_3

```
=csas25    parm=size=3000000
nciaoxt11,0.0in np,disp.24000.0gUO2 (21124.9g235, 6533.9gH2O hx=  9.90),fr=1.0e-04
238groupndf5 infhommedium
'HEU volume =3669.72477, SPACER volume    0.00000'
'HEU oxide, bulk density of oxide in cans=  6.54000 g/cm3'
'wrapped dry content can hx=0.79, CV void volume 6545.63717'
'oxide= 24000.0 g, sat. moisture in HEU oxide=1477.3 g, oxide htox= 1.83'
arbmuox    6.54000   2 0 0 0  92235   88.0203
                              8016   11.9797    1  1.0000  293  end
arbmastm  4.0256e-01  2 0 0 0   1001   11.1913
                              8016   88.8087    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0   1001   11.1913
                              8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                         8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
```

```
ss304                                              9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                             10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
```

```
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
nciaoxt11,0.0in np,disp.24000.0gUO2 (21124.9g235, 6533.9gH2O,hx=  9.90),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                   end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.276 in.]'
 cylinder  3  1    6.426200   77.72400  28.92123 com='cavity abv HEU'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
```

```
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   77.72400   0.0     com='kaolite'
 cylinder  19 1   21.722275   77.72400   0.0     com='drum'
 cuboid    20 1 4p22.866096   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
```

```
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    1120.337  0.0    com='bare package'
'cuboid    21  1 4p55.067200   1150.817 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.24Case nciask_9_15

```
=csas25    parm=size=3000000
nciask,0.0 21300.0g soc(19865.3uox,15672.8u235,  921.0c),hx= 12.82,fr=1.0e+00
238groupndf5 infhommedium
'  cm3: Skull oxide content 6974.5, SPACER    0.0, CV void 3240.9; CV htox=12.82'
'g/cm3: Skull oxide content  3.05400'
'U3O8   (19865.33gUOX,16816.3gU,15672.8g235U, 3801.4g.sat.H2O, HX=  7.43)'
'Carbon (  921.00gC,   58764.1mgC/g235U)'
'Poly   (  513.00gCH2)'
'Other  (    0.67gUnident (assumed H2O)'
''
'Increm (  921.0gC,15672.8g235U,   58764.1mgC/g235U)'
'GREP1:21300.00 19865.33 3.8014e+03    7.43 16816.35 15672.84   921.00  58764.1
'GREP2: 3235.07   513.00      12.82    0.67  1.0e+00
''
arbmuox    2.84830    3 0 0 0  92235   78.8954
                               92238    5.7563
                                8016   15.3483    1  1.0000  293  end
arbmc     1.3205e-01  1 0 0 0   6012  100.0000    1  1.0000  293  end
arbmastm  5.4505e-01  2 0 0 0   1001   11.1913
                                8016   88.8087    1  1.0000  293  end
arbmpoly   0.07355    2 0 0 0   1001   14.3798
                                6012   85.6202    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0   1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
```

```
                                8016   43.4251
                               11023    0.1174
                               12000    0.3378
                               13027   39.0479
                               14000    2.4672
                               16000    0.3083
                               20000   11.8336
                               26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
```

```
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  1       293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
nciask,0.0,21300.0g soc(19865.3uox,15672.8u235,  921.0c),hx= 12.82 fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                   end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.276 in.]'
 cylinder  3  1    6.426200   77.72400  54.39413 com='cavity abv HEU'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   77.72400   0.0     com='kaolite'
 cylinder  19 1   21.722275   77.72400   0.0     com='drum'
 cuboid    20 1 4p22.866096   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
```

```
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
```

```
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    1120.337  0.0    com='bare package'
'cuboid    21  1 4p55.067200   1150.817 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.25Case ncsrunhct11_9_1_15

```
=csas25    parm=size=3000000
ncsrunhct11 0.0innp,disp. 9000.0gUNHc( 4238.7g235, 6980.8gH2O hx= 54.99),fr=1.0e+00
238groupndf5 infhommedium
'U(enr)O2(NO3)2+6H2O [2.81 g/cc for U(nat)], gU/L= 414.9296'
'UNH crystals in cans  2.79329 g/cm3. wrapped dry content can hx=3.96'
arbmunh    2.79329  5 0 0 0   92235   47.0962
                              92238    0.0000
                               1001    2.4232
                               7014    5.6116
                               8016   44.8690    1  0.31541 293  end
arbmh2oc  6.8336e-01  2 0 0 0  1001   11.1913
                               8016   88.8087    1  1.0000  293  end
```

```
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  6.8336e-01  2 0 0 0   1001   11.1913
                                8016   88.8087     3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                              8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                              9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                             10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
```

```
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
ncsrunhct11 0.0innp,disp. 9000.0gUNHc( 4238.7g235, 6980.8gH2O,hx= 54.99),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
```

```
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   23.329900    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   23.177500   11.59510   0.0     com='kaolite'
 cylinder  19 1   23.329900   11.59510   0.0     com='drum'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
 cylinder  12 1   23.177500   77.72400   0.0     com='kaolite'
 cylinder  19 1   23.329900   77.72400   0.0     com='drum'
 cuboid    21 1 4p24.587200   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   23.177500    0.22860   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.22860   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.27000   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.27000   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
```

```
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   23.177500    2.92100   0.0     com='kaolite'
 cylinder  19 1   23.329900    2.92100   0.0     com='drum'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.01600   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.01600   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   23.177500    8.17880   0.0     com='kaolite'
 cylinder  19 1   23.329900    8.17880   0.0     com='drum'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   23.177500    4.44500   0.0     com='kaolite'
 cylinder  19 1   23.329900    4.44500   0.0     com='drum'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   23.177500    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   22.961600    1.90500   0.15240 com='void above lid'
 cylinder  19 1   23.114000    1.90500   0.0     com='drum lid'
 cylinder  21 1   23.177500    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   23.329900    1.90500   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
```

```
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.26Case icsrunhct12_15_1_15

```
=csas25    parm=size=3000000
icsrunhct12 0.0innp,disp.15000.0gUNHc( 7064.4g235, 6870.7gH2O hx= 52.91),fr=1.0e+00
238groupndf5 infhommedium
'U(enr)O2(NO3)2+6H2O [2.81 g/cc for U(nat)], gU/L= 429.1329 dispersed'
'UNH crystals in cans  2.79329 g/cm3. wrapped dry content can hx=2.37'
'UNHc in cv   9308.07449 g.'
'water in cv  6870.67680 g.'
arbmunh    2.79329  5 0 0 0   92235   47.0962
                              92238    0.0000
                               1001    2.4232
                               7014    5.6116
                               8016   44.8690    1  0.32620 293  end
arbmh2oc   0.99820  2 0 0 0    1001   11.1913
                               8016   88.8087    1  0.67380 293  end
'np277-4: spacer (HAC_MD&H)'
'HAC min.den.(95.3157 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07071e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.82995e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0    1001   11.1913
                                 8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                            8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                            9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                           10  0.94348 293  end
```

```
'np277-4: confinement -- neutron poison inner liner (HAC_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.516887 = (den.mult)(np277-4 min.den.) = 0.9935052*1.526803'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.80508e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                                8016   88.8087   12  1       293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                                8016   53.2430   12  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                                8016   30.0460   12  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                                8016   40.0465   12  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                                8016   28.5185   12  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                                8016   39.6831   12  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                                8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                8016   28.5185   13  0.307   293  end
```

```
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
'UNHc in cv well   5691.92551 g.'
'water in cv well  4201.44688 g.'
arbmunh    2.79329  5 0 0 0   92235   47.0962
                             92238    0.0000
                              1001    2.4232
                              7014    5.6116
                              8016   44.8690   15  0.32620 293  end
arbmh2oc   0.99820  2 0 0 0    1001   11.1913
                              8016   88.8087   15  0.67380 293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for HAC'
'nct density is multiplied by volume fraction 7.08030/5.74516'
ss304                                          18  1.23239 293  end
'steel: drum steel for HAC'
'nct density is multiplied by volume fraction 3.20482/2.95645'
ss304                                          19  1.08401 293  end
'void space external to drum'
'array density is assumed not reduced by hac'
'arbmwed    0.9982   2 0 0 0    1001   11.1913
'                              8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   21  1.0     293  end
end comp
icsrunhct12 0.0innp,disp.15000.0gUNHc( 7064.4g235, 6870.7gH2O,hx= 52.91),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   21.838092    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   21.838092    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p21.838092    0.26670   0.0     com='drum(chine)outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
'v1002=1.36748e+01  '
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.685692   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.838092   11.59510   0.0     com='drum'
 cuboid    21 1 4p21.838092   11.59510   0.0     com='drum(chine)outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
'v1003=4.43850e+03  '
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
```

```
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
 cylinder  12 1   21.685692   77.72400   0.0     com='kaolite'
 cylinder  19 1   21.838092   77.72400   0.0     com='drum'
 cuboid    21 1 4p21.838092   77.72400   0.0     com='drum(chine)outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
'v1010=8.70294e+00  '
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
'v1011=5.36220e+01  '
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.685692    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.22860   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.22860   0.0     com='drum(chine)outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
'v1012=7.43264e+01  '
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.27000   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.27000   0.0     com='drum(chine)outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
'v1013=1.70951e+02  '
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.685692    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.838092    2.92100   0.0     com='drum'
 cuboid    21 1 4p21.838092    2.92100   0.0     com='drum(chine)outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
'v1014=1.39785e+02  '
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.01600   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.01600   0.0     com='drum(chine)outer radius'
unit 1015
```

```
'2nd step in liner [Elev=37.530 in.]'
'v1015=5.71136e+01  '
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
'v1016=6.92877e+02  '
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.685692    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.838092    8.17880   0.0     com='drum'
 cuboid    21 1 4p21.838092    8.17880   0.0     com='drum(chine)outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
'v1017=1.83014e+02  '
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.685692    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.838092    4.44500   0.0     com='drum'
 cuboid    21 1 4p21.838092    4.44500   0.0     com='drum(chine)outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
'v1018=4.14168e+02  '
'Volume cv well=6.24674e+03  '
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.685692    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   21.469792    1.90500   0.15240 com='void above lid'
 cylinder  19 1   21.622192    1.90500   0.0     com='drum lid'
 cylinder  21 1   21.685692    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.838092    1.90500   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.90500   0.0     com='drum(chine)outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-21.838092     0.0
'cuboid     0  1 4p21.838092    110.4905  0.0    com='bare package'
 cuboid    21  1 4p52.318092   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
```

```
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.27Case ncsrtriga_1_15_15

```
=csas25    parm=size=3000000
ncsrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O hx=255.01),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=18.2, CV void volume 9014.40198'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
```

```
                              14000    2.4672
                              16000    0.3083
                              20000   11.8336
                              26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                               8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
```

```
ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
ncsrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O,hx=255.01),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   23.329900    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   23.177500   11.59510   0.0     com='kaolite'
 cylinder  19 1   23.329900   11.59510   0.0     com='drum'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   23.177500    0.63500   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
```

```
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   23.177500   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   23.329900   12.70050  -0.0005  com='drum'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   23.177500    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   23.329900    0.00020  -0.0001  com='drum'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   23.177500   38.98540   0.0     com='kaolite'
 cylinder  19 1   23.329900   38.98540   0.0     com='drum'
 cuboid    21 1 4p24.587200   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   23.177500    0.22860   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.22860   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.27000   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.27000   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
```

```
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   23.177500    2.92100   0.0     com='kaolite'
 cylinder  19 1   23.329900    2.92100   0.0     com='drum'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.01600   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.01600   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   23.177500    8.17880   0.0     com='kaolite'
 cylinder  19 1   23.329900    8.17880   0.0     com='drum'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   23.177500    4.44500   0.0     com='kaolite'
 cylinder  19 1   23.329900    4.44500   0.0     com='drum'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   23.177500    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   22.961600    1.90500   0.15240 com='void above lid'
 cylinder  19 1   23.114000    1.90500   0.0     com='drum lid'
 cylinder  21 1   23.177500    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   23.329900    1.90500   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
```

```
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.28Case nciatriga_1_15_3

```
=csas25    parm=size=3000000
nciatriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O hx=255.01),fr=1.0e-04
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=18.2, CV void volume 9014.40198'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                          8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                          9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                         10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
```

```
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
```

```
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                           16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                           17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                           18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                           18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                           19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                           19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
nciatriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O,hx=255.01),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                    end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.926 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
```

```
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.926 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   21.722275   12.70050  -0.0005  com='drum'
 cuboid    20 1 4p22.866096   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.926 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.276 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   38.98540   0.0     com='kaolite'
 cylinder  19 1   21.722275   38.98540   0.0     com='drum'
 cuboid    20 1 4p22.866096   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
```

```
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
```

```
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    110.4900  0.0    com='bare package'
'cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.29Case atdmr_7_8

```
=csas25    parm=size=300000
atdmr,[ 7000.0U, 7000.0U235,500.0CH2]g htox= 2.40,Rc= 6.02382cm
238groupndf5 multiregion
'U= 7000.0g, poly=500.0g, content hx=2.40'
'core htox= 2.40'
uranium  1 den=18.81109 0.4064 293  92235  100.00
                                    92238   0.000                end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  0.5936  293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv    0.9982   2 0 0 0   1001   11.1913
                               8016   88.8087    2  1.0     293  end
'steel: cv, drum liner, plug liner, angle iron, drum'
ss304                                          3  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087    4  0.0287  293  end
```

```
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610    4  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430    4  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460    4  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465    4  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185    4  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831    4  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039    4  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087    5  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610    5  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430    5  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460    5  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465    5  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185    5  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831    5  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039    5  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
arbmh2ok   0.61533  2 0 0 0    1001   11.1913
                               8016   88.8087    6  1.0e+00  293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                               8016   47.0610    6  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                               8016   53.2430    6  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                               8016   30.0460    6  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                               8016   40.0465    6  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                               8016   28.5185    6  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                               8016   39.6831    6  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                               8016   25.8039    6  0.020   293  end
```

```
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    7  1.0000  293  end
end comp
spherical end
1   6.02382
7  26.02382
end zone
atdmr,[ 7000.0U, 7000.0U235,500.0CH2]g htox= 2.40 Rc= 6.02382cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Mass of fm in core region   = 7000.00000 g'
'Mass of poly in core region =  500.00000 g'
'Mass of core region         = 7500.00000 g'
'Vol of fm                   =  372.12095 cm3'
'Vol of poly                 =  543.47826 cm3'
'Volume of core region       =  915.59921 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  =   2.3957'
read geometry
global
unit 1001
'uranium metal/poly dry core with 20.0 cm water reflection'
sphere  1  1   6.02382  com='uranium metal/poly core'
sphere  7  1  26.02382  com='20.0 cm water reflector'
end geometry
end data
end
```

### 6.9.7.30Case atdmsr_7_8_11

```
=csas25    parm=size=300000
atdmsr,[ 7000.0U, 7000.0U235,500.0CH2]g htox= 2.40,Rc= 6.02382cm, 33066.6gSS,Rs=10.6643cm
238groupndf5 multiregion
'U= 7000.0g, poly=500.0g, content hx=2.40'
'core htox= 2.40'
uranium  1 den=18.81109 0.4064 293  92235  100.00
                                    92238   0.000                end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                              6012   85.6202    1  0.5936  293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv    0.9982   2 0 0 0   1001   11.1913
                              8016   88.8087    2  1.0     293  end
'steel: cv, drum liner, plug liner, angle iron, drum'
ss304                                         3  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                              8016   88.8087    4  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                              8016   47.0610    4  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                              8016   53.2430    4  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                              8016   30.0460    4  0.067   293  end
```

```
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                              8016   40.0465    4  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                              8016   28.5185    4  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                              8016   39.6831    4  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                              8016   25.8039    4  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087    5  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610    5  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430    5  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460    5  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465    5  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185    5  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831    5  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039    5  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
arbmh2ok   0.61533  2 0 0 0    1001   11.1913
                              8016   88.8087    6  1.0e+00  293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                              8016   47.0610    6  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                              8016   53.2430    6  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                              8016   30.0460    6  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                              8016   40.0465    6  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                              8016   28.5185    6  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                              8016   39.6831    6  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                              8016   25.8039    6  0.020   293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    7  1.0000  293  end
end comp
spherical end
1   6.02382
```

```
3  10.66433
7  30.66433
end zone
atdmsr,[ 7000.0U, 7000.0U235,500.0CH2]g htox= 2.40 Rc= 6.02382cm, 33066.6gSS,Rs=10.6643cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Mass of fm in core region   = 7000.00000 g'
'Mass of poly in core region =  500.00000 g'
'Mass of core region         = 7500.00000 g'
'Vol of fm                   =  372.12095 cm3'
'Vol of poly                 =  543.47826 cm3'
'Volume of core region       =  915.59921 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  =   2.3957'
' '
'Mass of steel is derived from the mass of the steel in the CV,'
'steel liner, plug liner, angle iron and drum.  The mass of each'
'was taken directly from Case hciabmt12_36_1_8_1_in.output'
'Model volume taken as stainless steel mass divided by ss density'
'total mass of ss304=  66133.15000'
'total volume of ss304= 8329.1'
'maximum ss304 radius = 13.01972'
read geometry
global
unit 1001
'uranium metal/poly dry core, ss304 shell, 20.0 cm h2o reflector'
'increase ss304 shell by equal volume increments'
'8.32911e+02  cm3  volume of increment'
'5080.155 cm3               accumulative volume of core and ss304'
'10.66433 cm                accumulative radius of ss304 shell'
'3.30666e+04  g             accumulative mass of ss304 shell'
sphere  1  1   6.02382  com='uranium metal/poly core'
sphere  3  1  10.66433  com='ss304 shell around core'
sphere  7  1  30.66433  com='20cm h2o reflector around ss304 shell'
end geometry
end data
end
```

### 6.9.7.31Case atdmdkr_7_8_6

```
=csas25    parm=size=300000
atdmdkr,[ 7000.0U, 7000.0U235,500.0CH2]g htox= 2.40,Rc= 6.02382cm, 53419.1gKao,Rk=31.0802cm
238groupndf5 multiregion
'U= 7000.0g, poly=500.0g, content hx=2.40'
'core htox= 2.40'
uranium  1 den=18.81109 0.4064 293  92235  100.00
                                    92238   0.000                end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  0.5936  293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv    0.9982   2 0 0 0   1001   11.1913
                               8016   88.8087    2  1.0     293  end
'steel: cv, drum liner, plug liner, angle iron, drum'
ss304                                          3  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
```

```
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087    4  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610    4  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430    4  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460    4  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465    4  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185    4  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831    4  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039    4  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087    5  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610    5  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430    5  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460    5  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465    5  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185    5  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831    5  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039    5  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in 15lb free h2o-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in 15lb free h2o-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                               8016   88.8087    6 0.244736 293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                               8016   47.0610    6  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                               8016   53.2430    6  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                               8016   30.0460    6  0.067   293  end
```

```
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                              8016   40.0465    6  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                              8016   28.5185    6  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                              8016   39.6831    6  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                              8016   25.8039    6  0.020   293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    7  1.0000  293  end
end comp
spherical end
1   6.02382
6  31.08024
7  51.08024
end zone
atdmdkr,[ 7000.0U, 7000.0U235,500.0CH2]g htox= 2.40 Rc= 6.02382cm, 53419.1gKao,Rk=31.0802cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Mass of fm in core region   = 7000.00000 g'
'Mass of poly in core region =  500.00000 g'
'Mass of core region         = 7500.00000 g'
'Vol of fm                   =  372.12095 cm3'
'Vol of poly                 =  543.47826 cm3'
'Volume of core region       =  915.59921 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  =   2.3957'
read geometry
global
unit 1001
'uranium metal/poly dry core, 15lb free h2o-kaolite shell, 20.0 cm water reflection'
'maximum kaolite radius =  31.08014 cm'
'increase kaolite shell by equal volume increments'
'2.49686e+04  cm3 volume of increment'
'125758.5 cm3 accumulative volume of core and kaolite'
'31.08024 cm accumulative radius of kaolite shell'
'5.34191e+04  g accumulative mass of kaolite shell'
sphere  1  1   6.02382  com='uranium metal/poly core'
sphere  6  1  31.08024  com='dry-kaolite shell around core'
sphere  7  1  51.08024  com='20cm h2o reflector around kaolite shell'
end geometry
end data
end
```

### 6.9.7.32Case atdzr

```
=csas25    parm=size=300000
atdzr,[10400.UZrHx, 921.0U235,500.0CH2]g htox=43.37,Rc= 7.46774cm
238groupndf5 multiregion
'UZrHx=10400.0g, poly=500.0g, content hx=18.2'
'core htox=43.37'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  0.6885 293  end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  0.3115  293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    7  1.0000  293  end
end comp
```

```
spherical end
1   7.46774
7  27.46774
end zone
atdzr,[10400.UZrHx, 921.0U235,500.0CH2]g htox=43.37 Rc= 7.46774cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Mass of fm in core region   = 10400.0010 g'
'Mass of poly in core region =  500.00000 g'
'Mass of core region         = 10900.0010 g'
'Vol of fm                   = 1200.95996 cm3'
'Vol of poly                 =  543.47826 cm3'
'Volume of core region       = 1744.43822 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  =  43.3700'
read geometry
global
unit 1001
'fissile material dry core with 20.0 cm water reflection'
sphere  1  1   7.46774  com='HEU core'
sphere  7  1  27.46774  com='20.0 cm water reflector'
end geometry
end data
end
```

### 6.9.7.33Case athzp15kr_5

```
=csas25    parm=size=300000
athzp15kr,[10400.UZrHx, 921.0U235,500.0CH2,9008.5H2O]g htox=298.6,Rc=31.14838cm
238groupndf5 multiregion
'UZrHx=10400.0g poly=500.0g cont.hx=18.2, H2O in Kaolite=  9008.5g, homgcore hx=298.6'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  0.0095 293  end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  0.0043  293  end
arbmh2ok   0.07216   2 0 0 0    1001   11.1913
                               8016   88.8087    1  9.8620e-01    293  end
arbmal2o3  0.40458   2 0 0 0   13027   52.9390
                               8016   47.0610    1  0.096   293  end
arbmsio2   0.40458   2 0 0 0   14000   46.7570
                               8016   53.2430    1  0.367   293  end
arbmfe2o3  0.40458   2 0 0 0   26000   69.9540
                               8016   30.0460    1  0.067   293  end
arbmtio2   0.40458   2 0 0 0   22000   59.9535
                               8016   40.0465    1  0.012   293  end
arbmcao    0.40458   2 0 0 0   20000   71.4815
                               8016   28.5185    1  0.307   293  end
arbmmgo    0.40458   2 0 0 0   12000   60.3169
                               8016   39.6831    1  0.131   293  end
arbmna2o   0.40458   2 0 0 0   11023   74.1961
                               8016   25.8039    1  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    2  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                          3  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
```

```
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087    4  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610    4  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430    4  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460    4  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465    4  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185    4  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831    4  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039    4  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087    5  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610    5  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430    5  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460    5  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465    5  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185    5  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831    5  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039    5  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in 15lb free h2o-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in 15lb free h2o-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                               8016   88.8087    6  1.0e+00  293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                               8016   47.0610    6  0.096   293  end
```

```
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                              8016   53.2430    6  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                              8016   30.0460    6  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                              8016   40.0465    6  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                              8016   28.5185    6  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                              8016   39.6831    6  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                              8016   25.8039    6  0.020   293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    7  1.0000  293  end
end comp
spherical end
1  31.14838
7  51.14838
end zone
athzp15kr,[10400.UZrHx, 921.0U235,500.0CH2,9008.5H2O]g htox=298.6 Rc=31.14838cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                             CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                             CHECK=> 2204.746 g'
'Mass of kao from Kaolite = 51214.88 g'
'                             CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of homogenized fm             = 10400.0010 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 9008.54567 g'
'Mass of kao in homogenized region  = 51214.8849 g'
'Mass of homogenized region         = 71123.4316 g'
'Vol of homogenized fm              = 1200.95996 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 124841.264 cm3'
'Vol of kao                         = 124844.318 cm3'
'Volume of homogenized region       = 126588.757 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  = 298.6696'
read geometry
global
unit 1001
'homogenized UZrHx/poly/15lb free h2o-Kaolite, 20.0 cm refl'
sphere  1  1  31.14838  com='HEU core/water mixture'
sphere  7  1  51.14838  com='20.0 cm water reflector'
end geometry
end data
end
```

### 6.9.7.34Case athzpw15kr_5

```
=csas25    parm=size=300000
athzpw15kr,[10400.UZrHx, 921.0U235,500.0CH2,6803.8H2O]g
htox=236.1,Rc=12.69027cm,53419.6,Rs=31.69769cm
238groupndf5 multiregion
'UZrHx=10400.0g poly=500.0g cont.hx=18.2, H2O in Kaolite=  6803.8g, homgcore hx=236.1'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
```

```
                              92235    8.8558
                              92238   36.1442    1  0.1403 293  end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                              6012   85.6202    1  0.0635  293  end
arbmkh2o   0.9982    2 0 0 0   1001   11.1913
                              8016   88.8087    1  7.9622e-01    293  end
'kaolite 1600 shell'
arbmh2ok 1.7660e-02  2 0 0 0   1001   11.1913
                              8016   88.8087    2  1.000   293  end
arbmal2o3  0.41023   2 0 0 0   13027   52.9390
                              8016   47.0610    2  0.096   293  end
arbmsio2   0.41023   2 0 0 0   14000   46.7570
                              8016   53.2430    2  0.367   293  end
arbmfe2o3  0.41023   2 0 0 0   26000   69.9540
                              8016   30.0460    2  0.067   293  end
arbmtio2   0.41023   2 0 0 0   22000   59.9535
                              8016   40.0465    2  0.012   293  end
arbmcao    0.41023   2 0 0 0   20000   71.4815
                              8016   28.5185    2  0.307   293  end
arbmmgo    0.41023   2 0 0 0   12000   60.3169
                              8016   39.6831    2  0.131   293  end
arbmna2o   0.41023   2 0 0 0   11023   74.1961
                              8016   25.8039    2  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                          4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                              8016   88.8087    5  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                              8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                              8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                              8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                              8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                              8016   28.5185    5  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                              8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                              8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087    6  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
```

```
                                8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in wet-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in wet-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                                8016   88.8087    7  1.000   293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                                8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                                8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                                8016   30.0460    7  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                                8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                                8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                                8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                                8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087    8  1.0000  293  end
end comp
spherical end
1  12.69027
2  31.69769
8  51.69769
end zone
athzpw15kr,[10400.UZrHx, 921.0U235,500.0CH2,6803.8H2O]g htox=236.1
Rc=12.69027cm,53419.6,Rs=31.69769cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                           CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                           CHECK=> 2204.746 g'
'Mass of kao from Kaolite = 51214.88 g'
```

```
'                            CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of homogenized fm             = 10400.0010 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 6803.83024 g'
'Mass of homogenized region         = 17703.8312 g'
'Vol of homogenized fm              = 1200.95996 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 6816.09922 cm3'
'Volume of homogenized region       = 8560.53744 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  = 236.1886'
' '
'Mass of h2o in shell region        = 2204.71543 g'
'Mass of kao in shell region        = 51214.8849 g'
'Mass of kaolite in shell           = 53419.6003 g'
'Volume of kaolite in shell region  = 124843.000 cm3'
read geometry
global
unit 1001
'homogenized UZrHx/poly/excess water, wet-Kaolite shell, 20.0 cm refl'
sphere  1  1  12.69027  com='HEU core/water mixture'
sphere  2  1  31.69769  com='radius of kaolite shell'
sphere  8  1  51.69769  com='20.0 cm water reflector'
end geometry
end data
end
```

### 6.9.7.35Case athmp15kr_12_8_5

```
=csas25    parm=size=300000
athmp15kr,[ 7000.0U, 7000.0U235,500.0CH2,9008.5H2O]g htox=35.99,Rc=31.08025cm
238groupndf5 multiregion
'U= 7000.0g poly=500.0g cont.hx=2.40, H2O in Kaolite=  9008.5g, core hx=35.99'
uranium  1 den=18.81109 2.9590e-03   293   92235  100.00
                                           92238    0.000               end
arbmpoly   0.92000   2 0 0 0    1001   14.3798
                                6012   85.6202    1  4.3216e-03    293  end
arbmh2ok   0.07216   2 0 0 0    1001   11.1913
                                8016   88.8087    1  9.9270e-01    293  end
arbmal2o3  0.40724   2 0 0 0   13027   52.9390
                                8016   47.0610    1  0.096   293  end
arbmsio2   0.40724   2 0 0 0   14000   46.7570
                                8016   53.2430    1  0.367   293  end
arbmfe2o3  0.40724   2 0 0 0   26000   69.9540
                                8016   30.0460    1  0.067   293  end
arbmtio2   0.40724   2 0 0 0   22000   59.9535
                                8016   40.0465    1  0.012   293  end
arbmcao    0.40724   2 0 0 0   20000   71.4815
                                8016   28.5185    1  0.307   293  end
arbmmgo    0.40724   2 0 0 0   12000   60.3169
                                8016   39.6831    1  0.131   293  end
arbmna2o   0.40724   2 0 0 0   11023   74.1961
                                8016   25.8039    1  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    2  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                          3  1.0     293  end
'kaolite 1600 body'
```

```
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087    4  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610    4  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430    4  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460    4  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465    4  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185    4  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831    4  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039    4  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087    5  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610    5  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430    5  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460    5  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465    5  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185    5  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831    5  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039    5  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in 15lb free h2o-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in 15lb free h2o-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
```

```
                                8016   88.8087    6  1.0e+00  293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                                8016   47.0610    6  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                                8016   53.2430    6  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                                8016   30.0460    6  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                                8016   40.0465    6  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                                8016   28.5185    6  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                                8016   39.6831    6  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                                8016   25.8039    6  0.020   293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087    7  1.0000  293  end
end comp
spherical end
1  31.08025
7  51.08025
end zone
athmp15kr,[ 7000.0U, 7000.0U235,500.0CH2,9008.5H2O]g htox=35.99 Rc=31.08025cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                           CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                           CHECK=> 2204.746 g'
'Mass of kao from Kaolite = 51214.88 g'
'                           CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of homogenized fm             = 7000.00000 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 9008.54567 g'
'Mass of kao in homogenized region  = 51214.8849 g'
'Mass of homogenized region         = 67723.4306 g'
'Vol of homogenized fm              =  372.12095 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 124841.264 cm3'
'Vol of kao                         = 124844.318 cm3'
'Volume of homogenized region       = 125759.918 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  =  35.9859'
read geometry
global
unit 1001
'homogenized uranium/poly/15lb free h2o-Kaolite, 20.0 cm refl'
sphere  1  1  31.08025  com='HEU core/water mixture'
sphere  7  1  51.08025  com='20.0 cm water reflector'
end geometry
end data
end
```

### 6.9.7.36Case athmpw15kr_12_8_5

```
=csas25    parm=size=300000
athmpw15kr,[ 7000.0U, 7000.0U235,500.0CH2,6803.8H2O]g
htox=27.77,Rc=12.26673cm,53419.6,Rs=31.63191cm
238groupndf5 multiregion
```

```
'U= 7000.0g poly=500.0g cont.hx=2.40, H2O in Kaolite=  6803.8g, core hx=27.77'
uranium  1 den=18.81109 4.8129e-02   293   92235  100.00
                                           92238    0.000              end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  7.0292e-02    293  end
arbmkh2o   0.9982    2 0 0 0   1001   11.1913
                               8016   88.8087    1  8.8158e-01    293  end
'kaolite 1600 shell'
arbmh2ok 1.7660e-02  2 0 0 0   1001   11.1913
                               8016   88.8087    2  1.000   293  end
arbmal2o3  0.41023   2 0 0 0   13027   52.9390
                               8016   47.0610    2  0.096   293  end
arbmsio2   0.41023   2 0 0 0   14000   46.7570
                               8016   53.2430    2  0.367   293  end
arbmfe2o3  0.41023   2 0 0 0   26000   69.9540
                               8016   30.0460    2  0.067   293  end
arbmtio2   0.41023   2 0 0 0   22000   59.9535
                               8016   40.0465    2  0.012   293  end
arbmcao    0.41023   2 0 0 0   20000   71.4815
                               8016   28.5185    2  0.307   293  end
arbmmgo    0.41023   2 0 0 0   12000   60.3169
                               8016   39.6831    2  0.131   293  end
arbmna2o   0.41023   2 0 0 0   11023   74.1961
                               8016   25.8039    2  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                          4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087    5  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185    5  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087    6  0.0287  293  end
```

```
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in 15lb free h2o-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in 15lb free h2o-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                              8016   88.8087    7  1.000   293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                              8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                              8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                              8016   30.0460    7  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                              8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                              8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                              8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                              8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    8  1.0000  293  end
end comp
spherical end
1  12.26673
2  31.63191
8  51.63191
end zone
athmpw15kr,[ 7000.0U, 7000.0U235,500.0CH2,6803.8H2O]g htox=27.77
Rc=12.26673cm,53419.6,Rs=31.63191cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                           CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                           CHECK=> 2204.746 g'
```

```
'Mass of kao from Kaolite = 51214.88 g'
'                            CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of homogenized fm             = 7000.00000 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 6803.83024 g'
'Mass of homogenized region         = 14303.8302 g'
'Vol of homogenized fm              =  372.12095 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 6816.09922 cm3'
'Volume of homogenized region       = 7731.69843 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  =  27.7652'
' '
'Mass of h2o in shell region        = 2204.71543 g'
'Mass of kao in shell region        = 51214.8849 g'
'Mass of kaolite in shell           = 53419.6003 g'
'Volume of kaolite in shell region  = 124843.000 cm3'
read geometry
global
unit 1001
'homogenized uranium/poly/excess water, 15lb free h2o-Kaolite shell, 20.0 cm refl'
sphere  1  1  12.26673  com='HEU core/water mixture'
sphere  2  1  31.63191  com='radius of kaolite shell'
sphere  8  1  51.63191  com='20.0 cm water reflector'
end geometry
end data
end
```

### 6.9.7.37Case athmpw13kr_12_8_5

```
=csas25    parm=size=300000
athmpw13kr,[ 7000.0U, 7000.0U235,500.0CH2,5896.6H2O]g
htox=24.38,Rc=11.76592cm,53419.6,Rs=31.55946cm
238groupndf5 multiregion
'U= 7000.0g poly=500.0g cont.hx=2.40, H2O in Kaolite=  5896.6g, core hx=24.38'
uranium  1 den=18.81109 5.4540e-02   293   92235  100.00
                                           92238    0.000              end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  7.9656e-02    293  end
arbmkh2o   0.9982    2 0 0 0   1001   11.1913
                               8016   88.8087    1  8.6580e-01    293  end
'kaolite 1600 shell'
arbmh2ok 1.7660e-02  2 0 0 0   1001   11.1913
                               8016   88.8087    2  1.000   293  end
arbmal2o3  0.41023   2 0 0 0   13027   52.9390
                               8016   47.0610    2  0.096   293  end
arbmsio2   0.41023   2 0 0 0   14000   46.7570
                               8016   53.2430    2  0.367   293  end
arbmfe2o3  0.41023   2 0 0 0   26000   69.9540
                               8016   30.0460    2  0.067   293  end
arbmtio2   0.41023   2 0 0 0   22000   59.9535
                               8016   40.0465    2  0.012   293  end
arbmcao    0.41023   2 0 0 0   20000   71.4815
                               8016   28.5185    2  0.307   293  end
arbmmgo    0.41023   2 0 0 0   12000   60.3169
                               8016   39.6831    2  0.131   293  end
arbmna2o   0.41023   2 0 0 0   11023   74.1961
                               8016   25.8039    2  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
```

```
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                           4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087    5  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185    5  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087    6  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in 13lb free h2o-Kaolite = 8101.3937 = 5896.67 + 2204.7237 g'
```

```
'density of water in 13lb free h2o-Kaolite = 0.06489 g/cm3 = 8101.3937/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.272142 = 2204.7237/8101.3937'
arbmh2ok   0.06489  2 0 0 0    1001   11.1913
                               8016   88.8087    7  1.000   293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                               8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                               8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                               8016   30.0460    7  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                               8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                               8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                               8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                               8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    8  1.0000  293  end
end comp
spherical end
1  11.76592
2  31.55946
8  51.55946
end zone
athmpw13kr,[ 7000.0U, 7000.0U235,500.0CH2,5896.6H2O]g htox=24.38
Rc=11.76592cm,53419.6,Rs=31.55946cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 8101.342 g'
'                           CHECK=> 8101.062 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                           CHECK=> 2204.639 g'
'Mass of kao from Kaolite = 51214.88 g'
'                           CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of homogenized fm             = 7000.00000 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 5896.62664 g'
'Mass of homogenized region         = 13396.6266 g'
'Vol of homogenized fm              =  372.12095 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 5907.25971 cm3'
'Volume of homogenized region       = 6822.85892 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  =  24.3825'
' '
'Mass of h2o in shell region        = 2204.71543 g'
'Mass of kao in shell region        = 51214.8849 g'
'Mass of kaolite in shell           = 53419.6003 g'
'Volume of kaolite in shell region  = 124843.000 cm3'
read geometry
global
unit 1001
'homogenized uranium/poly/excess water, 13lb free h2o-Kaolite shell, 20.0 cm refl'
sphere  1  1  11.76592  com='HEU core/water mixture'
sphere  2  1  31.55946  com='radius of kaolite shell'
```

```
sphere  8  1  51.55946  com='20.0 cm water reflector'
end geometry
end data
end
```

### 6.9.7.38Case athmp15kmr_7_7_8_5

```
=csas25    parm=size=300000
athmp15kmr, 7.0kgU,[3500.0U235,500.0CH2, 9008.5H2O]g htox=
71.97,Rc=31.06492cm,3500.0U235,Rs=31.08035cm
238groupndf5 multiregion
'dry CV hx=2.40 for  7.0 kilograms HEU metal wrapped content'
'Core  3500.0g235U,500.0g Poly,  9008.5gH2O in Kaolite.  htox=71.97'
uranium  1 den=18.81109 1.4817e-03   293   92235  100.00
                                           92238    0.00                end
arbmpoly   0.92000   2 0 0 0    1001   14.3798
                                6012   85.6202    1  4.3280e-03    293  end
arbmh2ok   0.07216   2 0 0 0    1001   11.1913
                                8016   88.8087    1  9.9417e-01    293  end
arbmal2o3  0.40785   2 0 0 0   13027   52.9390
                                8016   47.0610    1  0.096   293  end
arbmsio2   0.40785   2 0 0 0   14000   46.7570
                                8016   53.2430    1  0.367   293  end
arbmfe2o3  0.40785   2 0 0 0   26000   69.9540
                                8016   30.0460    1  0.067   293  end
arbmtio2   0.40785   2 0 0 0   22000   59.9535
                                8016   40.0465    1  0.012   293  end
arbmcao    0.40785   2 0 0 0   20000   71.4815
                                8016   28.5185    1  0.307   293  end
arbmmgo    0.40785   2 0 0 0   12000   60.3169
                                8016   39.6831    1  0.131   293  end
arbmna2o   0.40785   2 0 0 0   11023   74.1961
                                8016   25.8039    1  0.020   293  end
uranium  2 den=18.81109  1.0   293   92235  100.00
                                      92238    0.00              end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                          4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087    5  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185    5  0.307   293  end
```

```
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                              8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                              8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087    6  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in 15lb free h2o-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in 15lb free h2o-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                              8016   88.8087    7  0.0287  293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                              8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                              8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                              8016   30.0460    7  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                              8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                              8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                              8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                              8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    8  1.0000  293  end
end comp
spherical end
```

```
1  31.06492
2  31.08035
8  51.08035
end zone
athmp15kmr, 7.0kgU,[3500.0U235,500.0CH2, 9008.5H2O]g htox= 71.97
Rc=31.06492cm,3500.0U235,Rs=31.08035cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                           CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                           CHECK=> 2204.746 g'
'Mass of kao from Kaolite = 51214.88 g'
'                           CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of homogenized fissile U     = 3500.00000 g'
'Mass of poly in homogenized region=  500.00000 g'
'Mass of h2o in homogenized region = 9008.54567 g'
'Mass of kao in homogenized region = 51214.8849 g'
'Mass of homogenized core region   = 64223.4306 g'
'Vol of homogenized fissile U      =  186.06048 cm3'
'Vol of poly                       =  543.47826 cm3'
'Vol of h2o                        = 124841.264 cm3'
'Vol of kao                        = 124844.318 cm3'
'Volume of homogenized core region = 125573.857 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'Core hydrogen to fissile U ratio  =  71.9718'
' '
read geometry
global
unit 1001
'fissile material, homog, remaining fm as shell around mixture, 20.0 cm refl'
'Radius of homogenized core         =   31.06492 cm'
'Mass of fm shell                   = 3500.00000 g'
'Vol of fm shell                    =  186.06048 cm3'
'Radius of fm shell                 =   31.08035 cm'
sphere  1  1  31.06492  com='HEU core/water mixture'
sphere  2  1  31.08035  com='radius of fissile material shell'
sphere  8  1  51.08035  com='20.0 cm water reflector'
end geometry
end data
end
```

### 6.9.7.39Case cvcrtriga_1_1

```
=csas25    parm=size=3000000
cvcrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235,    0.0gH2O hx=  0.00),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=18.2, CV void volume 9014.40198'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                               40000   54.0446
                               92235    8.8558
                               92238   36.1442    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
```

```
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1e-20   293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                                8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                                8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                                8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                                8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                                8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                                8016   25.8039   12  0.020   293  end
```

```
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235,    0.0gH2O,hx=  0.00),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                       end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
```

```
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
```

```
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.40 Case cvcrtriga_1_15

```
=csas25    parm=size=3000000
cvcrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O hx=255.01),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=18.2, CV void volume 9014.40198'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
```

```
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                             8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                             9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                            10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
```

```
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O,hx=255.01),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
```

```
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
```

```
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.41Case cvcrtriga_2_15

```
=csas25    parm=size=3000000
cvcrtriga 1.4in thk np,10400.0gUZrHx(  921.0g235, 8384.6gH2O hx=237.62),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume  614.68012'
'TRIGA wrapped dry content can hx=18.2, CV void volume 8399.72186'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                          8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                          9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                         10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
```

```
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
```

```
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  1       293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                              8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   21  1.0     293  end
end comp
cvcrtriga 1.4in thk np,10400.0gUZrHx(  921.0g235, 8384.6gH2O,hx=237.62),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev=11.321 in.]'
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
```

```
 cuboid    21 1 4p24.587200    3.55620  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'45.21560             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   31.87340   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   31.87340   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   31.87340   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
```

```
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.42Case cvcrtriga_70_1_1

```
=csas25    parm=size=3000000
cvcrtriga_70 0.0in thk np, 6847.1gUZrHx(  408.0g235,    0.0gH2O hx=  0.00),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=41.1, CV void volume 9014.40198'
arbmtriga  5.70132  4 0 0 0    1001    1.5894
                              40000   89.9107
                              92235    5.9587
                              92238    2.5412    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1e-20   293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                          8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                          9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                         10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
```

```
                              20000   11.8336
                              26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                               8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
```

```
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrtriga_70 0.0in thk np, 6847.1gUZrHx(  408.0g235,    0.0gH2O,hx=  0.00),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
```

```
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.43Case cvcrtriga_70_1_15

```
=csas25    parm=size=3000000
cvcrtriga_70 0.0in thk np, 6847.1gUZrHx(  408.0g235, 8998.2gH2O hx=575.64),fr=1.0e+00
238groupndf5 infhommedium
```

```
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=41.1, CV void volume 9014.40198'
arbmtriga  5.70132  4 0 0 0    1001    1.5894
                              40000   89.9107
                              92235    5.9587
                              92238    2.5412    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
```

```
                              8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                              8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                              8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                              8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                              8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                              8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                              8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                              8016   88.8087   20  1       293  end
'reflective water'
```

```
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   21  1.0     293  end
end comp
cvcrtriga_70 0.0in thk np, 6847.1gUZrHx(  408.0g235, 8998.2gH2O,hx=575.64),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
```

```
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.44Case cvcrtriga_70_2_15

```
=csas25    parm=size=3000000
cvcrtriga_70 1.4in thk np, 6847.1gUZrHx(  408.0g235, 8384.6gH2O hx=536.39),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume  614.68012'
'TRIGA wrapped dry content can hx=41.1, CV void volume 8399.72186'
arbmtriga  5.70132  4 0 0 0    1001    1.5894
                              40000   89.9107
                              92235    5.9587
                              92238    2.5412    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
```

```
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
```

```
                              8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                              8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   21  1.0     293  end
end comp
cvcrtriga_70 1.4in thk np, 6847.1gUZrHx(  408.0g235, 8384.6gH2O,hx=536.39),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                       end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
```

```
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev=11.321 in.]'
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    3.55620  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'45.21560             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   31.87340   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   31.87340   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   31.87340   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
```

```
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.45Case ncsrtriga_1_15_15

```
=csas25    parm=size=3000000
ncsrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O hx=255.01),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=18.2, CV void volume 9014.40198'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
```

```
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                               5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                               7014    0.0141
                               8016   43.4251
                              11023    0.1174
                              12000    0.3378
                              13027   39.0479
                              14000    2.4672
                              16000    0.3083
                              20000   11.8336
                              26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                               8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                              8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                              8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                              8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                              8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                              8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                              8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                              8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                              8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430   13  0.367   293  end
```

```
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
ncsrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O,hx=255.01),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   23.329900    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   23.177500   11.59510   0.0     com='kaolite'
 cylinder  19 1   23.329900   11.59510   0.0     com='drum'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
```

```
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   23.177500    0.63500   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   23.177500   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   23.329900   12.70050  -0.0005  com='drum'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   23.177500    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   23.329900    0.00020  -0.0001  com='drum'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   23.177500   38.98540   0.0     com='kaolite'
 cylinder  19 1   23.329900   38.98540   0.0     com='drum'
 cuboid    21 1 4p24.587200   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
```

```
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   23.177500    0.22860   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.22860   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.27000   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.27000   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   23.177500    2.92100   0.0     com='kaolite'
 cylinder  19 1   23.329900    2.92100   0.0     com='drum'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.01600   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.01600   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   23.177500    8.17880   0.0     com='kaolite'
 cylinder  19 1   23.329900    8.17880   0.0     com='drum'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
```

```
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   23.177500    4.44500   0.0     com='kaolite'
 cylinder  19 1   23.329900    4.44500   0.0     com='drum'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   23.177500    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   22.961600    1.90500   0.15240 com='void above lid'
 cylinder  19 1   23.114000    1.90500   0.0     com='drum lid'
 cylinder  21 1   23.177500    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   23.329900    1.90500   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.46Case ncsrtriga70_1_15_15

```
=csas25    parm=size=3000000
ncsrtriga_70 0.0in thk np, 6847.1gUZrHx(  408.0g235, 8998.2gH2O hx=575.64),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=41.1, CV void volume 9014.40198'
arbmtriga  5.70132  4 0 0 0    1001    1.5894
                              40000   89.9107
                              92235    5.9587
                              92238    2.5412    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
```

```
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
```

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                              8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                              8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   21  1.0     293  end
end comp
ncsrtriga_70 0.0in thk np, 6847.1gUZrHx(  408.0g235, 8998.2gH2O,hx=575.64),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                       end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   23.329900    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
```

```
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   23.177500   11.59510   0.0     com='kaolite'
 cylinder  19 1   23.329900   11.59510   0.0     com='drum'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   23.177500    0.63500   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   23.177500   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   23.329900   12.70050  -0.0005  com='drum'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   23.177500    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   23.329900    0.00020  -0.0001  com='drum'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
```

```
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   23.177500   38.98540   0.0     com='kaolite'
 cylinder  19 1   23.329900   38.98540   0.0     com='drum'
 cuboid    21 1 4p24.587200   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   23.177500    0.22860   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.22860   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.27000   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.27000   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   23.177500    2.92100   0.0     com='kaolite'
 cylinder  19 1   23.329900    2.92100   0.0     com='drum'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.01600   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.01600   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
```

```
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   23.177500    8.17880   0.0     com='kaolite'
 cylinder  19 1   23.329900    8.17880   0.0     com='drum'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   23.177500    4.44500   0.0     com='kaolite'
 cylinder  19 1   23.329900    4.44500   0.0     com='drum'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   23.177500    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   22.961600    1.90500   0.15240 com='void above lid'
 cylinder  19 1   23.114000    1.90500   0.0     com='drum lid'
 cylinder  21 1   23.177500    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   23.329900    1.90500   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.47Case ncsrt55d2_1_15_15

```
=csas25    parm=size=3000000
ncsrt55d2 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O hx=255.01),fr=1.0e+00
238groupndf5 infhommedium
```

```
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=18.2, CV void volume 9014.40198'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1   0.11756  293  end
arbmwicv 9.9820e-01  2 0 0 0   1001   11.1913
                               8016   88.8087    1   0.88244  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
```

```
                              8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                              8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                              8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                              8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                              8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                              8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                              8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                              8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
```

```
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   21  1.0     293  end
end comp
ncsrt55d2 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O,hx=255.01),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   23.329900    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   23.177500   11.59510   0.0     com='kaolite'
 cylinder  19 1   23.329900   11.59510   0.0     com='drum'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   23.177500    0.63500   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
 cylinder  1  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   23.177500   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   23.329900   12.70050  -0.0005  com='drum'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  1  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   23.177500    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   23.329900    0.00020  -0.0001  com='drum'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  1  1    6.426200   38.98540   0.0     com='cv well cavity'
```

```
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   23.177500   38.98540   0.0     com='kaolite'
 cylinder  19 1   23.329900   38.98540   0.0     com='drum'
 cuboid    21 1 4p24.587200   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  1  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  1  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   23.177500    0.22860   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.22860   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  1  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.27000   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.27000   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   23.177500    2.92100   0.0     com='kaolite'
 cylinder  19 1   23.329900    2.92100   0.0     com='drum'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.01600   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.01600   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
```

```
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   23.177500    8.17880   0.0     com='kaolite'
 cylinder  19 1   23.329900    8.17880   0.0     com='drum'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   23.177500    4.44500   0.0     com='kaolite'
 cylinder  19 1   23.329900    4.44500   0.0     com='drum'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   23.177500    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   22.961600    1.90500   0.15240 com='void above lid'
 cylinder  19 1   23.114000    1.90500   0.0     com='drum lid'
 cylinder  21 1   23.177500    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   23.329900    1.90500   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.48Case hcsrtriga_1_15_15

```
=csas25    parm=size=3000000
hcsrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O hx=255.01),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=18.2, CV void volume 9014.40198'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  1.0     293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
'np277-4: spacer (HAC_MD&H)'
'HAC min.den.(95.3157 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07071e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.82995e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (HAC_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.476265 = (den.mult)(np277-4 min.den.) = 0.9668933*1.526803'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.70316e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
```

```
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                                8016   88.8087   12  1       293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                                8016   53.2430   12  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                                8016   30.0460   12  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                                8016   40.0465   12  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                                8016   28.5185   12  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                                8016   39.6831   12  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                                8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                1001    8.1573
                                8016   21.5782
                               14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087   15  1       293  end
'steel: liner'
ss304                                           16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                           17  1.06388 293  end
'steel: angle iron (ai) for HAC'
'nct density is multiplied by volume fraction 7.08030/5.74516'
ss304                                           18  1.23239 293  end
'steel: drum steel for HAC'
'nct density is multiplied by volume fraction 3.20482/2.95645'
ss304                                           19  1.08401 293  end
```

```
'void space external to drum'
'array density is assumed not reduced by hac'
'arbmwed    0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
hcsrtriga 0.0in thk np,10400.0gU(  921.0g235, 8998.2gH2O,hx=255.01),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   21.838092    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   21.838092    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p21.838092    0.26670   0.0     com='drum(chine)outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.685692   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.838092   11.59510   0.0     com='drum'
 cuboid    21 1 4p21.838092   11.59510   0.0     com='drum(chine)outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.685692    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   21.685692   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   21.838092   12.70050  -0.0005  com='drum'
 cuboid    21 1 4p21.838092   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
```

```
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.685692    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.838092    0.00020  -0.0001  com='drum'
 cuboid    21 1 4p21.838092    0.00020  -0.0001  com='drum(chine)outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   21.685692   38.98540   0.0     com='kaolite'
 cylinder  19 1   21.838092   38.98540   0.0     com='drum'
 cuboid    21 1 4p21.838092   38.98540   0.0     com='drum(chine)outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.685692    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.22860   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.22860   0.0     com='drum(chine)outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.27000   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.27000   0.0     com='drum(chine)outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.685692    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.838092    2.92100   0.0     com='drum'
 cuboid    21 1 4p21.838092    2.92100   0.0     com='drum(chine)outer radius'
unit 1014
```

```
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.01600   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.01600   0.0     com='drum(chine)outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.685692    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.838092    8.17880   0.0     com='drum'
 cuboid    21 1 4p21.838092    8.17880   0.0     com='drum(chine)outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.685692    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.838092    4.44500   0.0     com='drum'
 cuboid    21 1 4p21.838092    4.44500   0.0     com='drum(chine)outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.685692    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   21.469792    1.90500   0.15240 com='void above lid'
 cylinder  19 1   21.622192    1.90500   0.0     com='drum lid'
 cylinder  21 1   21.685692    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.838092    1.90500   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.90500   0.0     com='drum(chine)outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-21.838092     0.0
'cuboid     0  1 4p21.838092    110.4905  0.0    com='bare package'
 cuboid    21  1 4p52.318092   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
```

```
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.49Case hcsrtriga70_1_15_15

```
=csas25    parm=size=3000000
hcsrtriag_70 0.0in thk np, 6847.1gUZrHx(  408.0g235, 8998.2gH2O hx=575.64),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=41.1, CV void volume 9014.40198'
arbmtriga  5.70132  4 0 0 0    1001    1.5894
                              40000   89.9107
                              92235    5.9587
                              92238    2.5412    1  1.0     293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
'np277-4: spacer (HAC_MD&H)'
'HAC min.den.(95.3157 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07071e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.82995e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (HAC_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.476265 = (den.mult)(np277-4 min.den.) = 0.9668933*1.526803'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
```

```
                                8016   43.4254
                               11023    0.1174
                               12000    0.3378
                               13027   39.0477
                               14000    2.4671
                               16000    0.3083
                               20000   11.8335
                               26000    0.5298   11  1.0000  293  end
arbmnph2o 3.70316e-1  2 0 0 0    1001   11.1913
                                8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                                8016   88.8087   12  1       293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                                8016   53.2430   12  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                                8016   30.0460   12  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                                8016   40.0465   12  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                                8016   28.5185   12  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                                8016   39.6831   12  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                                8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                1001    8.1573
                                8016   21.5782
                               14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
```

```
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for HAC'
'nct density is multiplied by volume fraction 7.08030/5.74516'
ss304                                          18  1.23239 293  end
'steel: drum steel for HAC'
'nct density is multiplied by volume fraction 3.20482/2.95645'
ss304                                          19  1.08401 293  end
'void space external to drum'
'array density is assumed not reduced by hac'
'arbmwed    0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
hcsrtriag_70 0.0in thk np, 6847.1gU(  408.0g235, 8998.2gH2O,hx=575.64),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   21.838092    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   21.838092    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p21.838092    0.26670   0.0     com='drum(chine)outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.685692   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.838092   11.59510   0.0     com='drum'
 cuboid    21 1 4p21.838092   11.59510   0.0     com='drum(chine)outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.685692    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
```

```
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   21.685692   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   21.838092   12.70050  -0.0005  com='drum'
 cuboid    21 1 4p21.838092   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.685692    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.838092    0.00020  -0.0001  com='drum'
 cuboid    21 1 4p21.838092    0.00020  -0.0001  com='drum(chine)outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   21.685692   38.98540   0.0     com='kaolite'
 cylinder  19 1   21.838092   38.98540   0.0     com='drum'
 cuboid    21 1 4p21.838092   38.98540   0.0     com='drum(chine)outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.685692    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.22860   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.22860   0.0     com='drum(chine)outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.27000   0.0     com='drum'
```

```
 cuboid    21 1 4p21.838092    1.27000   0.0     com='drum(chine)outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.685692    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.838092    2.92100   0.0     com='drum'
 cuboid    21 1 4p21.838092    2.92100   0.0     com='drum(chine)outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.01600   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.01600   0.0     com='drum(chine)outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.685692    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.838092    8.17880   0.0     com='drum'
 cuboid    21 1 4p21.838092    8.17880   0.0     com='drum(chine)outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.685692    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.838092    4.44500   0.0     com='drum'
 cuboid    21 1 4p21.838092    4.44500   0.0     com='drum(chine)outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.685692    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   21.469792    1.90500   0.15240 com='void above lid'
 cylinder  19 1   21.622192    1.90500   0.0     com='drum lid'
 cylinder  21 1   21.685692    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.838092    1.90500   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.90500   0.0     com='drum(chine)outer radius'
```

```
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-21.838092     0.0
'cuboid     0  1 4p21.838092    110.4905  0.0    com='bare package'
 cuboid    21  1 4p52.318092   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.50 Case nciatriga_1_15_3

```
=csas25    parm=size=3000000
nciatriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O hx=255.01),fr=1.0e-04
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=18.2, CV void volume 9014.40198'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                          8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                          9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
```

```
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
```

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                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                           16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                           17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                           18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                           18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                           19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                           19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
nciatriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O,hx=255.01),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                    end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.926 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
```

```
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.926 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   21.722275   12.70050  -0.0005  com='drum'
 cuboid    20 1 4p22.866096   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.926 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.276 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   38.98540   0.0     com='kaolite'
 cylinder  19 1   21.722275   38.98540   0.0     com='drum'
 cuboid    20 1 4p22.866096   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
```

```
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
```

```
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    110.4900  0.0    com='bare package'
'cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.51Case nciatriga70_1_15_3

```
=csas25    parm=size=3000000
nciatriga_70 0.0in thk np, 6847.1gUZrHx(  408.0g235, 8998.2gH2O hx=575.64),fr=1.0e-04
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=41.1, CV void volume 9014.40198'
arbmtriga  5.70132  4 0 0 0    1001    1.5894
                              40000   89.9107
                              92235    5.9587
                              92238    2.5412    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
```

```
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
```

```
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                              8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                              8016   88.8087   21  1.0     293  end
end comp
nciatriga_70 0.0in thk np, 6847.1gUZrHx(  408.0g235, 8998.2gH2O,hx=575.64),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                  end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
```

```
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.926 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.926 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   21.722275   12.70050  -0.0005  com='drum'
 cuboid    20 1 4p22.866096   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.926 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.276 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   38.98540   0.0     com='kaolite'
 cylinder  19 1   21.722275   38.98540   0.0     com='drum'
 cuboid    20 1 4p22.866096   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
```

```
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
```

```
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    110.4900  0.0    com='bare package'
'cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.52Case hciatriga_1_15_3

```
=csas25    parm=size=3000000
hciatriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O hx=255.01),fr=1.0e-04
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=18.2, CV void volume 9014.40198'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  1.0     293  end
```

```
'np277-4: spacer (HAC_MD&H)'
'HAC min.den.(95.3157 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07071e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.82995e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (HAC_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.476265 = (den.mult)(np277-4 min.den.) = 0.9668933*1.526803'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.70316e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
```

```
                              8016   53.2430   12  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                              8016   30.0460   12  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                              8016   40.0465   12  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                              8016   28.5185   12  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                              8016   39.6831   12  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                              8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for HAC'
'nct density is multiplied by volume fraction 7.08030/5.74516'
ss304                                         18  1.23239 293  end
'steel: drum steel for HAC'
'nct density is multiplied by volume fraction 3.20482/2.95645'
ss304                                         19  1.08401 293  end
'void space external to drum'
'array density is assumed not reduced by hac'
arbmwed    0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                             8016   88.8087   21  1.0     293  end
end comp
hciatriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O,hx=255.01),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                  end boun
```

```
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   21.838092    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   21.838092    0.26670   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p21.838092    0.26670   0.0     com='drum(chine)outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.685692   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.838092   11.59510   0.0     com='drum'
 cuboid    20 1 4p21.838092   11.59510   0.0     com='drum(chine)outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.685692    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   21.685692   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   21.838092   12.70050  -0.0005  com='drum'
 cuboid    20 1 4p21.838092   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.685692    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.838092    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p21.838092    0.00020  -0.0001  com='drum(chine)outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
```

```
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   21.685692   38.98540   0.0     com='kaolite'
 cylinder  19 1   21.838092   38.98540   0.0     com='drum'
 cuboid    20 1 4p21.838092   38.98540   0.0     com='drum(chine)outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.685692    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.22860   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.22860   0.0     com='drum(chine)outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.27000   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.27000   0.0     com='drum(chine)outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.685692    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.838092    2.92100   0.0     com='drum'
 cuboid    20 1 4p21.838092    2.92100   0.0     com='drum(chine)outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.01600   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.01600   0.0     com='drum(chine)outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
```

```
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.685692    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.838092    8.17880   0.0     com='drum'
 cuboid    20 1 4p21.838092    8.17880   0.0     com='drum(chine)outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.685692    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.838092    4.44500   0.0     com='drum'
 cuboid    20 1 4p21.838092    4.44500   0.0     com='drum(chine)outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.685692    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  20 1   21.469792    1.90500   0.15240 com='void above lid'
 cylinder  19 1   21.622192    1.90500   0.0     com='drum lid'
 cylinder  20 1   21.685692    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.838092    1.90500   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.90500   0.0     com='drum(chine)outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-21.838092     0.0
'cuboid     0  1 4p21.838092    110.4905  0.0    com='bare package'
'cuboid    21  1 4p52.318092   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.53Case hciatriga70_1_15_3

```
=csas25    parm=size=3000000
hciatriga_70 0.0in thk np, 6847.1gUZrHx(  408.0g235, 8998.2gH2O hx=575.64),fr=1.0e-04
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=41.1, CV void volume 9014.40198'
arbmtriga  5.70132  4 0 0 0    1001    1.5894
                              40000   89.9107
                              92235    5.9587
                              92238    2.5412    1  1.0     293  end
'np277-4: spacer (HAC_MD&H)'
'HAC min.den.(95.3157 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07071e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.82995e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (HAC_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.476265 = (den.mult)(np277-4 min.den.) = 0.9668933*1.526803'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.70316e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
```

```
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for HAC'
'nct density is multiplied by volume fraction 7.08030/5.74516'
ss304                                         18  1.23239 293  end
'steel: drum steel for HAC'
'nct density is multiplied by volume fraction 3.20482/2.95645'
ss304                                         19  1.08401 293  end
```

```
'void space external to drum'
'array density is assumed not reduced by hac'
arbmwed    0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                              8016   88.8087   21  1.0     293  end
end comp
hciatriga_70 0.0in thk np, 6847.1gUZrHx(  408.0g235, 8998.2gH2O,hx=575.64),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                    end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   21.838092    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   21.838092    0.26670   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p21.838092    0.26670   0.0     com='drum(chine)outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.685692   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.838092   11.59510   0.0     com='drum'
 cuboid    20 1 4p21.838092   11.59510   0.0     com='drum(chine)outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.685692    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   21.685692   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   21.838092   12.70050  -0.0005  com='drum'
 cuboid    20 1 4p21.838092   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
```

```
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.685692    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.838092    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p21.838092    0.00020  -0.0001  com='drum(chine)outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   21.685692   38.98540   0.0     com='kaolite'
 cylinder  19 1   21.838092   38.98540   0.0     com='drum'
 cuboid    20 1 4p21.838092   38.98540   0.0     com='drum(chine)outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.685692    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.22860   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.22860   0.0     com='drum(chine)outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.27000   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.27000   0.0     com='drum(chine)outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.685692    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.838092    2.92100   0.0     com='drum'
 cuboid    20 1 4p21.838092    2.92100   0.0     com='drum(chine)outer radius'
unit 1014
```

```
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.01600   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.01600   0.0     com='drum(chine)outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.685692    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.838092    8.17880   0.0     com='drum'
 cuboid    20 1 4p21.838092    8.17880   0.0     com='drum(chine)outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.685692    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.838092    4.44500   0.0     com='drum'
 cuboid    20 1 4p21.838092    4.44500   0.0     com='drum(chine)outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.685692    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  20 1   21.469792    1.90500   0.15240 com='void above lid'
 cylinder  19 1   21.622192    1.90500   0.0     com='drum lid'
 cylinder  20 1   21.685692    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.838092    1.90500   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.90500   0.0     com='drum(chine)outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-21.838092     0.0
'cuboid     0  1 4p21.838092    110.4905  0.0    com='bare package'
'cuboid    21  1 4p52.318092   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
```

```
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.54Case ncsrT70_131_1_15_15

```
=csas25    parm=size=3000000
ncsrT70131 0.0in thk np, 5666.6gUZrHx(  337.7g235, 9204.9gH2O hx=711.53),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume = 993.90789, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=49.6, CV void volume 9221.45406'
arbmtriga  5.70132  4 0 0 0    1001    1.5894
                              40000   89.9107
                              92235    5.9587
                              92238    2.5412    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                          8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                          9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                         10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
```

```
                              11023    0.1174
                              12000    0.3378
                              13027   39.0479
                              14000    2.4672
                              16000    0.3083
                              20000   11.8336
                              26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                               8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
```

```
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
ncsrT70131 0.0in thk np, 5666.6gUZrHx(  337.7g235, 9204.9gH2O,hx=711.53),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   23.329900    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   23.177500   11.59510   0.0     com='kaolite'
 cylinder  19 1   23.329900   11.59510   0.0     com='drum'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   23.177500    0.63500   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.663700   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
```

```
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   23.177500   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   23.329900   12.70050  -0.0005  com='drum'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   23.177500    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   23.329900    0.00020  -0.0001  com='drum'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   23.177500   38.98540   0.0     com='kaolite'
 cylinder  19 1   23.329900   38.98540   0.0     com='drum'
 cuboid    21 1 4p24.587200   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   23.177500    0.22860   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.22860   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.27000   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.27000   0.0     com='drum'
```

```
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   23.177500    2.92100   0.0     com='kaolite'
 cylinder  19 1   23.329900    2.92100   0.0     com='drum'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.01600   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.01600   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   23.177500    8.17880   0.0     com='kaolite'
 cylinder  19 1   23.329900    8.17880   0.0     com='drum'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   23.177500    4.44500   0.0     com='kaolite'
 cylinder  19 1   23.329900    4.44500   0.0     com='drum'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   23.177500    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   22.961600    1.90500   0.15240 com='void above lid'
 cylinder  19 1   23.114000    1.90500   0.0     com='drum lid'
 cylinder  21 1   23.177500    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   23.329900    1.90500   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
```

```
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.55Case nciaT70_131_1_15_3

```
=csas25    parm=size=3000000
nciaT70131 0.0in thk np, 5666.6gUZrHx(  337.7g235, 9204.9gH2O hx=711.53),fr=1.0e-04
238groupndf5 infhommedium
'TRIGA volume = 993.90789, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=49.6, CV void volume 9221.45406'
arbmtriga  5.70132  4 0 0 0    1001    1.5894
                              40000   89.9107
                              92235    5.9587
                              92238    2.5412    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                          8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                          9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
```

```
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
```

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                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                           16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                           17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                           18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                           18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                           19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                           19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
nciaT70131 0.0in thk np, 5666.6gUZrHx(  337.7g235, 9204.9gH2O,hx=711.53),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                    end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.926 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
```

```
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.663700   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.926 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   21.722275   12.70050  -0.0005  com='drum'
 cuboid    20 1 4p22.866096   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.926 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.276 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   38.98540   0.0     com='kaolite'
 cylinder  19 1   21.722275   38.98540   0.0     com='drum'
 cuboid    20 1 4p22.866096   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
```

```
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
```

```
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    110.4900  0.0    com='bare package'
'cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.56Case athopw15kr20_5

```
=csas25    parm=size=300000
athopw15kr20,[15763.u3o8al, 921.0U235,500.0CH2,6803.8H2O]g
htox=211.0,Rc=14.13813cm,53419.6,Rs=31.95515cm
238groupndf5 multiregion
'U3O8Al=15763.4g poly=500.0g cont.hx=18.2 Kao H2O=  6803.8g, homgcore hx=211.0'
'Rc=14.13813cm,53419.6,Rs=31.95515cm'
arbmTHAR   3.52015   4 0 0 0   8016    5.24773
                              13027   65.53981
                              92235    5.84249
                              92238   23.36997   1  0.3783  293  end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  0.0459  293  end
arbmkh2o   0.9982    2 0 0 0   1001   11.1913
                               8016   88.8087    1  5.7580e-01    293  end
'kaolite 1600 shell'
arbmh2ok 1.7660e-02  2 0 0 0   1001   11.1913
                               8016   88.8087    2  1.000   293  end
arbmal2o3  0.41023   2 0 0 0   13027   52.9390
                               8016   47.0610    2  0.096   293  end
arbmsio2   0.41023   2 0 0 0   14000   46.7570
                               8016   53.2430    2  0.367   293  end
arbmfe2o3  0.41023   2 0 0 0   26000   69.9540
```

```
                              8016   30.0460    2  0.067   293  end
arbmtio2   0.41023   2 0 0 0   22000   59.9535
                              8016   40.0465    2  0.012   293  end
arbmcao    0.41023   2 0 0 0   20000   71.4815
                              8016   28.5185    2  0.307   293  end
arbmmgo    0.41023   2 0 0 0   12000   60.3169
                              8016   39.6831    2  0.131   293  end
arbmna2o   0.41023   2 0 0 0   11023   74.1961
                              8016   25.8039    2  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                           4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                              8016   88.8087    5  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                              8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                              8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                              8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                              8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                              8016   28.5185    5  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                              8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                              8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087    6  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
```

```
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in wet-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in wet-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                               8016   88.8087    7  1.000   293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                               8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                               8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                               8016   30.0460    7  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                               8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                               8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                               8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                               8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    8  1.0000  293  end
end comp
spherical end
1  14.13813
2  31.95515
8  51.95515
end zone
athopw15kr20,[15763.u3o8al, 921.0U235,500.0CH2,6803.8H2O]g htox=211.0
Rc=14.13813cm,53419.6,Rs=31.95515cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                             CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                             CHECK=> 2204.746 g'
'Mass of kao from Kaolite = 51214.88 g'
'                             CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of fm in homogenized region   = 15763.3703 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 6803.83024 g'
'Mass of homogenized region         = 23067.2006 g'
'Vol of homogenized fm              = 4478.03940 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 6816.09922 cm3'
'Volume of homogenized region       = 11837.6168 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  = 211.0335'
' '
```

```
'Mass of h2o in shell region        = 2204.71543 g'
'Mass of kao in shell region        = 51214.8849 g'
'Mass of kaolite in shell           = 53419.6003 g'
'Volume of kaolite in shell region  = 124843.000 cm3'
read geometry
global
unit 1001
'homogenized UZrHx/poly/excess water, wet-Kaolite shell, 20.0 cm refl'
sphere  1  1  14.13813  com='HEU core/water mixture'
sphere  2  1  31.95515  com='radius of kaolite shell'
sphere  8  1  51.95515  com='20.0 cm water reflector'
end geometry
end data
end
```

### 6.9.7.57Case athopw15kr70_5

```
=csas25    parm=size=300000
athopw15kr70,[1995.7u3o8al, 408.0U235,500.0CH2,6803.8H2O]g
htox=476.3,Rc=12.36884cm,53419.6,Rs=31.64738cm
238groupndf5 multiregion
'U3O8Al= 1995.7g poly=500.0g cont.hx=41.1 Kao H2O=  6803.8g, homgcore hx=476.3'
'Rc=12.36884cm,53419.6,Rs=31.64738cm'
arbmTHAR   3.52095   4 0 0 0   8016    5.28002
                              13027   65.51412
                              92235   20.44410
                              92238    8.76176   1  0.0715  293  end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  0.0686  293  end
arbmkh2o   0.9982    2 0 0 0   1001   11.1913
                               8016   88.8087    1  8.5993e-01    293  end
'kaolite 1600 shell'
arbmh2ok 1.7660e-02  2 0 0 0   1001   11.1913
                               8016   88.8087    2  1.000   293  end
arbmal2o3  0.41023   2 0 0 0   13027   52.9390
                               8016   47.0610    2  0.096   293  end
arbmsio2   0.41023   2 0 0 0   14000   46.7570
                               8016   53.2430    2  0.367   293  end
arbmfe2o3  0.41023   2 0 0 0   26000   69.9540
                               8016   30.0460    2  0.067   293  end
arbmtio2   0.41023   2 0 0 0   22000   59.9535
                               8016   40.0465    2  0.012   293  end
arbmcao    0.41023   2 0 0 0   20000   71.4815
                               8016   28.5185    2  0.307   293  end
arbmmgo    0.41023   2 0 0 0   12000   60.3169
                               8016   39.6831    2  0.131   293  end
arbmna2o   0.41023   2 0 0 0   11023   74.1961
                               8016   25.8039    2  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                          4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
```

```
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087    5  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185    5  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087    6  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in wet-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in wet-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                               8016   88.8087    7  1.000   293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                               8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                               8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                               8016   30.0460    7  0.067   293  end
```

```
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                              8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                              8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                              8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                              8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    8  1.0000  293  end
end comp
spherical end
1  12.36884
2  31.64738
8  51.64738
end zone
athopw15kr70,[1995.7u3o8al, 408.0U235,500.0CH2,6803.8H2O]g htox=476.3
Rc=12.36884cm,53419.6,Rs=31.64738cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                             CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                             CHECK=> 2204.746 g'
'Mass of kao from Kaolite = 51214.88 g'
'                             CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of fm in homogenized region   = 1995.70127 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 6803.83024 g'
'Mass of homogenized region         = 9299.53151 g'
'Vol of homogenized fm              =  566.80762 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 6816.09922 cm3'
'Volume of homogenized region       = 7926.38510 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  = 476.3597'
' '
'Mass of h2o in shell region        = 2204.71543 g'
'Mass of kao in shell region        = 51214.8849 g'
'Mass of kaolite in shell           = 53419.6003 g'
'Volume of kaolite in shell region  = 124843.000 cm3'
read geometry
global
unit 1001
'homogenized UZrHx/poly/excess water, wet-Kaolite shell, 20.0 cm refl'
sphere  1  1  12.36884  com='HEU core/water mixture'
sphere  2  1  31.64738  com='radius of kaolite shell'
sphere  8  1  51.64738  com='20.0 cm water reflector'
end geometry
end data
end
```

### 6.9.7.58Case athopw15kr93_5

```
=csas25    parm=size=300000
athopw15kr93,[1505.0u3o8al, 408.0U235,500.0CH2,6803.8H2O]g
htox=476.3,Rc=12.29589cm,53419.6,Rs=31.63630cm
238groupndf5 multiregion
'U3O8Al= 1505.0g poly=500.0g cont.hx=41.1 Kao H2O=  6803.8g, homgcore hx=476.3'
```

```
'Rc=12.29589cm,53419.6,Rs=31.63630cm'
arbmTHAR   3.52132   4 0 0 0   8016    5.29500
                              13027   65.50220
                              92235   27.21701
                              92238    1.98579   1  0.0549  293  end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  0.0698  293  end
arbmkh2o   0.9982    2 0 0 0   1001   11.1913
                               8016   88.8087    1  8.7532e-01    293  end
'kaolite 1600 shell'
arbmh2ok 1.7660e-02  2 0 0 0   1001   11.1913
                               8016   88.8087    2  1.000   293  end
arbmal2o3  0.41023   2 0 0 0   13027   52.9390
                               8016   47.0610    2  0.096   293  end
arbmsio2   0.41023   2 0 0 0   14000   46.7570
                               8016   53.2430    2  0.367   293  end
arbmfe2o3  0.41023   2 0 0 0   26000   69.9540
                               8016   30.0460    2  0.067   293  end
arbmtio2   0.41023   2 0 0 0   22000   59.9535
                               8016   40.0465    2  0.012   293  end
arbmcao    0.41023   2 0 0 0   20000   71.4815
                               8016   28.5185    2  0.307   293  end
arbmmgo    0.41023   2 0 0 0   12000   60.3169
                               8016   39.6831    2  0.131   293  end
arbmna2o   0.41023   2 0 0 0   11023   74.1961
                               8016   25.8039    2  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                             4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087    5  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185    5  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
```

```
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087    6  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in wet-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in wet-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                              8016   88.8087    7  1.000   293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                              8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                              8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                              8016   30.0460    7  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                              8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                              8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                              8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                              8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    8  1.0000  293  end
end comp
spherical end
1  12.29589
2  31.63630
8  51.63630
end zone
athopw15kr93,[1505.0u3o8al, 408.0U235,500.0CH2,6803.8H2O]g htox=476.3
Rc=12.29589cm,53419.6,Rs=31.63630cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                           CHECK=> 9008.671 g'
```

```
'Minimum mass of water from Kaolite = 2204.715 g'
'                            CHECK=> 2204.746 g'
'Mass of kao from Kaolite = 51214.88 g'
'                            CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of fm in homogenized region   = 1505.00732 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 6803.83024 g'
'Mass of homogenized region         = 8808.83756 g'
'Vol of homogenized fm              =  427.39862 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 6816.09922 cm3'
'Volume of homogenized region       = 7786.97610 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  = 476.3681'
' '
'Mass of h2o in shell region        = 2204.71543 g'
'Mass of kao in shell region        = 51214.8849 g'
'Mass of kaolite in shell           = 53419.6003 g'
'Volume of kaolite in shell region  = 124843.000 cm3'
read geometry
global
unit 1001
'homogenized UZrHx/poly/excess water, wet-Kaolite shell, 20.0 cm refl'
sphere  1  1  12.29589  com='HEU core/water mixture'
sphere  2  1  31.63630  com='radius of kaolite shell'
sphere  8  1  51.63630  com='20.0 cm water reflector'
end geometry
end data
end
```

### 6.9.7.59Case athupw15kr93_5

```
=csas25    parm=size=300000
athupw15kr93,[ 920.5UO2MgAl, 408.0U235,500.0CH2,6803.8H2O]g
htox=476.3,Rc=12.25670cm,53419.6,Rs=31.63040cm
238groupndf5 multiregion
'UO2MgAl=  920.5g, poly=500.0g cont.hx=41.1 Kao H2O=  6803.8g, homgcore hx=476.3'
'Rc=12.25670cm,53419.6,Rs=31.63040cm'
arbmuo2mgal  2.60651  5 0 0 0  8016    6.46696
                              12000    7.61234
                              13027   38.36549
                              92235   44.32146
                              92238    3.23375   1  0.0458  293  end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  0.0705  293  end
arbmkh2o   0.9982    2 0 0 0   1001   11.1913
                               8016   88.8087    1  8.8374e-01    293  end
'kaolite 1600 shell'
arbmh2ok 1.7660e-02  2 0 0 0   1001   11.1913
                               8016   88.8087    2  1.000   293  end
arbmal2o3  0.41023   2 0 0 0   13027   52.9390
                               8016   47.0610    2  0.096   293  end
arbmsio2   0.41023   2 0 0 0   14000   46.7570
                               8016   53.2430    2  0.367   293  end
arbmfe2o3  0.41023   2 0 0 0   26000   69.9540
                               8016   30.0460    2  0.067   293  end
arbmtio2   0.41023   2 0 0 0   22000   59.9535
                               8016   40.0465    2  0.012   293  end
arbmcao    0.41023   2 0 0 0   20000   71.4815
```

```
                              8016   28.5185    2  0.307   293  end
arbmmgo    0.41023   2 0 0 0   12000   60.3169
                              8016   39.6831    2  0.131   293  end
arbmna2o   0.41023   2 0 0 0   11023   74.1961
                              8016   25.8039    2  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                           4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                              8016   88.8087    5  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                              8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                              8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                              8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                              8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                              8016   28.5185    5  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                              8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                              8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087    6  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
```

```
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in wet-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in wet-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                               8016   88.8087    7  1.000   293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                               8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                               8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                               8016   30.0460    7  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                               8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                               8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                               8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                               8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    8  1.0000  293  end
end comp
spherical end
1  12.25670
2  31.63040
8  51.63040
end zone
athupw15kr93,[ 920.5UO2MgAl, 408.0U235,500.0CH2,6803.8H2O]g htox=476.3
Rc=12.25670cm,53419.6,Rs=31.63040cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                             CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                             CHECK=> 2204.746 g'
'Mass of kao from Kaolite = 51214.88 g'
'                             CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of fm in homogenized region   =  920.54928 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 6803.83024 g'
'Mass of homogenized region         = 8224.37952 g'
'Vol of homogenized fm              =  353.17312 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 6816.09922 cm3'
'Volume of homogenized region       = 7712.75060 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  = 476.3624'
' '
'Mass of h2o in shell region        = 2204.71543 g'
'Mass of kao in shell region        = 51214.8849 g'
'Mass of kaolite in shell           = 53419.6003 g'
'Volume of kaolite in shell region  = 124843.000 cm3'
```

```
read geometry
global
unit 1001
'homogenized UZrHx/poly/excess water, wet-Kaolite shell, 20.0 cm refl'
sphere  1  1  12.25670  com='HEU core/water mixture'
sphere  2  1  31.63040  com='radius of kaolite shell'
sphere  8  1  51.63040  com='20.0 cm water reflector'
end geometry
end data
end
```

### 6.9.7.60Case athupw15kr20_5

```
=csas25    parm=size=300000
athupw15kr20,[9677.7UO2MgAl, 921.0U235,500.0CH2,6803.8H2O]g
htox=211.0,Rc=13.27685cm,53419.6,Rs=31.79582cm
238groupndf5 multiregion
'UO2MgAl= 9677.7g, poly=500.0g cont.hx=18.2 Kao H2O=  6803.8g, homgcore hx=211.0'
'Rc=13.27685cm,53419.6,Rs=31.79582cm'
arbmuo2mgal  3.96017  5 0 0 0  8016    6.41096
                              12000    7.61690
                              13027   38.38846
                              92235    9.51674
                              92238   38.06695   1  0.2493  293  end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  0.0554  293  end
arbmkh2o   0.9982    2 0 0 0   1001   11.1913
                               8016   88.8087    1  6.9528e-01    293  end
'kaolite 1600 shell'
arbmh2ok 1.7660e-02  2 0 0 0   1001   11.1913
                               8016   88.8087    2  1.000   293  end
arbmal2o3  0.41023   2 0 0 0   13027   52.9390
                               8016   47.0610    2  0.096   293  end
arbmsio2   0.41023   2 0 0 0   14000   46.7570
                               8016   53.2430    2  0.367   293  end
arbmfe2o3  0.41023   2 0 0 0   26000   69.9540
                               8016   30.0460    2  0.067   293  end
arbmtio2   0.41023   2 0 0 0   22000   59.9535
                               8016   40.0465    2  0.012   293  end
arbmcao    0.41023   2 0 0 0   20000   71.4815
                               8016   28.5185    2  0.307   293  end
arbmmgo    0.41023   2 0 0 0   12000   60.3169
                               8016   39.6831    2  0.131   293  end
arbmna2o   0.41023   2 0 0 0   11023   74.1961
                               8016   25.8039    2  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                          4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087    5  0.0287  293  end
```

```
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185    5  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087    6  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in wet-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in wet-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                               8016   88.8087    7  1.000   293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                               8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                               8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                               8016   30.0460    7  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                               8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
```

```
                              8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                              8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                              8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    8  1.0000  293  end
end comp
spherical end
1  13.27685
2  31.79582
8  51.79582
end zone
athupw15kr20,[9677.7UO2MgAl, 921.0U235,500.0CH2,6803.8H2O]g htox=211.0
Rc=13.27685cm,53419.6,Rs=31.79582cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                             CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                             CHECK=> 2204.746 g'
'Mass of kao from Kaolite = 51214.88 g'
'                             CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of fm in homogenized region   = 9677.70171 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 6803.83024 g'
'Mass of homogenized region         = 16981.5319 g'
'Vol of homogenized fm              = 2443.75916 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 6816.09922 cm3'
'Volume of homogenized region       = 9803.33664 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  = 211.0271'
' '
'Mass of h2o in shell region        = 2204.71543 g'
'Mass of kao in shell region        = 51214.8849 g'
'Mass of kaolite in shell           = 53419.6003 g'
'Volume of kaolite in shell region  = 124843.000 cm3'
read geometry
global
unit 1001
'homogenized UZrHx/poly/excess water, wet-Kaolite shell, 20.0 cm refl'
sphere  1  1  13.27685  com='HEU core/water mixture'
sphere  2  1  31.79582  com='radius of kaolite shell'
sphere  8  1  51.79582  com='20.0 cm water reflector'
end geometry
end data
end
```

### 6.9.7.61Case athupw15kr09_5

```
=csas25    parm=size=300000
athupw15kr09,[19592.UO2MgAl, 922.0U235,500.0CH2,6803.8H2O]g
htox=210.7,Rc=14.32268cm,53419.6,Rs=31.99170cm
238groupndf5 multiregion
'UO2MgAl=19592.0g, poly=500.0g cont.hx=18.1 Kao H2O=  6803.8g, homgcore hx=210.7'
'Rc=14.32268cm,53419.6,Rs=31.99170cm'
arbmuo2mgal  3.95984  5 0 0 0  8016    6.40322
                              12000    7.61753
```

```
                              13027   38.39164
                              92235    4.70615
                              92238   42.88147   1  0.4020  293  end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                              6012   85.6202    1  0.0442  293  end
arbmkh2o   0.9982    2 0 0 0   1001   11.1913
                              8016   88.8087    1  5.5383e-01    293  end
'kaolite 1600 shell'
arbmh2ok 1.7660e-02  2 0 0 0   1001   11.1913
                              8016   88.8087    2  1.000   293  end
arbmal2o3  0.41023   2 0 0 0   13027   52.9390
                              8016   47.0610    2  0.096   293  end
arbmsio2   0.41023   2 0 0 0   14000   46.7570
                              8016   53.2430    2  0.367   293  end
arbmfe2o3  0.41023   2 0 0 0   26000   69.9540
                              8016   30.0460    2  0.067   293  end
arbmtio2   0.41023   2 0 0 0   22000   59.9535
                              8016   40.0465    2  0.012   293  end
arbmcao    0.41023   2 0 0 0   20000   71.4815
                              8016   28.5185    2  0.307   293  end
arbmmgo    0.41023   2 0 0 0   12000   60.3169
                              8016   39.6831    2  0.131   293  end
arbmna2o   0.41023   2 0 0 0   11023   74.1961
                              8016   25.8039    2  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                           4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                              8016   88.8087    5  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                              8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                              8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                              8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                              8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                              8016   28.5185    5  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                              8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                              8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087    6  0.0287  293  end
```

```
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in wet-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in wet-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                              8016   88.8087    7  1.000   293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                              8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                              8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                              8016   30.0460    7  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                              8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                              8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                              8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                              8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    8  1.0000  293  end
end comp
spherical end
1  14.32268
2  31.99170
8  51.99170
end zone
athupw15kr09,[19592.UO2MgAl, 922.0U235,500.0CH2,6803.8H2O]g htox=210.7
Rc=14.32268cm,53419.6,Rs=31.99170cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                             CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                             CHECK=> 2204.746 g'
```

```
'Mass of kao from Kaolite = 51214.88 g'
'                           CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of fm in homogenized region   = 19592.0397 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 6803.83024 g'
'Mass of homogenized region         = 26895.8699 g'
'Vol of homogenized fm              = 4947.68469 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 6816.09922 cm3'
'Volume of homogenized region       = 12307.2621 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  = 210.7918'
' '
'Mass of h2o in shell region        = 2204.71543 g'
'Mass of kao in shell region        = 51214.8849 g'
'Mass of kaolite in shell           = 53419.6003 g'
'Volume of kaolite in shell region  = 124843.000 cm3'
read geometry
global
unit 1001
'homogenized UZrHx/poly/excess water, wet-Kaolite shell, 20.0 cm refl'
sphere  1  1  14.32268  com='HEU core/water mixture'
sphere  2  1  31.99170  com='radius of kaolite shell'
sphere  8  1  51.99170  com='20.0 cm water reflector'
end geometry
end data
end
```

### 6.9.7.62Case athbpw15kr93_5

```
=csas25    parm=size=300000
athbpw15kr93,[ 497.3uo2, 408.0U235,500.0CH2,6803.8H2O]g
htox=476.3,Rc=12.10567cm,53419.6,Rs=31.60798cm
238groupndf5 multiregion
'UO2=  497.3g poly=500.0g cont.hx=41.1 Kao H2O=  6803.8g, homgcore hx=476.3'
'Rc=12.10567cm,53419.6,Rs=31.60798cm'
arbmUO2   6.95000   3 0 0 0   8016   11.97094
                              92235   82.04308
                              92238    5.98598   1  9.6289e-03    293  end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  7.3135e-02    293  end
arbmkh2o   0.9982    2 0 0 0   1001   11.1913
                               8016   88.8087    1  9.1724e-01    293  end
'kaolite 1600 shell'
arbmh2ok 1.7660e-02  2 0 0 0   1001   11.1913
                               8016   88.8087    2  1.000   293  end
arbmal2o3  0.41023   2 0 0 0   13027   52.9390
                               8016   47.0610    2  0.096   293  end
arbmsio2   0.41023   2 0 0 0   14000   46.7570
                               8016   53.2430    2  0.367   293  end
arbmfe2o3  0.41023   2 0 0 0   26000   69.9540
                               8016   30.0460    2  0.067   293  end
arbmtio2   0.41023   2 0 0 0   22000   59.9535
                               8016   40.0465    2  0.012   293  end
arbmcao    0.41023   2 0 0 0   20000   71.4815
                               8016   28.5185    2  0.307   293  end
arbmmgo    0.41023   2 0 0 0   12000   60.3169
                               8016   39.6831    2  0.131   293  end
arbmna2o   0.41023   2 0 0 0   11023   74.1961
```

```
                              8016   25.8039    2  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                           4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                              8016   88.8087    5  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                              8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                              8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                              8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                              8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                              8016   28.5185    5  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                              8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                              8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087    6  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
```

```
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in wet-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in wet-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                               8016   88.8087    7  1.000   293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                               8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                               8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                               8016   30.0460    7  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                               8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                               8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                               8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                               8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    8  1.0000  293  end
end comp
spherical end
1  12.10567
2  31.60798
8  51.60798
end zone
athbpw15kr93,[ 497.3uo2, 408.0U235,500.0CH2,6803.8H2O]g htox=476.3
Rc=12.10567cm,53419.6,Rs=31.60798cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                             CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                             CHECK=> 2204.746 g'
'Mass of kao from Kaolite = 51214.88 g'
'                             CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of fm in homogenized region   =  497.29842 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 6803.83024 g'
'Mass of homogenized region         = 7801.12866 g'
'Vol of homogenized fm              =   71.55373 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 6816.09922 cm3'
'Volume of homogenized region       = 7431.13121 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  = 476.3646'
' '
'Mass of h2o in shell region        = 2204.71543 g'
'Mass of kao in shell region        = 51214.8849 g'
'Mass of kaolite in shell           = 53419.6003 g'
'Volume of kaolite in shell region  = 124843.000 cm3'
read geometry
global
unit 1001
'homogenized UO2/poly/excess water, wet-Kaolite shell, 20.0 cm refl'
```

```
sphere  1  1  12.10567  com='HEU core/water mixture'
sphere  2  1  31.60798  com='radius of kaolite shell'
sphere  8  1  51.60798  com='20.0 cm water reflector'
end geometry
end data
end
```

### 6.9.7.63Case cvcrcyat11_2_2

```
=csas25    parm=size=3000000
cvcrcyat11 3cyl,1.4in thk np,(30000.0g235, 7991.5gH2O hx=  6.95),sep=0.254,fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1594.80409, SPACER volume  614.68012'
'HEU wrapped dry content can hx=0.56, CV void volume 8005.87774'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
```

```
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                                 8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                                 8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                                 8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                                 8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                                 8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                                 8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                                 8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                                 8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                 8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                 8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                 8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                 8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                 8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                 8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                 8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                 8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                 1001    8.1573
                                 8016   21.5782
                                14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                                 8016   88.8087   15  1       293  end
'steel: liner'
ss304                                            16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                            17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                            18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                            18  1.25705 293  end
```

```
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrcyat11 3cyl,1.4in thk np,(30000.0g235, 7991.5gH2O,hx=  6.95),sep=0.254,fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1006
'content (centered) [Elev= 8.955 in.]'
 cylinder  1  1    4.114800   10.12099   0.12700    com='cylindrical content'
 cylinder  3  1    6.426200   10.24849  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200   10.24849  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   10.24849  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev=10.355 in.]'
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    3.55620  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'37.85956             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   39.22944   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   39.22944   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   39.22944   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
```

```
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.64Case cvcrcyat11_11_2

```
=csas25    parm=size=3000000
cvcrcyat11 3cyl,1.4in thk np,(30000.0g235, 7991.5gH2O hx=  6.95),sep=4.826,fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1594.80409, SPACER volume  614.68012'
'HEU wrapped dry content can hx=0.56, CV void volume 8005.87774'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
```

```
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
```

```
                              8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                              8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   21  1.0     293  end
end comp
cvcrcyat11 3cyl,1.4in thk np,(30000.0g235, 7991.5gH2O,hx=  6.95),sep=4.826,fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                       end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
```

```
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1006
'content (centered) [Elev=10.755 in.]'
 cylinder  1  1    4.114800   12.40699   2.41300    com='cylindrical content'
 cylinder  3  1    6.426200   14.82049  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200   14.82049  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   14.82049  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev=12.155 in.]'
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    3.55620  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'51.57556             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   25.51344   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   25.51344   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   25.51344   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
```

```
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.65Case cvcrpunhct11_10_15

```
=csas25    parm=size=3000000
cvcrpunhct11 10000.2gUNHc( 4709.7g235,2165.3gH2O) 6080.8gH2Ocv hx= 49.26 fr=1.0e+00
238groupndf5 infhommedium
'U(enr)O2(NO3)2+6H2O [2.81 g/cc for U(nat)]  2.79329 g/cm3, hx=12.0, gU/L= 461.0422'
'dry content (poly packed or wrapped) h/x=3.56, CV void volume 6091.80676 cm3'
arbmunh    2.79329  5 0 0 0   92235   47.0962
                              92238    0.0000
                               1001    2.4232
                               7014    5.6116
                               8016   44.8690    1  3.5046e-01   293  end
arbmh2oc   0.99820  2 0 0 0  1001   11.1913
                               8016   88.8087    1  5.9634e-01   293  end
arbmpoly   0.92000  2 0 0 0  1001   14.3798
                               6012   85.6202    1  5.3202e-02   293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  5.9526e-01  2 0 0 0   1001   11.1913
                                8016   88.8087     3  1.0     293  end
```

```
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                              8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                              9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                             10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
```

```
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrpunhct11 10000.2gUNHc( 4709.7g235,2165.3gH2O) 6080.8gH2Ocv,hx= 49.26 fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
```

```
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.66Case cvcrbpunhct11_24_15

(Note: For the following input file, the case name should read “cvcrbpunhct11” as opposed to “cvcrpunhct11”.)

```
=csas25    parm=size=3000000
cvcrpunhct11 24000.0gUNHc(11303.1g235,5196.7gH2O) 1077.9gH2Ocv hx= 15.97 fr=1.0e+00
238groupndf5 infhommedium
'U(enr)O2(NO3)2+6H2O [2.81 g/cc for U(nat)]  2.79329 g/cm3, hx=12.0'
```

```
'unhc= 24000.0 g, sat.h2o in UNHc=5196.7 g, unh h/x=12.0'
'dry content (poly bottle) h/x=1.48, CV void volume 1079.87091 cm3'
arbmunh    2.62712  5 0 0 0   92235   47.0962
                              92238    0.0000
                               1001    2.4232
                               7014    5.6116
                               8016   44.8690    1  1.0000  293  end
arbmpoly  5.4732e-02    2 0 0 0  1001   14.3798
                               6012   85.6202    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0   1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
```

```
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                              8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                              8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                              8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                              8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                              8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                              8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                              8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                              8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
```

```
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                              8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrpunhct11 24000.0gUNHc(11303.1g235,5196.7gH2O) 1077.9gH2Ocv,hx= 15.97 fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
 cylinder  3  1    6.426200   77.72400  71.05136 com='cavity abv UNHC'
 cylinder  1  1    6.426200   77.72400   0.63500 com='UNHC content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.00000 com='cavity abv UNHC'
 cylinder  1  1    6.426200    0.15240   0.0     com='UNHC content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.00000 com='cavity abv UNHC'
 cylinder  1  1    6.426200    0.22860   0.0     com='UNHC content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.00000 com='cavity abv UNHC'
 cylinder  1  1    6.426200    1.27000   0.0     com='UNHC content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
```

```
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.67Case nciapbmflt11_1_6_4_5

```
=csas25    parm=size=3000000
nciapbmflt11,0.0in thk np, 4000.2gU( 3200.2g235) 9442.7gH2Ocv hx= 82.26 fr=0.0001
238groupndf5 infhommedium
'nciapbmflt11 - n(nct), c(np277-4), ia(infinite array),'
'               pbm (poly homogenized with broken metal),'
'               f(can location height established by packing fraction),'
'               l(designated content in can locations and gap between canned'
'               spacers, and water above content in upper can location),'
'               t11 (NCT_MD&H)'
'HEU volume = 212.11396, SPACER volume    0.01729'
'HEU wrapped dry content can hx=5.24, CV void volume 9459.75243'
'Content in can location 1'
uranium  1 den=18.85873 0.23645 293      92235  80.000
                                         92238   20.000               end
arbmh2oi     0.99820  2 0 0 0  1001   11.1913
                               8016   88.8087    1  1.5773e-01   293  end
arbmpoly     0.92000  2 0 0 0  1001   14.3798
                               6012   85.6202    1  6.0582e-01   293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
```

```
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                8016   88.8087    2  1.0000  293  end
'Content in can location 2'
uranium  3 den=18.85873 0.23645 293      92235  80.000
                                         92238   20.000               end
arbmh2oi     0.99820  2 0 0 0  1001   11.1913
                               8016   88.8087    3  1.5773e-01   293  end
arbmpoly     0.92000  2 0 0 0  1001   14.3798
                               6012   85.6202    3  6.0582e-01   293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                5011   81.8520    4  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                7014    0.0141
                                8016   43.4251
                               11023    0.1174
                               12000    0.3378
                               13027   39.0479
                               14000    2.4672
                               16000    0.3083
                               20000   11.8336
                               26000    0.5298    4  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                8016   88.8087    4  1.0000  293  end
'Content in can location 3'
uranium  5 den=18.85873 0.23647 293      92235  80.000
                                         92238   20.000               end
arbmh2oi     0.99820  2 0 0 0  1001   11.1913
                               8016   88.8087    5  1.5765e-01   293  end
arbmpoly     0.92000  2 0 0 0  1001   14.3798
                               6012   85.6202    5  6.0588e-01   293  end
'void space internal to containment vessel above stacked content'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    6  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                7014    0.0141
                                8016   43.4251
                               11023    0.1174
                               12000    0.3378
                               13027   39.0479
                               14000    2.4672
                               16000    0.3083
                               20000   11.8336
```

```
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                                8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                                8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                                8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                                8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                                8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                                8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                                8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                1001    8.1573
                                8016   21.5782
                               14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
```

```
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
nciapbmflt11,0.0in thk np, 4000.2gU( 3200.2g235) 9442.7gH2Ocv,hx= 82.26 fr=0.0001
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                   end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.926 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1004
'content (collapsed) [Elev= 5.833 in.]'
' 2.30470            bottom of cv to top of 1st content      ASSIGNED
' 5.83319            elevation (inches)                       CALCULATED
' 6.426200    5.06   cv inner radius                          M2E801508A011_RvB
' 299.00051            volume of content in unit 1004           CALCULATED
 cylinder  1  1    6.426200    2.30470  0.0      com='homog. HEU poly content'
 cylinder  8  1    6.680200    2.30470  0.0      com='cv below 1st step'
 cylinder  15 1    7.924800    2.30470  0.0      com='void btw cv-np liner'
 cylinder  16 1    8.077200    2.30470  0.0      com='np277_4 liner'
 cylinder  11 1   10.922000    2.30470  0.0      com='np277_4'
 cylinder  16 1   11.074400    2.30470  0.0      com='kaolite liner'
 cylinder  12 1   21.555075    2.30470  0.0      com='kaolite'
 cylinder  19 1   21.722275    2.30470  0.0      com='drum'
 cuboid    20 1 4p22.866096    2.30470  0.0      com='drum chine outer radius'
unit 1005
'np277_4 spacer [Elev= 5.833 in.]'
```

```
' 0.00020            top of 1st content to top 1st spacer    ASSIGNED
' 5.83331            elevation (inches)                       CALCULATED
'   0.00864            volume of spacer in unit 1005            CALCULATED
'   0.03028            volume of void in unit 1005              CALCULATED
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  1  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1006
'content (collapsed) [Elev= 6.741 in.]'
' 299.00051            volume of content in unit 1006           CALCULATED
 cylinder  3  1    6.426200    2.30470  0.0      com='homog. HEU poly content'
 cylinder  8  1    6.680200    2.30470  0.0      com='cv below 1st step'
 cylinder  15 1    7.924800    2.30470  0.0      com='void btw cv-np liner'
 cylinder  16 1    8.077200    2.30470  0.0      com='np277_4 liner'
 cylinder  11 1   10.922000    2.30470  0.0      com='np277_4'
 cylinder  16 1   11.074400    2.30470  0.0      com='kaolite liner'
 cylinder  12 1   21.555075    2.30470  0.0      com='kaolite'
 cylinder  19 1   21.722275    2.30470  0.0      com='drum'
 cuboid    20 1 4p22.866096    2.30470  0.0      com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 6.741 in.]'
'   0.00864            volume of spacer in unit 1007            CALCULATED
'   0.03028            volume of void in unit 1007              CALCULATED
 cylinder  4  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'content (collapsed) [Elev= 7.648 in.]'
' 299.00051            volume of content in unit 1008           CALCULATED
 cylinder  5  1    6.426200    2.30470  0.0      com='homog. HEU poly content'
 cylinder  8  1    6.680200    2.30470  0.0      com='cv below 1st step'
 cylinder  15 1    7.924800    2.30470  0.0      com='void btw cv-np liner'
 cylinder  16 1    8.077200    2.30470  0.0      com='np277_4 liner'
 cylinder  11 1   10.922000    2.30470  0.0      com='np277_4'
 cylinder  16 1   11.074400    2.30470  0.0      com='kaolite liner'
 cylinder  12 1   21.555075    2.30470  0.0      com='kaolite'
 cylinder  19 1   21.722275    2.30470  0.0      com='drum'
 cuboid    20 1 4p22.866096    2.30470  0.0      com='drum chine outer radius'
unit 1009
'top of content stack to bottom of 1st step [Elev=35.276 in.]'
' 6.91469             stack height (3ccs plus 2 spacers)      CALCULATED
'35.27583            elevation (inches)                       CALCULATED
'35.27583            elevation (inches)                       VERIFIED
'9104.08949            volume of water in unit 1009             CALCULATED
 cylinder  6  1    6.426200   70.17431   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   70.17431   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   70.17431   0.0     com='void btw cv-np liner'
```

```
 cylinder  16 1    8.077200   70.17431   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   70.17431   0.0     com='np277_4'
 cylinder  16 1   11.074400   70.17431   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   70.17431   0.0     com='kaolite'
 cylinder  19 1   21.722275   70.17431   0.0     com='drum'
 cuboid    20 1 4p22.866096   70.17431   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
'  19.77167            volume of water in unit 1010            CALCULATED
 cylinder  6  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
'  29.65750            volume of water in unit 1011            CALCULATED
 cylinder  6  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
' 164.76390            volume of water in unit 1012            CALCULATED
 cylinder  6  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
```

```
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    42.62038  0.0    com='bare package'
'cuboid    21  1 4p55.067200   73.10038 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1004 1005 1006 1007 1008 1009 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.68Case nciapbmfdt11_1_6_4_5

```
=csas25    parm=size=3000000
nciapbmfdt11,0.0in thk np, 4000.2gU( 3200.2g235) 9442.7gH2Ocv hx= 82.26 fr=0.0001
238groupndf5 infhommedium
'nciapbmfdt11 - n(nct), c(np277-4), ia(infinite array),'
'               pbm (poly homogenized with broken metal),'
'               f(can location height established by packing fraction),'
'               d(content resides in can location and gap between canned'
'               spacer and cv, and distributed over upper can location),'
'               t11 (NCT_MD&H)'
'HEU volume = 212.11396, SPACER volume    0.01729'
'HEU wrapped dry content can hx=5.24, CV void volume 9459.75243'
'Content in can location 1'
uranium  1 den=18.85873 0.23645 293      92235  80.000
                                         92238   20.000               end
arbmh2oi     0.99820  2 0 0 0  1001   11.1913
                               8016   88.8087    1  1.5773e-01   293  end
arbmpoly     0.92000  2 0 0 0  1001   14.3798
                               6012   85.6202    1  6.0582e-01   293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'Content in can location 2'
uranium  3 den=18.85873 0.23645 293      92235  80.000
                                         92238   20.000               end
arbmh2oi     0.99820  2 0 0 0  1001   11.1913
                               8016   88.8087    3  1.5773e-01   293  end
arbmpoly     0.92000  2 0 0 0  1001   14.3798
                               6012   85.6202    3  6.0582e-01   293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    4  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    4  1.0000  293  end
```

```
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                  8016   88.8087    4  1.0000  293  end
'Content in can location 3'
uranium  5 den=18.85873 0.00735 293      92235  80.000
                                         92238   20.000               end
arbmh2oi     0.99820  2 0 0 0  1001   11.1913
                               8016   88.8087    5  9.7381e-01   293  end
arbmpoly     0.92000  2 0 0 0  1001   14.3798
                               6012   85.6202    5  1.8837e-02   293  end
'void space internal to containment vessel above stacked content'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    6  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                            8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                            9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                           10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                  5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                  7014    0.0141
                                  8016   43.4251
                                 11023    0.1174
                                 12000    0.3378
                                 13027   39.0479
                                 14000    2.4672
                                 16000    0.3083
                                 20000   11.8336
                                 26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                  8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
```

```
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                              8016   88.8087   21  1.0     293  end
end comp
nciapbmfdt11,0.0in thk np, 4000.2gU( 3200.2g235) 9442.7gH2Ocv,hx= 82.26 fr=0.0001
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                  end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
```

```
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.926 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1004
'content (collapsed) [Elev= 5.833 in.]'
' 2.30470            bottom of cv to top of 1st content      ASSIGNED
' 5.83319            elevation (inches)                       CALCULATED
' 6.426200    5.06   cv inner radius                          M2E801508A011_RvB
' 299.00051           volume of content in unit 1004           CALCULATED
 cylinder  1  1    6.426200    2.30470  0.0      com='homog. HEU poly content'
 cylinder  8  1    6.680200    2.30470  0.0      com='cv below 1st step'
 cylinder  15 1    7.924800    2.30470  0.0      com='void btw cv-np liner'
 cylinder  16 1    8.077200    2.30470  0.0      com='np277_4 liner'
 cylinder  11 1   10.922000    2.30470  0.0      com='np277_4'
 cylinder  16 1   11.074400    2.30470  0.0      com='kaolite liner'
 cylinder  12 1   21.555075    2.30470  0.0      com='kaolite'
 cylinder  19 1   21.722275    2.30470  0.0      com='drum'
 cuboid    20 1 4p22.866096    2.30470  0.0      com='drum chine outer radius'
unit 1005
'np277_4 spacer [Elev= 5.833 in.]'
' 0.00020            top of 1st content to top of 1st spacer ASSIGNED
' 5.83331            elevation (inches)                       CALCULATED
'   0.00864            volume of spacer in unit 1005            CALCULATED
'   0.03028            volume of void in unit 1005              CALCULATED
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  1  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1006
'content (collapsed) [Elev= 6.741 in.]'
' 299.00051            volume of content in unit 1006           CALCULATED
 cylinder  3  1    6.426200    2.30470  0.0      com='homog. HEU poly content'
 cylinder  8  1    6.680200    2.30470  0.0      com='cv below 1st step'
 cylinder  15 1    7.924800    2.30470  0.0      com='void btw cv-np liner'
 cylinder  16 1    8.077200    2.30470  0.0      com='np277_4 liner'
 cylinder  11 1   10.922000    2.30470  0.0      com='np277_4'
 cylinder  16 1   11.074400    2.30470  0.0      com='kaolite liner'
 cylinder  12 1   21.555075    2.30470  0.0      com='kaolite'
 cylinder  19 1   21.722275    2.30470  0.0      com='drum'
 cuboid    20 1 4p22.866096    2.30470  0.0      com='drum chine outer radius'
```

```
unit 1007
'np277_4 spacer [Elev= 6.741 in.]'
'   0.00864            volume of spacer in unit 1007            CALCULATED
'   0.03028            volume of void in unit 1007              CALCULATED
 cylinder  4  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'content (collapsed) [Elev= 7.648 in.]'
' 299.00051            volume of content in unit 1008           CALCULATED
 cylinder  5  1    6.426200    2.30470  0.0      com='homog. HEU poly content'
 cylinder  8  1    6.680200    2.30470  0.0      com='cv below 1st step'
 cylinder  15 1    7.924800    2.30470  0.0      com='void btw cv-np liner'
 cylinder  16 1    8.077200    2.30470  0.0      com='np277_4 liner'
 cylinder  11 1   10.922000    2.30470  0.0      com='np277_4'
 cylinder  16 1   11.074400    2.30470  0.0      com='kaolite liner'
 cylinder  12 1   21.555075    2.30470  0.0      com='kaolite'
 cylinder  19 1   21.722275    2.30470  0.0      com='drum'
 cuboid    20 1 4p22.866096    2.30470  0.0      com='drum chine outer radius'
unit 1009
'top of content stack to bottom of 1st step [Elev=35.276 in.]'
' 6.91469             stack height (3ccs plus 2 spacers)      CALCULATED
'35.27583            elevation (inches)                       CALCULATED
'35.27583            elevation (inches)                       VERIFIED
'9104.08949            volume of water in unit 1009             CALCULATED
 cylinder  5  1    6.426200   70.17431   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   70.17431   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   70.17431   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   70.17431   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   70.17431   0.0     com='np277_4'
 cylinder  16 1   11.074400   70.17431   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   70.17431   0.0     com='kaolite'
 cylinder  19 1   21.722275   70.17431   0.0     com='drum'
 cuboid    20 1 4p22.866096   70.17431   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
'  19.77167            volume of water in unit 1010             CALCULATED
 cylinder  5  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
'  29.65750            volume of water in unit 1011             CALCULATED
 cylinder  5  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
```

```
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
' 164.76390            volume of water in unit 1012            CALCULATED
 cylinder  5  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
```

```
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    42.62038  0.0    com='bare package'
'cuboid    21  1 4p55.067200   73.10038 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1004 1005 1006 1007 1008 1009 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.69Case ncsrpunhct11_8_15

```
=csas25    parm=size=3000000
ncsrpunhct11  8000.1gUNHc( 3767.7g235,1732.2gH2O) 6795.6gH2Ocv hx= 63.53 fr=1.0e+00
238groupndf5 infhommedium
'U(enr)O2(NO3)2+6H2O [2.81 g/cc for U(nat)]  2.79329 g/cm3, hx=12.0, gU/L= 368.8310'
'dry content (poly packed or wrapped) h/x=4.45, CV void volume 6807.84362 cm3'
arbmunh    2.79329  5 0 0 0   92235   47.0962
                              92238    0.0000
                               1001    2.4232
                               7014    5.6116
                               8016   44.8690    1  2.8037e-01   293  end
arbmh2oc   0.99820  2 0 0 0  1001   11.1913
                               8016   88.8087    1  6.6643e-01   293  end
arbmpoly   0.92000  2 0 0 0  1001   14.3798
                               6012   85.6202    1  5.3202e-02   293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
```

```
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  6.6523e-01  2 0 0 0    1001   11.1913
                                 8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                             8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                             9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                            10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
```

```
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
ncsrpunhct11  8000.1gUNHc( 3767.7g235,1732.2gH2O) 6795.6gH2Ocv,hx= 63.53 fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                       end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   23.329900    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
```

```
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   23.177500   11.59510   0.0     com='kaolite'
 cylinder  19 1   23.329900   11.59510   0.0     com='drum'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
 cylinder  12 1   23.177500   77.72400   0.0     com='kaolite'
 cylinder  19 1   23.329900   77.72400   0.0     com='drum'
 cuboid    21 1 4p24.587200   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   23.177500    0.22860   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.22860   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.27000   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.27000   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   23.177500    2.92100   0.0     com='kaolite'
 cylinder  19 1   23.329900    2.92100   0.0     com='drum'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
```

```
 cylinder  12 1   23.177500    1.01600   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.01600   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   23.177500    8.17880   0.0     com='kaolite'
 cylinder  19 1   23.329900    8.17880   0.0     com='drum'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   23.177500    4.44500   0.0     com='kaolite'
 cylinder  19 1   23.329900    4.44500   0.0     com='drum'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   23.177500    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   22.961600    1.90500   0.15240 com='void above lid'
 cylinder  19 1   23.114000    1.90500   0.0     com='drum lid'
 cylinder  21 1   23.177500    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   23.329900    1.90500   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
```

```
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

### 6.9.7.70 Case icsrpunhct12_15_15

```
=csas25    parm=size=3000000
icsrpunhct12 15000.0gUNHc( 7064.4g235,3247.9gH2O) 6397.6gH2Ocv hx= 53.28 fr=1.0e+00
238groupndf5 infhommedium
'U(enr)O2(NO3)2+6H2O [2.81 g/cc for U(nat)], UNHc  2.79329 g/cm3, UNH hx=12.0'
'gU/L= 443.7839 dispersed. Bottle hx=2.37 no meaning when dispersed'
'UNHc in cv   9113.74622 g. water in cv  6397.62120 g.'
'UNHc in well  5886.25378 g. water in well  4132.00248 g.'
arbmunh    2.79329  5 0 0 0   92235   47.0962
                              92238    0.0000
                               1001    2.4232
                               7014    5.6116
                               8016   44.8690    1  0.31939 293  end
arbmh2oc   0.99820  2 0 0 0    1001   11.1913
                               8016   88.8087    1  0.62740 293  end
arbmpoly   0.92000  2 0 0 0  1001   14.3798
                               6012   85.6202    1  5.3202e-02   293  end
'np277-4: spacer (HAC_MD&H)'
'HAC min.den.(95.3157 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07071e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.82995e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0    1001   11.1913
                                 8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                             8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                             9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                            10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (HAC_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.476265 = (den.mult)(np277-4 min.den.) = 0.9668933*1.526803'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
```

```
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.70316e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                                 8016   88.8087   12  1       293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                                 8016   47.0610   12  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                                 8016   53.2430   12  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                                 8016   30.0460   12  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                                 8016   40.0465   12  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                                 8016   28.5185   12  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                                 8016   39.6831   12  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                                 8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                 8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                 8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                 8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                 8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                 8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                 8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                 8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                 8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                 1001    8.1573
                                 8016   21.5782
```

```
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
'UNHc in cv well   5886.25378 g.'
'water in cv well  4132.00248 g.'
arbmunh    2.79329  5 0 0 0   92235   47.0962
                              92238    0.0000
                               1001    2.4232
                               7014    5.6116
                               8016   44.8690   15  0.33734 293  end
arbmh2oc   0.99820  2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.66266 293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for HAC'
'nct density is multiplied by volume fraction 7.08030/5.74516'
ss304                                          18  1.23239 293  end
'steel: drum steel for HAC'
'nct density is multiplied by volume fraction 3.20482/2.95645'
ss304                                          19  1.08401 293  end
'void space external to drum'
'array density is assumed not reduced by hac'
'arbmwed    0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
icsrpunhct12 15000.0gUNHc( 7064.4g235,3247.9gH2O) 6397.6gH2Ocv,hx= 53.28 fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   21.838092    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   21.838092    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p21.838092    0.26670   0.0     com='drum(chine)outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
'v1002=1.36748e+01  '
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.685692   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.838092   11.59510   0.0     com='drum'
 cuboid    21 1 4p21.838092   11.59510   0.0     com='drum(chine)outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
'v1003=4.43850e+03  '
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
 cylinder  12 1   21.685692   77.72400   0.0     com='kaolite'
 cylinder  19 1   21.838092   77.72400   0.0     com='drum'
 cuboid    21 1 4p21.838092   77.72400   0.0     com='drum(chine)outer radius'
```

```
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
'v1010=8.70294e+00  '
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
'v1011=5.36220e+01  '
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.685692    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.22860   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.22860   0.0     com='drum(chine)outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
'v1012=7.43264e+01  '
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.27000   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.27000   0.0     com='drum(chine)outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
'v1013=1.70951e+02  '
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.685692    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.838092    2.92100   0.0     com='drum'
 cuboid    21 1 4p21.838092    2.92100   0.0     com='drum(chine)outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
'v1014=1.39785e+02  '
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.01600   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.01600   0.0     com='drum(chine)outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
'v1015=5.71136e+01  '
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1016
```

```
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
'v1016=6.92877e+02  '
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.685692    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.838092    8.17880   0.0     com='drum'
 cuboid    21 1 4p21.838092    8.17880   0.0     com='drum(chine)outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
'v1017=1.83014e+02  '
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.685692    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.838092    4.44500   0.0     com='drum'
 cuboid    21 1 4p21.838092    4.44500   0.0     com='drum(chine)outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
'v1018=4.14168e+02  '
'Volume cv well=6.24674e+03  '
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.685692    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   21.469792    1.90500   0.15240 com='void above lid'
 cylinder  19 1   21.622192    1.90500   0.0     com='drum lid'
 cylinder  21 1   21.685692    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.838092    1.90500   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.90500   0.0     com='drum(chine)outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-21.838092     0.0
'cuboid     0  1 4p21.838092    110.4905  0.0    com='bare package'
 cuboid    21  1 4p52.318092   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

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# Appendix 6.9.8

## Criticality Evaluation of Additional/New Contents

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## Appendix 6.9.8

## Criticality Evaluation of Additional/New Contents

This appendix presents the criticality safety evaluation of additional/new package contents for the ES-3100 package. Calculations presented herein were performed using the Monte Carlo CSAS25 criticality code sequence and 238-group ENDFB-V cross section library of SCALE 5.0 (NUREG/CR-0200, Rev. 7), executed on identical Hewlett Packard (HP) Model zx6000 Itanium workstations (CMODC and CMODD). Criticality calculations documented in Sects. 6.4–6.6 were performed using SCALE 4.4a (NUREG/CR-0200, Rev. 6) executed on an HP Model J5600 RISC workstation (CMODB). The obsolete CMODB with HP-UX 10.20 operating system was recently retired from service. No longer supported by the code developer, SCALE 4.4a is not portable to the new computing platforms thus necessitating the use of SCALE 5.0.

SCALE5 incorporates minor improvements in the code modules for the Bondarenko and the Nordheim Integral Treatment processing of resonance cross sections and the KENO V.a module. Consequently, the USL used is validation dependent based on the SCALE-platform combination. The evaluation of additional/new contents based upon SCALE 5.0 calculations is documented in this appendix separate from the main body of Sect. 6 because this new work could not easily be folded into the existing SCALE 4.4a evaluation without inclusion of a patchwork of clarifications.

### 6.9.8.1 Description of the Criticality Design

The design features of the ES-3100 package addressed in Sect. 6.1.1 are not changed. The same codes and standards addressed in Sect. 6.1.2 apply. No change is employed in the methodology for demonstrating maximum reactivity.

The criticality safety evaluation documented in this appendix is a cursory analysis of the proposed contents listed in Table 6.9.8.1. In addition to uranium compounds, these contents comprise a variety of reactor fuel components and scrap materials composed of clad HEU metal or metal hydride, HEU alloy or oxide, or clad HEU alloy. In most cases, the HEU present in the components or scrap represents a small portion of the total mass. Because the HEU fissile material mass loading limits for the ES-3100 are specified in terms of the $^{235}U$ mass (Table 6.2a), package loading capacities on the order of 35,200 g of content are conceivable as physical dimensions of the content permit. The shipping limits for the additional/new contents are derived limits bounded by limits established for similar content types evaluated in Sects. 6.4–6.6, or are less restrictive limits based on further investigation using explicit models of particular components and materials. The revised fissile mass loading limits for specific contents are presented in Table 6.9.8.2 for surface only modes of transportation. The CSI is assigned as described in Sect. 6.1.4.

### 6.9.8.2 The Additional/New Contents for the ES-3100 Package

A variety of materials identified in Table 6.9.8.1 from various reactor programs, including bare, clad, or canned uranium metal alloy or oxide in various shapes as pellets, rods, plates, bundled components and fuel assemblies will be shipped in the ES-3100 package. The compounds of uranium identified in Table 6.9.8.1 included uranium tetrafluoride, uranyl fluoride, uranium carbide, and uranium nitride. The physical form of these uranium compounds is described as powder, beads, and ash. Both content moisture and content uniformity are not defined.

**Table 6.9.8.1. 12.1 MTU and RFS items**

| Name | Detailed description | Qty | Assay | Net wt (g) | U wt (g) | $^{235}$U wt (g) |
|---|---|---|---|---|---|---|
| ARMF Idaho | Mark I Elements – 15 plates/element | 14 | 93 | 5,511 ea. | 192 ea | 179 ea |
| | Mark II Elements – 8 flat and 6 bent plates/element | 1 | 93 | 4,831 ea. | 140 ea | 131 ea |
| | Plates – U/Al in Al matrix<br>overall 8.28 × 8.28 × 98 cm<br>flat plate 7.26 × 0.12 × 64.8 cm<br>bent plate var. × 0.12 × 64.8 cm | 27 | 93 | 239 ea. | 13 ea | 12.185 ea |
| | Plate tray and items | 1 | 37.5-93 | | 224 | 207 |
| | **Total** | **–** | **93** | **89,248** | **3,403** | **3,137** |
| BR2 Belgium | Bundles of MTR Type 2 U/Al fuel plates | 29 | 90 | 7,333 ea | 525.87 ea | 472.95 ea |
| | **Total** | **–** | **90** | **185,926** | **15,195** | **13,658** |
| Bulk Shielding Reactor ORNL | Fuel assembly scrap plates. $U_3O_8$ outer plates, U/Al alloy inner plates and control rods | 14 | 93 | 3,423 | 3,309 | 3,020 |
| CNEA RA-2 Argentina | Bundles of MTR Type 2 U/Al fuel plates – 25 plates/ bundle<br>flat plate 7.1 × 0.13 × 65.5 cm | 35 | 90 | 4,534.9 ea | 202.1 ea | 181.7 ea |
| | **Total** | **–** | **90** | **78,536** | **3,716** | **3,342** |
| Group 1 Hanford fuel elements | Bundles of MTR Type 2 U/Al fuel plates – 11 plates/ bundle<br>overall 27.125 × 2.5 × 2.845 in.<br>U/Al plate 25.625 × 0.07 × 2.845 in. | 21 | 93.18 | NA | 156 | 145.3 |
| | **Total** | **–** | **93.18** | **NA** | **3,276** | **3,053** |
| Group 13 CERCA | Powder (sintered $U_3O_8$ mixed with Al) in containers | 13 | ~45 | NA | < 328 ea. | < 137 ea. |
| | Mixture pressed cores and powder in container | 1 | ~45 | NA | 1,496 | 673 |
| | Mixture of fuel plates, pressed cores and powder in containers | 1 | ~45 | NA | 2,534 | 1,139 |
| | **Total** | **15** | **45** | **–** | **6,177** | **2,764** |
| Group 15 Y-12 CSMO | Sintered $U_3O_8$ mixed with Al | 5 | 93.2 | 11,665 | 8,013 | 7,464 |
| | UAl fuel plate bundles (FGZ-046) | 19 | 93.2 | 68,057 | 6,914.8 | 6,441.5 |
| | UAl fuel plate bundles (FGZ-046) | 35 | 93 | 139,646 | 13,575 | 12,646 |
| | (ID-93-13) | 15 | 93 | 34,119 | 23,319 | 21,701 |
| | UAl fuel plate bundles (ID-93-13) | 17 | 93.1 | 77,722 | 12,649 | 11,782 |
| | UAl fuel plate bundles (ID-93-13) | 16 | 93.1 | 77,823 | 13,282 | 12,372 |
| | UAl powder in cans (ID-93-13) | 15 | – | – | – | – |
| | UAl fuel plate bundles (ID-93-13) | 33 | – | – | – | – |
| | (ID-93-13) | 7 | 93.1 | 34,739 | 850 | 791 |

**Table 6.9.8.1. 12.1 MTU and RFS items**

| Name | Detailed description | Qty | Assay | Net wt (g) | U wt (g) | $^{235}$U wt (g) |
|---|---|---|---|---|---|---|
| Group 17A ORNL | Bundles of MTR Type 2 fuel U/Al fuel plates. Overall dimensions: 2.5 – 3.0 × 2.5 – 3.0 × 0.03 – 0.07 in. | 7 | 93 | – | 2,142 | 1,996 |
| | EU fuel elements & plates (FZB-949) | 14 | 93.2 | – | 2,044 | 1,905 |
| | Fuel plates (FZC-938) | 2 | 93 | – | 79 ea. | 67 ea. |
| | Fuel elements (FZB-881) | 7 | 93.3 | – | 151 ea. | ~140 ea. |
| | **Total** | **30** | **93** | **–** | **6,297** | **5,016** |
| Group 17B SNAP Reactor | Pin overall 1.25 in. OD × 12.45 in. $UZrH_2$ with Hastelloy-N cladding, 877 g H | 36 | 93 | 56,048 | 4,976 | 4,627 |
| Group 5B Georgia Tech | MTR Type 2 fuel Overall dimensions: 3.0 × 3.0 × 30 in. | 5 | 93 | – | 1,005 | 936 |
| | | 5 | 93 | – | 1,011 | 941 |
| | | 5 | 93 | – | 1,008 | 939 |
| | | 5 | 93.2 | – | 1,011 | 942 |
| | | 4 | 93.2 | – | 683 | 636 |
| | **Total** | **24** | **93** | **5,070** | **4,728** | **4,121** |
| Group 8 Omega West | MTR Type 2 fuel | 20 | 93.2 | – | 4,977 | 4,638 |
| | | 20 | 93.2 | – | 4,720 | 4,400 |
| | | 15 | 93.2 | – | 3,579 | 3,336 |
| | | 8 | 93.2 | – | 1,992 | 1,850 |
| | | 8 | 93.2 | – | 1,316 | 1,225 |
| | **Total** | **71** | **93.2** | **420,600** | **16,584** | **15,455** |
| PBF PWR | Fuel rods 0.422 in. diam × 39.9 in. Active fuel 0.374 in. diam × 36 in. Clad 0.024 in. RA-2 Zr Alloy | 2 | 34.9 | 1,555.9 | 1,101 | 384 |
| | | 2 | 93.2 | 1,551.0 | 1,095 | 1,021 |
| | **Total** | **–** | **93** | **3,107** | **2,196** | **1,405** |
| Uranium compounds | Uncladded fuel fab materials from TREAT and ROVER: EU oxides ($UO_2$, $U_3O_8$), uranium compounds, uranium alloys, carbon, graphite, $UF_4$, $UO_2F_2$, UC, UN | | 20–100 | 700,000 | 100,000 | – |

**Table 6.9.8.2. Fissile mass loading limits [a, b] for ground transport of 12.1 MTU and RFS items**

| Content [c] description | | Enrichment | CSI | No can spacers, [d] $^{235}U$ (g) | Basis for limit |
|---|---|---|---|---|---|
| HEU oxide ($UO_2$, $UO_3$, $U_3O_8$, $U_3O_8$-Al, $UO_2$-Mg, $UO_2$-$ZrO_2$) | | ≤ 100% | 0 | 9,682.g 235U [e]<br>921.g C [f] | Table 6.2a, HEU product oxides<br>Table 6.2a, HEU skull oxides |
| Research reactor fuel elements and components | $UZrH_x$ [g] | ≤20% | 0 | 921 g $^{235}U$ | TRIGA at 20% enrichment |
| | | >20%, ≤70% | 0 | 408 g $^{235}U$ | TRIGA at 70% enrichment |
| | | ≥93% | 0 | 11,164 g $UZrH_x$<br>857 g $^{235}U$ | SNAP at 93% enrichment |
| | U-Zr | ≤ 100% | – | See HEU broken metal limits in Table 6.2a [h] | |
| | U-Al | ≤ 100% | 0 | 7,333 g U-Al [i]<br>525 g U [i]<br>473 g $^{235}U$ [i] | BR-2 MTR Type 2 |
| | | ≤ 100% | 0 | 7,194 g U-Al [i]<br>1,117 g U [i]<br>1050 g $^{235}U$ [i] | 1 MIT U/Al element or bundled plates (up to 30 plates) |
| | $U_3O_8$-Al | ≤ 100% | 0 | See HEU oxide limits above | |
| | $UO_2$ | ≤ 100% | 0 | 21,937 g $UO_2$<br>19,308 g $^{235}U$ | |
| | Oxides of U-Zr [j] | ≤ 100% | – | See HEU oxide limits above | |
| | $UO_2$-Mg | ≤ 100% | 0 | See HEU oxide limits above | |
| | $U_3Si_2$-Al | ≤ 100% | 0 | 5.825 kg $U_3Si_2$-Al [i]<br>2.277 kg U [i]<br>450 g $^{235}U$ [i] | 1 element with 12 plates or bundled plates (up to 30) |
| Uranium compounds | $UF_4$ | ≤ 100% | 0 | 3,000 g $UF_4$<br>2,267 g $^{235}U$ | |
| | $UO_2F_2$ | ≤ 100% | 0 | 3,000 g $UO_2F_2$<br>2,067 g $^{235}U$ | |
| | UC | ≤ 100% | 0 | 2,000 g UC<br>1,815 g $^{235}U$ | |
| | UN | ≤ 100% | 0 | 2,000 g UN<br>1,888 g $^{235}U$ | |
| | TRISO | ≤ 100% | 0 | 2,000 g $UC_x$<br>1,815 g $^{235}U$ | Bounded by UC compounds |
| | $U_3Si_2$ | ≥19.7%, <40% | 0 | 13 kg $U_3Si_2$ | |
| | | ≥40%, ≤60% | 0 | 7 kg $U_3Si_2$ | |

[a] All limits are expressed in g $^{235}U$ unless otherwise indicated.
[b] The mass loading limit cannot be rounded up.
[c] Content in solution form is not permitted for shipment in the ES-3100.
[d] 277-4 can spacers as described on Drawing M2E801580A043 (Appendix 1.3.7) not required but are optional as dunnage.
[e] Mass limits for uranium oxide with aluminum ($\rho$=2.703 g/cm$^3$), zirconium ($\rho$=6.518 g/cm$^3$), or magnesium ($\rho$=1.738 g/cm$^3$) must assume that the non-uranium metallic constituents are $^{235}U$.
[f] As discussed in App. 6.9.10, the carbon limit of 921 g does not apply to HEU oxide in the form of $U_3O_8$ for ground transport.
[g] For SNAP $UZrH_x$, $x \leq 2$. For TRIGA $UZrH_x$, $x \leq 1.6$.
[h] Mass limits for alloys must assume the non-uranium portion is $^{235}U$.
[i] Mass limit is the most restrictive of the three values shown.
[j] Oxides of U-Zr are $UO_2$-Zr and $UO_2$-$ZrO_2$.

A general description of the Bulk Shielding Reactor-1 reveals that the core consisted of 30 subassemblies (MTR type stacked plates, 18 plates per subassembly), each subassembly with overall dimensions of 3.125 × 3 × 34.5 in., arranged into a parallelepiped with an active core ~15 × 18 × 24 in. The core contained 3,850-g $^{235}U$ (*Nuclear Reactor Plant Data*, Bulk Shielding Reactor, pp. 33–35).

A general description of the Oak Ridge Research Reactor reveals that the core consisted of 20–30 subassemblies (MTR type stacked plates, 19 plates per subassembly), each subassembly with overall dimensions of 3.015 × 3.15 × 38.375 in., arranged in 7 × 9 grid with an active core ~12 × 21 × 24 in. The core contained 3.5–4 kg $^{235}U$ (*Nuclear Reactor Plant Data*, Oak Ridge Research Reactor, pp. 102–110).

A general description of the Omega West Reactor reveals that the core consisted of 36 subassemblies (MTR type stacked plates, 18 plates per subassembly), each subassembly with overall dimensions of 2.966 × 3.069 × 30 in., arranged in 6 × 9 grid with an active core ~14 × 28 × 24 in. The core contained ~4-kg $^{235}U$ (Omega West Reactor).

Uranium tetrafluoride ($UF_4$), often called green-salt because of its characteristic color, is an intermediate product in the conversion of $UF_6$ to either uranium oxide ($U_3O_8$ or $UO_2$) or uranium metal. $UF_4$ is a solid composed of agglomerating particles with a texture similar to baking soda. It is non-volatile and non-hygroscopic, but only slightly soluble in water. After exposure to water, $UF_4$ slowly dissolves and undergoes hydrolysis, forming several possible uranium compounds and hydrogen fluoride (HF). The density of solid $UF_4$ is 6.7 g/cm$^3$.

Uranyl fluoride ($UO_2F_2$) is an intermediate product in the conversion of uranium hexafluoride ($UF_6$) to an uranium oxide. $UO_2F_2$ is a direct product of the reaction of $UF_6$ with moisture in the air. $UO_2F_2$ is very soluble in water and hygroscopic in air. It changes in color from brilliant orange to yellow after reacting with water. Deliquescence studies show that in room air (~50–60% relative humidity), deposits of $UO_2F_2$ reach an equilibrium point of hydration ($H/U \leq 4$) with the formation of uranyl fluoride dihydrate ($UO_2F_2 \cdot 2H_2O$) [JE/ER-4]. $UO_2F_2$ is reported to be stable in air to 300°C, above which slow decomposition to $U_3O_8$ occurs. When heated to decomposition, $UO_2F_2$ emits toxic fluoride fumes. The densities for $UO_2F_2$ and $UO_2F_2 \cdot 2H_2O$ are 6.37 and 4.76 g/cm$^3$, respectively (Barber).

Uranium carbide is a hard refractive ceramic material. It comes in several stoichiometries ($UC_x$) such as uranium monocarbide (UC), uranium sesquicarbide ($U_2C_3$), and uranium dicarbide ($UC_2$). Typically, uranium carbide is used as a nuclear fuel in gas-cooled fast reactors. Uranium carbide is a dull, dark charcoal-gray or flat black colored powder. Theoretical densities for UC, $U_2C_3$, and $UC_2$ are 13.63, 12.7, and 11.3 g/cm$^3$, respectively.

Uranium nitride (UN) is a ceramic material with a high uranium density and melting point (2805°C). These properties make it suitable for both liquid-metal cooled reactor and in-core nuclear thermionic applications. One process for the production of UN powder is hydride-dehydride-nitride process where the starting material is oxide-free uranium metal. Material testing of isostatically pressed and sintered UN cylinders has revealed the presence of uranium sesquinitride ($U_2N_3$). The theoretical densities for UN and $U_2N_3$ are 14.32 and 11.24 g/cm$^3$, respectively. The fact that $U_2N_3$ has a lower density than UN and decomposes into UN and nitrogen gas at 900°C eliminates it as a potential reactor fuel (ORNL-4608).

Other uranium compounds consist primarily of finished Tristructural-isotropic (TRISO) micro fuel particles; however, also included are pure/impure scrap materials generated during various stages of the manufacturing process. These materials have a $^{235}U$ assay $\leq$ 93.17% and are typically in a solid crystalline or granular form. A finished TRISO fuel particle consists of a kernel composed of $UO_X$ (or sometimes UC or UCO) coated with four exterior layers of three isotropic materials. The four layers are a porous buffer layer made of carbon, followed by a dense inner layer of pyrolytic carbon (PyC), followed

by a ceramic layer of SiC to retain fission products at elevated temperatures and to give the TRISO particle more structural integrity, followed by a dense outer layer of PyC. TRISO fuel particles are designed not to crack due to the stresses from processes (such as differential thermal expansion or fission gas pressure) at temperatures beyond 1600°C, and therefore can contain the fuel in the worst of accident scenarios in a properly designed reactor. TRISO fuel particles were originally developed in Germany for high-temperature gas-cooled reactors. Two current reactor designs are the pebble bed reactor (PBR) in which thousands of TRISO fuel particles are dispersed into graphite pebbles, and the prismatic-block gas-cooled reactor (such as the GT-MHR) in which the TRISO fuel particles are fabricated into compacts and placed in a graphite block matrix. Both of these reactor designs are very high temperature reactors (formally known as the high-temperature gas-cooled reactors).

The convenience cans, Teflon and polyethylene bottles, 277-4 canned spacers described in Sect. 6.2.2, and the packing materials described in Sect. 6.2.3 are not affected by inclusion of the new package contents. Other than a reference made to Table 6.9.8.2, the Packing Content Loading Restrictions stated in Sect. 6.2.4 are unchanged.

### 6.9.8.3 General Considerations

General considerations expressed in Sect. 6.3 regarding both assumptions made about the ES-3100 packaging and the calculation methodology for the evaluation are maintained. No changes are required to the calculation models of the containment vessel, the single-unit packaging (Sect. 6.3.1.1), the damaged packaging (Sect. 6.3.1.3), or the catastrophically-damaged packaging (Sect. 6.3.1.4). However, the array packaging calculation model used with some of the new content models employs the explicit triangular-pitch geometry specification also used in the evaluation of small array configurations (Sect. 6.3.1.2). Both the ETP and the reduced diameter square-pitch configuration for simulating triangular pitch spacing in an array of packages yields acceptable (and comparable) results. Finally, the material properties specification for the new content models are addressed in Sect. 6.9.8.3.2.

#### 6.9.8.3.1 Model configuration for supplemental contents

**Reactor Fuel Components and Scrap Materials**

A variety of materials identified in Table 6.9.8.1 from various reactor programs include bare, clad or canned uranium metal alloy, and bare or clad HEU oxide. These items will be shipped in the ES-3100 package as pellets, rods, plates, bundled components and fuel assemblies.

The calculation model for the U/Al fuel plates is based on the BR-2 MTR Type 2 fuel plate. Plate dimensions are 7.1 cm width × 0.1561 cm depth × 65.5 cm height based on data for the CNEA MTR Type 2 fuel. With an overall depth of 5.4627 cm, thirty-five BR-2 plates bundled together can be accommodated in the ES-3100 containment vessel. Data for Bundle 29 provides the basis for the calculation model. The net weight is 7,309 g, the uranium mass is 525.19 g, and the $^{235}U$ mass is 473.09 g. Three loading configurations are analyzed for evaluation of the effect of plate separation. One configuration models a compact array of 35 fuel plates side-by-side inside the containment vessel. The two other configurations model the plates with 0.06- and 0.12-cm separation between the plates. The bundle of plates intersect the containment vessel wall at 0.18-cm separation between the plates.

The Massachusetts Institute of Technology (MIT) U/Al fuel plate aluminum cladding outer dimensions are 2.552-in. (6.48208-cm) wide × 0.08-in. (0.2032-cm) deep (thickness) × 23-in. (58.42-cm) high. An element consists of 15 MIT fuel plates with 0.082 in. (0.20828 cm) separation between plates for an overall depth (thickness) of 2.348 in. (5.96392 cm) for the 0.082-in. (as designed/built) separation. With the as-fabricated element/grid structure, only one MIT fuel element can be accommodated in the ES-3100 containment vessel. If the MIT fuel plates were removed from the element structure and

bundled together with no separation between plates, the bundle of plates would be ~1.2-in. (3.048-cm) thick. Since the designed separation distance between plates is slightly larger than the fuel plates themselves (0.082 and 0.080 in., respectively), up to 30 loose fuel plates could be bundled together; in this configuration, 30 plates would occupy approximately the same volume as 15 plates in the fuel element structure. For conservatism, the uranium is modeled as HEU at 94% enrichment [U(94)] and the remainder is modeled as aluminum. Given that ~525-g $^{235}U$ is present in the fuel element, the 3,597 g of U/Al in the 15 MIT fuel plates would contain 558.5-g U(94). For two sets of fuel element plates bundled together without the fuel element grid structure, the 30 fuel plates would have ~1,050-g $^{235}U$ [1,117-g U(94)]. The evaluation in Sect. 6.9.8.5.1 covers both a single intact MIT U/Al element with 15 fuel plates and a bundled arrangement of up to 30 MIT U/Al fuel plates.

A uranium silicide ($U_3Si_2$) fuel plate measures 2.79-in. (7.0866 cm) wide × 0.05-in. (0.127-cm) deep (thickness) × 25-in. (63.5-cm) high. The fuel is 0.02-in. thick with 0.015-in. thick cladding on all sides. A fuel element consists of twelve plates, each plate weighing 161.6 g and containing on average 12.5-g $^{235}U$, 63.27-g U (19.7), 5.13-g Si, and 93.4 g of 6061-T0 aluminum cladding. The 12 fuel plates (net weight 1,942 g) bundled together contains 150-g $^{235}U$ [759-g U(19.7)]. A bundle of 36 fuel plates (net weight 5,825 g) contains 450-g $^{235}U$ [2,277-g U(19.7)]. $U_3Si_2$ fuel having similar dimensions and less fissile content is bounded by MIT U/Al fuel.

The evaluation of HEU oxide in Sects. 6.4.3, 6.5.3, and 6.6.3, focuses on product and skull oxides characterized as loose material with bulk densities ranging from 2.0 to 6.54 g/cm$^3$. Unlike bulk oxides, reactor components of HEU oxide consist of compressed, sintered pellets with densities approaching the theoretical 10.96 g/cm$^3$. Pellets measuring 1.25 in. in diameter and 3.5 in. in height are stacked into clad-tubing of various lengths. Calculation models consider both bare rods and rods clad with ~2-mil (0.002-in.) thickness of aluminum, stainless-steel or zirconium. Dimensions for a bare rod are 1.8288 cm (0.7200 in.) in diameter and 63.5000 cm (25.0 in.) in length. Dimensions for a clad rod are 1.8388 cm (0.7239 in.) in diameter and 63.5100 cm (25.0039 in.) in length. Seven different rod arrangements shown in Figs. 6.9.8.3.1-1a through 6.9.8.3.1-1g are analyzed for determining the most reactive configuration. Twelve rods in the containment vessel contain 19,308.9 g $^{235}U$ in 21,937.6 g $UO_2$.

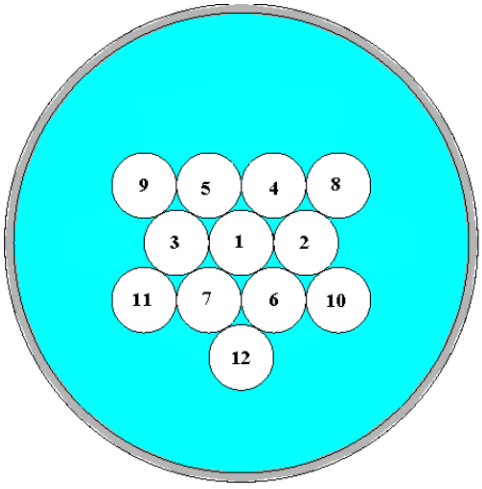



**Fig. 6.9.8.3.1-1a. Config. "UO2_A."**

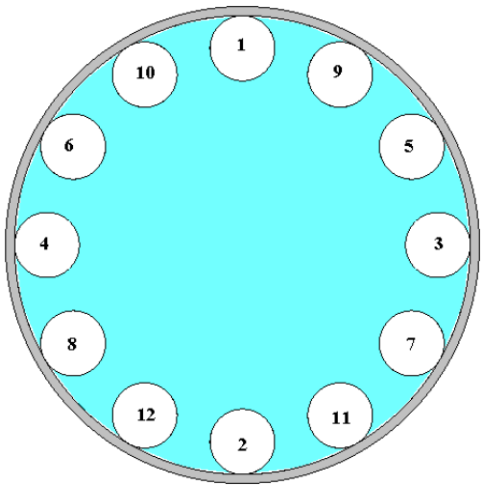



**Fig. 6.9.8.3.1-1b. Config. "UO2_B."**

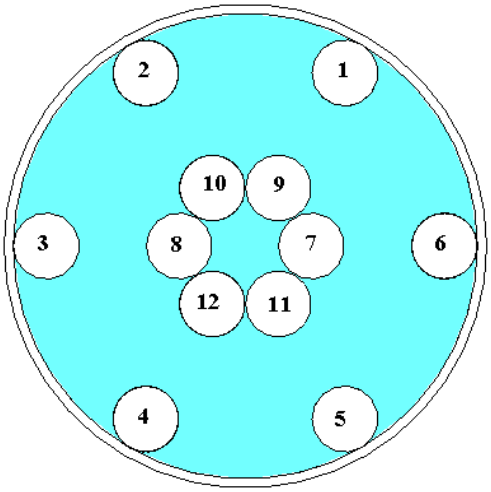



**Fig. 6.9.8.3.1-1c. Config. "UO2_C."**

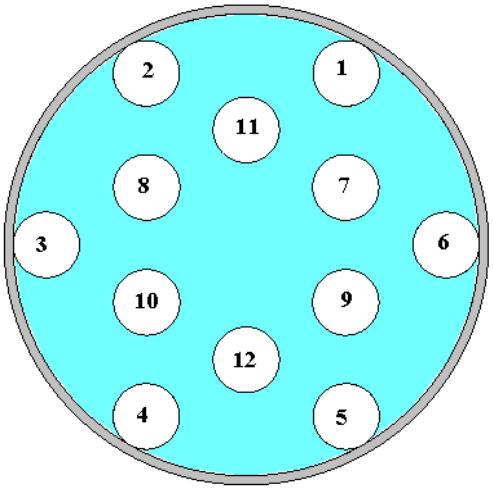



**Fig. 6.9.8.3.1-1d. Config. "UO2_D."**

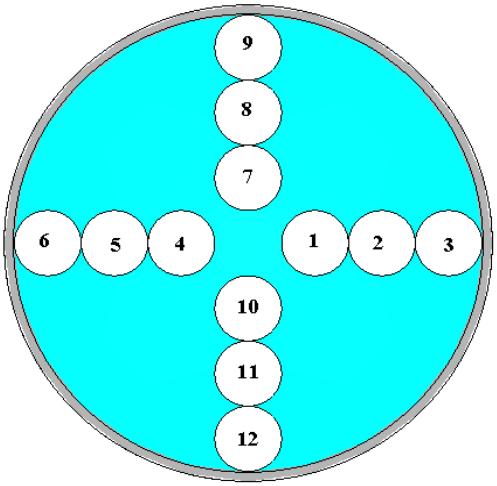



**Fig. 6.9.8.3.1-1e. Config. "UO2_E."**

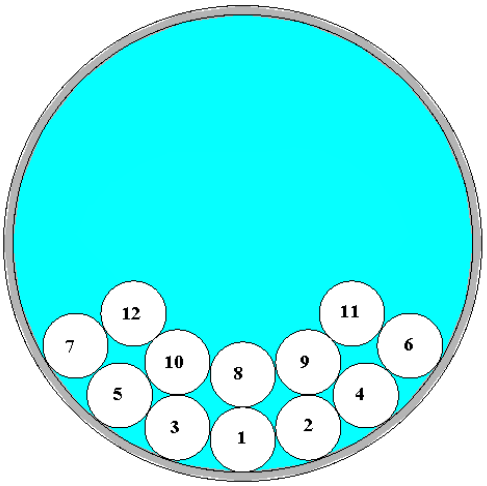



**Fig. 6.9.8.3.1-1f. Config. "UO2_F."**

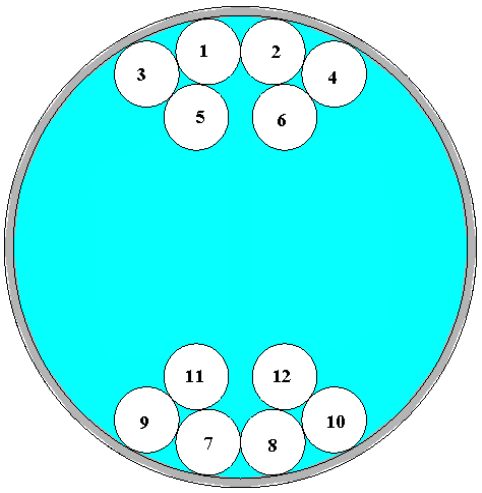



**Fig. 6.9.8.3.1-1g. Config. "UO2_G."**

Other proposed contents are U/Al alloy fuel plates and Al-clad HEU fuel plates. Alloys of uranium are not explicitly evaluated in Sects. 6.4.1, 6.4.2, 6.5.1, 6.5.2, 6.6.1, and 6.6.2. Instead, the uranium alloy is conservatively assessed by counting the neutron scattering constituents (aluminum, molybdenum, zirconium, etc.) as multiplying media ($^{235}U$). When the aluminum alloy or aluminum component of a fuel plate is conservatively assumed to be 100 wt % $^{235}U$, then the loading capacity is severely limited by limits given for HEU broken metal. The U/Al or aluminum clad plates are explicitly modeled as a homogenized mixture of 93% enriched uranium and aluminum distributed evenly throughout the plate.

A SNAP reactor fuel pin composed of $UZrH_2$ is ~1.25 in. in diameter and ~12.45 in. long. The calculation model for the TRIGA fuel ($UZrH_{1.6}$) was adapted for use by changing the pin dimensions, the enrichment to 93 wt % $^{235}U$, and the hydrogen component from 1.6 to 2.0.

**Uranium Compounds**

$UF_4$, $UO_2F_2$, $UO_2F_2 \cdot 2H_2O$, and $U_3Si_2$ powder are conservatively modeled as water soluble compounds like the UNH content (Sects. 6.4.4, 6.5.4, and 6.6.4). An assumed maximum of 500 g of polyethylene represents Teflon or polyethylene bottles, and hydrogenous material used for packing. A solution formed by $UF_4$, $UO_2F_2$, $UO_2F_2 \cdot 2H_2O$, or $U_3Si_2$ powder dissolved in water fills the entire volume of the containment vessel. The amounts of uranium compound and evaluation water in the containment vessel determines the most reactive content condition. Both flooding of the containment vessel and a partial load of uranium compound is required to achieve the most reactive configuration.

Uranium carbide, uranium nitride, and uranium silicide are known to have been fabricated into reactor fuel pellets, fuel plates, and cylinders as solid shapes. The physical form and the moisture content of these materials is not known. These uranium compounds are assumed to be a loose, granular or powdered material. UC, $U_2C_3$, $UC_2$, UN, and $U_3Si_2$ are conservatively modeled both as granular compounds like HEU oxide (Sects. 6.4.3, 6.5.3, and 6.6.3) and as water-soluble compounds like the UNH content (Sects. 6.4.4, 6.5.4, and 6.6.4). An assumed maximum of 500 g of polyethylene is included to represent hydrogenous packing material.

### 6.9.8.3.2 Content model material specifications

Material properties specification for the additional/ new content models are presented in Table 6.9.8.3.

### 6.9.8.4 Computer Codes and Cross-Section Libraries

Calculations presented herein were performed using the Monte Carlo CSAS25 criticality code sequence and 238-group ENDFB-V cross section library of SCALE 5.0 (NUREG/CR-0200, Rev. 7), executed on identical Hewlett Packard (HP) Model zx6000 Itanium workstations (CMODC and CMODD) of the Y-12 Safety Analysis Engineering (SAE) organization in Oak Ridge, Tennessee. Criticality calculations documented in Sects. 6.4–6.6 were performed using SCALE 4.4a (NUREG/CR-0200, Rev. 6) executed on an HP Model J5600 RISC workstation (CMODB). The obsolete CMODB with HP-UX 10.20 operating system was recently retired from service. SCALE 4.4a no longer supported by the code developer is not portable to the new computing platforms thus necessitating the use of SCALE 5.0.

**Table 6.9.8.3. Material compositions for additional/ new content calculation models**

| Material | Mix. No. | Theoretical density input parameter ($g/cm^3$) [a] | Volume fraction | Constituent | Atomic weight | Weight fraction | Atomic density (atoms/b-cm) |
|---|---|---|---|---|---|---|---|
| **Fissile material contents** | | | | | | | |
| Uranium/aluminum | 1 | 2.91688 | 1.0 | Al | 26.9818 | 92.5645 | 6.02620E-02 |
| | | | | $^{235}U$ | 235.0441 | 6.9150 | 5.16786E-04 |
| | | | | $^{238}U$ | 238.0510 | 0.5205 | 3.84064E-05 |
| Uranium/aluminum (MIT U/Al fuel plates) | 1 | 4.03371 | 1.0 | Al | 26.9818 | 61.4529 | 5.53257E-02 |
| | | | | $^{235}U$ | 235.0441 | 36.2343 | 3.74478E-03 |
| | | | | $^{238}U$ | 238.0510 | 2.3128 | 2.36009E-04 |
| Uranium oxide ($UO_2$) | 1 | 10.96000 | 1.0 | O | 15.9904 | 11.9827 | 4.46663E-02 |
| | | | | $^{235}U$ | 235.0441 | 88.0173 | 2.47161E-02 |
| Aluminum (clad) | 4 | 2.70200 | 1.0 | Al | 26.9818 | 100.0000 | 6.03067E-02 |
| Stainless steel (clad) | 4 | 7.94000 | 1.0 | C | 12.0111 | 0.0800 | 3.18477E-04 |
| | | | | Si | 28.0853 | 1.0000 | 1.70252E-03 |
| | | | | P | 30.9741 | 0.0450 | 6.94681E-05 |
| | | | | Cr | 51.9957 | 19.0000 | 1.74726E-02 |
| | | | | Mn | 54.9381 | 2.0000 | 1.74072E-03 |
| | | | | Fe | 55.8447 | 68.3750 | 5.85446E-02 |
| | | | | Ni | 58.6871 | 9.5000 | 7.74021E-03 |
| Zirconium (clad) | 4 | 6.49000 | 1.0 | Zr | 91.2196 | 100.0000 | 4.28457E-02 |
| 93% enriched $UZrH_2$ (11,1647 g) | 1 | 7.43210 | 1.0 | H | 1.0078 | 1.9835 | 8.80884E-02 |
| | | | | Zr | 91.2196 | 89.7628 | 4.40422E-02 |
| | | | | $^{235}U$ | 235.0441 | 7.6738 | 1.46124E-03 |
| | | | | $^{238}U$ | 238.0510 | 0.5799 | 1.09029E-04 |
| Uranium tetrafluoride ($UF_4$) (8,000 g) with 500 g polyethylene | 1 | 1.12580 | 1.0 | H | 1.0078 | 0.6252 | 4.20577E-03 |
| | | | | C | 12.0111 | 3.7226 | 2.10311E-03 |
| | | | | O | 15.9954 | 0.0000 | 2.61845E-22 |
| | | | | F | 18.9982 | 23.3698 | 8.33945E-03 |
| | | | | $^{235}U$ | 235.0441 | 72.2823 | 2.08486E-03 |
| | | | | $^{238}U$ | 238.0510 | 0.0000 | 2.72408E-25 |
| Uranyl fluoride ($UO_2F_2$) (14,000 g) with 500 g polyethylene | 1 | 1.41940 | 1.0 | H | 1.0078 | 0.4959 | 4.20577E-03 |
| | | | | C | 12.0111 | 2.9525 | 2.10311E-03 |
| | | | | O | 15.9954 | 10.1258 | 2.61845E-22 |
| | | | | F | 18.9982 | 12.0271 | 5.41137E-03 |
| | | | | $^{235}U$ | 235.0441 | 74.3989 | 2.70569E-03 |
| | | | | $^{238}U$ | 238.0510 | 0.0000 | 3.46697E-25 |
| Uranyl fluoride ($UO_2F_2$) (14,000 g) with 500 g poly and 7,439 g water in CV | 1 | 2.14760 | 1.0 | H | 1.0078 | 4.1225 | 5.29052E-02 |
| | | | | C | 12.0111 | 1.9513 | 2.10311E-03 |
| | | | | O | 15.9954 | 36.8057 | 2.97600E-02 |
| | | | | F | 18.9982 | 7.9489 | 5.41137E-03 |
| | | | | $^{235}U$ | 235.0441 | 49.1716 | 2.70569E-03 |
| | | | | $^{238}U$ | 238.0510 | 0.0000 | 3.46697E-25 |

**Table 6.9.8.3. Material compositions for additional/ new content calculation models**

| Material | Mix. No. | Theoretical density input parameter ($g/cm^3$) [a] | Volume fraction | Constituent | Atomic weight | Weight fraction | Atomic density (atoms/b-cm) |
|---|---|---|---|---|---|---|---|
| Uranyl fluoride dihydrate ($UO_2F_2 \cdot 2H_2O$) (14,000 g) with 500 g of polyethylene | 1 | 1.41940 | 1.0 | H | 1.0078 | 1.6371 | 1.38857E-02 |
| | | | | C | 12.0000 | 2.9524 | 2.10311E-03 |
| | | | | O | 15.9954 | 18.1130 | 9.67957E-03 |
| | | | | F | 18.9982 | 10.7570 | 4.83996E-03 |
| | | | | $^{235}U$ | 235.0441 | 66.5411 | 2.41997E-03 |
| | | | | $^{238}U$ | 238.0510 | 0.0000 | 3.46705E-25 |
| Uranyl fluoride dihydrate ($UO_2F_2 \cdot 2H_2O$) (14,000 g) with 500 g poly and 6,693 g water in CV | 1 | 2.07460 | 1.0 | H | 1.0078 | 4.6544 | 5.77001E-02 |
| | | | | C | 12.0000 | 2.0200 | 2.10311E-03 |
| | | | | O | 15.9954 | 40.4389 | 3.15860E-02 |
| | | | | F | 18.9982 | 7.3598 | 4.83996E-03 |
| | | | | $^{235}U$ | 235.0441 | 45.5270 | 2.41997E-03 |
| | | | | $^{238}U$ | 238.0510 | 0.0000 | 3.46705E-25 |
| Uranium carbide (UC) (2,000 g) with 500 g poly and 8,656 g water in CV | 1 | 2.17160 | 1.0 | H | 1.0078 | 4.9889 | 6.47374E-02 |
| | | | | C | 12.0000 | 15.6704 | 1.70774E-02 |
| | | | | O | 15.9954 | 22.5678 | 1.84509E-02 |
| | | | | $^{235}U$ | 235.0441 | 56.7729 | 3.15875E-03 |
| | | | | $^{238}U$ | 238.0510 | 0.0000 | 3.27808E-25 |
| Uranium sesquicarbide ($U_2C_3$) (2,000 g) with 500 g poly and 8656 g water in CV | 1 | 2.16460 | 1.0 | H | 1.0078 | 4.9690 | 6.42726E-02 |
| | | | | C | 12.0000 | 17.0712 | 1.85444E-02 |
| | | | | O | 15.9954 | 22.3551 | 1.82185E-02 |
| | | | | $^{235}U$ | 235.0441 | 56.7729 | 3.08385E-03 |
| | | | | $^{238}U$ | 238.0510 | 0.0000 | 3.27808E-25 |
| Uranium dicarbide ($UC_2$) (2,000 g) with 500 g poly and 8656 g water in CV | 1 | 2.15200 | 1.0 | H | 1.0078 | 4.9326 | 6.34293E-02 |
| | | | | C | 12.0000 | 18.4667 | 1.99435E-02 |
| | | | | O | 15.9954 | 21.9657 | 1.77969E-02 |
| | | | | $^{235}U$ | 235.0441 | 54.6351 | 3.01242E-03 |
| | | | | $^{238}U$ | 238.0510 | 0.0000 | 3.27808E-25 |
| Uranium silicide ($U_3Si_2$) (7,000 g) with 500 g poly and 8656 g water in CV | 1 | 1.62670 | 1.0 | H | 1.0078 | 6.5728 | 6.38895E-02 |
| | | | | C | 12.0000 | 2.5763 | 2.10312E-03 |
| | | | | O | 15.9954 | 48.7247 | 2.98408E-02 |
| | | | | $^{235}U$ | 235.0441 | 23.4195 | 9.76075E-04 |
| | | | | $^{238}U$ | 238.0510 | 15.6132 | 6.42506E-04 |
| | | | | Si | 28.0853 | 3.0936 | 1.07905E-03 |

[a] The theoretical density input parameter is specified for each material such that the required (or desired) mass of material is represented in the KENO V.a calculation model. The mass of material is computed by KENO V.a as the product of the theoretical density input parameter times the volume fraction times the volume of the geometry region in which the material resides in the calculation model.

The SCALE 4.4a criticality codes and cross-section library are addressed in Sect. 6.3.3. The 238-group ENDF/B-V cross-section library used by SCALE 5.0 is unchanged from the previous version SCALE 4.4a. Also, most of the modular codes in CSAS25 control sequence of SCALE 5.0 are unchanged except for the cross-section processing functional module NITAWL-III.

NITAWL-III applies the Nordheim integral treatment to perform neutron cross-section processing in the resonance energy range for nuclides that have ENDF/B resonance parameter data. This technique involves the numerical integration of ENDF/B resonance parameters using a calculated flux distribution, which is based on the calculated collision density across each resonance and subsequent weighing of the reaction cross section to the desired broad group structure. In the CSAS sequence, NITAWL-III assembles the group-to-group transfer arrays from the elastic and inelastic scattering components and performs other tasks to produce a problem-dependent working cross-section library which can be used by KENO V.a.

As noted in the user manual, several extensions to the Nordheim calculation have been implemented into the algorithm contained in NITAWL-III:

- Elements containing more than one isotope can be treated.
- Self-shielding is applied to resonance scattering. Transfer matrices are adjusted.
- g-, f-, d-, and p-wave as well as s-wave levels can be treated.
- The asymptotic approximation for the flux in the thermal energy range is assumed to have a Maxwellian energy distribution.
- A refined procedure for generating the energy mesh over which reaction rates are integrated has been developed.

As with the SCALE 4.4a calculations, the $k_{eff}$ values for each KENO V.a case are based on 500,000 neutron histories produced by running for 215 generations with 2,500 neutrons per generation and truncating the first 15 generations of data. The convergence of the KENO V.a calculation is related to trends in the average calculated $k_{eff}$. In general, the KENO V.a output table of $k_{eff}$ by generation skipped is reviewed for trends. If no trends are observed, the calculation is accepted, and the reported value of $k_{eff}$ is the one with the most neutron histories. There is usually no statistically significant difference between this result and the one with the smallest standard deviation.

No manual cross-section adjustment is performed for the criticality evaluation. Cross-section processing is performed automatically in the CSAS25 code sequence. Modeling the contents as precisely as possible improves the accuracy of cross-section processing.

The CSAS25 control module, the associated functional modules, the cross section library, and databases used in this evaluation reside in the verified configuration control area designated **/vcc/scale5** on CMODC and CMODD. Also, the computer input and output files for the criticality safety evaluation of the ES-3100 shipping package with the additional/new content reside in a configuration control area **/archive/sppkg_801940a002** on CMODC.

### 6.9.8.5 Single Package Evaluation (NCT and HAC)

The analyses presented in Sect. 6.4 demonstrate that the calculated $k_{eff} \pm 2\sigma$ values increase as a function of increasing MOIFR. Therefore, a fully flooded, reflected package is used to calculate the neutron multiplication factors for the single package analysis.

**Reactor Fuel Components and Scrap Materials**

### 6.9.8.5.1 U/Al fuel plates (Table 6.9.8.8-1a)

Uranium alloys may be loaded to the broken metal mass limits by assuming the mass of the alloy is all $^{235}U$. An explicit evaluation is performed for deriving less restrictive limits for contents where the constituents of the alloy are predominately non-fissile.

The calculation model for bundled U/Al fuel plates at 93% enrichment is based on the BR-2 MTR Type 2 fuel plate described in Sect. 6.9.8.3.1. Four configurations were developed for the analysis. Case **5cvsrualfp_1_1_15** represents a tight-packed bundle of 35 fuel plates side-by-side inside a flooded containment vessel reflected on all sides by 30.48 cm water. A very small portion of the total 7,333 g of U/Al in a bundle is $^{235}U$ (~473 g). Cases **5cvsrualfp_2_1_15**, **5cvsrualfp_3_1_15**, and **5cvsrualfp_4_1_15** model the plates with uniform spacing of 0.06 cm, 0.12 cm, and 0.18 cm separation between the plates, respectively. The calculated $k_{eff} \pm 2\sigma$ values range from 0.265 to 0.384. A result is not calculated for the fourth configuration because the bundle of plates intersects the containment vessel wall in the geometry model.

Similarly, the NCT Cases **5ncsrualfp_1_1_15**, **5ncsrualfp_2_1_15**, and **5ncsrualfp_3_1_15** model the U/Al plate configurations inside a flooded ES-3100 package with full water reflection. The calculated $k_{eff} \pm 2\sigma$ values range from 0.228 to 0.323. Comparison of NCT single package results with corresponding case results for the flooded, reflected containment vessel demonstrates that ES-3100 packaging is not as an effective moderator as full water reflection.

HAC Cases **5hcsrualfp_1_1_15**, **5hcsrualfp_2_1_15**, and **5hcsrualfp_3_1_15** model the U/Al plate configurations inside a damaged ES-3100 package with full water reflection. Comparison of HAC single package results with corresponding NCT results reaffirms that an insignificant difference is observed between the calculated $k_{eff} \pm 2\sigma$ values.

A single flooded, fully water reflected ES-3100 package, either undamaged or damaged, loaded with U/Al fuel plates (net weight 7,333 g) containing ~473 g of $^{235}U$ will remain adequately subcritical below the USL of 0.924.

Six loading configurations are analyzed for evaluation of the effect of plate separation for a 15-plate U/Al MIT fuel element. One configuration models a compact array of 15 fuel plates with no separation inside the containment vessel. The five other configurations model the plates with 0.020-, 0.050-, 0.082- (actual design value), 0.147- and 0.211-in. (maximum) separation between the plates. The two outermost plates would start to intersect the containment vessel wall with larger separation distances between the plates.

Case **5cvcrmitfpt11_1_1_15** represents a tight-packed bundle of 15 fuel plates face-to-face inside a flooded containment vessel that is reflected on all sides by 30.48 cm of water. Cases **5cvcrmitfpt11_2_1_15** through **5cvcrmitfpt11_6_1_15** model the same plates with uniform spacing of 0.020-, 0.050-, 0.082-, 0.147-, and 0.211-in. separation between the plates, respectively. The calculated $k_{eff} \pm 2\sigma$ values range from 0.270 to 0.473. These same separation values are used in all of the other calculation models for the 15-plate MIT element evaluation.

Similarly, the NCT Cases **5ncsrmitfpt11_1_1_15** through **5ncsrmitfpt11_6_1_15** model the MIT fuel plate configurations inside a flooded ES-3100 package with full water reflection. The calculated $k_{eff} \pm 2\sigma$ values range from 0.249 to 0.421.

HAC Cases **5hcsrmitfpt12_1_1_15** through **5hcsrmitfpt12_6_1_15** model the MIT 15-plate configurations inside a damaged ES-3100 package with full water reflection. Comparison of HAC single package results with corresponding NCT results reaffirms that an insignificant difference is observed between the calculated $k_{eff} \pm 2\sigma$ values.

Two loading configurations are analyzed for evaluation of the effect of plate separation for a 30-plate bundle of MIT fuel. One configuration models a compact array of 30 fuel plates with no separation inside the containment vessel. The other configuration models the plates with 0.065-in. separation between the plates. The two outermost plates would start to intersect the containment vessel wall with larger separation distances between the plates.

Case **5cvcr30mitfpt11_1_1_15** represents a tight-packed bundle of 30 fuel plates face-to-face inside a flooded containment vessel which is reflected on all sides by 30.48-cm water. Case **5cvcr30mitfpt11_6_1_15** models the same 30 plates with the maximum possible uniform spacing within the containment vessel of 0.065-in. separation between the plates. The calculated $k_{eff} \pm 2\sigma$ values for these two extremes are 0.305 and 0.443. These same separation values are used in all of the other calculation models for the evaluation of the 30-plate bundle of MIT U/Al fuel plates.

Similarly, the NCT Cases **5ncsr30mitfpt11_1_1_15** and **5ncsrmitfpt11_6_1_15** model the MIT fuel plate configurations inside a flooded ES-3100 package with full water reflection. The calculated $k_{eff} \pm 2\sigma$ values for these two extremes (tight-packed and maximum possible uniform spacing) are 0.265 and 0.372.

HAC Cases **5hcsr30mitfpt12_1_1_15** and **5hcsr30mitfpt12_6_1_15** model the MIT 30-plate bundle configurations inside a damaged ES-3100 package with full water reflection. Comparison of HAC single package results with corresponding NCT results reaffirms that an insignificant difference is observed between the calculated $k_{eff} \pm 2\sigma$ values.

A single flooded, fully water reflected ES-3100 package, either undamaged or damaged, loaded with a single MIT element consisting of 15 U/Al fuel plates (net weight 3,597 g) containing ~525 g of $^{235}U$, or loaded with a bundle of up to 30 MIT fuel plates (net weight 7,194 g) containing ~1,050 g of $^{235}U$, will remain adequately subcritical below the USL of 0.924.

#### 6.9.8.5.2 Reactor components of HEU oxide (Table 6.9.8.8-2)

Twelve $UO_2$ oxide rods in a containment vessel are modeled to determine whether the clad or unclad rods are the most reactive. Case **5cvsroxt11_1_4_1_15** models unclad $UO_2$ rods as shown in Fig. 6.9.8.3.1-1d. Case **5cvsroxt11_1_4_2_15** models Al-clad $UO_2$ rods. Case **5cvsroxt11_1_4_3_15** models Zr-clad rods. Case **5cvsroxt11_1_4_4_15** is for unclad $UO_2$ rods. The calculated $k_{eff} \pm 2\sigma$ values for unclad, Al-clad, SS304-clad, and Zr-clad $UO_2$ rods range from 0.799 to 0.801. The unclad $UO_2$ rods are the most reactive configuration.

The single unit analysis is performed with unclad rods modeled in the various rod arrangements shown in Figs. 6.9.8.3.1-1a through 6.9.8.3.1-1g. For NCT Cases **5ncsroxt11_1_1_1_15** through **5ncsroxt11_1_7_1_15,** the calculated $k_{eff} \pm 2\sigma$ values range from 0.604 to 0.745. For HAC Cases **5hcsroxt12_1_1_1_15** through **5hcsroxt12_1_7_1_15**, the calculated $k_{eff} \pm 2\sigma$ values range from 0.603 to 0.750. Configuration "**UO2_D**" shown in Fig. 6.9.8.3.1-1d is the most reactive one represented by Cases **5ncsroxt11_1_4_1_15** and **5hcsroxt12_1_4_1_15**. A single flooded, fully water reflected ES-3100 package with up to 12 clad or unclad $UO_2$ fuel rods, each containing ~1,609 g of $^{235}U$ are adequately subcritical, below the USL of 0.924.

### 6.9.8.5.3 $UZrH_2$ fuel (Table 6.9.8.8-3)

SNAP fuel elements are modeled as 12.45-in.-tall cylinders of $UZrH_2$. The analysis assumes that three SNAP fuel elements each are packed into both the bottom and middle can locations of the ES-3100, rather than the fuel being size reduced to fit into 10-in. or 8-3/4 in.-tall convenience cans. The top can location is assumed void. For calculations where canned spacers are modeled, two canned spacers are assumed present in the containment vessel. For configurations where canned spacers are not used, the $UZrH_2$ content is assumed stacked end-to-end. The three cylinders of the active fuel are modeled in triangular-pitch configuration within a radial boundary of 4.25 in. The pitch used in the criticality calculation models for the NCT and HAC ground transport is 4.9809 cm (1.96 in.).

NCT Cases **5ncsrsnap_93_1_15_15** and **5ncsrsnap_93_1_1_15** model the $UZrH_2$ cylinders inside a flooded or dry containment vessel in flooded ES-3100 packaging under full water reflection. The calculated $k_{eff} \pm 2\sigma$ values are 0.568 and 0.240, respectively. Cases **5ncsrsnap_93_2_15_15** and **5ncsrsnap_93_2_1_15** model the presence of canned spacers. The calculated $k_{eff} \pm 2\sigma$ values are 0.539 and 0.223, respectively.

HAC Cases **5hcsrsnap_93_1_15_15** and **5hcsrsnap_93_1_1_15** model the $UZrH_2$ cylinders inside a flooded or dry containment vessel in flooded damaged ES-3100 packaging under full water reflection. The calculated $k_{eff} \pm 2\sigma$ values are 0.568 and 0.244, respectively. The 1.4-in.-thick canned spacers are modeled in Cases **5hcsrsnap_93_2_15_15** and **5hcsrsnap_93_2_1_15**. The calculated $k_{eff} \pm 2\sigma$ values are 0.540 and 0.225, respectively. Comparison of HAC single package results with corresponding NCT results reaffirms that an insignificant difference is observed between the calculated $k_{eff} \pm 2\sigma$ values.

10 CFR 71.55(d)(2) requires the geometric form of a package's content not be substantially altered under the NCT. Also, 10 CFR 7155(e)(1) requires that the package be adequately subcritical under HAC with the package contents in the most reactive credible configuration. However, conclusions about damage to the fuel content cannot be extrapolated from test data because a mock (test weight) content rather than actual SNAP content is evaluated in the NCT and HAC tests of 10 CFR 71.71 and 10 CFR 71.73. Consequently, one way for addressing these requirements is to model the content in an extremely damaged condition and make a determination of subcriticality through a series of criticality calculations. Case **5ncsr9355d2_1_15_15** models the $UZrH_2$ homogenized with the water of a flooded containment vessel and dispersed over the free volume of the containment vessel, where the undamaged ES-3100 packaging is flooded and reflected by 30.48 cm of water. Similarly, Case **5ncsr9355d2_1_1_15** models the $UZrH_2$ dispersed over the free volume of a dry containment vessel of the ES-3100 packaging. The calculated $k_{eff} \pm 2\sigma$ values are 0.674 and 0.158, respectively. Cases **5ncsr9355d2_2_15_15** and **5ncsr9355d2_2_1_15** model the presence of the canned spacers. The calculated $k_{eff} \pm 2\sigma$ values for these cases are 0.645 and 0.151, respectively. These results indicate that extremely damaged content is more reactive than the unaltered configuration. Nevertheless, each set of cases is adequately below the USL of 0.924 and the requirement of 10 CFR 71.55(d)(2) is satisfied. Given that changes external to the containment vessel due to HAC do no result in an appreciable change in neutron multiplication for the single package, similar results are expected for the cases demonstrating compliance with 10 CFR 71.55(e)(1). Conclusions regarding compliance with 10 CFR 71.55(d)(2) equally apply regarding compliance with 10 CFR 71.55(e)(1).

A single flooded, fully water reflected ES-3100 package, either undamaged or damaged, loaded with $UZrH_2$ (net weight 11,164 g) containing ~857 g $^{235}U$ will remain adequately subcritical below the USL of 0.924.

#### 6.9.8.5.4 UZr fuel plates

As an alloy, UZr fuel plates may be loaded to the broken metal mass limits by assuming the mass of the alloy is all uranium.

**Uranium Compounds**

$UF_4$, $UO_2F_2$, and $UO_2F_2 \cdot 2H_2O$ are conservatively modeled as water soluble compounds like the UNH content (Sects. 6.4.4, 6.5.4, and 6.6.4). UC, $U_2C_3$, $UC_2$, and UN are conservatively modeled both as granular compounds like HEU oxide (Sects. 6.4.3, 6.5.3, and 6.6.3) and as water-soluble compounds like the UNH content (Sects. 6.4.4, 6.5.4, and 6.6.4). An assumed maximum of 500 g of polyethylene represents Teflon or polyethylene bottles, and hydrogenous material used for packing.

#### 6.9.8.5.5 UF compounds (Tables 6.9.8.8-5a, 6.9.8.8-5b)

Consider the flooded, water reflected containment vessel with the $UF_4$ content in solution and homogenized with 500 g polyethylene. The $UF_4$ content ranges from 24,000 to 1,000 g. For Cases **5cvcrpuf4t11_24_15** through **5cvcrpuf4t11_1_15** (Table 6.9.8.8-5a), the $k_{eff} \pm 2\sigma$ values range from 0.863 to 0.709 and optimum concentration occurs at ~11,000 g $UF_4$ ($k_{eff} \pm 2\sigma = 0.890$).

Consider a single, flooded ES-3100 package loaded with $UF_4$ content in solution and homogenized with 500 g polyethylene. The $UF_4$ content ranges from 24,000 to 1,000 g. For Cases **5ncsrpuf4t11_24_15** through **5ncsrpuf4t11_1_15**, the $k_{eff} \pm 2\sigma$ values range from 0.747 to 0.629 and optimum concentration occurs at ~9,000 g $UF_4$ ($k_{eff} \pm 2\sigma = 0.783$). Given that the water-reflected containment vessel is more reactive than the water-reflected package, the result for Case **5cvcrpuf4t11_11_15** is reported [10 CFR 71.55(b)].

Consider the flooded, water reflected containment vessel with the $UO_2F_2$ content in solution and homogenized with 500 g polyethylene. The $UO_2F_2$ content ranges from 24,000 to 1,000 g. For Cases **5cvcrpuofct11_24_15** through **5cvcrpuofct11_1_15** (Table 6.9.8.8-5b), the $k_{eff} \pm 2\sigma$ values range from 0.851 to 0.710 and optimum concentration occurs at ~8,000 g $UO_2F_2$ ($k_{eff} \pm 2\sigma = 0.887$). Consider $UO_2F_2 \cdot 2H_2O$ content in solution and homogenized with 500 g polyethylene. The $UO_2F_2 \cdot 2H_2O$ content ranges from 24,000 to 1,000 g. For Cases **5cvcrpuofhct11_24_15** through **5cvcrpuofhct11_1_15** (Table 6.9.8.8-5b), the $k_{eff} \pm 2\sigma$ values range from 0.898 to 0.696 and optimum concentration occurs at ~14,000 g $UO_2F_2 \cdot 2H_2O$ ($k_{eff} \pm 2\sigma = 0.907$). Given that $UO_2F_2 \cdot 2H_2O$ is more reactive than $UO_2F_2$, calculations with $UO_2F_2 \cdot 2H_2O$ are bounding.

Consider a single, flooded ES-3100 package loaded with $UO_2F_2 \cdot 2H_2O$ content in solution and homogenized with 500 g polyethylene. For Cases **5ncsrpuofhct11_24_15** through **5ncsrpuofhct11_1_15** (Table 6.9.8.8-5b), the $k_{eff} \pm 2\sigma$ values range from 0.787 to 0.614 and optimum concentration occurs at ~14,000 g $UO_2F_2 \cdot 2H_2O$ ($k_{eff} \pm 2\sigma = 0.798$). The water-reflected containment vessel is more reactive than the water-reflected package; therefore the result for Case **5cvcrpuofhct11_14_15** is reported [10 CFR 71.55(b)].

#### 6.9.8.5.6 UC and UN compounds (Tables 6.9.8.8-6a, 6.9.8.8-6b)

Consider the flooded, water reflected containment vessel with 500 g polyethylene homogenized with bulk saturated UC, $U_2C_3$, $UC_2$, or UN compound. These uranium compounds are evaluated over the range from 10,000 to 1,000 g. For Cases **5cvcrpuct11_1_10** through **5cvcrpuct11_1_1** (Table 6.9.8.8-6a), the $k_{eff} \pm 2\sigma$ values for UC content decrease from 0.945 to 0.648. For Cases **5cvcrpuct11_2_10** through **5cvcrpuct11_2_1**, the $k_{eff} \pm 2\sigma$ values for $U_2C_3$ decrease from 0.910 to 0.643. For Cases **5cvcrpuct11_3_10** through **5cvcrpuct11_3_1**, the $k_{eff} \pm 2\sigma$ values for $UC_2$ decrease from 0.901 to 0.637. For Cases **5cvcrpunt11_10** through **5cvcrpunt11_1** (Table 6.9.8.8-6b), the $k_{eff} \pm 2\sigma$ values for UN decrease from 0.909 to 0.646.

Consider a single ES-3100 package loaded with 500 g polyethylene homogenized with bulk saturated UC, $U_2C_3$, $UC_2$, or UN compound. These uranium compounds are evaluated over the range from 10,000 to 1,000 g. For Cases **5ncsrpuct11_1_10_15** through **5ncsrpuct11_1_1_15** (Table 6.9.8.8-6a), the $k_{eff} \pm 2\sigma$ values for UC content decrease from 0.814 to 0.575. For Cases **5ncsrpuct11_2_10_15** through **5ncsrpuct11_2_1_15**, the $k_{eff} \pm 2\sigma$ values for $U_2C_3$ decrease from 0.811 to 0.575. For Cases **5ncsrpuct11_3_10_15** through **5ncsrpuct11_3_1_15**, the $k_{eff} \pm 2\sigma$ values for $UC_2$ decrease from 0.802 to 0.570. For Cases **5ncsrpunt11_10_15** through **5ncsrpunt11_1_15** (Table 6.9.8.8-6b), the $k_{eff} \pm 2\sigma$ values for UN content decrease from 0.814 to 0.574. The water-reflected containment vessel cases are more reactive than the corresponding cases for the water-reflected package.

Consider a single ES-3100 package loaded with 500 g polyethylene homogenized with 2,000 g bulk saturated UC or UN compound. The water inside the containment vessel is varied from the flooded to the dry condition. For Cases **5ncsrpuct11_1_2_15** through **5ncsrpuct11_1_2_1** (Table 6.9.8.8-6a), the $k_{eff} \pm 2\sigma$ values for UC content decrease from 0.657 to 0.617. For Cases **5ncsrpunt11_2_15** through **5ncsrpunt11_2_1** (Table 6.9.8.8-6b), the $k_{eff} \pm 2\sigma$ values for UN content decrease from 0.657 to 0.615. These cases reveal that the addition of water in the void region of the containment vessel above the homogenized water saturated content has little effect on neutron multiplication.

#### 6.9.8.5.7 $U_3Si_2$ powder (Tables 6.9.8.8-7a, 6.9.8.8-7b)

Consider the flooded, water-reflected containment vessel loaded with 500-g polyethylene homogenized with bulk saturated $U_3Si_2$. This content is evaluated from 13,000- to 7,000-g $U_3Si_2$ over a density range of 7 to 2 g/cm$^3$. For Cases **5cvcrpdusit11_8_7_13_15** through **5cvcrpdusit11_8_2_13_15** (Table 6.9.8.8-7a), the $k_{eff} \pm 2\sigma$ values for $U_3Si_2$ content increase from 0.849 to 0.920 as the density decreases. For Cases **5cvcrdpust11_8_7_13_15** through **5cvcrdpust11_8_2_13_15** where the same content is dispersed over the internal volume of the containment vessel, $k_{eff} \pm 2\sigma = 0.929$. The uniform configuration—a column of 8656-g water is mixed with 13-kg $U_3Si_2$ and 500-g polyethylene—is more reactive than the discrete configuration—13-kg $U_3Si_2$ (plus 5,490-g saturation water) and 500-g polyethylene separated from the 3,166 g of water filling the remaining volume of the containment vessel.

For Cases **5cvcrdpustt11_8_7_13_15** through **5cvcrpdusit11_8_7_7_15** (Table 6.9.8.8-7a), the $k_{eff} \pm 2\sigma$ values for $U_3Si_2$ content decrease from 0.929 to 0.915 as the mass of $U_3Si_2$ decreases from 13- to 7-kg $U_3Si_2$ .

For Cases **5cvcrpdusit11_8_7_13_15** through **5cvcrpdusit11_1_7_13_15** (Table 6.9.8.8-7a), the $k_{eff} \pm 2\sigma$ values decrease from 0.849 to 0.624 as the enrichment decreases from 100 to 19.7% in the content (13-kg $U_3Si_2$ plus 5,490-g saturation water and 500-g polyethylene). Similarly for Cases **5cvcrdpust11_8_7_13_15** through **5cvcrdpust11_1_7_13_15**, the $k_{eff} \pm 2\sigma$ values decrease from 0.929 to 0.763 where this content is dispersed over the containment vessel. The same trend is evident in Cases **5cvcrdpust11_8_7_7_15** through **5cvcrdpust11_1_7_7_15** for a reduced amount of content, the $k_{eff} \pm 2\sigma$ values decrease from 0.915 to 0.724.

For Cases **5cvcrdpustt11_1_7_13_15** through **5cvcrpdusit11_1_7_7_15** (Table 6.9.8.8-7a), the $k_{eff} \pm 2\sigma$ values for $U_3Si_2$ content decrease from 0.763 to 0.724 as the mass of $U_3Si_2$ decreases from 13- to 7-kg $U_3Si_2$ at 19.7% enrichment.

Consider a single ES-3100 package loaded with 500-g polyethylene homogenized with bulk saturated $U_3Si_2$. This content is evaluated from 13,000- to 7,000-g $U_3Si_2$ over a density range of 7 to 2 g/cm$^3$. For Cases **5ncsrpdusit11_8_7_13_15** through **5ncsrpdusit11_8_2_13_15** (Table 6.9.8.8-7b), the $k_{eff} \pm 2\sigma$ values for $U_3Si_2$ content increase from 0.769 to 0.820 as the density decreases. For Cases **5ncsrdpust11_8_7_13_15** through **5ncsrdpust11_8_2_13_15** where the same content is dispersed

over the internal volume of the containment vessel, $k_{eff} \pm 2\sigma = 0.824$. For Cases **5ncsrdpust11_8_7_13_15** through **5ncsrdpust11_8_7_7_15** (Table 6.9.8.8-7b), the $k_{eff} \pm 2\sigma$ values for $U_3Si_2$ content decrease from 0.824 to 0.809 as the mass of $U_3Si_2$ decreases from 13- to 7-kg $U_3Si_2$.

For Cases **5ncsrpdusit11_8_7_13_15** through **5ncsrpdusit11_1_7_13_15** (Table 6.9.8.8-7b), the $k_{eff} \pm 2\sigma$ values decrease from 0.769 to 0.521 as the enrichment decreases from 100 to 19.7% in the content (13-kg $U_3Si_2$ plus 5,490-g saturation water and 500-g polyethylene). Similarly for Cases **5ncsrdpust11_8_7_13_15** through **5ncsrdpust11_1_7_13_15**, the $k_{eff} \pm 2\sigma$ values decrease from 0.824 to 0.662 where this content is dispersed over the containment vessel. The same trend is evident in Cases **5ncsrdpust11_8_7_7_15** through **5ncsrdpust11_1_7_7_15** for a reduced amount of content, the $k_{eff} \pm 2\sigma$ values decrease from 0.809 to 0.633.

The same trend observed for the flooded reflected containment vessel is apparent for the flooded reflected package; however, the water-reflected containment vessel cases are more reactive than the corresponding cases for the water-reflected package. The result for Case **5cvcrdpust11_8_7_7_15** (Table 6.9.8.8-7a) is reported [10 CFR 71.55(b)].

### 6.9.8.6 Array Package Evaluation (NCT and HAC)

The analyses presented in Sects. 6.5 and 6.6 demonstrate that maximum reactivity occurs in an array of packages when the containment vessel is flooded (MOCFR = 1.0) and the ES-3100 packaging is dry (MOIFR = 1e-04). A water fraction of MOIFR = 1e-04 pertains specifically to NCT or HAC packages where both the neutron poison of the body weldment liner inner cavity and the Kaolite are dry and both the recesses of the package external to the containment vessel and the interstitial space between drums of the array do no contain any residual moisture.

The analyses presented in Sects. 6.4, 6.5, and 6.6 demonstrate that an insignificant difference is observed between the calculated $k_{eff} \pm 2\sigma$ values for undamaged packages in NCT and damaged packages in HAC. Therefore, the HAC array analysis is redundant and not fully developed in this appendix.

**Reactor Fuel Components and Scrap Materials**

#### 6.9.8.6.1 U/Al fuel plates (Tables 6.9.8.8-1a, 6.9.8.8-1b)

As stated in Sect. 6.9.8.5.1, an explicit evaluation is performed for deriving less-restrictive loading limits for contents where the constituents of the U-Al alloy are predominately non-fissile. The infinite array packaging calculation model for bundled U/Al fuel plates at 93% enrichment is based on the BR-2 MTR Type 2 fuel plate described in Sect. 6.8.8.3.1. NCT Cases **5nciaualfp_1_1_3**, **5nciaualfp_2_1_3**, and **5nciaualfp_3_1_3** model infinite arrays of undamaged ES-3100 packages with the U/Al plates uniformly spaced at 0.0 cm, 0.06 cm, and 0.12 cm separation between plates. The ES-3100 packaging is dry while the containment vessel with content is flooded. A water fraction of MOIFR = 1e-04 signifies dry NCT packaging where both the neutron poison of the body weldment liner inner cavity and the Kaolite are dry (in the as-manufactured condition) and both the recesses of the package external to the containment vessel and the interstitial space between drums of the array do no contain any residual moisture. The calculated $k_{eff} \pm 2\sigma$ values range from 0.276 to 0.382.

HAC Cases **5hciaualfp_1_1_3** through **5hciaualfp_3_1_3** model the U/Al plate configurations inside damaged ES-3100 packages. The calculated $k_{eff} \pm 2\sigma$ values range from 0.275 to 0.380. Comparison of HAC array package results with corresponding HAC results reaffirms the insignificant difference observed between the calculated $k_{eff} \pm 2\sigma$ values.

Given that the results indicate adequate subcriticality below the USL of 0.924, ES-3100 packages loaded with U/Al fuel plates (net weight 7,333 g) containing ≤473 g of $^{235}U$ may be shipped under a CSI = 0.

The infinite array NCT Cases **5nciamitfpt11_1_1_3** through **5nciamitfpt11_6_1_3** model the MIT U/Al single element/15-plate configurations inside a flooded ES-3100 package with full water reflection. The calculated $k_{eff} \pm 2\sigma$ values range from 0.285 to 0.472.

HAC Cases **5hciamitfpt12_1_1_3** through **5hciamitfpt12_6_1_3** model the MIT single element/15-plate configurations inside a damaged ES-3100 package with full water reflection. Comparison of HAC single package results with corresponding NCT results reaffirms that an insignificant difference is observed between the calculated $k_{eff} \pm 2\sigma$ values.

The infinite array NCT Cases **5ncia30mitfpt11_1_1_3** and **5ncia30mitfpt11_6_1_3** model the 30 MIT U/Al fuel plates configurations inside a flooded ES-3100 package with full water reflection. The calculated $k_{eff} \pm 2\sigma$ values are 0.316 and 0.429.

HAC Cases **5hcia30mitfpt12_1_1_3** through **5hcia30mitfpt12_6_1_3** model the MIT 30-plate configurations inside a damaged ES-3100 package with full water reflection. Comparison of HAC single package results with corresponding NCT results reaffirms that an insignificant difference is observed between the calculated $k_{eff} \pm 2\sigma$ values.

Given that the results indicate adequate subcriticality below the USL of 0.924, ES-3100 packages loaded with one MIT U/Al element with 15 fuel plates (net weight 3,597 g) containing ~525-g $^{235}U$ or up to 30 bundled MIT U/Al fuel plates (net weight 7,194 g) containing ~1,050 g of $^{235}U$ may be shipped under a CSI = 0.

#### 6.9.8.6.2 Reactor components of HEU oxide (Table 6.9.8.8-2)

Unclad $UO_2$ rods are used in the infinite array analysis like the single unit analysis. Each rod arrangement (Figs. 6.9.8.3.1-1a through 6.9.8.3.1-1g) is evaluated for confirmation that Configuration "**UO2_D**" is the most reactive one. For NCT Cases **5nciaoxt11_1_1_1_3** through **5nciaoxt11_1_7_1_3**, the calculated $k_{eff} \pm 2\sigma$ values range from 0.715 to 0.885. For HAC Cases **5hciaoxt12_1_1_1_15** through **5hciaoxt12_1_7_1_15,** the calculated $k_{eff} \pm 2\sigma$ values range from 0.708 to 0.877. The most reactive configuration is **UO2_D** represented by Cases **5nciaoxt11_1_4_1_15** and **5hciaoxt12_1_4_1_15**. Calculation results for the configurations evaluated indicate adequate subcriticality below the USL of 0.924. The ES-3100 packages loaded with 12 $UO_2$ (net weight 21,938 g) containing ≤ 19,308 g of $^{235}U$ may be shipped under a CSI = 0.

#### 6.9.8.6.3 $UZrH_2$ fuel (Table 6.9.8.8-3)

NCT Cases **5nciasnap_93_1_15_3** and **5nciasnap_93_1_1_3** model infinite arrays of undamaged ES-3100 packages with $UZrH_2$ cylinders inside a flooded or dry containment vessels. The calculated $k_{eff} \pm 2\sigma$ values are 0.619 and 0.298, respectively. Cases **5nciasnap_93_2_15_3** and **5nciasnap_93_2_1_3** model the presence of canned spacers. The calculated $k_{eff} \pm 2\sigma$ values are 0.591 and 0.284, respectively.

HAC Cases **5hciasnap_93_1_15_3** and **5hciasnap_93_1_1_3** model infinite arrays of damaged ES-3100 packages with $UZrH_2$ cylinders inside a flooded or dry containment vessels. The calculated $k_{eff} \pm 2\sigma$ values are 0.620 and 0.298, respectively. The 1.4-in.-thick canned spacers are modeled in Cases **5hciasnap_93_2_15_3** and **5hcsrsnap_93_2_1_3**. The calculated $k_{eff} \pm 2\sigma$ values are 0.590 and 0.286, respectively. Comparison of HAC single package results with corresponding NCT results reaffirms that an insignificant difference is observed between the calculated $k_{eff} \pm 2\sigma$ values.

Case **5ncia9355d2_1_15_3** models infinite arrays of dry, undamaged ES-3100 packages with the $UZrH_2$ homogenized with the water of a flooded containment vessel and dispersed over the free volume of the containment vessel. Similarly, Case **5ncia9355d2_1_1_3** models the $UZrH_2$ dispersed over the free volume of a dry containment vessel of the dry ES-3100 packaging. The calculated $k_{eff} \pm 2\sigma$ values are 0.6744 and 0.1577, respectively. Cases **5ncia9355d2_2_15_15** and **5ncia9355d2_2_1_1**5 model the presence of the canned spacers. The calculated $k_{eff} \pm 2\sigma$ values for these cases are 0.6449 and 0.1509, respectively. These results indicate that extremely damaged content is more reactive than the unaltered configuration. Nevertheless, each set of cases is adequately below the USL of 0.924 and the requirement of 10 CFR 71.55(d)(2) is satisfied. Given that changes external to the containment vessel due to HAC do no result in an appreciable change in neutron multiplication for the single package, similar results are expected for the cases demonstrating compliance with 10 CFR 71.55(e)(1). Conclusions regarding compliance with 10 CFR 71.55(d)(2) equally apply regarding compliance with 10 CFR 7155(e)(1).

Given that the results indicate adequate subcriticality below the USL of 0.924, ES-3100 packages loaded with $UZrH_2$ (net weight 11,164 g) containing $\leq$ 857 g $^{235}U$ may be shipped under a CSI = 0.

#### 6.9.8.6.4 UZr fuel plates

As stated in Sect. 6.9.8.5.4, UZr fuel plates may be loaded to the broken metal mass limits by assuming the mass of the alloy is all $^{235}U$.

#### 6.9.8.6.5 UF compounds (Tables 6.9.8.8-5a, 6.9.8.8-5b)

Cases **5nciapuf4t11_24_1** through **5nciapuf4t11_24_15** (Table 6.9.8.8-5a) model infinite arrays of ES-3100 packages each loaded with 24,000 g $UF_4$ in solution and homogenized with 500 g polyethylene. The $k_{eff} \pm 2\sigma$ values decrease from 0.981 to 0.765 as the packaging external to the containment vessel and the interstitial space between the packages of the array floods. Comparison of results for Cases **5ncsrpuf4t11_24_15** through **5nciapuf4t11_24_15** confirms that flooded packages in a flooded array are nearly neutronically isolated from each other.

Consider an array of flooded ES-3100 packages loaded with $UF_4$ content in solution and homogenized with 500 g polyethylene. The $UF_4$ content ranges from 5,000 to 1,000 g. For Cases **5nciapuf4t11_5_3** through **5nciapuf4t11_1_3**, the $k_{eff} \pm 2\sigma$ value decreases from 0.947 to 0.738.

Given that the results indicate adequate subcriticality below the USL of 0.924, ES-3100 packages loaded with 3000 g $UF_4$ containing $\leq$ 2,267 g $^{235}U$ may be shipped under a CSI = 0.

Cases **5nciapuofhct11_24_1** through **5nciapuofhct11_24_15** (Table 6.9.8.8-5b) model infinite arrays of ES-3100 packages each loaded with 24,000-g $UO_2F_2 \cdot 2H_2O$ in solution and homogenized with 500-g polyethylene. The $k_{eff} \pm 2\sigma$ values decrease from 1.048 to 0.813 as the packaging external to the containment vessel and the interstitial space between the packages of the array floods. Comparison of results for Cases **5ncsrpuofhct11_24_15** and **5nciapuofhct11_24_15** confirms that flooded packages in a flooded array are nearly neutronically isolated from each other.

Consider an array of flooded ES-3100 packages loaded with $UO_2F_2 \cdot 2H_2O$ content in solution and homogenized with 500 g polyethylene. The $UO_2F_2 \cdot 2H_2O$ content ranges from 5,000 to 1,000 g. For Cases **5nciapuofhct11_5_3** through **5nciapuofhctt11_1_3**, the $k_{eff} \pm 2\sigma$ value decreases from 0.949 to 0.719.

Given that the results indicate adequate subcriticality below the USL of 0.924, ES-3100 packages loaded with 3000 g $UO_2F_2 \cdot 2H_2O$ containing $\leq$ 2,067 g $^{235}U$ may be shipped under a CSI = 0.

#### 6.9.8.6.6 UC and UN compounds (Tables 6.9.8.8-6a, 6.9.8.8-6b)

As shown in Table 6.9.8.8-6a, UC content bounds the other forms of uranium carbide compounds. Consider an array of flooded ES-3100 packages loaded with UC content homogenized with 500 g polyethylene. For Cases **5nciapuct11_1_10_3** through **5nciapuct11_1_1_3**, the UC content is conservatively modeled as granular compound like HEU oxide. Over the range of 10,000 to 1,000 g UC, the $k_{eff} \pm 2\sigma$ value decreases from 0.914 to 0.577. For Cases **5nciadpuct11_1_10_15_3** through **5nciadpuct11_1_1_15_3**, the UC content is conservatively modeled as a water-soluble compound dispersed over the free volume of the containment vessel, like the UNX, $UF_4$, $UO_2F_2$, and $UO_2F_2 \cdot 2H_2O$ contents. Over the range of 10,000 to 1,000 g UC, the $k_{eff} \pm 2\sigma$ value decreases from 1.031 to 0.785.

Given that the UC content may not be well characterized as bulk material like the HEU oxide content, the latter model is used for establishing the loading limits. On the basis of calculation results indicating adequate subcriticality below the USL of 0.924, ES-3100 packages loaded with 2,000 g UC, $U_2C_3$, or $UC_2$ containing $\leq$ 1,903 g $^{235}U$ may be shipped under a CSI = 0.

Consider an array of flooded ES-3100 packages loaded with UN content homogenized with 500 g polyethylene. For Cases **5nciapunt11_10_3** through **5nciapuct11_1_3**, the UN content is conservatively modeled as granular compound like HEU oxide. Over the range of 10,000 to 1,000 g UN, the $k_{eff} \pm 2\sigma$ value decreases from 0.927 to 0.578. For Cases **5nciadpunt11_10_15_3** through **5nciadpunt11_1_15_3**, the UN content is conservatively modeled as a water-soluble compound dispersed over the free volume of the containment vessel. Over the range of 10,000 to 1,000 g UN, the $k_{eff} \pm 2\sigma$ value decreases from 1.027 to 0.780.

Given that the UN content may not be well characterized as bulk material like the HEU oxide content, the latter model is used for establishing the loading limits. On the basis of calculation results indicating adequate subcriticality below the USL of 0.924, ES-3100 packages loaded with 2,000 g UN containing $\leq$ 1,888 g $^{235}U$ may be shipped under a CSI = 0.

#### 6.9.8.6.7 $U_3Si_2$ powder (Table 6.9.8.8-7c)

Consider an infinite array of ES-3100 packages loaded with saturated bulk $U_3Si_2$ content homogenized with 500 g of polyethylene in flooded containment vessels. The packaging external to the containment vessels and the interstitial void space between packages in the infinite array is assumed dry for maximizing neutronic interaction. For Cases **5nciapdusit11_8_7_13_3** through **5nciapdusit11_8_2_13_3** (Table 6.9.8.8-7c) where 13 kg of $U_3Si_2$ content is evaluated over a density range of 7 to 2 g/cm$^3$, the $k_{eff} \pm 2\sigma$ values increase from 0.831 to 0.963 as the density decreases. For Cases **5nciadpust11_8_7_13_3** through **5nciadpust11_8_2_13_3** where this same content is dispersed over the internal volume of the containment vessel, $k_{eff} \pm 2\sigma = 1.037$. In the latter set of cases, the density of the saturated content does not have an effect on neutron multiplication because the amount of water within which the content is dispersed is constant.

For Cases **5nciapdusit11_8_2_13_3** through **5nciapdusit11_8_2_7_3** (Table 6.9.8.8-7c), the $k_{eff} \pm 2\sigma$ values for $U_3Si_2$ content decrease from 0.964 to 0.863 as the mass of $U_3Si_2$ decreases from 13 to 7 kg. Similarly for Cases **5nciadpust11_8_7_13_3** through **5nciadpust11_8_7_7_3** (Table 6.9.8.8-7c), the $k_{eff} \pm 2\sigma$ values decrease from 1.037 to 1.006. While the discrete configuration modeled in Cases **5nciapdusit11** indicates that potentially high content loadings can be achieved, the uniform configuration modeled in Cases **5nciadpust11** indicates the contrary.

For Cases **5nciapdusit11_8_2_13_3** through **5nciapdusit11_1_2_13_3**, the $k_{eff} \pm 2\sigma$ values decrease from 0.964 to 0.739 as the enrichment decreases from 100 to 19.7% in the content (13-kg $U_3Si_2$ plus 5,490-g saturation water and 500-g polyethylene). For Cases **5nciadpust11_8_7_13_3** through

**5nciadpust11_1_7_13_3** where content is dispersed over the internal volume of the flooded containment vessel, the $k_{eff} \pm 2\sigma$ values decrease from 1.037 to 0.7993.

The last set of cases presented in Table 6.9.8.8-7c ranks the results for the uniform content configuration model Cases **5nciadpust11** and corresponding discrete configuration model Cases **5nciapdusit11** according to decreased neutron multiplication factor. Given that the $U_3Si_2$ content may not be as well characterized as bulk HEU oxide content, the uniform model is used for establishing the loading limits. On the basis of calculation results indicating adequate subcriticality below the USL of 0.924, ES-3100 packages may be shipped under a CSI = 0 for:

(A) loading not exceeding 7-kg $U_3Si_2$ at enrichments ≥40% but ≤ 60% and

(B) loading not exceeding 13-kg $U_3Si_2$ at enrichments ~19.7 but < 40%.

### 6.9.8.7 Benchmark Experiments and the Criticality Validation

The criticality validation for SCALE 5.0 is a repetition of the SCALE 4.4a validation based on benchmark experiments documented in the OECD Handbook [NEA/NSC/DOC(95)03]. Validation cases for SCALE 4.4a were executed on an HP Model J5600 RISC workstation under the HP-UX 10.20 operating system. For SCALE 5.0, these same validation cases were executed on an HP Model zx6000 Itanium workstation (CMODC).

The validation of CSAS25 control module of SCALE 5.0 with the 238-group ENDF/B-V cross-section library is documented in Y/DD-1220 and Y/DD-1221. Like Y/DD-896/R1, Y/DD-1220 addresses the establishment of bias, bias trends, and uncertainty associated with the use of SCALE 5.0 for performance of criticality calculations. Like Y/DD-972R1, Y/DD-1221 addresses determining USL and for incorporating uncertainty and margin into this USL.

SCALE5 incorporates minor improvements in the code modules for the Bondarenko and the Nordheim Integral Treatment processing of resonance cross sections and the KENO V.a module. Consequently, the USL used is validation dependent based on the SCALE-platform combination. The evaluation of additional/new contents based upon SCALE 5.0 calculations is documented in this appendix separate from the main body of Sect. 6 because this new work could not easily be folded into the existing SCALE 4.4a evaluation without inclusion of a patchwork of clarifications.

The USL is based on the non-parametric statistics-based lower tolerance limit (LTL) for greater than 0.99/99% where there is a probability of greater than 0.99 that 99% of the population is greater than a specified result, reduced by additional margin. From Table 1 of Y/DD-1221, the LTL combining bias and bias uncertainty is 0.974 for uranium systems, including HEU metal. Tables 4.2, 4.3, and 4.4 of Y/DD-1220 list the maximum (positive) and minimum (negative) biases for HEU (metal, compound, solution), IEU (metal, compound) and LEU (compound, solution) systems. Since the positive bias is conservatively treated as a "zero" bias in the validation analysis, the negative bias is applied to determine the USL for the systems. The minimum bias given for HEU, IEU, and LEU systems is given as −0.0230, −0.0055 and −0.0260, respectively.

The minimum bias given for HEU systems in Table 4.2 of Y/DD-1220 is -0.1423. However, this result is from one of the four k-infinite models which are somewhat different than the usual benchmark experiments. As discussed in Sect. 5.3 of Y/DD-1220, the four outlier results are for benchmark experiments that were modeled as infinite in extent, thereby amplifying the effects of imperfections in cross section data. The models also required additional interpretation and adjustment from the actual finite experimental configuration to create an infinite benchmark model. After eliminating outlier models from the bias determination, the minimum bias was determined to be -0.023 for HEU systems.

The global minimum bias results for these systems (−0.0260) is applied to all uranium enrichments. Ordinarily, the USL would be 0.954 where an additional margin of subcriticality of 0.02 is subtracted from the LTL of 0.974. However, NUREG/CR-5661 provides guidance that the USL should be established with a minimum margin of subcriticality of 0.05. Thus, the USL is equal to 0.95 plus the minimum bias (−0.026), giving a value of 0.924.

### 6.9.8.8 Calculation Results Tables for Additional/New Contents

Tables 6.9.8.8-1a through 6.9.8.8-7c contain a summary of the calculation results for the additional/new contents to be shipped in the ES-3100 shipping package. Table 6.9.8.8-4 has been omitted until such time when the Uranium Zirconium alloys are explicitly modeled. Currently these content items are to be treated as broken metal and shipped under these limits accordingly.

**Table 6.9.8.8-1a. Results for uranium aluminum fuel plate content, no polyethylene, no can spacers in the CV or ES-3100 packaging calculation models**

| case name | plates per bundle | plate spacing (in.) | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **flooded containment vessel (mocfr=1.0), reflected** | | | | | | | | | | |
| 5cvcrualfpt11_1_1_15 | 35 | 0.00 | 1.0E+00 | 0.26346 | 0.00082 | 0.26511 | | | | |
| 5cvcrualfpt11_2_1_15 | 35 | 0.02 | 1.0E+00 | 0.32679 | 0.00085 | 0.32849 | | | | |
| 5cvcrualfpt11_3_1_15 | 35 | 0.05 | 1.0E+00 | 0.38130 | 0.00116 | 0.38362 | | | | |
| 5cvcrualfpt11_4_1_15 | 35 | 0.07 | 1.0E+00 | – | – | – | | | | |
| **case name** | **plates per bundle** | **plate spacing (in.)** | **moifr** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** | **case name** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** |
| | | | **NCT** | | | | | **HAC** | | |
| **content in flooded CV (mocfr=1.0), single package, reflected** | | | | | | | | | | |
| 5ncsrualfpt11_1_1_15 | 35 | 0.00 | 1.0E+00 | 0.22621 | 0.00088 | 0.22798 | 5hcsrualfpt12_1_1_15 | 0.22703 | 0.00075 | 0.22852 |
| 5ncsrualfpt11_2_1_15 | 35 | 0.02 | 1.0E+00 | 0.27915 | 0.00119 | 0.28153 | 5hcsrualfpt12_2_1_15 | 0.27905 | 0.00092 | 0.28090 |
| 5ncsrualfpt11_3_1_15 | 35 | 0.05 | 1.0E+00 | 0.32203 | 0.00091 | 0.32386 | 5hcsrualfpt12_3_1_15 | 0.32153 | 0.00097 | 0.32348 |
| **content in flooded CV (mocfr=1.0), infinite array of packages** | | | | | | | | | | |
| 5nciaualfpt11_1_1_3 | 35 | 0.00 | 1.0E-04 | 0.27420 | 0.00087 | 0.27594 | 5hciaualfpt12_1_1_3 | 0.27367 | 0.00083 | 0.27533 |
| 5nciaualfpt11_2_1_3 | 35 | 0.02 | 1.0E-04 | 0.33182 | 0.00088 | 0.33358 | 5hciaualfpt12_2_1_3 | 0.33267 | 0.00111 | 0.33488 |
| 5nciaualfpt11_3_1_3 | 35 | 0.05 | 1.0E-04 | 0.38011 | 0.00094 | 0.38199 | 5hciaualfpt12_3_1_3 | 0.37838 | 0.00093 | 0.38024 |

**Table 6.9.8.8-1b. Results for MIT uranium aluminum fuel element and plate bundles, no polyethylene, no can spacers in the CV or ES-3100 packaging calculation models**

| | | Case suffix | Gap (in.) | moifr | NCT | | | HAC | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
| **15 fuel plates** | **Containment vessel** | | | | **5cvcrmitfpt11** | | | | | |
| | | _1_1_15 | 0.000 | 1.00E+00 | 0.26824 | 0.00088 | 0.27000 | | | |
| | | _2_1_15 | 0.020 | 1.00E+00 | 0.29481 | 0.00105 | 0.29691 | | | |
| | | _3_1_15 | 0.050 | 1.00E+00 | 0.33087 | 0.00095 | 0.33278 | | | |
| | | _4_1_15 | 0.082 | 1.00E+00 | 0.36892 | 0.00098 | 0.37088 | | | |
| | | _5_1_15 | 0.147 | 1.00E+00 | 0.42964 | 0.00117 | 0.43198 | | | |
| | | _6_1_15 | 0.211 | 1.00E+00 | 0.47026 | 0.00130 | 0.47286 | | | |
| | **Single unit** | | | | **5ncsrmitfpt11** | | | **5hcsrmitfpt12** | | |
| | | _1_1_15 | 0.000 | 1.00E+00 | 0.24690 | 0.00088 | 0.24865 | 0.24797 | 0.00087 | 0.24970 |
| | | _2_1_15 | 0.020 | 1.00E+00 | 0.27020 | 0.00086 | 0.27193 | 0.26973 | 0.00102 | 0.27176 |
| | | _3_1_15 | 0.050 | 1.00E+00 | 0.30386 | 0.00145 | 0.30676 | 0.30559 | 0.00093 | 0.30746 |
| | | _4_1_15 | 0.082 | 1.00E+00 | 0.33648 | 0.00111 | 0.33869 | 0.33850 | 0.00097 | 0.34045 |
| | | _5_1_15 | 0.147 | 1.00E+00 | 0.39116 | 0.00123 | 0.39361 | 0.39128 | 0.00109 | 0.39345 |
| | | _6_1_15 | 0.211 | 1.00E+00 | 0.41826 | 0.00115 | 0.42056 | 0.41894 | 0.00119 | 0.42132 |
| | **Infinite array** | | | | **5nciamitfpt11** | | | **5hciamitfpt12** | | |
| | | _1_1_3 | 0.000 | 1.00E-04 | 0.28290 | 0.00087 | 0.28465 | 0.28164 | 0.00105 | 0.28373 |
| | | _2_1_3 | 0.020 | 1.00E-04 | 0.30900 | 0.00086 | 0.31072 | 0.30697 | 0.00107 | 0.30911 |
| | | _3_1_3 | 0.050 | 1.00E-04 | 0.34843 | 0.00098 | 0.35040 | 0.34618 | 0.00097 | 0.34813 |
| | | _4_1_3 | 0.082 | 1.00E-04 | 0.38429 | 0.00104 | 0.38636 | 0.38492 | 0.00098 | 0.38688 |
| | | _5_1_3 | 0.147 | 1.00E-04 | 0.44035 | 0.00108 | 0.44251 | 0.44168 | 0.00117 | 0.44402 |
| | | _6_1_3 | 0.211 | 1.00E-04 | 0.46934 | 0.00141 | 0.47215 | 0.47218 | 0.00117 | 0.47453 |

**Table 6.9.8.8-1b. Results for MIT uranium aluminum fuel element and plate bundles, no polyethylene, no can spacers in the CV or ES-3100 packaging calculation models**

| | | Case suffix | Gap (in.) | moifr | NCT | | | HAC | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
| **30 fuel plates** | **Containment vessel** | | | | **5cvcr30mitfpt11** | | | | | |
| | | _1_1_15 | 0.000 | 1.00E+00 | 0.30325 | 0.00110 | 0.30545 | | | |
| | | _6_1_15 | 0.065 | 1.00E+00 | 0.44049 | 0.00105 | 0.44259 | | | |
| | **Single unit** | | | | **5ncsr30mitfpt11** | | | **5hcsr30mitfpt12** | | |
| | | _1_1_15 | 0.000 | 1.00E+00 | 0.26307 | 0.00107 | 0.26521 | 0.26464 | 0.00096 | 0.26655 |
| | | _6_1_15 | 0.065 | 1.00E+00 | 0.36977 | 0.00109 | 0.37195 | 0.37233 | 0.00107 | 0.37446 |
| | **Infinite array** | | | | **5ncia30mitfpt11** | | | **5hcia30mitfpt12** | | |
| | | _1_1_3 | 0.000 | 1.00E-04 | 0.31460 | 0.00089 | 0.31639 | 0.31507 | 0.00097 | 0.31701 |
| | | _6_1_3 | 0.065 | 1.00E-04 | 0.42644 | 0.00135 | 0.42915 | 0.42690 | 0.00100 | 0.42890 |

**Table 6.9.8.8-2. Results for uranium oxide fuel pin content, no polyethylene, no can spacers in the CV or ES-3100 packaging calculation models**

| case name | rod config. | Cladding | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **flooded containment vessel (mocfr=1.0), reflected** | | | | | | | | | | |
| 5cvsroxt11_1_4_1_15 | UO2_D | none | 1.0E+00 | 0.79880 | 0.00113 | 0.80106 | | | | |
| 5cvsroxt11_1_4_2_15 | UO2_D | Al | 1.0E+00 | 0.79780 | 0.00143 | 0.80066 | | | | |
| 5cvsroxt11_1_4_3_15 | UO2_D | SS304 | 1.0E+00 | 0.79704 | 0.00135 | 0.79974 | | | | |
| 5cvsroxt11_1_4_4_15 | UO2_D | Zr | 1.0E+00 | 0.79706 | 0.00133 | 0.79972 | | | | |
| **case name** | **rod config.** | **Cladding** | **moifr** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** | **case name** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** |
| | | **NCT** | | | | | | **HAC** | | |
| **content in flooded CV (mocfr=1.0), single package, reflected** | | | | | | | | | | |
| 5ncsroxt11_1_1_1_15 | UO2_A | none | 1.0E+00 | 0.63776 | 0.00113 | 0.64002 | 5hcsroxt12_1_1_1_15 | 0.63955 | 0.00102 | 0.64159 |
| 5ncsroxt11_1_2_1_15 | UO2_B | none | 1.0E+00 | 0.67647 | 0.00099 | 0.67844 | 5hcsroxt12_1_2_1_15 | 0.68016 | 0.00121 | 0.68258 |
| 5ncsroxt11_1_3_1_15 | UO2_C | none | 1.0E+00 | 0.71717 | 0.00117 | 0.71951 | 5hcsroxt12_1_3_1_15 | 0.72166 | 0.00133 | 0.72432 |
| 5ncsroxt11_1_4_1_15 | UO2_D | none | 1.0E+00 | 0.74420 | 0.00138 | 0.74697 | 5hcsroxt12_1_4_1_15 | 0.74679 | 0.00140 | 0.74959 |
| 5ncsroxt11_1_5_1_15 | UO2_E | none | 1.0E+00 | 0.69214 | 0.00115 | 0.69445 | 5hcsroxt12_1_5_1_15 | 0.69182 | 0.00128 | 0.69439 |
| 5ncsroxt11_1_6_1_15 | UO2_F | none | 1.0E+00 | 0.60129 | 0.00123 | 0.60374 | 5hcsroxt12_1_6_1_15 | 0.60188 | 0.00122 | 0.60433 |
| 5ncsroxt11_1_7_1_15 | UO2_G | none | 1.0E+00 | 0.60245 | 0.00098 | 0.60441 | 5hcsroxt12_1_7_1_15 | 0.60159 | 0.00123 | 0.60406 |
| **content in flooded CV (mocfr=1.0), infinite array of packages** | | | | | | | | | | |
| 5nciaoxt11_1_1_1_3 | UO2_A | none | 1.0E-04 | 0.72525 | 0.00114 | 0.72753 | 5hciaoxt12_1_1_1_3 | 0.71979 | 0.00110 | 0.72199 |
| 5nciaoxt11_1_2_1_3 | UO2_B | none | 1.0E-04 | 0.83897 | 0.00121 | 0.84138 | 5hciaoxt12_1_2_1_3 | 0.83380 | 0.00097 | 0.83575 |
| 5nciaoxt11_1_3_1_3 | UO2_C | none | 1.0E-04 | 0.84091 | 0.00106 | 0.84304 | 5hciaoxt12_1_3_1_3 | 0.83516 | 0.00121 | 0.83758 |
| 5nciaoxt11_1_4_1_3 | UO2_D | none | 1.0E-04 | 0.88193 | 0.00130 | 0.88454 | 5hciaoxt12_1_4_1_3 | 0.87513 | 0.00116 | 0.87746 |
| 5nciaoxt11_1_5_1_3 | UO2_E | none | 1.0E-04 | 0.80570 | 0.00128 | 0.80827 | 5hciaoxt12_1_5_1_3 | 0.79920 | 0.00117 | 0.80154 |
| 5nciaoxt11_1_6_1_3 | UO2_F | none | 1.0E-04 | 0.79000 | 0.00148 | 0.79297 | 5hciaoxt12_1_6_1_3 | 0.78673 | 0.00115 | 0.78904 |
| 5nciaoxt11_1_7_1_3 | UO2_G | none | 1.0E-04 | 0.71258 | 0.00101 | 0.71461 | 5hciaoxt12_1_7_1_3 | 0.70523 | 0.00114 | 0.70750 |

**Table 6.9.8.8-3. Results for $UZrH_2$ content at 93 wt % $^{235}U$, no polyethylene in the CV or ES-3100 packaging calculation models**

| case name (5ncsrsnap_93) | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name (5hcsrsnap_93) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **NCT** | | | | | | | | | **HAC** | | | |
| **content in flooded containment vessel (mocfr=1.0), single package reflected** | | | | | | | | | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | |
| _1_15_15 | 11,164 | 856.8 | 8,697.5 | 265.00 | 1.0E+00 | 0.56482 | 0.00132 | 0.56745 | _1_15_15 | 0.56496 | 0.00153 | 0.56802 |
| _1_15_1 | 11,164 | 856.8 | 8,697.5 | 265.00 | 1.0E-20 | 0.52691 | 0.00140 | 0.52971 | _1_15_1 | 0.52716 | 0.00115 | 0.52946 |
| **content in dry containment vessel (mocfr=1.0E-20), single package reflected** | | | | | | | | | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | |
| _1_1_15 | 11,164 | 856.8 | 0.0 | 0.00 | 1.0E+00 | 0.23835 | 0.00065 | 0.23965 | _1_1_15 | 0.24210 | 0.00086 | 0.24382 |
| _1_1_1 | 11,164 | 856.8 | 0.0 | 0.00 | 1.0E-20 | 0.14965 | 0.00071 | 0.15107 | _1_1_1 | 0.15269 | 0.00062 | 0.15392 |
| **content in flooded containment vessel (mocfr=1.0), single package reflected** | | | | | | | | | | | | |
| **can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | |
| _2_15_15 | 11,164 | 856.8 | 8,083.9 | 246.30 | 1.0E+00 | 0.53615 | 0.00136 | 0.53887 | _2_15_15 | 0.53767 | 0.00121 | 0.54010 |
| _2_15_1 | 11,164 | 856.8 | 8,083.9 | 246.30 | 1.0E-20 | 0.49949 | 0.00124 | 0.50197 | _2_15_1 | 0.50098 | 0.00147 | 0.50391 |
| **content in dry containment vessel (mocfr=1.0E-20), single package reflected** | | | | | | | | | | | | |
| **can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | |
| _2_1_15 | 11,164 | 856.8 | 0.0 | 0.00 | 1.0E+00 | 0.22128 | 0.00085 | 0.22297 | _2_1_15 | 0.22299 | 0.00099 | 0.22497 |
| _2_1_1 | 11,164 | 856.8 | 0.0 | 0.00 | 1.0E-20 | 0.14380 | 0.00076 | 0.14532 | _2_1_1 | 0.14446 | 0.00059 | 0.14564 |

**Table 6.9.8.8-3. Results for $UZrH_2$ content at 93 wt % $^{235}U$, no polyethylene in the CV or ES-3100 packaging calculation models**

| case name (5nciasnap_93) | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name (5hciasnap_93) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **NCT** | | | | | | | | | **HAC** | | | |
| **content in flooded or dry containment vessel, infinite array of packages (moifr=1.0E-04)** | | | | | | | | | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | |
| _1_15_3 | 11,164 | 856.8 | 8,697.5 | 265 | 1.0E+00 | 0.61697 | 0.00116 | 0.61929 | _1_15_3 | 0.61768 | 0.00126 | 0.62021 |
| _1_1_3 | 11,164 | 856.8 | 0.0 | 0 | 1.0E-20 | 0.29625 | 0.00088 | 0.29800 | _1_1_3 | 0.29628 | 0.00078 | 0.29784 |
| **can spacers (np thickness = 1.4 in.** | | | | | | | | | | | | |
| _2_15_3 | 11,164 | 856.8 | 8,083.9 | 246.3 | 1.0E+00 | 0.58841 | 0.00140 | 0.59121 | _2_15_3 | 0.58719 | 0.00116 | 0.58952 |
| _2_1_3 | 11,164 | 856.8 | 0.0 | 0 | 1.0E-20 | 0.28234 | 0.00082 | 0.28399 | _2_1_3 | 0.28400 | 0.00090 | 0.28580 |
| **case name (5ncsrs9355d2)** | **$UZrH_x$ (g)** | **$^{235}U$ (g)** | **$H_2O$ (g)** | **h/x** | **mocfr** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** | | | | |
| **NCT** | | | | | | | | | | | | |
| **content in flooded or dry containment vessel, single package, reflected** | | | | | | | | | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | | | | |
| _1_15_15 | 11,164 | 857 | 8,697.5 | 265.00 | 1.0E+00 | 0.67173 | 0.00134 | 0.67441 | | | | |
| _1_1_15 | 11,164 | 857 | 0.0 | 0.00 | 1.0E-20 | 0.15644 | 0.00064 | 0.15773 | | | | |
| **content in flooded or dry containment vessel, infinite array of NCT packages (moifr=1.0E-04)** | | | | | | | | | | | | |
| **can spacers (np thickness = 1.4 in.)** | | | | | | | | | | | | |
| _2_15_15 | 11,164 | 857 | 8,083.9 | 246.30 | 1.0E+00 | 0.64224 | 0.00135 | 0.64494 | | | | |
| _2_1_15 | 11,164 | 857 | 0.0 | 0.00 | 1.0E-20 | 0.14967 | 0.00059 | 0.15085 | | | | |

**Table 6.9.8.8-3. Results for $UZrH_2$ content at 93 wt % $^{235}U$, no polyethylene in the CV or ES-3100 packaging calculation models**

| case name (5ncias9355d2) | $UZrH_x$ (g) | $^{235}U$ (g) | $H_2O$ (g) | h/x | mocfr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | |
|---|---|---|---|---|---|---|---|---|---|
| **NCT** | | | | | | | | | |
| **content in flooded or dry containment vessel, infinite array of NCT packages (moifr=1.0E-04)** | | | | | | | | | |
| **no can spacers (np thickness = 0.0 in.)** | | | | | | | | | |
| _1_15_3 | 11,164 | 857 | 8,697.5 | 265.00 | 1.0E+00 | 0.77961 | 0.00125 | 0.78212 | |
| _1_1_3 | 11,164 | 857 | 0.0 | 0.00 | 1.0E-20 | 0.19477 | 0.00064 | 0.19606 | |
| **content in flooded or dry containment vessel, infinite array of NCT packages (moifr=1.0E-04)** | | | | | | | | | |
| **can spacers (np thickness = 1.4 in.)** | | | | | | | | | |
| _2_15_3 | 11,164 | 857 | 8,083.9 | 246.30 | 1.0E+00 | 0.73142 | 0.00125 | 0.73392 | |
| _2_1_3 | 11,164 | 857 | 0.0 | 0.00 | 1.0E-20 | 0.18427 | 0.00066 | 0.18559 | |

**Table 6.9.8.8-5a. Results for uranium tetrafluoride ($UF_4$) in the CV or ES-3100 packaging calculation models**

| case name | $UF_4$ (g) | $^{235}U$ (g) | CV $H_2O$ (g) | h/x | mocfr or moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|
| **$UF_4$ content and 500 g polyethylene, flooded containment vessel, reflected** | | | | | | | | |
| | | | | | **mocfr** | | | |
| 5cvcrpuf4t11_24_15 | 24,000 | 18,136 | 6,045 | 9.62 | 1.0E+00 | 0.85970 | 0.00145 | 0.86260 |
| 5cvcrpuf4t11_23_15 | 23,000 | 17,380 | 6,195 | 10.27 | 1.0E+00 | 0.86175 | 0.00129 | 0.86433 |
| 5cvcrpuf4t11_22_15 | 22,000 | 16,625 | 6,345 | 10.97 | 1.0E+00 | 0.86372 | 0.00151 | 0.86674 |
| 5cvcrpuf4t11_21_15 | 21,000 | 15,869 | 6,496 | 11.74 | 1.0E+00 | 0.86321 | 0.00152 | 0.86626 |
| 5cvcrpuf4t11_20_15 | 20,000 | 15,113 | 6,646 | 12.59 | 1.0E+00 | 0.86843 | 0.00121 | 0.87086 |
| 5cvcrpuf4t11_19_15 | 19,000 | 14,358 | 6,797 | 13.52 | 1.0E+00 | 0.87167 | 0.00120 | 0.87407 |
| 5cvcrpuf4t11_18_15 | 18,000 | 13,602 | 6,947 | 14.56 | 1.0E+00 | 0.86974 | 0.00152 | 0.87278 |
| 5cvcrpuf4t11_17_15 | 17,000 | 12,846 | 7,097 | 15.73 | 1.0E+00 | 0.87451 | 0.00130 | 0.87711 |
| 5cvcrpuf4t11_16_15 | 16,000 | 12,091 | 7,248 | 17.03 | 1.0E+00 | 0.87724 | 0.00175 | 0.88073 |
| 5cvcrpuf4t11_15_15 | 15,000 | 11,335 | 7,398 | 18.52 | 1.0E+00 | 0.87801 | 0.00156 | 0.88114 |
| 5cvcrpuf4t11_14_15 | 14,000 | 10,579 | 7,549 | 20.21 | 1.0E+00 | 0.88119 | 0.00147 | 0.88413 |
| 5cvcrpuf4t11_13_15 | 13,000 | 9,823 | 7,699 | 22.16 | 1.0E+00 | 0.88028 | 0.00136 | 0.88300 |
| 5cvcrpuf4t11_12_15 | 12,000 | 9,068 | 7,850 | 24.44 | 1.0E+00 | 0.88385 | 0.00139 | 0.88664 |
| **5cvcrpuf4t11_11_15** | **11,000** | **8,312** | **8,000** | **27.14** | **1.0E+00** | **0.88690** | **0.00131** | **0.88952** |
| 5cvcrpuf4t11_10_15 | 10,000 | 7,556 | 8,150 | 30.37 | 1.0E+00 | 0.88487 | 0.00144 | 0.88776 |
| 5cvcrpuf4t11_9_15 | 9,000 | 6,801 | 8,301 | 34.32 | 1.0E+00 | 0.88487 | 0.00179 | 0.88845 |
| 5cvcrpuf4t11_8_15 | 8,000 | 6,045 | 8,451 | 39.26 | 1.0E+00 | 0.88594 | 0.00132 | 0.88859 |
| 5cvcrpuf4t11_7_15 | 7,000 | 5,289 | 8,602 | 45.61 | 1.0E+00 | 0.88213 | 0.00157 | 0.88526 |
| 5cvcrpuf4t11_6_15 | 6,000 | 4,534 | 8,752 | 54.08 | 1.0E+00 | 0.87761 | 0.00155 | 0.88070 |
| 5cvcrpuf4t11_5_15 | 5,000 | 3,778 | 8,902 | 65.93 | 1.0E+00 | 0.87255 | 0.00120 | 0.87494 |
| 5cvcrpuf4t11_4_15 | 4,000 | 3,022 | 9,053 | 83.71 | 1.0E+00 | 0.86186 | 0.00130 | 0.86446 |
| 5cvcrpuf4t11_3_15 | 3,000 | 2,267 | 9,203 | 113.36 | 1.0E+00 | 0.84540 | 0.00143 | 0.84827 |
| 5cvcrpuf4t11_2_15 | 2,000 | 1,511 | 9,354 | 172.62 | 1.0E+00 | 0.80743 | 0.00150 | 0.81044 |
| 5cvcrpuf4t11_1_15 | 1,000 | 756 | 9,504 | 350.39 | 1.0E+00 | 0.70654 | 0.00129 | 0.70913 |

**Table 6.9.8.8-5a. Results for uranium tetrafluoride ($UF_4$) in the CV or ES-3100 packaging calculation models**

| case name | $UF_4$ (g) | $^{235}U$ (g) | CV $H_2O$ (g) | h/x | mocfr or moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|
| **$UF_4$ content with 500 g polyethylene in containment vessel, flooded package, reflected** | | | | | | | | |
| 5ncsrpuf4t11_24_15 | 24,000 | 18,136 | 6,045 | 9.62 | 1.0E+00 | 0.74487 | 0.00125 | 0.74738 |
| 5ncsrpuf4t11_23_15 | 23,000 | 17,380 | 6,195 | 10.27 | 1.0E+00 | 0.74674 | 0.00139 | 0.74953 |
| 5ncsrpuf4t11_22_15 | 22,000 | 16,625 | 6,345 | 10.97 | 1.0E+00 | 0.75066 | 0.00122 | 0.75310 |
| 5ncsrpuf4t11_21_15 | 21,000 | 15,869 | 6,496 | 11.74 | 1.0E+00 | 0.74939 | 0.00118 | 0.75175 |
| 5ncsrpuf4t11_20_15 | 20,000 | 15,113 | 6,646 | 12.59 | 1.0E+00 | 0.75270 | 0.00158 | 0.75587 |
| 5ncsrpuf4t11_19_15 | 19,000 | 14,358 | 6,797 | 13.52 | 1.0E+00 | 0.75465 | 0.00128 | 0.75720 |
| 5ncsrpuf4t11_18_15 | 18,000 | 13,602 | 6,947 | 14.56 | 1.0E+00 | 0.76103 | 0.00170 | 0.76442 |
| 5ncsrpuf4t11_17_15 | 17,000 | 12,846 | 7,097 | 15.73 | 1.0E+00 | 0.76089 | 0.00112 | 0.76312 |
| 5ncsrpuf4t11_16_15 | 16,000 | 12,091 | 7,248 | 17.03 | 1.0E+00 | 0.76404 | 0.00162 | 0.76727 |
| 5ncsrpuf4t11_15_15 | 15,000 | 11,335 | 7,398 | 18.52 | 1.0E+00 | 0.76718 | 0.00124 | 0.76966 |
| 5ncsrpuf4t11_14_15 | 14,000 | 10,579 | 7,549 | 20.21 | 1.0E+00 | 0.76630 | 0.00137 | 0.76904 |
| 5ncsrpuf4t11_13_15 | 13,000 | 9,823 | 7,699 | 22.16 | 1.0E+00 | 0.77064 | 0.00126 | 0.77316 |
| 5ncsrpuf4t11_12_15 | 12,000 | 9,068 | 7,850 | 24.44 | 1.0E+00 | 0.77019 | 0.00161 | 0.77340 |
| 5ncsrpuf4t11_11_15 | 11,000 | 8,312 | 8,000 | 27.14 | 1.0E+00 | 0.77412 | 0.00140 | 0.77691 |
| 5ncsrpuf4t11_10_15 | 10,000 | 7,556 | 8,150 | 30.37 | 1.0E+00 | 0.77743 | 0.00135 | 0.78013 |
| 5ncsrpuf4t11_9_15 | 9,000 | 6,801 | 8,301 | 34.32 | 1.0E+00 | 0.77855 | 0.00244 | 0.78344 |
| 5ncsrpuf4t11_8_15 | 8,000 | 6,045 | 8,451 | 39.26 | 1.0E+00 | 0.77398 | 0.00155 | 0.77709 |
| 5ncsrpuf4t11_7_15 | 7,000 | 5,289 | 8,602 | 45.61 | 1.0E+00 | 0.77431 | 0.00151 | 0.77733 |
| 5ncsrpuf4t11_6_15 | 6,000 | 4,534 | 8,752 | 54.08 | 1.0E+00 | 0.77174 | 0.00141 | 0.77455 |
| 5ncsrpuf4t11_5_15 | 5,000 | 3,778 | 8,902 | 65.93 | 1.0E+00 | 0.76857 | 0.00139 | 0.77135 |
| 5ncsrpuf4t11_4_15 | 4,000 | 3,022 | 9,053 | 83.71 | 1.0E+00 | 0.75863 | 0.00138 | 0.76139 |
| 5ncsrpuf4t11_3_15 | 3,000 | 2,267 | 9,203 | 113.36 | 1.0E+00 | 0.74294 | 0.00135 | 0.74563 |
| 5ncsrpuf4t11_2_15 | 2,000 | 1,511 | 9,354 | 172.62 | 1.0E+00 | 0.71219 | 0.00191 | 0.71600 |
| 5ncsrpuf4t11_1_15 | 1,000 | 756 | 9,504 | 350.39 | 1.0E+00 | 0.62599 | 0.00150 | 0.62899 |

**Table 6.9.8.8-5a. Results for uranium tetrafluoride ($UF_4$) in the CV or ES-3100 packaging calculation models**

| case name | $UF_4$ (g) | $^{235}U$ (g) | CV $H_2O$ (g) | h/x | mocfr or moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|
| **$UF_4$ content with 500 g poly, flooded containment vessel, infinite array of packages** | | | | | | | | |
| | | | | | **moifr** | | | |
| 5nciapuf4t11_24_1 | 24,000 | 18,136 | 6,045 | 9.62 | 1.0E-20 | 0.97902 | 0.00126 | 0.98155 |
| 5nciapuf4t11_24_2 | 24,000 | 18,136 | 6,045 | 9.62 | 1.0E-05 | 0.97881 | 0.00120 | 0.98121 |
| 5nciapuf4t11_24_3 | 24,000 | 18,136 | 6,045 | 9.62 | 1.0E-04 | 0.97816 | 0.00107 | 0.98030 |
| 5nciapuf4t11_24_4 | 24,000 | 18,136 | 6,045 | 9.62 | 1.0E-03 | 0.97536 | 0.00113 | 0.97762 |
| 5nciapuf4t11_24_5 | 24,000 | 18,136 | 6,045 | 9.62 | 1.0E-02 | 0.95053 | 0.00135 | 0.95323 |
| 5nciapuf4t11_24_6 | 24,000 | 18,136 | 6,045 | 9.62 | 1.0E-01 | 0.82769 | 0.00123 | 0.83014 |
| 5nciapuf4t11_24_8 | 24,000 | 18,136 | 6,045 | 9.62 | 3.0E-01 | 0.75894 | 0.00131 | 0.76155 |
| 5nciapuf4t11_24_15 | 24,000 | 18,136 | 6,045 | 9.62 | 1.0E+00 | 0.76205 | 0.00140 | 0.76486 |
| | | | | | | | | |
| 5nciapuf4t11_5_3 | 5,000 | 3,778 | 8,902 | 65.93 | 1.0E-04 | 0.94398 | 0.00143 | 0.94684 |
| 5nciapuf4t11_4_3 | 4,000 | 3,022 | 9,053 | 83.71 | 1.0E-04 | 0.92856 | 0.00174 | 0.93205 |
| **5nciapuf4t11_3_3** | **3,000** | **2,267** | **9,203** | **113.36** | **1.0E-04** | **0.90021** | **0.00130** | **0.90280** |
| 5nciapuf4t11_2_3 | 2,000 | 1,511 | 9,354 | 172.62 | 1.0E-04 | 0.85169 | 0.00129 | 0.85426 |
| 5nciapuf4t11_1_3 | 1,000 | 756 | 9,504 | 350.39 | 1.0E-04 | 0.73511 | 0.00144 | 0.73800 |

**Table 6.9.8.8-5b. Results for uranyl fluoride ($UO_2F_2$) and dihydrate ($UO_2F_2 \cdot 2H_2O$) in the CV or ES-3100 packaging calculation models**

| case name | $UO_2F_2$ or $UO_2F_2 \cdot 2H_2O$ (g) | $^{235}U$ (g) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | mocfr or moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| **$UO_2F_2$ content and 500-g polyethylene, flooded containment vessel, reflected** | | | | | | | | | |
| | | | | | | **mocfr** | | | |
| 5cvcrpuofct11_24_15 | 24,000 | 18,493 | | 5,857 | 9.17 | 1.0E+00 | 0.84805 | 0.00126 | 0.85056 |
| 5cvcrpuofct11_23_15 | 23,000 | 17,722 | | 6,015 | 9.80 | 1.0E+00 | 0.85040 | 0.00128 | 0.85295 |
| 5cvcrpuofct11_22_15 | 22,000 | 16,952 | | 6,173 | 10.49 | 1.0E+00 | 0.85175 | 0.00121 | 0.85417 |
| 5cvcrpuofct11_21_15 | 21,000 | 16,181 | | 6,332 | 11.25 | 1.0E+00 | 0.85382 | 0.00131 | 0.85644 |
| 5cvcrpuofct11_20_15 | 20,000 | 15,411 | | 6,490 | 12.08 | 1.0E+00 | 0.85633 | 0.00119 | 0.85872 |
| 5cvcrpuofct11_19_15 | 19,000 | 14,640 | | 6,648 | 13.00 | 1.0E+00 | 0.85906 | 0.00171 | 0.86249 |
| 5cvcrpuofct11_18_15 | 18,000 | 13,870 | | 6,806 | 14.02 | 1.0E+00 | 0.86443 | 0.00141 | 0.86725 |
| 5cvcrpuofct11_17_15 | 17,000 | 13,099 | | 6,964 | 15.16 | 1.0E+00 | 0.86435 | 0.00148 | 0.86731 |
| 5cvcrpuofct11_16_15 | 16,000 | 12,329 | | 7,123 | 16.44 | 1.0E+00 | 0.86719 | 0.00135 | 0.86988 |
| 5cvcrpuofct11_15_15 | 15,000 | 11,558 | | 7,281 | 17.89 | 1.0E+00 | 0.87051 | 0.00155 | 0.87361 |
| 5cvcrpuofct11_14_15 | 14,000 | 10,787 | | 7,439 | 19.55 | 1.0E+00 | 0.87447 | 0.00125 | 0.87698 |
| 5cvcrpuofct11_13_15 | 13,000 | 10,017 | | 7,597 | 21.47 | 1.0E+00 | 0.87165 | 0.00112 | 0.87388 |
| 5cvcrpuofct11_12_15 | 12,000 | 9,246 | | 7,756 | 23.71 | 1.0E+00 | 0.87889 | 0.00139 | 0.88167 |
| 5cvcrpuofct11_11_15 | 11,000 | 8,476 | | 7,914 | 26.35 | 1.0E+00 | 0.87819 | 0.00144 | 0.88107 |
| 5cvcrpuofct11_10_15 | 10,000 | 7,705 | | 8,072 | 29.52 | 1.0E+00 | 0.88027 | 0.00153 | 0.88333 |
| 5cvcrpuofct11_9_15 | 9,000 | 6,935 | | 8,230 | 33.39 | 1.0E+00 | 0.88126 | 0.00141 | 0.88409 |
| **5cvcrpuofct11_8_15** | **8,000** | **6,164** | | **8,389** | **38.24** | **1.0E+00** | **0.88397** | **0.00130** | **0.88656** |
| 5cvcrpuofct11_7_15 | 7,000 | 5,394 | | 8,547 | 44.47 | 1.0E+00 | 0.87931 | 0.00143 | 0.88216 |
| 5cvcrpuofct11_6_15 | 6,000 | 4,623 | | 8,705 | 52.77 | 1.0E+00 | 0.87723 | 0.00133 | 0.87990 |
| 5cvcrpuofct11_5_15 | 5,000 | 3,852 | | 8,863 | 64.40 | 1.0E+00 | 0.87189 | 0.00128 | 0.87446 |
| 5cvcrpuofct11_4_15 | 4,000 | 3,082 | | 9,022 | 81.83 | 1.0E+00 | 0.86035 | 0.00130 | 0.86296 |
| 5cvcrpuofct11_3_15 | 3,000 | 2,311 | | 9,180 | 110.90 | 1.0E+00 | 0.84392 | 0.00129 | 0.84650 |

**Table 6.9.8.8-5b. Results for uranyl fluoride ($UO_2F_2$) and dihydrate ($UO_2F_2 \cdot 2H_2O$) in the CV or ES-3100 packaging calculation models**

| case name | $UO_2F_2$ or $UO_2F_2 \cdot 2H_2O$ (g) | $^{235}U$ (g) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | mocfr or moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| 5cvcrpuofct11_2_15 | 2,000 | 1,541 | | 9,338 | 169.02 | 1.0E+00 | 0.80710 | 0.00149 | 0.81008 |
| 5cvcrpuofct11_1_15 | 1,000 | 771 | | 9,496 | 343.36 | 1.0E+00 | 0.70780 | 0.00112 | 0.71005 |
| **$UO_2F_2 \cdot 2H_2O$ content and 500-g polyethylene, flooded containment vessel, reflected** | | | | | | | | | |
| 5cvcrpuofhct11_24_15 | 24,000 | 16,540 | 2,534 | 4,578 | 12.24 | 1.0E+00 | 0.89612 | 0.00117 | 0.89845 |
| 5cvcrpuofhct11_23_15 | 23,000 | 15,851 | 2,429 | 4,789 | 12.94 | 1.0E+00 | 0.89625 | 0.00162 | 0.89949 |
| 5cvcrpuofhct11_22_15 | 22,000 | 15,161 | 2,323 | 5,000 | 13.71 | 1.0E+00 | 0.89566 | 0.00151 | 0.89867 |
| 5cvcrpuofhct11_21_15 | 21,000 | 14,472 | 2,217 | 5,212 | 14.56 | 1.0E+00 | 0.90107 | 0.00128 | 0.90363 |
| 5cvcrpuofhct11_20_15 | 20,000 | 13,783 | 2,112 | 5,424 | 15.49 | 1.0E+00 | 0.89826 | 0.00199 | 0.90224 |
| 5cvcrpuofhct11_19_15 | 19,000 | 13,094 | 2,006 | 5,635 | 16.51 | 1.0E+00 | 0.89957 | 0.00136 | 0.90230 |
| 5cvcrpuofhct11_18_15 | 18,000 | 12,405 | 1,901 | 5,847 | 17.65 | 1.0E+00 | 0.89897 | 0.00131 | 0.90160 |
| 5cvcrpuofhct11_17_15 | 17,000 | 11,716 | 1,795 | 6,058 | 18.93 | 1.0E+00 | 0.89947 | 0.00145 | 0.90236 |
| 5cvcrpuofhct11_16_15 | 16,000 | 11,026 | 1,689 | 6,270 | 20.36 | 1.0E+00 | 0.89980 | 0.00123 | 0.90226 |
| 5cvcrpuofhct11_15_15 | 15,000 | 10,337 | 1,584 | 6,481 | 21.99 | 1.0E+00 | 0.90038 | 0.00137 | 0.90312 |
| **5cvcrpuofhct11_14_15** | **14,000** | **9,648** | **1,478** | **6,693** | **23.84** | **1.0E+00** | **0.90268** | **0.00196** | **0.90661** |
| 5cvcrpuofhct11_13_15 | 13,000 | 8,959 | 1,373 | 6,904 | 25.99 | 1.0E+00 | 0.90135 | 0.00156 | 0.90446 |
| 5cvcrpuofhct11_12_15 | 12,000 | 8,270 | 1,267 | 7,116 | 28.49 | 1.0E+00 | 0.90033 | 0.00137 | 0.90306 |
| 5cvcrpuofhct11_11_15 | 11,000 | 7,580 | 1,161 | 7,328 | 31.44 | 1.0E+00 | 0.90064 | 0.00155 | 0.90373 |
| 5cvcrpuofhct11_10_15 | 10,000 | 6,891 | 1,056 | 7,539 | 34.99 | 1.0E+00 | 0.90163 | 0.00127 | 0.90418 |
| 5cvcrpuofhct11_9_15 | 9,000 | 6,202 | 950 | 7,751 | 39.32 | 1.0E+00 | 0.90041 | 0.00143 | 0.90327 |
| 5cvcrpuofhct11_8_15 | 8,000 | 5,513 | 844 | 7,962 | 44.73 | 1.0E+00 | 0.89433 | 0.00159 | 0.89751 |
| 5cvcrpuofhct11_7_15 | 7,000 | 4,824 | 739 | 8,174 | 51.70 | 1.0E+00 | 0.89222 | 0.00163 | 0.89547 |
| 5cvcrpuofhct11_6_15 | 6,000 | 4,135 | 633 | 8,385 | 60.98 | 1.0E+00 | 0.88507 | 0.00142 | 0.88791 |
| 5cvcrpuofhct11_5_15 | 5,000 | 3,445 | 528 | 8,597 | 73.98 | 1.0E+00 | 0.87613 | 0.00179 | 0.87972 |
| 5cvcrpuofhct11_4_15 | 4,000 | 2,756 | 422 | 8,808 | 93.48 | 1.0E+00 | 0.86244 | 0.00121 | 0.86486 |

**Table 6.9.8.8-5b. Results for uranyl fluoride ($UO_2F_2$) and dihydrate ($UO_2F_2 \cdot 2H_2O$) in the CV or ES-3100 packaging calculation models**

| case name | $UO_2F_2$ or $UO_2F_2 \cdot 2H_2O$ (g) | $^{235}U$ (g) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | mocfr or moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| 5cvcrpuofhct11_3_15 | 3,000 | 2,067 | 316 | 9,020 | 125.98 | 1.0E+00 | 0.84181 | 0.00137 | 0.84456 |
| 5cvcrpuofhct11_2_15 | 2,000 | 1,378 | 211 | 9,231 | 190.97 | 1.0E+00 | 0.79635 | 0.00128 | 0.79892 |
| 5cvcrpuofhct11_1_15 | 1,000 | 689 | 105 | 9,443 | 385.88 | 1.0E+00 | 0.69241 | 0.00157 | 0.69554 |
| **$UO_2F_2 \cdot 2H_2O$ content and 500-g polyethylene, flooded containment vessel, package reflected** | | | | | | | | | |
| | | | | | | **moifr** | | | |
| 5ncsrpuofhct11_24_1 | 24,000 | 16,540 | 2,534 | 0 | 5.01 | 1.0E-20 | 0.49256 | 0.00113 | 0.49483 |
| 5ncsrpuofhct11_24_2 | 24,000 | 16,540 | 2,534 | 0 | 5.01 | 1.0E-05 | 0.49385 | 0.00104 | 0.49593 |
| 5ncsrpuofhct11_24_3 | 24,000 | 16,540 | 2,534 | 0 | 5.01 | 1.0E-04 | 0.49252 | 0.00089 | 0.49430 |
| 5ncsrpuofhct11_24_4 | 24,000 | 16,540 | 2,534 | 5 | 5.02 | 1.0E-03 | 0.49420 | 0.00095 | 0.49609 |
| 5ncsrpuofhct11_24_5 | 24,000 | 16,540 | 2,534 | 46 | 5.09 | 1.0E-02 | 0.49714 | 0.00115 | 0.49945 |
| 5ncsrpuofhct11_24_6 | 24,000 | 16,540 | 2,534 | 458 | 5.74 | 1.0E-01 | 0.52171 | 0.00098 | 0.52366 |
| 5ncsrpuofhct11_24_8 | 24,000 | 16,540 | 2,534 | 1,373 | 7.18 | 3.0E-01 | 0.58684 | 0.00114 | 0.58913 |
| 5ncsrpuofhct11_24_15 | 24,000 | 16,540 | 2,534 | 4,578 | 12.24 | 1.0E+00 | 0.78391 | 0.00172 | 0.78736 |
| 5ncsrpuofhct11_23_15 | 23,000 | 15,851 | 2,429 | 4,789 | 12.94 | 1.0E+00 | 0.78964 | 0.00172 | 0.79308 |
| 5ncsrpuofhct11_22_15 | 22,000 | 15,161 | 2,323 | 5,000 | 13.71 | 1.0E+00 | 0.78880 | 0.00124 | 0.79129 |
| 5ncsrpuofhct11_21_15 | 21,000 | 14,472 | 2,217 | 5,212 | 14.56 | 1.0E+00 | 0.78867 | 0.00131 | 0.79129 |
| 5ncsrpuofhct11_20_15 | 20,000 | 13,783 | 2,112 | 5,424 | 15.49 | 1.0E+00 | 0.78987 | 0.00144 | 0.79274 |
| 5ncsrpuofhct11_19_15 | 19,000 | 13,094 | 2,006 | 5,635 | 16.51 | 1.0E+00 | 0.78903 | 0.00171 | 0.79245 |
| 5ncsrpuofhct11_18_15 | 18,000 | 12,405 | 1,901 | 5,847 | 17.65 | 1.0E+00 | 0.79165 | 0.00153 | 0.79471 |
| 5ncsrpuofhct11_17_15 | 17,000 | 11,716 | 1,795 | 6,058 | 18.93 | 1.0E+00 | 0.79090 | 0.00142 | 0.79373 |
| 5ncsrpuofhct11_16_15 | 16,000 | 11,026 | 1,689 | 6,270 | 20.36 | 1.0E+00 | 0.79393 | 0.00145 | 0.79682 |
| 5ncsrpuofhct11_15_15 | 15,000 | 10,337 | 1,584 | 6,481 | 21.99 | 1.0E+00 | 0.79337 | 0.00139 | 0.79615 |
| 5ncsrpuofhct11_14_15 | 14,000 | 9,648 | 1,478 | 6,693 | 23.84 | 1.0E+00 | 0.79414 | 0.00172 | 0.79759 |
| 5ncsrpuofhct11_13_15 | 13,000 | 8,959 | 1,373 | 6,904 | 25.99 | 1.0E+00 | 0.79139 | 0.00126 | 0.79390 |

**Table 6.9.8.8-5b. Results for uranyl fluoride ($UO_2F_2$) and dihydrate ($UO_2F_2 \cdot 2H_2O$) in the CV or ES-3100 packaging calculation models**

| case name | $UO_2F_2$ or $UO_2F_2 \cdot 2H_2O$ (g) | $^{235}U$ (g) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | mocfr or moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| 5ncsrpuofhct11_12_15 | 12,000 | 8,270 | 1,267 | 7,116 | 28.49 | 1.0E+00 | 0.79345 | 0.00138 | 0.79622 |
| 5ncsrpuofhct11_11_15 | 11,000 | 7,580 | 1,161 | 7,328 | 31.44 | 1.0E+00 | 0.79315 | 0.00194 | 0.79702 |
| 5ncsrpuofhct11_10_15 | 10,000 | 6,891 | 1,056 | 7,539 | 34.99 | 1.0E+00 | 0.79148 | 0.00161 | 0.79470 |
| 5ncsrpuofhct11_9_15 | 9,000 | 6,202 | 950 | 7,751 | 39.32 | 1.0E+00 | 0.79130 | 0.00138 | 0.79407 |
| 5ncsrpuofhct11_8_15 | 8,000 | 5,513 | 844 | 7,962 | 44.73 | 1.0E+00 | 0.78925 | 0.00147 | 0.79219 |
| 5ncsrpuofhct11_7_15 | 7,000 | 4,824 | 739 | 8,174 | 51.70 | 1.0E+00 | 0.78731 | 0.00167 | 0.79066 |
| 5ncsrpuofhct11_6_15 | 6,000 | 4,135 | 633 | 8,385 | 60.98 | 1.0E+00 | 0.78183 | 0.00158 | 0.78500 |
| 5ncsrpuofhct11_5_15 | 5,000 | 3,445 | 528 | 8,597 | 73.98 | 1.0E+00 | 0.77586 | 0.00153 | 0.77893 |
| 5ncsrpuofhct11_4_15 | 4,000 | 2,756 | 422 | 8,808 | 93.48 | 1.0E+00 | 0.76058 | 0.00162 | 0.76382 |
| 5ncsrpuofhct11_3_15 | 3,000 | 2,067 | 316 | 9,020 | 125.98 | 1.0E+00 | 0.74131 | 0.00163 | 0.74457 |
| 5ncsrpuofhct11_2_15 | 2,000 | 1,378 | 211 | 9,231 | 190.97 | 1.0E+00 | 0.70445 | 0.00111 | 0.70667 |
| 5ncsrpuofhct11_1_15 | 1,000 | 689 | 105 | 9,443 | 385.88 | 1.0E+00 | 0.61078 | 0.00155 | 0.61388 |
| **$UO_2F_2 \cdot 2H_2O$ content, 500-g polyethylene, flooded containment vessel, infinite array of packages** | | | | | | | | | |
| 5nciapuofhct11_24_1 | 24,000 | 16,540 | 2,534 | 4578 | 12.24 | 1.0E-20 | 1.01183 | 0.00147 | 1.01477 |
| 5nciapuofhct11_24_2 | 24,000 | 16,540 | 2,534 | 4578 | 12.24 | 1.0E-05 | 1.01204 | 0.00140 | 1.01484 |
| 5nciapuofhct11_24_3 | 24,000 | 16,540 | 2,534 | 4578 | 12.24 | 1.0E-04 | 1.01068 | 0.00131 | 1.01331 |
| 5nciapuofhct11_24_4 | 24,000 | 16,540 | 2,534 | 4578 | 12.24 | 1.0E-03 | 1.01093 | 0.00141 | 1.01376 |
| 5nciapuofhct11_24_5 | 24,000 | 16,540 | 2,534 | 4578 | 12.24 | 1.0E-02 | 0.98858 | 0.00125 | 0.99109 |
| 5nciapuofhct11_24_6 | 24,000 | 16,540 | 2,534 | 4578 | 12.24 | 1.0E-01 | 0.86983 | 0.00146 | 0.87275 |
| 5nciapuofhct11_24_8 | 24,000 | 16,540 | 2,534 | 4578 | 12.24 | 3.0E-01 | 0.80292 | 0.00136 | 0.80563 |
| 5nciapuofhct11_24_15 | 24,000 | 16,540 | 2,534 | 4578 | 12.24 | 1.0E+00 | 0.80947 | 0.00166 | 0.81279 |
| | | | | | | | | | |
| 5nciapuofhct11_5_3 | 5,000 | 3,445 | 528 | 8597 | 73.98 | 1.0E-04 | 0.94605 | 0.00142 | 0.94889 |
| 5nciapuofhct11_4_3 | 4,000 | 2,756 | 422 | 8808 | 93.48 | 1.0E-04 | 0.92472 | 0.00122 | 0.92717 |

**Table 6.9.8.8-5b. Results for uranyl fluoride ($UO_2F_2$) and dihydrate ($UO_2F_2 \cdot 2H_2O$) in the CV or ES-3100 packaging calculation models**

| case name | $UO_2F_2$ or $UO_2F_2 \cdot 2H_2O$ (g) | $^{235}U$ (g) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | mocfr or moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| **5nciapuofhct11_3_3** | **3,000** | **2,067** | **316** | **9020** | **125.98** | **1.0E-04** | **0.89532** | **0.00125** | **0.89782** |
| 5nciapuofhct11_2_3 | 2,000 | 1,378 | 211 | 9231 | 190.97 | 1.0E-04 | 0.84144 | 0.00123 | 0.84391 |
| 5nciapuofhct11_1_3 | 1,000 | 689 | 105 | 9443 | 385.88 | 1.0E-04 | 0.71661 | 0.00117 | 0.71896 |

**Table 6.9.8.8-6a. Results for uranium carbide compounds in the CV or ES-3100 packaging calculation models**

| case name | $UC_x$ (g) | $^{235}U$ (g) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | mocfr or moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| **UC content and 500 g polyethylene, flooded containment vessel, reflected** | | | | | | | | | |
| | | | | | | **mocfr** | | | |
| 5cvcrpuct11_1_10 | 10,000 | 9,514 | 4,259 | 4,663 | 26.24 | 1.0E+00 | 0.91168 | 0.00161 | 0.91491 |
| 5cvcrpuct11_1_9 | 9,000 | 8,563 | 3,833 | 5,163 | 29.38 | 1.0E+00 | 0.90134 | 0.00158 | 0.90450 |
| 5cvcrpuct11_1_8 | 8,000 | 7,612 | 3,407 | 5,662 | 33.30 | 1.0E+00 | 0.89789 | 0.00126 | 0.90041 |
| 5cvcrpuct11_1_7 | 7,000 | 6,660 | 2,981 | 6,161 | 38.34 | 1.0E+00 | 0.88176 | 0.00129 | 0.88435 |
| 5cvcrpuct11_1_6 | 6,000 | 5,709 | 2,555 | 6,660 | 45.07 | 1.0E+00 | 0.86805 | 0.00174 | 0.87154 |
| 5cvcrpuct11_1_5 | 5,000 | 4,757 | 2,129 | 7,159 | 54.49 | 1.0E+00 | 0.84990 | 0.00147 | 0.85284 |
| 5cvcrpuct11_1_4 | 4,000 | 3,806 | 1,704 | 7,658 | 68.61 | 1.0E+00 | 0.82598 | 0.00192 | 0.82982 |
| 5cvcrpuct11_1_3 | 3,000 | 2,854 | 1,278 | 8,157 | 92.15 | 1.0E+00 | 0.78650 | 0.00210 | 0.79070 |
| 5cvcrpuct11_1_2 | 2,000 | 1,903 | 852 | 8,656 | 139.22 | 1.0E+00 | 0.73220 | 0.00137 | 0.73494 |
| 5cvcrpuct11_1_1 | 1,000 | 952 | 426 | 9,155 | 280.42 | 1.0E+00 | 0.64502 | 0.00133 | 0.64769 |
| **$U_2C_3$ content and 500 g polyethylene, flooded containment vessel, reflected** | | | | | | | | | |
| 5cvcrpuct11_2_10 | 10,000 | 9,289 | 4,205 | 4,663 | 26.73 | 1.0E+00 | 0.90748 | 0.00130 | 0.91008 |
| 5cvcrpuct11_2_9 | 9,000 | 8,360 | 3,784 | 5,163 | 29.94 | 1.0E+00 | 0.89950 | 0.00134 | 0.90218 |
| 5cvcrpuct11_2_8 | 8,000 | 7,431 | 3,364 | 5,662 | 33.96 | 1.0E+00 | 0.89139 | 0.00134 | 0.89408 |
| 5cvcrpuct11_2_7 | 7,000 | 6,502 | 2,944 | 6,161 | 39.12 | 1.0E+00 | 0.87929 | 0.00146 | 0.88220 |
| 5cvcrpuct11_2_6 | 6,000 | 5,573 | 2,523 | 6,660 | 46.02 | 1.0E+00 | 0.86494 | 0.00134 | 0.86763 |
| 5cvcrpuct11_2_5 | 5,000 | 4,644 | 2,102 | 7,159 | 55.66 | 1.0E+00 | 0.84909 | 0.00165 | 0.85239 |
| 5cvcrpuct11_2_4 | 4,000 | 3,716 | 1,682 | 7,658 | 70.12 | 1.0E+00 | 0.81915 | 0.00155 | 0.82225 |
| 5cvcrpuct11_2_3 | 3,000 | 2,787 | 1,262 | 8,157 | 94.24 | 1.0E+00 | 0.78499 | 0.00137 | 0.78773 |
| 5cvcrpuct11_2_2 | 2,000 | 1,858 | 841 | 8,656 | 142.46 | 1.0E+00 | 0.72911 | 0.00158 | 0.73227 |
| 5cvcrpuct11_2_1 | 1,000 | 929 | 421 | 9,155 | 287.08 | 1.0E+00 | 0.64063 | 0.00142 | 0.64347 |

**Table 6.9.8.8-6a. Results for uranium carbide compounds in the CV or ES-3100 packaging calculation models**

| case name | $UC_x$ (g) | $^{235}U$ (g) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | mocfr or moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| **$UC_2$ content and 500 g polyethylene, flooded containment vessel, reflected** | | | | | | | | | |
| 5cvcrpuct11_3_10 | 10,000 | 9,074 | 4,108 | 4,663 | 27.08 | 1.0E+00 | 0.89850 | 0.00141 | 0.90132 |
| 5cvcrpuct11_3_9 | 9,000 | 8,166 | 3,697 | 5,163 | 30.37 | 1.0E+00 | 0.88960 | 0.00148 | 0.89255 |
| 5cvcrpuct11_3_8 | 8,000 | 7,259 | 3,286 | 5,662 | 34.48 | 1.0E+00 | 0.88297 | 0.00163 | 0.88623 |
| 5cvcrpuct11_3_7 | 7,000 | 6,352 | 2,875 | 6,161 | 39.77 | 1.0E+00 | 0.87224 | 0.00126 | 0.87476 |
| 5cvcrpuct11_3_6 | 6,000 | 5,444 | 2,465 | 6,660 | 46.83 | 1.0E+00 | 0.85667 | 0.00180 | 0.86028 |
| 5cvcrpuct11_3_5 | 5,000 | 4,537 | 2,054 | 7,159 | 56.70 | 1.0E+00 | 0.83768 | 0.00164 | 0.84095 |
| 5cvcrpuct11_3_4 | 4,000 | 3,630 | 1,643 | 7,658 | 71.51 | 1.0E+00 | 0.81450 | 0.00137 | 0.81724 |
| 5cvcrpuct11_3_3 | 3,000 | 2,722 | 1,232 | 8,157 | 96.19 | 1.0E+00 | 0.77746 | 0.00141 | 0.78028 |
| 5cvcrpuct11_3_2 | 2,000 | 1,815 | 822 | 8,656 | 145.55 | 1.0E+00 | 0.72120 | 0.00129 | 0.72377 |
| 5cvcrpuct11_3_1 | 1,000 | 908 | 411 | 9,155 | 293.60 | 1.0E+00 | 0.63468 | 0.00121 | 0.63711 |
| **UC content with 500 g polyethylene, flooded containment vessel, flooded package, reflected** | | | | | | | | | |
| | | | | | | **mocfr** | | | |
| 5ncsrpuct11_1_10_15 | 10,000 | 9,514 | 4,259 | 4,663 | 26.24 | 1.0E+00 | 0.81163 | 0.00116 | 0.81395 |
| 5ncsrpuct11_1_9_15 | 9,000 | 8,563 | 3,833 | 5,163 | 29.38 | 1.0E+00 | 0.80769 | 0.00145 | 0.81060 |
| 5ncsrpuct11_1_8_15 | 8,000 | 7,612 | 3,407 | 5,662 | 33.30 | 1.0E+00 | 0.79915 | 0.00170 | 0.80254 |
| 5ncsrpuct11_1_7_15 | 7,000 | 6,660 | 2,981 | 6,161 | 38.34 | 1.0E+00 | 0.78922 | 0.00142 | 0.79207 |
| 5ncsrpuct11_1_6_15 | 6,000 | 5,709 | 2,555 | 6,660 | 45.07 | 1.0E+00 | 0.77601 | 0.00157 | 0.77915 |
| 5ncsrpuct11_1_5_15 | 5,000 | 4,757 | 2,129 | 7,159 | 54.49 | 1.0E+00 | 0.75825 | 0.00153 | 0.76130 |
| 5ncsrpuct11_1_4_15 | 4,000 | 3,806 | 1,704 | 7,658 | 68.61 | 1.0E+00 | 0.73808 | 0.00130 | 0.74068 |
| 5ncsrpuct11_1_3_15 | 3,000 | 2,854 | 1,278 | 8,157 | 92.15 | 1.0E+00 | 0.70280 | 0.00142 | 0.70564 |

**Table 6.9.8.8-6a. Results for uranium carbide compounds in the CV or ES-3100 packaging calculation models**

| case name | $UC_x$ (g) | $^{235}U$ (g) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | mocfr or moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | moifr | | | |
| 5ncsrpuct11_1_2_15 | 2,000 | 1,903 | 852 | 8,656 | 139.22 | 1.0E+00 | 0.65451 | 0.00136 | 0.65724 |
| 5ncsrpuct11_1_2_8 | 2,000 | 1,903 | 852 | 2,597 | 56.11 | 3.0E-01 | 0.62741 | 0.00153 | 0.63046 |
| 5ncsrpuct11_1_2_6 | 2,000 | 1,903 | 852 | 866 | 32.37 | 1.0E-01 | 0.61746 | 0.00123 | 0.61991 |
| 5ncsrpuct11_1_2_5 | 2,000 | 1,903 | 852 | 87 | 21.68 | 1.0E-02 | 0.61244 | 0.00119 | 0.61482 |
| 5ncsrpuct11_1_2_4 | 2,000 | 1,903 | 852 | 9 | 20.61 | 1.0E-03 | 0.61168 | 0.00122 | 0.61413 |
| 5ncsrpuct11_1_2_3 | 2,000 | 1,903 | 852 | 1 | 20.51 | 1.0E-04 | 0.61271 | 0.00127 | 0.61524 |
| 5ncsrpuct11_1_2_2 | 2,000 | 1,903 | 852 | 0 | 20.50 | 1.0E-05 | 0.61238 | 0.00127 | 0.61493 |
| 5ncsrpuct11_1_2_1 | 2,000 | 1,903 | 852 | 0 | 20.50 | 1.0E-20 | 0.61350 | 0.00158 | 0.61667 |
| 5ncsrpuct11_1_1_15 | 1,000 | 952 | 426 | 9,155 | 280.42 | 1.0E+00 | 0.57240 | 0.00136 | 0.57511 |
| **$U_2C_3$ content with 500 g polyethylene, flooded containment vessel, flooded package, reflected** | | | | | | | | | |
| | | | | | | moifr | | | |
| 5ncsrpuct11_2_10_15 | 10,000 | 9,289 | 4,205 | 4,663 | 26.73 | 1.0E+00 | 0.80860 | 0.00134 | 0.81128 |
| 5ncsrpuct11_2_9_15 | 9,000 | 8,360 | 3,785 | 5,163 | 29.94 | 1.0E+00 | 0.80156 | 0.00146 | 0.80447 |
| 5ncsrpuct11_2_8_15 | 8,000 | 7,431 | 3,364 | 5,662 | 33.96 | 1.0E+00 | 0.79658 | 0.00136 | 0.79931 |
| 5ncsrpuct11_2_7_15 | 7,000 | 6,502 | 2,944 | 6,161 | 39.12 | 1.0E+00 | 0.78449 | 0.00152 | 0.78753 |
| 5ncsrpuct11_2_6_15 | 6,000 | 5,573 | 2,523 | 6,660 | 46.02 | 1.0E+00 | 0.77423 | 0.00147 | 0.77717 |
| 5ncsrpuct11_2_5_15 | 5,000 | 4,644 | 2,103 | 7,159 | 55.66 | 1.0E+00 | 0.75640 | 0.00143 | 0.75925 |
| 5ncsrpuct11_2_4_15 | 4,000 | 3,716 | 1,682 | 7,658 | 70.12 | 1.0E+00 | 0.73260 | 0.00131 | 0.73522 |
| 5ncsrpuct11_2_3_15 | 3,000 | 2,787 | 1,262 | 8,157 | 94.24 | 1.0E+00 | 0.70111 | 0.00164 | 0.70438 |
| 5ncsrpuct11_2_2_15 | 2,000 | 1,858 | 841 | 8,656 | 142.46 | 1.0E+00 | 0.65046 | 0.00117 | 0.65280 |
| 5ncsrpuct11_2_1_15 | 1,000 | 929 | 421 | 9,155 | 287.08 | 1.0E+00 | 0.57215 | 0.00122 | 0.57458 |

**Table 6.9.8.8-6a. Results for uranium carbide compounds in the CV or ES-3100 packaging calculation models**

| case name | $UC_x$ (g) | $^{235}U$ (g) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | mocfr or moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| **$UC_2$ content with 500 g polyethylene, flooded containment vessel, flooded package, reflected** | | | | | | | | | |
| | | | | | | **moifr** | | | |
| 5ncsrpuct11_3_10_15 | 10,000 | 9,074 | 4,108 | 4,663 | 27.08 | 1.0E+00 | 0.79965 | 0.00134 | 0.80232 |
| 5ncsrpuct11_3_9_15 | 9,000 | 8,166 | 3,697 | 5,163 | 30.37 | 1.0E+00 | 0.79317 | 0.00125 | 0.79568 |
| 5ncsrpuct11_3_8_15 | 8,000 | 7,259 | 3,286 | 5,662 | 34.48 | 1.0E+00 | 0.78608 | 0.00155 | 0.78918 |
| 5ncsrpuct11_3_7_15 | 7,000 | 6,352 | 2,875 | 6,161 | 39.77 | 1.0E+00 | 0.77715 | 0.00129 | 0.77973 |
| 5ncsrpuct11_3_6_15 | 6,000 | 5,444 | 2,465 | 6,660 | 46.83 | 1.0E+00 | 0.76221 | 0.00128 | 0.76476 |
| 5ncsrpuct11_3_5_15 | 5,000 | 4,537 | 2,054 | 7,159 | 56.70 | 1.0E+00 | 0.74673 | 0.00139 | 0.74950 |
| 5ncsrpuct11_3_4_15 | 4,000 | 3,630 | 1,643 | 7,658 | 71.51 | 1.0E+00 | 0.72415 | 0.00126 | 0.72666 |
| 5ncsrpuct11_3_3_15 | 3,000 | 2,722 | 1,232 | 8,157 | 96.19 | 1.0E+00 | 0.69399 | 0.00134 | 0.69666 |
| 5ncsrpuct11_3_2_15 | 2,000 | 1,815 | 822 | 8,656 | 145.55 | 1.0E+00 | 0.64590 | 0.00152 | 0.64895 |
| 5ncsrpuct11_3_1_15 | 1,000 | 908 | 411 | 9,155 | 293.60 | 1.0E+00 | 0.56666 | 0.00165 | 0.56995 |
| **UC content, 500 g poly, flooded containment vessel, infinite array of packages** | | | | | | | | | |
| | | | | | | **moifr** | | | |
| 5nciapuct11_1_9_3 | 9,000 | 8,563 | 3,833 | 5,163 | 29.38 | 1.0E-04 | 0.90795 | 0.00136 | 0.91066 |
| 5nciapuct11_1_8_3 | 8,000 | 7,612 | 3,407 | 5,662 | 33.30 | 1.0E-04 | 0.89136 | 0.00139 | 0.89414 |
| 5nciapuct11_1_7_3 | 7,000 | 6,660 | 2,981 | 6,161 | 38.34 | 1.0E-04 | 0.87019 | 0.00131 | 0.87281 |
| 5nciapuct11_1_6_3 | 6,000 | 5,709 | 2,555 | 6,660 | 45.07 | 1.0E-04 | 0.84331 | 0.00140 | 0.84610 |
| 5nciapuct11_1_5_3 | 5,000 | 4,757 | 2,129 | 7,159 | 54.49 | 1.0E-04 | 0.81542 | 0.00127 | 0.81796 |
| 5nciapuct11_1_4_3 | 4,000 | 3,806 | 1,704 | 7,658 | 68.61 | 1.0E-04 | 0.78005 | 0.00139 | 0.78283 |
| 5nciapuct11_1_3_3 | 3,000 | 2,854 | 1,278 | 8,157 | 92.15 | 1.0E-04 | 0.73291 | 0.00130 | 0.73550 |

**Table 6.9.8.8-6a. Results for uranium carbide compounds in the CV or ES-3100 packaging calculation models**

| case name | $UC_x$ (g) | $^{235}U$ (g) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | mocfr or moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| 5nciaputt11_1_2_3 | 2,000 | 1,903 | 852 | 8,656 | 139.22 | 1.0E-04 | 0.67136 | 0.00129 | 0.67394 |
| 5nciaputt11_1_1_3 | 1,000 | 952 | 426 | 9,155 | 280.42 | 1.0E-04 | 0.57485 | 0.00114 | 0.57712 |

| case name | $UC_x$ (g) | $^{235}U$ (g) | CV $H_2O$ (g) | h/x | mocfr or moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|
| **UC content, 500 g poly, dispersed in flooded containment vessel, infinite array of packages** | | | | | | | | |
| 5nciadputt11_1_9_15_3 | 9,000 | 8,563 | 8,995 | 29.38 | 1.0E-04 | 1.02430 | 0.00136 | 1.02702 |
| 5nciadputt11_1_8_15_3 | 8,000 | 7,612 | 9,069 | 33.30 | 1.0E-04 | 1.01560 | 0.00151 | 1.01862 |
| 5nciadputt11_1_7_15_3 | 7,000 | 6,660 | 9,142 | 38.34 | 1.0E-04 | 1.00614 | 0.00147 | 1.00907 |
| 5nciadputt11_1_6_15_3 | 6,000 | 5,709 | 9,215 | 45.07 | 1.0E-04 | 0.99808 | 0.00135 | 1.00078 |
| 5nciadputt11_1_5_15_3 | 5,000 | 4,757 | 9,288 | 54.49 | 1.0E-04 | 0.98482 | 0.00115 | 0.98712 |
| 5nciadputt11_1_4_15_3 | 4,000 | 3,806 | 9,362 | 68.61 | 1.0E-04 | 0.96658 | 0.00121 | 0.96899 |
| 5nciadputt11_1_3_15_3 | 3,000 | 2,854 | 9,435 | 92.15 | 1.0E-04 | 0.94085 | 0.00131 | 0.94347 |
| **5nciadputt11_1_2_15_3** | **2,000** | **1,903** | **9,508** | **139.22** | **1.0E-04** | **0.89104** | **0.00175** | **0.89453** |
| 5nciadputt11_1_1_15_3 | 1,000 | 952 | 9,581 | 280.42 | 1.0E-04 | 0.78231 | 0.00129 | 0.78488 |

**Table 6.9.8.8-6b. Results for uranium nitride in the CV or ES-3100 packaging calculation models**

| case name | UN (g) | $^{235}U$ (g) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | mocfr or moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| **UN content and 500 g polyethylene, flooded containment vessel, reflected** | | | | | | | | | |
| | | | | | | **mocfr** | | | |
| 5cvcrpunt11_10 | 10,000 | 9,438 | 4,294 | 4,663 | 26.55 | 1.0E+00 | 0.90649 | 0.00145 | 0.90939 |
| 5cvcrpunt11_9 | 9,000 | 8,494 | 3,864 | 5,163 | 29.71 | 1.0E+00 | 0.90302 | 0.00131 | 0.90563 |
| 5cvcrpunt11_8 | 8,000 | 7,550 | 3,435 | 5,662 | 33.67 | 1.0E+00 | 0.89305 | 0.00115 | 0.89534 |
| 5cvcrpunt11_7 | 7,000 | 6,607 | 3,006 | 6,161 | 38.75 | 1.0E+00 | 0.88246 | 0.00212 | 0.88671 |
| 5cvcrpunt11_6 | 6,000 | 5,663 | 2,576 | 6,660 | 45.53 | 1.0E+00 | 0.86740 | 0.00137 | 0.87014 |
| 5cvcrpunt11_5 | 5,000 | 4,719 | 2,147 | 7,159 | 55.03 | 1.0E+00 | 0.84695 | 0.00158 | 0.85011 |
| 5cvcrpunt11_4 | 4,000 | 3,775 | 1,718 | 7,658 | 69.26 | 1.0E+00 | 0.82223 | 0.00148 | 0.82518 |
| 5cvcrpunt11_3 | 3,000 | 2,831 | 1,288 | 8,157 | 93.00 | 1.0E+00 | 0.78572 | 0.00124 | 0.78819 |
| 5cvcrpunt11_2 | 2,000 | 1,888 | 859 | 8,656 | 140.45 | 1.0E+00 | 0.73107 | 0.00156 | 0.73418 |
| 5cvcrpunt11_1 | 1,000 | 944 | 430 | 9,155 | 282.79 | 1.0E+00 | 0.64271 | 0.00170 | 0.64611 |
| **UN content with 500 g polyethylene, flooded containment vessel, flooded package, reflected** | | | | | | | | | |
| | | | | | | **moifr** | | | |
| 5ncsrpunt11_10_1 | 10,000 | 9,438 | 4,294 | 0.00 | 13.65 | 1.0E-20 | 0.80847 | 0.00142 | 0.81131 |
| 5ncsrpunt11_10_2 | 10,000 | 9,438 | 4,294 | 0.00 | 13.65 | 1.0E-05 | 0.80937 | 0.00123 | 0.81184 |
| 5ncsrpunt11_10_3 | 10,000 | 9,438 | 4,294 | 0.50 | 13.65 | 1.0E-04 | 0.80771 | 0.00139 | 0.81048 |
| 5ncsrpunt11_10_4 | 10,000 | 9,438 | 4,294 | 4.70 | 13.67 | 1.0E-03 | 0.80868 | 0.00145 | 0.81158 |
| 5ncsrpunt11_10_5 | 10,000 | 9,438 | 4,294 | 46.60 | 13.78 | 1.0E-02 | 0.80964 | 0.00140 | 0.81243 |
| 5ncsrpunt11_10_6 | 10,000 | 9,438 | 4,294 | 466 | 14.94 | 1.0E-01 | 0.80771 | 0.00167 | 0.81105 |
| 5ncsrpunt11_10_8 | 10,000 | 9,438 | 4,294 | 1,399 | 17.52 | 3.0E-01 | 0.81176 | 0.00165 | 0.81506 |
| 5ncsrpunt11_10_15 | 10,000 | 9,438 | 4,294 | 4,663 | 26.55 | 1.0E+00 | 0.81120 | 0.00138 | 0.81395 |
| 5ncsrpunt11_9_15 | 9,000 | 8,494 | 3,864 | 5,163 | 29.71 | 1.0E+00 | 0.80784 | 0.00147 | 0.81079 |
| 5ncsrpunt11_8_15 | 8,000 | 7,550 | 3,435 | 5,662 | 33.67 | 1.0E+00 | 0.79743 | 0.00124 | 0.79990 |

**Table 6.9.8.8-6b. Results for uranium nitride in the CV or ES-3100 packaging calculation models**

| case name | UN (g) | $^{235}U$ (g) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | mocfr or moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| 5ncsrpunt11_7_15 | 7,000 | 6,607 | 3,006 | 6,161 | 38.75 | 1.0E+00 | 0.78734 | 0.00139 | 0.79012 |
| 5ncsrpunt11_6_15 | 6,000 | 5,663 | 2,576 | 6,660 | 45.53 | 1.0E+00 | 0.77284 | 0.00207 | 0.77698 |
| 5ncsrpunt11_5_15 | 5,000 | 4,719 | 2,147 | 7,159 | 55.03 | 1.0E+00 | 0.76092 | 0.00146 | 0.76383 |
| 5ncsrpunt11_4_15 | 4,000 | 3,775 | 1,718 | 7,658 | 69.26 | 1.0E+00 | 0.73456 | 0.00132 | 0.73719 |
| 5ncsrpunt11_3_15 | 3,000 | 2,831 | 1,288 | 8,157 | 93.00 | 1.0E+00 | 0.70343 | 0.00120 | 0.70583 |
| 5ncsrpunt11_2_15 | 2,000 | 1,888 | 859 | 8,656 | 140.45 | 1.0E+00 | 0.65433 | 0.00136 | 0.65706 |
| 5ncsrpunt11_2_8 | 2,000 | 1,888 | 859 | 2,597 | 56.67 | 3.0E-01 | 0.62697 | 0.00121 | 0.62939 |
| 5ncsrpunt11_2_6 | 2,000 | 1,888 | 859 | 866 | 32.73 | 1.0E-01 | 0.61816 | 0.00117 | 0.62050 |
| 5ncsrpunt11_2_5 | 2,000 | 1,888 | 859 | 86.60 | 21.96 | 1.0E-02 | 0.61304 | 0.00124 | 0.61553 |
| 5ncsrpunt11_2_4 | 2,000 | 1,888 | 859 | 8.70 | 20.88 | 1.0E-03 | 0.61327 | 0.00134 | 0.61594 |
| 5ncsrpunt11_2_3 | 2,000 | 1,888 | 859 | 0.90 | 20.77 | 1.0E-04 | 0.61276 | 0.00152 | 0.61581 |
| 5ncsrpunt11_2_2 | 2,000 | 1,888 | 859 | 0.10 | 20.76 | 1.0E-05 | 0.61295 | 0.00136 | 0.61568 |
| 5ncsrpunt11_2_1 | 2,000 | 1,888 | 859 | 0.00 | 20.76 | 1.0E-20 | 0.61292 | 0.00107 | 0.61505 |
| 5ncsrpunt11_1_15 | 1,000 | 944 | 430 | 9,155 | 282.79 | 1.0E+00 | 0.57154 | 0.00116 | 0.57387 |
| **UN content, 500 g poly, flooded containment vessel, infinite array of packages** | | | | | | | | | |
| | | | | | | **moifr** | | | |
| 5nciapunt11_10_3 | 10,000 | 9,438 | 4,294 | 4,663 | 26.55 | 1.0E-04 | 0.92423 | 0.00151 | 0.92725 |
| 5nciapunt11_9_3 | 9,000 | 8,494 | 3,864 | 5,163 | 29.71 | 1.0E-04 | 0.90687 | 0.00131 | 0.90950 |
| 5nciapunt11_8_3 | 8,000 | 7,550 | 3,435 | 5,662 | 33.67 | 1.0E-04 | 0.88819 | 0.00172 | 0.89163 |
| 5nciapunt11_7_3 | 7,000 | 6,607 | 3,006 | 6,161 | 38.75 | 1.0E-04 | 0.86369 | 0.00147 | 0.86662 |
| 5nciapunt11_6_3 | 6,000 | 5,663 | 2,576 | 6,660 | 45.53 | 1.0E-04 | 0.84576 | 0.00143 | 0.84862 |
| 5nciapunt11_5_3 | 5,000 | 4,719 | 2,147 | 7,159 | 55.03 | 1.0E-04 | 0.81575 | 0.00130 | 0.81835 |
| 5nciapunt11_4_3 | 4,000 | 3,775 | 1,718 | 7,658 | 69.26 | 1.0E-04 | 0.77916 | 0.00132 | 0.78181 |
| 5nciapunt11_3_3 | 3,000 | 2,831 | 1,288 | 8,157 | 93.00 | 1.0E-04 | 0.73422 | 0.00140 | 0.73702 |

**Table 6.9.8.8-6b. Results for uranium nitride in the CV or ES-3100 packaging calculation models**

| case name | UN (g) | $^{235}U$ (g) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | mocfr or moifr | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| 5nciapunt11_2_3 | 2,000 | 1,888 | 859 | 8,656 | 140.45 | 1.0E-04 | 0.67190 | 0.00129 | 0.67448 |
| 5nciapunt11_1_3 | 1,000 | 944 | 430 | 9,155 | 282.79 | 1.0E-04 | 0.57515 | 0.00132 | 0.57778 |
| **case name** | **UN (g)** | **$^{235}U$ (g)** | | **CV $H_2O$ (g)** | **h/x** | **moifr** | **$k_{eff}$** | **σ** | **$k_{eff}+2\sigma$** |
| **UN and 500 g poly dispersed inside flooded containment vessel, infinite array of packages** | | | | | | | | | |
| | | | | | | **moifr** | | | |
| 5nciadpunt11_10_15_3 | 10,000 | 9,438 | | 8,957 | 26.55 | 1.0E+00 | 1.02413 | 0.00140 | 1.02692 |
| 5nciadpunt11_9_15_3 | 9,000 | 8,494 | | 9,027 | 29.71 | 1.0E+00 | 1.01877 | 0.00156 | 1.02190 |
| 5nciadpunt11_8_15_3 | 8,000 | 7,550 | | 9,097 | 33.67 | 1.0E+00 | 1.01312 | 0.00134 | 1.01581 |
| 5nciadpunt11_7_15_3 | 7,000 | 6,607 | | 9,166 | 38.75 | 1.0E+00 | 1.00582 | 0.00149 | 1.00879 |
| 5nciadpunt11_6_15_3 | 6,000 | 5,663 | | 9,236 | 45.53 | 1.0E+00 | 0.99488 | 0.00139 | 0.99766 |
| 5nciadpunt11_5_15_3 | 5,000 | 4,719 | | 9,306 | 55.03 | 1.0E+00 | 0.98037 | 0.00152 | 0.98341 |
| 5nciadpunt11_4_15_3 | 4,000 | 3,775 | | 9,376 | 69.26 | 1.0E+00 | 0.96456 | 0.00166 | 0.96787 |
| 5nciadpunt11_3_15_3 | 3,000 | 2,831 | | 9,445 | 93.00 | 1.0E+00 | 0.93621 | 0.00125 | 0.93872 |
| **5nciadpunt11_2_15_3** | **2,000** | **1,888** | | **9,515** | **140.45** | **1.0E+00** | **0.88902** | **0.00129** | **0.89159** |
| 5nciadpunt11_1_15_3 | 1,000 | 944 | | 9,585 | 282.79 | 1.0E+00 | 0.77903 | 0.00149 | 0.78200 |

**Table 6.9.8.8-7a. Results for uranium silicide in the CV calculation models**

| case name (5cvcrpdusit11) | $U_3Si_2$ (g) | $^{235}U$ (g) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | variable | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name (5cvcrdpust11) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **13 kg sat. $U_3Si_2$ and 500 g poly in flooded CV, density from 7 to 2 g/cm$^3$** | | | | | | | | | | **Content dispersed in flooded CV** | | | |
| _8_7_13_15 | 13,000 | 12,041 | 856 | 7,801 | 20.16 | 7 | 0.84659 | 0.00129 | 0.84917 | _8_7_13_15 | 0.92539 | 0.00156 | 0.92852 |
| _8_6_13_15 | 13,000 | 12,041 | 1,165 | 7,492 | 20.16 | 6 | 0.85534 | 0.00136 | 0.85806 | _8_6_13_15 | 0.92539 | 0.00156 | 0.92852 |
| _8_5_13_15 | 13,000 | 12,041 | 1,597 | 7,059 | 20.16 | 5 | 0.86758 | 0.00115 | 0.86987 | _8_5_13_15 | 0.92539 | 0.00156 | 0.92852 |
| _8_4_13_15 | 13,000 | 12,041 | 2,246 | 6,410 | 20.16 | 4 | 0.88301 | 0.00147 | 0.88595 | _8_4_13_15 | 0.92539 | 0.00156 | 0.92852 |
| _8_3_13_15 | 13,000 | 12,041 | 3,327 | 5,329 | 20.16 | 3 | 0.89897 | 0.00133 | 0.90163 | _8_3_13_15 | 0.92539 | 0.00156 | 0.92852 |
| _8_2_13_15 | 13,000 | 12,041 | 5,490 | 3,166 | 20.16 | 2 | 0.91671 | 0.00154 | 0.91978 | _8_2_13_15 | 0.92539 | 0.00156 | 0.92852 |
| **From 13 to 7 kg sat. $U_3Si_2$ at 7 g/cm$^3$ and 500 g poly in flooded CV** | | | | | | | | | | **Content dispersed in flooded CV** | | | |
| _8_7_13_15 | 13,000 | 12,041 | 856 | 7,801 | 20.16 | - | 0.84659 | 0.00129 | 0.84917 | _8_7_13_15 | 0.92539 | 0.00156 | 0.92852 |
| | 12,000 | 11,115 | 790 | 7,943 | 22.02 | | | | | _8_7_12_15 | 0.92346 | 0.00136 | 0.92619 |
| | 11,000 | 10,189 | 724 | 8,086 | 24.22 | | | | | _8_7_11_15 | 0.92254 | 0.00144 | 0.92542 |
| | 10,000 | 9,262 | 658 | 8,228 | 26.85 | | | | | _8_7_10_15 | 0.92257 | 0.00141 | 0.92539 |
| | 9,000 | 8,336 | 592 | 8,371 | 30.08 | | | | | _8_7_9_15 | 0.91555 | 0.00187 | 0.91929 |
| | 8,000 | 7,410 | 527 | 8,514 | 34.11 | | | | | _8_7_8_15 | 0.91645 | 0.00169 | 0.91984 |
| | 7,000 | 6,484 | 461 | 8,656 | 39.29 | | | | | _8_7_7_15 | 0.91284 | 0.00124 | 0.91532 |
| **13 kg sat. $U_3Si_2$ at 7 g/cm$^3$ and 500 g poly in flooded CV, enrichment from 100 to 19.7 wt % $^{235}U$** | | | | | | | | | | **Content dispersed in flooded CV** | | | |
| _8_7_13_15 | 13,000 | 12,041 | 856 | 7,801 | 20.16 | 100 | 0.84659 | 0.00129 | 0.84917 | _8_7_13_15 | 0.92539 | 0.00156 | 0.92852 |
| _7_7_13_15 | 13,000 | 11,440 | 856 | 7,801 | 21.22 | 95 | 0.83163 | 0.00132 | 0.83427 | _7_7_13_15 | 0.91534 | 0.00129 | 0.91791 |
| _6_7_13_15 | 13,000 | 10,838 | 856 | 7,801 | 22.39 | 90 | 0.81948 | 0.00126 | 0.82200 | _6_7_13_15 | 0.90311 | 0.00132 | 0.90574 |
| _5_7_13_15 | 13,000 | 9,635 | 856 | 7,801 | 25.19 | 80 | 0.79868 | 0.00135 | 0.80139 | _5_7_13_15 | 0.88874 | 0.00134 | 0.89142 |
| _4_7_13_15 | 13,000 | 8,431 | 856 | 7,801 | 28.79 | 70 | 0.77451 | 0.00126 | 0.77702 | _4_7_13_15 | 0.87598 | 0.00127 | 0.87853 |
| _3_7_13_15 | 13,000 | 7,227 | 856 | 7,801 | 33.58 | 60 | 0.75204 | 0.00113 | 0.75431 | _3_7_13_15 | 0.86402 | 0.00155 | 0.86712 |
| _2_7_13_15 | 13,000 | 4,819 | 856 | 7,801 | 50.36 | 40 | 0.69967 | 0.00122 | 0.70211 | _2_7_13_15 | 0.82956 | 0.00140 | 0.83237 |
| _1_7_13_15 | 13,000 | 2,290 | 856 | 7,801 | 106.01 | 19.7 | 0.62192 | 0.00116 | 0.62424 | _1_7_13_15 | 0.76076 | 0.00137 | 0.76349 |

**Table 6.9.8.8-7a. Results for uranium silicide in the CV calculation models**

| case name (5cvcrpdusit11) | $U_3Si_2$ (g) | $^{235}U$ (g) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | variable | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name (5cvcrdpust11) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **7 kg sat. $U_3Si_2$ at 7 g/cm$^3$ and 500 g poly in flooded CV, enrichment from 100 to 19.7 wt % $^{235}U$** | | | | | | | | | | **Content dispersed in flooded CV** | | | |
| | 7,000 | 6,484 | 461 | 8,656 | 39.29 | 100 | | | | _8_7_7_15 | 0.91284 | 0.00124 | 0.91532 |
| | 7,000 | 6,160 | 461 | 8,656 | 41.35 | 95 | | | | _7_7_7_15 | 0.90261 | 0.00143 | 0.90547 |
| | 7,000 | 5,836 | 461 | 8,656 | 43.65 | 90 | | | | _6_7_7_15 | 0.89613 | 0.00137 | 0.89886 |
| | 7,000 | 5,188 | 461 | 8,656 | 49.10 | 80 | | | | _5_7_7_15 | 0.87984 | 0.00178 | 0.88339 |
| | 7,000 | 4,540 | 461 | 8,656 | 56.11 | 70 | | | | _4_7_7_15 | 0.86767 | 0.00166 | 0.87099 |
| | 7,000 | 3,892 | 461 | 8,656 | 65.46 | 60 | | | | _3_7_7_15 | 0.85292 | 0.00168 | 0.85627 |
| | 7,000 | 2,595 | 461 | 8,656 | 98.16 | 40 | | | | _2_7_7_15 | 0.81300 | 0.00139 | 0.81579 |
| | 7,000 | 1,233 | 461 | 8,656 | 206.62 | 19.7 | | | | _1_7_7_15 | 0.72136 | 0.00111 | 0.72358 |
| **From 13 to 7 kg sat. $U_3Si_2$ at 19.7 wt % $^{235}U$ and 7 g/cm$^3$, and 500 g poly in flooded CV** | | | | | | | | | | **Content dispersed in flooded CV** | | | |
| _1_7_13_15 | 13,000 | 2,290 | 856 | 7,801 | 106.01 | 19.7 | 0.62192 | 0.00116 | 0.62424 | _1_7_13_15 | 0.76076 | 0.00137 | 0.76349 |
| | 12,000 | 2,113 | 790 | 7,943 | 115.79 | 19.7 | | | | _1_7_12_15 | 0.75612 | 0.00133 | 0.75878 |
| | 11,000 | 1,937 | 724 | 8,086 | 127.35 | 19.7 | | | | _1_7_11_15 | 0.75182 | 0.00127 | 0.75437 |
| | 10,000 | 1,761 | 658 | 8,228 | 141.22 | 19.7 | | | | _1_7_10_15 | 0.75022 | 0.00124 | 0.75270 |
| | 9,000 | 1,585 | 592 | 8,371 | 158.18 | 19.7 | | | | _1_7_9_15 | 0.74197 | 0.00116 | 0.74428 |
| | 8,000 | 1,409 | 527 | 8,514 | 179.38 | 19.7 | | | | _1_7_8_15 | 0.73321 | 0.00114 | 0.73549 |
| | 7,000 | 1,233 | 461 | 8,656 | 206.62 | 19.7 | | | | _1_7_7_15 | 0.72136 | 0.00111 | 0.72358 |

**Table 6.9.8.8-7b. Results for uranium silicide in the ES-3100 packaging calculation models**

| case name (5ncsrpdusit11) | $U_3Si_2$ (g) | $^{235}U$ (g) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | variable | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name (5ncsrdpust11) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **13 kg sat. $U_3Si_2$ and 500 g poly, density from 7 to 2 g/cm$^3$, flooded packaging** | | | | | | | | | | **Content dispersed in flooded CV** | | | |
| _8_7_13_15 | 13,000 | 12,041 | 856 | 7,801 | 20.16 | 7 | 0.76684 | 0.00127 | 0.76937 | _8_7_13_15 | 0.82110 | 0.00168 | 0.82447 |
| _8_6_13_15 | 13,000 | 12,041 | 1,165 | 7,492 | 20.16 | 6 | 0.77522 | 0.00120 | 0.77761 | _8_6_13_15 | 0.82110 | 0.00168 | 0.82447 |
| _8_5_13_15 | 13,000 | 12,041 | 1,597 | 7,059 | 20.16 | 5 | 0.78285 | 0.00135 | 0.78556 | _8_5_13_15 | 0.82110 | 0.00168 | 0.82447 |
| _8_4_13_15 | 13,000 | 12,041 | 2,246 | 6,410 | 20.16 | 4 | 0.79399 | 0.00181 | 0.79760 | _8_4_13_15 | 0.82110 | 0.00168 | 0.82447 |
| _8_3_13_15 | 13,000 | 12,041 | 3,327 | 5,329 | 20.16 | 3 | 0.80614 | 0.00139 | 0.80892 | _8_3_13_15 | 0.82110 | 0.00168 | 0.82447 |
| _8_2_13_15 | 13,000 | 12,041 | 5,490 | 3,166 | 20.16 | 2 | 0.81686 | 0.00139 | 0.81964 | _8_2_13_15 | 0.82110 | 0.00168 | 0.82447 |
| **From 13 to 7 kg sat. $U_3Si_2$ at 7 g/cm$^3$ and 500 g poly, flooded packaging** | | | | | | | | | | **Content dispersed in flooded CV** | | | |
| | 13,000 | 12,041 | 856 | 7,801 | 20.16 | | | | | _8_7_13_15 | 0.82110 | 0.00168 | 0.82447 |
| | 12,000 | 11,115 | 790 | 7,943 | 22.02 | | | | | _8_7_12_15 | 0.81912 | 0.00152 | 0.82215 |
| | 11,000 | 10,189 | 724 | 8,086 | 24.22 | | | | | _8_7_11_15 | 0.81836 | 0.00127 | 0.82089 |
| | 10,000 | 9,262 | 658 | 8,228 | 26.85 | | | | | _8_7_10_15 | 0.81763 | 0.00161 | 0.82084 |
| | 9,000 | 8,336 | 592 | 8,371 | 30.08 | | | | | _8_7_9_15 | 0.81283 | 0.00174 | 0.81632 |
| | 8,000 | 7,410 | 527 | 8,514 | 34.11 | | | | | _8_7_8_15 | 0.81090 | 0.00166 | 0.81422 |
| | 7,000 | 6,484 | 461 | 8,656 | 39.29 | | | | | _8_7_7_15 | 0.80563 | 0.00159 | 0.80881 |
| **13 kg sat. $U_3Si_2$ at 7 g/cm$^3$ and 500 g poly, 100% to 19.7 wt % $^{235}U$, flooded packaging** | | | | | | | | | | **Content dispersed in flooded CV** | | | |
| _8_7_13_15 | 13,000 | 12,041 | 856 | 7,801 | 20.16 | 100 | 0.76684 | 0.00127 | 0.76937 | _8_7_13_15 | 0.82110 | 0.00168 | 0.82447 |
| _7_7_13_15 | 13,000 | 11,440 | 856 | 7,801 | 21.22 | 95 | 0.75001 | 0.00114 | 0.75229 | _7_7_13_15 | 0.81010 | 0.00128 | 0.81266 |
| _6_7_13_15 | 13,000 | 10,838 | 856 | 7,801 | 22.39 | 90 | 0.73588 | 0.00131 | 0.73851 | _6_7_13_15 | 0.79989 | 0.00136 | 0.80261 |
| _5_7_13_15 | 13,000 | 9,635 | 856 | 7,801 | 25.19 | 80 | 0.71293 | 0.00128 | 0.71548 | _5_7_13_15 | 0.78850 | 0.00156 | 0.79162 |
| _4_7_13_15 | 13,000 | 8,431 | 856 | 7,801 | 28.79 | 70 | 0.68734 | 0.00121 | 0.68976 | _4_7_13_15 | 0.77146 | 0.00176 | 0.77498 |
| _3_7_13_15 | 13,000 | 7,227 | 856 | 7,801 | 33.58 | 60 | 0.66250 | 0.00104 | 0.66458 | _3_7_13_15 | 0.75908 | 0.00138 | 0.76185 |
| _2_7_13_15 | 13,000 | 4,819 | 856 | 7,801 | 50.36 | 40 | 0.60190 | 0.00110 | 0.60410 | _2_7_13_15 | 0.72556 | 0.00126 | 0.72807 |
| _1_7_13_15 | 13,000 | 2,290 | 856 | 7,801 | 106.01 | 19.7 | 0.51868 | 0.00099 | 0.52066 | _1_7_13_15 | 0.65956 | 0.00122 | 0.66199 |

**Table 6.9.8.8-7b. Results for uranium silicide in the ES-3100 packaging calculation models**

| case name (5ncsrpdusit11) | $U_3Si_2$ (g) | $^{235}U$ (g) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | variable | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name (5ncsrdpust11) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **7 kg sat. $U_3Si_2$ at 7 g/cm$^3$ and 500 g poly, 100 to 19.7 wt % $^{235}U$, flooded packaging** | | | | | | | | | | **Content dispersed in flooded CV** | | | |
| | 7,000 | 6,484 | 461 | 8,656 | 39.29 | 100 | | | | _8_7_7_15 | 0.80563 | 0.00159 | 0.80881 |
| | 7,000 | 6,160 | 461 | 8,656 | 41.35 | 95 | | | | _7_7_7_15 | 0.79796 | 0.00165 | 0.80127 |
| | 7,000 | 5,836 | 461 | 8,656 | 43.65 | 90 | | | | _6_7_7_15 | 0.79084 | 0.00143 | 0.79371 |
| | 7,000 | 5,188 | 461 | 8,656 | 49.10 | 80 | | | | _5_7_7_15 | 0.77879 | 0.00148 | 0.78175 |
| | 7,000 | 4,540 | 461 | 8,656 | 56.11 | 70 | | | | _4_7_7_15 | 0.76685 | 0.00132 | 0.76949 |
| | 7,000 | 3,892 | 461 | 8,656 | 65.46 | 60 | | | | _3_7_7_15 | 0.74828 | 0.00130 | 0.75087 |
| | 7,000 | 2,595 | 461 | 8,656 | 98.16 | 40 | | | | _2_7_7_15 | 0.71419 | 0.00146 | 0.71711 |
| | 7,000 | 1,233 | 461 | 8,656 | 206.62 | 19.7 | | | | _1_7_7_15 | 0.63031 | 0.00137 | 0.63304 |
| **From 13 to 7 kg sat. $U_3Si_2$ at 19.7 wt % $^{235}U$ and 7 g/cm$^3$, and 500 g poly, flooded packaging** | | | | | | | | | | **Content dispersed in flooded CV** | | | |
| | 13,000 | 2,290 | 856 | 7,801 | 106.01 | 19.7 | | | | _1_7_13_15 | 0.65956 | 0.00122 | 0.66199 |
| | 12,000 | 2,113 | 790 | 7,943 | 115.79 | 19.7 | | | | _1_7_12_15 | 0.65808 | 0.00126 | 0.66061 |
| | 11,000 | 1,937 | 724 | 8,086 | 127.35 | 19.7 | | | | _1_7_11_15 | 0.65479 | 0.00129 | 0.65737 |
| | 10,000 | 1,761 | 658 | 8,228 | 141.22 | 19.7 | | | | _1_7_10_15 | 0.65377 | 0.00130 | 0.65636 |
| | 9,000 | 1,585 | 592 | 8,371 | 158.18 | 19.7 | | | | _1_7_9_15 | 0.64727 | 0.00141 | 0.65010 |
| | 8,000 | 1,409 | 527 | 8,514 | 179.38 | 19.7 | | | | _1_7_8_15 | 0.64207 | 0.00122 | 0.64450 |
| | 7,000 | 1,233 | 461 | 8,656 | 206.62 | 19.7 | | | | _1_7_7_15 | 0.63031 | 0.00137 | 0.63304 |

**Table 6.9.8.8-7c. Results for uranium silicide in infinite array packaging calculation models**

| case name (5nciapdusit11) | $U_3Si_2$ (g) | $^{235}U$ (g) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | variable | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name (5nciadpust11) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **13 kg sat. $U_3Si_2$ and 500 g poly, density from 7 to 2 g/cm$^3$, flooded CV, dry packaging** | | | | | | | | | | **Content dispersed in flooded CV** | | | |
| _8_7_13_3 | 13,000 | 12,041 | 856 | 7,801 | 20.16 | 7 | 0.82896 | 0.00118 | 0.83132 | _8_7_13_3 | 1.03457 | 0.00130 | 1.03718 |
| _8_6_13_3 | 13,000 | 12,041 | 1,165 | 7,492 | 20.16 | 6 | 0.84437 | 0.00109 | 0.84654 | _8_6_13_3 | 1.03457 | 0.00130 | 1.03718 |
| _8_5_13_3 | 13,000 | 12,041 | 1,597 | 7,059 | 20.16 | 5 | 0.86019 | 0.00124 | 0.86266 | _8_5_13_3 | 1.03457 | 0.00130 | 1.03718 |
| _8_4_13_3 | 13,000 | 12,041 | 2,246 | 6,410 | 20.16 | 4 | 0.88450 | 0.00126 | 0.88701 | _8_4_13_3 | 1.03457 | 0.00130 | 1.03718 |
| _8_3_13_3 | 13,000 | 12,041 | 3,327 | 5,329 | 20.16 | 3 | 0.91535 | 0.00125 | 0.91785 | _8_3_13_3 | 1.03457 | 0.00130 | 1.03718 |
| _8_2_13_3 | 13,000 | 12,041 | 5,490 | 3,166 | 20.16 | 2 | 0.96155 | 0.00120 | 0.96394 | _8_2_13_3 | 1.03457 | 0.00130 | 1.03718 |
| **From 13 to 7 kg sat. $U_3Si_2$ at 2 g/cm$^3$ and 500 g poly, flooded CV, dry packaging** | | | | | | | | | | **Content dispersed in flooded CV** | | | |
| _8_2_13_3 | 13,000 | 12,041 | 5,490 | 3,166 | 20.16 | | 0.96155 | 0.00120 | 0.96394 | _8_7_13_3 | 1.03457 | 0.00130 | 1.03718 |
| _8_2_12_3 | 12,000 | 11,115 | 5,068 | 3,665 | 22.02 | | 0.94644 | 0.00133 | 0.94911 | _8_7_12_3 | 1.03086 | 0.00130 | 1.03347 |
| _8_2_11_3 | 11,000 | 10,189 | 4,646 | 4,164 | 24.22 | | 0.93327 | 0.00127 | 0.93582 | _8_7_11_3 | 1.03002 | 0.00144 | 1.03290 |
| _8_2_10_3 | 10,000 | 9,262 | 4,223 | 4,663 | 26.85 | | 0.91583 | 0.00134 | 0.91851 | _8_7_10_3 | 1.02139 | 0.00141 | 1.02422 |
| _8_2_9_3 | 9,000 | 8,336 | 3,801 | 5,163 | 30.08 | | 0.90106 | 0.00154 | 0.90414 | _8_7_9_3 | 1.01603 | 0.00133 | 1.01869 |
| _8_2_8_3 | 8,000 | 7,410 | 3,379 | 5,662 | 34.11 | | 0.87888 | 0.00127 | 0.88142 | _8_7_8_3 | 1.00932 | 0.00134 | 1.01201 |
| _8_2_7_3 | 7,000 | 6,484 | 2,956 | 6,161 | 39.29 | | 0.86058 | 0.00128 | 0.86314 | _8_7_7_3 | 1.00313 | 0.00155 | 1.00622 |
| **13 kg sat. $U_3Si_2$ at 7 g/cm$^3$ and 500 g poly in flooded CV, enrichment from 100 to 19.7 wt % $^{235}U$** | | | | | | | | | | **Content dispersed in flooded CV** | | | |
| _8_2_13_3 | 13,000 | 12,041 | 5,490 | 3,166 | 20.16 | 100 | 0.96155 | 0.00120 | 0.96394 | _8_7_13_3 | 1.03457 | 0.00130 | 1.03718 |
| _7_2_13_3 | 13,000 | 11,440 | 5,490 | 3,166 | 21.22 | 95 | 0.94505 | 0.00185 | 0.94876 | _7_7_13_3 | 1.01921 | 0.00142 | 1.02206 |
| _6_2_13_3 | 13,000 | 10,838 | 5,490 | 3,166 | 22.39 | 90 | 0.93320 | 0.00114 | 0.93548 | _6_7_13_3 | 1.00777 | 0.00148 | 1.01073 |
| _5_2_13_3 | 13,000 | 9,635 | 5,490 | 3,166 | 25.19 | 80 | 0.91090 | 0.00142 | 0.91374 | _5_7_13_3 | 0.98358 | 0.00113 | 0.98585 |
| _4_2_13_3 | 13,000 | 8,431 | 5,490 | 3,166 | 28.79 | 70 | 0.89033 | 0.00116 | 0.89266 | _4_7_13_3 | 0.96399 | 0.00144 | 0.96687 |
| _3_2_13_3 | 13,000 | 7,227 | 5,490 | 3,166 | 33.58 | 60 | 0.86922 | 0.00140 | 0.87203 | _3_7_13_3 | 0.94189 | 0.00119 | 0.94427 |
| _2_2_13_3 | 13,000 | 4,819 | 5,490 | 3,166 | 50.36 | 40 | 0.81852 | 0.00119 | 0.82089 | _2_7_13_3 | 0.88761 | 0.00140 | 0.89041 |
| _1_2_13_3 | 13,000 | 2,290 | 5,490 | 3,166 | 106.01 | 19.7 | 0.73631 | 0.00133 | 0.73897 | _1_7_13_3 | 0.79676 | 0.00126 | 0.79927 |

**Table 6.9.8.8-7c. Results for uranium silicide in infinite array packaging calculation models**

| case name (5nciapdusit11) | $U_3Si_2$ (g) | $^{235}U$ (g) | Sat. $H_2O$ (g) | CV $H_2O$ (g) | h/x | variable | $k_{eff}$ | σ | $k_{eff}+2\sigma$ | case name (5nciadpust11) | $k_{eff}$ | σ | $k_{eff}+2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sat. $U_3Si_2$ at 2 g/cm$^3$ and 500 g poly in flooded CV, enrichment from 60 to 19.7 wt % $^{235}U$** | | | | | | | | | | **Content dispersed in flooded CV** | | | |
| **_3_2_7_3** | **7,000** | **3,892** | **2,956** | **6,161** | **65.46** | **60** | **0.77671** | **0.00138** | **0.77946** | **_3_7_7_3** | **0.91662** | **0.00139** | **0.91940** |
| _2_2_12_3 | 12,000 | 4,448 | 5,068 | 3,665 | 55.01 | 40 | 0.80799 | 0.00121 | 0.81040 | _2_7_12_3 | 0.88898 | 0.00169 | 0.89237 |
| _2_2_13_3 | 13,000 | 4,819 | 5,490 | 3,166 | 50.36 | 40 | 0.81852 | 0.00119 | 0.82089 | _2_7_13_3 | 0.88761 | 0.00140 | 0.89041 |
| _2_2_11_3 | 11,000 | 4,078 | 4,646 | 4,164 | 60.50 | 40 | 0.79496 | 0.00136 | 0.79768 | _2_7_11_3 | 0.88471 | 0.00127 | 0.88725 |
| 2_2_10_3 | 10,000 | 3,707 | 4,223 | 4,663 | 67.09 | 40 | 0.77941 | 0.00193 | 0.78326 | _2_7_10_3 | 0.88229 | 0.00129 | 0.88488 |
| _2_2_9_3 | 9,000 | 3,336 | 3,801 | 5,163 | 75.15 | 40 | 0.76650 | 0.00132 | 0.76914 | _2_7_9_3 | 0.87546 | 0.00124 | 0.87793 |
| _2_2_8_3 | 8,000 | 2,966 | 3,379 | 5,662 | 85.22 | 40 | 0.75084 | 0.00119 | 0.75323 | _2_7_8_3 | 0.87016 | 0.00146 | 0.87307 |
| _2_2_7_3 | 7,000 | 2,595 | 2,956 | 6,161 | 98.16 | 40 | 0.73288 | 0.00134 | 0.73556 | _2_7_7_3 | 0.86217 | 0.00131 | 0.86480 |
| _1_2_13_3 | 13,000 | 2,290 | 5,490 | 3,166 | 106.01 | 19.7 | 0.73631 | 0.00133 | 0.73897 | _1_7_13_3 | 0.79676 | 0.00126 | 0.79927 |
| _1_2_12_3 | 12,000 | 2,113 | 5,068 | 3,665 | 115.79 | 19.7 | 0.72483 | 0.00112 | 0.72707 | _1_7_12_3 | 0.79291 | 0.00125 | 0.79541 |
| _1_2_11_3 | 11,000 | 1,937 | 4,646 | 4,164 | 127.35 | 19.7 | 0.71315 | 0.00131 | 0.71577 | _1_7_11_3 | 0.78832 | 0.00135 | 0.79102 |
| _1_2_10_3 | 10,000 | 1,761 | 4,223 | 4,663 | 141.22 | 19.7 | 0.69947 | 0.00113 | 0.70172 | _1_7_10_3 | 0.78068 | 0.00149 | 0.78365 |
| _1_2_9_3 | 9,000 | 1,585 | 3,801 | 5,163 | 158.18 | 19.7 | 0.68896 | 0.00163 | 0.69221 | _1_7_9_3 | 0.77294 | 0.00120 | 0.77535 |
| _1_2_8_3 | 8,000 | 1,409 | 3,379 | 5,662 | 179.38 | 19.7 | 0.67532 | 0.00117 | 0.67767 | _1_7_8_3 | 0.76297 | 0.00117 | 0.76531 |
| _1_2_7_3 | 7,000 | 1,233 | 2,956 | 6,161 | 206.62 | 19.7 | 0.65751 | 0.00119 | 0.65988 | _1_7_7_3 | 0.75056 | 0.00113 | 0.75282 |

# Appendix 6.9.9

# Criticality Evaluation of HEU Oxide Product Content for Air Transportation

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## Appendix 6.9.9

## Criticality Evaluation of HEU Oxide Product Content for Air Transportation

Highly enriched uranium (HEU) product oxides ($UO_2$, $UO_3$, and $U_3O_8$) are evaluated as ES-3100 package contents for ground transport in Sects. 6.4–6.6. The criticality safety evaluation presented in this appendix is required for the approval of these oxides as a package content under the air transport mode. This analysis is simply an extension of the analysis presented in Sect. 6.7 for HEU metal. The catastrophically damaged package calculation models for HEU described in Sect. 6.3.1.4 for metal content were modified to address HEU product oxide under the air transport mode. Calculations presented in this appendix were performed using the Monte Carlo CSAS25 criticality code sequence and 238-group ENDFB-V cross-section library of SCALE 5.0 discussed in Sect. 6.9.8.4 (Appendix 6.9.8). Related discussion of the benchmark experiments and criticality evaluation is contained in Sect. 6.9.8.7 (Appendix 6.9.8).

### 6.9.9.1 Description of the Criticality Design

Changes to the design features of the ES-3100 package addressed in Sect. 6.1.1 are not required for air transport. However, the total free water permitted in the Kaolite is limited to 12 lb (5,443.1 g) as in the case of HEU metal content assuming the containment vessel well and other void spaces external to the containment vessel are dry. The codes and standards addressed in Sect. 6.1.2 apply to HEU product oxide as a package content for air transport. Moreover, the methodology for demonstrating maximum reactivity is not changed. The fissile mass loading limits for these contents listed in Table 6.9.9.1 are presented in Tables 6.9.9.2 and 6.2b for the air mode of transportation. Finally, the assignment of the criticality safety index (CSI) as to the ES-3100 package as described in Sect. 6.1.4 is unchanged.

### 6.9.9.2 The HEU Product Oxide Contents for the ES-3100 Package for Air Transport

HEU product oxide content for shipment by air in the ES-3100 is identified in Table 6.9.9.1. Physically, these uranium oxides ($UO_2$, $UO_3$, and $U_3O_8$) are non-rigid, bulk material in loose, granular, or powdered form. Both content moisture and content uniformity are undefined. The convenience cans, Teflon and polyethylene bottles, 277-4 canned spacers described in Sect. 6.2.2, and the packing materials described in Sect. 6.2.3 are not affected by inclusion of HEU product oxide as a package content for air transport. The Packing Content Loading Restrictions stated in Sect. 6.2.4 are unchanged.

**Table 6.9.9.1. HEU product oxide contents**

| Name | Detailed description | Assay (wt % $^{235}U$) | Net wt [a] (g) | U wt (g) | $^{235}U$ wt (g) |
|---|---|---|---|---|---|
| $UO_2$, $UO_3$, $U_3O_8$ | 2.0 g/cm$^3$ ≤ density ≤ 6.54 g/cm$^3$ | ≤100 | 6,000 | 5,281 | 5,281 |

[a] 5,281-g $^{235}U$ corresponds to 6-kg U(100)$O_2$. The net weight of $UO_3$ and $U_3O_8$ are 6,359.4 and 6,239.6 g, respectively for 5,281-g $^{235}U$ at 100% enrichment. A lower enrichment level will result in a larger net weight of the particular oxide form at the 5,281-g $^{235}U$ limit. Thus, "g $^{235}U$" not the net weight, is a limit.

**Table 6.9.9.2. Fissile mass loading limits [a] for air transport of HEU product oxide**

| Content [b] description | Enrichment | No can spacers, [c] $^{235}U$ (g) | Basis for limit |
|---|---|---|---|
| HEU oxide ($UO_2$, $UO_3$, $U_3O_8$, $U_3O_8$-Al, $UO_2$-Mg, $UO_2$-$ZrO_2$) | ≤ 100% | 5,281 [d] | Table 6.9.9.9-1, HEU product oxides |

[a] The mass loading limit cannot be rounded up.
[b] Content in solution form is not permitted for shipment in the ES-3100. Content may be a combination of these oxides.
[c] 277-4 can spacers as described on Drawing M2E801580A043 (Appendix 1.3.7) are not required but are optional as dunnage.
[d] Mass limits for uranium oxide with aluminum ($\rho$=2.703 g/cm$^3$), zirconium ($\rho$=6.518 g/cm$^3$), or magnesium ($\rho$=1.738 g/cm$^3$) must assume that the non-uranium metallic constituents are $^{235}U$.

### 6.9.9.3 General Considerations

The general considerations expressed in Sect. 6.3 regarding both the calculation methodology for the ground and air transport modes, and the assumptions made about the ES-3100 packaging regarding geometry and material composition are unchanged. Only modifications to the calculation models for the catastrophically damaged package (Sect. 6.3.1.4) were required for evaluating HEU product oxide as a package content in the air transport mode.

#### 6.9.9.3.1 Model configuration

The general modeling technique for the ES-3100 package described in Sect. 6.3.1, the single-unit packaging calculation models (Sect. 6.3.1.1), the infinite array and finite array packaging calculation models (Sect. 6.3.1.2), and the calculation models for damaged packages (Sect. 6.3.1.3) are specific to the ground transport. Only the content portion of the six calculation models for the catastrophically damaged package specific to HEU metal as a package content under the air transport (Sect. 6.3.1.4) were appropriately modified for evaluating HEU product oxide as a package content in the air transport mode. This was accomplished by replacing the homogeneous mixture of HEU metal and 500 g of polyethylene in the original models with a homogeneous mixture of water-saturated HEU oxide and 500 g of polyethylene. The 500-g polyethylene represents a limit on Teflon or polyethylene bottles as well as hydrogenous packing material. Given the requirement that containment vessels be flooded in the ground transport analysis; credit for product oxide quality (dryness) is not taken in the air transport analysis either. The HEU product oxide is assumed water-saturated in the air transport analysis.

The general arrangements of materials depicted in Figs. 6.11–6.16 (Sect. 6.1.3.4) remains the same for the HEU metal and HEU product oxide content configurations. Note that model dimensions are presented in the calculation results summary tables rather than depicted in these figures. Changes in dimensions of each model resulting from switching content from HEU metal to HEU product oxide content are slight and not visible in the figures. Consequently, new figures were not drawn for HEU product oxide; instead, Figs. 6.11–6.16 are referenced accordingly in this appendix.

The content description for the HEU product oxide given in Table 6.9.9.1 provides the basis for the calculation model. The 6-kg $UO_2$ will be shown to be the largest amount allowable for air transport in Table 6.9.9.9-1). The uranium oxide mass is 6 kg, the uranium mass is 5,281 g, and the $^{235}U$ mass is 5,281 g at 100% enrichment for $UO_2$. There are three major oxides of uranium—$UO_2$, $UO_3$ , and $U_3O_8$. $UO_3$ and $U_3O_8$ are bounded by calculations using $UO_2$ for two reasons: (1) for the same net weight (6-kg oxide), there is more $^{235}U$ in $UO_2$ than in $UO_3$ or $U_3O_8$ and (2) for the same $^{235}U$ content (5,281 g), the $UO_3$ and $U_3O_8$ have more oxygen atoms per uranium atom and, therefore, have lower uranium densities. However, the neutron scattering and absorption in the additional oxygen is a minor

effect compared to reactivity changes due to the uranium mass/density differences. For this reason, Table 6.9.9.9-1 contains only a few calculations of $UO_3$ and $U_3O_8$ at the 6-kg oxide net weight amount included to demonstrate that the $UO_2$ is obviously bounding for the other two oxides.

HEU product oxide evaluated for ground transport in Sects. 6.4.3, 6.5.3, and 6.6.3 is characterized as non-hydroscopic or mildly hydroscopic, non-rigid, bulk material in clumped, loose, granular, or powdered form having a bulk density ranging from 2.0 to 6.54 g/cm$^3$. Oxide impurity (unidentified constituents) is treated as $^{235}$U [Sect. 6.2.4(8)]. This same criteria is applied in the criticality evaluation for the air transport mode. Given the requirement that containment vessels be flooded in the ground transport analysis, credit for product quality (dryness) is not taken in the air transport analysis either. The HEU product oxide is assumed water-saturated.

As explained in Sect. 6.3.1.4, the air-transport calculation models incorporate features exhibiting the worst-case assumptions made regarding the geometric arrangement of the packaging and package contents. No credit is taken for the geometric form of the package content. Spherical geometry is used to represent the ultimate configuration of the ES-3100 package which undergoes catastrophic destruction.

The criticality analysis for air transport does not credit the ES-3100 for maintaining the geometrical configuration of the packaged content. Fissile material is configured spherical in shape for optimization of neutron multiplication. Also, the criticality analysis does not credit the ES-3100 packaging for structural integrity of the containment and the confinement. Therefore, the reactivity "enhancing" materials of the packaging may be interspersed with the fissile material content. A calculation model in which the fissile material is homogenized with moderating material is an appropriate representation because the form of HEU product uranium oxide being shipped consists of a bulk material in clumped, loose, granular, or powdered form. However, homogenization of fissile material with moderating material is not performed with exclusive preference given to specific constituents of the moderating material. Selective removal of the neutron-absorbing materials of the package (i.e., Kaolite and stainless steel) accompanied by retention of the moderating constituents of the neutron-absorbing material (i.e., bound water in the Kaolite) for enhancing content reactivity is not a credible condition.

Concerning the "no water inleakage" condition of 10 CFR 71.55(f)(1) and (f)(2), the focus is on the Kaolite region of the ES-3100 package. The 53,419 g of dry-baked Kaolite in the drum body weldment and drum top plug consists of 51,214.9 g of vermiculite-cement constituents and 2,204.7 g of bound water. For establishing the loading limits for air transport, the total **free** water permitted in wet Kaolite was conservatively evaluated up to 15 lb (6,803.8 g). As in the case of HEU metal content, this limit assumes that the containment vessel well and other void spaces external to the containment vessel are dry.

A set of six calculation models are constructed in order to determine the worst case or most reactive configuration with consideration given to the efficiency of moderators, loss of neutron absorbers, rearrangement of packaging components and contents, geometry changes, and temperature effects. In each case, fissile material content in the core consists of HEU product oxide saturated with water (e.g., 2,448.1-g $H_2O$ for $UO_2$ at 2 g/cm$^3$) and homogenized with 500-g polyethylene which models the allowed hydrogenous packing material.

Model 1 (Fig. 6.11, Sect. 6.3.1.4) represents the fissile material content configured into a spherical core with a 20.0-cm thick water reflector. All ES-3100 packaging material (Kaolite, stainless steel, 277-4 neutron poison, etc.) is excluded from Model 1. The fissile material content considered in the calculation model consists of a specific material form: HEU product oxide (6- to 14-kg $UO_2$ containing 5,281- to 12,323-g $^{235}$U). The presence of hydrogenous packing material inside the containment vessel is also addressed in this calculation model where 500 g of polyethylene is used to represent a maximum amount of hydrogenous packing material allowed in the ES-3100. For 6-kg HEU product oxide

(5,281-g $^{235}U$) homogenized with 500 g of polyethylene, the radius of the core is 6.3861 cm. HEU product oxide is assumed to be saturated with water that is 2,448.1-g $H_2O$ for $UO_2$ at 2.0 g/cm$^3$. The parametric variation of both the $^{235}U$ mass and the density of the water-saturated oxide in Model 1 is used to establish a reference point for the evaluation neutron reflection and absorption effects on $k_{eff}$ provided by the stainless steel and Kaolite packaging materials, which are addressed separately in Models 2 and 3. Case names for Model 1 are designated with the prefix "5atdor." The leading "5" in alphanumeric prefix indicates calculations were run with SCALE5 rather than with the SCALE4.4a. $UO_2$ is shown to be the most reactive uranium oxide; therefore, the oxide content is modeled as $UO_2$ at various densities ranging from 2.0 to 6.54 g/cm$^3$. The amount of saturation water varies from a low of 369.3 g for an oxide density of 6.54 g/cm$^3$ to the high of 2,448.1 g for a lower oxide density of 2 g/cm$^3$. Details are provided in Table 6.9.9.9-1 for each density evaluated.

Model 2 (Fig. 6.12, Sect. 6.3.1.4) represents a spherical core of Model 1 blanketed by a variable-thickness shell of stainless steel and a 20.0-cm-thick water reflector external to the shell. The shell at maximum thickness corresponds to the 66,133-g stainless steel of the containment vessel and the liner and drum assembly. For a homogeneous mixture of 6-kg HEU product oxide (5,281-g $^{235}U$), 2,448.1 g of saturation water (consistent with an oxide density of 2 g/cm$^3$) and 500 g of polyethylene, the radius of the core is 9.4576 cm while the outer radius of the stainless steel shell is 14.1521 cm. Case names in Table 6.9.9.9-1 for Model 2 are designated with the prefix "5atdosr."

Model 3 (Fig. 6.13, Sect. 6.3.1.4) is configured the same as Model 2 with the exception that instead of stainless steel, the variable-thickness shell is composed of dry Kaolite in one set of cases and wet Kaolite in the other set. Dry Kaolite from inside the body weldment outer liner and the drum top plug consists of 51,214.3-g vermiculite-cement and 2,204.8-g bound water. Wet Kaolite to a maximum of 60,223 g consists of the dry Kaolite and up to 6,803.9-g free water—moisture which dampens the Kaolite and may also be present in the containment vessel well. Because the Kaolite is constrained within the liners of the ES-3100 packaging, the Kaolite density rather than its volume changes when water is added to the material. Therefore, at maximum shell thickness, the outer radius of the Kaolite shell, wet or dry, is 31.2952 cm. Like Model 2, the radius of the core is 9.4576 cm for a homogeneous mixture of 6-kg HEU product oxide (5,281-g $^{235}U$), 2,448.1 g of saturation water, and 500 g of polyethylene. Case names for Model 3 designated with the prefix "5atdodkr" are for HEU product oxide content with a dry Kaolite shell (Kaolite only contains bound water) while case names designated with the prefix "5atdo15kr" are for HEU product oxide content with a wet Kaolite having 15-lb free water. The parametric variation of shell thickness/composition in Models 2 and 3 is performed for the purpose of evaluating the effect on $k_{eff}$ of neutron reflection and absorption provided by each packaging material.

Models 1–3 for water-saturated HEU product oxide evaluate scenarios where containment and confinement of the content are assumed but the physical shape of the packaging is destroyed. Models 4–6 evaluate scenarios where the package content blends with the other materials of the packaging in the air transport accident given the physical form of the HEU product oxide is bulk material in clumped, loose, granular, or powdered form.

Model 4 (Fig. 6.14, Sect. 6.3.1.4) depicts a spherical core of HEU product oxide and 2,448.1 g of saturation water homogenized with wet Kaolite (variable amount) and hydrogenous packing materials from inside the containment vessel represented by 500 g of polyethylene. A 20-cm-thick water reflector blankets the spherical core. All other ES-3100 packaging material (stainless steel, 277-4 neutron poison, etc.) is excluded from Model 4. For the homogenized core containing 6 kg of HEU product oxide (5,281 g of $^{235}U$), 2,448.1 g of saturation water for the oxide at 2 g/cm$^3$, 500 g of polyethylene and wet Kaolite, the radius of the core is 31.2953 cm. The amount of water in wet Kaolite ranges from 2,204.7-g bound water in baked-dry Kaolite to 9,008.6 g (2,204.7-g bound plus 15-lb free water). Case names in Table 6.9.9.9-1 for Model 4 are designated with the prefix "5athop15kr" for the HEU product oxide.

Model 5 (Fig. 6.15, Sect. 6.3.1.4) is an extension of Model 3 applied to HEU product oxide contents. Excess water from wet Kaolite is homogenized with the fissile material in the core along with the water of saturation and the hydrogenous packing materials (modeled as polyethylene). For a homogeneous mixture of 6-kg HEU product oxide (5,281-g $^{235}U$), 2,448.1 g of saturation water, 500 g of polyethylene, and 0.0 g of free water from wet Kaolite, the radius of the spherical core is 9.4576 cm. The corresponding exterior Kaolite shell, containing 9,008.5 g (2,204.7-g bound plus 15-lb free water) of water homogenized with the 51,214.9 g of vermiculite-cement constituents, has an outer radius of 31.2952 cm. For the extreme condition where the entire 6,803.8 g of water from wet Kaolite is homogenized with the core, the radius of the spherical core is 13.5234 cm. The corresponding exterior shell of dry Kaolite, containing 2,204.7 g of bound water and 51,214.9 g of vermiculite-cement constituents, has an outer radius of 31.8395 cm. Case names in Table 6.9.9.9-1 for Model 5 are designated with the prefix "5athopw15kr" for 15-lb free water in the Kaolite and "5athopw13kr" for 13-lb free water in the Kaolite.

Model 6 (Fig. 6.16, Sect. 6.3.1.4) is configured similar to Model 4 with the exception that only a partial amount of HEU product oxide resides in the homogenized core. The remainder of the fissile material is modeled as a shell external to the spherical core and internal to the 20.0-cm-thick water reflector. A series cases is run with suffixes "**_f_a_b**" is run where the first number "**f**"designates variable water mass in the fissile core region, the second number "**a**" designates oxide mass in the fissile core, and the third number "**b**"designates oxide mass in shell around the core. For Cases **5athop15kor_f_a_b**, the amount of water-saturated HEU oxide in the homogenized core is varied in 1-kg increments from 5 kg for **"a"**=5 (the full 6-kg amount in Model 5 minus 1 kg) to 1 kg for "**a**"=1. The unsaturated HEU product oxide removed from the core to form the shell adjacent to the core correspondingly increases from 1 to 5 kg for "**b**"=1 to 5 where "**b=6-a**." For maximization of reactivity, it is assumed that all the saturation water present in the 6-kg oxide remains in the core. The effect of varying the free water in the core is evaluated in cases designated by the suffix "**f**." In Cases **5athop15kor_1_a_b**, the 11,456.8-g water represents the saturated water in the oxide plus both the free water and bound water in Kaolite. In Cases **5athop15kor_5_a_b**, the 4,653.0-g water represents the saturated water in the oxide plus the bound water in Kaolite. Case names in Table 6.9.9.9-2 for Model 6 are designated with the prefix "5athop15kor" for the HEU product oxide contents. Model 6 addresses potential redistribution of fissile material consisting of HEU product oxide content. The parametric variation of shell thickness in Model 6 is performed for the purpose of evaluating the effect on $k_{eff}$ of moderation efficiency of the core and enhanced neutron multiplication of the shell.

Models 1–6 are applicable to air transport of the ES-3100 package given that the physical integrity of the fissile content following the air-transport accident cannot be established and that the physical form of fissile material content is oxide.

### 6.9.9.3.2 Content model material specifications for HEU product oxide

The material properties for the ES-3100 package addressed in Sect. 6.3.2 remain unchanged for the air transport analysis. However, additional specification data is provided in Table 6.9.9.3 for addressing the HEU product oxide content modeled in the air-transport analysis.

**Table 6.9.9.3. Material compositions for HEU product oxide content calculation models for air transport**

| Material | Mix. No. | Theoretical density input parameter ($g/cm^3$) [a] | Volume fraction | Constituent | Atomic weight | Weight fraction | Atomic density (atoms/b-cm) [b] |
|---|---|---|---|---|---|---|---|
| **Fissile material contents** | | | | | | | |
| Uranium oxide ($UO_2$) | 1 | 10.96000 | 1.0 | O | 15.9954 | 11.9827 | 4.46663E-02 |
| | | | | $^{235}U$ | 235.0441 | 88.0173 | 2.47161E-02 |
| HEU product oxide ($UO_2$) at 2 $g/cm^3$, 2,448.1-g saturation water, and 500-g poly | 1 | 1.69325 | 1.0 | O | 15.9954 | 88.0203 | 3.07374E-02 |
| | | | | $^{235}U$ | 235.0441 | 11.9797 | 3.81861E-03 |
| | 1 | 0.69089 | 1.0 | H | 1.0078 | 11.1913 | 5.83269E-02 |
| | | | | O | 15.9954 | 88.8087 | |
| | 1 | 0.14110 | 1.0 | C | 12.0111 | 14.3798 | 6.06280E-03 |
| | | | | H | 1.0078 | 85.6202 | |
| HEU product oxide ($UO_2$) at 3 $g/cm^3$, 1,449.9-g saturation water, and 500-g poly | 1 | 2.35897 | 1.0 | O | 15.9954 | 88.0203 | 2.97000E-02 |
| | | | | $^{235}U$ | 235.0441 | 11.9797 | 5.31994E-03 |
| | 1 | 0.57006 | 1.0 | H | 1.0078 | 11.1913 | 5.50137E-02 |
| | | | | O | 15.9954 | 88.8087 | |
| | 1 | 0.19658 | 1.0 | C | 12.0111 | 14.3798 | 8.44667E-03 |
| | | | | H | 1.0078 | 85.6202 | |
| HEU product oxide ($UO_2$) at 4 $g/cm^3$, 950.8-g saturation water, and 500-g poly | 1 | 2.93617 | 1.0 | O | 15.9954 | 88.0203 | 2.88006E-02 |
| | | | | $^{235}U$ | 235.0441 | 11.9797 | 6.62164E-03 |
| | 1 | 0.46530 | 1.0 | H | 1.0078 | 11.1913 | 5.21411E-02 |
| | | | | O | 15.9954 | 88.8087 | |
| | 1 | 0.24468 | 1.0 | C | 12.0111 | 14.3798 | 1.05134E-02 |
| | | | | H | 1.0078 | 85.6202 | |
| HEU product oxide ($UO_2$) at 5 $g/cm^3$, 651.4-g saturation water, and 500-g poly | 1 | 3.44140 | 1.0 | O | 15.9954 | 88.0203 | 2.80136E-02 |
| | | | | $^{235}U$ | 235.0441 | 11.9797 | 7.76104E-03 |
| | 1 | 0.37361 | 1.0 | H | 1.0078 | 11.1913 | 4.96269E-02 |
| | | | | O | 15.9954 | 88.8087 | |
| | 1 | 0.28678 | 1.0 | C | 12.0111 | 14.3798 | 1.23224E-02 |
| | | | | H | 1.0078 | 85.6202 | |
| HEU product oxide ($UO_2$) at 6.54 $g/cm^3$, 369.3-g saturation water, and 500-g poly | 1 | 4.10703 | 1.0 | O | 15.9954 | 88.0203 | 2.69763E-02 |
| | | | | $^{235}U$ | 235.0441 | 11.9797 | 9.26216E-03 |
| | 1 | 0.25280 | 1.0 | H | 1.0078 | 11.1913 | 4.63142E-02 |
| | | | | O | 15.9954 | 88.8087 | |
| | 1 | 0.34225 | 1.0 | C | 12.0111 | 14.3798 | 1.47058E-02 |
| | | | | H | 1.0078 | 85.6202 | |

[a] The theoretical density input parameter is specified for each material such that the required (or desired) mass of material is represented in the KENO V.a calculation model. The mass of material is computed by KENO V.a as the product of the theoretical density input parameter times the volume fraction times the volume of the geometry region in which the material resides in the calculation model.

[b] Atomic densities are specified for the total isotope in a homogenized material as Mix No. 1.

### 6.9.9.4 Computer Codes and Cross-Section Libraries

This information is discussed in Section 6.9.8.4.

### 6.9.9.5 Single Package Evaluation (NCT and HAC)

The evaluation of a single ES-3100 package with HEU product oxide content in the ground mode of transportation is presented in Sect. 6.4.3 while the evaluation of a catastrophically damaged package in air transport mode is addressed in Appendix 6.9.9.7.

### 6.9.9.6 Array Package Evaluation (NCT and HAC)

The evaluation of arrays of packages in NCT and in HAC for the ground transport mode are presented in Sects. 6.5.3 and 6.6.3, respectively. The array evaluations are not required by 10 CFR 71.55(f) for the air mode of transportation. However, the CSI established for the ground transport mode establishes the maximum number of packages which can be loaded onto an aircraft for criticality safety purposes.

### 6.9.9.7 Fissile Material Packages with HEU Product Oxide for Air Transport

As discussed in Sect. 6.7, a series of calculations are performed for determining the most reactive configuration of the content and surrounding packaging material in an ES-3100 package that undergoes catastrophic destruction. Subcriticality is demonstrated after due consideration of such aspects as the efficiency of moderator, loss of neutron absorbers, rearrangement of packaging components and contents, geometry changes and temperature effects. Details of the six calculation models used in this evaluation are described in Sect. 6.9.9.3.1. Key model dimensions and parameters are provided in Tables 6.9.9.9-1 and 6.9.9.9-2.

Model 1 (Fig. 6.11, Sect. 6.3.1.4) represents fissile material content configured into a spherical core with a 20.0-cm-thick water reflector taking no credit for the geometry or structure of the container. In addition, all ES-3100 packaging material (Kaolite, stainless steel, 277-4 neutron poison, etc.) is excluded from Model 1. The parametric variation of both the $^{235}U$ mass and the density of the oxide along with its corresponding saturation water in Model 1 is used to establish a reference point for the evaluation of neutron reflection and absorption effects on $k_{eff}$ provided by the stainless steel and Kaolite packaging materials, which are addressed separately in Models 2 and 3. The purpose of the variations in Model 1 is to identify the most reactive oxide type ($UO_2$, $UO_3$, or $U_3O_8$) and density (from 2 to 6.54 g/cm$^3$) for water-saturated HEU product oxide (saturation water ranging from 369.3 to 2,448.1 g for corresponding oxide densities from 6.54 to 2 g/cm$^3$). In Cases **5atdor_1_5_6** through **5atdor_1_5_14** (Table 6.9.9.9-1), the $k_{eff} + 2\sigma$ values increase from 0.751 to 0.871 as the mass of saturated HEU product oxide increases from 6-kg $UO_2$ (5,281-g $^{235}U$) to 14-kg $UO_2$ (12,323-g $^{235}U$) at 6.54 g/cm$^3$. In Cases **5atdor_1_1_6** through **5atdor_1_5_6** for $UO_2$, Cases **5atdor_2_1_6** through **5atdor_2_5_6** for $U_3O_8$, and Cases **5atdor_3_1_6** through **5atdor_3_5_6** for $UO_3$, the densities of the three oxides are varied from 2 to 6.54 g/cm$^3$. These contents are most reactive at minimum density where the $k_{eff} + 2\sigma$ values range from 0.671 for $UO_3$ (**Case 5atdor_3_5_6**) to 0.917 for $UO_2$ (**Case 5atdor_1_1_6**). $UO_2$ is the most reactive of the product oxides evaluated. In Cases **5atdor_1_1_6** through **5atdor_1_1_14** (Table 6.9.9.9-1), the $k_{eff} + 2\sigma$ values range from 0.917 to 1.073 as the mass of saturated HEU product oxide is varied from 6- to 14-kg $UO_2$ for oxide at minimum density (2 g/cm$^3$). Only the result for Case **5atdor_1_1_6** is adequately below the USL of 0.924; therefore, 6-kg (5,281-g $^{235}U$) HEU product oxide is the limiting mass and 2 g/cm$^3$ is the optimum density for consideration of this material for air transport in the ES-3100.

Model 2 (Fig. 6.12, Sect. 6.3.1.4) represents a spherical core of water-saturated HEU product oxide and polyethylene (Model 1) blanketed by a variable thickness shell of stainless steel, with a

20.0-cm-thick water reflector external to the shell. The shell at maximum thickness corresponds to the 66,133-g stainless steel of the containment vessel and the liner and drum assembly. The thickness of the stainless steel shell is varied from zero to 4.6944 cm in Cases **5atdosr_1** through **5atdosr_11** (Table 6.9.9.9-1). The maximum $k_{eff} + 2\sigma$ is 0.915 for 6 kg of HEU product oxide and zero stainless-steel thickness. The $k_{eff} + 2\sigma$ values decrease to a minimum of 0.863 at 1.84-cm stainless-steel shell thickness (Case **5atdosr_4**). The $k_{eff} + 2\sigma$ values increase to within 0.02 of the maximum at the maximum stainless steel thickness (Case **5atdosr_11**). The overall effect of adding the stainless steel of the ES-3100 packaging to the configuration is the reduction in the neutron multiplication factor for the system. The $k_{eff} + 2\sigma$ values are substantially below the USL of 0.924.

Model 3 (Fig. 6.13, Sect. 6.3.1.4) is configured the same as Model 2 with the exception that instead of stainless steel, the variable-thickness shell is composed of dry Kaolite (Cases **5atdodrk_1** through **5atdodkr_6**) or wet Kaolite (Cases **5atdo15rk_1** through **5atdo15kr_6**). Dry Kaolite from inside the body weldment outer liner and the drum top plug consists of 51,214.9-g vermiculite-cement and 2,204.7-g bound water. Wet Kaolite to a maximum of 60,223 g consists of the dry Kaolite and up to 6,803.8-g free water—moisture which dampens the Kaolite and may also be present in the containment vessel well. Because the Kaolite is constrained within the liners of the packaging, the Kaolite density rather than its volume changes when water is added to the material. Consequently, the shell thickness in Model 3 does not change as free water is added. The $k_{eff} + 2\sigma$ decreases from 0.915 to 0.719 for dry Kaolite (Cases **5atdodkr_1** through **5atdodkr_6**) and decreases from 0.916 to 0.729 for wet Kaolite (Cases **5atdo15kr_1** − **5atdo15kr_6**). NCT Kaolite of the ES-3100 packaging or wet Kaolite is not as effective a reflector as 20 cm water surrounding the core.

Model 4 (Fig. 6.14, Sect. 6.3.1.4) represents a spherical core of water-saturated HEU product oxide and polyethylene (Model 1) homogenized with wet Kaolite. A 20-cm-thick water reflector blankets the spherical core. All other ES-3100 packaging material (stainless steel, 277-4 neutron poison, etc.) is excluded from Model 4. In Cases **5athop15kr_1** through **5athop15kr_5** (Table 6.9.9.9-1), $k_{eff} + 2\sigma$ increases from 0.484 to 0.574 as free water is added to the 15-lb limit. Again, the core radius is constant with changing moisture conditions because the volume of the porous Kaolite constrained within the liners of the packaging does not change appreciably as the material is dried out or absorbs water. Small amounts of free water in the Kaolite can have a significant moderating effect if introduced to the fissile core.

Model 5 (Fig. 6.15, Sect. 6.3.1.4) is an extension of Model 3 applied to HEU product oxide contents. Excess water from wet Kaolite is homogenized with the spherical core of water-saturated HEU product oxide and polyethylene (Model 3). Two variations are evaluated: a maximum 13-lb free water from the Kaolite for Cases **5athopw13kr_1** through **5athopw13kr_5** with the $k_{eff} + 2\sigma$ varying from 0.286 to 0.782 and a maximum 15-lb free water for Cases **5athopw15kr_1** through **5athopw15kr_5** with the $k_{eff} + 2\sigma$ varying from 0.292 to 0.830. The homogenized core is under moderated because sufficient water is not present in the wet Kaolite and containment vessel well to reach the point of optimum moderation. While 15-lb water appears an acceptable amount of free water in Kaolite for HEU product oxide content, the 12-lb limit on free water established in Sect. 6.7.3 for the more reactive HEU metal content applies to HEU product oxide in order for it to be shipped by air transport.

Model 6 (Fig. 6.16, Sect. 6.3.1.4) is configured similar to Model 4 with the exception that only a partial amount of HEU product oxide resides in the homogenized core; the remainder of the unsaturated HEU product oxide is modeled as a shell external to the spherical core and internal to the 20.0 cm thick water reflector. As discussed in Sect. 6.9.9.3.1, the amount of HEU product oxide in the homogenized core is varied in 1-kg increments from the full 6-kg amount of Model 5 minus 1 kg (Cases **5athop15kor_1_5_1** to **5athop15kor_5_5_1** with the $k_{eff} + 2\sigma$ ranging varying from 0.483 to 0.572) to an amount of 1-kg HEU product oxide (Cases **5athop15kor_1_1_5** to **5athop15kor_5_1_5** with the $k_{eff} + 2\sigma$ varying from 0.496 to 0.579). The most reactive variation of Model 6 occurs for Case **5athop15kor_5_2_4** ($k_{eff} + 2\sigma = 0.584$)

where 2-kg HEU product oxide (1,761-g $^{235}U$) is homogenized in the core with 11,456.8-g water and 500-g polyethylene, and the remaining 4-kg HEU product oxide (3,521-g $^{235}U$) forms a shell between the core and the 20-cm-thick water reflector.

The most reactive case from all six models is Cases **5atdor_1_1_6** (Table 6.9.9.9-1) which has a $k_{eff} + 2\sigma = 0.917$ and represents a single $UO_2$ sphere of 6-kg HEU product oxide (5,281-g $^{235}U$) at a minimum oxide density of 2-g/cm$^3$ homogenized with 2,448.1-g water and 500-g polyethylene.

### 6.9.9.8 Benchmark Experiments and the Criticality Validation

This information is discussed in Sect. 6.9.8.7. The USL is 0.924 for calculations run using SCALE 5.

### 6.9.9.9 Calculation Results Tables for HEU Product Oxide Contents for Air Transport

Tables 6.9.9.9-1 and 6.9.9.9-2 contain a summary of the calculation results for the HEU product oxide contents to be shipped by air transport as contents in the ES-3100 shipping package.

**Table 6.9.9.9-1. Results for HEU oxide content for air transportation (Models 1–5)**

| Case name | Core | | | | | | | Shell | | | | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oxide (g) | $^{235}U$ (g) | $H_2O$ (g) | $CH_2$ (g) | Kaolite (g) | h/x | Rc (cm) | Kaolite (g) | $H_2O$ (g) | Shell (g) | Rs (cm) | | | | |
| **Compromised package, HEU-poly core in spherical configuration, 20.0-cm water reflector (Model 1)** | | | | | | | | | | | | | | | |
| **$UO_2$ saturated oxide at 6.54 g/cm$^3$** | | | | | | | | | | | | | | | |
| 5atdor_1_5_14 | 14,000 | 12,323 | 861.8 | 500 | na | 3.19 | 8.6213 | na | na | na | na | 0.0633 | 0.86843 | 0.00141 | 0.87125 |
| 5atdor_1_5_13 | 13,000 | 11,443 | 800.2 | 500 | na | 3.29 | 8.4544 | na | na | na | na | 0.0637 | 0.85690 | 0.00144 | 0.85978 |
| 5atdor_1_5_12 | 12,000 | 10,562 | 738.6 | 500 | na | 3.41 | 8.2806 | na | na | na | na | 0.0645 | 0.84384 | 0.00137 | 0.84658 |
| 5atdor_1_5_11 | 11,000 | 9,682 | 677.1 | 500 | na | 3.56 | 8.0992 | na | na | na | na | 0.0651 | 0.83277 | 0.00119 | 0.83515 |
| 5atdor_1_5_10 | 10,000 | 8,802 | 615.5 | 500 | na | 3.73 | 7.9093 | na | na | na | na | 0.0660 | 0.81625 | 0.00152 | 0.81929 |
| 5atdor_1_5_9 | 9,000 | 7,922 | 554.0 | 500 | na | 3.94 | 7.7098 | na | na | na | na | 0.0677 | 0.80044 | 0.00135 | 0.80314 |
| 5atdor_1_5_8 | 8,000 | 7,042 | 492.4 | 500 | na | 4.21 | 7.4994 | na | na | na | na | 0.0690 | 0.78520 | 0.00157 | 0.78834 |
| 5atdor_1_5_7 | 7,000 | 6,162 | 430.9 | 500 | na | 4.55 | 7.2765 | na | na | na | na | 0.0702 | 0.76642 | 0.00132 | 0.76906 |
| 5atdor_1_5_6 | 6,000 | 5,281 | 369.3 | 500 | na | 5.00 | 7.0390 | na | na | na | na | 0.0715 | 0.74917 | 0.00114 | 0.75145 |
| **$UO_2$ saturated oxide, density increasing from 2.0 to 6.54 g/cm$^3$ in 1-g/cm$^3$ increments** | | | | | | | | | | | | | | | |
| 5atdor_1_1_6 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | na | na | na | na | 0.0557 | 0.91417 | 0.00131 | 0.91679 |
| 5atdor_1_2_6 | 6,000 | 5,281 | 1,449.9 | 500 | na | 10.34 | 8.4680 | na | na | na | na | 0.0616 | 0.84504 | 0.00131 | 0.84766 |
| 5atdor_1_3_6 | 6,000 | 5,281 | 950.8 | 500 | na | 7.87 | 7.8722 | na | na | na | na | 0.0655 | 0.80424 | 0.00143 | 0.80710 |
| 5atdor_1_4_6 | 6,000 | 5,281 | 651.4 | 500 | na | 6.39 | 7.4664 | na | na | na | na | 0.0684 | 0.77776 | 0.00140 | 0.78056 |
| 5atdor_1_5_6 | 6,000 | 5,281 | 369.3 | 500 | na | 5.00 | 7.0390 | na | na | na | na | 0.0715 | 0.74917 | 0.00114 | 0.75145 |
| **$U_3O_8$ saturated oxide, density increasing from 2.0 to 6.54 g/cm$^3$ in 1-g/cm$^3$ increments** | | | | | | | | | | | | | | | |
| 5atdor_2_1_6 | 6,000 | 5,078 | 2,273.0 | 500 | na | 14.98 | 9.4576 | na | na | na | na | 0.0579 | 0.88563 | 0.00150 | 0.88863 |
| 5atdor_2_2_6 | 6,000 | 5,078 | 1,274.8 | 500 | na | 9.85 | 8.4680 | na | na | na | na | 0.0637 | 0.81028 | 0.00142 | 0.81312 |
| 5atdor_2_3_6 | 6,000 | 5,078 | 775.7 | 500 | na | 7.29 | 7.8722 | na | na | na | na | 0.0689 | 0.76364 | 0.00147 | 0.76658 |
| 5atdor_2_4_6 | 6,000 | 5,078 | 476.2 | 500 | na | 5.75 | 7.4664 | na | na | na | na | 0.0714 | 0.73359 | 0.00133 | 0.73625 |
| 5atdor_2_5_6 | 6,000 | 5,078 | 194.2 | 500 | na | 4.30 | 7.0390 | na | na | na | na | 0.0751 | 0.69773 | 0.00112 | 0.69997 |

**Table 6.9.9.9-1. Results for HEU oxide content for air transportation (Models 1–5)**

| Case name | Core | | | | | | | Shell | | | | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oxide (g) | $^{235}U$ (g) | $H_2O$ (g) | $CH_2$ (g) | Kaolite (g) | h/x | Rc (cm) | Kaolite (g) | $H_2O$ (g) | Shell (g) | Rs (cm) | | | | |
| **$UO_3$ saturated oxide, density increasing from 2.0 to 6.54 g/cm$^3$ in 1-g/cm$^3$ increments** | | | | | | | | | | | | | | | |
| 5atdor_3_1_6 | 6,000 | 4,983 | 2,173.0 | 500 | na | 14.75 | 9.4576 | na | na | na | na | 0.0582 | 0.87189 | 0.00138 | 0.87465 |
| 5atdor_3_2_6 | 6,000 | 4,983 | 1,174.8 | 500 | na | 9.52 | 8.4680 | na | na | na | na | 0.0647 | 0.79330 | 0.00132 | 0.79594 |
| 5atdor_3_3_6 | 6,000 | 4,983 | 675.7 | 500 | na | 6.91 | 7.8722 | na | na | na | na | 0.0695 | 0.74451 | 0.00130 | 0.74711 |
| 5atdor_3_4_6 | 6,000 | 4,983 | 376.3 | 500 | na | 5.34 | 7.4664 | na | na | na | na | 0.0735 | 0.70743 | 0.00127 | 0.70997 |
| 5atdor_3_5_6 | 6,000 | 4,983 | 94.2 | 500 | na | 3.86 | 7.0390 | na | na | na | na | 0.0774 | 0.66826 | 0.00120 | 0.67066 |
| **$UO_2$ saturated oxide at 2.0 g/cm$^3$** | | | | | | | | | | | | | | | |
| 5atdor_1_1_14 | 14,000 | 12,323 | 5,712.4 | 500 | na | 13.46 | 12.1664 | na | na | na | na | 0.0449 | 1.06986 | 0.00138 | 1.07262 |
| 5atdor_1_1_13 | 13,000 | 11,443 | 5,304.4 | 500 | na | 13.56 | 11.8915 | na | na | na | na | 0.0462 | 1.05375 | 0.00152 | 1.05679 |
| 5atdor_1_1_12 | 12,000 | 10,562 | 4,896.3 | 500 | na | 13.69 | 11.6031 | na | na | na | na | 0.0470 | 1.04068 | 0.00156 | 1.04380 |
| 5atdor_1_1_11 | 11,000 | 9,682 | 4,488.3 | 500 | na | 13.83 | 11.2997 | na | na | na | na | 0.0478 | 1.02468 | 0.00141 | 1.02750 |
| 5atdor_1_1_10 | 10,000 | 8,802 | 4,080.3 | 500 | na | 14.00 | 10.9791 | na | na | na | na | 0.0493 | 1.00466 | 0.00125 | 1.00716 |
| 5atdor_1_1_9 | 9,000 | 7,922 | 3,672.2 | 500 | na | 14.22 | 10.6385 | na | na | na | na | 0.0507 | 0.98663 | 0.00148 | 0.98959 |
| 5atdor_1_1_8 | 8,000 | 7,042 | 3,264.2 | 500 | na | 14.48 | 10.2740 | na | na | na | na | 0.0527 | 0.96167 | 0.00137 | 0.96441 |
| 5atdor_1_1_7 | 7,000 | 6,162 | 2,856.2 | 500 | na | 14.82 | 9.8831 | na | na | na | na | 0.0542 | 0.93946 | 0.00158 | 0.94262 |
| 5atdor_1_1_6 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | na | na | na | na | 0.0557 | 0.91417 | 0.00131 | 0.91679 |
| **Compromised package, HEU-poly core in spherical configuration, stainless-steel shell, 20.0-cm water reflector (Model 2)** | | | | | | | | | | | | | | | |
| **$UO_2$ saturated oxide at 2.0 g/cm$^3$, steel from full amount in the packaging (66,113 g) to none** | | | | | | | | | | | | | | | |
| 5atdosr_11 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | na | na | 66,133 | 14.1521 | 0.0292 | 0.89162 | 0.00136 | 0.89434 |
| 5atdosr_10 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | na | na | 59,520 | 13.8131 | 0.0301 | 0.88373 | 0.00183 | 0.88739 |
| 5atdosr_9 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | na | na | 52,907 | 13.4566 | 0.0313 | 0.88073 | 0.00128 | 0.88329 |
| 5atdosr_8 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | na | na | 46,293 | 13.0802 | 0.0330 | 0.87977 | 0.00157 | 0.88291 |
| 5atdosr_7 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | na | na | 39,680 | 12.6807 | 0.0347 | 0.87051 | 0.00153 | 0.87357 |
| 5atdosr_6 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | na | na | 33,067 | 12.2543 | 0.0367 | 0.86825 | 0.00149 | 0.87123 |
| 5atdosr_5 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | na | na | 26,453 | 11.7960 | 0.0393 | 0.86201 | 0.00170 | 0.86541 |

**Table 6.9.9.9-1. Results for HEU oxide content for air transportation (Models 1–5)**

| Case name | Core | | | | | | | Shell | | | | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oxide (g) | $^{235}U$ (g) | $H_2O$ (g) | $CH_2$ (g) | Kaolite (g) | h/x | Rc (cm) | Kaolite (g) | $H_2O$ (g) | Shell (g) | Rs (cm) | | | | |
| 5atdosr_4 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | na | na | 19,840 | 11.2990 | 0.0420 | 0.85884 | 0.00223 | 0.86330 |
| 5atdosr_3 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | na | na | 13,227 | 10.7539 | 0.0461 | 0.86209 | 0.00210 | 0.86629 |
| 5atdosr_2 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | na | na | 6,613 | 10.1472 | 0.0499 | 0.87559 | 0.00144 | 0.87847 |
| 5atdosr_1 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | na | na | 0 | 9.4577 | 0.0557 | 0.91194 | 0.00135 | 0.91464 |
| **Compromised package, HEU-poly core in spherical configuration, dry (bound water) Kaolite shell, 20.0-cm water reflector (Model 3) $UO_2$ saturated oxide at 2.0 g/cm$^3$, Kaolite from full amount in the packaging (53,419.1 g) to none** | | | | | | | | | | | | | | | |
| 5atdodkr_6 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | 51,214.3 | 2,204.8 | 53,419.1 | 31.2952 | 0.0420 | 0.71552 | 0.00154 | 0.71860 |
| 5atdodkr_5 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | 40,971.5 | 1,763.8 | 42,735.3 | 29.1186 | 0.0435 | 0.72104 | 0.00132 | 0.72368 |
| 5atdodkr_4 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | 30,728.6 | 1,322.9 | 32,051.5 | 26.5564 | 0.0451 | 0.72819 | 0.00126 | 0.73071 |
| 5atdodkr_3 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | 20,485.7 | 881.9 | 21,367.6 | 23.3725 | 0.0476 | 0.74581 | 0.00142 | 0.74865 |
| 5atdodkr_2 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | 10,242.9 | 440.9 | 10,683.8 | 18.9517 | 0.0514 | 0.77362 | 0.00188 | 0.77738 |
| 5atdodkr_1 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | 0.0 | 0.0 | 0.0 | 9.4577 | 0.0556 | 0.91160 | 0.00180 | 0.91520 |
| **Compromised package, HEU-poly core in sph. config., wet (bound plus 15-lb free water) Kaolite shell, 20.0-cm water reflector (Model 3) $UO_2$ saturated oxide at 2.0 g/cm$^3$, Kaolite from full amount in the packaging (53,419.1 g plus 6803.9 g water) to none** | | | | | | | | | | | | | | | |
| 5atdo15kr_6 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | 51,214.3 | 9,008.7 | 60,223.0 | 31.2952 | 0.0352 | 0.72501 | 0.00179 | 0.72859 |
| 5atdo15kr_5 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | 40,971.5 | 7,206.9 | 48,178.4 | 29.1186 | 0.0371 | 0.73185 | 0.00123 | 0.73431 |
| 5atdo15kr_4 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | 30,728.6 | 5,405.2 | 36,133.8 | 26.5564 | 0.0394 | 0.73706 | 0.00135 | 0.73976 |
| 5atdo15kr_3 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | 20,485.7 | 3,603.5 | 24,089.2 | 23.3725 | 0.0424 | 0.74768 | 0.00162 | 0.75092 |
| 5atdo15kr_2 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | 10,242.9 | 1,801.7 | 12,044.6 | 18.9517 | 0.0474 | 0.77452 | 0.00119 | 0.77690 |
| 5atdo15kr_1 | 6,000 | 5,281 | 2,448.1 | 500 | na | 15.27 | 9.4576 | 0.0 | 0.0 | 0.0 | 9.45770 | 0.0561 | 0.91134 | 0.00212 | 0.91558 |

**Table 6.9.9.9-1. Results for HEU oxide content for air transportation (Models 1–5)**

| Case name | Core | | | | | | | Shell | | | | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oxide (g) | $^{235}U$ (g) | $H_2O$ (g) | $CH_2$ (g) | Kaolite (g) | h/x | Rc (cm) | Kaolite (g) | $H_2O$ (g) | Shell (g) | Rs (cm) | | | | |
| **Compromised package, homogeneous fixed-radius core [HEU, poly, wet Kaolite], 20.0-cm water reflector (Model 4)** | | | | | | | | | | | | | | | |
| **$UO_2$ saturated oxide at 2.0 g/cm$^3$** | | | | | | | | | | | | | | | |
| 5athop15kr_5 | 6,000 | 5,281 | 11,456.8 | 500 | 51,214.9 | 59.80 | 31.2953 | na | na | na | na | 0.0581 | 0.57123 | 0.00147 | 0.57417 |
| 5athop15kr_4 | 6,000 | 5,281 | 9,755.7 | 500 | 51,214.9 | 51.39 | 31.2953 | na | na | na | na | 0.0601 | 0.54795 | 0.00112 | 0.55019 |
| 5athop15kr_3 | 6,000 | 5,281 | 8,054.8 | 500 | 51,214.9 | 42.98 | 31.2953 | na | na | na | na | 0.0615 | 0.52486 | 0.00109 | 0.52704 |
| 5athop15kr_2 | 6,000 | 5,281 | 6,353.8 | 500 | 51,214.9 | 34.58 | 31.2953 | na | na | na | na | 0.0639 | 0.50302 | 0.00102 | 0.50506 |
| 5athop15kr_1 | 6,000 | 5,281 | 4,652.9 | 500 | 51,214.9 | 26.17 | 31.2953 | na | na | na | na | 0.0666 | 0.48198 | 0.00105 | 0.48408 |
| **Compromised package, homogeneous core [HEU, poly, free water from wet Kaolite], wet Kaolite shell, 20.0-cm water reflector (Model 5)** | | | | | | | | | | | | | | | |
| **$UO_2$ saturated oxide at 2.0 g/cm$^3$, maximum free water in wet Kaolite limited to 15 lb** | | | | | | | | | | | | | | | |
| 5athopw15kr_5 | 6,000 | 5,281 | 9252.0 | 500 | na | 48.90 | 13.5234 | 51214.9 | 2204.7 | 53419.6 | 31.8395 | 0.0392 | 0.82713 | 0.00145 | 0.83003 |
| 5athopw15kr_4 | 6,000 | 5,281 | 7551.0 | 500 | na | 40.49 | 12.7371 | 51214.9 | 3905.7 | 55120.6 | 31.7052 | 0.0408 | 0.74649 | 0.00140 | 0.74929 |
| 5athopw15kr_3 | 6,000 | 5,281 | 5850.1 | 500 | na | 32.09 | 11.8394 | 51214.9 | 5606.6 | 56821.5 | 31.5697 | 0.0428 | 0.63699 | 0.00131 | 0.63961 |
| 5athopw15kr_2 | 6,000 | 5,281 | 4149.1 | 500 | na | 23.68 | 10.7801 | 51214.9 | 7307.6 | 58522.5 | 31.4331 | 0.0465 | 0.48742 | 0.00132 | 0.49006 |
| 5athopw15kr_1 | 6,000 | 5,281 | 2448.1 | 500 | na | 15.27 | 9.4576 | 51214.9 | 9008.5 | 60223.4 | 31.2952 | 0.0557 | 0.29031 | 0.00072 | 0.29175 |
| **$UO_2$ saturated oxide at 2.0 g/cm$^3$, maximum free water in wet Kaolite limited to 13 lb** | | | | | | | | | | | | | | | |
| 5athopw13kr_5 | 6,000 | 5,281 | 8344.7 | 500 | na | 44.42 | 13.1157 | 51214.9 | 2204.7 | 53419.6 | 31.7680 | 0.0416 | 0.77874 | 0.00159 | 0.78192 |
| 5athopw13kr_4 | 6,000 | 5,281 | 6870.6 | 500 | na | 37.13 | 12.3935 | 51214.9 | 3678.9 | 54893.8 | 31.6512 | 0.0428 | 0.70043 | 0.00128 | 0.70299 |
| 5athopw13kr_3 | 6,000 | 5,281 | 5396.5 | 500 | na | 29.85 | 11.5756 | 51214.9 | 5153.0 | 56367.9 | 31.5334 | 0.0453 | 0.59483 | 0.00127 | 0.59737 |
| 5athopw13kr_2 | 6,000 | 5,281 | 3922.3 | 500 | na | 22.56 | 10.6222 | 51214.9 | 6627.2 | 57842.1 | 31.4148 | 0.0496 | 0.45474 | 0.00112 | 0.45698 |
| 5athopw13kr_1 | 6,000 | 5,281 | 2448.1 | 500 | na | 15.27 | 9.4576 | 51214.9 | 8101.3 | 59316.2 | 31.2952 | 0.0578 | 0.28459 | 0.00072 | 0.28603 |

**Table 6.9.9.9-2. Results for HEU oxide content for air transportation (Model 6)**

| Case name | Core | | | | | | | Shell | | | | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oxide (g) | $^{235}U$ (g) | $H_2O$ (g) | $CH_2$ (g) | Kaolite (g) | h/x | Rc (cm) | $H_2O$ (g) | Oxide (g) | $^{235}U$ (g) | Rs (cm) | | | | |
| **Compromised package, homogeneous core [HEU, poly, wet Kaolite, sat moisture from oxide], dry oxide shell, 20.0-cm water reflector $UO_2$ saturated oxide at 2.0 g/cm$^3$, maximum free water in wet Kaolite limited to 15 lb** | | | | | | | | | | | | | | | |
| 5athop15kor | | | | | | | | | | | | | | | |
| _5_5_1 | 5,000 | 4,401 | 11,456.8 | 500 | 51,214.9 | 71.76 | 31.9731 | na | 1000 | 880 | 32.0075 | 0.0579 | 0.56957 | 0.00117 | 0.57191 |
| _4_5_1 | 5,000 | 4,401 | 9,755.9 | 500 | 51,214.9 | 61.67 | 31.8399 | na | 1000 | 880 | 31.8745 | 0.0598 | 0.54395 | 0.00114 | 0.54623 |
| _3_5_1 | 5,000 | 4,401 | 8,054.9 | 500 | 51,214.9 | 51.58 | 31.7056 | na | 1000 | 880 | 31.7405 | 0.0618 | 0.52367 | 0.00103 | 0.52573 |
| _2_5_1 | 5,000 | 4,401 | 6,353.9 | 500 | 51,214.9 | 41.49 | 31.5701 | na | 1000 | 880 | 31.6053 | 0.0634 | 0.50176 | 0.00107 | 0.50390 |
| _1_5_1 | 5,000 | 4,401 | 4,653.0 | 500 | 51,214.9 | 31.41 | 31.4335 | na | 1000 | 880 | 31.4690 | 0.0665 | 0.48060 | 0.00100 | 0.48260 |
| 5athop15kor | | | | | | | | | | | | | | | |
| _5_4_2 | 4,000 | 3,521 | 11,456.8 | 500 | 51,214.9 | 89.69 | 31.9342 | na | 2000 | 1,761 | 32.0028 | 0.0572 | 0.57314 | 0.00130 | 0.57574 |
| _4_4_2 | 4,000 | 3,521 | 9,755.9 | 500 | 51,214.9 | 77.08 | 31.8006 | na | 2000 | 1,761 | 31.8698 | 0.0587 | 0.55395 | 0.00110 | 0.55615 |
| _3_4_2 | 4,000 | 3,521 | 8,054.9 | 500 | 51,214.9 | 64.47 | 31.6660 | na | 2000 | 1,761 | 31.7358 | 0.0604 | 0.53308 | 0.00132 | 0.53572 |
| _2_4_2 | 4,000 | 3,521 | 6,353.9 | 500 | 51,214.9 | 51.86 | 31.5302 | na | 2000 | 1,761 | 31.6006 | 0.0621 | 0.50942 | 0.00125 | 0.51192 |
| _1_4_2 | 4,000 | 3,521 | 4,653.0 | 500 | 51,214.9 | 39.26 | 31.3932 | na | 2000 | 1,761 | 31.4642 | 0.0642 | 0.48878 | 0.00120 | 0.49118 |
| 5athop15kor | | | | | | | | | | | | | | | |
| _5_3_3 | 3,000 | 2,641 | 11,456.7 | 500 | 51,214.9 | 119.59 | 31.8951 | na | 3000 | 2,641 | 31.9981 | 0.0559 | 0.57798 | 0.00103 | 0.58004 |
| _4_3_3 | 3,000 | 2,641 | 9,755.7 | 500 | 51,214.9 | 102.78 | 31.7612 | na | 3000 | 2,641 | 31.8651 | 0.0574 | 0.55885 | 0.00120 | 0.56125 |
| _3_3_3 | 3,000 | 2,641 | 8,054.8 | 500 | 51,214.9 | 85.97 | 31.6262 | na | 3000 | 2,641 | 31.7310 | 0.0594 | 0.53632 | 0.00102 | 0.53836 |
| _2_3_3 | 3,000 | 2,641 | 6,353.8 | 500 | 51,214.9 | 69.15 | 31.4901 | na | 3000 | 2,641 | 31.5958 | 0.0614 | 0.51426 | 0.00104 | 0.51634 |
| _1_3_3 | 3,000 | 2,641 | 4,652.9 | 500 | 51,214.9 | 52.34 | 31.3527 | na | 3000 | 2,641 | 31.4594 | 0.0632 | 0.49194 | 0.00108 | 0.49410 |
| 5athop15kor | | | | | | | | | | | | | | | |
| _5_2_4 | 2,000 | 1,761 | 11,456.8 | 500 | 51,214.9 | 179.38 | 31.8559 | na | 4000 | 3,521 | 31.9935 | 0.0552 | 0.58113 | 0.00119 | 0.58351 |
| _4_2_4 | 2,000 | 1,761 | 9,755.9 | 500 | 51,214.9 | 154.17 | 31.7217 | na | 4000 | 3,521 | 31.8605 | 0.0566 | 0.55859 | 0.00114 | 0.56087 |
| _3_2_4 | 2,000 | 1,761 | 8,054.9 | 500 | 51,214.9 | 128.95 | 31.5864 | na | 4000 | 3,521 | 31.7263 | 0.0586 | 0.53825 | 0.00116 | 0.54057 |

**Table 6.9.9.9-2. Results for HEU oxide content for air transportation (Model 6)**

| Case name | Core | | | | | | | Shell | | | | nlf | $k_{eff}$ | σ | $k_{eff} + 2\sigma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oxide (g) | $^{235}U$ (g) | $H_2O$ (g) | $CH_2$ (g) | Kaolite (g) | h/x | Rc (cm) | $H_2O$ (g) | Oxide (g) | $^{235}U$ (g) | Rs (cm) | | | | |
| _2_2_4 | 2,000 | 1,761 | 6,353.9 | 500 | 51,214.9 | 103.73 | 31.4499 | na | 4000 | 3,521 | 31.5910 | 0.0604 | 0.51481 | 0.00120 | 0.51721 |
| _1_2_4 | 2,000 | 1,761 | 4,653.0 | 500 | 51,214.9 | 78.51 | 31.3122 | na | 4000 | 3,521 | 31.4545 | 0.0617 | 0.49484 | 0.00121 | 0.49726 |
| 5athop15kor | | | | | | | | | | | | | | | |
| _5_1_5 | 1,000 | 880 | 11,456.8 | 500 | 51,214.9 | 358.71 | 31.8167 | na | 5000 | 4,401 | 31.9888 | 0.0546 | 0.57631 | 0.00127 | 0.57885 |
| _4_1_5 | 1,000 | 880 | 9,755.9 | 500 | 51,214.9 | 308.28 | 31.6822 | na | 5000 | 4,401 | 31.8558 | 0.0555 | 0.55694 | 0.00118 | 0.55930 |
| _3_1_5 | 1,000 | 880 | 8,054.9 | 500 | 51,214.9 | 257.85 | 31.5465 | na | 5000 | 4,401 | 31.7216 | 0.0569 | 0.53685 | 0.00094 | 0.53873 |
| _2_1_5 | 1,000 | 880 | 6,353.9 | 500 | 51,214.9 | 207.43 | 31.4096 | na | 5000 | 4,401 | 31.5862 | 0.0586 | 0.51698 | 0.00112 | 0.51922 |
| _1_1_5 | 1,000 | 880 | 4,653.0 | 500 | 51,214.9 | 157.00 | 31.2716 | na | 5000 | 4,401 | 31.4497 | 0.0604 | 0.49388 | 0.00101 | 0.49590 |

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## Appendix 6.9.10

## Analysis of HEU Oxide ($U_3O_8$) with Carbon Concentrations for Shipment in the ES-3100

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## Appendix 6.9.10

## Analysis of HEU Oxide ($U_3O_8$) with Carbon Concentrations for Shipment in the ES-3100

Calculations were performed examining varying the amount of $U_3O_8$ and carbon (often referred to as skull oxide) in the containment vessel (CV) of the ES-3100 package. In these calculations a mixture of $U_3O_8$, carbon and 513 g of polyethylene was modeled together with a net weight of 16,000 g. The skull oxide is modeled at bulk densities from 3.054 to 2.0 g/cm$^3$. The methodologies for calculating the densities, volumes, etc. are presented in Sect. 6.9.3.1 under the "HEU Oxide" subheading.

Calculations were performed for the fully reflected CV and single unit (NCT and HAC) with varying the specific gravity of water inside the CV as well as varying the combination of $U_3O_8$ and carbon inside the CV. Calculations were also performed for an infinite array (NCT and HAC) with the CV dry and flooded varying the specific gravity of water outside the CV and varying the combination of $U_3O_8$ and carbon inside the CV.

KENO V.a calculations were performed using CSAS5 in SCALE 6.1 on the Microway Parallel Linux Cluster ENGHPC01 at the Y-12 National Security Complex (Engineering organization) in Oak Ridge, Tennessee. The upper subcriticality limit (USL) is 0.957 as documented in RP 02-F-0014 000 00, *Critical Experiment Benchmark Calculations with CSAS5 from SCALE6.1 for Interim Criticality Safety Analyses on the HP Integrity Series rx3600 (CMODH),* and Y/DD-1221, *Determination of the Upper Subcritical Limit for Criticality Calculations for Criticality Safety Analyses*. The results for all cases presented in this appendix are below the USL.

For the CV model analysis, calculations were performed examining the density of skull oxide at 3.054, 2.5, and 2.0 g/cm$^3$ while varying the specific gravity of water in the CV and varying the combination of $U_3O_8$ and carbon inside the CV. The results are shown in Tables 6.9.10-1 through 6.9.10-3.

**Table 6.9.10-1. CV model, skull oxide at 3.054 g/cm$^3$**

| MOCFR | $U_3O_8$ mass (g) / carbon mass (g) [a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **15,487 / 0** | **14,487 / 1,000** | **13,487 / 2,000** | **11,487 / 4,000** | **7,487 / 8,000** | **5,487 / 10,000** | **1,487 / 14,000** | **1,000 / 14,487** |
| | **$k_{eff}$ + 2σ, USL = 0.957** | | | | | | | |
| 1.0E-20 | 0.56460 | 0.56160 | 0.55930 | 0.55240 | 0.53620 | 0.51910 | 0.45820 | 0.46240 |
| 0.001 | 0.56460 | 0.56220 | 0.55980 | 0.55060 | 0.53540 | 0.52170 | 0.45840 | 0.43440 |
| 0.1 | 0.59035 | 0.58800 | 0.58480 | 0.57910 | 0.55770 | 0.54190 | 0.47790 | 0.45120 |
| 0.3 | 0.64760 | 0.64120 | 0.63480 | 0.62746 | 0.60254 | 0.58430 | 0.51600 | 0.48700 |
| 0.5 | 0.70170 | 0.69500 | 0.68760 | 0.67760 | 0.65020 | 0.62990 | 0.55290 | 0.52370 |
| 0.7 | 0.75220 | 0.75080 | 0.74910 | 0.73200 | 0.69430 | 0.67470 | 0.58850 | 0.55978 |
| 0.9 | 0.81000 | 0.80650 | 0.79770 | 0.78000 | 0.74400 | 0.71830 | 0.63190 | 0.59650 |
| 1.0 | 0.83560 | 0.82840 | 0.82450 | 0.80560 | 0.76620 | 0.74070 | 0.64760 | 0.61450 |

[a] Total mass of contents (oxide and carbon) is 15,487 g. Included is 513 g of polyethylene.

**Table 6.9.10-2. CV model, skull oxide at 2.5 g/cm$^3$**

| MOCFR | $U_3O_8$ mass (g) / carbon mass (g) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **15,487 / 0** | **14,487 / 1,000** | **13,487 / 2,000** | **11,487 / 4,000** | **7,487 / 8,000** | **5,487 / 10,000** | **1,487 / 14,000** | **1,000 / 14,487** |
| | **$k_{eff}$ + 2σ, USL = 0.957** | | | | | | | |
| 1.0E-20 | 0.53860 | 0.53586 | 0.53170 | 0.52370 | 0.50350 | 0.48630 | 0.41650 | 0.38909 |
| 0.001 | 0.53992 | 0.53564 | 0.53130 | 0.52450 | 0.50320 | 0.48800 | 0.41760 | 0.39106 |
| 0.1 | 0.56790 | 0.54580 | 0.56078 | 0.55200 | 0.52970 | 0.51400 | 0.44332 | 0.41630 |
| 0.3 | 0.63010 | 0.62730 | 0.62161 | 0.61360 | 0.58740 | 0.57130 | 0.49800 | 0.46640 |
| 0.5 | 0.69700 | 0.69030 | 0.68634 | 0.67450 | 0.64860 | 0.63170 | 0.55280 | 0.52010 |
| 0.7 | 0.76060 | 0.75710 | 0.74850 | 0.73737 | 0.70970 | 0.69050 | 0.61300 | 0.57760 |
| 0.9 | 0.82310 | 0.81790 | 0.81290 | 0.80190 | 0.77060 | 0.75190 | 0.66700 | 0.63240 |
| 1.0 | 0.85740 | 0.85020 | 0.84190 | 0.83160 | 0.79780 | 0.77840 | 0.63295 | 0.65740 |

**Table 6.9.10-3. CV model, skull oxide at 2.0 g/cm$^3$**

| MOCFR | $U_3O_8$ mass (g) / carbon mass (g) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **15,487 / 0** | **14,487 / 1,000** | **13,487 / 2,000** | **11,487 / 4,000** | **7,487 / 8,000** | **5,487 / 10,000** | **1,487 / 14,000** | **1,000 / 14,487** |
| | **$k_{eff}$ + 2σ, USL = 0.957** | | | | | | | |
| 1.0E-20 | 0.51310 | 0.50961 | 0.50522 | 0.49726 | 0.47280 | 0.45687 | 0.38237 | 0.35444 |
| 0.001 | 0.51260 | 0.50980 | 0.50420 | 0.49780 | 0.47260 | 0.45770 | 0.38286 | 0.35398 |
| 0.1 | 0.54530 | 0.54270 | 0.53830 | 0.52870 | 0.50630 | 0.48891 | 0.41130 | 0.38140 |
| 0.3 | 0.61710 | 0.61240 | 0.60660 | 0.59870 | 0.57390 | 0.55650 | 0.47640 | 0.44290 |
| 0.5 | 0.68790 | 0.68250 | 0.67810 | 0.67340 | 0.64700 | 0.62850 | 0.54680 | 0.51108 |
| 0.7 | 0.76380 | 0.75860 | 0.75530 | 0.74130 | 0.72130 | 0.70150 | 0.61450 | 0.57880 |
| 0.9 | 0.83800 | 0.82840 | 0.82740 | 0.81920 | 0.79420 | 0.77520 | 0.68520 | 0.64520 |
| 1.0 | 0.87210 | 0.86790 | 0.86220 | 0.85430 | 0.82400 | 0.81210 | 0.71780 | 0.67670 |

From the results in Tables 6.9.10-1 through 6.9.10-3, reactivity decreases when carbon is substituted for $U_3O_8$, regardless of the water content inside of the CV and the density of the skull oxide. The lower density skull oxide is more reactive for the flooded CV cases (MOCFR = 1.0), while the higher density skull oxide is more reactive for the dry CV cases (MOCFR = 1.0E-20). The lower density skull oxide has more void space that allows more water to mix with the skull oxide resulting in a more moderated system.

The carbon concentration is varied from 0 to 93% in these cases. Based on the trend of reactivity as carbon is increased (and oxide is conversely decreased), there is no need to limit carbon concentration in this ES-3100 content.

In the single unit cases for both NCT and HAC, calculations were performed examining the density of skull oxide at 3.054 and 2.0 g/cm$^3$ while varying the specific gravity of water in the CV

(MOCFR) and the combination of $U_3O_8$ and carbon inside the CV as in the previous calculations. The single package results are in Tables 6.9.10-4 through 6.9.10-7.

**Table 6.9.10-4. Single package NCT model, skull oxide at 3.054 g/cm$^3$**

| MOCFR | $U_3O_8$ mass (g) / carbon mass (g) | | | | |
|---|---|---|---|---|---|
| | **15,487 / 0** | **14,487 / 1,000** | **13,487 / 2,000** | **7,487 / 8,000** | **1,000 / 14,487** |
| | **$k_{eff}$ + 2σ, USL = 0.957** | | | | |
| 1.0E-20 | 0.40423 | 0.39839 | 0.39696 | 0.36324 | 0.25784 |
| 0.001 | 0.40381 | 0.39996 | 0.39609 | 0.36189 | 0.25851 |
| 0.3 | 0.49703 | 0.49580 | 0.48887 | 0.44880 | 0.32640 |
| 0.7 | 0.63302 | 0.62974 | 0.62020 | 0.56390 | 0.42030 |
| 0.9 | 0.67990 | 0.69180 | 0.68540 | 0.62370 | 0.46150 |
| 1.0 | 0.73320 | 0.72280 | 0.71550 | 0.64870 | 0.48640 |

**Table 6.9.10-5. Single package HAC model, skull oxide at 3.054 g/cm$^3$**

| MOCFR | $U_3O_8$ mass (g) / carbon mass (g) | | | | |
|---|---|---|---|---|---|
| | **15,487 / 0** | **14,487 / 1,000** | **13,487 / 2,000** | **7,487 / 8,000** | **1,000 / 14,487** |
| | **$k_{eff}$ + 2σ, USL = 0.957** | | | | |
| 1.0E-20 | 0.40600 | 0.40309 | 0.39853 | 0.36580 | 0.26009 |
| 0.001 | 0.40783 | 0.40187 | 0.39867 | 0.36376 | 0.25961 |
| 0.3 | 0.50207 | 0.49697 | 0.49170 | 0.44810 | 0.32660 |
| 0.7 | 0.63670 | 0.62710 | 0.62160 | 0.56630 | 0.41870 |
| 0.9 | 0.70330 | 0.69450 | 0.68530 | 0.62300 | 0.46470 |
| 1.0 | 0.73180 | 0.72480 | 0.71950 | 0.65150 | 0.48760 |

**Table 6.9.10-6. Single package NCT model, skull oxide at 2.0 g/cm$^3$**

| MOCFR | $U_3O_8$ mass (g) / carbon mass (g) | | | | |
|---|---|---|---|---|---|
| | **15,487 / 0** | **14,487 / 1,000** | **13,487 / 2,000** | **7,487 / 8,000** | **1,000 / 14,487** |
| | **$k_{eff}$ + 2σ, USL = 0.957** | | | | |
| 1.0E-20 | 0.32541 | 0.32053 | 0.31509 | 0.27326 | 0.15994 |
| 0.001 | 0.32783 | 0.32155 | 0.31695 | 0.27208 | 0.15932 |
| 0.3 | 0.44860 | 0.44499 | 0.43910 | 0.39593 | 0.27473 |
| 0.7 | 0.63010 | 0.62370 | 0.62150 | 0.57880 | 0.44830 |
| 0.9 | 0.71870 | 0.71430 | 0.70750 | 0.67020 | 0.52880 |
| 1.0 | 0.76230 | 0.75960 | 0.75170 | 0.71360 | 0.56920 |

**Table 6.9.10-7. Single package HAC model, skull oxide at 2.0 g/cm$^3$**

| MOCFR | $U_3O_8$ mass (g) / carbon mass (g) | | | | |
|---|---|---|---|---|---|
| | 15,487 / 0 | 14,487 1,000 | 13,487 / 2,000 | 7,487 / 8,000 | 1,000 / 14,487 |
| | $k_{eff}$ + 2σ, USL = 0.957 | | | | |
| 1.0E-20 | 0.32923 | 0.32350 | 0.31813 | 0.27483 | 0.16122 |
| 0.001 | 0.33068 | 0.32465 | 0.31935 | 0.27373 | 0.16128 |
| 0.3 | 0.45118 | 0.44533 | 0.44050 | 0.39870 | 0.27790 |
| 0.7 | 0.63180 | 0.62680 | 0.62140 | 0.58460 | 0.46990 |
| 0.9 | 0.71940 | 0.71450 | 0.71190 | 0.67260 | 0.53150 |
| 1.0 | 0.76340 | 0.76210 | 0.75780 | 0.71490 | 0.57080 |

From the results in the Tables 6.9.10-4 through 6.9.10-7 as in the CV model cases, reactivity decreases when carbon is substituted for $U_3O_8$, regardless of the water content inside of the CV and the density of the skull oxide. As in the CV model cases, the lower density skull oxide is more reactive for the flooded CV cases, while the higher density skull oxide is more reactive for the dry CV cases.

The comparison of the single package case results with corresponding case results for the reflected CV reveals that flooded ES-3100 packaging is not as good a reflector as 30.48 cm water surrounding the CV.

In the array cases with a dry CV for both NCT and HAC, calculations were performed examining the density of skull oxide at 3.054 and 2.0 g/cm$^3$ while varying the specific gravity of water outside the CV (MOIFR) and varying the combination of $U_3O_8$ and carbon inside the CV as in the previous calculations. The results are shown in Tables 6.9.10-8 through 6.9.10-11 for an infinite array of packages with a dry CV.

**Table 6.9.10-8. Array NCT model, dry CV, skull oxide at 3.054 g/cm$^3$**

| MOIFR | $U_3O_8$ mass (g) / carbon mass (g) | | | | |
|---|---|---|---|---|---|
| | 15,487 / 0 | 14,487 / 1,000 | 13,487 / 2,000 | 7,487 / 8,000 | 1,000 / 14,487 |
| | $k_{eff}$ + 2σ, USL = 0.957 | | | | |
| 1.0E-20 | 0.56165 | 0.54870 | 0.53862 | 0.45151 | 0.25300 |
| 1.0E-5 | 0.56180 | 0.55003 | 0.53785 | 0.45108 | 0.25550 |
| 1.0E-4 | 0.56017 | 0.54945 | 0.53821 | 0.45210 | 0.25383 |
| 0.1 | 0.45517 | 0.44516 | 0.43835 | 0.37301 | 0.21741 |
| 0.5 | 0.39469 | 0.39060 | 0.38402 | 0.34017 | 0.21939 |
| 1.0 | 0.42080 | 0.41890 | 0.41091 | 0.37447 | 0.26306 |

**Table 6.9.10-9. Array HAC model, dry CV, skull oxide at 3.054 g/cm$^3$**

| MOIFR | $U_3O_8$ mass (g) / carbon mass (g) | | | | |
|---|---|---|---|---|---|
| | **15,487 / 0** | **14,487 / 1,000** | **13,487 / 2,000** | **7,487 / 8,000** | **1,000 / 14,487** |
| | **$k_{eff}$ + 2σ, USL = 0.957** | | | | |
| 1.0E-20 | 0.56103 | 0.54934 | 0.54061 | 0.45186 | 0.25352 |
| 1.0E-5 | 0.56149 | 0.55022 | 0.53791 | 0.44956 | 0.25319 |
| 1.0E-4 | 0.56313 | 0.54946 | 0.53832 | 0.45197 | 0.25274 |
| 0.1 | 0.46388 | 0.45686 | 0.44660 | 0.38164 | 0.22138 |
| 0.5 | 0.40292 | 0.39590 | 0.38932 | 0.34667 | 0.22153 |
| 1.0 | 0.42604 | 0.42273 | 0.41710 | 0.37920 | 0.26615 |

**Table 6.9.10-10. Array NCT model, dry CV, skull oxide at 2.0 g/cm$^3$**

| MOIFR | $U_3O_8$ mass (g) / carbon mass (g) | | | | |
|---|---|---|---|---|---|
| | **15,487 / 0** | **14,487 / 1,000** | **13,487 / 2,000** | **7,487 / 8,000** | **1,000 / 14,487** |
| | **$k_{eff}$ + 2σ, USL = 0.957** | | | | |
| 1.0E-20 | 0.52816 | 0.51332 | 0.50093 | 0.39537 | 0.16320 |
| 1.0E-5 | 0.53034 | 0.51517 | 0.49982 | 0.39497 | 0.16186 |
| 1.0E-4 | 0.52718 | 0.51458 | 0.49841 | 0.39540 | 0.16346 |
| 0.1 | 0.39146 | 0.37887 | 0.36902 | 0.29331 | 0.12435 |
| 0.5 | 0.31940 | 0.31237 | 0.30568 | 0.24990 | 0.12377 |
| 1.0 | 0.34726 | 0.34230 | 0.33551 | 0.29028 | 0.16864 |

**Table 6.9.10-11. Array HAC model, dry CV, skull oxide at 2.0 g/cm$^3$**

| MOIFR | $U_3O_8$ mass (g) / carbon mass (g) | | | | |
|---|---|---|---|---|---|
| | **15,487 / 0** | **14,487 / 1,000** | **13,487 / 2,000** | **7,487 / 8,000** | **1,000 / 14,487** |
| | **$k_{eff}$ + 2σ, USL = 0.957** | | | | |
| 1.0E-20 | 0.52950 | 0.51564 | 0.50131 | 0.39554 | 0.16276 |
| 1.0E-5 | 0.52934 | 0.51587 | 0.49931 | 0.39621 | 0.16264 |
| 1.0E-4 | 0.52813 | 0.51486 | 0.50064 | 0.39490 | 0.16349 |
| 0.1 | 0.40195 | 0.39206 | 0.38067 | 0.30319 | 0.12908 |
| 0.5 | 0.32642 | 0.32061 | 0.31447 | 0.25763 | 0.12661 |
| 1.0 | 0.35284 | 0.34675 | 0.34003 | 0.29260 | 0.17106 |

From the results in the Tables 6.9.10-8 through 6.9.10-11 as in the CV model and single package cases, reactivity decreases when carbon is substituted for $U_3O_8$. Increasing the interstitial water moderation between the packages also results in decreasing reactivity.

In the array cases with a flooded CV for both NCT and HAC, calculations were performed examining the density of skull oxide at 3.054 and 2.0 g/cm$^3$ while varying the specific gravity of water outside the CV (MOIFR) and varying the combination of $U_3O_8$ and carbon inside the CV as in the previous calculations. The results are shown in Tables 6.9.10-12 through 6.9.10-15 for an infinite array of packages with flooded CVs.

**Table 6.9.10-12. Array NCT model, flooded CV, skull oxide at 3.054 g/cm$^3$**

| MOIFR | $U_3O_8$ mass (g) / carbon mass (g) | | | | |
|---|---|---|---|---|---|
| | **15,487 / 0** | **14,487 / 1,000** | **13,487 / 2,000** | **7,487 / 8,000** | **1,000 / 14,487** |
| | **$k_{eff}$ + 2σ, USL = 0.957** | | | | |
| 1.0E-20 | 0.85860 | 0.84436 | 0.83310 | 0.73440 | 0.50100 |
| 1.0E-5 | 0.86230 | 0.84750 | 0.83510 | 0.73400 | 0.50090 |
| 1.0E-4 | 0.86110 | 0.84760 | 0.83440 | 0.73360 | 0.50210 |
| 0.1 | 0.76870 | 0.76100 | 0.74720 | 0.66350 | 0.45900 |
| 0.5 | 0.72440 | 0.71580 | 0.70880 | 0.63610 | 0.45590 |
| 1.0 | 0.74760 | 0.74080 | 0.72870 | 0.66260 | 0.49630 |

**Table 6.9.10-13. Array HAC model, flooded CV, skull oxide at 3.054 g/cm$^3$**

| MOIFR | $U_3O_8$ mass (g) / carbon mass (g) | | | | |
|---|---|---|---|---|---|
| | **15,487 / 0** | **14,487 / 1,000** | **13,487 / 2,000** | **7,487 / 8,000** | **1,000 / 14,487** |
| | **$k_{eff}$ + 2σ, USL = 0.957** | | | | |
| 1.0E-20 | 0.85990 | 0.84650 | 0.83380 | 0.73750 | 0.50210 |
| 1.0E-5 | 0.85952 | 0.84710 | 0.83390 | 0.73770 | 0.50000 |
| 1.0E-4 | 0.86000 | 0.84900 | 0.83380 | 0.73400 | 0.49910 |
| 0.1 | 0.78030 | 0.76690 | 0.75690 | 0.66791 | 0.46087 |
| 0.5 | 0.73100 | 0.72430 | 0.71373 | 0.64050 | 0.45890 |
| 1.0 | 0.75070 | 0.74260 | 0.73387 | 0.66610 | 0.49900 |

**Table 6.9.10-14. Array NCT model, flooded CV, skull oxide at 2.0 g/cm$^3$**

| MOIFR | $U_3O_8$ mass (g) / carbon mass (g) | | | | |
|---|---|---|---|---|---|
| | **15,487/ 0** | **14,487/ 1,000** | **13,487/ 2,000** | **7,487/ 8,000** | **1,000/ 14,487** |
| | **$k_{eff}$ + 2σ, USL = 0.957** | | | | |
| 1.0E-20 | 0.93580 | 0.93000 | 0.91590 | 0.84750 | 0.62600 |
| 1.0E-5 | 0.93740 | 0.92490 | 0.91720 | 0.84840 | 0.62500 |
| 1.0E-4 | 0.93680 | 0.92580 | 0.91620 | 0.84500 | 0.62470 |
| 0.1 | 0.82120 | 0.81400 | 0.80540 | 0.74740 | 0.56400 |
| 0.5 | 0.76010 | 0.75310 | 0.75070 | 0.70810 | 0.54820 |
| 1.0 | 0.77990 | 0.77440 | 0.77000 | 0.72940 | 0.58170 |

**Table 6.9.10-15. Array HAC model, flooded CV, skull oxide at 2.0 g/cm$^3$**

| MOIFR | $U_3O_8$ mass (g) / carbon mass (g) | | | | |
|---|---|---|---|---|---|
| | **15,487/ 0** | **14,487/ 1,000** | **13,487/ 2,000** | **7,487/ 8,000** | **1,000/ 14,487** |
| | **$k_{eff}$ + 2σ, USL = 0.957** | | | | |
| 1.0E-20 | 0.93320 | 0.92510 | 0.91530 | 0.84470 | 0.62600 |
| 1.0E-5 | 0.93500 | 0.92740 | 0.91563 | 0.84370 | 0.62730 |
| 1.0E-4 | 0.93360 | 0.92790 | 0.91830 | 0.84490 | 0.62580 |
| 0.1 | 0.83010 | 0.82290 | 0.81510 | 0.75700 | 0.57190 |
| 0.5 | 0.76890 | 0.76190 | 0.75700 | 0.71370 | 0.55380 |
| 1.0 | 0.78540 | 0.77880 | 0.77240 | 0.73250 | 0.58200 |

From the results in the Tables 6.9.10-12 through 6.9.10-15 as in the CV model, single package, and arrays with dry CV cases—reactivity decreases when carbon is substituted for $U_3O_8$. Increasing the interstitial water moderation between the packages also results in decreasing reactivity.

Based on the results of these cases, it is concluded that reactivity decreases when carbon is substituted for $U_3O_8$. This holds true regardless of the density of the bulk oxide or the amount of moderation material (water) in the $U_3O_8$ oxide matrix. Thus, substituting carbon for $U_3O_8$ oxide is bounded by the $U_3O_8$ oxide mass limit, and there should be no limit on the carbon concentration.

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# 7. PACKAGE OPERATIONS

Radioactive material packages shall be operated in accordance with applicable U.S. Nuclear Regulatory Commission (NRC), U.S. Department of Transportation (DOT), and other federal, state, and local regulations to protect the health and safety of the public, workers, and the environment. Furthermore, the packages shall be operated according to a quality assurance (QA) plan approved by the U.S. Department of Energy (DOE), Office of Environmental Management; or DOE, National Nuclear Security Administration (DOE/NNSA); as appropriate.

The user is responsible for following the established NRC regulations for packaging, preparation for shipment, and transportation of radioactive materials given in Title 10, Part 71, of the Code of Federal Regulations (CFR) [10 CFR 71] as well as DOT regulations for packaging and shipment of hazardous materials given in Title 49 CFR. DOE nuclear facility users are responsible for implementing DOE regulations given in Title 10, Parts 830 and 835, of the CFR in addition to directives conveyed in DOE Order (O) 232.2, DOE O 414.1D, and DOE O 460.1C or DOE O 461.1B, as appropriate.

Specific operational criteria for the ES-3100 package with highly enriched uranium (HEU) content are presented in this section. Where appropriate, facility management may authorize the adjustment of the explicit implementation sequence in this section to accommodate facility-specific workflow logistics and operational requirements. The package user shall develop detailed, written site-specific operating procedures based on the Certificate of Compliance (CoC), the criteria contained herein, and the facility's operational requirements. These procedures shall be in accordance with 10 CFR 71, Subparts A, G, and H; DOT and DOE regulations; and applicable state, tribal, and local regulations not preempted by DOT. The operating procedures should also describe interim activities to be performed if the package is to be temporarily stored prior to shipment. Storage incident to transportation shall be in accordance with the facility Safety Analysis Report (10 CFR 830) or the Transportation Safety Document (TSD) [DOE O 460.1C or DOE O 461.2, as applicable].

The package operations should be consistent with maintaining occupational radiation exposures as low as reasonably achievable (ALARA) [10 CFR 71.87(i)] in addition to addressing applicable safety aspects or activities such as personal protection (radiation, chemical, and physical); contamination or radiation surveys; nuclear criticality safety; provisions for reporting safety concerns associated with the packaging or its use; and the records and reporting requirements cited in Appendix 7.5.1. The user of the packaging shall:

1. have authorization to acquire, package, or transport radioactive, fissile, or special nuclear materials;

2. have the latest CoC and safety analysis report for packaging (SARP) for the ES-3100 package with HEU content, and comply with all actions and restrictions therein;

3. be registered as a user of the ES-3100 packaging with DOE;

4. comply with the applicable requirements of the DOT regulations in Title 49 CFR, Parts 107, 171–180, and 390–397, as appropriate to the mode of transport (10 CFR 71.5); and

5. have a site-approved QA program that meets the requirements of 10 CFR 71, Subpart H.

The ES-3100 package description is presented in Sect. 1.2 with a schematic shown in Fig. 1.1, and an exploded view of the packaging components is presented in Fig. 1.2. The ES-3100 certification drawing can be found in Appendix 1.3.1. The packaging design drawings (Appendix 1.3.7) provide material lists, dimensions, safety components, welding requirements, and gasket requirements. The largest nominal gross shipping weight of the ES-3100 package with bulk HEU content is 187.81 kg (414.05 lb) and the maximum allowable gross weight is 190.5 kg (420 lb).

The ES-3100 is handled using industry-standard drum-handling equipment. When using a forklift, the ES-3100 can be placed on the tines of the forklift from below, or it is designed for a forklift pincher assembly that can be used to grasp the exterior of the drum assembly. Forklift gripping forces of up to 5400 lb can be used with no detrimental effects on the package (Sect. 1.2.1.1).

The site-specific operating procedures which include the facility's operational requirements shall ensure that:

1. All appropriate documents have been reviewed by operating personnel and are available for further review, if necessary.

2. Certified equipment is used (e.g., torque wrenches, instrumentation, scales, lifting hardware, and radiation survey instruments) in accordance with the site-approved QA program.

3. Segregated work stations, curtains, lead blankets, personnel protective equipment, or other equipment is used, as necessary, to protect workers and nearby personnel from radioactive material hazards.

4. Appropriate material handling equipment is available and approved for use (e.g., forklifts, hoists, and drum handlers). Operating controls shall be implemented for any forklift pincher assembly to limit clamping forces on the drum body (i.e., $\leq$ 5400 lb).

5. Appropriate provisions to decontaminate packages and packaging components are provided consistent with ALARA principles.

6. An optional radio-frequency identification (RFID) monitoring system tag may be secured to the drum assembly in accordance with the applicable requirements of ANL/DIS-09-5. The mounting bracket for the RFID monitoring system tag shall provide the equivalent contact area of a drum washer and the thread engagement for the drum hex nuts shall remain unchanged. When attached, the RFID tag will extend beyond the outside diameter of the drum body, and controls shall be implemented to avoid damage to the RFID tag.

Care should be exercised to control the packaging components when they are removed to ensure that parts are kept with the packaging and not mixed with other loose parts or parts from other packagings. Other preparations should be made to minimize damage or loss of packaging components. The drum and CV are marked with their serial numbers. The numbers are used to control these parts and to accumulate their respective operational and maintenance histories. Applicable serial numbers of packaging components should be verified to ensure that these components are maintained together. Loose parts (e.g., hex nuts, washers, and O-rings) may be reused if it can be shown that they were the parts that were removed and that no damage to the parts has occurred. Otherwise, they shall be discarded and replaced with certified parts. In order to maintain configuration control of the packaging components, the user shall ensure that there are no unauthorized modifications and no substitution of components with unauthorized components. The user may replace certain parts identified in Table 7.1, and the certification of all replacement parts must be traceable. The user shall document any part replacement identifying it to a specific packaging by model and serial number.

If packaging components are stored for an extended period of time, they may be bagged. The packaging components will be stored in weather-protected indoor facilities and transferred between facilities in an enclosed conveyance for protection from environmental elements. Generally, the exterior surface of the packaging components will remain relatively clean; however, each user will include provisions in the operating procedures to clean packaging components as necessary. Additionally, special precautions should be taken to protect the packaging from inadvertent contamination by radioactive materials. In radiological contamination areas, the packaging or package should be placed onto surfaces that are covered with a disposable covering, such as plastic or paper, to minimize the transfer of contamination.

The reference to nonfixed (removable) surface contamination is repeated throughout the various operating sections. It is essential that radiation exposure be minimized to protect the health and safety of the public, workers, and the environment. As the package is prepared to enter the public domain, the surface contamination level of the package and the conveyance will be maintained ALARA.

All personnel who support and/or perform packaging, transfer and transportation operations will be appropriately trained and qualified in accordance with the site-approved QA program; 49 CFR 171.1; and 49 CFR 172, Subpart H, as appropriate. Auditable training records will be maintained in accordance with site record retention requirements.

## 7.1 PACKAGE LOADING

This section addresses the operational criteria relating to the preparation for loading, loading of contents, and preparation for transport of the ES-3100 package. Implementation of the operational criteria in this section along with the conditions of the CoC and the requirements of 10 CFR 71.5 will ensure that the package is properly prepared for transport.

### 7.1.1 Preparation for Loading

The user shall develop detailed operating procedures which include, at a minimum, the process steps listed below for content and packaging preparation activities.

#### 7.1.1.1 Content preparation

Operating personnel shall ensure that:

1. The HEU material has been verified as being within the limits specified in this SARP and the CoC for content form, material mass, material dimensions, uranium content, and $^{235}U$ enrichment as presented in Sect. 1.2.2. The contents shall be verified using accountability records and weight measurements.

   **Note:** A radiation survey of the contents may be conducted prior to loading to measure the content dose rate. The measured dose rate should be compared with known or calculated values. This is not a requirement and generally should only be performed if there are shielding concerns.

**Table 7.1. Replacement parts for the ES-3100 packaging**

| Part | Description | Material | Specification/ Data Sheet [a] |
|---|---|---|---|
| **ES-3100 drum assembly (Drawing M2E801580A001, Appendix 1.3.7)** | | | |
| Drum lid hex nut | 5/8-11 UNC hex nut | Silicon bronze | ASTM F 467 per ASME B18.2.2<br>M2E801580A005-3 |
| Drum lid washer | 0.844-in. ID × 1.375-in. OD × 0.25-in.-thick | Stainless steel | ASTM A 240 or<br>ASTM A 276<br>M2E801580A005-4 |
| Nylon plug | Vent-hole plug (installed around circumference of the drum body and on top of the top plug) | Nylon 6/6 | Micro Plastic, Inc. Part 62MP0312 or equivalent<br>M2E801580A002-8<br>M2E801580A008-7 |
| Silicone rubber pads (CV bottom, CV flange, and plug) | | Silicone rubber 22 ± 5 Shore A | M2E801580A009-1<br>M2E801580A009-2<br>M2E801580A009-3 |
| Aluminum tape | Duct tape, low temperature (−40 to +250°F), 2-in. wide | Aluminum foil | M2E801580A002-11<br>McMaster-Carr Part 7616A21 or equivalent |
| **ES-3100 containment vessel assembly (Drawing M2E801580A011, Appendix 1.3.7)** | | | |
| Outer O-ring [b] | 5.859-in. ID × 0.139-in. diam cross section | Ethylene propylene diene monomer (EPDM); or fluorocarbon elastomer (Viton) Parker Compound VM835-75 | ASTM D 2000, M2E801580A013-2;<br>or<br>SAE AMS-R-83485, Type 1, M801580-0013-2 |
| Inner O-ring [b] | 5.359-in. ID × 0.139-in. diam cross section | EPDM; or fluorocarbon elastomer (Viton) Parker Compound VM835-75 | ASTM D 2000, M2E801580A013-1;<br>or<br>SAE AMS-R-83485, Type 1, M801580-0013-1 |
| Modified VCO [c] threaded plug with O-ring | Leak-test-port plug | Brass | Volunteer Industrial P/N 04-2126<br>M2E801580A011-6 |

[a] All items beginning with"M2E" or "M8" are part numbers and the parts are shown on the corresponding drawings in Appendix 1.3.7.
[b] Containment vessel O-rings shall be installed in sets of EPDM or fluorocarbon elastomer. Dissimilar O-rings are not permitted (i.e., one EPDM and one fluorocarbon elastomer O-ring).
[c] VCO—Vacuum coupling O-ring.

2. Packing materials (e.g., convenience cans or bottles, polyethylene bags, silicone can pads, can spacers, stainless-steel scrubbers, etc.) are visually inspected for signs of moisture, corrosion, or physical damage.

3. If the contents are broken HEU metal and alloy, proceed to Step 4. For all other contents, proceed to Step 7.

4. For proper handling of broken HEU metal and alloy, pyrophoric concerns will be addressed by one of the following options:

   a. Treat all broken HEU metal and alloy content as pyrophoric and proceed to Step 6; or

   b. Determine whether or not the broken HEU metal and alloy content is pyrophoric in accordance with Step 5.

5. For pyrophoric categorization of broken HEU metal and alloy content, the specific surface area of the metal pieces (surface area to mass ratio) is evaluated. If the specific surface area is $\leq$1.00 $cm^2/g$, then the metal pieces are not pyrophoric and are acceptable for loading according to Step 7. If the specific surface area is >1.00 $cm^2/g$ or if the specific surface area cannot be evaluated, characterize the metal using the following methods:

   a. Solid-metal pieces that are clearly larger than 3/8 in. in every dimension do not require additional size-grading determinations and are acceptable for loading according to Step 7.

   b. Items which are unacceptable by definition (Sect. 1.2.2), such as powders, foils, wires, and turnings, will be rejected and do not require additional size-grading determinations. These items will be loaded according to Step 6.

   c. Any items that are not obviously larger than the 3/8 in. in every dimension must be size-graded using a 3/8-in. (9.5-mm) mesh sieve as follows:

      **Note:** With facility management approval, equivalent size-grading methods may be used [e.g., 3/8-in. (9.5 mm) mesh screens, visual comparison to size standards, etc.].

      i. Any item that falls through the sieve must be rejected and will be loaded according to Step 6.

      **Note:** Operators need to be alert to items which may not fall through the sieve but can be rejected based on the following criteria:

         - Long, thin shapes such as wires and turnings may not fall through the sieve when shaken. If the wire or turning could be picked up and poked through the mesh it must be rejected, even if it did not fall through unassisted.

         - Wires or turnings may form a tangled ball which will not fall through the sieve. If the wire or turning could be separated and poked through the sieve, it must be rejected.

         - Foils, thin chips or shards (any item less than 1/8-in. thick) must be rejected.

      ii. The metal pieces that are not rejected by the criteria above are acceptable for loading according to Step 7.

6. Load the rejected broken HEU metal and alloy content in a sealed container under an inert cover gas (e.g., argon or nitrogen).

   **Note:** The sealed container with an inert atmosphere will be leaktight as defined in ANSI N14.5-1997.

7. All contents are loaded in appropriate cans, bottles, or bags with associated packing material in accordance with the allowable loading limits and restrictions specified in Sect. 1.2.2.

#### 7.1.1.2 Packaging preparation

Operating personnel shall ensure that:

1. A valid leak-test sticker is present on the drum to ensure that the required periodic maintenance (Sect. 8.2) and leak testing has been performed.

2. For planning purposes, the following conditions will be satisfied:

   a. The package will arrive at its destination prior to the expiration of the CoC;

   b. The package must be loaded in the approved conveyance and the conveyance operator must take custody of the package prior to the leak-test expiration date [recorded on the leak-test label (see Fig. 8.1) on the exterior of the drum]; and

   c. When shipping HEU oxides or uranyl nitrate crystals (UNX), the shipper must verify that the shipment can be completed within the time period allotted [2 or 4 months from CV closure for UNX crystals (Table 1.3a) or 1 year from CV closure for HEU oxides (Table 1.3)].

3. The level of nonfixed radioactive contamination on the external surfaces of the packaging is ALARA and within the limits specified in 49 CFR 173.443 for alpha-, beta-, and gamma-emitting radionuclides or the user's site-specific criteria (whichever is more stringent).

4. The exterior surface of the packaging is visually inspected for signs of moisture, corrosion, or physical damage and is in good condition.

5. If installed on the empty packaging, the tamper-indicating devices (TIDs) are removed when authorized.

6. The drum hex nuts and washers are removed.

   **Note:** If the optional RFID monitoring system tag is installed, remove the RFID tag in accordance with the applicable requirements of ANL/DIS-09-5.

7. The drum lid is removed.

8. Site-approved lifting hardware is attached to the top plug threaded lifting holes and the top plug is removed.

9. Accessible portions of the interior of the drum body and top plug are visually inspected for signs of moisture, corrosion, or physical damage and are in good condition.

10. The silicone rubber CV flange pad is removed from the top of the CV.

    **Note:** A contamination survey of the exposed drum liner and top of the CV may be conducted if there are contamination concerns.

11. The silicone rubber CV flange pad and plug pad are visually inspected for signs of moisture and physical damage. There are no gouges, cuts, tears, or nondesign voids in the pads.

12. The top of the CV is visually inspected for signs of moisture, corrosion, or physical damage and is in good condition. There are no visible signs of damage and the CV sealing lid is secure.

13. The swivel hoist ring is installed in the CV sealing lid and torqued to 16.27 ± 1.36 N·m (12 ± 1 ft-lb) [Drawing M2E801580A011, Appendix 1.3.7].

14. The CV is lifted from the drum body using the swivel hoist ring and site-approved lifting equipment, and the exterior surface of the CV is visually inspected for signs of moisture, corrosion, or physical damage.

15. Comparisons of the serial number etched on the following locations are in agreement:

    a. trefoil data plate located on the side of the drum body,
    b. side of the CV body,
    c. top of the CV sealing lid, and
    d. top of the CV lid closure nut.

16. The leak-test labels are present on the drum and the CV with the recorded expiration date.

17. The drum liner is visually inspected for signs of moisture, corrosion, or physical damage.

18. The aluminum foil tape applied over the neutron-absorbing material cavity fill and vent holes (four places) located on the drum liner lower shelf (Drawing M2E801580A002, Appendix 1.3.7) is visually inspected for damage such as tears, holes, or loose edges.

19. The silicone rubber CV bottom pad is installed in the bottom of the drum cavity. If necessary, the CV bottom pad is removed and visually inspected for signs of moisture and physical damage. There are no gouges, cuts, tears, or nondesign voids in the pad.

20. In order to support the CV during disassembly and loading operations, users have two options:

    a. Install a site-approved support plate on the top of the drum body and lower the CV into the drum body with the CV flange resting on the support plate; or

    b. Lower the CV into a site-approved support stand.

21. The swivel hoist ring is removed from the CV sealing lid.

22. The CV lid assembly is removed and placed on a protective surface to prevent scratching of the sealing surface.

    **Note:** A contamination survey of the CV interior surfaces may be conducted if there are contamination concerns.

23. Any packing materials (e.g., convenience cans or bottles, polyethylene bags, silicone rubber can pads, can spacers, stainless-steel metal scrubbers), if present, are removed from the CV.

24. The interior of the CV is visually inspected for signs of moisture, corrosion, or physical damage and is in good condition.

25. Isopropyl alcohol and lint-free gloves, cloths, or swabs are used to clean the CV interior surface, as necessary.

### 7.1.2 Loading of Contents

The user shall develop detailed operating procedures which include, at a minimum, the process steps listed below for loading content into the CV. Operating personnel shall ensure that:

1. The CV has been emptied of radioactive contents as far as practical.

2. The O-rings and the O-ring grooves on the CV flange are protected from damage during loading operations.

3. The HEU content and associated packing materials (e.g., convenience cans or bottles, polyethylene bags, silicone rubber can pads, can spacers, stainless-steel metal scrubbers) are prepared for loading in accordance with the requirements of Sect. 1.2.2. The weight of the CV payload (HEU content including all packing materials) shall not exceed 40.82 kg (90 lb).

4. The CV payload is loaded into the CV body in accordance with Sect. 1.2.2.

#### 7.1.2.1 CV assembly and leak testing

The user shall develop detailed operating procedures which include, at a minimum, the process steps listed below for preparing the CV for closure and leak testing. Operating personnel shall ensure that:

1. The CV O-rings and sealing surfaces are cleaned and inspected as follows:

    **Note:** The O-rings are retained in half-dovetail grooves and may be removed from the CV flange grooves as necessary to facilitate cleaning and inspection activities. Exercise care during removal and installation to avoid damage to the O-rings and O-ring grooves.

    a. Clean the sealing surfaces and O-rings, as required, with isopropyl alcohol and lint-free gloves, cloths, or swabs.

    b. Visually inspect the sealing surfaces for foreign matter, nicks, and scratches. If nicks or scratches are found, review Sect. 8.2.2 for evaluation criteria.

c. Visually inspect the inner and outer O-rings for roughness, porosity, or surface defects. Damaged O-rings may be replaced with certified replacement O-rings (Table 7.1) subject to the requirements of Sect. 8.1.5.1 and the following:

i. If the outer O-ring is damaged and requires replacement, then it can be replaced without performing the maintenance leakage rate testing (Sect. 8.2.2).

**Note:** The outer O-ring is not part of the containment boundary. The outer O-ring functions as a seal to create the annulus between the O-rings in support of preshipment leak testing.

ii. If the inner O-ring is damaged and requires replacement, the HEU content shall be removed (see Steps 14-16 in Sect. 7.2.2), and the leakage testing of the containment boundary shall be performed in accordance with Sect. 8.2.2 by qualified personnel.

**Note:** Although only the inner O-ring is installed during the leakage testing (Sect. 8.2.2), both O-rings will be replaced during periodic maintenance in accordance with Sect. 8.2.3.1.

2. The O-rings are lubricated as necessary with a thin coat of Super-O-Lube and inserted into the CV flange grooves.

3. The CV lid closure nut threads are visually inspected for damage and foreign matter. If necessary, clean the threads with lint-free gloves, cloths, or swabs.

4. A thin coat of Krytox grease, Grade 240 AC, is applied as necessary to the CV lid closure nut threads (Drawing M2E801580A011, Appendix 1.3.7).

5. The CV lid assembly is positioned over the CV body with the two alignment pins in the CV flange engaged in the slots on the underside of the CV lid assembly.

6. The CV lid closure nut is torqued to 162.7 ± 6.78 N·m (120 ± 5 ft-lb) [Drawing M2E801580A011, Appendix 1.3.7].

**Note:** If the content is HEU oxide or uranyl nitrate crystals (UNX), the seal date is recorded (see Sect. 7.1.1.2, Step 2c).

7. The annulus between the CV O-rings is leak tested to either (1) a leakage rate of not more than the reference air leakage rate, $L_R$, or (2) no detected leakage when tested to a sensitivity of at least $1 \times 10^{-3}$ ref-cm$^3$/s in accordance with the requirements of ANSI N14.5-1997, Subclause 7.6, *Preshipment leakage rate test*. The preshipment leak-test procedure shall meet the requirements of ANSI N14.5-1997 and the site-approved QA program. Y-12 Product Specification Procedure Y51-01-B2-R-074, *Shipping Container Leak Test* (Appendix 7.5.2) is provided as an example preshipment leak-test procedure. It should be noted that the leakage rate acceptance criteria stated in Procedure Y51-01-B2-R-074 is lower (i.e., more conservative) than the ANSI N14.5-1997 requirements noted above for a preshipment leak test. Operating personnel shall perform the following at a minimum:

a. Ensure that the preshipment leak testing is performed in accordance with procedures that meet the criteria presented above and that the results are properly documented.

b. Ensure that leak-test instrumentation has been properly calibrated.

c. Remove the modified VCO threaded brass plug from the CV lid assembly leak-test port.

**Note:** If the plug O-ring is not retained on the VCO threaded plug during plug removal, then use caution when extracting the plug O-ring to prevent damage of the leak-test port O-ring sealing surface.

d. Connect the leak-test equipment to the leak-test port.

e. Perform the preshipment leak test under isothermal conditions.

f. Disconnect the leak-test equipment.

g. Install the modified VCO threaded brass plug in the CV lid assembly leak-test port.

Following a successful preshipment leak test, the CV is ready to be loaded into the drum body assembly per Sect. 7.1.2.2. However, if the preshipment leak test fails to reach the required vacuum/pressure or fails the leak test, then the following measures should be taken: (1) review the operating procedures; (2) check the leak-test equipment and connections; (3) check the test gauges and instrumentation including verification of calibration and certification records, as necessary; and (4) verify isothermal test conditions. The user is also cautioned to allow sufficient time after applying the required vacuum or pressure for the O-ring annulus to reach thermal equilibrium.

The CV lid assembly shall be removed if none of the measures described above reveal the root cause for the leak-test failure. Care should be taken to control all parts on removal and then Steps 1-7 specified above shall be repeated. If the preshipment leak test fails again, the HEU content shall be removed by performing Steps 14–16 in Sect. 7.2.2. The packaging and O-rings shall be tagged as "potential" nonconforming parts and returned to the packaging maintenance organization for closer examination and disposition.

### 7.1.2.2 Drum closure

The user shall develop detailed operating procedures which include, at a minimum, the process steps listed below for preparing the drum assembly for closure. Operating personnel shall ensure that:

1. The CV assembly with HEU content was prepared for loading into the drum body assembly in accordance with Sect. 7.1.2.1.

2. The loaded CV, top plug, drum lid, plug pad, CV bottom pad, CV flange pad, drum nuts and washers, TIDs, and optional RFID monitoring system tag are available.

3. The swivel hoist ring is installed in the CV sealing lid and torqued to 16.27 ± 1.36 N·m (12 ± 1 ft-lb) [Drawing M2E801580A011, Appendix 1.3.7].

4. The loaded CV is lifted using the swivel hoist ring and site-approved lifting equipment.

5. If the CV was loaded while supported in the drum body, then remove the site-approved support plate.

6. The loaded CV is lowered into the drum body cavity and the swivel hoist ring is removed.

7. The CV flange pad is placed over the top of the CV and the plug pad is placed on the top shelf of the drum liner (Drawing M2E801580A001, Appendix 1.3.7).

8. The nylon plug is installed in the top plug vent hole and site-approved lifting hardware is attached to the top plug threaded lifting holes.

9. The top plug is installed in the drum (Drawing M2E801580A001, Appendix 1.3.7) and the lifting hardware is removed.

10. The drum weld studs and hex nut threads are visually inspected for damage and foreign matter. If necessary, clean the threads with lint-free gloves, cloths, or swabs.

11. The drum lid is positioned over the drum with the holes in the lid aligned with the weld studs and the TID lugs, and the lid is lowered into position.

12. The eight 5/8-11 UNC-2B hex nuts with washers (Drawing M2E801580A005, Appendix 1.3.7) are installed and the nuts are torqued to 40.67 ± 6.78 N·m (30 ± 5 ft-lb) [Drawing M2E801580A001, Appendix 1.3.7]. **An impact wrench shall not be used.**

    **Note:** An optional RFID monitoring system tag may be installed in accordance with the applicable requirements of ANL/DIS-09-5.

13. A nylon plug is installed in each of the four drum vent holes (Drawing M2E801580A002, Appendix 1.3.7).

14. As required by site-specific requirements, either one or two TIDs are attached through the drum TID links.

15. The gross weight of the package does not exceed 190.5 kg (420 lb).

16. All "EMPTY" or inappropriate labels previously affixed to the drum body in conformance with 49 CFR 172, Subpart E are removed, obliterated, or covered. Leak-test labels should not be removed. The drum body is cleaned as necessary including the removal of any adhesive residue from removed labels.

17. The level of nonfixed radioactive contamination on the external surfaces of the package is ALARA and within the limits specified in 49 CFR 173.443 for alpha-, beta-, and gamma-emitting radionuclides or the user's site-specific criteria (whichever is the most stringent).

18. The maximum radiation level at the package surface is measured. In addition, the maximum radiation level at 1 m from the external surface shall be measured to establish the transport index (TI) for the package. The radiation levels should be compared with the expected levels (Sect. 5), as appropriate, and evaluated against the allowable radiation levels prescribed in 10 CFR 71.47 and 49 CFR 173.441.

19. The package is labeled in accordance with 49 CFR 172, Subpart E, and the user shall particularly note the requirements of 49 CFR 172.403, *Class 7 (radioactive) material*.

    **Note:** It is recommended that all labels should be vinyl type or placed on plain vinyl tape and applied to the packaging to facilitate removal during maintenance.

20. The package is marked in accordance with 49 CFR 172, Subpart D. The user shall particularly note the requirements of 49 CFR 172.301, *General marking requirements for non-bulk packagings* and 49 CFR 172.310, *Class 7 (radioactive) materials*.

    **Note:** If the proper shipping name and identification number etched on the ES-3100 data plate (Drawing M2E801580A010, Appendix 1.3.7) is not appropriate for the contents, then the "Radioactive Material" and "Package, Fissile UN3328" marking on the data plate will be covered with opaque vinyl tape, and the package will be marked as required by 49 CFR 172.301.

21. The DOE CoC number [USA/9315/B(U)F-96 (DOE)] is marked on the drum body by one of the following methods:

    a. **Preferred method.** The NRC CoC number [USA/9315/B(U)F-96] will be covered with opaque vinyl tape and the package will be marked near the data plate with the DOE CoC number in letters at least ½-in. high.

    b. **Alternate method.** A "(DOE)" marking in letters at least ½-in. high will be added adjacent to right-hand side of the data plate in line with the NRC CoC number.

### 7.1.3 Preparation for Transport

The transfer of the package to an onsite storage or staging area prior to offsite shipment shall be accomplished in accordance with the facility Safety Analysis Report or the TSD, as applicable. The criticality safety index (CSI) may vary from 0–3.2 for the authorized content and fissile mass loading limits (Table 1.3). Because the dose rate (and therefore the TI) presented in Sect. 5 is conservative, the actual TI, which is measured at the time of shipment, should be lower than the maximum calculated TI value for the HEU content (TI = 5.8 for 36 kg of HEU metal and TI = 4.9 for 24 kg of HEU oxide (Tables 5.1 and 5.2, respectively). These TI values are greater than or equal to the TI values for the other authorized content and fissile mass loading limits (Sect. 5.1.1).

In support of criticality safety evaluations (Sect. 6.3.1.4) and due to the potential exposure to environmental elements during transfer or handling operations, all packages prepared for air transport will be appropriately covered with an industry-standard drum cover or other waterproof cover to protect against water from entering the drum cavity. After loading in the aircraft, the drum covering may be removed to facilitate tie down of the package.

### 7.1.3.1 Package transfer or handling

The user shall develop detailed operating procedures which include, at a minimum, the process steps listed below for preparing the package for transfer or handling**.** Operating personnel shall ensure that:

1. The level of nonfixed radioactive contamination on the external surfaces of the package is ALARA and within the limits specified in 49 CFR 173.443 for alpha-, beta-, and gamma-emitting radionuclides or the user's site-specific criteria (whichever is more stringent).

2. Appropriate package labels are affixed to the package's surface and TIDs are properly installed.

3. Placement restrictions associated with onsite handling, storage, staging, or transfer of radioactive materials for onsite operations are identified. These activities are governed by the applicable requirements of the TSD (DOE O 460.1C or DOE O 461.2, as appropriate) and the facility Safety Analysis Report (10 CFR 830).

4. All packages prepared for air transport will be appropriately covered with an industry-standard drum cover or other waterproof cover to protect against water from entering the drum cavity. After loading in the aircraft, the drum covering may be removed to facilitate tie down of the package.

### 7.1.3.2 Decontamination

As the package is prepared to enter the public domain, the surface contamination level of the package will be maintained ALARA. The user shall develop detailed operating procedures for decontaminating packages that consider, at a minimum, the items listed below:

1. The drum is austenitic stainless steel.
2. The drum nuts are silicon bronze.
3. The drum vent holes are covered with nylon plugs (Drawing M2E801580A002, Appendix 1.3.7).
4. The labels and markings on the drum must remain legible.

### 7.1.3.3 Requirements prior to shipment

The shipper shall notify the receiver of the scheduled shipment [49 CFR 173.22(c)] and verify that the receiver has agreed to accept the shipment. If needed, the shipper shall provide any special instructions to the receiver to safely open the package (10 CFR 71.89), including special tools and precautions for handling or unloading. In addition, the shipper will submit appropriate documentation to the receiver to ensure that the physical characteristics and hazards of the HEU content are conveyed (49 CFR 172, Subpart C).

Before each shipment, the shipper shall ensure that the appropriate routine determinations (10 CFR 71.87) and the quality control requirements (49 CFR 173.475) have been satisfied. Detailed operating procedures shall provide evidence that the requirements stated above are met and ensure that:

1. The package has been loaded properly and preparation for shipment has been followed, witnessed, and checked.

2. When shipping HEU oxides or UNX, the shipper provides the receiver with the date that the CV was sealed. The shipper must verify that the shipment can be completed within the time period allotted [2 or 4 months for UNX crystals (Table 1.3a) or 1 year for HEU oxides (Table 1.3)].

3. All records for the shipment are prepared and maintained (Sect. 7.5.1.1) [10 CFR 71.91(a)].

4. The shipping papers including the appropriate shipper's certification (declaration) statement are prepared in accordance with 49 CFR 172, Subpart C.

5. The placarding requirements of 49 CFR 172, Subpart F, are addressed.

6. The emergency response information in accordance with 49 CFR 172, Subpart G, is addressed.

7. As determined by 49 CFR 172.800, security plans are developed in accordance with 49 CFR 172, Subpart I.

#### 7.1.3.4 Securing to the approved conveyance

The package shall be secured against movement within the conveyance in which it is being transported under conditions normally incident to transportation. The user shall develop detailed operating procedures that include, at a minimum, the process steps listed below for loading and securing the package on the approved conveyance. Operating personnel shall ensure that:

1. An approved conveyance is used in accordance with the CoC-authorized mode of transport.

2. Reasonable precautions such as wheel chocking are taken to prevent motion of the conveyance during package loading.

3. The package must be loaded in the approved conveyance and the conveyance operator must take custody of the package prior to the leak-test expiration date [recorded on the leak-test label (see Fig. 8.1) on the exterior of the drum].

4. The consignment is positioned on the conveyance under the direction of qualified personnel in such a way that the weight is properly distributed over the width and length of the conveyance.

5. The ends, sides, or doors of the conveyance are not relied upon to prevent shifting of loads.

6. The package is secured in the conveyance using blocking, bracing, and tie-down equipment that meet industry-standard practices to prevent shifting during Normal Conditions of Transport (NCT) [49 CFR 173.448(a); 49 CFR 175.88(c) and 49 CFR 177.842(d)].

## 7.2 PACKAGE UNLOADING

Placement restrictions associated with onsite handling, storage, staging, or transfer of radioactive materials for onsite operations will be identified. These activities are governed by the applicable requirements of the TSD (DOE O 460.1C or DOE O 461.2, as appropriate) and the facility Safety Analysis Report (10 CFR 830).

If HEU oxide or UNX are being shipped, the receiver shall check the seal time and date before opening the container (shipment time restrictions for these contents are discussed in Sect. 1.2.2.8). The receiver shall open the CV prior to the seal time expiring or take special precautions in accordance with the facility Safety Analysis Report requirements when handling and opening the container. Special precautions are associated with the potential buildup of >5 mol % hydrogen in the CV (Appendix 3.5.4). Typical precautions may include, but are not limited to, elimination of ignition sources, gradually opening the CV in a well-ventilated area, or opening the CV in an inert glove box.

### 7.2.1 Receipt of Package from Carrier

The user shall develop detailed operating procedures that include, at a minimum, the process steps listed below for receiving a package and performing contamination and radiation surveys of the package. Operating personnel shall ensure that:

1. Documentation is received that conveys the physical characteristics and hazards of the package including any special instructions provided in accordance with Sect. 7.1.3.3.

2. When offered by the carrier for delivery, the TIDs on the conveyance (if required) and on the package are examined for signs of tampering. The general appearance of the conveyance and the package are noted.

3. The shipping papers are compared with the consignment, and the package is accepted.

4. The enclosed cargo space of the conveyance is examined for moisture and free liquids. If present, they will be surveyed for contamination and removed.

5. The external surfaces of the package are surveyed for removable radioactive contamination and radiation levels (10 CFR 835.405).

    a. The package nonfixed surface contamination levels are within the limits specified in 49 CFR 173.443 for alpha-, beta-, and gamma-emitting radionuclides or the user's site-specific criteria (whichever is more stringent).

    b. The radiation levels do not exceed the limits specified in 10 CFR 71.47 and 49 CFR 173.441.

6. The conveyance restraint gear was properly used to secure the package.

7. Appropriate labeling and marking of the package is checked for compliance.

8. The package restraint gear is removed and the package is removed from the conveyance.

9. The package is visually inspected for exterior surface damage during shipping or handling.

    **Note:** If the package surface is damaged, a nonconformance tag shall be completed and attached to the package for subsequent maintenance (10 CFR 71.131).

All users shall include provisions for reporting safety concerns associated with the packaging or its use. The user shall comply with reporting requirements in accordance with DOE O 232.2, which delineates specific reporting periods in accordance with the category of the occurrence. In addition to the requirements of Sect. 7.5.1.3, incidents requiring notification include the following:

1. Nonfixed radioactive surface contamination is in excess of the limits specified in 49 CFR 173.443.

2. Radiation levels are in excess of the limits specified in 10 CFR 71.47 and 49 CFR 173.441.

3. Discrepancies exist between the shipping papers and the consignment.

4. TIDs are found to be compromised.

5. Adverse conditions are found (i.e., entrapped moisture, noncompliant items/conditions, or visible damage that may significantly reduce the package performance).

### 7.2.2 Removal of Contents

The user shall develop detailed operating procedures that include, at a minimum, the process steps listed below for removing the contents from the package. Operating personnel shall ensure that:

1. Appropriate labels and markings for the content are affixed to the exterior surface of the drum body.

2. The TIDs remain intact until authorized for removal.

   **Note:** Notify DOE in accordance with DOE O 232.2 if they are found to be compromised.

3. The drum hex nuts and washers are removed.

   **Note:** If the optional RFID monitoring system tag is installed, remove the RFID tag in accordance with the applicable requirements of ANL/DIS-09-5.

4. The drum lid is removed.

5. Accessible portions of the top plug and interior of the drum body are visually inspected for signs of moisture, corrosion, or physical damage and are in good condition.

6. Site-approved lifting hardware is attached to the top plug threaded lifting holes, and the top plug is removed.

7. The silicone rubber CV flange pad is removed from the top of the CV.

8. A contamination survey of the exposed drum liner and top of the CV is conducted to determine if there was a release of radioactive material.

   **Note:** If the nonfixed surface contamination levels exceed the limits specified in 49 CFR 173.443 for alpha-, beta-, and gamma-emitting radionuclides, notify DOE in accordance with DOE O 232.2.

9. The top of the CV is visually inspected for signs of moisture, corrosion, or physical damage and is in good condition.

10. The swivel hoist ring is installed in the CV sealing lid and torqued to 16.27 ± 1.36 N·m (12 ± 1 ft-lb) [Drawing M2E801580A011, Appendix 1.3.7].

11. The CV is lifted from the drum body using the swivel hoist ring and site-approved lifting equipment and the external surfaces of the CV are visually inspected for signs of moisture, corrosion, or physical damage.

12. In order to support the CV during disassembly and unloading operations, users have two options:

    a. Install a site-approved support plate on the top of the drum body and lower the CV into the drum body with the CV flange resting on the support plate; or

    b. Lower the CV into a site-approved support stand.

13. The swivel hoist ring is removed from the CV sealing lid.

14. The CV lid assembly is removed and placed on a protective surface to prevent scratching of the sealing surface.

    **Note:** A contamination survey of the CV interior surface may be conducted if there are contamination concerns.

15. The O-rings and the O-ring grooves on the CV flange are protected from damage.

16. The HEU content and associated packing materials (e.g., convenience cans or bottles, polyethylene bags, silicone rubber can pads, can spacers, stainless-steel metal scrubbers) are removed from the CV in accordance with site-specific radioactive material handling procedures.

    **Note:** A contamination survey of the CV interior surfaces and packing materials may be conducted if there are contamination concerns.

17. The HEU content and shipping configuration are compared with the applicable information on the shipping papers and the conditions of approval in the CoC. Instances in which the conditions of approval in the CoC were not observed in making a shipment shall be reported in accordance with Sect. 7.5.1.3.

## 7.3 PREPARATION OF EMPTY PACKAGE FOR TRANSPORT

General requirements for shipping an empty packaging are provided in 49 CFR 173.428, *Empty Class 7 (radioactive) materials packaging.* The user shall develop detailed operating procedures which include, at a minimum, the process steps listed below to prepare an empty package for transport. Operating personnel shall ensure that:

1. The package has been emptied of radioactive contents as far as practical and the CV internal contamination level does not exceed 100 times the limits in 49 CFR 173.443(a).

2. Isopropyl alcohol and lint-free gloves, cloths, or swabs are used to clean the CV as necessary.

3. The CV sealing surfaces are visually checked for foreign matter, nicks, and scratches. If nicks or scratches are found, review Sect. 8.2.2 for evaluation criteria.

4. The O-rings are free from debris and have not been damaged. The O-rings can be cleaned with isopropyl alcohol and wiped with lint-free gloves, cloths, or swabs.

5. The O-rings are lubricated as necessary with a thin coat of Super-O-Lube and inserted into the CV flange grooves.

6. The CV lid closure nut threads are visually inspected for damage and foreign matter. If necessary, clean the threads with lint-free gloves, cloths, or swabs.

7. A thin coat of Krytox grease, Grade 240 AC, is applied as necessary to the CV lid closure nut threads (Drawing M2E801580A011, Appendix 1.3.7).

8. The CV lid assembly is positioned over the CV body with the two alignment pins in the CV flange engaged in the slots on the underside of the CV lid assembly.

9. The CV lid closure nut is torqued to 162.7 ± 6.78 N·m (120 ± 5 ft-lb) [Drawing M2E801580A011, Appendix 1.3.7].

10. The modified VCO threaded brass plug is installed in the CV lid assembly leak-test port.

11. The CV, top plug, drum lid, plug pad, CV bottom pad, CV flange pad, drum nuts and washers, TIDs, and optional RFID monitoring system tag (depending on site-specific requirements) are available.

12. The aluminum foil tape applied over the neutron-absorbing material cavity fill and vent holes (four places) located on the drum liner lower shelf (Drawing M2E801580A002, Appendix 1.3.7) is visually inspected for damage such as tears, holes, or loose edges.

13. The swivel hoist ring is installed in the CV sealing lid and torqued to 16.27 ± 1.36 N·m (12 ± 1 ft-lb) [Drawing M2E801580A011, Appendix 1.3.7].

14. The CV is lifted using the swivel hoist ring and site-approved lifting equipment.

15. If the CV was supported in the drum body, then remove the site-approved support plate.

16. The CV bottom pad is installed in the bottom of the drum cavity.

17. The CV is lowered into the drum body cavity and the swivel hoist ring is removed.

18. The CV flange pad is placed over the top of the CV and the plug pad is placed on the top shelf of the drum liner (Drawing M2E801580A001, Appendix 1.3.7).

19. The nylon plug is installed in the top plug vent hole and site-approved lifting hardware is attached to the top plug threaded lifting holes.

20. The top plug is installed in the drum (Drawing M2E801580A001, Appendix 1.3.7) and the lifting hardware is removed.

21. The drum weld studs and hex nut threads are visually inspected for damage and foreign matter. If necessary, clean the threads with lint-free gloves, cloths, or swabs.

22. The drum lid is positioned over the drum with the holes in the lid aligned with the weld studs and the TID lugs, and the lid is lowered into position.

23. The eight, 5/8-11 UNC-2B, hex nuts with washers (Drawing M2E801580A005, Appendix 1.3.7) are installed and the nuts are torqued to 40.67 ± 6.78 N·m (30 ± 5 ft-lb) [Drawing M2E801580A001, Appendix 1.3.7]. **An impact wrench shall not be used.**

    **Note:** An optional RFID monitoring system tag may be installed in accordance with the applicable requirements of ANL/DIS-09-5.

24. A nylon plug is installed in each of the four drum vent holes (Drawing M2E801580A002, Appendix 1.3.7).

25. If required by site-specific requirements, TIDs are attached through the drum TID links.

26. Any inappropriate labels previously affixed to the drum body in conformance with 49 CFR 172, Subpart E are removed, obliterated, or covered. Leak-test labels should not be removed. The drum body is cleaned as necessary including the removal of any adhesive residue from removed labels.

27. The level of nonfixed radioactive contamination on the external surfaces of the package is ALARA and within the limits specified in 49 CFR 173.443(a) for alpha-, beta-, and gamma-emitting radionuclides or the user's site-specific criteria (whichever is more stringent).

28. The "EMPTY" label prescribed in 49 CFR 172.450 is affixed to the drum. Labels should be vinyl type or placed on plain vinyl tape and applied to the packaging to facilitate removal during maintenance.

29. The "Radioactive Material, Type B(U) Package, Fissile UN3328" marking on the ES-3100 data plate is covered with opaque vinyl tape, and the package is marked "UN2908" in accordance with 49 CFR 173.428.

30. The radiation level at any point on the external surface of the package does not exceed 0.5 mrem/h.

31. The package is prepared for shipment as specified in 49 CFR 173.422.

## 7.4 OTHER OPERATIONS

There are no additional special controls unique to this package.

## 7.5 APPENDICES

7.5.1 Records and Reporting Requirements

7.5.2 Example Leak-test Procedure, Y-12 Product Specification Procedure Y51-01-B2-R-074, *Shipping Container Leak Test*

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## Appendix 7.5.1

## Records and Reporting Requirements

### 7.5.1.1 Records for each shipment

A record of each shipment shall be maintained for a period of 3 years after the shipment in accordance with Title 10, Part 71, Sect. 91(a), of the Code of Federal Regulations (CFR) [10 CFR 71.91(a)]. As specified in 10 CFR 71.91(c), records are only valid if stamped, initialed, or signed and dated by authorized personnel, or otherwise authenticated. These records shall include:

1. The identification of the packaging by model and serial number.
2. Verification that there were no significant defects in the packaging as shipped.
3. Type and quantity of radioactive material in each package and total quantity for each shipment.
4. Date of the shipment.
5. Any special controls exercised.
6. Name and address of the transferee (receiver).
7. Address to which the shipment was made.
8. Results of the determinations required by 10 CFR 71.87 and 49 CFR 173.475 (including documentation of replacement parts) and conditions of approval in the Certificate of Compliance (CoC).

If requested, records of the package shipping history or other information shall be forwarded to the Y-12 National Security Complex in support of recertification efforts. Additionally, each packaging user shall maintain a file of procedures and operating records associated with the ES-3100. These records shall be available for the U.S. Department of Energy (DOE) Headquarters Certifying Official audits and appraisals upon reasonable notice.

### 7.5.1.2 Records of packaging history

Users shall maintain sufficient written records to furnish evidence of the quality of packagings for a period of three years after the life of the packaging to which they apply in accordance with 10 CFR 71.91(d). As specified in 10 CFR 71.91(c), records are only valid if stamped, initialed, or signed and dated by authorized personnel, or otherwise authenticated. Inspection, tests, and audit records must identify the packaging by model and serial number, the inspector, the type of observation, the results, the acceptability, and the action taken in connection with any deficiencies noted. These records shall include:

1. Results of determinations required by 10 CFR 71.85 and 49 CFR 173.474.
2. Design, fabrication, and assembly records.
3. Results of reviews, inspections, tests, and audits.
4. Results of monitoring work performance and materials analyses.
5. Results of maintenance, modification, and repair activities.

The user shall permit the DOE Headquarters Certifying Official, or designee, at all reasonable times to inspect the radioactive material, packaging, premises, and facilities in which the radioactive material or packaging is used, provided, constructed, fabricated, tested, stored, or shipped [10 CFR 71.93(a)]. Authorized users shall perform any tests deemed necessary or appropriate by the DOE Headquarters Certifying Official in accordance with 10 CFR 71.93(b).

#### 7.5.1.3 Reports

Users shall include provisions in their operating procedures for reporting safety concerns associated with the packaging or its use. The user shall comply with 10 CFR 71.95 by providing written notification to the DOE Headquarters Certifying Official in accordance with DOE O 232.2 for the following:

1. Instances where there is a significant reduction in the effectiveness of the packaging during use.

2. Details of any defects with safety significance of the packaging after first use.

3. Instances in which the conditions of approval in the CoC were not observed in making a shipment.

In addition, the U.S. Department of Transportation will be notified of hazardous materials incidents during loading, unloading, and temporary storage operations in accordance with 49 CFR 171.15 and 171.16, as appropriate. The user shall particularly note the requirements of 49 CFR 171.15(b)(2) and 49 CFR 171.16(a)(2) and (4).

## Appendix 7.5.2

**Example Leak-Test Procedure, Y-12 Product Specification Procedure Y51-01-B2-R-074,**
***Shipping Container Leak Test***

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Master Distribution Being Maintained

| Consolidated Nuclear Security, LLC Y-12 Management Requirements | Product Specification Procedure Title: Shipping Container Leak Test | Number: Y51-01-B2-R-074<br>Revision: A.8<br>Supersedes: A.7<br>Page: 1 of 10<br>Use Category: REFERENCE |
|---|---|---|

| Responsible Organization/Department<br>Assembly/Disassembly Operations | | |
|---|---|---|
| | Responsible Manager<br>for R. Mullins — Signature; 4/14/2015 — Date | |
| Quality Engineer<br>Signature; 4/22/15 — Date | Packaging Engineer<br>Signature; 4-28-2015 — Date | CC Review<br>PTH — Initials; 04-28-15 — Date |
| | Approved for Practice<br>Signature — Date | |
| Verified to be the latest revision<br>Initials — Date | 4-30-15<br>Effective Date | |
| Concurrence by the following is documented in the Procedure History File: | | |
| ADO Support Manager<br>Criticality Safety Officer<br>Facility Operations Management<br>(Operations Manager)<br>(Shift Technical Advisor) | Industrial Safety and Hygiene<br>(Industrial Hygiene)<br>(Industrial Safety)<br>Radiological Control | Safety Analysis Engineering<br>(Nuclear Criticality Safety)<br>Subject Matter Expert |

This document has been reviewed by a Y-12 DC/UCNI-RO and has been determined to be UNCLASSIFIED and contains no UCNI. This review does not constitute clearance for Public Release.

Name: Paul Lott / Engr

Date: 29-Jan-15

| Revision Number | Modification Description | Affected Page(s) |
|---|---|---|
| A.7 | On Record | |
| A.8 | **14-PMR-787**, Non-intent modification to incorporate bluesheet changes. | 1 |

## TABLE OF CONTENTS

1 APPLICABILITY AND SCOPE ..... 4
2 PRECAUTIONS AND LIMITATIONS ..... 4
3 ACCEPTANCE CRITERIA ..... 4
4 PREREQUISITE ACTIONS ..... 5
4.1 Special Tools, Test Equipment, Parts and Supplies ..... 5
4.2 Field Preparations ..... 5
4.3 Approvals and Notifications ..... 5
5 PERFORMANCE ACTIVITIES ..... 6
5.1 VTI Smart Station ..... 6
5.1.1 VTI Smart Station - System Functional Check ..... 6
5.1.2 VTI Smart Station – Leak Testing ..... 8
6 POST-PERFORMANCE ACTIVITIES ..... 9
6.1 Extended Shutdown ..... 9
7 RECORDS ..... 9
8 APPENDIX ..... 9

## 1 APPLICABILITY AND SCOPE

To provide instructions for operating the shipping container leak test stations. The VTI Smart Station consists of a touch screen PC, printer, two MKS vacuum gauges, reference volume, vacuum pump, air compressor, automatic valve manifold, and temperature sensor mounted on a rolling cart. Either one of the systems may be used to perform leak tests on shipping containers.

Applies to the leak test of the O-ring seal found in leak testable inner containers. The VTI Smart Station is capable of determining a leak rate of $1.0 \times 10^{-4}$ atm-$cm^3$/sec.

The Orifice Leak Test Station correlates the pressure drop across an orifice as compared to the pressure drop across the orifice when a calibrated leak is installed.

The VTI Smart Station performs a pressure (vacuum) rate of rise test using air as the test gas with the part under vacuum.

Program: WC

## 2 PRECAUTIONS AND LIMITATIONS

**A.** Use of standard tools and equipment, as needed, is acceptable without being listed in the tooling/equipment list.

**B.** The VTI Smart Station leak rate is displayed with the units of measure of "atm-cc/s" which is equivalent to "atm-$cm^3$/sec."

## 3 ACCEPTANCE CRITERIA

**A.** Container has passed the leak test **WHEN** the test result is PASS.

## 4 PREREQUISITE ACTIONS

### 4.1 Special Tools, Test Equipment, Parts and Supplies

**Supervisor**

**[1]** Ensure the following equipment is available:

- Leak Tester (Appendix A)
- Test Cap
- FAIL Test Standard Leak
- O-ring lube
- Container Leak Test Adapter.

### 4.2 Field Preparations

**Assemblyperson**

**NOTE** *Facility Instrument Air may be connected to the VTI Smart Station via quick disconnect (if equipped) in lieu of on-board compressor.*

**[1]** Verify leak tester vacuum pump oil level is between minimum and maximum line on gauge.

**[2]** **IF** the leak tester vacuum pump is **NOT** between the minimum and maximum line on the gauge, **THEN** notify Supervisor.

**[3]** Ensure printer is ready (i.e., turned on, has paper and ink) for operation.

**[4]** Ensure leak tester is turned on.

**[5]** **IF** system was started from power off condition, **THEN** ensure MKS Baratron transducer is allowed at least four (4) hours warm up time.

**[6]** **WHEN** compressor has stopped charging the accumulator, **THEN** purge leak tester air compressor to remove water accumulation using drain valve or drain plug.

**[7]** Verify certification sticker(s) is **NOT** expired.

### 4.3 Approvals and Notifications

**Supervisor**

**[1]** Obtain permission from the Shift Manager to start the Performance Section of this procedure.

## 5 PERFORMANCE ACTIVITIES

### 5.1 VTI Smart Station

#### 5.1.1 VTI Smart Station - System Functional Check

**Assemblyperson**

**NOTE 1** *The operator may log in to the leak tester, as necessary, by entering login password.*

**NOTE 2** *After the login password is entered, a "Manual Commands" screen may display momentarily, but the screen is not used.*

**NOTE 3** *If "Welcome to HP Product Assistant" screen appears, the operator may clear this screen and continue.*

**NOTE 4** *A system functional check is to be performed prior to the first leak test of the day/shift in order to verify proper function of the leak tester. Two test volumes (one PASS test and one FAIL test) are run to ensure acceptable operation.*

**NOTE 5** *Operator I.D. time limit may expire. Operator I.D. may be re-entered, as necessary.*

**[1]** **IF** system functional check has already been performed during the current shift, **THEN GO TO** Section **5.1.2**, *VTI Smart Station – Leak Testing.*

**[2]** Ensure pigtail at back of leak tester is installed.

**[3]** Perform a PASS function test as follows:

- **[a]** Ensure free end of pigtail is capped.
- **[b]** Double touch VTI icon, as needed.
- **[c]** Enter Operator ID (badge number).
- **[d]** Enter "DT22" in the location designated for Package Model.
- **[e]** Enter "CAP" in the location designated for serial number.
- **[f]** Press the "Start Test" icon.
- **[g]** **IF** alarm lights (e.g., evac. fault or settle press, etc.) activate during test, **THEN** press "ABORT TEST" icon **AND** notify Supervisor.
- **[h]** Receive the printout of the test results.
- **[i]** **IF** result is FAIL (the first attempt), **THEN REPEAT** Steps **5.1.1[3]** - **5.1.1[3][h]** to perform test again.
- **[j]** **IF** result is FAIL (the second attempt), **THEN** notify Supervisor.
- **[k]** **IF** result is PASS, **THEN GO TO** Step **5.1.1[4]**.

### 5.1.1 VTI Smart Station - System Functional Check (cont.)

**Assemblyperson**

**[4]** Perform a FAIL function test as follows:

**[a]** Remove cap from free end of pigtail.

**[b]** Connect the FAIL Test Standard Leak (labeled "FAIL") to the free end of the pigtail.

**[c]** Double touch VTI icon, as needed.

**[d]** Enter Operator ID (badge number).

**[e]** Enter "DT22" in the location designated for Package Model.

**[f]** Enter "FAIL" and the serial number on the standard leak tag (if applicable) in the location designated for serial number.

**[g]** Press the "Start Test" icon.

**[h]** **IF** alarm lights (e.g., evac. fault or settle press) activate during test, **THEN** press "ABORT TEST" icon **AND** notify Supervisor.

**[i]** Receive the printout of the test results.

**[j]** **IF** result is PASS (the first attempt), **THEN REPEAT** Steps **5.1.1[4]** - **5.1.1[4][i]** to perform test again.

**[k]** **IF** result is PASS (the second attempt), **THEN** notify Supervisor.

**[l]** **IF** result is FAIL, **THEN** remove FAIL Test Standard Leak **AND GO TO** Step **5.1.2**.

### 5.1.2 VTI Smart Station – Leak Testing

**Assemblyperson**

**NOTE 1** *The operator may log in to the leak tester, as necessary, by entering login password.*

**NOTE 2** *After the login password is entered, a "Manual Commands" screen may display momentarily, but the screen is not used.*

**NOTE 3** *If "Welcome to HP Product Assistant" screen appears, the operator may clear this screen and continue.*

**NOTE 4** *Operator I.D. time limit may expire. Operator I.D. may be re-entered, as necessary.*

**[1]** Ensure the leak test port plug has been removed from the test port on the container to be tested.

**[2]** Ensure flexible hose from the VTI Smart Station to the container test port, (using the container leak test adapter if necessary is connected).

**[3]** Double touch VTI icon, as needed.

**[4]** Enter Operator ID (badge number).

**[5]** Enter Package Model (e.g., DT22, ES 3100, etc).

**[6]** Enter Serial Number (last five digits of inner container serial number).

**[7]** Press "Start Test" icon.

**[8]** **IF** alarm occurs, **THEN** press "ABORT TEST" icon, **AND** notify Supervisor.

**[9]** **IF** test results printout is "FAIL," **THEN** perform the following:

- **[a]** Clean **OR** replace O-ring at the end of the pigtail **AND** add O-ring lube, as necessary.
- **[b]** Check pigtail for leaks at leak tester connection **AND** repair or replace, using new metal sealing washer, as necessary.
- **[c]** Notify Supervisor for determination on whether to **RETURN TO** Step **5.1.2[2] OR** disconnect drum **AND** exit procedure.

### 5.1.2 VTI Smart Station – Leak Testing (cont.)

**Assemblyperson**

**[10]** **IF** test result is PASS, **THEN** perform the following:

**[a]** Attach leak test printout to the associated container documentation.

**[b]** Verify the serial number of the container matches the serial number of the container on the printout.

**[c]** Disconnect pigtail from container.

**[d]** **IF** additional containers will be leak tested, **THEN REPEAT** Steps **5.1.2[1] – 5.1.2[10][c]** until all containers are leak tested.

**[e]** Install cap onto pigtail.

## 6 POST-PERFORMANCE ACTIVITIES

### 6.1 Extended Shutdown

**Assemblyperson**

**[1]** **IF** placing the VTI Smart Station into extended shutdown, **THEN** turn off all power to VTI Smart Station.

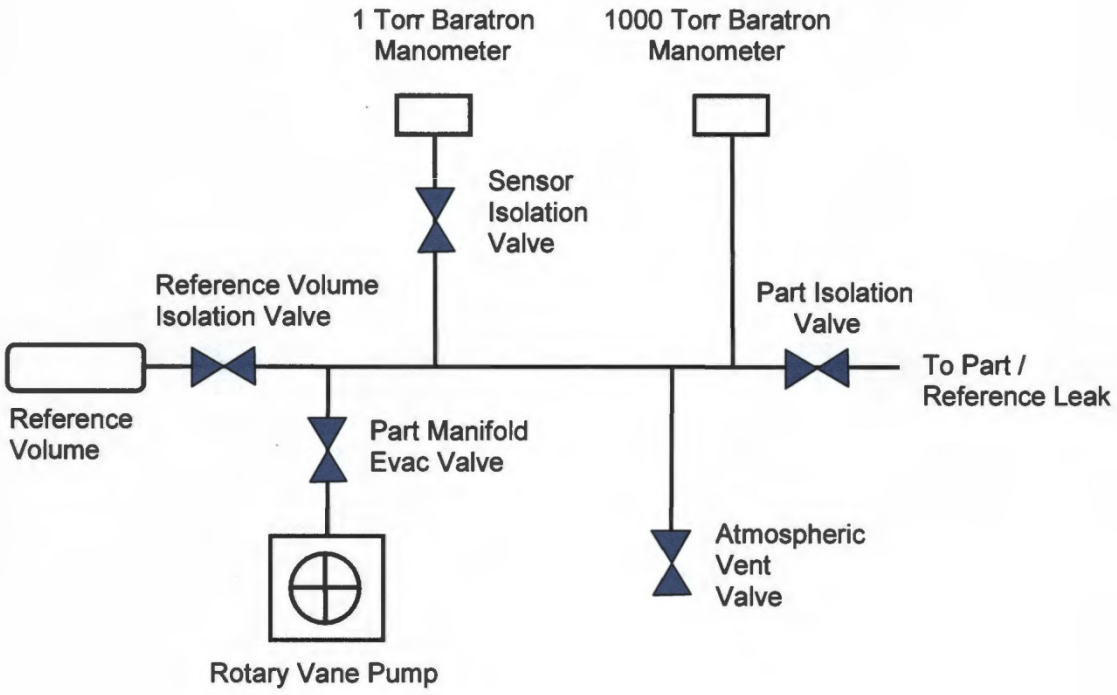
## 7 RECORDS

No records are generated by the performance of this procedure.

## 8 APPENDIX

**A.** VTI Smart Station Manifold

APPENDIX A
VTI Smart Station Manifold
(Page 1 of 1)



## SECTION 7 REFERENCES


10 CFR 71, *Packaging and Transportation of Radioactive Material*, January 2015.

10 CFR 830, *Nuclear Safety Management*, January 2015.

10 CFR 835, *Occupational Radiation Protection*, January 2015.

49 CFR, *Transportation*, October 2014.

ANL/DIS-09-5, *Guide to the RFID Monitoring System*, Argonne Natl. Lab., latest revision.

ANSI N14.5-1997, *Radioactive Materials—Leakage Tests on Packages for Shipment*, American Natl. Standards Institute, Feb. 5, 1998.

ASME B18.2.2, *Nuts for General Applications: Machine Screw Nuts, Hex, Square, Hex Flange, and Coupling Nuts (Inch Series)*, American Society of Mechanical Engineers, New York, revision at time of procurement.

ASTM A 240/A 240M, *Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications*, ASTM International, *Annual Book of ASTM Standards*, Sect. 1, Vol. 01.03, West Conshohocken, Pa., revision at time of fabrication.

ASTM A 276/A 276M, *Standard Specification for Stainless Steel Bars and Shapes*, ASTM International, *Annual Book of ASTM Standards*, Sect. 1, Vol. 01.03, West Conshohocken, Pa., revision at time of fabrication.

ASTM D 2000, *Standard Classification System for Rubber Products in Automotive Applications*, ASTM International, *Annual Book of ASTM Standards*, Sect. 9, Vol. 09.02, West Conshohocken, Pa., revision at time of procurement.

ASTM F 467, *Standard Specification for Nonferrous Nuts for General Use*, ASTM International, *Annual Book of ASTM Standards*, Sect. 1, Vol. 01.08, West Conshohocken, Pa., revision at time of procurement.

DOE O 232.2, Admin Chg 1, *Occurrence Reporting and Processing of Operations Information*, U.S. DOE, March 2014.

DOE O 414.1D, Admin Chg 1, *Quality Assurance*, U.S. DOE, May 2013.

DOE O 460.1C, *Packaging and Transportation Safety*, U.S. DOE, May 2010.

DOE O 461.1B, *Packaging and Transportation for Offsite Shipment of Materials of National Security Interest*, U.S. DOE, December 2010.

DOE O 461.2, *Onsite Packaging and Transfer of Materials of National Security Interest*, U.S. DOE, November 2010.

SAE AMS-R-83485, *Rubber, Fluorocarbon Elastomer, Improved Performance at Low Temperatures*, Aerospace Material Specification, SAE International, Warrendale, Pa., May 1998.

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# 8. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

Radioactive material packagings shall be fabricated, procured, and maintained in accordance with applicable U.S. Nuclear Regulatory Commission (NRC), U.S. Department of Transportation (DOT), and other federal, state, and local regulations to protect the health and safety of the public, the workers, and the environment. The basis of the ES-3100 acceptance tests and maintenance requirements is primarily established in the design drawings and equipment specifications that are applied to the packaging components during design and fabrication. The packaging must continue to meet these requirements during its useful lifetime. Acceptance tests and maintenance activities are used to ensure that the design requirements and the conditions of approval in the Certificate of Compliance (CoC) are satisfied in addition to ensuring the integrity of the packaging components with respect to the structural, thermal, containment, shielding, and criticality evaluations in this safety analysis report for packaging (SARP). Furthermore, the packagings shall be fabricated, procured, and maintained according to a quality assurance (QA) plan approved by the U.S. Department of Energy (DOE), Office of Environmental Management; or DOE, National Nuclear Security Administration (DOE/NNSA), as appropriate.

The user is responsible for following the established NRC regulations for packaging, preparation for shipment, and transportation of radioactive materials given in Title 10, Part 71, of the Code of Federal Regulations (CFR) [10 CFR 71] as well as DOT regulations for packaging and shipment of hazardous materials given in Title 49 CFR. DOE nuclear facility users are responsible for implementing DOE regulations given in Title 10, Parts 830 and 835, of the CFR in addition to directives conveyed in DOE Order (O) 232.2, DOE O 414.1D, and DOE O 460.1C or DOE O 461.1B, as appropriate.

Specific acceptance testing and maintenance criteria for the ES-3100 are presented in this section. Where appropriate, facility management may authorize the adjustment of the explicit implementation sequence in this section to accommodate facility-specific workflow logistics and operational requirements. The packaging owner and user shall develop detailed, written site-specific procedures based on the CoC and the criteria contained herein. These procedures shall be in accordance with 10 CFR 71, Subparts A, G, and H; DOT and DOE regulations; and applicable state, tribal, and local regulations not preempted by DOT.

The packaging acceptance testing and maintenance operations should be consistent with maintaining occupational radiation exposures as low as reasonably achievable (ALARA) [10 CFR 71.87(i)] in addition to addressing applicable safety aspects or activities such as personal protection (radiation, chemical, and physical); contamination or radiation surveys; provisions for reporting safety concerns associated with the packaging or its use; and the records and reporting requirements cited in Appendix 7.5.1.

The ES-3100 packaging description is presented in Sect. 1.2 with a schematic shown in Fig. 1.1 and an exploded view of the packaging components presented in Fig. 1.2. The ES-3100 certification drawing can be found in Appendix 1.3.1. The packaging design drawings (Appendix 1.3.7) provide material lists, dimensions, safety components, welding requirements, and gasket requirements. The maximum gross weight of the ES-3100 package is 190.5 kg (420 lb).

The requirements for fabricating, procuring, and maintaining the packaging are presented in this section. Nonconforming conditions or deficiencies will be appropriately dispositioned to satisfy the applicable design requirements in accordance with 10 CFR 71.131. Rework or repair authorization for packaging components would include applicable nondestructive examinations and pressure/leak testing as specified in the design requirements. Fabrication requirements for the ES-3100 components are listed on the design drawings (Appendix 1.3.7) and the following specifications:

1. JS-YMN3-801580-A001, *ES-3100 Containment Vessel* (Appendix 1.3.3);

2. JS-YMN3-801580-A002, *ES-3100 Drum Assembly* (Appendix 1.3.2);

3. JS-YMN3-801580-A003, *Manufacturing Process Specification for Casting Kaolite 1600TM into the ES-3100 Shipping Package* (Appendix 1.3.4);

4. JS-YMN3-801580-A005, *Casting Catalog No. 277-4 Neutron Absorber for the ES-3100 Shipping Package* (Appendix 1.3.5);

5. SPC-M801580-0001, *ES-3100 Fluorocarbon Elastomer (Viton) Containment Vessel (CV) O-rings* (Appendix 1.3.9); and

6. SPC-M801580-0002, *ES-3100 Ethylene Propylene Diene Monomer (EPDM) Containment Vessel (CV) O-rings* (Appendix 1.3.10).

The containment vessel (CV) is designed and built to meet American Society of Mechanical Engineers *Boiler and Pressure Vessel Code* (ASME Code), Sect. III, Div. 1, Subsection NB. The ES-3100 includes the following packaging components/assemblies:

1. A drum assembly: body weldment, lid weldment, top plug weldment, CV bottom pad, CV flange pad, plug pad, hex nuts, washers, and paint (Drawing M2E801580A001, Appendix 1.3.7); with a data plate and a trefoil data plate (Drawing M2E801580A010, Appendix 1.3.7).

2. A CV assembly: CV body assembly; CV lid assembly (sealing lid, closure nut, and retaining ring); O-rings; brass VCO (vacuum coupling O-ring) threaded plug; and swivel hoist ring (Drawing M2E801580A011, Appendix 1.3.7).

3. Packing materials, as appropriate: convenience cans or bottles, polyethylene bags, metal scrubbers, silicone rubber can pads (Drawing M2E801580A024, Appendix 1.3.7), and heavy can spacer assemblies (Drawing M2E801580A043, Appendix 1.3.7).

Care should be exercised to control the packaging components when they are removed to ensure that parts are kept with the packaging and not mixed with other loose parts or parts from other packagings. Other preparations should be made to minimize damage or loss of packaging components. The drum assembly and containment vessel are marked with serial numbers. The numbers are used to control these parts and to accumulate their respective operational and maintenance histories. Applicable serial numbers of packaging components should be verified to ensure that these components are maintained together. Loose parts (e.g., hex nuts, washers, O-rings) may be reused if it can be shown that they were the parts that were removed and that no damage to the parts has occurred. Otherwise, they shall be discarded and replaced with certified parts. In order to maintain configuration control of the packaging components, the user shall ensure that there are no unauthorized modifications and no substitution of components with unauthorized components. The certification of all replacement parts must be traceable. The user shall document any part replacement identifying it to a specific packaging by model and serial number.

The ES-3100 is handled using industry-standard drum-handling equipment. When being moved using a forklift, it can be placed on the tines of the forklift from below. The ES-3100 is also designed for a forklift pincher assembly that can be used to grasp the exterior of the drum assembly. Forklift gripping forces of up to 5400 lb can be used with no detrimental effects on the packaging (Sect. 1.2.1.1).

Site-specific maintenance procedures including the facility's operational requirements shall ensure the following:

1. All appropriate documents have been reviewed by operating personnel and are available for further review, if necessary.

2. Certified equipment is used (e.g., torque wrenches, instrumentation, scales, lifting hardware, and radiation survey instruments) in accordance with the site-approved QA program.

3. Segregated work stations, curtains, lead blankets, personnel protective equipment, or other equipment are used, as necessary, to protect workers and nearby personnel from radioactive material hazards.

4. Appropriate material handling equipment is available and approved for use (e.g., forklifts, hoists, drum handlers). Operating controls shall be implemented for any forklift pincher assembly to limit clamping forces on the drum body (i.e., $\leq$ 5400 lb).

5. Appropriate provisions to decontaminate packaging components are provided consistent with ALARA principles.

All personnel who support and/or perform fabrication, assembly, testing, and maintenance operations will be appropriately trained and qualified in accordance with the site-approved QA program; 49 CFR 171.1; and 49 CFR 172, Subpart H, as appropriate. Auditable training records will be maintained in accordance with site record retention requirements.

## 8.1 ACCEPTANCE TESTS

Before the first use of the packaging, the owner shall determine that the packaging has been fabricated in accordance with the approved design including the preliminary determinations (10 CFR 71.85), the quality control for construction of packaging (49 CFR 173.474), and the conditions of approval in the CoC. Guidance provided in NUREG/CR-6314, *Quality Assurance Inspections for Shipping and Storage Containers*, for conducting QA inspections of packaging suppliers may be used as necessary. Acceptance test requirements in Sect. 8.1 are derived from the design drawings and equipment specifications, and their determinations shall be present in the owner's or appropriate supplier's fabrication records as described in Sect. 7.5.1.2. The minimum certification requirements are shown on the ES-3100 certification drawing (Appendix 1.3.1).

The design drawings and specifications indicate the applicable inspections, testing, records, and reports required to properly document the quality of the packaging. The minimum acceptance test and inspection requirements for the packaging components (Tables 8.1 and 8.2) and packing materials (Table 8.3) are presented in the following sections. Prior to first use of the packaging, the user, packaging suppliers, or both shall meet these requirements.

### 8.1.1 Visual Inspections and Measurements

Visual inspections with the unaided eye of all pertinent features of the packaging shall be performed during fabrication. There shall be no cracks, pinholes, uncontrolled voids, or other defects that could significantly reduce the effectiveness of the packaging [10 CFR 71.85(a)]. These inspections include paint color; surface condition; marking content; gauging (toleranced dimensions, positioning, edge breaks, surface finish); and welding. The required inspections are summarized in Tables 8.1–8.3.

**Table 8.1. Acceptance tests for the drum assembly**

| Component [a] | Inspection | Structural and pressure tests | Leak tests |
|---|---|---|---|
| Double open head drum | Material certification [b], gauging [c], marking, liquid penetrant, weld examinations [d], corrosion, dents | Tensile, percent elongation, yield point, chemistry, pneumatic pressure test [e], rough handling test [e] | NA [f] |
| Weld studs | Part certifications, gauging | Tensile, percent elongation, yield point, chemistry | NA |
| Inner liner weldment | Material certification, weld examinations, gauging | Tensile, percent elongation, yield point, chemistry | NA |
| Flat cover (drum bottom) | Material certification, gauging | Tensile, percent elongation, yield point, chemistry | NA |
| Lid weldment | Material certification, weld examinations, gauging | Tensile, percent elongation, yield point, chemistry | NA |
| Top plug weldment | Material certification, weld examinations, gauging | Tensile, percent elongation, yield point, chemistry | NA |
| Kaolite 1600 insulation | C of C [g], damage | NA | NA |
| Cat 277-4 neutron-absorber material | C of C, damage | NA | NA |
| Hex nuts | C of C, gauging, damage | NA | NA |
| Washers | C of C, damage | NA | NA |
| TID [h] lugs | C of C, damage | NA | NA |
| Data plate and trefoil data plate | Material certification, gauging, marking | NA | NA |
| Nylon plug | C of C | NA | NA |
| Paint | C of C, color comparison | NA | NA |
| Aluminum tape | C of C, damage | NA | NA |
| Silicone rubber pads (CV bottom pad, CV flange pad, and plug pad) | C of C, damage, marking | NA | NA |
| RFID monitoring system [i] | NA | NA | NA |

[a] ES-3100 drum assembly components (Drawing M2E801580A001, Appendix 1.3.7).
[b] Material certification – Certified quantitative data (physical, mechanical, chemical, functional, dimensional, and/or visual) demonstrating compliance with the drawing/specification requirements.
[c] Gauging refers to dimensional inspections for height, width, thickness, diameter, position, edge breaks, and surface finish.
[d] Weld examinations in accordance with Sect. 8.1.2.
[e] Pneumatic pressure test and rough handling test in accordance with Sect. 8.1.3.3.
[f] NA—Not applicable.
[g] C of C—Certificate of Conformance. A document signed or otherwise authenticated by an authorized individual certifying the degree to which items or services meet the specified requirements.
[h] TID—Tamper-indicating device.
[i] An optional radio-frequency identification (RFID) monitoring system tag may be secured to the drum assembly in accordance with the applicable requirements of ANL/DIS-09-5.

**Table 8.2. Acceptance tests for the CV assembly**

| Component [a] | Inspection | Structural and pressure tests | Leak tests |
|---|---|---|---|
| Body assembly and lid assembly (as applicable) | Material certification [b], gauging [c], marking, liquid penetrant, weld examinations, qualification tests, corrosion, scratches | Tensile, percent elongation, yield point, chemistry, hydrostatic pressure test [d] | Helium leak test [e] |
| Inner O-ring | Material certification, gauging, packaging, marking | Shore A durometer, elongation | NA [f] |
| Outer O-ring | Material certification, gauging, packaging, marking | Shore A durometer, elongation | NA |
| External retaining ring | C of C [g], damage | NA | NA |
| Modified VCO [h] threaded plug with O-ring | C of C, damage | NA | NA |

[a] ES-3100 CV assembly components (Drawing M2E801580A011, Appendix 1.3.7).
[b] Material certification – Certified quantitative data (physical, mechanical, chemical, functional, dimensional, and/or visual) demonstrating compliance with the drawing/specification requirements.
[c] Gauging refers to dimensional inspections for height, width, thickness, diameter, position, edge breaks, and surface finish.
[d] Hydrostatic pressure test in accordance with Sect. 8.1.3.3.
[e] Leakage test in accordance with Sect. 8.1.4.
[f] NA—Not applicable.
[g] C of C—Certificate of Conformance. A document signed or otherwise authenticated by an authorized individual certifying the degree to which items or services meet specified requirements.
[h] VCO—Vacuum coupling O-ring.

**Table 8.3. Acceptance tests for packing materials**

| Component [a] | Inspection | Structural and pressure tests | Leak tests |
|---|---|---|---|
| Silicone rubber pad [b] (can pad) | C of C [c], damage, marking | NA [d] | NA |
| Heavy can spacer assembly [e] | Material certification [f], sample pour | NA | NA |
| Convenience cans | C of C, damage | NA | NA |
| Convenience bottles | C of C, damage | NA | NA |
| Polyethylene bags | C of C, damage | NA | NA |
| Metal scrubbers | C of C | NA | NA |

[a] ES-3100 CV packing materials, as appropriate (see Sect 1.2.2.4).
[b] Drawing M2E801580A024, Appendix 1.3.7.
[c] C of C—Certificate of Conformance. A document signed or otherwise authenticated by an authorized individual certifying the degree to which items or services meet specified requirements.
[d] NA—Not applicable.
[e] Packing material, as appropriate, not part of CV (Drawing M2E801580A043, Appendix 1.3.7).
[f] Material certification – Certified quantitative data (physical, mechanical, chemical, functional, dimensional, and/or visual) demonstrating compliance with the drawing/specification requirements.

#### 8.1.1.1 Paint color

Paint color, which is not a safety item, is used to identify, segregate, and document packagings. The acceptance criteria for paint color are given in the drawings (Appendix 1.3.7). Incorrect or incomplete application of paint is cause for rejection. An application of incorrect letters or misspelled words is also cause for rejection.

#### 8.1.1.2 Surface condition

The surfaces of the drum assembly and CV shall be visually inspected for penetrations, dents, and corrosion. Dents >1-in. deep in the drum body will be cause for the drum body to be reworked to remove the dent. The CV surfaces must be in accordance with the dimensional requirements on the drawings (Appendix 1.3.7). Penetrations (e.g., cracks, pinholes, other defects) in the drum or CV will be cause for the component to be rejected.

The packaging components will be stored in weather-protected indoor facilities. However, before acceptance of any component, accessible surfaces shall be inspected for corrosion. The presence of surface corrosion on any component will be cause for further inspection. If the corrosion can be easily wiped off and no pitting is apparent beneath it, the component is acceptable. If the corrosion cannot be easily wiped off, if scaling is present, or if pitting is observed, the component must undergo a dimensional inspection, including nondestructive examinations as necessary, to determine the extent of the damage before the packaging component can be used. If the corrosion has compromised the structural integrity of the component (i.e., the component no longer meets dimensional or surface finish criteria for a new part as specified on the design drawings), then the component shall be rejected.

#### 8.1.1.3 Marking packaging components

Markings on the packaging components provide traceability for the fabrication, operation, and maintenance of the packaging components. All markings (e.g., model number, serial numbers, instructions, identification) shall be compared with the acceptance criteria (e.g., paint color, etching, dimensions) for markings on the design drawings (Appendix 1.3.7) or equipment specifications, as appropriate. Incorrect or incomplete marking is cause for rejection.

#### 8.1.1.4 Gauging

The ES-3100 design drawings list the dimensions/tolerances; positions (e.g., bolt holes, grooves, leak-test port); edge breaks; and surface finishes. A “Diamond I” symbol is used on the drawings or equipment specifications to designate significant dimensions or features, which are specifically inspected and documented in the inspection reports. Inspection of gauging features will be performed on dimensions to ensure that each component meets the applicable tolerances, which are provided on the drawings. Gauging outside the tolerance is cause for rejection.

### 8.1.2 Weld Examinations

As discussed in Sect. 2.3, *Fabrication and Examination,* all welded or weld-repair surfaces shall be visually examined by a qualified weld examiner for indications of inclusions, cracks, or porosity using a written weld examination procedure. Weld examiners are qualified to perform weld inspections in accordance with the techniques specified on the applicable design drawings and equipment specifications. Weld symbols are provided on the design drawings indicating for each weld the type of weld and dimensions of weld. These weld symbols are interpreted in accordance with American Welding Society (AWS) A2.4. For a detailed description of the drum assembly and CV manufacturing requirements, see the appropriate equipment specification and the following SARP sections:

**Drum Assembly** [JS-YMN3-801580-A002 (Appendix 1.3.2)]

- Section 2.3.1.1, Drum assembly fabrication.
- Section 2.3.2.1, Examination of the drum assembly fabrication.

**Containment Vessel** [JS-YMN3-801580-A001 (Appendix 1.3.3)]

- Section 2.3.1.2, Containment boundary fabrication.
- Section 2.3.2.2, Examination of the containment vessel fabrication.

### 8.1.3 Structural and Pressure Tests

Structural tests for the drum and CV include mechanical properties and chemical tests to ensure that the correct materials are used. The CV is hydrostatically pressure tested to ensure that the supplier's fabrication meets the requirements. These tests are discussed below. The drum body is mechanically tested (handling test) and pressure tested (Sect. 8.1.3.3) in accordance with the QA provisions in Military Specification MIL-D-6054F, *Drum, Metal—Shipping and Storage*.

#### 8.1.3.1 Mechanical property tests

The design drawings or equipment specifications specify the requirements for the packaging materials. The mechanical properties and specifications for these materials are discussed in Sect. 2.2.1 and summarized in Tables 2.12–2.17. Visual examination and mechanical property testing requirements for the O-rings are discussed in Sect. 8.1.5.1. An out-of-specification property is cause for rejection.

#### 8.1.3.2 Chemical tests

Tests shall be performed to determine the chemical properties of the packaging materials. The acceptance criteria and their sensitivity are provided in the appropriate national material standard specified on the design drawings (Appendix 1.3.7). An out-of-specification chemical property is cause for rejection. Material that cannot be traced to the mill or heat-treatment lot shall be rejected.

#### 8.1.3.3 Pressure tests

The CV assembly shall be hydrostatically pressure tested at 150 ± 5 psig per Sect. 3.7 of JS-YMN3-801580-A001 (Appendix 1.3.3). Visible indication of a leak on the exterior surface of the CV is cause for rejection. This testing exceeds the regulatory requirement in 10 CFR 71.85(b) [1.5 × maximum normal operating pressure] and the requirement stipulated in ASME Code, Sect. III, Div. 1, NB-6200 (1.25 × design pressure). The CV maximum normal operating pressure is 16.518 psig (Appendix 3.5.1) and the CV design pressure is 101.5 psig (DAC-M900000-0003).

The drum pressure test is performed in accordance with Drawing M2E801580A004 (Appendix 1.3.7) to verify the integrity of the welded seam. Typically, two sample drums in each lot fabricated are pressure tested; one drum is only pressure tested (MIL-D-6054F, Para. 4.6.1), while the other drum is pressure tested following "rough handling" tests (MIL-D-6054F, Para. 4.6.2). The pressure test is performed prior to the drilling of the four vent holes with the opened ends of the drum sealed. This test is observed by the owner during the First Article Evaluation of the drum. To conduct the pressure test, the drum is pressurized with air to 10 psig as specified in MIL-D-6054F. The compressed air supply line is closed, but the pressure gauge is left connected to the drum. The initial pressure is recorded. All joints and seams are coated with a bubble-supporting film. The drum is turned so that all surfaces may be observed for leakage. Five minutes after the initial pressure is recorded, the final gauge pressure is recorded. If a loss of pressure is observed and no leaks were detected by bubbles, the bubble-supporting film operation is repeated to find any leaks that were not detected initially. Any evidence of leakage is cause for rejection.

### 8.1.4 Leakage Tests

Following the hydrostatic pressure test, a leak test of the containment boundary shall be performed with the inner O-ring installed in accordance with American National Standards Institute (ANSI) N14.5-1997, Subclause 7.3, *Fabrication leakage rate test*, as prescribed in Sect. 3.9 of JS-YMN3-801580-A001 (Appendix 1.3.3). This leak testing demonstrates that the CV is fabricated properly and that the containment boundary is "leaktight." An integrated air leakage rate exceeding $1 \times 10^{-7}$ ref-cm$^3$/s (or equivalent) is cause for rejection. Per ANSI N14.5-1997, the test procedure shall have a sensitivity of $5 \times 10^{-8}$ ref-cm$^3$/s (one-half the reference air leakage rate) or equivalent.

As required in JS-YMN3-801580-A001 (Appendix 1.3.3), the containment vessel leakage rate testing will be performed by trained and qualified personnel using certified equipment and written leak-test procedures in accordance with the applicable sections of ANSI N14.5-1997. Y-12 Product Specification Procedure Y51-01-B2-R-140, *He Leak Testing in B2* (Appendix 8.3.1) is provided as an example leak-test procedure.

In addition, a leakage rate test will be performed at initial fabrication on the fully assembled CV with both O-rings installed to demonstrate the functionality of the leak-test port and sealing capability of the outer O-ring. The leak testing acceptance criterion is that the CV shall not have an air leakage rate $>1 \times 10^{-4}$ ref-cm$^3$/s. Y-12 Product Specification Procedure Y51-01-B2-R-074, *Shipping Container Leak Test* (Appendix 7.5.2) is provided as an example leak-test procedure.

### 8.1.5 Component and Material Tests

#### 8.1.5.1 Containment vessel O-rings

The O-ring visual inspection and mechanical tests are described below. Additionally, the fabrication leak test (Sect. 8.1.4), the periodic and maintenance leak tests (Sect. 8.2.2), and the preshipment leak test (Sect. 7.1.2.1) verify the functionality of the O-rings.

**Visual inspection**

A visual inspection of the O-ring surface shall be performed. The surface shall be smooth, nonporous, and free of skin defects. O-rings that do not meet these requirements shall be rejected.

Each O-ring shall be packaged separately to provide traceability. Each O-ring package shall be marked with the O-ring identification number, lot number, cure date, compound number, and established expiration date. The material identification numbers shall be assigned uniquely to each lot and to each size of O-ring. The identifications shall be adequate to trace the O-rings to their raw material

master batch. Improper packaging or marking is cause for rejection. Additionally, no O-ring shall be installed after the established expiration date noted on the manufacturer's packaging.

**Mechanical properties**

The O-ring material mechanical properties and acceptance criteria shall be in accordance with SPC-M801580-0001 (Appendix 1.3.9) for fluorocarbon elastomer (Viton) O-rings or SPC-M801580-0002 (Appendix 1.3.10) for EPDM O-rings.

#### 8.1.5.2 Valves and pressure-relief devices

The ES-3100 packaging does not incorporate any valves or pressure-relief devices.

#### 8.1.5.3 Neutron-absorber material

The Cat 277-4 neutron-absorber material is specifically designed for criticality safety. Acceptance testing for the Cat 277-4 procurement, preparation, and casting is described in JS-YMN3-801580-A005 (Appendix 1.3.5).

### 8.1.6 Shielding Tests

No gamma or neutron radiation shielding features are integral to the packaging.

### 8.1.7 Thermal Tests

A thermal acceptance test is not required for the passive thermal features of this packaging. The maximum decay heat generated by the radioactive material is 5 W (Sects. 1.2.2.7 and 3.1.2), which is negligible. The QA and technical requirements for weighing, mixing, pouring, vibrating, curing and baking the Kaolite 1600 thermal insulation is described in JS-YMN3-801580-A003 (Appendix 1.3.4).

### 8.1.8 Miscellaneous Tests

No additional tests are required prior to the use of the ES-3100 packaging.

## 8.2 MAINTENANCE PROGRAM

The ES-3100 maintenance program ensures that the packaging continues to meet the design requirements and the conditions of approval in the CoC. Periodic maintenance inspections and testing requirements verify that the performance of the packaging has not deviated or degraded during use from the authorized configuration. Incidental maintenance activities and routine determinations/quality control requirements (10 CFR 71.87 and 49 CFR 173.475) are authorized and performed during package operations as described in Sect. 7 of this SARP.

Periodic maintenance of the ES-3100 packaging shall be performed on a 1-year basis; however, this scheduled maintenance is not required during a period of nonuse (i.e., extended storage or inactivity). The user shall verify that the ES-3100 periodic leakage rate testing (ANSI N14.5-1997, Subclause 7.5) and any necessary maintenance leakage rate testing (ANSI N14.5-1997, Subclause 7.4) [including any required corrective maintenance associated with noncompliant conditions] have been performed within the 1-year period prior to shipment to ensure full compliance with the containment requirements of 10 CFR 71.

Maintenance requirements presented in Sect. 8.2 shall be considered as minimum requirements, and their determinations shall be included in the owner's or user's packaging maintenance records as described in Sect 7.5.1.2. Packaging components may be repaired, reworked, or replaced in accordance with the requirements specified in 10 CFR 71.131 and Sect. 9.3.15.

### 8.2.1 Structural and Pressure Tests

The ES-3100 packaging does not require any structural tests or pressure tests during periodic maintenance. Welding and structural repair/rework of the containment vessel or drum assembly would involve operations that are considered beyond the scope of routine maintenance.

### 8.2.2 Leakage Tests

The fabrication leak test (Sect. 8.1.4) must be performed before the first use of the packaging and the periodic leak test is performed on a 1-year basis thereafter while the packaging is in use. The maintenance leak test is performed following the structural repair/rework or replacement of a containment boundary component (e.g., weld repair or inner O-ring replacement).

The user shall develop detailed maintenance procedures which include, at a minimum, the process steps listed below for CV leak testing. Maintenance personnel shall ensure that:

1. The CV periodic maintenance has been performed in accordance with Sect. 8.2.5.2 and the O-ring grooves and sealing surfaces are cleaned, as necessary, with isopropyl alcohol and lint-free gloves, cloths, or swabs.

2. Certified replacement O-rings are obtained in accordance with Sect. 8.2.3.1 and the O-rings are cleaned, as necessary, with isopropyl alcohol and lint-free gloves, cloths, or swabs.

3. The inner O-ring is lubricated with a thin coat of Super-O-Lube and inserted into the CV flange groove.

   **Note:** Only the inner O-ring is installed during the maintenance or periodic leakage rate testing of the containment boundary.

4. The leak-test fixture is installed as follows:

   a. The leak check flange assembly (Drawing T2E801827A008, Appendix 1.3.7) is positioned over the CV body and lowered into the CV flange.

   b. The leak check flange O-ring has been installed in the O-ring groove.

   c. The CV lid assembly is placed on top of the leak check flange assembly.

      **Note:** The above fixture installation sequence assumes the use of a leak check flange assembly (Drawing T2E801827A008, Appendix 1.3.7). With facility management approval, an alternate leak-test fixture and installation sequence may be used.

5. The CV is leak tested with the inner O-ring installed in accordance with ANSI N14.5-1997, Subclause 7.4, *Maintenance leakage rate test*, or Subclause 7.5, *Periodic leakage rate test*, to demonstrate that the containment boundary is "leaktight." An integrated air leakage rate exceeding $1 \times 10^{-7}$ ref-cm$^3$/s (or equivalent) is cause for rejection. Per ANSI N14.5-1997, the test procedure shall have a sensitivity of $5 \times 10^{-8}$ ref-cm$^3$/s (one-half the reference air leakage rate) or equivalent. Maintenance personnel shall ensure the following, at a minimum:

    a. The leak testing is performed by trained and qualified personnel in accordance with the requirements of ANSI N14.5-1997 and the site-approved QA program.

        **Note:** Y51-01-B2-R-140 (Appendix 8.3.1) is provided as an example leak-test procedure.

    b. Leak-test instrumentation has been properly calibrated.

    c. The leak-test equipment is connected to the leak-test port in the leak check flange assembly.

    d. The leak test is performed under isothermal conditions.

        **Note:** If the leak test fails, the following measures should be performed: (1) review the operating procedures; (2) check the leak-test equipment and connections; and (3) check the test gauges and instrumentation including verification of calibration and certification records, as necessary. If none of these measures reveal the root cause for the leak-test failure, the following inspections should be considered: (1) visually inspect the O-rings per Sect. 8.2.3.1; (2) visually inspect the O-ring grooves and sealing surfaces per Sect. 8.2.5.2; (3) visually inspect the containment boundary; and (4) perform other nondestructive examinations, as appropriate.

6. Following successful completion of the leak test, the leak-test equipment is disconnected.

7. The CV lid assembly and the leak check flange assembly (or approved alternate leak-test fixture) are removed from the CV body.

8. The outer O-ring is lubricated with a thin coat of Super-O-Lube and inserted into the CV flange groove.

9. The CV lid closure nut threads are visually inspected for foreign matter. If necessary, clean the threads with lint-free gloves, cloths, or swabs and apply a thin coat of Krytox grease, Grade 240 AC, to the threads, as required [Drawing M2E801580A011, Appendix 1.3.7].

10. The CV lid assembly is positioned over the CV body with the two alignment pins in the CV flange engaged in the slots on the underside of the CV lid assembly.

11. The CV lid closure nut is hand tightened.

12. The CV lid assembly has a brass VCO threaded plug installed in the leak-test port.

13. The expiration date (1 year from the leak-test date) and signature of the person who performed the testing or certified the test results shall be entered on two copies of a leak-test label (see example label in Fig. 8.1). One label will be attached to the exterior surface of the CV, and the second label will be attached to the exterior surface of the drum. The leak-test label must contain organization information, "LEAK TEST APPROVED," "DO NOT REMOVE," expiration date, and the name of the person (who performed the testing or certified the test results), at a minimum.

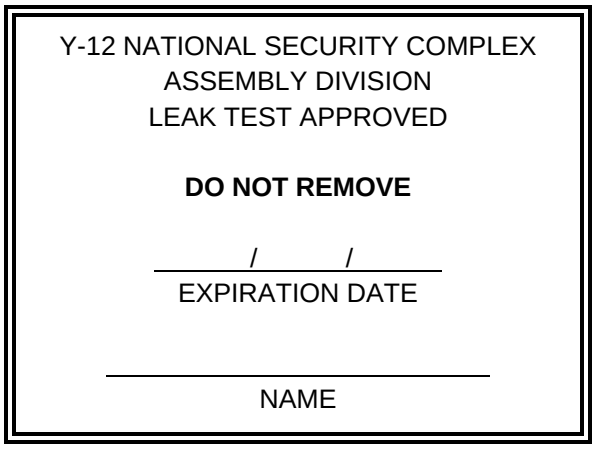



**Fig. 8.1. Example label for use on the exterior surface of the containment vessel and the drum.**

14. An optional radio-frequency identification (RFID) monitoring system tag may be secured to the drum assembly in accordance with the applicable requirements of ANL/DIS-09-5.

    **Note:** The mounting bracket for the RFID monitoring system tag shall provide the equivalent contact area of a drum washer and the thread engagement for the drum hex nuts shall remain unchanged.

### 8.2.3 Component and Material Tests

#### 8.2.3.1 Containment vessel O-rings

The inner and outer O-rings will be replaced during periodic maintenance of the packaging. Certified replacement O-rings (see Sect. 8.1.5.1) are visually inspected for defects such as roughness, porosity, and surface defects. Defective O-rings are discarded. Replacement O-rings (stored in sealed containers) will have an established expiration date marked on the O-ring manufacturer's packaging, and no O-rings shall be installed after the established expiration date.

#### 8.2.3.2 Thermal insulation and neutron-absorber material

Since the Kaolite insulation and Cat 277-4 are encapsulated within the stainless-steel liner, no damage or deterioration is expected. However, the drum, liner, internal flange, flat cover, and top plug shall all be visually inspected for tears or punctures or other defects that would allow for the escape of insulating or neutron-absorbing material. The drum assembly and top plug will be weighed prior to first use and during periodic maintenance to evaluate density variations in the Kaolite 1600 or the Cat 277-4. For the purpose of weight comparisons, the drum does not include the lid, pads, nuts, or washers. Weights recorded during periodic maintenance will be compared to the recorded weights prior to first use, and the packaging components will be rejected and evaluated for rework if the weight change of the drum is >10 lb or the weight change of the top plug is >2 lb.

### 8.2.4 Thermal Tests

There are no periodic maintenance thermal test requirements for the passive thermal features of this packaging.

### 8.2.5 Miscellaneous Tests

#### 8.2.5.1 Visual inspection for corrosion

The ES-3100 packaging will be stored in weather-protected indoor facilities; thus, surface corrosion is not expected. However, during periodic maintenance inspections, accessible surfaces shall be visually inspected for corrosion, moisture, and damage. The observation of surface corrosion on any component will be cause for further inspection. If the corrosion can be easily wiped off and no pitting is apparent beneath it, the package is acceptable for use. If the corrosion cannot be easily wiped off, if scaling is present, or if pitting is observed, the component must undergo a dimensional inspection, including nondestructive examinations as necessary, to determine the extent of the damage before the packaging component can be used. If the corrosion has compromised the structural integrity of the component (i.e., the component no longer meets dimensional or surface finish criteria for a new part as specified on the design drawings), then the component shall be rejected.

#### 8.2.5.2 Containment vessel maintenance

The CV must be removed from the drum assembly for periodic maintenance inspections. After removing the CV lid assembly, interior and exterior CV surfaces shall be examined for signs of moisture, corrosion, or physical damage. Any CV exhibiting signs of moisture inside will be tagged and segregated until the cause is determined and corrected and the CV has been successfully reinspected. If physical damage has compromised the structural integrity of the CV [i.e., the component no longer meets dimensional requirements specified on the design drawings (Appendix 1.3.7) or JS-YMN3-801580-A001 (Appendix 1.3.3)] the component shall be rejected. Repair/rework authorization of damaged surfaces would include any nondestructive examinations and pressure/leak-test requirements in accordance with the design requirements. A repaired component shall meet the established acceptance criteria in Sect. 8.1.

The CV closure nut and CV flange threads shall be cleaned, as necessary, and visually inspected for damage. Minor defects such as small nicks or burrs may be smoothed with a thread file; however, components with damaged threads (evidence of cross-threading, or flattened threads) or excessive wear (visually apparent rounding of the fastener threads) are cause for rejection. Repair/rework of damaged threads on the CV closure nut or body flange would involve operations that are considered beyond the scope of routine maintenance.

The CV sealing lid leak-test port and brass VCO plug threads shall be cleaned, as necessary, and visually inspected for damage. Minor defects such as small nicks or burrs may be smoothed with a thread file or chased with a tap or die, as appropriate; however, components with damaged threads (as determined by the criteria noted above) must be replaced with certified replacement parts. Repair/rework of damaged threads on the CV sealing lid leak-test port would involve operations that are considered beyond the scope of routine maintenance.

The CV lid assembly (Drawing M2E801580A014, Appendix 1.3.7) will be evaluated to ensure that the CV closure nut rotates freely on the CV sealing lid. If there is excessive binding or varying resistance, the external retaining ring will be removed, and the CV lid assembly will be disassembled. The contact surface between the CV sealing lid and closure nut will be cleaned and lubricated with a thin film of Krytox grease, Grade 240 AC (Drawing M2E801580A011, Appendix 1.3.7). The CV sealing lid, closure nut, and external retaining ring will be assembled per Drawing M2E801580A014 (Appendix 1.3.7), and a thin coat of Krytox grease, Grade 240 AC, will be applied to the CV closure nut threads.

If installed, the O-rings will be removed from the CV flange grooves. The sealing surfaces of the CV sealing lid and CV flange grooves will be cleaned, as necessary, with isopropyl alcohol and lint-free

gloves, cloths, or swabs. The O-ring grooves and sealing surfaces will be visually inspected for foreign matter, nicks, and scratches. If nicks or scratches are found, the affected sealing surfaces may be smoothed with a stone or with fine sandpaper to return them to specification. Surface defects or imperfections that impact containment performance and cannot be removed without taking the component out of dimensional specification constitute cause for rejection of the component. Welding and structural repair/rework of the CV would involve operations that are considered beyond the scope of routine maintenance.

#### 8.2.5.3 Subsystem maintenance

Touch-up paint that complies with drawing requirements should be applied to worn or faded packaging markings as necessary. The data plate and trefoil data plate (Drawing M2E801580A010, Appendix 1.3.7) shall be visually examined for legibility of all required information, and the plates will be securely attached to the drum as shown in Drawing M2E801580A031 (Appendix 1.3.7). Interior and exterior surfaces of the drum body shall be visually inspected for signs of moisture, corrosion, or physical damage. Defects in the drum assembly (e.g., tears, broken welds, dents >1-in. deep) are cause for rejection and possible reporting in accordance with Sect. 7.5.1.3.

#### 8.2.5.4 Drum fastener inspection

The drum lid fasteners (5/8-11 UNC silicon-bronze hex nuts and stainless-steel weld studs) shall be cleaned as necessary and visually inspected for damage. Minor defects such as small nicks or burrs may be smoothed with a thread file or chased with a tap, as appropriate; however, fasteners with damaged threads (evidence of cross-threading, or flattened threads) or excessive wear (visually apparent rounding of the fastener threads) must be replaced with certified replacement parts. In addition, the drum hex nuts will be inspected for proper certification markings. If there is any question about the certification status of the hex nuts, all suspect parts shall be replaced with certified replacement parts. Welding and structural repair/rework of a drum weld stud would involve operations that are considered beyond the scope of routine maintenance.

#### 8.2.5.5 Valves and pressure-relief devices

The ES-3100 packaging does not incorporate any valves or pressure-relief devices.

#### 8.2.5.6 Miscellaneous

The silicone rubber pads (Drawing M2E801580A009, Appendix 1.3.7) shall be visually inspected during periodic maintenance to verify that there are no signs of moisture and no gouges, cuts, tears, or nondesign voids in the pads.

## 8.3 APPENDIX

8.3.1 Example Leak-test Procedure, Y-12 Product Specification Procedure Y51-01-B2-R-140, *He Leak Testing in B2*

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## Appendix 8.3.1

## Example Leak-test Procedure, Y-12 Product Specification Procedure Y51-01-B2-R-140, *He Leak Testing in B2*

| Babcock & Wilcox Technical Services Y-12, LLC Management Requirements | Product Specification Procedure Title: He Leak Testing in B2 | Number: Y51-01-B2-R-140<br>Revision: B.2<br>Supersedes: B.1<br>Page: 1 of 11<br>Use Category: REFERENCE |
|---|---|---|

| Responsible Organization/Department<br>Assembly/Quality Evaluation Production | | |
|---|---|---|
| | **Responsible Manager**<br>J. A. Hagemann (Signature) 12/18/2013 (Date) | |
| **Quality Engineer**<br>J. C. Chang (Signature) 12/19/2013 (Date) | **Packaging Engineer**<br>Rick D. Michelhaugh (Signature) 12/18/2013 (Date) | **CC Review**<br>C. Lowery (Signature) 12/18/2013 (Date) |
| | **Approved for Practice**<br>(Signature) (Date) | |
| **Verified to be the latest revision**<br>(Initials) (Date) | | 12/19/2013<br>Effective Date |
| **Concurrence by the following is documented in the Procedure History File:** | | |
| Subject Matter Expert<br>AQEP<br>Industrial Hygiene | Packaging Engineer<br>Safety<br>Shift Technical Advisor | Systems Engineer<br>Radiological Control<br>Weapons Quality Engineer |

| Revision Number | Modification Description | Affected Page(s) |
|---|---|---|
| B.1 | On Record. | |
| B.2 | 13-PMR-840, On-the-Spot Intent to clarify leak test station component certification. Certification performed on components of leak test station, not the overall leak test station assembly. Delete leak test station from certification requirements. Deletions are not denoted by a revision bar. | 4 |

This document has been reviewed by a Y-12 DC/ UCNI-RO and has been determined to be UNCLASSIFIED and contains no UCNI. This review does not constitute clearance for Public Release.

Name: Eddie Price Date: 12/18/2013

## TABLE OF CONTENTS


1 APPLICABILITY AND SCOPE ..... 3
2 PRECAUTIONS AND LIMITATIONS ..... 3
3 ACCEPTANCE CRITERIA ..... 3
4 PREREQUISITE ACTIONS ..... 4
4.1 Special Tools, Test Equipment, Parts and Supplies ..... 4
4.2 Field Preparations ..... 4
5 PERFORMANCE ACTIVITIES ..... 5
5.1 Veeco Operational Check ..... 5
5.2 Pumping Down ..... 7
5.3 Leak Testing ..... 8
6 POST-PERFORMANCE ACTIVITIES ..... 10
7 RECORDS ..... 10
8 SOURCE REQUIREMENTS ..... 10
9 APPENDIXES ..... 10
Appendix A, Leak Test Station ..... 11

## 1 APPLICABILITY AND SCOPE

To provide instructions for operating the helium leak test stations in Building 9204-2. The leak stations consist of Veeco MS-50 leak detectors, vacuum pumps, pressure gauges, and the connecting valve manifold. This system has a multiple unit capability which allows the system operator to pump down the other units while running a leak test. Although there are multiple roughing pump valves, multiple manifold valves, and multiple vacuum gauges, during Section **5.2**, *Pumping Down*, **NO** specific valve number alpha designator is given. These valves and gauges are referred to as "valve (gauge) associated with the part under test" to allow the operator to perform a leak test on whichever unit roughs down first.

Applies to leak test equipment used to determine leak rates. The equipment, as currently set-up, is sensitive to Helium leak rates as low as $1 \times 10^{-8}$ cc/sec.

The component to be tested is first vacuum evacuated. Then the component's exterior surfaces are exposed to a helium atmosphere. The atmosphere internal to the part is then valved into the leak detector to check for the presence of helium. A gross leak is indicated by a severe leak rate that exceeds the value normally encountered for the component being tested, and in some instances, may also exceed the pumping capacity of the vacuum system. A gross leak may be the result of an unacceptable part, or a poor quality vacuum test connection.

Program: WC (Weapons Container)

## 2 PRECAUTIONS AND LIMITATIONS

### Industrial Hygiene

**A.** Nitrile gloves SHALL be worn when using organic solvents (isopropyl alcohol, Right Stuff, etc.).

### Safety

**B.** Safety shoes SHALL be worn while performing material activities detailed in this procedure.

**C.** Leather gloves or approved work gloves SHALL be worn, as needed, for work requiring tooling.

### Radiological Control

**D.** RADCON SHALL perform any surveys requested or surveys that are deemed necessary by RADCON.

## 3 ACCEPTANCE CRITERIA

None

## 4 PREREQUISITE ACTIONS

### 4.1 Special Tools, Test Equipment, Parts and Supplies

**Supervisor**

**[1]** Ensure the following equipment is available to perform this procedure, as needed:

- LT-283, LT-285, LT-286, or LT-287 Leak Test Station(s)
- Helium supply bottle with regulator and tubing
- Leak Rate Results form.

### 4.2 Field Preparations

**Assemblyperson**

**[1]** Ensure all equipment, fixtures, and accessories are:

- Operable
- Current on required inspection and/or maintenance
- Determined to be in good condition.

**[2]** Ensure helium supply bottle pressure is 200 psig or greater.

**[3]** Ensure certification stickers are attached and **NOT** expired on the following:

- Internal Standard Leak
- Internal Thermistor
- Vacuum Gauges.

**[4]** Ensure printer is on and ON LINE or READY/DATA is displayed **AND** Leak Rate Results forms are in the paper tray.

## 5 PERFORMANCE ACTIVITIES

**NOTE 1** *A Veeco operational check is performed, once per day, before each day's run.*

**NOTE 2** *Valve number labels will consist of the appropriate Leak Test system ID (i.e., LT-283, LT-285, LT-286, LT-287) and the valve number.*

### 5.1 Veeco Operational Check

**Assemblyperson**

**[1]** Ensure the following valves are CLOSED:

- -PV-101A, TEST POINT A PUMP ISOLATION
- -PV-102A, TEST POINT A LD ISOLATION
- -PV-101B, TEST POINT B PUMP ISOLATION
- -PV-102B, TEST POINT B LD ISOLATION
- -PV-101C, TEST POINT C PUMP ISOLATION
- -PV-102C, TEST POINT C LD ISOLATION
- -PV-101D, TEST POINT D PUMP ISOLATION
- -PV-102D, TEST POINT D LD ISOLATION.

**NOTE** *The vertically arranged blue soft-keys (numbered 1-5) correspond to settings and selections that appear on the CRT.*

**[2]** **IF** Veeco Screen Saver is on, **THEN** press any key to wake up.

**[3]** **IF** Veeco is in SLEEP MODE, **THEN** press 1, POWER UP, on the front panel **AND GO TO** Step **5.1[5]**.

**[4]** **IF** the Veeco is turned off, **THEN** turn on the POWER I/O switch located on the unit's front panel.

**[5]** Verify the READY TO TEST screen is displayed.

**5.1 Veeco Operational Check (cont.)**

**Assemblyperson**

**[6]** **IF** the FIL ON/OFF LED light is off, **THEN** press the FIL ON/OFF key **AND** wait 15 seconds.

**[7]** Perform calibration check.

**[a]** Press the CAL CHECK key.

**[b]** **IF** ABORT is displayed, **THEN** press CAL CHECK key again.

**[c]** **WHEN** the Display Screen displays *Leak Rate Should Read*, **THEN** compare the TEST PORT reading to the value of the LEAK RATE reading.

**[8]** **IF** the TEST PORT reading is within ± 10% of the internal LEAK RATE reading, **THEN** press 3, END CAL CHECK, **AND GO TO** Section **5.2,** *Pumping Down*.

**[9]** **IF** reading is within ± 15% of the LEAK RATE reading, **THEN** press 1, CALIBRATE.

**[10]** **IF** reading is now within ± 10% of the LEAK RATE reading, **THEN** press 3, END CAL CHECK, **AND GO TO** Section **5.2**.

**[11]** **IF** reading is greater than ± 15% of the LEAK RATE reading, **THEN** press 2, FINE TUNE, **AND REPEAT** Steps **5.1[7], 5.1[8],** and **5.1[9]** once each.

**[12]** **IF** the CAL Check is **NOT** within ± 10% of the internal leak rate standard, **THEN** notify Supervisor.

### 5.2 Pumping Down

**Assemblyperson**

**[1]** Ensure the following valves are CLOSED:

- -PV-101A, TEST POINT A PUMP ISOLATION
- -PV-102A, TEST POINT A LD ISOLATION
- -PV-101B, TEST POINT B PUMP ISOLATION
- -PV-102B, TEST POINT B LD ISOLATION
- -PV-101C, TEST POINT C PUMP ISOLATION
- -PV-102C, TEST POINT C LD ISOLATION
- -PV-101D, TEST POINT D PUMP ISOLATION
- -PV-102D, TEST POINT D LD ISOLATION.

**NOTE** *A vacuum source may be used to aid in collapsing the bag and removing air pockets.*

**[2]** Encapsulate, fully, the Containment Vessel (CV) to be leak tested within a plastic bag.

**[3]** Remove the air in the bag as far as practical to ensure the leak rate will be correctly measured.

**[4]** **IF** test line(s) are capped, **THEN** remove cap.

**[5]** Connect each CV's Leak Test Flange to station test line(s).

**[6]** Open PUMP ISOLATION valve(s) (-PV-101A through -PV-101D) associated with the parts under test to evacuate parts.

## 5.3 Leak Testing

**Assemblyperson**

**NOTE 1** *Leaks may be repaired and the test repeated, as directed by Supervisor.*

**NOTE 2** *To ensure a helium atmosphere, helium must flow into the bag and be purged from a point below the part being tested throughout the test. This continuous purge may be at a lower helium pressure than the pressure used to inflate the bag.*

**[1]** Insert the helium fill tube **AND** secure, as needed.

**[2]** Open the Helium Tank Valve **AND** fill the plastic bag with Helium.

**[3]** **WHEN** Granville Phillips (GP) vacuum gauge, for the Containment Vessel (CV) being tested, reads 15 mTorr or less, **THEN** close the PUMP ISOLATION valve (i.e., -PV-101A, -101B, -101C, or -101D).

**[4]** Verify the CRT shows READY TO TEST **AND** the appropriate REJECT POINT is displayed.

**[5]** **IF** the appropriate REJECT POINT is **NOT** displayed, **THEN** perform the following steps:

- **[a]** Press 5, SETTINGS/HELP on READY TO TEST screen.
- **[b]** Press 3, SELECT UP, **OR** 4, SELECT DOWN, on HELP/SETTINGS menu, until TEST RECIPE field is highlighted.
- **[c]** Press 2, CHANGE, to access SELECT TEST RECIPE menu.
- **[d]** Press 3, SELECT UP, or 4, SELECT DOWN, to specify test recipe with appropriate REJECT point.
- **[e]** Press 5, EXIT, to return to test mode.

**[6]** Open the leak detector (LD) isolation (LD ISOLATION) valve (i.e., -PV-102A, -102B, -102C, or -102D) associated with the part under test.

**NOTE 1** *Pressing START a second time after testing begins will halt testing.*

**NOTE 2** *To ensure a helium atmosphere, a slight purge of helium may be necessary during testing.*

**NOTE 3** *Based on initial pressure, the system requires 1½ to 2 minutes to accurately read the calibrated standard leak.*

**[7]** Press and hold START button until leak test begins.

**[8]** Leak test for at least two minutes (minimum time to assure detector stability) before continuing with procedure.

**5.3 Leak Testing (cont.)**
**Assemblyperson**

**[9]** **IF** LEAK RATE is less than REJECT set point **AND** the ACCEPT is displayed, **THEN** end test by performing the following:

**[a]** Press **AND** hold VENT button until test ends.

**[b]** Close leak detector (LD) isolation valve.

**[10]** The Leak Detector will print the leak test results.

**[11]** Record part number and expiration date, Standard Leak SAP # and Expiration Date on the Leak Rate Results form **AND** attach to the part card.

**[12]** **IF** LEAK RATE is more than REJECT set point **AND** the REJECT is displayed, **THEN** end test by performing the following:

**[a]** Press **AND** hold VENT button until test ends.

**[b]** Close leak detector (LD) isolation valve.

**[c]** Print leak test results **AND** discard.

**[d]** Repair leaks **AND** repeat test, as necessary.

**[e]** **IF** CV continues to fail leak test, **THEN** contact Supervisor.

**[13]** **IF** another part has been attached **AND** the part has been roughed down (i.e., pumped down) for testing, **THEN GO TO** Step **5.3[1]**.

**[14]** Ensure the following valves are CLOSED:

- -PV-101A, TEST POINT A PUMP ISOLATION
- -PV-102A, TEST POINT A LD ISOLATION
- -PV-101B, TEST POINT B PUMP ISOLATION
- -PV-102B, TEST POINT B LD ISOLATION
- -PV-101C, TEST POINT C PUMP ISOLATION
- -PV-102C, TEST POINT C LD ISOLATION
- -PV-101D, TEST POINT D PUMP ISOLATION
- -PV-102D, TEST POINT D LD ISOLATION.

**[15]** Disconnect CV from/leak test station test line(s).

**[16]** Turn off Helium Supply.

**[17]** **IF NO** other CVs are to be leak tested, **THEN** replace cap.

## 6 POST-PERFORMANCE ACTIVITIES

None

## 7 RECORDS

All records generated as a result of this procedure are maintained in accordance with Y15-101, *Records and Controlled Documents*.

| Record Copy Owner | Record Type |
|---|---|
| Assembly & Quality Evaluation Production | Print outs of leak test results. |

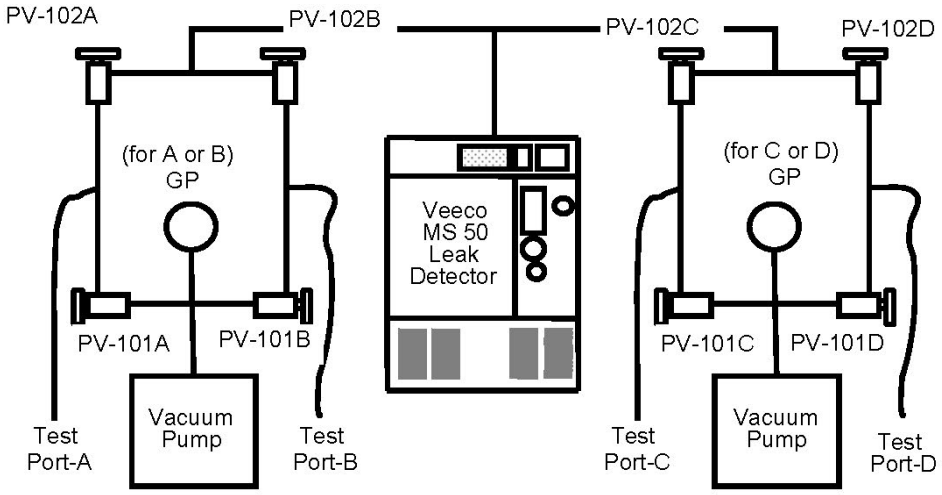
## 8 SOURCE REQUIREMENTS

- *VIC Leak Detection, MS-50 Automatic Leak Detector, Operation and Maintenance Manual, Vacuum Instrument Corporation, Vacuum Metrology Division, New York.*

## 9 APPENDIXES

**A.** Leak Test Station

## Appendix A
## Leak Test Station



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## SECTION 8 REFERENCES


10 CFR 71, *Packaging and Transportation of Radioactive Material*, January 2015.

10 CFR 830, *Nuclear Safety Management*, January 2015.

10 CFR 835, *Occupational Radiation Protection*, January 2015.

49 CFR, *Transportation*, October 2014.

ANL/DIS-09-5, *Guide to the RFID Monitoring System*, Argonne Natl. Lab., latest revision.

ANSI N14.5-1997, *Radioactive Materials—Leakage Tests on Packages for Shipment*, American Natl. Standards Institute, Feb. 5, 1998.

*ASME Boiler and Pressure Vessel Code*, Sect. III, Div. 1, Subsection NB, *Class 1 Components*, American Society of Mechanical Engineers, New York, revision at time of fabrication.

AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*, American Welding Society, Miami, Fla., 2012.

DAC-M900000-0003, C. R. Hammond, *Stress Analysis of ES-3100 Containment Vessel with Viton O-rings*, B&W Y-12, Y-12 National Security Complex, May 23, 2012.

DOE O 232.2, Admin Chg 1, *Occurrence Reporting and Processing of Operations Information*, U.S. DOE, March 2014.

DOE O 414.1D, Admin Chg 1, *Quality Assurance*, U.S. DOE, May 2013.

DOE O 460.1C, *Packaging and Transportation Safety*, U.S. DOE, May 2010.

DOE O 461.1B, *Packaging and Transportation for Offsite Shipment of Materials of National Security Interest*, U.S. DOE, December 2010.

MIL-D-6054F, Amendment 1, *Drum, Metal—Shipping and Storage*, U.S. DoD, June 30, 1989.

NUREG/CR-6314, H. M. Stromberg et al., *Quality Assurance Inspections for Shipping and Storage Containers*, U.S. NRC and Idaho Natl. Engineering Lab., April 1996.

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# 9. QUALITY ASSURANCE

This section of the safety analysis report for packaging (SARP) describes the ES-3100 package quality assurance (QA) requirements that apply to packaging-related activities necessary for the design, fabrication, assembly, testing, maintenance, and use in accordance with applicable U.S. Nuclear Regulatory Commission (NRC), U.S. Department of Transportation (DOT), and other federal, state, and local regulations to protect the health and safety of the public, workers, and the environment. Furthermore, these packaging-related activities shall be performed according to a QA program approved by the U.S. Department of Energy (DOE), Office of Environmental Management; or National Nuclear Security Administration (NNSA), as appropriate.

The established NRC regulations for packaging, preparation for shipment, and transportation of radioactive materials are given in Title 10, Part 71, of the Code of Federal Regulations (CFR) [10 CFR 71] and DOT regulations for packaging and shipment of hazardous materials are given in Title 49 CFR. DOE nuclear facility users are also responsible for implementing DOE regulations given in Title 10, Parts 830 and 835, of the CFR in addition to directives conveyed in DOE Order (O) 232.2, DOE O 414.1D, and DOE O 460.1C or DOE O 461.1B, as appropriate.

Title 10 CFR 71.101 requires the establishment, maintenance, and implementation of a QA program that satisfies each of the applicable criteria of 10 CFR 71, Subpart H. The applicable criteria shall be executed in a graded approach to an extent that is commensurate with their respective importance to safety in accordance with implementing guidance from NRC Regulatory Guide 7.10. All personnel including users, subcontractors, and suppliers who perform quality-affecting activities relative to the packaging shall be subject to the requirements of this section in accordance with their degree of involvement in the packaging activities.

As used in 10 CFR 71, QA comprises all planned and systematic actions necessary to provide adequate confidence that a system or component will perform satisfactorily in service. Consequently, QA includes quality control, which comprises those QA actions related to control of the physical characteristics and quality of the material or component to predetermined requirements.

## 9.1 INTRODUCTION

A packaging QA program is established at the Y-12 National Security Complex (Y-12) in accordance with the *Packaging and Transportation Quality Assurance Program Plan* (QAPP) [QAP-Y-91-273860-1], which is approved by the NNSA Office of Packaging and Transportation. The program uses a graded approach to selectively apply the QA elements contained in 10 CFR 830, DOE O 414.1D, 10 CFR 71, American Society of Mechanical Engineers (ASME) NQA-1-2008 with 2009 Addenda, DOE O 460.1C, and DOE O 461.1B, as applicable.

This program applies to all activities related to the storage, transfer, or transportation of hazardous materials, radioactive/hazardous waste, and materials of national security interest. The QA requirements and quality control provisions of the program apply to packaging-related activities and services necessary for the design, purchase, fabrication, handling, shipping, storing, cleaning, assembly, inspection, testing, operation, maintenance, repair, and modification of radioactive material packagings.

These requirements are incorporated into an integrated body of packaging activities established to ensure quality. Achieving quality of design, conformance, and performance that meets or exceeds all packaging standards is the essential purpose of this program.

## 9.2 SCOPE

The design agency (Y-12) and owners of the ES-3100 packaging will implement a QA program that addresses appropriate suspect/counterfeit item (S/CI) and software quality assurance (SQA) requirements as well as the following 18 QA elements of 10 CFR 71, Subpart H:

- § 71.103, *Quality assurance organization*;
- § 71.105, *Quality assurance program*;
- § 71.107, *Package design control*;
- § 71.109, *Procurement document control*;
- § 71.111, *Instructions, procedures, and drawings*;
- § 71.113, *Document control*;
- § 71.115, *Control of purchased material, equipment, and services*;
- § 71.117, *Identification and control of materials, parts, and components*;
- § 71.119, *Control of special processes*;
- § 71.121, *Internal inspection*;
- § 71.123, *Test control*;
- § 71.125, *Control of measuring and test equipment*;
- § 71.127, *Handling, storage, and shipping control*;
- § 71.129, *Inspection, test, and operating status*;
- § 71.131, *Nonconforming materials, parts, or components*;
- § 71.133, *Corrective action*;
- § 71.135, *Quality assurance records*; and
- § 71.137, *Audits*.

In accordance with their site-approved QA program, authorized users of the ES-3100 packaging must address the following QA elements, as a minimum:

- § 71.103, *Quality assurance organization*;
- § 71.105, *Quality assurance program*;
- § 71.111, *Instructions, procedures, and drawings*;
- § 71.113, *Document control*;
- § 71.115, *Control of purchased material, equipment, and services*;
- § 71.117, *Identification and control of materials, parts, and components*;
- § 71.121, *Internal inspection*;
- § 71.123, *Test control*;
- § 71.125, *Control of measuring and test equipment*;
- § 71.127, *Handling, storage, and shipping control*;
- § 71.129, *Inspection, test, and operating status*;
- § 71.131, *Nonconforming materials, parts, or components*;
- § 71.133, *Corrective action*;
- § 71.135, *Quality assurance records*; and
- § 71.137, *Audits*.

Additional QA elements may also be addressed as commensurate with the user's scope of responsibility (i.e., if authorized for packaging-related design, fabrication, maintenance, repair, or modification activities). All providers of items and/or services must demonstrate that they meet the applicable QA requirements for their respective work scope. Each user of the ES-3100 package must also develop an appropriate site-approved QA plan and related implementing documentation.

## 9.3 QUALITY ASSURANCE PLAN

The QA requirements from 10 CFR 71, Subpart H are to be selectively applied using a graded approach to the specific packaging programs being developed and implemented. This selective application requires that the detail and magnitude of resources expended for a packaging-related activity be commensurate with the activity's importance to safe and reliable operations, environmental compliance, safeguards and security, programmatic mission, and/or other packaging-specific requirements. As stated in NRC Regulatory Guide 7.10, "structures, systems, and components important to safety mean the features of a Type B or fissile material package that are intended to (1) maintain the conditions required to safely transport the package contents; (2) prevent damage to the package during transport; or (3) provide reasonable assurance that the radioactive contents can be received, handled, transported, and retrieved without undue risk to the health and safety of the public or the environment."

Y-12 has embraced the quality concepts and principles identified in the ASME Nuclear Quality Assurance document NQA-1. This national consensus standard is integrated, where practicable and consistent with contractual or regulatory requirements, as the basis for the Y-12 QA Program. The Y-12 QAPP identifies the requirements that apply to packaging-related activities for radioactive material packages for offsite transportation and describes the method of control over those structures, systems, and components (SSCs) important to safety. A crosswalk matrix that documents the Y-12 packaging QA program conformance to the 18 QA elements of 10 CFR 71, Subpart H as well as requirements for SQA is provided in Y17-69-PE-335PD. Section 9.3 discusses how these requirements are implemented at Y-12 for the ES-3100 package with highly enriched uranium content.

### 9.3.1 Quality Assurance Organization

As described in Sect. 1 of the QAPP, the organizations ultimately responsible for QA within the Y-12 offsite packaging and transportation program are: (1) Packaging and Transportation Engineering (PTE); (2) Production Operations; (3) Quality Performance & Analysis (QP&A); (4) Program Integration; and (5) Transportation. Other Y-12 organizations have QA functions in support of the organizations identified above. An organization chart that depicts PTE and its relationship with the functional and technical support groups that provide items and services or that conduct other activities in support of radioactive material packagings is provided in Fig. 9.1.

PTE is responsible for the development of the QAPP and quality requirements for packaging components designed at Y-12. The manager of PTE has the responsibility for the technical leadership of the program. The PTE organization is part of the Y-12 Engineering division, which reports to the vice president of Mission Engineering (Fig. 9.1). They also ensure that packagings fully comply with the applicable regulations, requirements, and standards. PTE and the Y-12 QA organizations ensure that the quality of packagings is maintained throughout the design, testing, fabrication, and maintenance processes. PTE is the design authority and primary contact for all packaging-related activities and services necessary for the design, purchase, fabrication, handling, shipping, storing, cleaning, assembly, inspection, testing, operation, maintenance, repair, and modification of Y-12 Type B and Type AF radioactive material packagings, such as the ES-3100. PTE provides requested technical assistance for other Type B radioactive material packages. The complete description of the engineering roles and responsibilities is described in Y17-69-PE- 335PD.

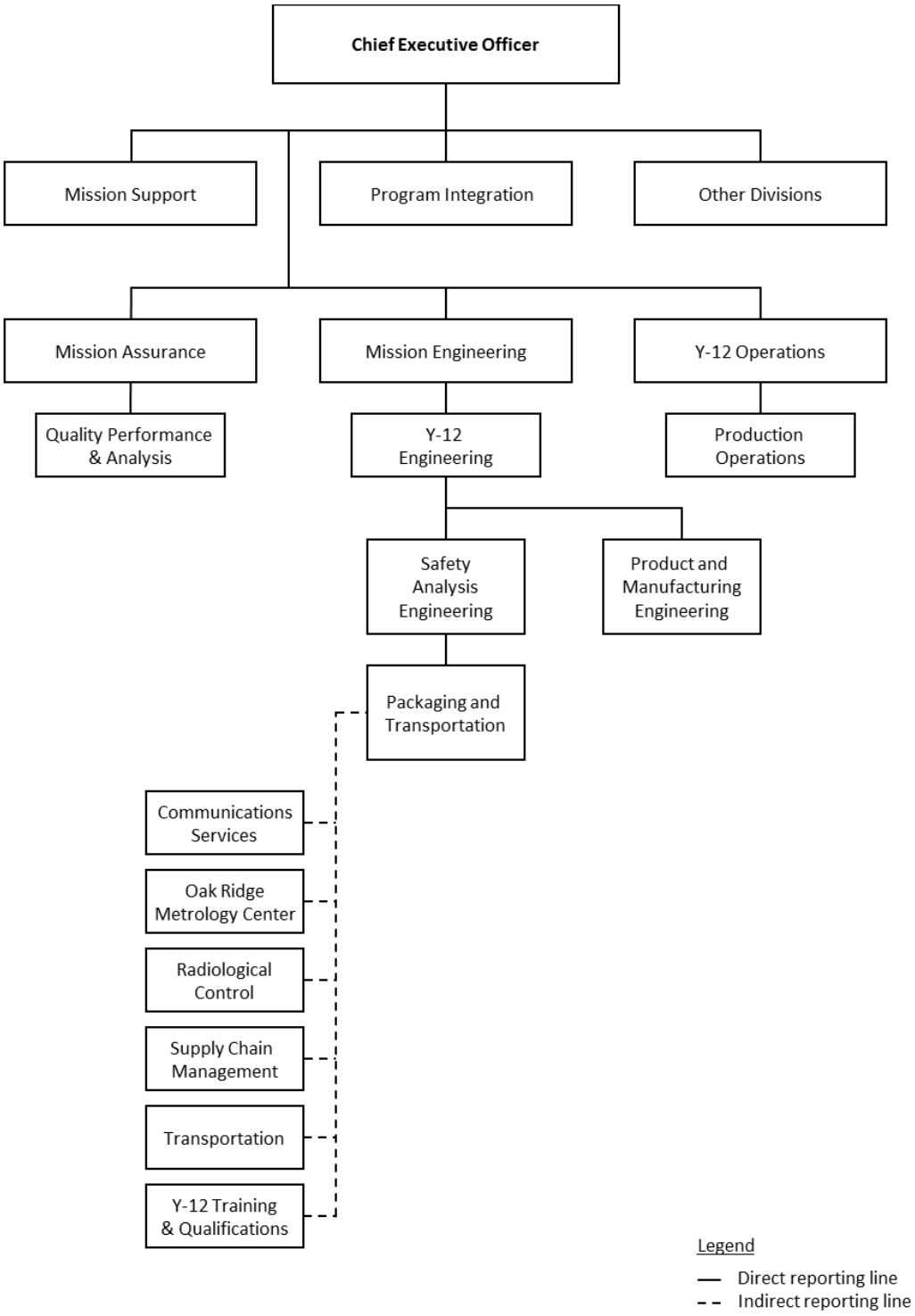



**Fig. 9.1. Y-12 Packaging and Transportation Engineering organizational support.**

In conjunction with Program Integration management, the PTE manager plans, schedules, and assigns work activities and also obtains adequate funding to accomplish program goals and milestones. Production Operations conducts packing, maintenance, loading, and material handling activities with qualified personnel. Production Operations activities related to packaging are controlled by procedures approved by PTE and overseen by the QP&A organization. Production Operations reports to the Y-12 Site Manager, is funded by the program integration organizations, and receives technical support from PTE and quality oversight from QP&A. Production Operations is responsible for complying with implementing procedures, instructions, and/or checklists for loading, unloading, and maintenance of the packagings. Production Operations owns the content and the packaging and has the primary responsibility for the proper use of the package.

The QP&A organization is responsible for the management and execution of the overall Y-12 QA Program. QP&A is also responsible for providing qualified personnel for assessments and oversight for operations, vendor qualifications, and independent component inspections. The QP&A manager reports to the vice president of Mission Assurance.

Program Integration management provides the funding for the daily maintenance and compliance activities necessary to ensure that the Y-12 packaging and transportation program complies with NRC, DOT, and DOE regulations. These activities include DOE order compliance, programmatic training, assessments, QA, investigations, shipping package maintenance, and user support. The vice president of Program Integration reports to the Chief Executive Officer.

The Transportation organization provides compliance oversight to ensure compliance with DOE orders and federal, state, and local laws for the offsite shipment of radioactive materials. Other organizations provide services to PTE as shown in Fig. 9.1. Every individual and organization that produces an item, performs an activity, or provides a service for radioactive material packagings has direct responsibility for the quality of that item, activity, or service. Every organization using a package is responsible for ensuring proper procedures, training, and qualifications are in place.

### 9.3.2 Quality Assurance Program

Through the effective implementation of the QAPP, Y-12 management provides control over activities affecting the quality of ES-3100 packaging materials and components to the extent commensurate with their importance to safety. The QAPP provides for activities affecting quality to be accomplished under suitably controlled conditions to ensure conformance with the approved design of the packaging. The QAPP complies and implements the requirements of 10 CFR 71.101 through 71.137 through the implementation of an ASME NQA-1–based QA program. In accordance with Sect. 2 of the QAPP, packaging responsibilities are delineated to the PTE manager, and activities affecting quality are verified by individuals who are not directly responsible for performance of work. Personnel or organizations responsible for establishing and executing the QAPP may delegate work; however, they retain overall responsibility for delegated work.

The management assessment process is designed to focus on the compliance and flow down of contractual requirements, including applicable standards and codes, how those requirements are implemented in procedures, and the measurement of implementation effectiveness. Management assessments are conducted by members of the line organization or program to evaluate and determine whether packaging-related activities are properly focused on achieving desired results. These assessments serve as a periodic self-analysis tool and include reviewing the processes, systems, and programs that are important to the specified mission, goals, and objectives as well as identifying areas for continuous improvement. The assessment process includes provisions to appropriately evaluate all aspects of the Y-12 packaging process, determine how well the management system meets specified requirements, and assess methods to safely perform packaging-related activities.

Training and qualifications are required for personnel within Y-12 performing packaging activities related to design, fabrication, testing, procurement, loading, unloading, leak testing, quality oversight, transportation, and record keeping. Each activity is evaluated and the proper training plan is developed and documented in accordance with established procedures. Vendors performing packaging activities will require training or qualifications as defined in accordance with the established contract. Activities involving special processes as defined in 10 CFR 71, Subpart H, may require specialized qualifications in accordance with established approved training requirements or through a nationally recognized standard such as the American Society for Nondestructive Testing, ASME, or American National Standards Institute.

As previously discussed, Y-12 uses a graded approach to selectively apply QA requirements to the ES-3100 packaging components and related services and activities in accordance with 10 CFR 71.105. The purpose of the graded approach is to select the appropriate QA controls and verification actions to be applied (selective application) to the various types of packagings and packaging-related components. To ensure conditions are controlled in accordance with their safety importance, a documented graded approach has been adopted. The degree to which the plan is applied is based on a graded approach to quality, commensurate with the identified risk associated with the failure of items, processes, or services related to the safety of employees and the public, protection of the environment, and achievement of Y-12 programmatic missions.

The graded approach is consistent with that defined in NRC Regulatory Guide 7.10. This process involves (1) classifying packaging SSCs as "important to safety" or "not important to safety" (NITS); (2) grouping SSCs classified as "important to safety" into quality categories; and (3) specifying the applicable level of QA effort for each category. Approved procedures provide instructions to analyze packaging SSCs to determine whether their functions or physical characteristics are essential to safety, and they provide the criteria for grouping SSCs into one of the following quality categories as defined below. Table 9.1 shows the typical level of QA effort for each element of 10 CFR 71, Subpart H, relative to the graded safety-related quality categories. Each packaging component is graded by the Quality Category Committee using the quality category definitions in a manner similar to the procedure described in NRC Regulatory Guide 7.10, Appendix A. The results of the quality category grading for ES-3100 packaging components are given in Table 9.2, and the correlation between the NRC Regulatory Guide 7.10–based quality categories and the Y-12 quality levels (based on ASME NQA-1) is presented in the QAPP.

- **Category A** (critical to safe operation) components whose failure or malfunction will directly result in an unacceptable condition of containment, shielding, or nuclear criticality.
- **Category B** (major impact on safety) components whose failure or malfunction will indirectly result in an unacceptable condition of containment, shielding, or nuclear criticality (if the primary event occurred in conjunction with a secondary event, another failure, or an environmental event).
- **Category C** (minor impact on safety) components whose failure or malfunction does not result in an unacceptable condition of containment, shielding, or nuclear criticality regardless of other failures in this category.
- **NITS** (not important to safety).

As described in Sect. 2 of the QAPP, document and record requirements have been developed for packaging design drawings, specifications, safety documentation, policies, procedures, assessments, surveillances, records, forms, procurement requisitions, communications, and training. Documents for activities that affect quality relative to procurement, fabrication, assembly, and the use of packaging are considered to be records and will be maintained in compliance with appropriate regulations. Controlled documents affecting quality will be maintained under revision control as required and in an appropriate document management system.

**Table 9.1. Typical level of quality assurance effort by graded quality category**

| 10 CFR 71, Subpart H, level of quality assurance effort | Graded quality category | | |
|---|---|---|---|
| | A | B | C |
| § 71.103, *Quality assurance organization* | | | |
| – Quality assurance program established | ✓ | ✓ | ✓ |
| – Responsibilities defined | ✓ | ✓ | ✓ |
| – Quality assurance functions executed | ✓ | ✓ | ✓ |
| – Reporting levels established | ✓ | ✓ | ✓ |
| – Management endorsement | ✓ | ✓ | ✓ |
| § 71.105, *Quality assurance program* | | | |
| – 10 CFR 71, Subpart H, compliant quality assurance program | ✓ | ✓ | |
| – Written procedures and instructions | ✓ | ✓ | ✓ |
| – Activities affecting quality are appropriately controlled and performed by trained personnel | ✓ | ✓ | ✓ |
| – Management review | ✓ | ✓ | ✓ |
| § 71.107, *Package design control* | | | |
| – Most stringent Codes and Standards | ✓ | | |
| – Formal test for complex items (first article evaluation) | ✓ | | |
| – Codes and Standards | ✓ | ✓ | |
| – Formal engineering design process (control of design inputs, outputs, reviews, verifications, testing, changes/deviations, analyses, and interfaces) | ✓ | ✓ | |
| – Software quality assurance | ✓ | ✓ | |
| – Catalog/off-the-shelf components | | | ✓ |
| – Design change approval required for certifier controlled design conditions | ✓ | ✓ | ✓ |
| § 71.109, *Procurement document control* | | | |
| – Traceability | ✓ | ✓ | |
| – Qualified supplier lists | ✓ | ✓ | |
| – Suppliers and subtier suppliers meet the applicable provisions of 10 CFR 71, Subpart H–*Quality Assurance* | ✓ | ✓ | |
| – Commercial grade dedication of items or services | ✓ | ✓ | |
| – Catalog/off-the-shelf components | | | ✓ |
| § 71.111, *Instructions, procedures, and drawings* | | | |
| – Written and controlled | ✓ | ✓ | |
| – Quantitative or qualitative acceptance criteria | ✓ | ✓ | |
| – Controlled changes and deviations for certifier controlled design conditions | ✓ | ✓ | ✓ |
| § 71.113, *Document control* | | | |
| – Controlled issuance | ✓ | ✓ | |
| – Controlled changes and deviations | ✓ | ✓ | |

**Table 9.1. Typical level of quality assurance effort by graded quality category**

| 10 CFR 71, Subpart H, level of quality assurance effort | Graded quality category | | |
|---|---|---|---|
| | A | B | C |
| § 71.115, *Control of purchased material, equipment, and services* | | | |
| – Source evaluation and selection | ✓ | | |
| – Inspections, audits, or surveillances at supplier facilities in accordance with specified requirements | ✓ | ✓ | |
| – Objective evidence of quality furnished by the supplier | ✓ | ✓ | |
| – Commercial grade dedication of items or services | ✓ | ✓ | |
| – Documentary evidence provided to ensure that material, equipment, and services conform to the procurement documents and specified requirements | ✓ | ✓ | ✓ |
| – Packaging components identified upon receipt and checked for damage | ✓ | ✓ | ✓ |
| § 71.117, *Identification and control of materials, parts, and components* | | | |
| – Positive identification and traceability of each packaging component | ✓ | | |
| – Control, identification, and traceability to heat number, part number, or other appropriate means throughout fabrication, installation, and use | ✓ | ✓ | |
| – Identification to end use instructions, procedures, specifications, or drawings | ✓ | ✓ | ✓ |
| § 71.119, *Control of special processes* | | | |
| – Special processes including welding, heat treating, and nondestructive testing performed with qualified personnel and procedures | ✓ | ✓ | |
| – Special process qualification records | ✓ | ✓ | |
| – Special processes conducted in accordance with specified requirements | ✓ | ✓ | ✓ |
| § 71.121, *Internal inspection* | | | |
| – Documented inspection to verify conformance with instructions, procedures, drawings, and specifications | ✓ | ✓ | |
| – Process monitoring provided as appropriate to assure quality control | ✓ | ✓ | |
| – Examination, measurements, or tests of material or products processed in accordance with specified requirements | ✓ | ✓ | |
| – Qualified inspectors independent of those performing the activities being inspected | ✓ | ✓ | |
| – Visual examination in accordance with specified requirements | ✓ | ✓ | ✓ |
| § 71.123, *Test control* | | | |
| – Formal test program implemented using written test procedures | ✓ | ✓ | |
| – Formal test for complex items (first article evaluation) | ✓ | | |
| – Test results are documented and evaluated | ✓ | ✓ | |
| – Observation and evaluation of supplier acceptance tests in accordance with specified requirements | ✓ | ✓ | |
| – Testing and acceptance criteria in accordance with specified requirements | ✓ | ✓ | ✓ |
| § 71.125, *Control of measuring and test equipment* | | | |
| – Formal calibration program to ensure that tools, gauges, instruments, and other measuring and testing devices are controlled, calibrated, and adjusted | ✓ | ✓ | |
| § 71.127, *Handling, storage, and shipping control* | | | |
| – Written procedures for handling, storing, shipping, cleaning, and preservation of packaging components to prevent damage or deterioration | ✓ | ✓ | |
| – Routine handling activities | | | ✓ |

**Table 9.1. Typical level of quality assurance effort by graded quality category**

| 10 CFR 71, Subpart H, level of quality assurance effort | Graded quality category | | |
|---|---|---|---|
| | **A** | **B** | **C** |
| § 71.129, *Inspection, test, and operating status* | | | |
| – Status or condition of individual packaging components is identified | ✓ | ✓ | |
| – Stamps, tags, labels, or other suitable means indicate the status or condition | ✓ | ✓ | ✓ |
| § 71.131, *Nonconforming materials, parts, or components* | | | |
| – Written procedures to identify, document, segregate, disposition, notify affected organizations, and to prevent inadvertent use or installation | ✓ | ✓ | ✓ |
| – Nonconforming conditions must be documented and closed in accordance with written procedures | ✓ | ✓ | ✓ |
| – Records of disposal (i.e., reject or scrap) required | ✓ | ✓ | |
| § 71.133, *Corrective action* | | | |
| – Written procedures to identify and correct conditions adverse to quality | ✓ | ✓ | ✓ |
| – Cause and corrective action documented | ✓ | ✓ | |
| – Significant conditions adverse to quality reported | ✓ | ✓ | ✓ |
| § 71.135, *Quality assurance records* | | | |
| – Records of reviews, inspections, tests, audits, surveillances, and material analyses | ✓ | ✓ | |
| – Records of design, fabrication, acceptance testing, and maintenance retained for the life of the packaging plus 3 years | ✓ | ✓ | |
| – Records of each shipment of radioactive materials for 3 years after the shipment | ✓ | ✓ | ✓ |
| – Qualification records of personnel, procedures, and equipment in accordance with specified requirements | ✓ | ✓ | ✓ |
| – Procurement records and nonconformance reports | ✓ | ✓ | ✓ |
| – Records managed by written program | ✓ | ✓ | ✓ |
| § 71.137, *Audits* | | | |
| – All auditors are qualified | ✓ | | |
| – Lead auditor is qualified | ✓ | ✓ | |
| – Written plan of periodic audits | ✓ | ✓ | ✓ |
| – Implementation by written procedures or checklists | ✓ | ✓ | ✓ |

**Table 9.2. Quality category for ES-3100 packaging components**

| ES-3100 component | Quality category |
|---|---|
| **ES-3100 drum assembly (Drawing M2E801580A001, Appendix 1.3.7)** | |
| Drum, inner liner, lid, and top plug weldments | B |
| Weld studs | B |
| Hex nuts | B |
| Washers | C |
| TID lugs, data plate, and trefoil data plate | C |
| Kaolite 1600 insulation | B |
| 277-4 neutron-absorbing material | A |
| Silicone rubber pads (CV bottom pad, CV flange pad, and plug pad) | C |
| Aluminum foil duct tape | C |
| Nylon plug | C |
| Paint | C |
| RFID monitoring system tag | NITS [a] |
| **ES-3100 containment vessel assembly (Drawing M2E801580A011, Appendix 1.3.7)** | |
| Body [b] | A |
| Lid assembly | |
| Sealing lid and closure nut | A |
| Round bar and weld filler material | B |
| External retaining ring | C |
| Inner O-ring | A |
| Outer O-ring | C |
| Super-O-Lube | C |
| Modified VCO threaded plug with O-ring | C |
| Krytox grease, grade 240 AC | C |
| Hoist ring | C |
| **ES-3100 packing materials (Sect. 1.2.2.4)** | |
| Convenience cans | C |
| Convenience bottles | C |
| Silicone rubber pad [c] (can pad) | C |
| Heavy can spacer assembly [d] | |
| Can body and end cover | B |
| 277-4 neutron-absorbing material | A |
| Lanyard, band clamp, and labels | C |
| Metal scrubbers | C |
| Polyethylene bag | C |

[a] An optional radio-frequency identification (RFID) monitoring system tag (categorized as not important to safety) may be secured to the drum assembly. The QA requirements for the design, procurement, operation, and maintenance of the RFID monitoring system tag and support programs are presented in ANL/DIS-09-5.
[b] Component including any weld filler material.
[c] Drawing M2E801580A024, Appendix 1.3.7.
[d] Drawing M2E801580A043, Appendix 1.3.7.

### 9.3.3 Package Design Control

PTE is responsible for the ES-3100 package design control. This organization develops, prepares, approves, and issues the packaging system requirements document that includes the physical, functional, and performance requirements and identifies the regulatory requirements. In accordance with Sect. 3 of the QAPP, PTE is also responsible for the design process, including design verification activities. Design input such as the design basis, structural analysis, thermal analysis, radiation shielding analysis, and nuclear criticality analysis for the ES-3100 package are identified and documented, and their selection is reviewed and approved by the PTE manager.

Once the design has been translated into drawings and specifications, a design review is conducted and documented. The ES-3100 packaging certification drawing (Appendix 1.3.1) specifies those details of the package design that affect its evaluation under 10 CFR 71. The packaging design drawings (Appendix 1.3.7) and the equipment specifications (Appendices 1.3.2–1.3.5, 1.3.9, and 1.3.10) provide detailed fabrication and acceptance criteria for the packaging components.

Test requirements for the conduct of the physical testing to ensure compliance with 10 CFR 71.71 and 71.73 are identified. A test plan, test procedures, and the test report are prepared by the testing organization and submitted to PTE for review and approval. Results of the package-testing program are incorporated into the certification documentation (SARP). All packaging activities, including design, are controlled with the use of approved procedures and instructions.

A change to Category A and B components (Sect. 9.3.2 and Tables 9.1 and 9.2) that affects a design feature, requirement, or specification shown on the ES-3100 certification drawing (Appendix 1.3.1) or condition of approval in the Certificate of Compliance shall be submitted to DOE Headquarters Certifying Official for review and approval, and the change shall not be implemented until the DOE Headquarters Certifying Official has provided approval of the change in writing. Once approved, PTE must revise the affected packaging design documents and/or SARP sections, as applicable, and provide copies of the changes to the Certifying Official and all the organizations having a controlled copy of the SARP as soon as possible.

A change to Category C or NITS components may be approved by PTE (the design authority and SARP owner). PTE must revise the affected packaging design documents and/or SARP sections, as applicable, and provide copies of the changes to the Certifying Official and all the organizations having a controlled copy of the SARP in a timely manner.

### 9.3.4 Procurement Document Control

In accordance with Sect. 4 of the QAPP, the Y-12 procurement process, which is ASME NQA-1 based, establishes the system to ensure that applicable technical and quality requirements are included in the procurement documents for packaging material, equipment, and services, whether purchased by Y-12 or its suppliers. This procurement process ensures that those items and/or services provided by approved suppliers meet the 10 CFR 71, Subpart H requirements. Using a graded approach, Y-12 executes the procurement process by performing vendor qualification reviews, assessments, and first article evaluations, as required, ensuring that:

- requirements are accurately, completely, and clearly communicated to the supplier;
- suppliers comply with regulatory qualification requirements;
- suppliers fabricate according to the design documentation, and
- the requested documentation is provided.

Applicable QA requirements are flowed down and verified through reviews, assessments, audits, and inspections of suppliers and sub-tier suppliers, as required, to ensure that they are capable of and continue to meet the specified technical and quality requirements. Packaging components identified as either Category A or B must be purchased from qualified vendors or through commercial grade dedication in accordance with established procedures.

Controls are implemented to ensure that procurements are planned and applicable technical and quality requirements are included or referenced in the procurement documents, that procurement documents are reviewed, and that changes are subject to the same degree of control used in preparation of the original documents. These controls also ensure that the items, materials, or services have been assigned a quality category. The proper quality category for each component is determined and documented by the Quality Category Committee (Sect. 9.3.2).

### 9.3.5 Instructions, Procedures, and Drawings

In accordance with Sect. 5 of the QAPP, packaging activities that affect quality are performed in accordance with written and approved instructions, procedures, drawings, and specifications that identify the QA requirements and acceptance criteria applicable to each packaging-related item, service, or activity. Y-12 organizations responsible for specific packaging-related operations and activities prepare the required procedures, instructions, checklists, and other required implementing documents for their particular packaging activities. These documents provide quantitative or qualitative acceptance criteria to ensure that the activities are performed satisfactorily and that they meet the applicable requirements.

The packaging activities that are important to safety are accomplished and controlled in accordance with written and approved instructions, procedures, drawings, and other documents that identify the quality requirements for each item, service, or activity and should include the methods for complying with applicable sections in 10 CFR 71, Subpart H. Packaging activities will be described to a level of detail commensurate with the complexity of the operation and the need to ensure consistent and acceptable results.

### 9.3.6 Document Control

In accordance with Sect. 6 of the QAPP, Y-12 has an established system to ensure that documents within the scope of the QAPP, including changes thereto, are prepared, reviewed for adequacy and completeness, approved for release, and used at the work location. The documents necessary to accomplish and/or verify packaging activities affecting quality are identified and controlled. Typical documents that are controlled include design documents, procurement documents, QA manual, procedures, nonconformance reports (NCRs), design change requests, and corrective action reports.

The PTE manager ensures that necessary controlled documents are identified, prepared, reviewed, and approved. PTE maintains responsibility for and control of packaging-related documents that are issued by PTE. These documents are reviewed and approved for adequacy by the PTE manager, the designee, or the packaging engineer. This control system ensures:

- changes to documents are reviewed and approved by the same organizations that performed the original review and approval;
- approved documents are available at all locations when operations, which are essential to the effective functioning of the quality system, are performed; and
- recipients are notified when documents are superseded, so they can be promptly removed from all points of issue or use, and originals are maintained for establishing history and maintaining traceability.

### 9.3.7 Control of Purchased Material, Equipment, and Services

In accordance with Sect. 7 of the QAPP, PTE has an established system for planning and executing packaging-related procurements to ensure that purchased material, equipment, and services conform to the procurement documents. Y-12 procedures document the methods and responsibilities for procuring packaging-related items and services to ensure that they conform to the specified requirements. The procurement documents specify the test/inspection requirements, the acceptance criteria for safety-related items, and the identity of all documents to be submitted for information, review, or approval by the purchaser. The time of submittal of the required documentation is established in the procurement documents. These documented evidence files must be determined to be acceptable before an item can be used in a packaging. When PTE requires the supplier to maintain specific records, the retention times and disposition requirements are prescribed in the purchase order.

Purchased items and services are controlled using the Y-12 procurement procedures and instructions, which include QA requirements for commercial grade dedication of items or services in accordance with ASME NQA-1. Depending on the quality category level required, control measures for purchased items and services may include verifying the supplier's capability before the order is placed. This process also includes the evaluation and selection of packaging component suppliers. Procurement documents contain provisions from the Y-12 S/CI program to ensure that suppliers are aware of any S/CI issues.

First article evaluations are used for items of a critical nature or to evaluate a supplier's performance. The evaluation, which is performed at the supplier's location, is completed before release for production is granted. NUREG/CR-6314 may also be used to conduct QA inspections of the supplier's QA programs and operations.

Supplier performance is monitored and reviewed at intervals consistent with the complexity and technical requirements of the packaging component supplied. Records are prepared and maintained to identify each supplier's acceptability.

### 9.3.8 Identification and Control of Materials, Parts, and Components

In accordance with Sect. 8 of the QAPP, Y-12 has an established process for the identification and control of packaging-related materials, parts, and components. Implementing procedures require that proper identification shall be maintained on the items, in documents traceable to the items, or in a manner that ensures identification is established and maintained. Serial numbers are permanently marked on the ES-3100 containment vessels and drum assemblies according to the design drawings and equipment specifications. Users shall segregate and maintain certified replacement part inventories to ensure traceability according to their site-approved QA plan.

Controls are established to ensure that only correct and accepted items are used or installed. Various methods for acceptance of packaging-related materials, parts, and components include supplier evaluations, certificates of conformance, source verifications, receiving inspections, post-installation testing, or a combination of these methods. Items designated for destructive testing or special evaluations are controlled to prevent their inadvertent use. Limited life materials or components such as O-rings are identified and controlled to preclude use of expired items and to provide for recall if necessary.

Y-12 has incorporated DOE guidance regarding S/CIs. This guidance strengthens the procurement process, identifies and eliminates S/CIs, and improves the S/CI reporting process. The purpose of this program is to control or eliminate the hazards posed by the use of S/CIs, which can lead to unexpected equipment failures and undue risks to the NNSA mission, the environment, and personnel.

### 9.3.9 Control of Special Processes

In accordance with Sect. 9 of the QAPP, Y-12 has an established system to ensure that special processes are performed by trained and qualified personnel under controlled conditions using approved and qualified procedures or instructions in accordance with applicable codes, standards, specifications, criteria, and other requirements. Processes to be controlled as special processes shall meet the following criteria: (1) the results are highly dependent on the control of the process; (2) the results are highly dependent on the skill of the operator; and (3) the quality of the results cannot be readily determined by inspection or test of the item or component. Implementing procedures or instructions shall be used to ensure that process parameters are controlled and that the specified environmental conditions are maintained.

The special processes identified for the ES-3100 packaging are those that involve mixing, casting, and curing of Kaolite 1600 insulation and 277-4 neutron-absorbing material; welding; heat treating of materials; and conducting nondestructive examinations (such as radiographic, liquid penetrant, etc.). For welded components, certified welders perform welding operations in accordance with Y-12 or approved supplier welding procedures. The welding records for each of these operations identify the welder and the welding procedures used for each weld. Qualification records for special processes, including personnel qualifications where required, are maintained for the life of the packaging plus 3 years.

### 9.3.10 Internal Inspection

Inspection activities are planned and performed using approved instructions, procedures, and checklists to verify conformance of an item or activity to specified requirements. In accordance with Sect. 10 of the QAPP, these documents will include methods for inspection, acceptance and rejection criteria, and identification of those responsible for performing the inspection. Inspections for acceptance shall be performed by individuals other than those who performed or directly supervised the work being inspected, and those individuals shall not report directly to the supervisor immediately responsible for performance of the work.

Inspections include receipt inspections, in-process inspections, nondestructive evaluations, destructive testing, and required national standards and code inspections. Inspections shall be conducted on activities or items affecting quality and/or nuclear safety to verify conformance with applicable codes, standards, regulatory requirements, procedures, and procurement documents or because of specific management requests. Inspection activities shall be documented and controlled by instructions, procedures, specifications, drawings, checklists, travelers, or other appropriate means. These requirements apply to both procured items and items produced in-house at Y-12. Qualified inspectors document the inspection results before the ES-3100 packaging is approved for use.

As described in Sect. 8.1.1.4, a “Diamond I” symbol is used on the drawings or equipment specifications to designate significant dimensions or features, which are specifically inspected and documented by qualified personnel during fabrication. Minimum certification requirements are shown on the ES-3100 certification drawing (Drawing M2E801580A037, Appendix 1.3.1).

The package operations (Sect. 7) and maintenance program (Sect. 8) requirements are derived from the design drawings and equipment specifications, and their determinations shall be present in documentation records as described in Sects. 7.5.1.1 and 7.5.1.2. Detailed site-specific operations and maintenance procedures shall include appropriate inspection provisions, including quality control hold points, to ensure that the compulsory minimum requirements in Sects. 7 and 8 are properly performed.

### 9.3.11 Test Control

PTE has established a test program in accordance with Sect. 11 of the QAPP, which ensures required testing will demonstrate that the packaging components will perform satisfactorily in service/use. This testing is performed in accordance with written and approved test procedures, which incorporate the necessary requirements and acceptance limits (contained in the package design documents and federal regulations) and ensure that qualification testing of prototype packages is performed under the most adverse design conditions. The packaging and certain components are subject to acceptance and verification testing in accordance with written test procedures to ensure compliance with 10 CFR 71.71, *Normal conditions of transport*, and 10 CFR 71.73, *Hypothetical accident conditions*. Testing records and results documentation are maintained by the organization responsible for the tests, and copies are sent to PTE. Approved test reports describing the ES-3100 compliance testing were compiled for use in the preparation of this SARP. Pertinent information from these test reports is discussed primarily in Sects. 2, 3, and 4, as appropriate.

The ES-3100 packaging design drawings and equipment specifications as well as the procurement documents, indicate the tests required for the acceptance of the packaging components. Either PTE or the supplier prepares the required test plans that identify the tests to be performed and the requirements and conditions of each test. The test procedures define the test objectives, prerequisites, equipment, test conditions, and acceptance criteria.

### 9.3.12 Control of Measuring and Test Equipment

The Y-12 Standards and Calibration Program is administered by the Y-12 Oak Ridge Metrology Center through established procedures in accordance with Sect. 12 of the QAPP. The Standards and Calibration Program ensures measuring and test equipment (M&TE) is calibrated and controlled. This control process ensures that tools, gauges, and other instruments used for packaging-related inspections, tests, and measurement activities are of the proper range, type, accuracy, and precision and that they are handled, stored, and maintained within specified calibration limits. Typical packaging-related M&TE includes torque wrenches, scales, leak-testing equipment, calipers, micrometers, and tape measures.

Calibration of M&TE is required whenever the equipment is used to determine conformance or acceptance to customer or regulatory compliance or whenever the measurement is required to meet safety, health, environmental, or quality parameters. Y-12 calibration organizations supporting packaging and transportation activities (e.g., Analytical Chemistry; Industrial Hygiene; Oak Ridge Metrology Center; Radiological Control) are responsible for maintaining measurement standards and calibrating M&TE by trained personnel and approved procedures or work instructions.

The ES-3100 packaging suppliers are required to provide a system for calibration of M&TE in accordance with the guidance provided by Y-12 procurement documents and the supplier's QA program. Other users will control M&TE in accordance with their site-approved QA plan.

### 9.3.13 Handling, Storage, and Shipping Control

In accordance with Sect. 13 of the QAPP, Y-12 has established procedures for handling, storing, shipping, cleaning, loading, unloading, and maintenance of ES-3100 packaging that satisfies the 10 CFR 71 requirements. If packaging components will be stored for an extended period of time, they may be bagged. The packaging components will be stored in weather-protected indoor facilities and transferred between facilities in an enclosed conveyance for protection from environmental elements. The organizations that use the ES-3100 package follow approved procedures (Sect. 7) for all operations related to handling, loading, shipping, and unloading of hazardous materials. Prior to shipment, operators will ensure (1) that packages have been prepared in accordance with the approved drawings, procedures,

specifications, regulatory requirements, DOE directives, SARP, and Certificate of Compliance; (2) that packages have passed all applicable inspections and tests; (3) that packages are properly identified by physical markings or tags; and (4) that all shipping papers have been prepared as required and reviewed by qualified personnel to verify completeness and accuracy.

### 9.3.14 Inspection, Test, and Operating Status

The status of inspection and test activities is provided on packaging items and in documents traceable to those items. This provision applies to Y-12 and suppliers of Category A and B packaging components. A component or item that does not pass inspection is not allowed to be used or installed in a package. In accordance with Sect. 14 of the QAPP, procedures describe the use of markings such as stamps, tags, labels, routing cards, or other suitable means and the status of inspections, tests, and operating conditions (including maintenance of items) that may be performed on packaging components. Status shall be maintained through indicators, such as physical location and tags, markings, travelers, stamps, inspection records, or other suitable means. The authority for application and removal of tags, markings, labels, and stamps shall be specified in implementing procedures.

Y-12 uses a production control system in which scheduled inspections, tests, or other activities are recorded. The Y-12 production control system is a developed software package, which contains operations, routes, bills of materials, data collection, operator instructions, error actions, and inventory movement for product being produced at Y-12. Lots (work in process inventory) are created to represent serialized parts. Manufacturing areas use the production control system to track these lots across the shop floor. Complete histories of lot transactions are stored along with lot genealogy and traceability. In addition, the production control system is used in inventory processes for accountable materials, and it is also the mechanism for communicating schedule requirements and work prioritization reports to manufacturing areas. After assembling the components into a packaging, the inspection, test, and operational statuses can be determined from the database entries. The QA organization uses data stored in the production control system for the certification of parts and materials.

### 9.3.15 Nonconforming Materials, Parts, or Components

Nonconformances represent a deficiency in a characteristic, documentation, or procedure that renders the quality of an item or activity unacceptable or indeterminate. Once identified, the nonconforming materials, parts, or components will be appropriately tagged, segregated when practical, and dispositioned in accordance with approved procedures. These nonconformance control activities are necessary to prevent further processing, delivery, installation, or inadvertent use of nonconforming items until affected organizations (including QA) are notified and the proposed technical disposition, remedial actions, or corrective actions are approved.

In accordance with Sect. 15 of the QAPP, Y-12 staff members are responsible for identifying and documenting nonconformances. Procurement documents will include provisions for (1) supplier reporting of nonconformances that do not meet specified requirements and (2) obtaining Y-12 approval of the NCR disposition. Noncompliances to the procurement specification, drawings, statement of work, or any other procurement document must be documented and dispositioned using the request for waiver or deviation (RFWD) process before the item can be accepted and released for shipment to Y-12. The packaging engineer and packaging design engineer must be involved in the review of RFWDs and concur with their disposition. If the RFWD alters QA requirements or QA activities (e.g., hold or witness points), then the Procurement quality engineer must review and sign the RFWD. Items that cannot be returned to an acceptable condition are appropriately controlled to prevent inadvertent installation or use.

Each user of the ES-3100 package is responsible for processing NCRs in accordance with their site-approved QA program. At the direction of the DOE Headquarters Packaging Certification Program, the user is also responsible for obtaining approval from the PTE organization for NCRs that are dispositioned "use-as-is" or "repair." In support of package recertification efforts and for trending purposes, the user will forward a copy of the NCR, including supporting documentation, to:

Consolidated Nuclear Security, LLC
Y-12 National Security Complex
Attn: Packaging and Transportation Engineering Manager
P.O. Box 2009
Oak Ridge, TN 37831-8008.

### 9.3.16 Corrective Action

Corrective actions related to packaging items, components, or activities are submitted to the PTE manager and processed in accordance with established Y-12 procedures. These procedures ensure that the identification, cause, and corrective actions for conditions adverse to quality are documented and reported to the appropriate levels of management. For significant conditions adverse to quality, the cause of the condition is determined, and corrective action is taken to prevent recurrence.

In accordance with the Sect. 16 of the QAPP, Y-12 procedures establish the process to be used for conditions that may be noncompliant with respect to the Consolidated Nuclear Security, LLC contractual requirements or that are adverse to safety, health, environment, operations, quality, safeguards and security, or mission performance. These issues are managed in accordance with the significance of the issues and the associated risk.

### 9.3.17 Quality Assurance Records

The Y-12 records management process is established in accordance with approved formal written procedures (QAPP, Sect. 17) and implemented to ensure that sufficient records are specified, prepared, completed, reviewed, approved, and maintained to accurately reflect completed work. A QA record is a completed document that furnishes evidence of the quality of items and/or activities affecting quality. General examples of quality records are listed in Table 9.3; specific records associated with operations are listed in Appendix 7.5.1.

Records are to be legible, complete, retrievable, and protected from damage, deterioration, and loss. Approved procedures provide for the retention, protection, preservation, traceability, accountability, and retrievability of records. In accordance with 10 CFR 71.91(a), records of each shipment of radioactive material are maintained for 3 years after the shipment, and quality records are maintained for 3 years beyond the life of the packaging (i.e., following decommissioning and destruction of the packaging) as required by 10 CFR 71.91(d). Users shall maintain records in accordance with 10 CFR 71.91 and their site-approved QA plan, and these records shall be made available upon request.

**Table 9.3. Typical quality assurance records**

| | |
|---|---|
| System requirements documents | SARPs |
| Design drawings | Work requests |
| Data sheets | Manufacturing and assembly procedures |
| Design criteria documents | Personnel qualification records |
| Graded approach results | Operating and maintenance procedures |
| Equipment specifications | Supplier certification evidence |
| Design review documentation | Product Information and Control Summary |
| Design change documentation | Preshipment leak-test records |
| Test plans and procedures | Offsite fissile material container inspection forms |
| Test reports | NCRs and log sheets |
| QA/control manuals | Corrective action reports |
| Procurement specifications | Quality Certification and Procurement Instructions |
| Material specifications | Certification data verification work requests |
| Manufacturing specifications | Certification procedures |
| Supplier QA program evaluation results | Self-appraisal reports |
| Audit reports | Surveillance reports |
| Weld radiographs | Liquid penetrant reports |
| Prototype data certification | Dimensional inspection results |
| Packing follow sheets | Maintenance follow sheets |
| Calibration procedures | Equipment calibration records |

### 9.3.18 Audits

In accordance with Sect. 18 of the QAPP, a comprehensive system of planned and scheduled audits, assessments, and surveillances are conducted using written procedures to: (1) verify compliance with the requirements of all packaging-related activities in accordance with the QAPP; (2) determine the plan's effectiveness; and (3) focus on improving items and processes. The results of each audit report are reviewed, and the managers assigned responsibility for an issue shall ensure that corrective actions addressing the cause are planned, implemented, and tracked to closure. Completion of corrective actions shall be verified. Areas of improvement that are not findings but may warrant strengthening are also considered as potential quality improvements.

The Y-12 Performance Assurance organization is responsible for planning, scheduling, and conducting independent internal audits (assessments). The independent assessment process is primarily designed to focus on the compliance and flow down of contractual requirements, including applicable standards and codes, how requirements are implemented in procedures, and the measurement of implementation effectiveness. Independent assessments are led by a qualified lead assessor and conducted by qualified personnel who are: (1) technically knowledgeable/experienced in the functional area being assessed; (2) independent with no direct responsibilities in the functional area being assessed; and (3) granted organizational freedom and authority to perform an effective assessment. Once the audit is complete and the report has been submitted to the responsible parties, management will review the results and will take appropriate action to resolve any findings.

Management assessments are conducted by members of the line organization or program to evaluate and determine whether packaging-related activities are properly focused on achieving desired results. These assessments serve as a periodic self-analysis tool and include reviewing the processes, systems, and programs that are important to the specified mission, goals, and objectives as well as identifying areas for continuous improvement. Whether compliance-based or performance-based, the process includes provisions to appropriately evaluate all aspects of the Y-12 packaging and transportation

QA program, determine how well the management system meets specified requirements, and assess methods to safely perform packaging-related activities. Management assessments are administered by the Y-12 Performance Assurance organization in compliance with the annual assessment schedule.

Internal surveillances provide monitoring or observation of ongoing packaging-related activities to evaluate compliance with specified requirements. PTE surveillance plans and checklists are developed and executed on a routine basis by personnel who are qualified in surveillance techniques with sufficient authority, technical expertise, and knowledge for the subject area being assessed. The PTE surveillance coordinator provides administrative oversight of the annual surveillance program. These surveillances are documented and identified issues are processed in accordance with the requirements of the Y-12 Issues Management System.

Audits of suppliers are based on the component graded quality category. Category A and B item/service suppliers are audited to determine the adequacy and effectiveness of implementation of the supplier's QA program using a methodology that evaluates processes or activities on the basis of their performance and reviews documentation generated by the supplier and their sub-tier(s). An Evaluated Suppliers List (ESL), which is maintained by the Materials and Suppliers QA organization, identifies suppliers, the commodity for which the evaluation was conducted (if a specific commodity was evaluated), supplier status (i.e., approved or disapproved), any restrictions noted, and the minimum re-evaluation timeframe. To remain active on the ESL, re-evaluations of Category A and B item/service suppliers are primarily performed within 3 years of the effective date designated on the ESL. However, some evaluations are performed annually or when appropriate to ensure that suppliers continue to provide acceptable items and services. Category C and NITS commodities are commercial off-the-shelf items/services, and their suppliers are typically not audited, but supplier-generated paperwork is subject to an in-house quality desk audit before the items are used to ensure their compliance with applicable drawings, specifications, and subcontract requirements.

### 9.3.19 Software Quality Assurance

Y-12 has developed and implemented computer software programs, including configuration controls, which will improve safety, increase the reliability of packaging operations and data, and support the achievement of programmatic missions. Software controls include verification, validation, and configuration management. Software is used in accordance with the responsibilities and requirements for developing, procuring, implementing, maintaining, and applying computer software as described in Sect. 19 of the QAPP.

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## SECTION 9 REFERENCES


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