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		Design Authority				1	/	BWHC JF Henderson	[signature]		L1-03
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T. Romano [signature] 9-25-97 Signature of EDT Originator / Date	Authorized Representative for Receiving Organization / Date	J. G. Field [signature] 9/25/97 Design Authority/ Cognizant Manager / Date	Ctrl. No. [] Approved [] Approved w/comments [] Disapproved w/comments

Safety Evaluation for Packaging (Onsite) Plutonium Recycle Test Reactor Graphite Cask

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Waste Management Federal Services, Inc., Northwest Operations
Richland, Washington 99352
U.S. Department of Energy Contract DE-AC06-96RL13200

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Abstract: This safety evaluation for packaging (SEP) provides the evaluation necessary to demonstrate that the Plutonium Recycle Test Reactor (PRTR) Graphite Cask meets the requirements of WHC-CM-2-14, *Hazardous Material Packaging and Shipping*, for transfer of Type B, fissile, non-highway route controlled quantities of radioactive material within the 300 Area of the Hanford Site. The scope of this SEP includes risk, shielding, criticality, and tiedown analyses to demonstrate that onsite transportation safety requirements are satisfied. This SEP also establishes operational and maintenance guidelines to ensure that transport of the PRTR Graphite Cask is performed safely in accordance with WHC-CM-2-14. This SEP is valid until October 1, 1999. After this date, an update or upgrade to this document is required.

Janis Bishop 9/29/97
Release Approval Date

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LIST OF TERMS

ANSI	American National Standards Institute
ARF	airborne release fraction
atm	atmosphere
Bq/cm^2	becquerels per square centimeter
CFR	*Code of Federal Regulations*
Ci	curie
cm	centimeter
cm^3	cubic centimeter
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
dpm/cm^2	disintegrations per minute per square centimeter
EDE	effective dose equivalent
FFTF	Fast Flux Test Facility
ft	foot
ft/s^2	feet per second squared
g	gram
g/cm^3	grams per cubic centimeter
Gy	gray
Gy/h	gray per hour
Hz	hertz
IAEA	International Atomic Energy Agency
in.	inch
kg	kilogram
km	kilometer
km/h	kilometers per hour
kPa	kilopascal
lb	pound
$\mu Ci/cm^2$	microcuries per square centimeter
MAP	mixed activation products
MeV	megaelectronvolt
MFP	mixed fission products
mi	mile
mi/h	miles per hour
MPa	megapascal
mrem/h	millirem per hour
m/s^2	meters per second squared
mSv/h	millisievert per hour
N	newton
non-HRCQ	non-highway route controlled quantity
NTC	normal transport conditions
PCF	probability of release from crush failure
PIF	probability of release from impact failure
PFF	probability of release from fire failure
PNC	Power Reactor and Nuclear Fuel Development Corporation
PPF	probability of release from puncture failure
PRTR	Plutonium Recycle Test Reactor
psi	pounds per square inch
QA	quality assurance
QL	quality level
RF	respirable fraction
SEP	safety evaluation for packaging
SERF	Special Environmental Radiometallurgy Facility
Sv	sievert

LIST OF TERMS (cont)

Sv/h	sievert per hour
TBq	terabecquerel
THI	Transportation Hazard Index
W	watt
W/Ci	watts per curie

SAFETY EVALUATION FOR PACKAGING (ONSITE) PLUTONIUM RECYCLE TEST REACTOR GRAPHITE CASK

PART A: DESCRIPTION AND OPERATIONS

1.0 INTRODUCTION

1.1 GENERAL INFORMATION

The Plutonium Recycle Test Reactor (PRTR) Graphite Cask is used by B&W Hanford Company to transport radioactive materials among the 323, 324, 325, 326, 327, and 3270 Buildings. The radioactive materials most frequently transported among buildings are mixed oxide fuel, metal oxide fuel, and activated structural materials from reactors. The cask will be used to transport Type B, fissile, non-highway route controlled quantities of radioactive materials within the 300 Area of the Hanford Site.

This safety evaluation for packaging (SEP) provides the evaluation necessary to demonstrate that the PRTR Graphite Cask meets the requirements for onsite transportation of a Type B package. The packaging meets all WHC-CM-2-14, *Hazardous Material Packaging and Shipping*, requirements for the Hanford Site. The scope of this SEP includes risk, shielding, criticality, and tiedown analyses to demonstrate that onsite transportation safety requirements are satisfied. This SEP also establishes operational and maintenance guidelines to ensure that transport is performed safely in accordance with WHC-CM-2-14.

1.2 SYSTEM DESCRIPTION

The cask is a horizontal, cylindrical, stainless steel transfer cask with 13.7 cm (5.38 in.) of lead shielding. The outside diameter is 35.6 cm (14.0 in.), and the length is 99.0 cm (39.0 in.). The interior cavity is 7.9 cm (3.1 in.) in diameter and 63.5 cm (25.0 in.) long. The empty weight of the cask is 1,089 kg (2,400 lb), and the maximum gross weight of the cask is 1,202 kg (2,650 lb).

1.3 REVIEW AND UPDATE CYCLES

This SEP is valid until October 1, 1999. An update or upgrade to this document is required beyond that date.

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2.0 PACKAGING SYSTEM

2.1 CONFIGURATION AND DIMENSIONS

The PRTR Graphite Cask is fundamentally a right circular cylinder of lead and stainless steel composite construction. The lead is sandwiched between outer and inner stainless steel tubular shells. At each end of the cask is a thick circular plate that is welded to both inner and outer shells, which encapsulates the lead. At the top, closure of the inner cavity is provided by a bolted blind flange with an attached shield plug of composite lead-stainless steel construction. The cask is equipped with a manually actuated, rotating, shielded drum door, which provides closure at the bottom end. None of the end closures are sealed. A handling yoke is provided on the cask and welded to the outer shell. Attached to the yoke is a lifting bail, which can be locked into position for lifting and handling of the cask. Support plates are welded to the outer bottom housing to provide support during transport.

The cask is 35.6 cm (14.0 in.) in diameter and 99.0 cm (39.0 in.) in length. Dimensions of the inner cavity are 7.95 cm (3.13 in.) in diameter by 63.5 cm (25.0 in.) in length. Lead between the outer and inner shells provides shielding.

2.2 MATERIALS OF CONSTRUCTION

All structural components are constructed of 304 stainless steel. Lead is used for shielding.

2.3 WEIGHTS AND CENTER OF GRAVITY

The empty weight of the cask is 1,089 kg (2,400 lb). The maximum weight with contents is 1,202 kg (2,650 lb). The center of gravity of the PRTR Graphite Cask is approximately the geometric center of the cask.

2.4 CONTAINMENT BOUNDARY

The containment system consists of the inner container. The cask retains the contents, but is not considered to be a containment boundary. No credit is taken for containment provided by the cask.

2.5 CAVITY SIZE

The available space within the cask consists of a cylindrical volume 7.9 cm (3.1 in.) in diameter and 63.5 cm (25.0 in.) in length.

2.6 SHIELDING

The interior of the cask is lined with lead shielding, which is 13.7 cm (5.38 in.) thick.

2.7 LIFTING DEVICES

The lifting device consists of two support arms attached to a lifting yoke. Each support arm is secured to the yoke by three ⅝ in.-11 stainless steel cap screws and is secured to the cask shell by a ½ in.-13 stainless steel cap screw. The lifting assembly is positionable and is equipped with a locking device.

2.8 TIEDOWN DEVICES

There are no tiedown devices attached to the cask.

3.0 PACKAGE CONTENTS

3.1 GENERAL DESCRIPTION

Materials to be transported in the PRTR Graphite Cask include irradiated structural materials and solid pieces of irradiated fuel containing uranium and plutonium isotopes.

3.2 CONTENTS RESTRICTIONS

The materials specified in this section are the only materials authorized for shipment in the PRTR Graphite Cask within the 300 Area of the Hanford Site. Contact dose rates shall be less than 2.0 mSv/h (200 mrem/h). Gas-generating materials shall not be loaded into the cask. Absorbed and unabsorbed liquids are not authorized for shipment in the cask. Organic materials are not authorized except plastic bags/wrapping.

3.2.1 Radioactive Materials

The cask will transport Type B, fissile, non-highway route controlled quantities of radioactive materials. Table A3-1 gives the radioactive contents limits for the cask. Fissile limitations are given in Table A3-2 for shipments of fissionable material scrap of various compositions. The source term limits in Table A3-1 are a result of the limited shielding ability of the cask as described in Part B, Section 5.0.

Table A3-1. Maximum Allowable Source Term.

Material	Activity limit	
	TBq	Ci
Fissile materials and α emitters*	0.401	10.9
Mixed fission products	13.9	375
Mixed activation products	0.185	5.00

*Fissile/fissionable materials limited by criticality safety as shown in Part B, Section 2.1.1.

Contents to be transported in the PRTR Graphite Cask shall consist of small pieces or test samples of irradiated fuel pieces and various activated materials. The contents shall be limited to the maximum allowable source term as shown in Table A3-1. The cask may also be used to transport metallographic samples and waste from the 327 Facility examination process.

All materials shall be enclosed in an inner container to prevent the spread of removable contamination. Table A3-3 provides a description of authorized inner containers and their contents.

3.2.2 Nonradioactive Hazardous Materials

No nonradioactive hazardous materials can be shipped in the PRTR Graphite Cask.

Table A3-2. Fissile/Fissionable Material Limits in the Plutonium Recycle Test Reactor Graphite Cask.

Material	Limit
^{235}U	275 g* or
^{239}Pu, ^{233}U, ^{237}Np, ^{241}Am, ^{243}Am, ^{244}Cm, and ^{247}Cm	175 g aggregate total*
^{242m}Am, ^{243}Cm, ^{245}Cm, ^{249}Cf, or ^{251}Cf	Not analyzed and cannot be shipped in excess of safeguards accountability limits*

Source: Larson, S. L., 1996, *Limits for Fissionable Material in Small Bore Transfer Casks and Lead Pigs* (NCS Basis Memo 96-2 to M. Dec, December 30), Battelle Pacific Northwest Laboratories, Richland, Washington.

*Mixtures of fissionable material are possible provided that the sum-of-fractions method shown in PNL (1994) and referenced in Larson (1996), attached in Part B, Section 6.0, are followed.

PNL, 1994, *Criticality Safety*, PNL-MA-25, Battelle Pacific Northwest Laboratories, Richland, Washington.

Table A3-3. Inner Container Description.

Inner container	Contents	Examples of contents
Pin tubes--tubes and fittings must have a working rating of 20.68 MPa (3000 psi), with an outer diameter of 1.3 cm (0.50 in.) or 1.9 cm (0.75 in.). The tubes are welded on one end. A Swagelok* fitting is used as closure.	Dispersible solid materials	Irradiated structural materials; solid pieces of irradiated FFTF, PNC, and N Reactor fuel pins; and small pieces or test samples of irradiated fuel and structural materials
DOT Specification 2R per 49 CFR 178.360	Dispersible solid materials	Irradiated structural materials; solid pieces of irradiated FFTF, PNC, and N Reactor fuel pins; and small pieces or test samples of irradiated fuel and structural materials in glass or plastic vials with screw cap
Large solid item put directly into the cask	Nondispersible solid structural material and activated metals put directly into the cask**	Large solid items with fixed surface contamination

DOT = U.S. Department of Transportation.
FFTF = Fast Flux Test Facility.
PNC = Power Reactor and Nuclear Fuel Development Corporation.

*Swagelok is a trademark of the Crawford Fitting Company.
**Surface contamination limits not to exceed 100 times the Table A4-1 limits. Verification by survey or the use of a fixative, such as paint, is required.

49 CFR 178, 1997, "Specifications for Packagings," *Code of Federal Regulations*, as amended.

4.0 TRANSPORT SYSTEM

4.1 TRANSPORTER

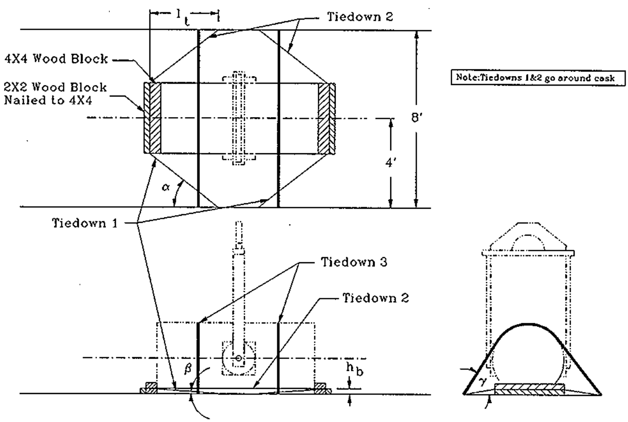
The transporter consists of a low boy or flatbed trailer and tractor. The trailer shall be rated for the weight of the loaded cask and have a large enough bed to prevent the cask from protruding over the edges of the trailer.

4.2 TIEDOWN SYSTEM

The cask shall be centered and placed horizontally on the bed of the trailer for shipment. The long axis of the cask shall be centered along the long axis of the trailer.

The package is to be secured in accordance with U.S. Department of Transportation regulations (49 CFR 393.100). The cask is to be secured to the trailer by two sets of tiedowns as shown in Figure 4-1. One set acts as chocks to block and brace the cask from horizontal movement. The other set acts as vertical restraints. There are two 4x4 wood blocks placed at each end of the cask. These 4x4 blocks have a 2x2 nailed to the side at the bottom to form landings for the tiedowns. Each of the chocking tiedowns is looped around the cask from opposite sides of the trailer and attached to the trailer. The chocking tiedowns lay on the landing and bear against the wood blocks when drawn tight. The vertical restraint tiedowns are placed over the cask on each side of the lifting yoke. These tiedowns are then attached to the trailer on opposite sides and drawn tight.

Figure 4-1. Cask Tiedown Configuration.



Each tiedown and trailer attachment point must have a minimum working strength of 11,120 N (2,500 lb). The 2x2 wood blocks must be nailed to the 4x4 wood blocks with a minimum of three 10 d nails. The length of the blocks is specified as the same as the diameter of the cask to within a tolerance of 0.32 cm (⅛ in.).

Alternative configurations that have been shown to meet 49 CFR 393, Subpart I, are acceptable.

4.3 SPECIAL TRANSPORT REQUIREMENTS

4.3.1 Routing and Access Control

The PRTR Graphite Cask is authorized for onsite transport only within the 300 Area. Transfers shall be made in accordance with WHC-CM-2-14 over a predetermined route.

4.3.2 Radiological Limitations

The dose rate must be less than 2 mSv/h (200 mrem/h) at the surface of the cask, 0.1 mSv/h (10 mrem/h) at 1 m from the cask surface, and 0.02 mSv/h (2 mrem/h) in any normally occupied space. Transport of the PRTR Graphite Cask above these limits is not authorized. The shielding analysis in Part B, Section 5.0, shows the projected dose rates meet these limits for the authorized source term.

External contamination limits for the exterior of the PRTR Graphite Cask are as shown in Table A4-1.

Table A4-1. External Container Contamination Limits.

Contaminant	Maximum permissible limits		
	Bq/cm^2	$\mu Ci/cm^2$	dpm/cm^2
Beta and gamma emitters and low toxicity alpha emitters	0.4	10^{-5}	22
All other alpha-emitting radionuclides	0.04	10^{-6}	2.2

Source: 49 CFR 173.443, 1995, "Shippers--General Requirements for Shipments and Packagings," *Code of Federal Regulations*, as amended.

4.3.3 Speed Limitations

The PRTR Graphite Cask shall not exceed a speed of 8 km/h (5 mi/h) during transport.

4.3.4 Environmental Conditions

In order to reduce the possibility of an accident, there shall be no transfers at temperatures below 0 °C (32 °F) or during periods of dense fog or adverse road conditions (such as snow or ice).

4.3.5 Frequency of Use and Mileage Limitations

A risk analysis was performed on the 327 Building casks to determine mileage limitations. The results of the evaluation have determined that transfers shall not exceed a total of 16.0 km (10.0 mi) per year for the 327 Building family of casks, which includes the Special Environmental Radiometallurgy Facility Cask, the Radioactive Waste Disposal Cask, and the PRTR Graphite Cask. This limit allows up to 40 transfers of 0.40 km (0.25 mi) per year. This limit does not apply to empty cask shipments.

4.3.6 Emergency Response

Emergency responders shall be notified prior to transfers of the cask. The shipping and receiving facilities, Radiation Protection, Safety, Packaging Engineering, and Transportation Logistics shall be notified of all accidents involving radioactive material shipment that result in vehicle damage, container damage, personnel injury, or contamination spread.

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5.0 ACCEPTANCE OF PACKAGING FOR USE

5.1 NEW PACKAGING

The PRTR Graphite Cask was originally accepted for use in the 1960s. That acceptance is documented in *Hazardous Materials Packaging and Shipping Manual* (HEDL 1987). The cask has been used for shipments within the 300 Area for approximately 20 years without incident. The PRTR Graphite Cask has a frequency of use of approximately six transfers per year. No new casks will be manufactured, so new packaging acceptance requirements do not apply.

5.2 PACKAGING FOR REUSE

In order to continue using the PRTR Graphite Cask, the maintenance and operating plans must be followed. A visual inspection for physical damage and corrosion on the cask and a check of the closing mechanism for proper operation shall occur prior to reuse. These inspections shall be documented in accordance with facility operating procedures.

If required, the cask shall be decontaminated prior to use to meet external contamination limits per Table A4-1.

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6.0 OPERATING REQUIREMENTS

6.1 GENERAL REQUIREMENTS

The following are requirements for the use of the PRTR Graphite Cask. Prior to loading and shipment of the cask, specific operating procedures with appropriate Quality Assurance/Quality Control hold points shall be written by the user and approved per WHC-CM-2-14. The procedures shall implement the requirements of this section and the additional requirements found in this SEP.

For loading and unloading operations, the following general requirements shall be performed.

1. Visually inspect the PRTR Graphite Cask for cracks or damage.
2. Visually inspect the lifting attachments for cracks and damage.
3. Verify that radiological contamination limits are within the allowable limits shown in Table A4-1 of this SEP.
4. Verify radiological dose rates are acceptable prior to shipment of the cask in accordance with Part A, Section 4.3.2, of this SEP. The dose rate limits are 2 mSv/h (200 mrem/h) on any surface of the cask, 0.1 mSv/h (10 mrem/h) at 1 m from the cask, and 0.02 mSv/h (2 mrem/h) in any normally occupied space.
5. Verify that the number of transfers or mileage shipped in a year has not exceeded the amount established by the risk assessment (40 shipments of approximately 0.40 km [0.25 mi] each or 16.0 km [10.0 mi] per year).

6.2 LOADING OF CONTENTS INTO THE CASK

6.2.1 Inner Container Loading

1. Prior to loading contents, visually inspect the inner container to be used.
2. If vials are to be used, visually inspect them for damage.
3. Place cushioning material in the inner container to protect glass vials. Multiple vials may be placed in the inner container. Plastic vials may be packaged as glass vials.
4. After placing the vials in the inner container, fill the void spaces with cushioning material.
5. Close the inner container.

6.2.2 Preparing the Cask for Loading

1. Verify that the contents to be loaded into the cask are as authorized in Part A, Section 3.0, of this SEP and that criticality limits have not been exceeded.
2. Verify that the cask is positioned properly at the cell loading port and is ready to receive the contents. Open the cell loading port.

6.2.3 Loading Contents into the Cask

1. Attach the push/pull rod to the rear end of the cask scoop fixture, commonly called the cask boat.

2. Release the locking mechanism and rotate the closure valve 90°.

3. Release the locking pin holding the boat and push the boat into the cell to the desired position.

4. Load the materials onto the boat and pull the boat back into the cask. Secure the locking pin.

5. Rotate the closure valve 90° and secure the locking mechanism.

6. Close the cell loading port and move the cask away from the cell.

7. Perform radiological dose and contamination surveys to verify levels have not exceeded the limits authorized in Part A, Section 4.0, of this SEP. Decontaminate if contamination limits are exceeded. Do not ship if radiological dose has exceeded 2 mSv/h (200 mrem/h) on the surface of the cask, 0.1 mSv/h (10 mrem/h) at 1 m from the cask, and 0.02 mSv/h (2 mrem/h) in any normally occupied space.

8. Following radiological survey, wrap the ends of the cask with 10-mil plastic and tape to the cask body using duct tape.

6.3 PREPARATION OF THE CASK FOR SHIPMENT

1. Verify that the shipping papers have been prepared properly and the cask is properly marked and labeled per the requirements of WHC-CM-2-14.

2. Position the transport vehicle where it will be accessible to the overhead crane.

3. Verify the lifting equipment is in accordance with the *Hanford Site Hoisting and Rigging Manual*, DOE/RL-92-36 (RL 1996).

4. Attach the lifting equipment to the cask lifting attachment and the crane hook.

5. Lift the cask from the floor to allow a radiological survey of the cask to be performed.

6. Move the cask over the vehicle and slowly lower it into position on the transport vehicle.

7. Unhook the lifting equipment from the cask and install tiedown attachments per the requirements of Part A, Section 4.2.

8. Prior to transport, verify that the shipping documentation has been completed per WHC-CM-2-14 and signed by a trained Hazardous Material Shipper.

6.4 UNLOADING THE CASK

1. Position the transport vehicle where it will be accessible to the overhead crane.

2. Perform radiological contamination and dose surveys of the cask to verify that the limits in Part A, Section 4.0, have not been exceeded.

3. Remove the tiedown equipment from the cask and transport vehicle.

4. Attach the lifting equipment to the cask lifting attachment and the crane hook.

5. Lift the cask off of the transport vehicle and move to a designated location. Remove the plastic from the ends of the cask.

6. Perform a radiological contamination survey of the cask ends to verify the contamination limits have not been exceeded.

7. Position the cask at the cell loading port and remove the rigging equipment from the cask.

8. Open the cell loading port.

9. Attach the push/pull rod to the rear end of the cask scoop fixture, commonly called the cask boat.

10. Release the closure valve locking mechanism and rotate the closure valve 90°.

11. Release the locking pin holding the boat and push the boat into the cell to the desired position.

12. Unload the materials from the boat and pull the boat back into the cask. Secure the locking pin.

13. Rotate the closure valve and secure the locking mechanism.

14. Close the cell loading port and move the cask away from the cell.

15. Perform radiological dose and contamination surveys to verify levels have not exceeded limits authorized in Part A, Section 4.0, of this SEP. Decontaminate if contamination limits are exceeded.

6.5 EMPTY PACKAGING

To be transported as an empty radioactive container, the cask must be prepared for transport in accordance with 49 CFR 173.428 (1995 version).

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7.0 QUALITY ASSURANCE REQUIREMENTS

7.1 INTRODUCTION

This section describes the quality assurance (QA) requirements for operation of the PRTR Graphite Cask. The packaging was fabricated in the 1960s following a quality program in effect at the time. The PRTR Graphite Cask is used to perform onsite shipments at the Hanford Site. The format and requirements for the use of the PRTR Graphite Cask on the Hanford Site are in accordance with WHC-CM-4-2, *Quality Assurance Manual*, and WHC-CM-2-14.

7.2 GENERAL REQUIREMENTS

These requirements apply to activities, which include loading, unloading, and transportation operations, that could affect the quality of the packaging and associated hardware. The overall packaging is classified per WHC-CM-2-14 as a Transportation Hazard Index (THI) 1.

THI 1 packaging systems, defined in WHC-CM-2-14, represent the highest level of hazard for the contents. A packaging system assigned this level has the potential of causing a dose consequence to an individual in excess of 25 rem at the Hanford Site boundary if fully released.

Each THI invokes a quality level (QL) designator (defined in WHC-CM-2-14) consisting of two parts: an alpha designator and a numerical designator. The alpha designator assigns the fabrication, testing, use, maintenance standards, and quality requirements for each component of the packaging system. The numeric designator following the letter is the THI number of the packaging system. Because the PRTR Graphite Cask ships a Type B quantity of material with potentially high hazards, the package as a whole is assigned a QL designator of A-1.

Documentation and review requirements are based upon the QL of the package. Changes or discoveries of noncompliance for all QL A-1 components and activities shall be reviewed by the unreviewed safety question screening process to ensure the quality and safety of the change or discovery. Changes to the SEP safety bases (contents, shielding, structural, containment, criticality) will require unreviewed safety question screening regardless of QL.

7.3 ORGANIZATION

The organizational structure and the assignment of responsibility shall be such that quality is achieved and maintained by those who have been assigned responsibility for performing the work. Quality achievement is to be verified by persons or organizations not directly responsible for performing the work.

Packaging Engineering and the onsite user are responsible for the quality of the work performed by their respective organizations and for performing the following activities:

- Follow the current requirements of this SEP, WHC-CM-4-2, and WHC-CM-2-14
- Provide instructions for implementing QA requirements.

The cognizant manager, Quality Assurance, is responsible for establishing and administering the Hanford QA program as stated in WHC-CM-4-2.

7.4 QA PLAN AND ACTIVITIES

7.4.1 Design Control

Design control is not applicable. This cask was fabricated over 30 years ago, and no design changes will be made. B&W Hanford Company is the design authority for the package.

7.4.2 Procurement and Fabrication Control

Procurement and fabrication control is not applicable. This package is over 30 years old, and no casks will be procured in the future.

7.4.3 Control of Operations/Processes

Loading/unloading procedures written by the user will be used to ensure acceptable operation of the packaging. Those loading/unloading procedures shall be consistent with this SEP. The loading/unloading procedures identify actions required by personnel to safely and properly load and unload the packaging in accordance with this SEP.

Quality Control inspection checklists are established to ensure that final inspection verifies compliance with the following items.

- The PRTR Graphite Cask is properly assembled.
- All acceptance criteria (Part A, Section 5.0) are met for use of the package.
- Operational (Part A, Section 6.0) and maintenance procedures (Part A, Section 8.0) are properly completed.

7.4.4 Control of Inspection

Control of inspection and testing will be accomplished by facility procedures incorporating the requirements of Part A, Section 7.4.3.

7.4.5 Test Control

Test control is not applicable. No testing is required on this package.

7.4.6 Control of Measuring and Test Equipment

Any measuring equipment that is used shall meet the accuracy and calibration requirements as required by WHC-CM-4-2; i.e., radiation survey equipment.

7.4.7 Control of Nonconforming Items

Identification, documentation, evaluation, and disposition of nonconforming items and activities shall be accomplished per WHC-CM-4-2, regardless of the assigned QL.

7.4.8 Corrective Action

Nonconformance, or conditions adverse to quality, are evaluated as described in Part A, Section 7.4.8, and the need for corrective action is determined in accordance with WHC-CM-4-2.

7.4.9 QA Records and Document Control

Records that furnish documentary evidence of quality shall be specified, prepared, and maintained per WHC-CM-4-2. This includes all procedures, inspection reports, the SEP, and any nonconformance reports that are developed while this cask is used.

7.4.10 Audits

Internal and external independent assessments are performed in accordance with WHC-CM-4-2.

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8.0 MAINTENANCE

8.1 GENERAL REQUIREMENTS

The 327 Facility shall provide the procedures for the required maintenance and inspections of the PRTR Graphite Cask.

8.2 INSPECTION AND VERIFICATION SCHEDULES

The PRTR Graphite Cask shall undergo a user inspection every two years. Inspections shall be performed using the *Radioactive Material Shipping Container User Biennial Inspection Checklist* (Part A, Section 10.2). Nondestructive testing of the welds on the lifting apparatus shall be performed every five years using the *Radioactive Material Shipping Container NDT of Lifting Apparatus (5 Year)* (Part A, Section 10.2).

8.3 RECORDS AND DOCUMENTATION

The maintenance records shall be maintained for the length of time the PRTR Graphite Cask is owned, plus one year. The inspection records of the PRTR Graphite Cask shall be maintained until the next inspection of the same type is successfully completed.

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9.0 REFERENCES

49 CFR 173, 1995, "Shippers--General Requirements for Shipments and Packagings," *Code of Federal Regulations*, as amended.

49 CFR 178, 1997, "Specifications for Packagings," *Code of Federal Regulations*, as amended.

49 CFR 393, 1997, "Parts and Accessories Necessary for Safe Operation," *Code of Federal Regulations*, as amended.

HEDL, 1987, *Hazardous Materials Packaging and Shipping Manual*, MG-137, Rev. 10, Hanford Engineering Development Laboratory, Richland, Washington.

Larson, S. L., 1996, *Limits for Fissionable Material in Small Bore Transfer Casks and Lead Pigs* (NCS Basis Memo 96-2 to M. Dec, December 30), Battelle Pacific Northwest Laboratories, Richland, Washington.

PNL, 1994, *Criticality Safety*, PNL-MA-25, Battelle Pacific Northwest Laboratories, Richland, Washington.

RL, 1996, *Hanford Site Hoisting and Rigging Manual*, DOE/RL-92-36, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

WHC-CM-2-14, *Hazardous Material Packaging and Shipping*, Westinghouse Hanford Company, Richland, Washington.

WHC-CM-4-2, *Quality Assurance Manual*, Westinghouse Hanford Company, Richland, Washington.

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10.0 APPENDICES

10.1 DRAWINGS

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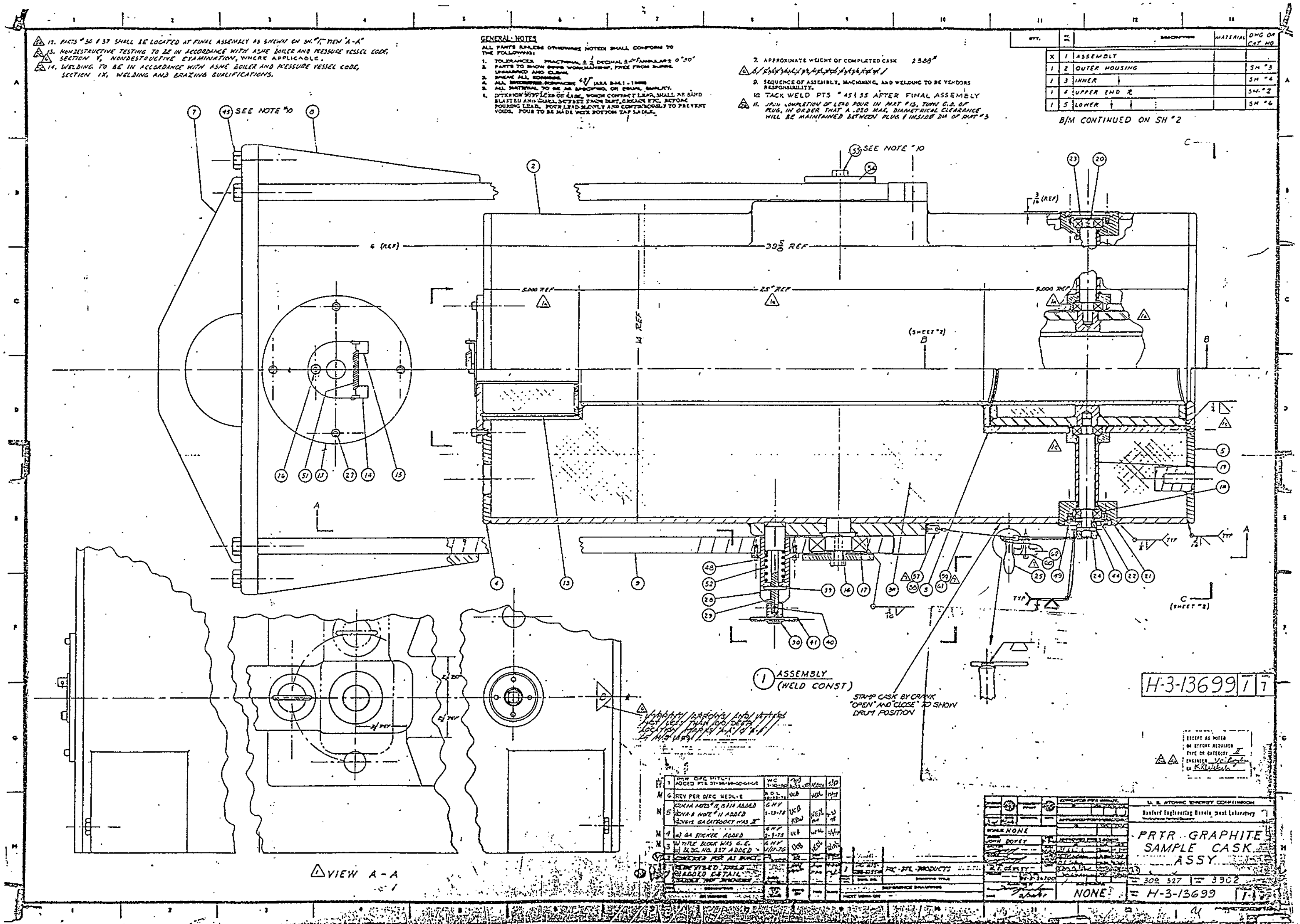
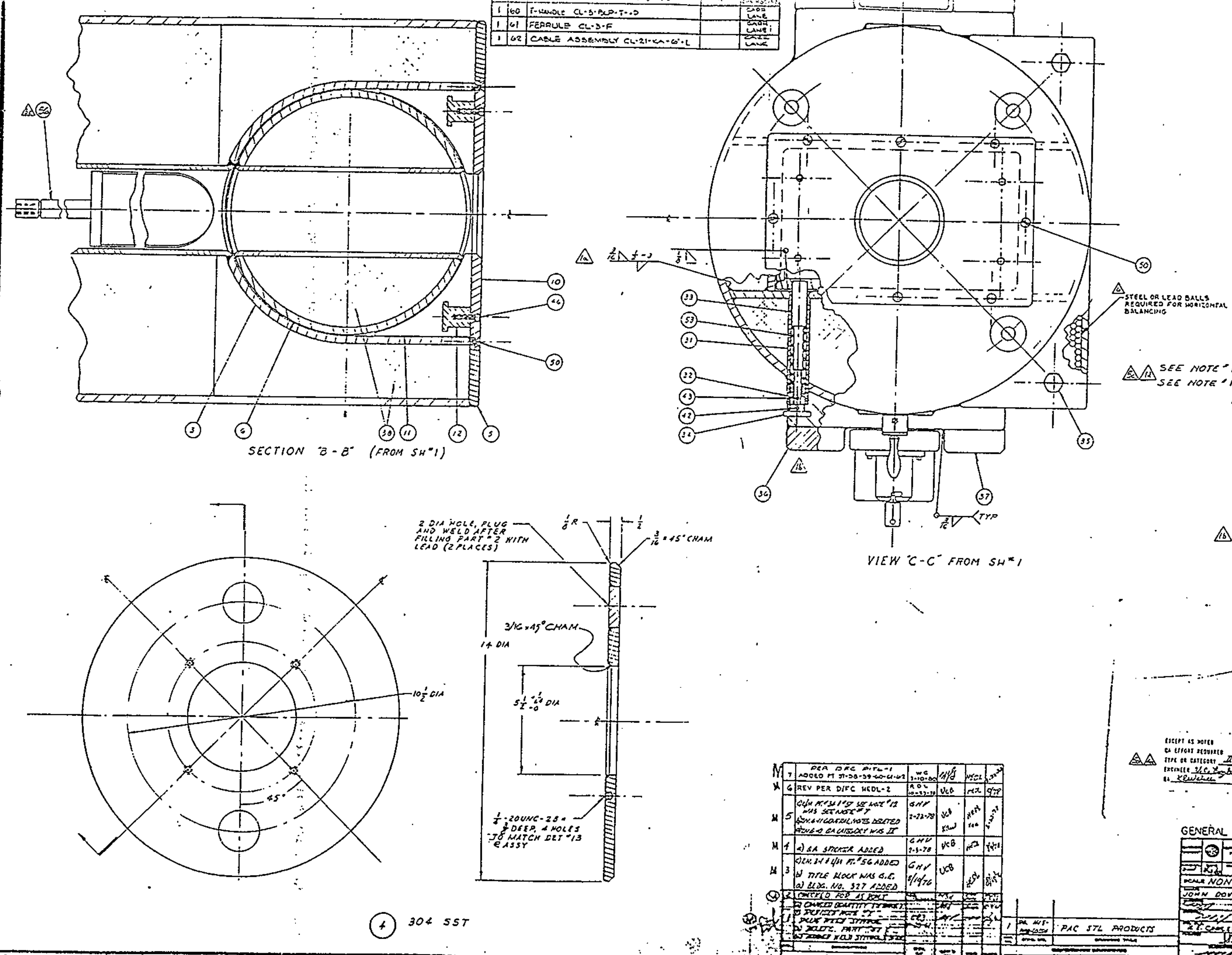

12. PARTS #56 & 57 SHALL BE LOCATED AT FINAL ASSEMBLY AS SHOWN ON SH. 1, VIEW "A-A"
13. NONDESTRUCTIVE TESTING TO BE IN ACCORDANCE WITH ASME BOILER AND PRESSURE VESSEL CODE, SECTION V, NONDESTRUCTIVE EXAMINATION, WHERE APPLICABLE.
14. WELDING TO BE IN ACCORDANCE WITH ASME BOILER AND PRESSURE VESSEL CODE, SECTION IX, WELDING AND BRAZING QUALIFICATIONS.
GENERAL NOTES
7. APPROXIMATE WEIGHT OF COMPLETED CASK 2388#
9. SEQUENCE OF ASSEMBLY, MACHINING, AND WELDING TO BE VENDORS RESPONSIBILITY.
10. TACK WELD PTS #45 & 55 AFTER FINAL ASSEMBLY
ASSEMBLY
OUTER HOUSING
INNER
UPPER END
LOWER
B/M CONTINUED ON SH #2
SEE NOTE #10
6 (REF)
39 5/8 REF
14 REF
25" REF
5.000 REF
9.000 REF
3/16 (REF)
(SHEET #2)
ASSEMBLY
(WELD CONST)
STAMP CASK BY CRANK "OPEN" AND "CLOSE" TO SHOW DRUM POSITION
VIEW A-A
H-3-13699
U. S. ATOMIC ENERGY COMMISSION
Hanford Engineering Development Laboratory
PRTR GRAPHITE SAMPLE CASK ASSY
NONE
H-3-13699

B/M CONTINUED

QTY.	PT. NO.	DESCRIPTION	MATERIAL	DWG OR CAT NO
2	54	YOKE SHAFT RETAINER		SH #7
2	55	AP SCREW, ½ 13 UNC-2A × 1½ LG, HH	SST	
1	56	BOAT ASSEMBLY		H-3-40421
1	57	LANYARD CUP		SH 6
1	58	SKT BTNHD CAP SCR ¼-20UNC-2A × ½ LG	SST	
1	59	STRAP-EYE END [illegible]	SST	AMERICAN [illegible]
1	60	T-HANDLE CL-3-PLP-T-D		CARR LANE
1	61	FERRULE CL-3-F		CARR LANE
1	62	CABLE ASSEMBLY CL-21-KA-6"-L		CARR LANE

QTY.	PT. NO.	DESCRIPTION	MATERIAL	DWG OR CAT NO
1	6	ROTATING DRUM		SH #4
1	7	YOKE		SH #5
1	8	ARM		
1	9	(LOCKING)		
1	10	ROTATING PLUG RETAINING ℄		SH #6
2	11	BLOCK		
1	12	LUG		
1	13	HANDLE HOUSING		SH #7
1	14	CLAMP RING		SH #4
1	15			
2	16	PIN		SH #3
2	17	BEARING, RADIAL, ADEC-1 (NEW DEPARTURE)		#99606
4	18			#99504
1	19	CRANK SHAFT		SH #5
1	20	SHAFT		
2	21	HOUSING		SH #3
1	22	RETAINER CAP		SH #5
1	23			
1	24	CRANK ARM		SH #6
1	25	HANDLE "HA-37 "REID" (MODIFIED)		
1	26	SHOULDER SCREW		SH #6
4	27	CAP SCREW ¼-20UNC-2A × ⅜ LG, SOC HD	SST	
1	28	YOKE LOCK HOUSING		SH #5
1	29	LOCK SHAFT		
1	30	SELECTOR KNOB		
1	31	DRUM LOCK HOUSING		SH #7
1	32	SPRING RETAINER		
1	33	SHAFT		
1	34	SHAFT KNOB		
6	35	PLUG, ½ PIPE	SST	
	36	YOKE STOP		SH #7
	37			
AR	38	FILL, (ABOUT 2200 #)	MIL-STD QQL-171C-GRADE C	
1	39	GROOVE PIN, 3/16 DIA × 1⅜ LG	SST	TYPE "E"
1	40	3/16 DIA × 1" LG		
1	41	¼ DIA × 2½ LG		
1	42	ROLL PIN .125 DIA × 3/16 LG (ESNA)		79-020-125-562
1	43	.156 DIA × 11/16 LG		79-032-156-687
1	44	.187 DIA × 1¼ LG		79-040-187-1250
6	45	CAP SCREW, ⅝-11UNC-2A × 2¼ LG, HEX HD	SST	
4	46	5/16-18UNC-2A × ⅝ LG, SOC HD		
~~4~~	~~47~~	~~½-13UNC-2A × ⅝ LG.~~		
4	48	¼-20UNC-2A × ¾ LG.		
8	49	#10-24UNC-2A × 7/16 LG.		
8	50	MACH SCREW #10-24UNC-2A × ⅜ LG, FL HD		
1	51	EXTENSION SPRING, (ASSOCIATED SPRING CORP)		#E240-031-037
1	52	COMPRESSION SPRING, 1⅛ OD, .062 DIA WIRE, 2½ FREE LG, 11 COILS, SQ & GROUND ENDS	HARD DRAWN 302 SST WIRE	
1	53	COMPRESSION SPRING, ¾ OD, .044 DIA WIRE, 2½ FREE LG, 20 COILS, SQ & GROUND ENDS		



GENERAL NOTES, SHEET 1

U. S. ATOMIC ENERGY COMMISSION
Hanford Engineering Development Laboratory

PRTR GRAPHITE SAMPLE CASK SECTIONS & DETAILS

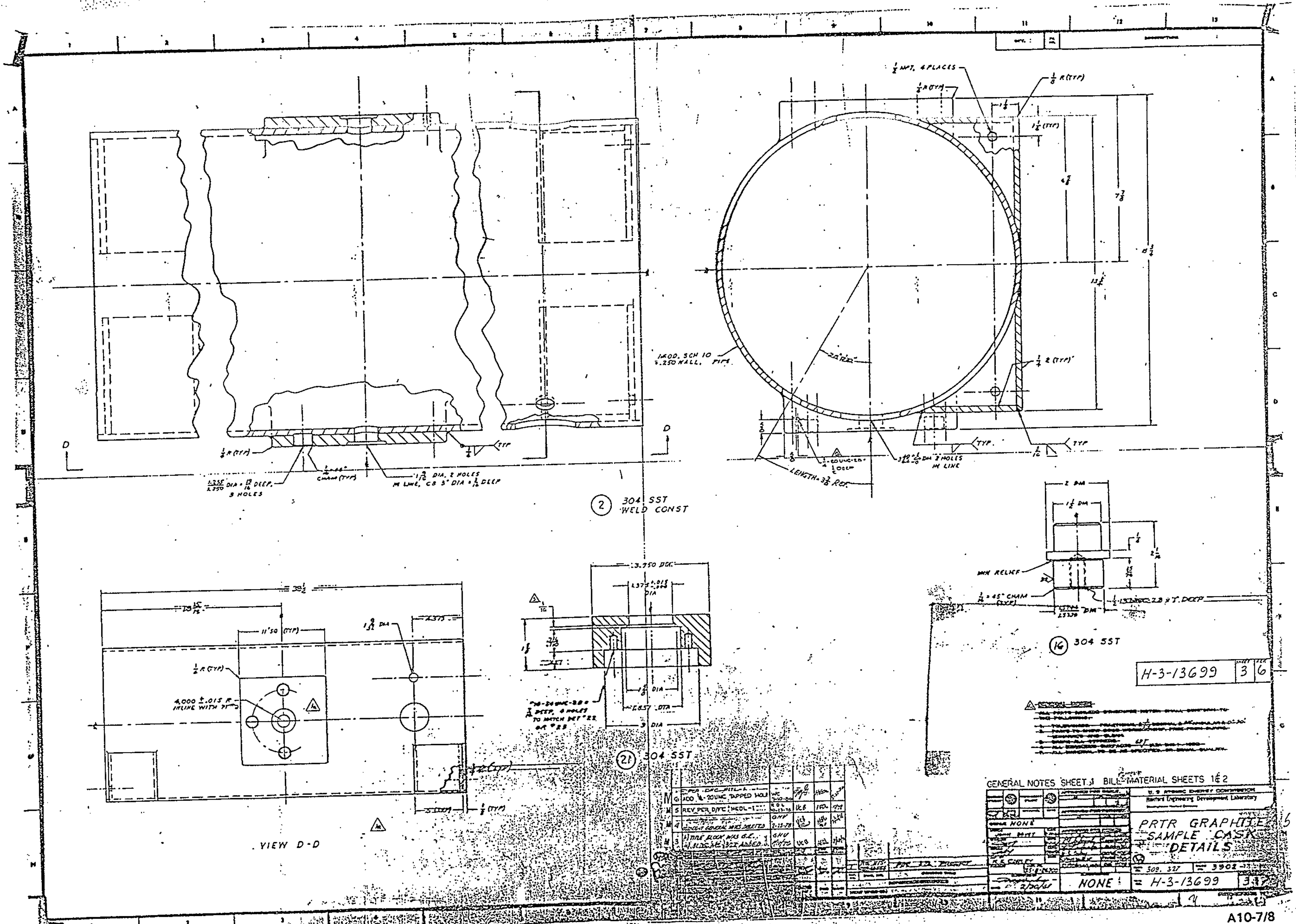
SCALE NONE

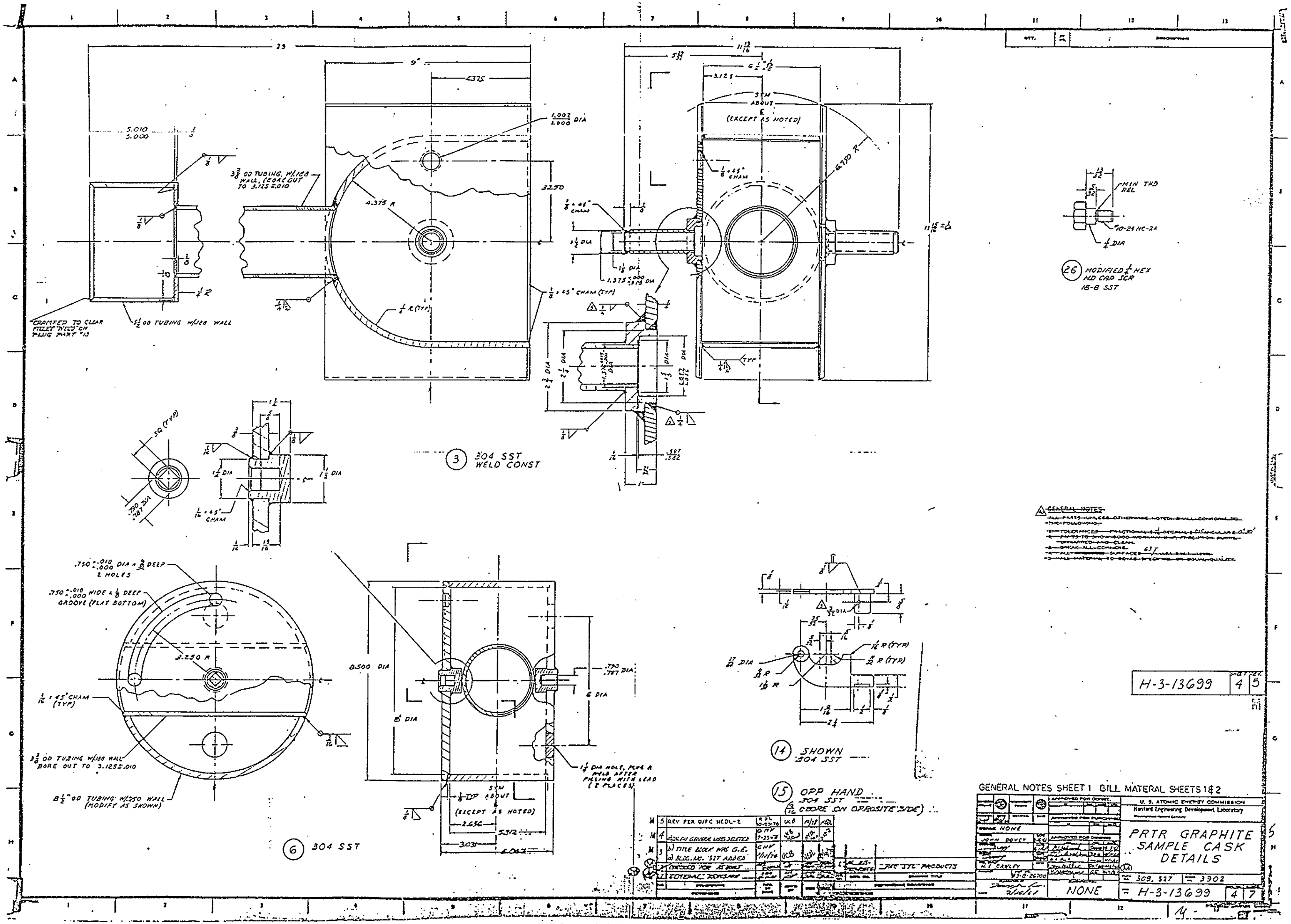
JOHN DOVEY

309, 327 — 3902

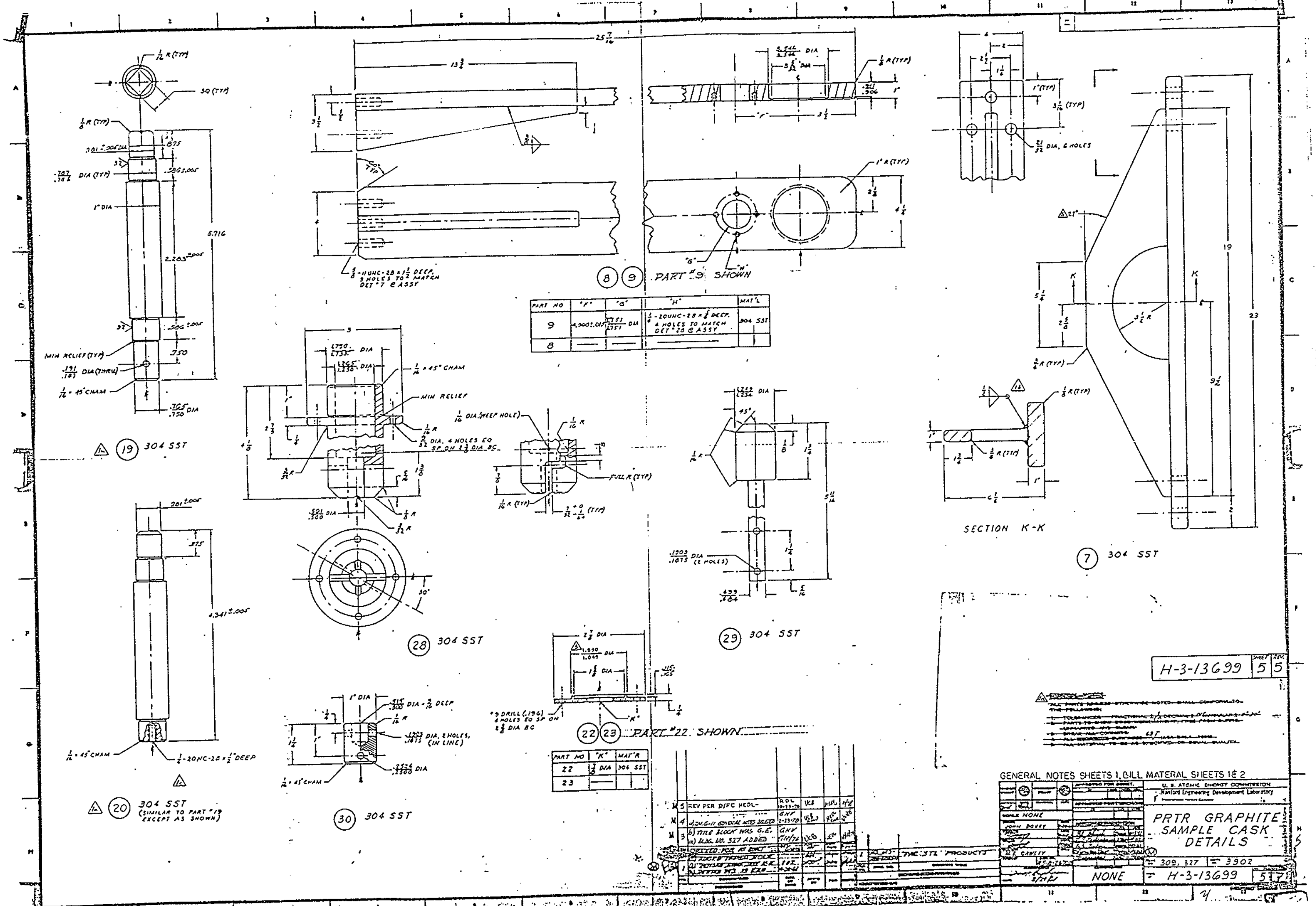
H-3-13699 | 2 | 7

PAC STL PRODUCTS


2 304 SST WELD CONST
VIEW D-D
21 304 SST
16 304 SST
H-3-13699 3 6
GENERAL NOTES SHEET 1 BILL OF MATERIAL SHEETS 1 & 2
PRTR GRAPHITE SAMPLE CASK DETAILS
NONE
H-3-13699

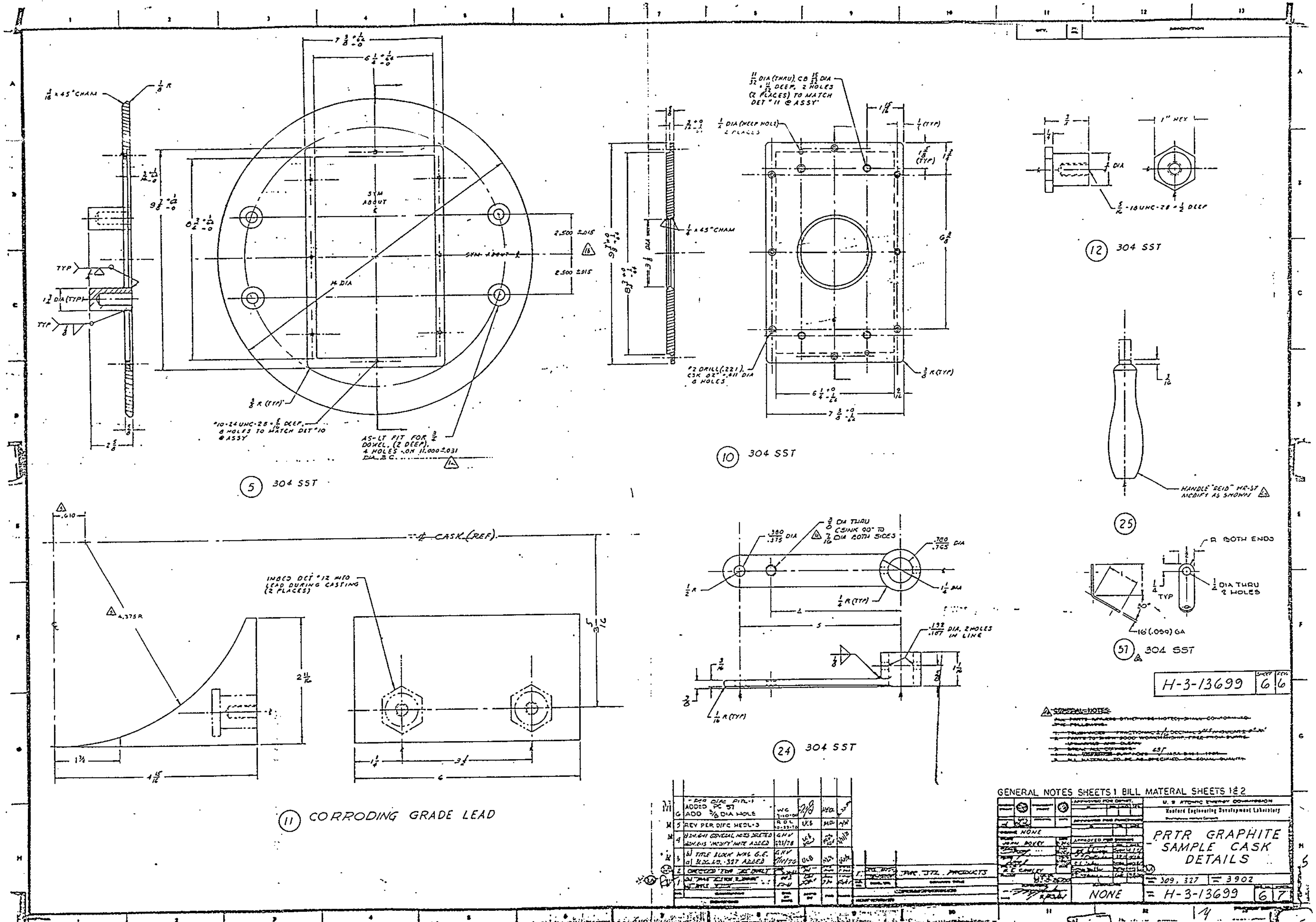


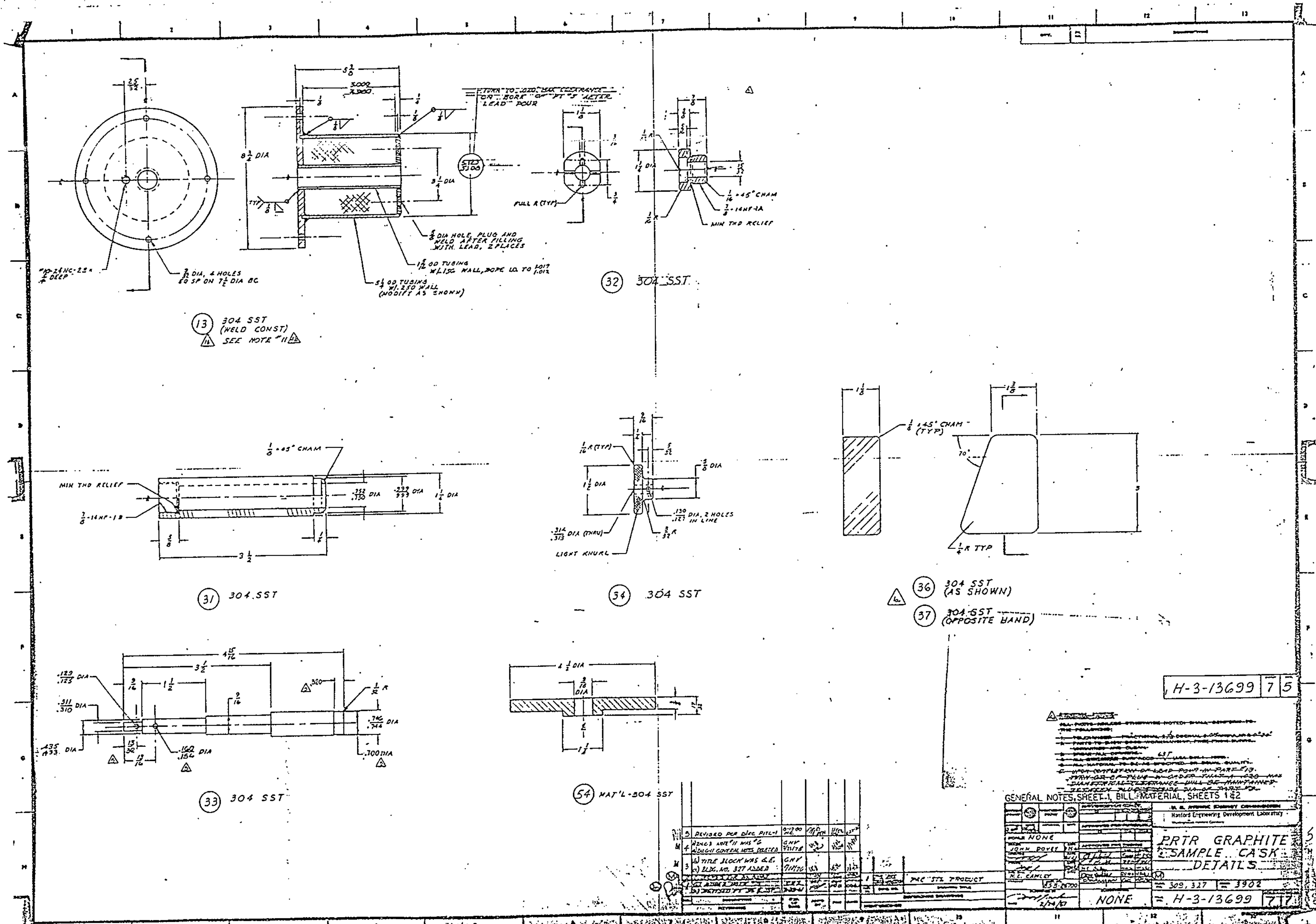
3 304 SST WELD CONST
6 304 SST
14 SHOWN 304 SST
15 OPP HAND 304 SST
26 MODIFIED 1/4 HEX HD CAP SCR 18-8 SST
GENERAL NOTES
GENERAL NOTES SHEET 1 BILL MATERIAL SHEETS 1 & 2
U. S. ATOMIC ENERGY COMMISSION
Hanford Engineering Development Laboratory
PRTR GRAPHITE SAMPLE CASK DETAILS
H-3-13699
NONE



PART NO	"F"	"G"	"H"	MAT'L
9			$\frac{1}{4}$-20UNC-2B x $\frac{3}{8}$ DEEP, 4 HOLES TO MATCH DET #28 ASSY	304 SST
8	—	—	—	

PART NO	"K"	MAT'R
22	$\frac{3}{8}$ DIA	304 SST
23	—	


5 304 SST
10 304 SST
12 304 SST
25
51 304 SST
11 CORRODING GRADE LEAD
24 304 SST
CASK (REF)
HANDLE "REID" MR-57 MODIFY AS SHOWN
GENERAL NOTES SHEETS 1 BILL MATERIAL SHEETS 1 & 2
PRTR GRAPHITE SAMPLE CASK DETAILS
NONE
H-3-13699
H-3-13699 6 6


13 304 SST (WELD CONST) SEE NOTE #11
32 304 SST
31 304 SST
34 304 SST
36 304 SST (AS SHOWN)
37 304 SST (OPPOSITE HAND)
33 304 SST
54 MAT'L-304 SST
MIN THD RELIEF
LIGHT KNURL
FULL R (TYP)
GENERAL NOTES, SHEET 1, BILL MATERIAL SHEETS 1&2
Hanford Engineering Development Laboratory
PRTR GRAPHITE SAMPLE CASK DETAILS
NONE
H-3-13699
H-3-13699 7 5

10.2 USER BIENNIAL INSPECTION CHECKLIST AND NONDESTRUCTIVE TESTING OF LIFTING APPARATUS

BATTELLE
Pacific Northwest Laboratories
Remote Systems Technology Department

RADIOACTIVE MATERIAL SHIPPING CONTAINER
BIENNIAL USER INSPECTION CHECKLIST

Container No: 2701 Inspection Date: ______ Next Inspection Due: ______

Item No.	Spec: Section or Dwg: View	Characteristic/Requirement	Reference or Test Method	Inspected By (Init.)
1.	H-3-13699 Sheet #1	Closure "drum" position marked "OPEN" and "CLOSED" on cask.	Visual Inspection	______
2.	H-3-13699 Sheet #1	Closure "drum" handle position is correct in reference to the "OPEN" and "CLOSED" markings.	Functional Test	______
3.	H-3-13699 Sheet #2	Closure "drum" locking device functions properly.	Functional Test	______
4.	H-3-13699 Sheet #2	Closure "drum" will close properly with transfer "boat" positioned to rear of cask.	Functional Test	______
5.	H-3-13699 Sheet #1	Rear locking device holds the transfer "boat" in position.	Functional Test	______
6.	H-3-13699 Sheet #2	Verify that closure "drum" rotates freely.	Functional Test	______
7.	H-3-13699 Sheet #1	Verify that locking pin will lock lifting "bail" in the horizontal/vertical position.	Functional Test	______
8.	JHB 327-5	Verify surface is free of damage and rust.	Visual Inspection	______
9.	JHB 327-5	Verify that no weld cracking is evident.	Visual Inspection	______
10.	JHB 327-5	Check for loose bolts and/or broken parts.	Visual Inspection	______

Custodian Signature: ____________________

BATTELLE
Pacific Northwest Laboratories
Remote Systems Technology Department

RADIOACTIVE MATERIAL SHIPPING CONTAINER
NDT OF LIFTING APPARATUS (5 YEAR)

Container No: 2701 Inspection Date: _______ Next Inspection Due: _______

Item No.	Spec; Section or Dwg; View	Characteristic/Requirement	Test Method	Inspected By (Init.)
1.	H-3-13699 Sheet #1	Welds attaching Part #7 to 1" thick Cross Bar.	Dye penetrant	_______
2.	H-3-13699 Sheet #1	Welds attaching Part #8 to Part #9.	Dye penetrant	_______

EQUIPMENT TEST INFORMATION

1. Requester verifies that the equipment to be examined is:
   ___ Safe.
   ___ Possible unsafe conditions. _______________
   ___ Radiation - Dose Rate. _______________
2. Anticipated part temperature: ___ Ambient ___Other _______________
3. Material type to be examined: _______________
4. Area to be inspected: ___ Spot Inspection _______________
   ___ Full Inspection (100% of area requested).
5. QA Plan: _______ Impact Level: _______ Test Procedure: _______
6. Acceptance Standard: _______________
7. Comments: _______________
8. QA Rep. contacted: _______________ Test Date: _______ Time: _____

Custodian Signature: _______________

PART B: PACKAGE EVALUATION

1.0 INTRODUCTION

1.1 SAFETY EVALUATION METHODOLOGY

The Plutonium Recycle Test Reactor (PRTR) Graphite Cask was evaluated against the requirements of WHC-CM-2-14, *Hazardous Material Packaging and Shipping*, for onsite transportation of solid, Type B, fissile, non-highway route controlled quantities (non-HRCQ) of radioactive materials. The analyses presented in this safety evaluation for packaging verify the PRTR Graphite Cask meets the onsite transportation safety requirements based on a risk evaluation.

1.2 EVALUATION SUMMARY AND CONCLUSIONS

As shown by the following evaluations, the PRTR Graphite Cask is safe for the onsite transportation of solid, Type B, fissile radioactive materials. The cask will prevent loss of contents for normal transport conditions (NTC). A risk evaluation demonstrates that the frequency of an accident resulting in loss of contents is less than the required criteria of 10^{-7}.

1.2.1 Contents

The typical contents of the PRTR Graphite Cask are evaluated in Part B, Section 2.0.

1.2.2 Radiological Risk

The risk evaluation for the PRTR Graphite Cask demonstrates that the PRTR Graphite Cask meets the onsite transportation safety criteria. In order to satisfy that criteria, the 327 Building casks, which include the One-Ton Lab Cask, the Long Bore Cask, the Large Bore Cask, the Radioactive Waste Disposal Cask, the Special Environmental Radiometallurgy Facility (SERF) Cask, and the PRTR Graphite Cask, cannot be transported more than a total of 16.0 km (10.0 mi) in any calendar year.

1.2.3 Containment

The containment system consists of the PRTR Graphite Cask and the inner container. The radioactive contents are contained inside the inner container, which is either a glass or plastic vial. The vials are placed in a slip lid container, which, in turn, is placed in two 10-mil plastic bags that are sealed with duct tape. The plastic vials can also be placed in two 10-mil plastic bags that are sealed with duct tape. Both types of vials are closed with screw caps. The containment evaluation is presented in Part B, Section 4.0.

1.2.4 Shielding

The shielding analysis for the source term is presented in Part B, Section 5.0. The cask provides the shielding required to meet the established radiological dose rate criteria.

1.2.5 Criticality

The criticality analysis for the PRTR Graphite Cask is contained in *Limits for Fissionable Material in Small Bore Transfer Casks and Lead Pigs* (Larson 1996). The limit for ^{235}U only is 275 g, while the limit for other fissionable materials is 175 g.

1.2.6 Structural

The structural analysis for the PRTR Graphite Cask is contained in Part B, Section 7.0. This analysis shows the PRTR Graphite Cask and the inner containers contain the contents and maintain shielding during all NTC. Accident conditions are addressed in the risk evaluation.

1.2.7 Thermal

The thermal analysis for the PRTR Graphite Cask is contained in Part B, Section 8.0. This analysis demonstrates that the PRTR Graphite Cask performs acceptably during extreme weather conditions on the Hanford Site.

1.2.8 Gas Generation

The contents of the PRTR Graphite Cask will be dry to prevent gas generation from radiolysis.

1.2.9 Tiedown System

The package tiedown evaluation in Part B, Section 10.0, ensures that the PRTR Graphite Cask will remain on the trailer under NTC.

1.3 REFERENCES

Larson, S. L., 1996, *Limits for Fissionable Material in Small Bore Transfer Casks and Lead Pigs* (NCS Basis Memo 96-2 to M. Dec, December 30), Battelle Pacific Northwest Laboratories, Richland, Washington.

WHC-CM-2-14, *Hazardous Material Packaging and Shipping*, Westinghouse Hanford Company, Richland, Washington.

2.0 CONTENTS EVALUATION

2.1 CHARACTERIZATION

Contents to be transported in the PRTR Graphite Cask shall consist of irradiated fuel assemblies, fuel pieces, and various activated materials. The contents shall be limited to the maximum allowable source term shown in Table B2-1.

Table B2-1. Maximum Allowable Source Term.

Material	Activity limit	
	TBq	Ci
Fissile materials and α emitters*	0.401	10.9
Mixed fission products	13.9	375
Mixed activation products	0.185	5.00

*Fissile/fissionable materials limited by criticality safety as shown in Part B, Section 2.1.1.

The maximum number of A_2s and thermal characteristics of the contents are determined as shown Table B2-2. Note that the isotopes assumed for A_2 calculations are for the worst-case inventory.

Table B2-2. Decay Heat and A_2 Calculation for the Plutonium Recycle Test Reactor Graphite Cask.

Nuclide	Activity		Heat production factor (W/Ci)	Heat generation rate (W)	A_2 (Ci)	A_2s
	Bq	Ci				
^{90}Sr	1.39 E+13	3.75 E+02	1.16 E-03	0.44	2.70 E+00	1.39 E+02
^{90}Y	1.39 E+13	3.75 E+02	5.54 E-03	2.08	0.00 E+00	0.00 E+00
^{60}Co	1.85 E+11	5.00 E+00	1.54 E-02	0.08	1.08 E+01	4.63 E-01
^{239}Pu	4.01 E+11	1.09 E+01	3.06 E-02	0.33	5.41 E-03	2.01 E+03
Total	2.83 E+13	7.66 E+02		2.92		2.14 E+03

As shown in Table B2-2, the number of A_2s is less than 3,000; therefore, the maximum radioactive material inventory is a fissile, Type-B, non-HRCQ (49 CFR 173).

2.1.1 Fissile Material Content

The fissile/fissionable material limits for the PRTR Graphite Cask are shown in Table B2-3. These limits are 275 g of ^{235}U or an aggregate total of 175 g of ^{239}Pu, ^{233}U, ^{237}Np, ^{241}Am, ^{243}Am, ^{244}Cm, and ^{247}Cm. Note that mixtures of fissionable material are possible provided that the sum-of-fractions method shown in *Criticality Safety* (PNL 1994) is followed.

Table B2-3. Fissile/Fissionable Material Limits in the Plutonium Recycle Test Reactor Graphite Cask.

Material	Limit
^{235}U	275 g* or
^{239}Pu, ^{233}U, ^{237}Np, ^{241}Am, ^{243}Am, ^{244}Cm, and ^{247}Cm	175 g aggregate total*
^{242m}Am, ^{243}Cm, ^{245}Cm, ^{249}Cf, or ^{251}Cf	Not analyzed and cannot be shipped in excess of safeguards accountability limits*

Source: Larson, S. L., 1996, *Limits for Fissionable Material in Small Bore Transfer Casks and Lead Pigs* (NCS Basis Memo 96-2 to M. Dec, December 30), Battelle Pacific Northwest Laboratories, Richland, Washington.

*Mixtures of fissionable material are possible provided that the sum-of-fractions method shown in PNL (1994) and referenced in Larson (1996), attached in Part B, Section 6.0, is followed.

PNL, 1994, *Criticality Safety*, PNL-MA-25, Battelle Pacific Northwest Laboratories, Richland, Washington.

2.2 RESTRICTIONS

Contents as shown in Part B, Tables B2-1 and B2-3, including daughter isotopes, are the only contents authorized for the PRTR Graphite Cask. All contents shall be in inner containers as described in Table B2-4.

2.3 SIZE AND WEIGHT

Only contents smaller than the internal cavity can be shipped in the PRTR Graphite Cask. The empty weight of the cask is 1,089 kg (2,400 lb). The total gross weight of the PRTR Graphite Cask and its contents shall not exceed 1,202 kg (2,650 lb).

2.4 CONCLUSIONS

The fissionable material limits described in *Limits for Fissionable Material in Small Bore Transfer Casks and Lead Pigs* (Larson 1996) and discussed in Part B, Section 6.0, and the shielding analyses, shown in Part B, Section 5.0, demonstrate that the PRTR Graphite Cask can ship the contents shown in Tables B2-1 and B2-3 safely. The established limits will preclude the possibility of a criticality and minimize radiological exposure to personnel during transport.

As shown in Table B2-2, the maximum quantity of material to be shipped is a fissile, Type B non-HRCQ (49 CFR 173).

Table B2-4. Inner Container Description.

Inner container	Contents	Examples of contents
Pin tubes--tubes and fittings must have a working rating of 20.68 MPa (3000 psi), with an outer diameter of 1.3 cm (0.50 in.) or 1.9 cm (0.75 in.). The tubes are welded on one end. A Swagelok* fitting is used as closure.	Dispersible solid materials	Irradiated structural materials; solid pieces of irradiated FFTF, PNC, and N Reactor fuel pins; and small pieces or test samples of irradiated fuel and structural materials
DOT Specification 2R per 49 CFR 178.360	Dispersible solid materials	Irradiated structural materials; solid pieces of irradiated FFTF, PNC, and N Reactor fuel pins; and small pieces or test samples of irradiated fuel and structural materials in glass or plastic vials with screw cap
Large solid item put directly into the cask	Nondispersible solid structural material and activated metals put directly into the cask**	Large solid items with fixed surface contamination

DOT = U.S. Department of Transportation.
FFTF = Fast Flux Test Facility.
PNC = Power Reactor and Nuclear Fuel Development Corporation.

*Swagelok is a trademark of the Crawford Fitting Company.
**Surface contamination limits not to exceed 100 times the Table A4-1 limits. Verification by survey or the use of a fixative, such as paint, is required.

49 CFR 178, 1997, "Specifications for Packagings," *Code of Federal Regulations*, as amended.

2.5 REFERENCES

49 CFR 173, 1997, "Shippers--General Requirements for Shipments and Packagings," *Code of Federal Regulations*, as amended.

49 CFR 178, 1997, "Specifications for Packagings," *Code of Federal Regulations*, as amended.

Larson, S. L., 1996, *Limits for Fissionable Material in Small Bore Transfer Casks and Lead Pigs* (NCS Basis Memo 96-2 to M. Dec, December 30), Battelle Pacific Northwest Laboratories, Richland, Washington.

PNL, 1994, *Criticality Safety*, PNL-MA-25, Battelle Pacific Northwest Laboratories, Richland, Washington.

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3.0 RADIOLOGICAL RISK EVALUATION

3.1 INTRODUCTION

The 327 Building casks, which include the One-Ton Lab Cask, the Long Bore Cask, the Large Bore Cask, the Radioactive Waste Disposal Cask, the SERF Cask, and the PRTR Graphite Cask, are used to transport Type B non-HRCQs of solid activated metals, irradiated fuel, and other solid radioactive materials among the 300 Area laboratories. Because none of the 327 Building casks are certified Type B containers, radiological risks are evaluated to determine compliance with onsite transportation safety requirements per WHC-CM-2-14. Although separate safety documentation has been issued for each cask, the radiological risk evaluation is prepared for the 327 Building casks as a composite analysis. The composite analysis was prepared due to the similarity in payload, cask type, and transport environment.

The 327 Building casks are used routinely over short distances (less than 0.40 km [0.25 mi]) within the 300 Area. The casks are transported by truck.

The assumptions for the radiological risk evaluation are summed as follows:

- Highway mode
- Approximately 0.40 km (0.25 mi) per trip
- A maximum of 24 trips per year
- One cask per shipment.

For accident environments, the 327 Building casks must meet onsite transportation safety requirements as outlined in WHC-CM-2-14 and Mercado (1994). The required safety is determined by a radiological risk evaluation that uses dose consequences, risk acceptance criteria, cask failure threshold values, and Hanford Site accident frequencies. For the evaluation, accidents are categorized as resulting in impact, crush, puncture, and fire forces. Risk acceptance criteria are outlined in Part B, Section 3.2, and the dose consequence analyses results are provided in Part B, Section 3.3. Cask failure thresholds are given in Part B, Section 3.4. The analysis of accident release frequencies for associated failure thresholds is documented in Part B, Section 3.5. The accident release frequencies are compared to the risk acceptance criteria determined from the dose consequence analysis to evaluate the acceptability of the risks related to the 327 Building cask shipments.

3.1.1 Summary of Results

Based on the transport of one 327 Building cask per shipment, the dose consequence analysis resulted in a risk acceptance criterion of an annual accident release frequency of less than 10^{-7}. The release frequency and conditional probability analysis showed that the criterion is met for shipments totaling over 16.0 km (10.0 mi) per year. Therefore, 24 shipments per year of 0.40 km (0.25 mi) each easily falls within the range of the acceptable risks as required to meet onsite transportation safety per WHC-CM-2-14. The risk evaluation shows that up to 40 transfers of 0.40 km (0.25 mi) may be made per year.

3.2 RISK ACCEPTANCE CRITERIA

Graded dose limitations for probable, credible, and incredible accident frequencies ensure safety in radioactive material packaging and transportation (Mercado 1994). The dose limitations to the offsite and onsite individual for probable, credible, and incredible accident frequencies are shown in Table B3-1.

Table B3-1. Risk Acceptance Criteria Limits.

Description	Annual frequency	Offsite dose limit* (rem)	Onsite dose limit* (rem)
Incredible	$< 10^{-7}$	None	None
Incredible	10^{-7} to $< 10^{-6}$	25	None
Credible	10^{-6} to 10^{-3}	0.5	5
Probable	10^{-3} to 1	0.01	0.2

*Total effective dose equivalent.

3.3 DOSE CONSEQUENCE ANALYSIS RESULTS

The dose consequence study for the 327 Building casks is presented in Part B, Section 4.0, of this safety evaluation for packaging. The analysis does not take credit for the package, rather it follows International Atomic Energy Agency (IAEA) guidelines and evaluates doses for a release of 100% of the material at risk. The accident results are shown in Table B3-2 for a ground-level release at the worst location with worst-case (0.5%) meteorology. The doses shown in Table B3-2 are the total committed effective dose equivalents (EDE), which are integrated over 50 years.

Table B3-2. Summary of Doses.

Exposure pathway	Offsite receptor (rem)	Onsite worker (rem)
Total effective dose equivalent	68	2000

When compared to the risk criteria given in Table B3-1, the potential dose to the offsite receptor requires that the 327 Building casks maintain annual accident release frequencies of less than 10^{-7} probability of occurrence per year. Therefore, the annual accident release frequency is limited to less than 10^{-7} per year.

3.4 PACKAGE FAILURE THRESHOLD ANALYSIS

Accident performance of a package is determined by the probability, given an accident, that a package is subjected to a force more severe than the package failure threshold level for that accident scenario. For the 327 Building casks, the failure thresholds are assumed to be minimal, and the package is assumed to fail if an accident occurs. The failure threshold of the 327 Building casks has been determined for puncture.

- *Impact*: No impact analysis was performed; the 327 Building casks are assumed to fail in the event of an impact.
- *Puncture*: The puncture failure threshold is based on the equivalent steel thickness of the package. The equivalent steel thickness for each of the six casks is at least 6.4 cm (2.5 in.). This evaluation is documented in Part B, Section 7.0, page B7-15.

- *Crush*: No crush analysis was performed; the 327 Building casks are assumed to fail in any accident involving crush.

- *Fire*: No fire failure analysis was performed, therefore the 327 Building casks are assumed to fail any accident involving a fire.

3.5 ACCIDENT RELEASE FREQUENCY ASSESSMENT

3.5.1 Approach

The accident release frequency assessment is based on the assumption that all failure modes from the different forces described as impact, puncture, crush, and fire result in the same level of consequence. The union of the package conditional release probabilities from different scenarios with similar consequences is multiplied by the frequency of truck accidents to arrive at a total annual accident release frequency.

The frequency (F) of a truck accident is the product of the annual number of trips, the number of miles per trip, and the accident rate per mile.

$$F = \frac{number\ of\ trips}{year} \times \frac{miles}{trip} \times \frac{accidents}{mile}$$

Hanford Site truck accidents have been compiled in a report using Site-specific data (Green et al. 1996), which gives the accident rate for trucks as 2.0×10^{-7} accidents per mile. For a shipment of radioactive materials that is carried out by trained truck drivers during daylight hours in good road conditions, a reduction factor of 20 can be applied to lower the rate to 1×10^{-8} (H&R 1995) accidents per mile. Appendix B of *Recommended Onsite Transportation Risk Management Methodology* (H&R 1995) summarizes statistics from the U.S. Department of Transportation (DOT) and the studies conducted by Sandia National Laboratory on accident responses of small and large packages. The report recommends reducing truck accident rates by 10 for "safe" truck drivers and another factor of two for shipment of radioactive material. These reduction factors are based on the following logic.

- *Safe truck drivers*: Hanford Site truck drivers have special training. Drivers must complete several driver's education courses, have a valid commercial driver's license with hazardous endorsement, complete specific training for highway route controlled quantities of radioactive material, and complete radiation worker and hazardous materials training. References show that drivers who participate in special safety programs reduce single-vehicle accident rates by up to a factor of 100. The H&R report (H&R 1995) recommends using an overall accident reduction factor of 10.

- *Radioactive material*: An additional factor of two is recommended based on the higher level of training required for drivers of vehicles carrying radioactive material and the higher level of caution that would be expected from drivers of cargos consisting of radioactive material.

After the frequency of accidents is calculated, it is then multiplied by the union of the conditional release probabilities determined in Part B, Section 3.5.2, to arrive at an annual accident release frequency. The annual release frequency is compared to the criteria determined from the dose consequence analysis ($<10^{-7}$).

3.5.2 Accident Release Frequency Analysis

Information for the probability of occurrence and conditional probabilities of failure is taken from *Severities of Transportation Accidents Involving Large Packages* (Dennis et al. 1978), *Severities of Transportation Accidents Volume III - Motor Carriers* (Clarke et al. 1976), and H&R (1995). A simplified generic flow chart, shown in Figure B3-1, has been developed using statistics presented in Clarke et al. (1976) and Dennis et al. (1978). It visually depicts events that may occur as a result of a truck accident on the Hanford Site. Scenarios, such as immersion, that are not pertinent to the shipment of radioactive material on the Hanford Site are not included. Package failure and material release may occur from fire, impact, crush, and puncture, which for purposes of the joint probability calculations are assumed to be independent events.

The probability of an event in the flow chart, given a preceding event, is determined from the studies presented with large and small packages in Clarke et al. (1976) and Dennis et al. (1978). Thus, as can be seen in Figure B3-1, the probability of a fire only given a truck accident is 0.0110, and the probability of an accident resulting in collision or overturn is 0.8935 (Clarke et al. 1976 [p.13]). Trivial accidents are defined only in terms of the cargo and refer to those accidents that do not affect the payload (for example accidents with objects of much lesser mass).

The crush force in the flow chart represents static crush. For large packages inertial crush falls under the category of an impact force, and impact failure thresholds are accordingly evaluated for either impact or inertial crush failure, whichever is the limiting value. The conditional probability of static crush given a collision or overturn accident is found in Dennis et al. (1978 [p. II-25]) as 0.05. This means that 1 in 20 collision or overturn accidents results in static crush to the package. Use of the 0.05 value is recommended in Dennis et al. (1978) even though the study states that accident statistics indicate a lower rate would be more representative of accident conditions.

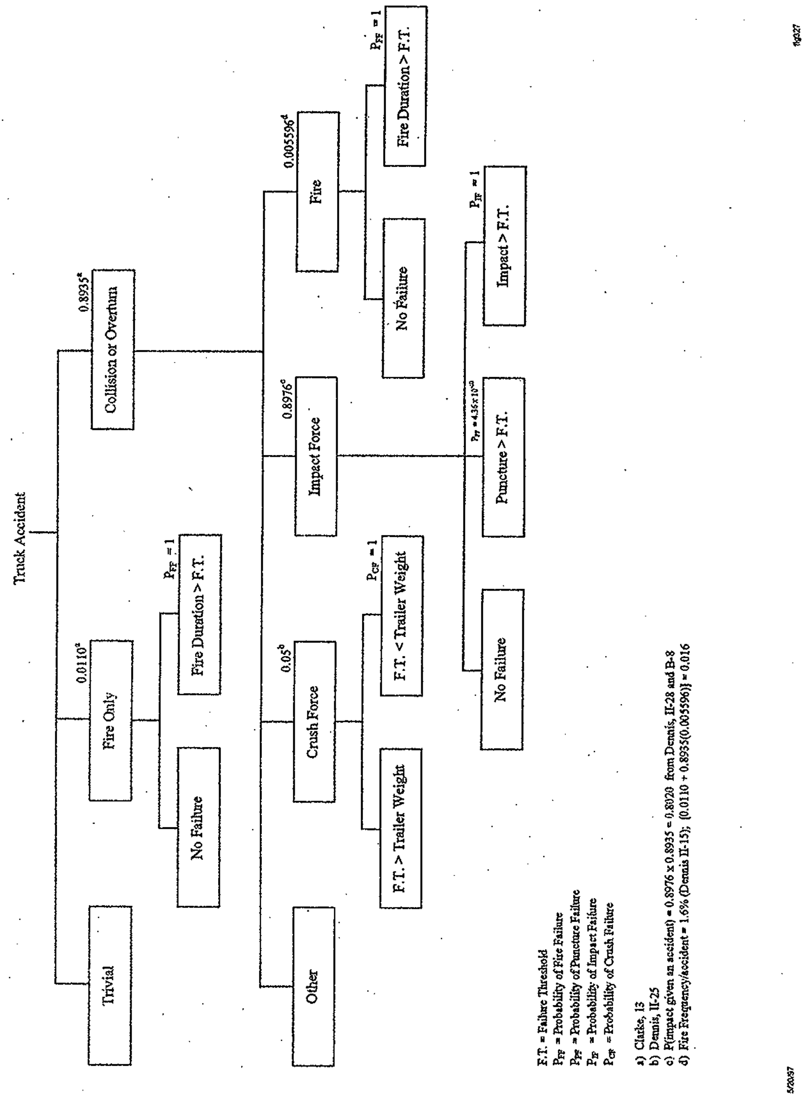
The impact environment may result in puncture or impact failure for large packages. Dennis et al. (1978) cites a value of 0.8020 for the probability of an impact or inertial crush force given an accident. Accordingly, the probability of an impact force occurring given a collision or overturn is calculated to be 0.8976 (0.8020/0.8935). In a similar manner, the conditional probability of fire given a collision or overturn is calculated from the fire frequency per accident of 1.6% (Dennis et al. 1978 [p. II-15]) and the value for the fire-only scenario of 0.0110. It is worth noting that the statistics in Dennis et al. (1978) do not discriminate between fires that affect cargo and fires that do not affect cargo. Therefore, some overconservatism may result from the assumption that all fires affect the cargo.

3.5.2.1 Conditional Release Probabilities. Conditional release probabilities for crush are either 1.0 for failure or 0 for no failure. In an accident involving crush, for example, failure occurs if the static crush failure threshold for the package is less than the weight of the truck trailer. No other static crush force will occur on the Hanford Site. For the 327 Building casks, the conditional release probability due to crush-induced failure (PCF) is 1.0 because the casks are assumed to fail in any accident involving crush forces.

The conditional probability of release from failure from fire (PFF) is determined from an H&R report (H&R 1995), which incorporates Hanford Site information for emergency response time and fire duration. The value represents the probability that the fire duration is greater than the length of time determined to be the failure point for the package. For the 327 Building casks, PFF is equal to 1.0 because the package is assumed to fail any fire.

The conditional probability of release from puncture given an impact event (PPF) represents the probability that an impact event will result in a puncture force large enough to penetrate and fail the equivalent steel thickness of the package. The PPF values are found in Dennis et al. (1978 [p. II-35]). The 327 Building casks have an equivalent steel thickness of 6.6 cm (2.6 in), which is rounded down to 6.4 cm (2.5 in.) for a PPF value of 4.36×10^{-10}.

Figure B3-1. Flow Chart for Hanford Site Large Package Truck Accidents.



The conditional probability of release from impact forces given an impact event (PIF) represents the probability that the package will be subjected to an impact resulting in a velocity change greater than that which could fail the package. As previously stated, inertial crush is included in this category. The values for the impact conditional release probabilities are found in Dennis et al. (1978 [p. II-23]). For the 327 Building casks, the PIF is conservatively assumed to be 1.0.

Table B3-3. Failure Thresholds and Conditional Release Probabilities.

Force type	Failure threshold	Conditional release probability
Crush	Fails crush	1.0
Puncture	6.4 cm (2.5 in.)	4.36×10^{-10}
Fire	Fails any fire	1.0
Impact	Fails any impact	1.0

3.5.2.2 Joint Probabilities. Conditional release probabilities and failure thresholds are shown in Table B3-3. The joint probability is calculated by taking the union of events (McCormick 1981). The equation represents the sum of the probabilities of independent events while the subtracted terms eliminate double counting arising from the overlap caused by the intersection of the events. The general equation is given as:

$$P(A_1+A_2+\ldots+A_N)=\sum_{n=1}^{N} P(A_n)-\sum_{n=1}^{N-1}\sum_{m=n+1}^{N} P(A_nA_m)+-$$
$$\ldots.+(-1)^{N-1}P(A_1A_2\ldots A_N).$$

where

P(f|a) = the probability of fire given that an accident has occurred
P(fc|a) = the probability of fire and crush given that an accident has occurred

and

P(FTE f|f) = the probability that the failure threshold is exceeded by fire given that a fire has occurred

then the above equation can be expanded and written as:

P = P(f|a) P(FTE f|f) + P(c|a) P(FTE c|c) + P(I|a) P(FTE I|I) +
P(p|a) P(FTE p|p) - P(fc|a) P(FTE f|f) P(FTE c|c) -
P(fi|a) P(FTE f|f) P(FTE I|I) - . . .

When substituted in the above equation, the values from the flow chart in Figure B3-1 and the conditional probabilities from Table 3-3 yield a total conditional release probability of 0.978.

3.6 EVALUATION AND CONCLUSION

The total conditional release probability of 0.978 is multiplied by the frequency (F) to arrive at an annual accident release frequency. The annual accident release frequency for 24 shipments of

327 Building casks is 5.9×10^{-8}. This value is less than the 1×10^{-7} required. In fact, the 327 Building casks can be shipped for up to 16.0 km (10.0 mi) per year, and the release frequency is less than the criterion.

3.7 REFERENCES

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WHC-CM-2-14, *Hazardous Material Packaging and Shipping*, Westinghouse Hanford Company, Richland, Washington.

3.8 APPENDIX: CHECKLIST FOR REVIEW

CHECKLIST FOR REVIEW

Document Reviewed: 327 Building Casks Risk Evaluation

Scope of Review: entire document

Yes	No	NA		
[ ]	[ ]	[X]	*	Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
[X]	[ ]	[ ]		Problem completely defined.
[X]	[ ]	[ ]		Accident scenarios developed in a clear and logical manner.
[X]	[ ]	[ ]		Necessary assumptions explicitly stated and supported.
[X]	[ ]	[ ]		Computer codes and data files documented.
[X]	[ ]	[ ]		Data used in calculations explicitly stated in document.
[X]	[ ]	[ ]		Data checked for consistency with original source information as applicable.
[X]	[ ]	[ ]		Mathematical derivations checked including dimensional consistency of results.
[X]	[ ]	[ ]		Models appropriate and used within range of validity or use outside range of established validity justified.
[X]	[ ]	[ ]		Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
[X]	[ ]	[ ]		Software input correct and consistent with document reviewed.
[X]	[ ]	[ ]		Software output consistent with input and with results reported in document reviewed.
[X]	[ ]	[ ]		Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
[X]	[ ]	[ ]		Safety margins consistent with good engineering practices.
[X]	[ ]	[ ]		Conclusions consistent with analytical results and applicable limits.
[X]	[ ]	[ ]		Results and conclusions address all points required in the problem statement.
[X]	[ ]	[ ]		Format consistent with appropriate NRC Regulatory Guide or other standards
[ ]		[X]	*	Review calculations, comments, and/or notes are attached.
[X]	[ ]	[ ]		Document approved.

J G McFadden   J G McFadden   7/8/97
Reviewer (Printed Name and Signature)   Date

* Any calculations, comments, or notes generated as part of this review should be signed, dated and attached to this checklist. Such material should be labeled and recorded in such a manner as to be intelligible to a technically qualified third party.

4.0 CONTAINMENT EVALUATION

4.1 INTRODUCTION

The containment system consists of the PRTR Graphite Cask and the inner container. The inner container can be either a stainless steel tube 1.3 cm (0.50 in.) or 1.9 cm (0.75 in.) in diameter or a DOT Specification 2R container per 49 CFR 178.360. An authorized exception to having an inner container would be a large solid item with fixed surface contamination. Items such as described can be placed directly into the cask. See Table B2-4.

4.2 CONTAINMENT SOURCE SPECIFICATION

The authorized radioactive contents of the PRTR Graphite Cask are described in Part B, Section 2.1. For conservatism, the containment analysis assumes that the inner container consists of the two 10-mil plastic bags, which are placed one inside the other.

4.3 NORMAL TRANSPORT CONDITIONS

4.3.1 Conditions To Be Evaluated

The structural performance of the cask was assessed for the Hanford Site normal conditions that are listed in Part B, Section 7.3.1.

4.3.2 Containment Acceptance Criteria

The acceptance criteria for the cask for NTC are that the cask shall retain the inner container and the inner container (plastic or glass vial) shall retain the radioactive material payload.

4.4 ACCIDENT CONDITIONS

4.4.1 Conditions To Be Evaluated

Accident conditions are evaluated for the PRTR Graphite Cask by radiological risk and dose consequence analyses. The radiological risk evaluation is given in Part B, Section 3.0, of this safety evaluation. The dose consequence and associated Transportation Hazard Index (THI) are given in Part B, Section 4.6.

4.5 CONTAINMENT EVALUATION AND CONCLUSIONS

4.5.1 Normal Transport Conditions

The PRTR Graphite Cask will provide the structural integrity necessary to transport the payload. The PRTR Graphite Cask has been used for shipments within the 300 Area for approximately 20 years. Prior approval for use of the cask to ship radioactive material was given in MG 137, *Hazardous Materials Packaging and Shipping Manual*, Rev. 1 (HEDL 1981). Although the PRTR Graphite Cask does not provide containment in the traditional sense, the contents are limited to dry, nondispersible items packaged in inner containers that are double wrapped in plastic. The cask provides shielding and, in conjunction with the inner container and plastic wrapping, prevents the release of the contents under the NTC evaluated in Part B, Section 7.0.

4.5.2 Accident Conditions

Based on the radiological risk evaluation in Part B, Section 3.0, and the dose consequence evaluation given in Part B, Section 4.6, the PRTR Graphite Cask, in conjunction with the other 327 Building casks, can be transported a maximum of 16.0 km (10.0 mi) per year while still remaining within the acceptable limits for onsite and offsite receptor doses.

4.6 SUMMARY OF DOSE CONSEQUENCE RESULTS

This section documents the dose consequence calculations used to support the THI evaluation for the 327 Building casks. Six casks are used to transport radioactive materials among several buildings in the 300 Area. The casks used for these transfers are the One-Ton Lab Cask, the Long Bore Cask, the Large Bore Cask, the Radioactive Waste Disposal Cask, the SERF Cask, and the PRTR Graphite Cask. The authorized contents for each of the casks was reviewed, and the PRTR Graphite Cask was found to have the lowest allowable radioactive inventory. The other 327 Building Casks (One-Ton Lab Cask, Long Bore Cask, Large Bore Cask, Radioactive Waste Disposal Cask, and SERF Cask) have radioactive inventories that exceed that for the PRTR Graphite Cask; therefore, the dose consequences for the other five casks will be greater than that for the PRTR Graphite Cask. Because the PRTR Graphite Cask has to meet the highest level of requirements (i.e., those associated with a THI of 1), the other five casks will also have to meet the requirements for a THI of 1, and no additional analysis is required to demonstrate this.

Table B4-1 shows the dose consequence results from each exposure pathway for the maximum authorized contents for the PRTR Graphite Cask. The table also shows the dose to each receptor, which is obtained by summing the dose contributions from each pathway. Because the offsite worker dose is greater than 25 rem, the packaging must be designed to THI 1 requirements. The criteria for a THI of 1, as stated in WHC-CM-2-14:

> "THI-1: This represents the highest level of hazard from the contents. A packaging system assigned this level transports material that has the potential of causing a dose consequence, to an individual, in excess of 25 rem at the Hanford site boundary if fully released."

Table B4-1. Summary of Doses (rem) for the Plutonium Recycle Test Reactor Graphite Cask.

Exposure pathway	Hanford Site worker at 3 m	Public receptor*
External photon dose	2.8	NA
External dose from β-particles	5.0	NA
Inhalation and submersion from the airborne transport pathway	2000	68
Total effective dose equivalent	2000	68

Note: 100 rem = 1 sievert (Sv).
*This receptor is located 100 m N of the 300 Area.

4.6.1 Introduction and Overview

Six casks are used to transport radioactive materials among several buildings in the 300 Area. The casks used for these transfers are the One-Ton Lab Cask, the Long Bore Cask, the Large Bore Cask, the Radioactive Waste Disposal Cask, the SERF Cask, and the PRTR Graphite Cask. The radioactive materials most frequently transported among buildings are irradiated Fast Flux Test Facility and Power Reactor and Nuclear Fuel Development Corporation fuel, spent N Reactor fuel, mixed oxide, metal oxide, activated structural materials from reactors, and cesium chloride capsules.

An estimate of the dose consequences for various exposure pathways is necessary to determine the THI for the 327 Building casks. Part B, Section 4.6.2, discusses the general methodology used to perform the dose consequence calculations. Part B, Section 4.6.3, addresses the source term, and Part B, Sections 4.6.4 through 4.6.9, summarize the results for various exposure pathways. The analysis assumes the casks will only be transported within the 300 Area.

4.6.2 Dose Consequence Analysis Methodology

IAEA (1990) defines a standardized approach for evaluating transportation packaging requirements, called the Q-system. The Q-system methods, as outlined in IAEA (1990), have been incorporated into the document, *Report on Equivalent Safety for Transportation and Packaging of Radioactive Materials* (Mercado 1994). This document (Mercado 1994) is used to demonstrate that onsite shipments meet onsite transportation safety requirements per WHC-CM-2-14.

In the Q-system, the following five exposure pathways are considered: (1) external exposure to photons, (2) external exposure to β-particles, (3) inhalation, (4) skin contamination and ingestion, and (5) submersion in a cloud of gaseous isotopes. In special cases, such as α-particle or neutron emitters, other exposure routes are considered. In some cases a pathway will be judged to be small with respect to the others, and consideration will be minimal. Modifications to the IAEA scenarios are incorporated to more closely describe the particular conditions of the shipment. Detailed calculations for the postulated accident are performed whenever possible. However, in some cases, the IAEA guide's (IAEA 1990) worst-case rules-of-thumb are used.

The Q-system was developed as an all-encompassing generalized methodology using only the isotope as the defining variable. In this report, the specifics of the package are considered. Some of the dose pathways may be considered incredible (frequency $<10^{-6}$/yr), and although these pathways are covered in the IAEA guide, they are disregarded in the analysis.

In the IAEA system, the Q-values that are calculated are the radionuclide activities corresponding to each exposure route that causes the individual to receive the effective dose equivalent limit. The minimum Q-values define the A_2 values for the shipped materials. In the case of nondispersible materials (limited by the A_1 values), only the first two Q-values (based on exposure to external photon and external beta particles) are used. Note that for all radiation except neutrons, protons, and heavier charged particles (including α-particles), 1 gray (Gy) = 1 sievert (Sv), and 1 rad = 1 rem.

There are two receptors of interest in the Q-system. They are the Hanford Site worker and the public receptor. The Hanford Site worker is assumed to be located about 3 m from the package. The public receptor is assumed to be located at the nearest point of public access.

4.6.3 Source Term

The authorized contents for the PRTR Graphite Cask are shown in Table B4-2. The external dose due to gamma exposure was calculated assuming the mixed fission products (MFP) consist of ^{137}Cs, and the mixed activation products (MAP) consist of ^{60}Co, which produce the highest gamma dose rates. The external dose due to beta particle exposure was calculated assuming the MFP consists of $^{90}Sr/^{90}Y$ and the MAP consists of ^{59}Fe, which produce the highest beta dose rates. The inhalation dose was calculated assuming the MFP consists of ^{90}Sr, the MAP consists of ^{59}Fe, and the fissile material consists of 175 g (10.85 Ci) of ^{239}Pu, which produce the highest inhalation dose. The use of 175 g of ^{239}Pu bounds the 2-Ci limit for α emitters for the PRTR Graphite Cask. Note that the alpha emitters and fissile material have a negligible impact on the external gamma and beta dose rates due to the high content of ^{137}Cs, ^{90}Sr, and ^{60}Co assumed in the analyses.

Table B4-2. Plutonium Recycle Test Reactor Graphite Casks Radioactive Inventory.

Radioactive material	Cask (Ci)
Fissile material and α emitters	10.9
Mixed fission products[a]	375
Mixed activation products[b]	5.00

[a]Mixed fission products; e.g., ^{90}Sr, ^{137}Cs, etc.
[b]Mixed activation products; e.g., ^{60}Co, ^{54}Mn, ^{59}Fe.

4.6.4 External Dose Due to Photon (Gamma) Exposure

The IAEA scenario assumes that a person is exposed to a damaged transport package following an accident. The shielding of the package is assumed to be completely lost in the accident. This analysis will be done assuming a person remains 3 m from the source for a period of 15 minutes.

The computer code ISO-PC (Rittmann 1995) was used to calculate the dose rate 3 m from the source. The fluence-to-dose conversion factors used were the anterior-to-posterior irradiation pattern as outlined in American National Standards Institute (ANSI) standard ANSI/ANS-6.1.1-1991 (ANS 1991).

It was conservatively assumed that the MFP (375-Ci limit) consisted of ^{137}Cs and the MAP (5-Ci limit) consisted of ^{60}Co for this analysis. The other radioactive materials (α emitters, others, and fissile materials) will have a negligible contribution to the gamma dose rate compared to that from ^{137}Cs and ^{60}Co.

The PRTR Graphite Cask has an internal diameter of 7.94 cm (3.125 in.) and a length of 62 cm (24.5 in.). The source term was assumed to be homogeneously distributed throughout the cavity of the cask.

The payload for the PRTR Graphite Cask consists of mainly activated metal structural materials with a density of 7.86 g/cm^3. For this analysis, the source was taken to be iron with a density of 2.0 g/cm^3, which is about one-fourth the density of steel. The lower source density is conservative for this analysis because it results in higher dose rates due to reduced self-shielding and attenuation effects. Note that the results are not very sensitive to the selection of the source material.

The resulting dose rate from ISO-PC is 11 rem/h (0.11 Sv/h) at 3 m from the unshielded source. Therefore, the maximum total external gamma EDE for the Hanford Site worker is 2.8 rem (0.028 Sv) for a 15-minute exposure period. The ISO-PC input deck is included as Part B, Section 4.8.1.

4.6.5 External Dose Due to β-Particle Emitters

Because of the limited range of β-particles relative to that of photons, a shielding factor is used by the IAEA to account for residual shielding from material such as package debris. Except for this factor, no effort is made to account for either self-shielding or shielding from an accurate model of the damaged package. Shielding and dose rate factors are graphed in the IAEA Safety Guide No. 7 (IAEA 1990) as a function of the maximum energy of the β-particle. The IAEA beta dose rate calculation methods are based on an individual located 1 m from the unshielded source.

This analysis assumes an individual remains at a distance of 3 m from the source for a 15-minute exposure period. A factor will be applied to the dose rates calculated using the IAEA method to account for the difference between the 1-m distance assumed in developing the shielding factors and the 3-m distance in this analysis. This factor was conservatively taken to be 0.333 [(1 m/3 m)] since the dose rate falls off between $1/r^2$ and $1/r$, where r is the distance from the source. This also conservatively ignores any attenuation of the beta particles over the 3-m distance.

Table B4-3 shows the β-particle dose calculations for the inventory in Table B4-2, assuming the MFP consists of $^{90}Sr/^{90}Y$ and the MAP consists of ^{59}Fe. Note that ^{239}Pu and ^{235}U are not beta emitters. The total β-particle dose rate to the skin for an individual located 3 m from the source is 2.0×10^3 rem/h (2.0×10^1 Sv/h). This results in a β-particle dose of 5.0×10^2 rem (5.0 Sv) to the skin for a 15-minute exposure. Because the tissue weighting factor for the skin is 0.01 (ICRP 1991), the whole body EDE is then 5.0 rem (0.05 Sv). Note that 98.9% of the β-particle dose is due to the high-energy (2.28 MeV) β-particle emitted by ^{90}Y.

Table B4-3. β-Particle Dose Rate for Beta Emitters Contributing > 0.01% to the Total Dose.

Isotope	Activity (Ci)	Activity (Bq)	Branching ratio	E_{max} (MeV)	Dose rate factor[a]	Shielding factor[b]	Dose rate (rem/h)[c]	% Dose
^{90}Sr	3.75 E+02	1.39 E+13	1	0.54600	1.8 E-04	100	2.25 E+01	1.15
^{90}Y	3.75 E+02	1.39 E+13	0.99989	2.28390	3.1 E-04	2	1.94 E+03	98.85
Totals for beta emitters contributing > 0.01%							1.96 E+03	100.00
Totals for all beta emitters							1.96 E+03	100.00

[a]Dose rate factor in units of Gy/h or Sv/h for a 1-m Ci source from IAEA (1990).
[b]Shielding factor from IAEA (1990).
[c]Note that a factor of 0.333 is applied to the dose rates to account for a source-to-receptor distance of 3 m for this analysis, versus the 1-m distance assumed in the development of the dose rate factors from IAEA (1990).

IAEA, 1990, *Explanatory Material for the IAEA Regulations for the Safe Transport of Radioactive Material*, Safety Series No. 7, Second Edition (As Amended 1990), International Atomic Energy Agency, Vienna, Austria.

4.6.6 Inhalation and Ingestion Dose

Radioactive material may be inhaled following an accident due to resuspension or volatization of radioactive material released from the package. This section addresses the dose received by workers and the public due to exposure to airborne radioactivity during a postulated accident event.

4.6.6.1 Selection of Airborne Release Fraction. The U.S. Department of Energy (DOE) handbook, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities* (DOE 1994), was reviewed to identify applicable airborne release fractions (ARF) and respirable fractions (RF) for the authorized contents of the 327 Building casks. The PRTR Graphite Cask is only authorized to transport irradiated structural materials or encapsulated solid materials. DOE (1994) identifies a bounding ARF x RF of 1 x 10^{-3} for contaminated noncombustible materials not undergoing brittle fracture during shock vibration. This is a conservative airborne release fraction for the cask contents considering that the authorized contents specify that "All materials shall be enclosed in an inner container. The type of inner containment shall be sufficient to contain the item and prevent spread of removable contamination." Although the casks have not been analyzed to withstand hypothetical accident conditions, the inner container and the thick lead walls of the casks will likely prevent any catastrophic loss of the cask contents. The accident scenario envisioned for this analysis is an energetic event causing a loss of the cask closure lid, which exposes the cask contents and results in the radioactivity becoming airborne. No credit is taken for any containment provided by the inner container or the cask.

The ARF x RF of 1 x 10^{-3} is applied to the material at risk, which is assumed to be the entire cask radioactive inventory, to obtain the quantity of radioactive material that is made airborne for the postulated accident scenario. As mentioned in Part B, Section 4.6.3, the inhalation dose for the PRTR Graphite Cask is calculated assuming the MFP consists of ^{90}Sr, the MAP consists of ^{59}Fe, and the fissile material consists of 175 g (10.85 Ci) of ^{239}Pu, which produce the highest inhalation dose. The accident release quantities are listed in Table B4-4.

Table B4-4. Accident Airborne Release Quantities, Ci.

Nuclide	Plutonium Recycle Test Reactor Graphite Cask
$^{90}Sr/^{90}Y$	0.375
^{59}Fe	0.005
^{239}Pu	0.011

4.6.6.1.1 Discussion of Integrated Normalized Air Concentration Value (χ/Q'). After the radioactive material becomes airborne, it is transported downwind and inhaled by onsite workers or the public. The concentration of this material is reduced, or diluted, as it is being transported due to atmospheric mixing and turbulence. χ/Q' (s/m^3) is used to characterize the dilution of the airborne contaminants during atmospheric transport and dispersion. It is equal to the time-integrated normalized air concentration at the receptor. χ/Q' is a function of the atmospheric conditions (i.e., wind speed, stability class) and the distance to the receptor.

Bounding χ/Q' values are generated consistent with the methods described in *Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants,* Regulatory Guide 1.145 (NRC 1982). Because atmospheric conditions fluctuate, a bounding atmospheric condition is determined to be that condition that causes a downwind concentration of airborne contaminants that is exceeded only a small fraction of time because of weather fluctuations. Regulatory Guide 1.145 (NRC 1982) defines this fraction of exceedance as 0.5% for each sector or 5% for the overall Hanford Site. The Hanford Site is broken up into 16 sectors that represent 16 compass directions; i.e., S, SSW, SW, . . . , ESE, SE, SSE. χ/Q' values are generated for weather conditions that result in downwind concentrations exceeded only 0.5% of the time in the maximum sector or 5% of the time for the overall Site. These χ/Q' values are also referred to as 99.5% maximum sector and 95% overall Site χ/Q' values. The greater of these two values is called the bounding χ/Q' value and is used to assess the dose consequences for accident scenarios. The bounding χ/Q' value represents minimum dispersing conditions that result in maximum downwind concentrations; i.e., concentrations exceeded only a very small fraction of the time. This χ/Q' value will therefore result in very conservative estimates of accident consequences.

The χ/Q' values in this report were generated using the GXQ computer program, Version 3.1C (Hey 1993a, 1993b). The meteorological data used by GXQ are in the form of joint frequency tables. The joint frequency data are the most recent data available; they are nine-year-averaged data (1983-1991) from the Hanford Site meteorology towers located in the 300 Area. The χ/Q' values are generated using the methods described in Regulatory Guide 1.145 (NRC 1982) for a ground release with no credit taken for plume rise, plume meander, plume depletion, or any other models. This is conservative because all of these models reduce the airborne concentration at the downwind receptor locations.

Although we are interested in the dose to a Hanford Site worker at 3 m, the dose to an onsite receptor located 100 m from the release point is calculated using the worst-case χ/Q' value at 100 m. This dose is then multiplied by a factor of 30 to obtain the dose to the Hanford Site worker at 1 m in accordance with IAEA (1990). This approach is taken because the Gaussian equation, along with the parameters used to calculate the χ/Q' values, are only valid for distances of 100 m or greater. Although this analysis assumes the transport worker remains 3 m from the package, the inhalation portion of the transport worker dose is conservatively taken to be that calculated using the IAEA method for a worker located 1 m from the package.

The 327 Building casks will be transported within the 300 Area. The maximum χ/Q' value for an onsite receptor is 4.21×10^{-2} s/m^3 and occurs for an individual located 100 m N of the release point in the 300 Area.

The 300 Area is not a public exclusion area. Even though the roads may be closed during movement of the 327 Building casks, members of the public may be in the area. Therefore, it is conservatively assumed for this analysis that the public receptor is located 100 m from the release point in any compass direction. The maximum onsite and public receptor χ/Q' value will therefore be the same, i.e., the maximum public receptor χ/Q' value is 4.21×10^{-2} s/m^3. The GXQ input file for the maximum χ/Q' case is listed in Part B, Section 4.8.2. The title of the joint frequency file used by GXQ is 300 AREA - 10 M - Pasquill A - G (1983 - 1991 Average).

4.6.6.1.2 Inhalation and Submersion Dose Calculations. Because the GENII computer code Version 1.485 (Napier 1988) is the Site standard computer code for environmental release dose calculations, it was used to calculate the inhalation and submersion dose for the maximum onsite and public receptors. The airborne release quantities used in GENII are shown in Table B4-4. An example GENII input deck is listed in Part B, Section 4.8.3. The Worst Case Solubility class library was used, which is the most conservative library. The GENII libraries used were as follows:

- GENII Default Parameter Values (28-Mar-90 RAP)
- Radionuclide Library - Times<100 years (23-July-93 PDR)
- External Dose Factors for GENII in person Sv/yr per Bq/n (8-May-90)
- Worst Case Solubilities, Yearly Dose Increments (23-Jul-93 PDR).

The EDE from GENII for the inhalation and submersion pathways is 1.2×10^2 rem (1.2 Sv) for the maximum onsite receptor at 100 m N of the 300 Area. The inhalation dose contribution to the EDE is based on a 50-year dose commitment period. The maximum χ/Q' value from GENII was 7.4×10^{-2} s/m^3 for the maximum onsite receptor. The dose rates calculated by GENII are proportional to the χ/Q' values. The GXQ code calculates the 99.5% maximum sector and 95% overall Site χ/Q' values consistent with Regulatory Guide 1.145 (NRC 1982) methods, while GENII is inconsistent with Regulatory Guide 1.145 methods. As mentioned in the previous section, the maximum onsite receptor χ/Q' value from GXQ is 4.21×10^{-02} s/m^3. Therefore, the EDE for the inhalation and submersion pathways is 6.8×10^1 rem (6.8×10^{-1} Sv) for the maximum onsite receptor at 100 m using the GXQ χ/Q' value. This value was obtained by multiplying the GENII dose rate by the ratio of the GXQ χ/Q' value to the GENII χ/Q' value. Therefore the maximum public receptor dose is 6.8×10^1 rem (6.8×10^{-1} Sv).

To compensate for the fact that the onsite dose is calculated at a source-to-receptor distance of 100 m, this dose is multiplied by a factor of 30 to obtain the dose to the transport worker at 1 m in accordance with IAEA (1990). Although this analysis assumes the transport worker remains 3 m from the package, the inhalation portion of the transport worker dose is conservatively taken to be that calculated using the IAEA method for a worker located 1 m from the package. This results in an EDE of 2.0×10^3 rem (20.0 Sv) for the Hanford Site worker. Table B4-5 shows the doses for the postulated accident scenario.

Table B4-5. Inhalation and Submersion Dose (rem).

	Hanford worker (at 3 m)	Public receptor*
Effective dose equivalent	2000	68

Note: 100 rem = 1 Sv.
*This receptor is located 100 m N of the 300 Area.

4.6.6.1.3 Ingestion and Ground Shine Dose. The other potential internal exposure pathway for the public receptor is the ingestion pathway. Exposure through the ingestion pathway occurs when radioactive materials that have been deposited offsite during passage of the plume are ingested either by eating crops grown in, or animals raised on, contaminated soil or through drinking contaminated water. There are DOE; DOE, Richland Operations Office; state; and federal programs in place to prevent ingestion of contaminated food in the event of an accident (RL 1994, WSDOH 1993, WS 1994, EPA 1992). The primary determinant of exposure from the ingestion pathway is the effectiveness of public health measures (i.e., interdiction) rather than the severity of the accident itself. The ingestion pathway, if it occurs, is a slow-to-develop pathway and is not considered an immediate threat to an exposed population in the same sense as airborne plume exposures.

The ground shine pathway is an additional potential external exposure pathway for the public receptor. Ground shine refers to the external dose received by a person standing on ground contaminated by radioactive materials deposited during passage of the airborne radioactive plume. Similar to the ingestion pathway, the primary determinant of exposure from the ground shine pathway is the effectiveness of public health measures (i.e., interdiction) rather than the severity of the accident itself. The ground shine pathway is a slow-to-develop pathway and is not considered an immediate threat to an exposed population in the same sense as airborne plume exposures.

Because of the large radioactive inventory contained in the casks, it is argued that in the event of an accident scenario that results in the release of a large portion of the inventory, interdictive measures (RL 1994, WSDOH 1993, WS 1994, EPA 1992) would be taken to prevent ingestion of contaminated food and exposure through the ground shine pathway. Therefore, the ingestion and ground shine pathway doses were not calculated in this report.

4.6.7 Skin Contamination and Ingestion Dose

In the IAEA guide (IAEA 1990), it is assumed that 1% of the package contents are spread over an area of 1 m^2 and handling of debris results in contamination of the hands to 10% of this level. It is further assumed that the worker is not wearing gloves but that he recognizes the possibility of contamination and washes his hands within five hours. The effective dose equivalent to the skin received by the individual is estimated from a graph provided in the IAEA guide.

The IAEA scenario for the uptake of activity due to ingestion of the material assumes that the person ingests all of the contamination from 10 cm^2 of skin over a 24-hour period. Because the dose per unit uptake via inhalation is generally the same order or larger than that via ingestion, the inhalation pathway will normally be limiting for internal contamination due to β-ray emitters. In particular, if the skin contamination dose is much larger than the inhalation dose, the ingestion pathway is not considered.

Both these pathways are ordinarily neglected when calculating the dose consequences from an onsite transportation accident. The transportation workers are trained in the appropriate response to protect themselves from experiencing unnecessary radiation exposure, including preventing skin contamination and ingestion.

4.6.8 Submersion Dose Due to Gaseous Vapor

This exposure pathway is caused by submersion in a cloud of gaseous isotopes that are not taken into the body. A rapid release of 100% of the package contents is assumed. The IAEA guide (IAEA 1990) concentrates entirely on releases within confined structures. No guidance is given for outside releases.

There are no gaseous vapors present in the cask; therefore, this exposure pathway is not applicable.

4.6.9 Special Considerations

Alpha particle emitters are not of significance in the material considered in this report. The alpha particle emitters are of a low concentration, and their effect will be through the mechanism of inhalation that has been considered separately. Therefore, they are not addressed in this report. The quantity of radon present in the fuel is insignificant; therefore, radon is not addressed in this report.

The fuel (e.g., plutonium) contained in the casks emits neutrons through (α,n) and spontaneous fission reactions. These neutron emitters will contribute to the dose received by the Hanford Site worker, but will have a negligible impact on the public receptor. A conservative estimate of the neutron dose was made using the method described in Nelson (1996). The results indicate that the neutron dose contribution is negligible compared to the gamma dose due to the large MFP and MAP inventory. Therefore, the neutron dose was not calculated separately in this report.

Bremsstrahlung has been included in the consideration of photon effects, and the effects of short-lived daughter products have been included in all of the calculations. Where these isotopes are significant, they are assumed to be in equilibrium with their longer-lived parent isotopes.

4.6.10 Total Dose

Table B4-1 in Part B, Section 4.6, shows the dose from each exposure pathway.

4.7 REFERENCES

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WS, 1994, "Fixed Nuclear Facility Emergency Response Procedure," Section 10.6 - Department of Agriculture, Washington State.

4.8 APPENDICES

4.8.1 ISO-PC Input File

```
0       2  PRTR Cask Side Dose Rate - Unshielded
Cyl. Source Geom - Dose Rate at 3 m Side Surface
&Input Next= 1 , ISpec= 3 , IGeom= 7 ,  ICONC=0,  SFACT=1, DUNIT=7,
 NTheta= 30, NPsi= 20, NShld= 1 , JBuf= 1, OPTION=1,
 Slth= 62.2,
 Y= 31.1  ,
 T(1)=3.969,
 X= 303.969,
 WEIGHT(335) =    375 ,
 WEIGHT(336) =    354.75,
 WEIGHT(472) =    5,     &
1Sourc   9   2.0
End of Input
&Input Next= 6 &
```

4.8.2 GXQ Input File

```
300 Area - Sector 99.5% X/Q Values - 100 m
c GXQ Version 4.0 Input File
c  mode
   1
c
c MODE CHOICE:
c mode = 1 then X/Q based on Hanford site specific meteorology
c mode = 2 then X/Q based on atmospheric stability class and wind speed
c mode = 3 then X/Q plot file is created
c
c LOGICAL CHOICES:
c  ifox inorm icdf ichk isite ipop
   T    F     F    F    F     F
c ifox  = t then joint frequency used to compute frequency to exceed X/Q
c       = f then joint frequency used to compute annual average X/Q
c inorm = t then joint frequency data is normalized (as in GENII)
c       = f then joint frequency data is un-normalized
c icdf  = t then cumulative distribution file created (CDF.OUT)
c       = f then no cumulative distribution file created
c ichk  = t then X/Q parameter print option turned on
c       = f then no parameter print
c isite = t then X/Q based on joint frequency data for all 16 sectors
c       = f then X/Q based on joint frequency data of individual sectors
c ipop  = t then X/Q is population weighted
c       = f then no population weighting
c
c X/Q AND WIND SPEED ADJUSTMENT MODELS:
c  ipuff idep isrc iwind
   0     0    0    0
c DIFFUSION COEFFICIENT ADJUSTMENT MODELS:
c  iwake ipm  iflow ientr
   0     0    0     0
c EFFECTIVE RELEASE HEIGHT ADJUSTMENT MODELS:
c  (irise igrnd)iwash igrav
   0     0      0     0
c ipuff = 1 then X/Q calculated using puff model
c       = 0 then X/Q calculated using default continuous plume model
c idep  = 1 then plume depletion model turned on (Chamberlain model)
c isrc  = 1 then X/Q multiplied by scalar
c       = 2 then X/Q adjusted by wind speed function
c iwind = 1 then wind speed corrected for plume height
c isize = 1 then NRC RG 1.145 building wake model turned on
c       = 2 then MACCS virtual distance building wake model turned on
c ipm   = 1 then NRC RG 1.145 plume meander model turned on
c       = 2 then 5th Power Law plume meander model turned on
c       = 3 then sector average model turned on
c iflow = 1 then sigmas adjusted for volume flow rate
c ientr = 1 then method of Pasquill used to account for entrainment
c irise = 1 then MACCS buoyant plume rise model turned on
c       = 2 then ISC2 momentum/buoyancy plume rise model turned on
c igrnd = 1 then Mills buoyant plume rise modification for ground effects
c iwash = 1 then stack downwash model turned on
c igrav = 1 then gravitational settling model turned on
c       = 0 unless specified otherwise, 0 turns model off
c
c PARAMETER INPUT:
c              reference                frequency
c  release     anemometer    mixing        to
c  height      height        height      exceed
c  hs(m)       ha(m)         hm(m)        Cx(%)
c  __________  __________  __________  __________
   0.00000E+00 1.00000E+01 1.00000E+03 5.00000E-01
c
c  initial     initial                         gravitational
c  plume       plume       release   deposition   settling
c  width       height      duration   velocity    velocity
```

```
c  Wb(m)        Hb(m)        trd(hr)      vd(m/s)      vg(m/s)
c  __________   __________   __________   __________   __________
   0.00000E+00  0.00000E+00  0.00000E+00  1.00000E-03  1.00000E-03
c
c               initial      initial                   convective
c  ambient      plume        plume        release      heat release
c  temperature  temperature  flow rate    diameter     rate(1)
c  Tamb(C)      T0(C)        V0(m3/s)     d(m)         qh(w)
c  __________   __________   __________   __________   __________
   2.00000E+01  2.20000E+01  1.00000E+00  1.00000E+00  0.00000E+00
c
c (1) If zero then buoyant flux based on plume/ambient temperature difference.
c
c  X/Q          Wind
c  scaling      Speed
c  factor       Exponent
c  c(?)         a(?)
c  __________   __________
   1.00000E+00  7.80000E-01
c
c RECEPTOR DEPENDENT DATA (no line limit)
c FOR MODE    make         RECEPTOR DEPENDENT DATA
c 1 (site specific)        sector distance receptor-height
c 2 (by class & wind speed) class windspeed distance offset receptor-height
c 3 (create plot file)     class windspeed xmax imax ymax jmax xqmin power
c
c RECEPTOR PARAMETER DESCRIPTION
c sector = 0, 1, 2... (all, S, SSW, etc.)
c distance = receptor distance (m)
c receptor height = height of receptor (m)
c class = 1, 2, 3, 4, 5, 6, 7 (P-G stability class A, B, C, D, E, F, G)
c windspeed = anemometer wind speed (m/s)
c offset = offset from plume centerline (m)
c xmax = maximum distance to plot or calculate to (m)
c imax = distance intervals
c ymax = maximum offset to plot (m)
c jmax = offset intervals
c xqmin = minimum scaled X/Q to calculate
c power = exponent in power function step size
0 100 0
```

4.8.3 GENII Input File

```
######################### Program GENII Input File ############ 8 Jul 88 ####
Title: PRTR Graphite Cask - 300 Area Onsite - Inhalation & Submersion
    \SAMPL\G-AIR.AC                    Created on 01-22-1990 at 07:30
OPTIONS=============================== Default
========================================
F   Near-field scenario?    (Far-field)   NEAR-FIELD: narrowly-focused
F   Population dose?        (Individual)          release, single site
T   Acute release?          (Chronic)     FAR-FIELD:  wide-scale release,
    Maximum Individual data set used              multiple sites
                   Complete                        Complete
TRANSPORT OPTIONS============ Section  EXPOSURE PATHWAY OPTIONS===== Section
T  Air Transport              1    F  Finite plume, external      5
F  Surface Water Transport     2    T  Infinite plume, external    5
F  Biotic Transport (near-field) 3,4  F  Ground, external           5
F  Waste Form Degradation (near) 3,4  F  Recreation, external       5
                                 T  Inhalation uptake          5,6
REPORT OPTIONS=======================   F  Drinking water ingestion     7,8
T  Report AEDE only              F  Aquatic foods ingestion      7,8
F  Report by radionuclide        F  Terrestrial foods ingestion  7,9
F  Report by exposure pathway      F  Animal product ingestion     7,10
F  Debug report on screen         F  Inadvertent soil ingestion

INVENTORY ###################################################################

 4  Inventory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 0  Surface soil source units (1- m2  2- m3  3- kg)
    Equilibrium question goes here

    --------|----Release Terms------|----------Basic Concentrations---------|
    Use when|  transport selected   |  near-field scenario, optionally      |
    --------|-----------------------|---------------------------------------|
    Release |      Surface Buried |     Surface Deep   Ground  Surface|
    Radio-  |Air    Water   Waste  |Air     Soil    Soil    Water   Water  |
    nuclide |/yr    /yr     /m3    |/m3     /unit   /m3     /L      /L     |
    --------|------- ------- -------|------- ------- ------- ------- -------|
    SR90    3.75E-01
    Y 90    3.75E-01
    FE59    5.00E-03
    PU239   1.09E-02
    --------|----Derived Concentrations-----|
    Use when|  measured values are known    |
    --------|-------------------------------|
    Release |Terres. Animal  Drink   Aquatic|
    Radio-  |Plant   Product Water   Food   |
    nuclide |/kg     /kg     /L      /kg    |
    --------|------- ------- ------- -------|

TIME ########################################################################

1   Intake ends after (yr)
50  Dose calc. ends after (yr)
1   Release ends after (yr)
0   No. of years of air deposition prior to the intake period
0   No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) ####################################

0        Definition option: 1-Use population grid in file POP.IN
0                           2-Use total entered on this line

NEAR-FIELD SCENARIOS ########################################################

         Prior to the beginning of the intake period: (yr)
0          When was the inventory disposed?  (Package degradation starts)
0          When was LOIC?  (Biotic transport starts)
0        Fraction of roots in upper soil (top 15 cm)
```

0 Fraction of roots in deep soil
0 Manual redistribution: deep soil/surface soil dilution factor
0 Source area for external dose modification factor (m2)

TRANSPORT ##

====AIR TRANSPORT===SECTION 1=====

```
        0-Calculate PM          |0    Release type (0-3)
3       Option: 1-Use chi/Q or PM value  |F   Stack release (T/F)
        2-Select MI dist & dir  |0    Stack height (m)
        3-Specify MI dist & dir |0    Stack flow (m3/sec)
1       Chi/Q or PM value       |0    Stack radius (m)
14      MI sector index (1=S)   |0    Effluent temp. (C)
100.    MI distance from release point (m)|0   Building x-section (m2)
T       Use jf data, (T/F) else chi/Q grid|0   Building height (m)
```

====SURFACE WATER TRANSPORT=================================SECTION 2=====

0 Mixing ratio model: 0-use value, 1-river, 2-lake
0 Mixing ratio, dimensionless
0 Average river flow rate for: MIXFLG=0 (m3/s), MIXFLG=1,2 (m/s),
0 Transit time to irrigation withdrawl location (hr)
If mixing ratio model > 0:
0 Rate of effluent discharge to receiving water body (m3/s)
0 Longshore distance from release point to usage location (m)
0 Offshore distance to the water intake (m)
0 Average water depth in surface water body (m)
0 Average river width (m), MIXFLG=1 only
0 Depth of effluent discharge point to surface water (m), lake only

====WASTE FORM AVAILABILITY=================================SECTION 3=====

0 Waste form/package half life, (yr)
0 Waste thickness, (m)
0 Depth of soil overburden, m

====BIOTIC TRANSPORT OF BURIED SOURCE================SECTION 4=====

```
T       Consider during inventory decay/buildup period (T/F)?
T       Consider during intake period (T/F)?  | 1-Arid non agricultural
0       Pre-Intake site condition..............| 2-Humid non agricultural
                                               | 3-Agricultural
```

EXPOSURE ##

====EXTERNAL EXPOSURE==================================SECTION 5=====

```
        Exposure time:               | Residential irrigation:
0         Plume (hr)                 | T    Consider: (T/F)
0         Soil contamination (hr)    | 0      Source: 1-ground water
0         Swimming (hr)              |               2-surface water
0         Boating (hr)               | 0    Application rate (in/yr)
0         Shoreline activities (hr)  | 0      Duration (mo/yr)
0       Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin)
0       Transit time for release to reach aquatic recreation (hr)
1.0     Average fraction of time submersed in acute cloud (hr/person hr)
```

====INHALATION==SECTION 6=====

```
8766.0  Hours of exposure to contamination per year
0       0-No resus-  1-Use Mass Loading         2-Use Anspaugh model
0         pension    Mass loading factor (g/m3)  Top soil available (cm)
```

====INGESTION POPULATION==================================SECTION 7=====

0 Atmospheric production definition (select option):
0 0-Use food-weighted chi/Q, (food-sec/m3), enter value on this line
1-Use population-weighted chi/Q
2-Use uniform production
3-Use chi/Q and production grids (PRODUCTION will be overridden)
0 Population ingesting aquatic foods, 0 defaults to total (person)

```
0        Population ingesting drinking water, 0 defaults to total (person)
F        Consider dose from food exported out of region (default=F)

         Note below: S* or Source: 0-none, 1-ground water, 2-surface water
                          3-Derived concentration entered above
         ==== AQUATIC FOODS / DRINKING WATER INGESTION=========SECTION 8====

F        Salt water? (default is fresh)

         USE      TRAN-  PROD-    -CONSUMPTION- |
         ?  FOOD   SIT    UCTION  HOLDUP  RATE |
         T/F TYPE  hr     kg/yr    da     kg/yr |    DRINKING WATER
         --- ------ ----- ------- ------ ----- |------------------------
         F  FISH    0.00  0.0E+00   0.00    0.0 | 0    Source (see above)
         F  MOLLUS  0.00  0.0E+00   0.00    0.0 | T    Treatment? T/F
         F  CRUSTA  0.00  0.0E+00   0.00    0.0 | 0    Holdup/transit(da)
         F  PLANTS  0.00  0.0E+00   0.00    0.0 | 0    Consumption (L/yr)

         ====TERRESTRIAL FOOD INGESTION========================SECTION 9=====

         USE     GROW  --IRRIGATION--        PROD-   --CONSUMPTION--
         ?  FOOD   TIME   S RATE  TIME   YIELD  UCTION  HOLDUP  RATE
         T/F TYPE  da     * in/yr  mo/yr  kg/m2  kg/yr    da     kg/yr
         --- ------ ----- - ----- -----  -----  ------- ------  ------
         F  LEAF V  0.00  0  0.0  0.0    0.0  0.0E+00    0.0     0.0
         F  ROOT V  0.00  0  0.0  0.0    0.0  0.0E+00    0.0     0.0
         F  FRUIT   0.00  0  0.0  0.0    0.0  0.0E+00    0.0     0.0
         F  GRAIN   0.00  0  0.0  0.0    0.0  0.0E+00    0.0     0.0

         ====ANIMAL PRODUCTION CONSUMPTION===================SECTION 10====

         ---HUMAN---- TOTAL  DRINK  ------------STORED FEED-------------
USE        CONSUMPTION PROD-  WATER  DIET  GROW  -IRRIGATION--     STOR-
?  FOOD    RATE HOLDUP UCTION CONTAM FRAC- TIME S RATE TIME  YIELD AGE
T/F TYPE  kg/yr  da    kg/yr  FRACT. TION  da  * in/yr mo/yr kg/m3 da
--- ------ ------ ----- ------ ------- ---- ---- - ----- ----- ----- -----
F  BEEF     0.0   0.0   0.00   0.00  0.00  0.0  0  0.0  0.00  0.00  0.0
F  POULTR   0.0   0.0   0.00   0.00  0.00  0.0  0  0.0  0.00  0.00  0.0
F  MILK     0.0   0.0   0.00   0.00  0.00  0.0  0  0.0  0.00  0.00  0.0
F  EGG      0.0   0.0   0.00   0.00  0.00  0.0  0  0.0  0.00  0.00  0.0
                              ------------FRESH FORAGE-----------
   BEEF                       0.00  0.0  0  0.0  0.00  0.00  0.0
   MILK                       0.00  0.0  0  0.0  0.00  0.00  0.0

##############################################################################
```

4.8.4 Checklist for Technical Peer Review

CHECKLIST FOR REVIEW

Document Reviewed: THI for the 327 Building Family of Casks

Scope of Review: entire document

Yes	No	NA		
[ ]	[ ]	[✓]	*	Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
[✓]	[ ]	[ ]		Problem completely defined.
[✓]	[ ]	[ ]		Accident scenarios developed in a clear and logical manner.
[✓]	[ ]	[ ]		Necessary assumptions explicitly stated and supported.
[✓]	[ ]	[ ]		Computer codes and data files documented.
[✓]	[ ]	[ ]		Data used in calculations explicitly stated in document.
[✓]	[ ]	[ ]		Data checked for consistency with original source information as applicable.
[✓]	[ ]	[ ]		Mathematical derivations checked including dimensional consistency of results.
[✓]	[ ]	[ ]		Models appropriate and used within range of validity or use outside range of established validity justified.
[✓]	[ ]	[ ]		Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
[✓]	[ ]	[ ]		Software input correct and consistent with document reviewed.
[✓]	[ ]	[ ]		Software output consistent with input and with results reported in document reviewed.
[✓]	[ ]	[ ]		Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
[✓]	[ ]	[ ]		Safety margins consistent with good engineering practices.
[✓]	[ ]	[ ]		Conclusions consistent with analytical results and applicable limits.
[✓]	[ ]	[ ]		Results and conclusions address all points required in the problem statement.
[✓]	[ ]	[ ]		Format consistent with appropriate NRC Regulatory Guide or other standards
[ ]		[✓]	*	Review calculations, comments, and/or notes are attached.
[✓]	[ ]	[ ]		Document approved.

J. G. McFadden — J G McFadden (signature) — 7/21/97

Reviewer (Printed Name and Signature) Date

* Any calculations, comments, or notes generated as part of this review should be signed, dated and attached to this checklist. Such material should be labeled and recorded in such a manner as to be intelligible to a technically qualified third party.

4.8.5 HEDOP Review Checklist

**HEDOP REVIEW CHECKLIST
for
Radiological and Nonradiological Release Calculations**

Document: Transportation Hazard Index (THI) Analysis for the 327 Building Casks SEPs," May 9, 1997.

Scope of Review: Inhalation/Air Submersion Dose Calculations

YES	NO*	N/A		
[x]	[ ]	[ ]	1.	A detailed technical review and approval of the environmental transport and dose calculation portion of the analysis has been performed and documented.
[ ]	[ ]	[x]	2.	Detailed technical review(s) and approval(s) of scenario and release determinations have been performed and documented.
[ ]	[x]	[ ]	3.	HEDOP-approved code(s) were used.
[x]	[ ]	[ ]	4.	Receptor locations were selected according to HEDOP recommendations.
[x]	[ ]	[ ]	5.	All applicable environmental pathways and code options were included and are appropriate for the calculations.
[x]	[ ]	[ ]	6.	Hanford site data were used.
[x]	[ ]	[ ]	7.	Model adjustments external to the computer program were justified and performed correctly.
[x]	[ ]	[ ]	8.	The analysis is consistent with HEDOP recommendations.
[x]		[ ]	9.	Supporting notes, calculations, comments, comment resolutions, or other information is attached. (Use the "Page 1 of X" page numbering format and sign and date each added page.)
[x]	[ ]		10.	Approval is granted on behalf of the Hanford Environmental Dose Overview Panel.

* All "NO" responses must be explained and use of nonstandard methods justified.

Kathy Rhoads *K Rhoads* 5/30/97

HEDOP-Approved Reviewer (Printed Name and Signature) Date

COMMENTS (add additional signed and dated pages if necessary):

Item 3: GXQ used for air transport calculations; GENII results are included for comparison.

5.0 SHIELDING EVALUATION

5.1 INTRODUCTION

This shielding evaluation supports the shipment of activated materials and fuel components in the PRTR Graphite Cask within the Hanford 300 Area.

5.2 DIRECT RADIATION SOURCE SPECIFICATION

The source term for the materials transported by the cask will be variable and, therefore, is described generally and evaluated on the basis of bounding conditions for gamma and neutron emissions. The source term evaluated for shielding is shown in Table B5-1. Isotopes other than those listed may be shipped in the cask, but the surface dose rate is limited to those shown in Part B, Section 5.4, in all cases.

Table B5-1. Maximum Allowable Shielding Source Term.

Material	Activity limit		Comments
	TBq	Ci	
Fissile materials and α emitters*	0.401	10.9	α-emitting materials, except for 175 g (10.85 Ci) ^{239}Pu, were not considered for shielding. The neutron dose rate from ^{239}Pu bounds the neutron dose rate for all other materials in this category.
Mixed fission products	13.9	375	Considered to be all ^{137}Cs for shielding
Mixed activation products	0.185	5.00	Considered to be all ^{60}Co for shielding

*Fissile/fissionable materials limited by criticality safety as shown in Part B, Section 2.1.1.

5.2.1 Gamma Source

The gamma source term evaluated is a mixed inventory of ^{60}Co and ^{137}Cs with an equilibrium amount of the ^{137}Cs daughter, ^{137m}Ba. Although the mixed inventory may have additional gamma sources, these are bounded by the ^{60}Co and ^{137}Cs terms and were not considered separately.

5.2.2 Beta Source

Beta particles originating in the source do not contribute directly to the dose rate outside the casks because of the shielding provided. Although the bremsstrahlung radiation produced by the deceleration of the beta particles in the source is a potential contribution to the source, the contribution is minimal and bounded by the gamma source term discussed in Part B, Section 5.1.2. For the isotopes evaluated, however, bremsstrahlung was considered.

5.2.3 Neutron Source

The neutron source term for the mixed materials inventory was calculated using the ORIGEN2 (Schmittroth 1994) computer code. The worst-case neutron source term was found to be from ^{239}Pu and was found to occur prior to any decay being considered. Although ^{235}U was considered, the neutron source term is negligible compared to ^{239}Pu. The source term is shown in Table B5-2, and the ORIGEN2 input file is included in Part B, Section 5.8.

Table B5-2. Neutron Source Term for 175g of ^{239}Pu

Component of source	Source strength (neutrons/s)
(α,n)	7.927 E+03
Spontaneous fission	3.967
Total	7.931 E+03

The cesium capsule inventory has no neutron emitters.

5.3 SUMMARY OF SHIELDING PROPERTIES OF MATERIALS

The shielding in the PRTR Graphite Cask is provided by lead encased in a stainless steel shell. The default densities for iron and lead provided in the ISO-PC (Rittmann 1995) computer code were used for shielding calculations.

5.4 NORMAL TRANSPORT CONDITIONS

5.4.1 Conditions To Be Evaluated

Gamma dose rates were evaluated at the surface of the cask (with an offset of 1.0 cm) and at 2.0 m (6.6 ft) from the cask surface. Neutron dose rates were estimated at the surface of the cask.

5.4.2 Acceptance Criteria

Transportation safety specifies a maximum of 2 mSv/h (200 mrem/h) on any surface of the cask, 0.1 mSv/h (10 mrem/h) at 2.0 m (6.6 ft) from the cask surface, and 0.02 mSv/h (2 mrem/h) in any normally occupied space. If these limits are exceeded, material will be removed from the cask.

5.4.3 Assumptions

The following assumptions were made and applied to the shielding model.

1. The steel in the closure mechanism tube was combined with the steel covering the outside of the mechanism to make a single inner shell and outer shell.

2. The air space in the closure mechanism was added to the distance to the detector.

3. The cask end opposite the closure contains a steel plunger mechanism that extends through the shielding (see drawing H-3-13699 [Part A, Section 10.1]). A cylindrical source with a diameter equivalent to the plunger mechanism and a length equivalent to the cask cavity was used to determine the dose outside the plunger. This dose was

added to the dose considered at the cask end, assuming a uniform steel and lead plug without the plunger. It is assumed that the cask is transported with the sample boat in place and that a steel rod fills the hole through the plunger mechanism.

4. The contents were assumed to be mainly iron pieces with a nominal density of 2.0 g/cm^3. This density was arrived at by considering that the cask is filled with uniformly distributed iron pieces with a density approximately one-fourth of the nominal iron density of 7.86 g/cm^3. Note that dose rates are more sensitive to material density than material type; therefore, this is a conservative approach that reduces the effects of self-shielding in the payload.

5. The mixed activation products were conservatively assumed to be all ^{60}Co.

6. The mixed fission products were conservatively assumed to be all ^{137}Cs.

7. Bremsstrahlung was only considered for isotopes evaluated; e.g., ^{137}Cs, and not for any other isotopes that may be present, such as ^{90}Sr.

5.4.4 Shielding Model

The shielding source term considered is shown in Tables B5-1 and B5-2. The source parameters are shown in Table B5-3, and the shielding parameters are shown in Table B5-4. The data for the shielding and source parameters were taken from drawing H-3-13699.

Table B5-3. Source Parameters.

Source	Diameter		Length		Volume (cm^3)
	cm	in.	cm	in.	
Overall (entire cask interior volume)	7.938	3.125	62.2	24.49	3082.300
Plunger only (part of source directly below plunger area)	3.334	1.3125	62.2	24.49	543.718

Table B5-4. Shielding Parameters.

Detector location	Steel inner wall thickness		Lead thickness		Steel outer wall thickness		Distance to surface detector (Including source thickness)	
	cm	in.	cm	in.	cm	in.	cm	in.
Side	0.318	0.125	12.860	5.063	0.635	0.250	17.781	7.001
Closure end	0.953	0.375	10.133	3.989	0.953	0.375	83.796	32.990
Plunger end	1.905	0.750	12.065	4.750	0.953	0.375	77.127	30.365
Plunger	Diameter		Length					
	cm	in.	cm	in.				
	3.334	1.3125	14.923	5.875				

The ISO-PC program (Rittmann 1995) was used for the gamma-ray dose rate calculations. ISO-PC uses the point-kernel integration method to compute the dose rate at a detector location. Bremsstrahlung photons are accounted for in the dose rate calculations. Fluence-to-dose conversion factors were based on an anterior-to-posterior irradiation pattern (ANS 1991).

The neutron dose rate was determined using a method discussed in *Estimation of Neutron Dose Rates from Nuclear Waste Packages* (Nelson 1996). This is a very conservative method that does not take shielding or moderation into account.

5.4.5 Shielding Calculations

Table B5-5 shows the gamma dose rate estimates calculated by ISO-PC for the mixed material inventory. The neutron dose rate calculations utilized data for α,n and spontaneous fission neutron production rates generated by ORIGEN. The neutron production rate information was then used in the dose rate calculation method described in *Estimation of Neutron Dose Rates from Nuclear Waste Packages* (Nelson 1996). The neutron dose rate was determined to be 0.0125 mSv/h (1.25 mrem/h) at the cask surface. The neutron dose rate falls of by a factor of $1/r^2$ and is negligible at 2.0 m (6.6 ft). The ISO-PC input file, the ORIGEN input file, and the neutron dose calculations are attached in Part B, Section 5.8.

Table B5-5. Maximum Dose Rates Around the Plutonium Recycle Test Reactor Graphite Cask.

Detector orientation	Detector location			
	Surface (1cm offset)		2 m	
	mSv/h	mrem/h	mSv/h	mrem/h
Side (gamma and neutron)	1.09	108.65	3.20 E-03	0.32
Closure end (gamma only)	1.87	187.00	3.20 E-03	0.32
Plunger end plus plunger (gamma only)	1.94	194.21	1.79 E-02	1.79
Criteria	2.00	200.00	1.00 E-01	10.00

5.5 ACCIDENT CONDITIONS

5.5.1 Conditions To Be Evaluated

A handling accident in which the source material was concentrated against the plunger end of the cask was considered.

5.5.2 Acceptance Criteria

The maximum dose rate at 1.0 m (3.3 ft) shall be less than 10 mSv/h (1,000 mrem/h).

5.5.3 Assumptions

The same assumptions as shown in Part B, Section 5.4.3, shall be used except that the source material will be concentrated in a cylinder that is the same diameter as the cask interior and 5.08 cm (2.0 in.) tall. The material density will be conservatively maintained as 2.0 g/cm^3.

5.5.4 Shielding Model

The shielding model shall be the same as used in Part B, Section 5.4.4, except that the source length will 5.08 cm (2.0 in.).

5.5.5 Shielding Calculations

Table B5-6 shows the gamma dose rate estimates for accident conditions as calculated by ISO-PC (Rittmann 1995). The neutron dose rate was not calculated as it is was already shown to be insignificant when compared to the gamma dose rate, even without shielding, in Part B, Section 5.4. The ISO-PC input file is attached in Part B, Section 5.8.

Table B5-6. Maximum Dose Rates Around the Plutonium Recycle Test Reactor Graphite Cask for Accident Conditions.

Detector orientation	Detector location (1 m)	
	mSv/h	mrem/h
Side	1.11 E-02	1.11
Closure end	2.50 E-02	2.50
Plunger end plus plunger	3.62 E-01	36.17

5.6 CONCLUSIONS

The gamma dose rates shown in Table B5-5 for the mixed materials inventory are within the NTC acceptance criteria for a surface dose rate of less than 2 mSv/h (200 mrem/h), 0.1 mSv/h (10 mrem/h) at 2.0 m (6.6 ft), and 0.02 mSv/h (2 mrem/h) at the driver's position, assuming the driver is no closer to the cask than 2.5 m. As shown in Table B5-6, the maximum allowed accident condition dose rate is also met for the conditions evaluated. The neutron dose rate of 0.0125 mSv/h (1.25 mrem/h) at the cask surface is inconsequential for the material inventory considered as it falls off by a factor of $1/r^2$ and is negligible in comparison to the gamma dose rate.

It should be noted that the shielding model is very conservative, assuming a contents density of 2.0 g/cm^3 that is evenly distributed in the cask volume and assuming that the activated materials inventory is all ^{60}Co. During use, the dose rates are measured prior to shipment in accordance with facility procedures. Particular attention must be paid to the plunger end of the cask due to the reduced shielding in this area. If the dose rate on any surface exceeds the NTC requirements, payload material will be removed in order to meet the dose rate limits.

5.7 REFERENCES

ANS, 1991, *Neutron and Gamma-Ray Fluence-to-Dose Factors,* ANSI/ANS-6.1.1-1991, American Nuclear Society, La Grange Park, Illinois.

Nelson, J. V., 1996, *Estimation of Neutron Dose Rates from Nuclear Waste Packages*, (internal memo 8M730-JVN-96-007 to J. R. Green, March 8), Westinghouse Hanford Company, Richland, Washington.

Rittmann, P. D., 1995, *ISO-PC Version 1.98 - User's Guide,* WHC-SD-WM-UM-030, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Schmittroth, F. A., 1994, *Conversion of ORIGEN2 to Sun Workstations*, WHC-SD-NR-SWD-00, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

5.8 APPENDICES

5.8.1 ISO-PC Input Files

```
0       2  PRTR Cask
 Case Side
&Input Next= 1, IPrnt=0, IGeom= 7, ICONC=0, SFACT=1,
 DUNIT=1,  NTheta= 30, NPsi= 30, NShld= 4, JBuf= 3, OPTION=0,
 Slth= 62.2,
 T(1)= 3.969,
 T(2)= 0.318,
 T(3)= 12.860,
 T(4)= 0.635,
 X= 18.782,
 Y= 31.1,
 WEIGHT(335) =  375.0 ,
 WEIGHT(336) =  354.75 ,
 WEIGHT(472) =  5.0, &
 Steel  9     2.0
 Steel  9            7.86
 Lead  14                       11.35
1Steel  9                                  7.86
Dose Rate at 2 m
&Input Next=4, X = 217.782, &
 Case Closure End
&Input Next= 1, IPrnt=0, IGeom= 9, ICONC=0, SFACT=1,
 DUNIT= 1, NTheta= 30, NPsi= 30, NShld= 4, JBuf= 3, OPTION=0,
 Slth= 3.969,
 T(1)= 62.2,
 T(2)= 0.953,
 T(3)= 10.133,
 T(4)= 0.953,
 X= 84.796,
 WEIGHT(335) =  375.0 ,
 WEIGHT(336) =  354.75 ,
 WEIGHT(472) =  5.0, &
 Steel  9    2.0
 Steel  9            7.86
 Lead  14                       11.35
1Steel  9                                  7.86
Dose Rate at 2 m
&Input Next=4, X = 283.796, &
 Case Plunger End
&Input Next= 1, IPrnt=0, IGeom= 9, ICONC=0, SFACT=1,
 DUNIT= 1, NTheta= 30, NPsi= 30, NShld= 4, JBuf= 3, OPTION=0,
 Slth= 3.969,
 T(1)= 62.2,
```

```
 T(2)= 1.905,
 T(3)= 12.065,
 T(4)= 0.953,
 X= 78.127,
 WEIGHT(335) = 375.0 ,
 WEIGHT(336) = 354.75 ,
 WEIGHT(472) = 5.0, &
 Steel 9 2.0
 Steel 9 7.86
 Lead 14 11.35
1Steel 9 7.86
Dose Rate at 2 m
&Input Next=4, X = 277.127, &
Estimate Driver Position (2 m)
&Input Next=4, X = 277.127, &
 Case Plunger
&Input Next= 1, IPrnt=0, IGeom= 9, ICONC=0, SFACT= 0.176,
 DUNIT= 1, NTheta= 30, NPsi= 30, NShld= 2, JBuf= 2, OPTION=0,
 Slth= 1.667,
 T(1)= 62.2,
 T(2)= 14.923,
 X= 78.123,
 WEIGHT(335) = 375.0 ,
 WEIGHT(336) = 354.75 ,
 WEIGHT(472) = 5.0, &
 Steel 9 2.0
1Steel 9 7.86
Dose Rate at 2 m
&Input Next=4, X = 277.123, &
Estimate Driver Position (2 m)
&Input Next=4, X = 277.123, &
 Case Side Accident
&Input Next= 1, IPrnt=0, IGeom= 7, ICONC=0, SFACT=1,
 DUNIT=1, NTheta= 30, NPsi= 30, NShld= 4, JBuf= 3, OPTION=0,
 Slth= 5.08,
 T(1)= 3.969,
 T(2)= 0.318,
 T(3)= 12.860,
 T(4)= 0.635,
 X= 118.782,
 Y= 31.1,
 WEIGHT(335) = 375.0 ,
 WEIGHT(336) = 354.75 ,
 WEIGHT(472) = 5.0, &
 Steel 9 2.0
 Steel 9 7.86
 Lead 14 11.35
1Steel 9 7.86
 Case Closure End Accident
&Input Next= 1, IPrnt=0, IGeom= 9, ICONC=0, SFACT=1,
 DUNIT= 1, NTheta= 30, NPsi= 30, NShld= 5, JBuf= 4, OPTION=0,
 Slth= 3.969,
 T(1)= 5.08,
 T(2)= 57.12,
 T(3)= 0.953,
 T(4)= 10.133,
 T(5)= 0.953,
 X= 184.796,
 WEIGHT(335) = 375.0 ,
 WEIGHT(336) = 354.75 ,
 WEIGHT(472) = 5.0, &
 Steel 9 2.0
 Air 3 0.00129
 Steel 9 7.86
 Lead 14 11.35
1Steel 9 7.86
 Case Plunger End Accident
&Input Next= 1, IPrnt=0, IGeom= 9, ICONC=0, SFACT=1,
 DUNIT= 1, NTheta= 30, NPsi= 30, NShld= 4, JBuf= 3, OPTION=0,
```

```
 Slth= 3.969,
 T(1)= 5.08,
 T(2)= 1.905,
 T(3)= 12.065,
 T(4)= 0.953,
 X= 121.003,
 WEIGHT(335) =  375.0 ,
 WEIGHT(336) =  354.75 ,
 WEIGHT(472) =  5.0, &
 Steel  9    2.0
 Steel  9          7.86
 Lead   14                  11.35
1Steel  9                           7.86
 Case Plunger Accident
&Input Next= 1, IPrnt=0, IGeom= 9, ICONC=0, SFACT= 0.176,
 DUNIT= 1, NTheta= 30, NPsi= 30, NShld= 2, JBuf= 2, OPTION=0,
 Slth= 1.667,
 T(1)= 5.08,
 T(2)= 14.923,
 X= 121.003,
 WEIGHT(335) =  375.0 ,
 WEIGHT(336) =  354.75 ,
 WEIGHT(472) =  5.0, &
 Steel  9   2.0
1Steel  9          7.86
End of Input
&Input Next= 6 &
```

5.8.2 ORIGEN Input File

```
-1
-1
-1
TIT    PU DECAY - 175 g Pu239/ 275 g U235 - Neutron Emission Calc
BAS     PLUTONIUM DECAY IN 5 YEAR INTERVALS
LIP    0 0 0
LIB    0 1 2 3 381 382 383 9 0 0 1 1
PHO     101 102 103 10
RDA     1 METRIC TON PLUTONIUM
INP    -1 1 -1 -1 1 1
RDA     DECAY FUEL
MOV     -1 1 0 1.00
RDA
DEC    50.0         1  2  4  0
DEC     1.0         2  3  5  0
DEC    10.0         3  4  5  0
DEC    20.0         4  5  5  0
DEC    30.0         5  6  5  0
DEC    40.0         6  7  5  0
DEC    50.0         7  8  5  0
DEC    60.0         8  9  5  0
DEC    70.0         9 10  5  0
DEC    80.0        10 11  5  0
RDA
CUT    5  1.E-10  7  1.E-10  9  1.E-10  -1
OPTL    24*8
OPTF    24*8
OPTA    4*8 7 7 7 8 7 8 14*8
OUT     11 1 -1 0
STP    4
2  942390  175.000 922350 275.00  0    0    0    0
0
END
```

5.8.3 Neutron Dose Calculations

The neutron dose rate was determined using the method described in *Estimation of Neutron Dose Rates from Nuclear Waste Packages* (Nelson 1996). In this method, the total neutron source term S(T), which accounts for neutron multiplication, is determined by adding the spontaneous fission source term (S(SF)) and the α,n source term (S(α,n)) and dividing by 1 minus the k_{eff}.

$$S(ST) = \frac{(S(SF) - S(\alpha,\ n))}{(1 - k_{eff})}$$

S(SF) and S(α,n) are determined either from Nelson (1996) or ORIGEN (see Part B, Section 5.8.2). After S(ST) is determined, it is used to determine the dose rate in the equation;

$$D(r) = \frac{0.01 \cdot S(ST)}{r^2}$$

where r is the distance from the source and D(r) is the dose in mrem/h as a function of r.

Therefore, the neutron dose for the PRTR Graphite Cask is estimated as follows. Using S(SF) and S(α,n) from ORIGEN and conservatively assuming a k_{eff} of 0.8 (Part B, Section 6.0), S(ST) is determined to be,

$$S(ST) = \frac{3.967 + 7.927 \times 10^3}{(1 - 0.8)} = 3.965 \times 10^4 \ n/s.$$

Assuming r to be 17.78 cm (the approximate surface of cask as measured radially), the total neutron dose rate is estimated to be,

$$D(r) = \frac{0.01 \cdot 3.965 \times 10^4}{17.78^2} = 1.25 \ mrem/h$$

5.8.4 Peer Review Checklist for Shielding

CHECKLIST FOR TECHNICAL PEER REVIEW

Document: Safety Evaluation for Packaging (Onsite) PRTR Cask, June 4, 1997, by John McCoy.

Scope: Shielding portion of the analysis.

Yes	No	NA	
[ ]	[ ]	[X]	Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
[X]	[ ]	[ ]	Problem completely defined.
[ ]	[ ]	[X]	Accident scenarios developed in a clear and logical manner.
[X]	[ ]	[ ]	Necessary assumptions explicitly stated and supported.
[X]	[ ]	[ ]	Computer codes and data files documented.
[X]	[ ]	[ ]	Data used in calculations explicitly stated in document.
[X]	[ ]	[ ]	Data checked for consistency with original source information as applicable.
[X]	[ ]	[ ]	Mathematical derivations checked including dimensional consistency of results.
[X]	[ ]	[ ]	Models appropriate and used within range of validity or use outside range of established validity justified.
[X]	[ ]	[ ]	Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
[X]	[ ]	[ ]	Software input correct and consistent with document reviewed.
[X]	[ ]	[ ]	Software output consistent with input and with results reported in document reviewed.
[X]	[ ]	[ ]	Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
[X]	[ ]	[ ]	Safety margins consistent with good engineering practices.
[X]	[ ]	[ ]	Conclusions consistent with analytical results and applicable limits.
[X]	[ ]	[ ]	Results and conclusions address all points required in the problem statement.
[X]	[ ]	[ ]	Format consistent with appropriate NRC Regulatory Guide or other standards
[ ]		[X]	Review calculations, comments, and/or notes are attached.
[X]	[ ]	[ ]	Document approved.

Anthony Savino *[signature]* 6/ 4/97

Reviewer (Printed Name and Signature) Date

6.0 CRITICALITY EVALUATION

The criticality analysis of the PRTR Graphite Cask was completed in *Limits for Fissionable Material in Small Bore Transfer Casks and Lead Pigs* (see Section 6.1). This analysis demonstrates that the PRTR Graphite Cask remains subcritical when loaded with 275 g or less of ^{235}U. The package is also subcritical when loaded with 175 g or less of ^{239}Pu, ^{233}U, ^{237}Np, ^{241}Am, ^{243}Am, ^{244}Cm, and ^{247}Cm. The following fissionable materials were not analyzed and cannot be shipped in excess of safeguards accountability limits: ^{242m}Am, ^{243}Cm, ^{245}Cm, ^{249}Cf, or ^{251}Cf.

6.1 APPENDIX: CRITICALITY SAFETY ANALYSIS

Battelle
Pacific Northwest Laboratories

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Date December 30, 1996

To M Dec

From SL Larson SL Larson

Subject <u>NCS Basis Memo 96-2. Limits for Fissionable Material in Small Bore Transfer Casks and Lead Pigs</u>

Reference 1: PNL Laboratory Safety, "Criticality Safety," PNL-MA-25, January 1994.

Reference 2: Oak Ridge National Laboratory, <u>SCALE 4.2 Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation</u>, v1-3, CCC-545, November 1993.

Reference 3: SL Larson, "A Systematic Approach to Establishing Criticality Biases," Proceedings of the International Conference on Nuclear Criticality 1995, Albuquerque, NM, September 17-21, 1995.

Reference 4: LE Hansen, ED Clayton, RC Lloyd, SR Bierman and RD Johnson, "Critical Parameters of Plutonium Solutions," Parts I and II, *Nuclear Applications*, <u>6</u> 371-390, 1969.

Reference 5: BM Durst, SR Bierman and ED Clayton, "Handbook of Critical Experiments Benchmarks," PNL-2700, March 1978.

Reference 6: RC Lloyd, CR Richey, ED Clayton, and DR Skeen, "Criticality Studies with Plutonium Solutions," *Nuclear Science and Engineering*, vol 25, pp 165-173, 1966.

Reference 7: NEA Nuclear Science Committee, <u>International Handbook of Evaluated Criticality Safety Benchmark Experiments</u>, Experiment HEU-MET-FAST-004, NEA/MSC/DOC(95)03/II, 1995.

Reference 8: SR Bierman, BM Durst and ED Clayton, "Critical Experiments with Subcritical Clusters of 2.35 wt% and 4.31 wt% ^{235}U Enriched UO_2 Rods in Water with Uranium or Lead Reflecting Walls," NUREG/CR-0796, vol 2, 1979.

This basis memo establishes the nuclear criticality safety limits for the loading, unloading, storage and on-site transportation of fissionable material in the following casks: the Large Bore Cask, the Long Bore Cask, the PRTR Graphite Cask and the One Ton Cask and any other lead shielded cask with a maximum inner volume of 5 liters. This memo validates the limits against the requirements of DOE Order 5480.24 issued 8/12/92 and ANSI/ANS-8.1-1983 [Reaffirmed 1988].

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Review of Methods Used Previously

The mass limits for water reflected fissionable material were previously used for the transfer casks. The casks were not specifically analyzed previously. However, calculations have shown that the lead used for shielding may be a better reflector than water thereby possibly reducing the minimum critical mass.

Validation of the Technical Bases per ANSI/ANS-8.1-1983 [1988] Requirements

An analysis was conducted per the requirements of ANSI/ANS-8.1-1983 [Reaffirmed 1988]. The results are as follows:

(1) Describe the method with sufficient detail, clarity, and lack of ambiguity to allow independent duplication of results.

The transfer casks analyzed in this memo have a small inner bore which limits the contents. Because a large number of fuel pins can not fit into the casks, a mass limit but not a pin limit was determined for the casks. Fuel pins and pieces can be transported and stored in the casks under the mass limit.

(1.1) Optimum Concentration Determination

The first step in analyzing the lead shielded casks was to determine the optimum concentration of an aqueous spherical solution of fissile material with a tight fitting spherical lead reflector. The mass of material modeled is equal to a double batch under the current water reflected limits for these materials. A lead reflector thickness of 8" was chosen because the casks have a comparable lead thickness. The results as given in Table 1 indicate that the optimum fissile concentrations with lead reflection are 32 g/l for ^{239}Pu and 55 g/l for ^{235}U. These values are comparable to the optimum water reflected concentrations found in previous work. A $K_{95/95}$ value was not calculated as these calculations are for comparison only. However, notice the systems are supercritical with a lead reflector although the mass is less than the minimum critical water reflected mass (530 g ^{239}Pu or 738 g ^{235}U). This point indicates that lead is a significantly better reflector than water for an aqueous solution system of ^{239}Pu or ^{235}U.

Table 1 Optimum Fissile Concentration with Lead Reflection

Case [a]	Fissile density (g/l)	KENO $k_{effective}$	KENO Uncertainty
^{239}Pu Scrap			
460 g sphere	27	1.05221	0.00114
460 g sphere	32	1.05610	0.00113
460 g sphere	37	1.05152	0.00113
460 g sphere	42	1.04596	0.00150

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Table 1 Optimum Fissile Concentration with Lead Reflection			
Case [a]	Fissile density (g/l)	KENO $k_{effective}$	KENO Uncertainty
^{235}U Scrap			
738 g sphere	45	1.04042	0.00123
738 g sphere	50	1.04452	0.00116
738 g sphere	**55**	**1.04661**	**0.00120**
738 g sphere	60	1.04492	0.00123
[a] Each case models a sphere of fissile material surrounded by an 8" tight fitting spherical lead reflector. Full water reflection was also modeled around the lead.			

(1.2) Large Bore, Long Bore, PRTR Graphite and One Ton Sample Cask Analyses

The four casks specifically analyzed were the Large Bore, the Long Bore, the PRTR Graphite and the One Ton Sample Casks. The casks were modeled using the KENO-Va code to ensure subcriticality of the water reflected mass limit for ^{235}U and ^{239}Pu in the cylindrical geometry of the casks during normal operations and in the event of a single loss of contingency. The inner diameter of the cask was increased in the KENO model by 0.4" to allow for tolerance and create a more optimum concentration of material in the cask. The interior length of the cask was modeled as 1" longer than the actual length for the same reasons. Lead has a large thermal scattering cross section and small thermal absorption cross section. Therefore, the lead thickness of the cask was also increased in the model to allow for tolerance as a thicker lead reflector is more reactive for thermal, optimally moderated system. The actual dimensions and the as modeled dimensions for each of the four casks modeled are given in Table 2.

Table 2 Cask Dimensions						
	Nominal Dimensions			Modeled Dimensions		
Cask	Inner Diameter	Inner Length	Lead Thickness	Inner Diameter	Inner Length	Lead Thickness
Large Bore	4"	26"	7.75"	4.4"	27"	8.34"
Long Bore	3"	39"	7.5"	3.4"	40"	8.09"
PRTR Graphite	3.25"	25"	5.375"	3.6"	26"	5.96"
One Ton Sample	3"	13.125"	6.5"	3.4"	14.25"	7.09"

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The casks were modeled with the fissionable material in a homogeneous water solution filling the bore. Full water reflection (≥12") was included around the lead shielding to model the most reactive reflection scenario possible. Three cases with different fissile masses and concentrations were modeled. The first case demonstrates subcriticality in the event the mass limit is exceeded while the latter two cases demonstrate that normal operations will have a reactivity less than the normal operations limit of 0.95. In the first case, the minimum critical mass of material, 820 g ^{235}U or 530 g ^{239}Pu, was modeled with the concentration of the material determined by the volume of the cask. In the second case, the cask was filled with the water reflected mass limit of material, 369 g ^{235}U or 230 g ^{239}Pu, with the concentration again determined by the volume of the cask. The final case modeled the material at the optimum concentration, 55 g/l for ^{235}U or 32 g/l for ^{239}Pu, with the mass of material determined by the volume of the cask. As shown in Table 3, each case was subcritical. Note the reactivity is too low in these cases to accurately determine a $K_{95/95}$ value. Because the statistical analysis of the code was performed on critical benchmarks, extrapolation to these low reactivities is not possible. However, these low reactivities indicate the systems are very subcritical with a $k_{effective}$ certainly less than 0.90.

Table 3 Water Moderated Scrap Limits in Small Bore Casks

Cask	Max Cask Diameter (in)	Fissile density (g/l)	Fissile mass (g)	Keno $k_{effective}$	Keno Uncertainty
		^{235}U Scrap			
Large Bore	4.4	122.2	820	0.78525	0.00137
	4.4	55	369	0.64529	0.00112
Long Bore	3.4	138.3	820	0.61548	0.00105
	3.4	62.3	369	0.49988	0.00104
	3.4	55	326	0.47577	0.00100
PRTR Graphite	3.6	184.6	820	0.66289	0.00127
	3.6	83.1	369	0.56227	0.00108
	3.6	55	244	0.49308	0.00098
One Ton Sample	3.4	391.7	820	0.60800	0.00122
	3.4	176.3	369	0.54668	0.00125
	3.4	55	115	0.39872	0.00094
		^{239}Pu Scrap			
Large Bore	4.4	79	530	0.78995	0.00130
	4.4	34.3	230	0.66425	0.00107
	4.4	32	215	0.64965	0.00119
Long Bore	3.4	89.4	530	0.62651	0.00117
	3.4	38.8	230	0.51776	0.00094
	3.4	32	190	0.48584	0.00088

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Table 3 Water Moderated Scrap Limits in Small Bore Casks					
Cask	Max Cask Diameter (in)	Fissile density (g/l)	Fissile mass (g)	Keno $k_{effective}$	Keno Uncertainty
PRTR Graphite	3.6	119.4	530	0.66219	0.00130
	3.6	51.8	230	0.57143	0.00114
	3.6	32	142	0.49819	0.00082
One Ton Sample	3.4	253.2	530	0.59768	0.00121
	3.4	110	230	0.54649	0.00113
	3.4	32	67	0.40650	0.00093
Benchmark Statistics					
Bias = 0.00032					
Standard Deviation = 0.01163					
Variance = 0.00014					

The lead thickness of the Large Bore Cask containing 230 g of ^{239}Pu, the most reactive case at the mass limit as given in Table 3, was increased by 4" to 28" to model a loss of reflection limit accident. This scenario could occur if lead bricks were stacked around the cask or two casks were placed side by side. As determined in Section 1.3, 28" of lead is considered critically infinite such that increasing the thickness would not increase reactivity. The $k_{effective}$ of the cask increased to 0.73001 ± 0.00111 which is clearly still subcritical.

Note the calculations shown here indicate the water reflected limits in use at the Laboratory are appropriate for these lead shielded casks. This fact does not, however, indicate that lead is a comparable reflector to water for thermal systems. In these cases, the geometry of the casks limits the mass and concentration such that optimum conditions can not be realized.

(1.3) Five Liter Cask Analysis

Instead of analyzing every small bore cask and lead transfer pig in use at the Laboratory, the maximum fissionable mass limit for a cask with an inner volume of 5 L and an infinite lead thickness was determined. The fissile material was modeled as a sphere surrounded by a tight fitting spherical lead reflector as this case is most reactive. A mass limit of 275 g ^{235}U or 175 g ^{239}Pu ensures the system will remain subcritical under all loss of contingency scenarios as given in Table 4. Note ^{235}U was not modeled with an increased volume as the normal condition results in an optimally moderated solution.

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Table 4 Maximum Allowable Volume with Full Lead Reflection

Case[b]	Cask Volume (l)	Fissile density (g/l)	Fissile mass (g)	Lead Thickness (in)	KENO $k_{effective}$	KENO Uncertainty	$K_{95/95}$
			²³⁹Pu Scrap				
Normal Conditions	5	35	175	28	0.84919	0.00100	0.873
Loss of Mass Limit	5	70	350	28	0.93479	0.00108	0.986
Loss of Reflector Limit	5	35	175	32	0.86916	0.00133	0.877
Loss of Volume Limit	7.47	32	175	28	0.88350	0.00108	0.880
			²³⁵U Scrap				
Normal Conditions	5	55	275	28	0.83077	0.00114	0.858
Loss of Mass Limit	5	110	550	28	0.96002	0.00140	0.987
Loss of Reflector Limit	5	55	275	32	0.83255	0.00117	0.859

[b] Each case models a sphere of fissile material surrounded by a tight fitting spherical lead reflector of the indicated thickness. Full water reflection is also modeled around the lead.

Benchmark Statistics
Bias = 0.00032
Standard Deviation = 0.01163
Variance = 0.00014

Therefore the mass limit for the Large Bore, the Long Bore, the One Ton Sample Cask and the PRTR Graphite Cask as well as any lead shielded cask with a maximum inner volume of 5 L is set at 275 g ^{235}U or 175 g ^{239}Pu to provide consistency between the casks. The scrap limit found for ^{239}Pu is applicable to all other fissionable materials with a minimum critical mass greater than that of ^{239}Pu as given in Table 6.5 of Reference 1. Fissionable material more reactive than ^{239}Pu, i.e., ^{242m}Am, ^{243}Cm, ^{245}Cm, ^{249}Cf, or ^{251}Cf have not been analyzed; however these materials are considered to be insignificant for the purposes of criticality safety provided the mass does not exceed the safeguards accountability limits. None of these restricted materials are currently accounted for at the Pacific Northwest National Laboratory; therefore violation of this limit is not credible. Sum of Fractions method (Ref. 1, Table 6.1) may be used to determine limit compliance for mixtures of fissionable material.

(1.4) Spacing Requirements

The minimum 12" edge-to-edge spacing requirement for batches of fissionable material is applicable to the transfer casks and lead pigs. Because the lead in the casks is not of an infinite thickness for criticality, material around the cask will affect the reactivity of the cask. However, the cask was proven to be subcritical with an infinite lead thickness in all directions. Therefore, the 12" edge-to-edge spacing requirement is in effect between the cask and other batches of

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fissionable material but no spacing requirements are needed between the cask and other reflectors.

(2) **State computer programs used, the options, the recipes for choosing mesh points where applicable, the cross section sets, and any numerical parameters necessary to describe the input.**

The SCALE 4.2 system of codes[2] was used to model the casks. The codes were executed on either a HP 755 with HP-UNIX version 9.03 or a HP 735 running HP-UNIX version 9.05. Code quality assurance documentation verifies the two operating systems give identical results. The NITAWL code was used to process cross-section data and KENO-Va was used to model the cask geometry and predict $k_{effective}$. The standard 27-group ENDF/B-IV cross-section library was used throughout. All calculations ran 120 generations with 5000 neutrons tracked per generation in KENO-Va. The first 20 generations were skipped when determining the standard deviation of the run. All input files containing geometry specification and material atom densities are included in Appendix A.

(3) **Identify experimental data and list parameters derived therefrom for use in the validation of the model.**

The results of the experimental benchmarks modeled with the SCALE 4.2 codes are shown in Table 5. These cases were chosen to represent the materials and geometries used in the cask calculations such that the code calculational scheme and cross section libraries are benchmarked. Therefore, ^{239}Pu solution and ^{235}U solution benchmarks are included in the set to represent the fissile solution and the lead wall benchmarks are included to represent the lead walls of the casks. The benchmark results define the code statistics used in the determination of the $K_{95/95}$ value for each run. Each benchmark case tracked 5000 neutrons per KENO generation for 120 generations with 20 generations skipped. The same scheme was employed in generating cross-sections sets and calculating $k_{effective}$ as was used to model the worst case geometries. All parameters required to model these benchmarks are described in the input files given in Appendix B and the references indicated in Table 5.

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Table 5 Experimental Benchmarks Modeled with SCALE 4.2

Description	Reference	KENO $k_{effective}$	KENO Uncertainty
$Pu(NO_3)_4$ Spheres with Spherical Reflectors			
24.4 g Pu/l sphere with full water reflection	4	1.01407	0.00111
26.3 g Pu/l with thin steel shell + full water	5	1.01064	0.00112
34.3 g Pu/l with thin steel shell	5	0.99318	0.00127
35.5 g Pu/l with 4" concrete shell	5	1.02249	0.00105
32.8 g Pu/l with 4" concrete shell	6	1.02516	0.00115
29.6 g Pu/l with 10" concrete shell	6	1.01282	0.00101
Concrete Reflected Arrays of 93.2 wt% Enriched Uranyl Nitrate			
4x4 Array with 67.28 gU/l Solution	7	1.01074	0.00112
2x2 Array with 76.09 gU/l Solution	7	1.00676	0.00116
4x4 Array with 360.37 gU/l Solution	7	1.01108	0.00132
4.31 wt% Enriched Optimum Moderated UO_2 Pins			
Square array with lead wall at 0"	8	1.00195	0.00103
Square array with lead wall at 0.26"	8	1.00430	0.00113
Square array with lead wall at 0.77"	8	1.00043	0.00111
Square array with lead wall at 2.13"	8	0.98598	0.00104
Square array without lead wall	8	0.98120	0.00101
4.31 wt% Enriched Undermoderated UO_2 Pins			
Square array with lead wall at 0"	8	1.00225	0.00105
Square array with lead wall at 0.26"	8	1.00165	0.00098
Square array with lead wall at 0.77"	8	0.99710	0.00106
Square array with lead wall at 2.13"	8	0.99544	0.00111
Square array without lead wall	8	0.99568	0.00105
2.35 wt% Enriched Optimum Moderated UO_2 Pins			
Square array with lead wall at 0"	8	0.99550	0.00083
Square array with lead wall at 0.26"	8	0.99414	0.00096
Square array with lead wall at 1.29"	8	0.99176	0.00084

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Table 5 Experimental Benchmarks Modeled with SCALE 4.2

Description	Reference	KENO $k_{effective}$	KENO Uncertainty
Square array without lead wall	8	0.98542	0.00086
2.35 wt% Enriched Undermoderated UO_2 Pins			
Square array with lead wall at 0"	8	0.99022	0.00093
Square array with lead wall at 0.26"	8	0.99414	0.00099
Square array with lead wall at 1.29"	8	0.99176	0.00099
Square array without lead wall	8	0.98365	0.00097
Benchmark Statistics			
Bias = 0.00032			
Standard Deviation = 0.01163			
Variance = 0.00014			

(4) State the area(s) of applicability.

The mass limits for fissionable materials applicable to the loading, unloading, storage and on-site transportation of specified fissionable material in the Large Bore, the Long Bore, the PRTR Graphite, the One Ton Sample or any cask with a maximum inner volume of 5 L are shown below.

275 g for ^{235}U,
175 g for ^{239}Pu, ^{233}U, ^{237}Np, ^{241}Am, ^{243}Am, ^{244}Cm, and ^{247}Cm,

The Sum of Fractions method defined in Table 6.1 in PNL-MA-25 may be used to determine compliance for mixtures of fissionable material. Fissionable material more reactive than ^{239}Pu, i.e., ^{242m}Am, ^{243}Cm, ^{245}Cm, ^{249}Cf, or ^{251}Cf have not been analyzed and thus are not allowed under these limits; however these materials are considered to be insignificant for the purposes of criticality safety provided the mass does not exceed the safeguards accountability limits. Pacific Northwest National Laboratory currently has none of these restricted materials in accountable quantities. These materials can only be obtained in accountable quantities as a source and thus could not be accidentally obtained. Therefore, violation of this restriction is not credible.

The 12" edge-to-edge spacing requirement is in effect between the cask and other fissionable material. Spacing requirements between the cask and other heavy metal reflectors are not necessary because the cask was proven to be subcritical with an infinite lead reflector.

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(5) **State the bias and the prescribed margin of subcriticality over the area(s) of applicability. State the basis for the margin.**

Calculational results indicate that the overall code bias based on benchmark calculations given in Table 5 calculated using KENO-Va tracking 5000 neutrons per generation is 0.3 mk. The mean of all benchmarks is 0.9997 and the standard deviation of the mean is 12 mk. If these values are applied to the modeled scenarios using the methodology given in Reference 3, the reactivity will not exceed 0.988 including experimental error and biases. The margin of subcriticality is therefore at least 12 mk and assumes optimum conditions and a loss of contingency error. The margin of subcriticality was calculated with a 95%/95% confidence.

Discussion of Loss of Contingencies

The Large Bore, Long Bore, PRTR Graphite and One Ton Sample Cask scenarios were modeled with tolerances on each of the geometric parameters of the casks. The direction of the tolerance was chosen to create a more reactive situation such as allowing a larger mass in the cask or allowing a more reactive concentration of material. In addition, the maximum cask volume limit is set based on a spherical geometry; most casks at the Laboratory have a cylindrical bore and thus will be less reactive. Therefore, the most reactive geometric models were considered.

A loss of mass contingency error would be caused by exceeding the mass limit in the cask. This scenario was examined by modeling the minimum water reflected critical mass (820 g ^{235}U and 530 g ^{239}Pu) in each of the casks. In all cases, the margin of subcriticality was greater than 100 mk. This accident scenario was also modeled in the 5 L lead cask. The result was a subcritical margin of 12 mk. Therefore, an accident where the mass limit is exceeded will not result in criticality.

An increase in the volume of the cask is not a credible accident for the Large Bore, the Long Bore, the PRTR Graphite and the One Ton Sample Casks as their geometry is known and documented and tolerances were added to the nominal dimensions when modeled. However, the use of the 5 L volume limit on a larger cask which does not meet this requirement is possible. Therefore, the spherical cask was modeled with the fissile material at the mass limit and at optimum concentration in an increased volume. These cases were subcritical with a margin of at least 100 mk.

An increase in the thickness of the lead shielding or stacking lead bricks around the cask will also not result in criticality. To ensure this, the 5 L cask and the Large Bore Cask were modeled at the mass limit with an critically infinite lead thickness of 28". The subcritical margin was greater than 100 mk in all cases.

Conclusions

The purpose of this memo was to provide the technical bases for the subcriticality of storage and handling of fissionable material scrap of various compositions in small bore transfer casks and lead pigs with lead shielding. The analyses assumed optimum water moderation of the fissionable material

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located inside the casks and demonstrated subcriticality during normal operations and following the loss of a single contingency including over batching, an increase in the reflector thickness (i.e. stacking lead bricks around the cask) and an increase in the cask volume (using the mass limit for a larger cask). These analyses bound all possible loss of contingency scenarios and ensure the double contingency principle is met. In conclusion, batch limits for the amount of scrap in the Large Bore, the Long Bore, the PRTR Graphite and the One Ton Sample Casks have been determined. The limit for ^{235}U as the only fissionable material is 275 g ^{235}U. The limit for other types of fissionable material except ^{242m}Am, ^{243}Cm, ^{245}Cm, ^{249}Cf, and ^{251}Cf is 175 g of fissionable material. These limits are also valid for lead shielded casks with a maximum inner volume of 5 liters and an unlimited lead thickness. The 12" edge-to-edge spacing requirement is in effect between the cask and other fissionable material but spacing requirements between the cask and other heavy metal reflectors are not necessary.

Concurrence: [signature] 30 Dec 96
Senior Specialist
Criticality Safety Analysis

Appendix A Input Files for Worst Case Scenarios

Input file for Optimum Pu Concentration Determination as given in Table 1

```
=nitawl
0$$   82              2           3           4          18
         19           9          15          20
1$$  500              8           0           0           0
          0           0           4           0           0
          0           0
t
2$$                94239      -23927      -23932      -23937
     -23942        82000        1001        8016
3**  23927           293           3     15.9625      0.0000
         0.0 6.8018E-05            1      1.0079  2.0024E+04
          1     15.9994   1.8179E+03           1           1
       23932         293           3     15.0836      0.0000
         0.0 8.0614E-05            1      1.0079  1.6691E+04
          1     15.9994   1.5335E+03           1           1
       23937         293           3     14.3710      0.0000
         0.0 9.3209E-05            1      1.0079  1.4605E+04
          1     15.9994   1.3259E+03           1           1
        23942        293           3     13.7765      0.0000
         0.0 1.0581E-04            1      1.0079  1.2863E+04
          1     15.9994   1.1678E+03           1       1.000
4**         f293
t
end
=kenova
460 g Pu Sphere at 27.0 g/l     6.3" Radius    8" Lead Refl + FWR
read param
tme=700      gen=120     nsk=20      lib=4        npg=5000
flx=yes      fdn=yes                 tba=60.0     nfb=8000
end param
'*******************
'* MIXTURES *
'*******************
read mixt    sct=1
mix=1
'Pu at 27.0 g/l
       23927  6.8018E-05
        8016  3.3383E-02
        1001  6.6765E-02
mix=2
'Lead
       82000  3.3133E-02
mix=3
'Water
        8016  3.3428E-02
        1001  6.6856E-02
end mixt
'*******************
'* GEOMETRY  *
'*******************
read geom
unit 1
com="Pu Sphere with Lead Shielding and FWR"
sphere       1  1               15.96
sphere       2  1               36.28
cuboid       3  1             6p66.28
end geom
end data
end
=kenova
460 g Pu Sphere at 32.0 g/l     5.9" Radius    8" Lead Refl + FWR
read param
tme=700      gen=120     nsk=20      lib=4        npg=5000
flx=yes      fdn=yes                 tba=60.0     nfb=6000
end param
'*******************
'* MIXTURES *
'*******************
read mixt    sct=1
mix=1
'Pu at 32.0 g/l
       23932  8.0614E-05
        8016  3.3374E-02
        1001  6.6748E-02
mix=2
'Lead
       82000  3.3133E-02
mix=3
'Water
        8016  3.3428E-02
        1001  6.6856E-02
end mixt
'*******************
'* GEOMETRY  *
'*******************
read geom
unit 1
com="Pu Sphere with Lead Shielding and FWR"
sphere       1  1               15.08
sphere       2  1               35.40
cuboid       3  1             6p65.40
end geom
end data
end
=kenova
460 g Pu Sphere at 37.0 g/l     5.7" Radius    8" Lead Refl + FWR
read param
tme=700      gen=120     nsk=20      lib=4        npg=5000
flx=yes      fdn=yes                 tba=60.0     nfb=8000
end param
'*******************
'* MIXTURES *
'*******************
read mixt    sct=1
mix=1
'Pu at 37.0 g/l
       23937  9.3209E-05
        8016  3.3366E-02
        1001  6.6731E-02
mix=2
'Lead
       82000  3.3133E-02
mix=3
'Water
        8016  3.3428E-02
        1001  6.6856E-02
end mixt
'*******************
'* GEOMETRY  *
'*******************
read geom
unit 1
com="Pu Sphere with Lead Shielding and FWR"
sphere       1  1               14.37
sphere       2  1               34.69
cuboid       3  1             6p64.69
end geom
end data
end
=kenova
460 g Pu Sphere at 42.0 g/l     5.4" Radius    8" Lead Refl + FWR
read param
tme=700      gen=120     nsk=20      lib=4        npg=5000
flx=yes      fdn=yes                 tba=60.0     nfb=8000
end param
'*******************
'* MIXTURES *
'*******************
read mixt    sct=1
mix=1
'Pu at 42.0 g/l
       23942  1.0581E-04
        8016  3.3357E-02
        1001  6.6714E-02
mix=2
'Lead
```

```
      82000  3.3133E-02
mix=3
'''~er
       8016  3.3428E-02
       1001  6.6856E-02
end mixt
'******************
'* GEOMETRY  *
'******************
read geom
unit 1
com="Pu Sphere with Lead Shielding and FWR"
sphere        1  1               13.78
sphere        2  1               34.10
cuboid        3  1            6p64.10
end geom
end data
end
```

Input file for Optimum ^{235}U Concentration Determination as given in Table 1

```
=nitawl
0$$   82            2           3          4          18
         19         9          15         20
1$$  500            8           0          0           0
          0         0           4          0           0
          0         0
t
2$$             92235      -23550     -23555      -23560
     -23545     82000        1001       8016
3**   23545       293           3    15.7610      0.0000
        0.0 1.1530E-04          1     1.0079  1.1801E+04
          1   15.9994  1.0714E+03          1       1.000
      23555       293           3    14.7412      0.0000
        0.0 1.4092E-04          1     1.0079  9.6503E+03
          1   15.9994  8.7610E+02          1       1.000
      23550       293           3    15.2171      0.0000
        0.0 1.2811E-04          1     1.0079  1.0618E+04
          1   15.9994  9.6396E+02          1           1
      23560       293           3    14.3198      0.0000
        0.0 1.5373E-04          1     1.0079  8.8438E+03
          1   15.9994  8.0288E+02          1       1.000
4**        f293
t
end
=kenova
738 g U235 Sphere at 45.0 g/l    6.2" Radius    8" Lead Refl + FWR
read param
tme=700      gen=120     nsk=20       lib=4        npg=5000
flx=yes      fdn=yes                  tba=60.0     nfb=8000
end param
'******************
'* MIXTURES *
'******************
read mixt    sct=1
mix=1
'U235 at 45.0 g/l
      23545  1.1530E-04
       8016  3.3348E-02
       1001  6.6697E-02
mix=2
'Lead
      82000  3.3133E-02
mix=3
'Water
       8016  3.3428E-02
       1001  6.6556E-02
    ixt
   ***************
'* GEOMETRY  *
'******************
read geom
unit 1
com="U235 Sphere with Lead Shielding and FWR"
sphere        1  1               15.76
sphere        2  1               36.08
cuboid        3  1            6p66.08
end geom
end data
end
=kenova
738 g U235 Sphere at 50.0 g/l    6.0" Radius    8" Lead Refl + FWR
read param
tme=700      gen=120     nsk=20       lib=4        npg=5000
flx=yes      fdn=yes                  tba=60.0     nfb=8000
end param
'******************
'* MIXTURES *
'******************
read mixt    sct=1
mix=1
'U235 at 50.0 g/l
      23550  1.2811E-04
       8016  3.3340E-02
       1001  6.6679E-02
mix=2
'Lead
      82000  3.3133E-02
mix=3
'Water
       8016  3.3428E-02
       1001  6.6856E-02
end mixt
'******************
'* GEOMETRY  *
'******************
read geom
unit 1
com="U235 Sphere with Lead Shielding and FWR"
sphere        1  1               15.22
sphere        2  1               35.54
cuboid        3  1            6p65.54
end geom
end data
end
=kenova
738 g U235 Sphere at 55.0 g/l    5.8" Radius    8" Lead Refl + FWR
read param
tme=700      gen=120     nsk=20       lib=4        npg=5000
flx=yes      fdn=yes                  tba=60.0     nfb=8000
end param
'******************
'* MIXTURES *
'******************
read mixt    sct=1
mix=1
'U235 at 55.0 g/l
      23555  1.4092E-04
       8016  3.3331E-02
       1001  6.6662E-02
mix=2
'Lead
      82000  3.3133E-02
mix=3
'Water
       8016  3.3428E-02
       1001  6.6856E-02
end mixt
'******************
'* GEOMETRY  *
'******************
read geom
unit 1
com="U235 Sphere with Lead Shielding and FWR"
sphere        1  1               14.74
sphere        2  1               35.06
cuboid        3  1            6p65.06
end geom
end data
end
```

```
=kenova
738 g U235 Sphere at 60.0 g/l    5.6" Radius   6" Lead Refl + FWR
read param
tme=700      gen=120     nsk=20      lib=4       npg=5000
flx=yes      fdn=yes                 tba=60.0    nfb=8000
end param
'*******************
'* MIXTURES *
'*******************
read mixt    sct=1
mix=1
'U235 at 60.0 g/l
      23560  1.5373E-04
       8016  3.3322E-02
       1001  6.6644E-02
mix=2
'Lead
      82000  3.3133E-02
mix=3
'Water
       8016  3.3428E-02
       1001  6.6856E-02
end mixt
'*******************
'* GEOMETRY  *
'*******************
read geom
unit 1
com="U235 Sphere with Lead Shielding and FWR"
sphere       1  1              14.32
sphere       2  1              34.64
cuboid       3  1           6p64.64
end geom
end data
end
```

Input File for ^{235}U Scrap in the Large Bore Cask as given in Table 3

```
=nitawl
0$$               82          2          3          4         18
                  19          9         15         20
1$$              500          7          0          0          0
                   0          0          3          0          0
                   0          0
t
2$$            92235     -35122      -3555      -3560
               82000       1001       8016
3**            35122        293          2     5.5799     0.0000
                 0.0 3.1335E-04          1     1.0079  4.3244E+03
                   1    15.9994 3.9259E+02          1      1.000
                3555        293          2     5.5799     0.0000
                 0.0 1.4097E-04          1     1.0079  9.6468E+03
                   1    15.9994 8.7578E+02          1          1
                3560        293          2     5.5799     0.0000
                 0.0 1.5373E-04          1     1.0079  8.8438E+03
                   1    15.9994 8.0286E+02          1          1
4**          f293
t
end
=kenova
820 g U235  Cylinder a 122.3 g/l in Large Bore Increase D
read param
tme=700     gen=120     nsk=20      lib=4      npg=5000    nfb=8000
flx=yes     fdn=yes     plt=yes     run=yes    tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt   sct=1
'Fuel
mix=1
     35122 3.1335E-04
      8016  3.3212E-02
      1001  6.6424E-02
'Lead
mix=2
     82000  3.3130E-02
'Water
mix=3
      8016  3.3428E-02
      1001  6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="U235    Cylinder    Large Bore  Cask"
cylinder    1  1         5.5799     68.5800     0.0000
cylinder    3  1         5.5800     68.5800     0.0000
            orig         0.0000     0.0001
cylinder    2  1         26.7650    95.4800    -26.9000
            orig         0.0000     0.0001
cylinder    3  1         56.7650    125.4800   -56.9000
            orig         0.0000     0.0001
end geom
end data
end
=kenova
369 g U235  Cylinder a 55.0 g/l in Large Bore Increase D
read param
tme=700     gen=120     nsk=20      lib=4      npg=5000    nfb=8000
flx=yes     fdn=yes     plt=yes     run=yes    tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt   sct=1
'Fuel
mix=1
      3555 1.4097E-04
      8016  3.3331E-02
      1001  6.6662E-02
'Lead
mix=2
     82000  3.3130E-02
'Water
mix=3
      8016  3.3428E-02
      1001  6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="U235    Cylinder    Large Bore  Cask"
cylinder    1  1         5.5799     68.5800     0.0000
cylinder    3  1         5.5800     68.5800     0.0000
            orig         0.0000     0.0001
cylinder    2  1         26.7650    95.4800    -26.9000
            orig         0.0000     0.0001
cylinder    3  1         56.7650    125.4800   -56.9000
            orig         0.0000     0.0001
end geom
end data
end
```

Input File for ^{235}U Scrap in the Long Bore Cask as given in Table 3

```
=nitawl
0$$               82          2          3          4         18
                  19          9         15         20
1$$              500          7          0          0          0
                   0          0          3          0          0
                   0          0
t
2$$            92235     -35138      -3562      -3555
               82000       1001       8016
3**            35138        293          2     4.3099     0.0000
                 0.0 3.5437E-04          1     1.0079  3.8206E-03
                   1    15.9994 3.4666E-02          1      1.000
```

```
         3562       293          2     4.3099     0.0000
          0.0 1.5962E-04         1     1.0079 8.5162E+03
            1    15.9994 7.7314E+02       1          1
         3555       293          2     4.3099     0.0000
          0.0 1.4092E-04         1     1.0079 9.6503E+03
            1    15.9994 8.7610E+02       1      1.000
4**       f293
t
end
=kenova
820 g U235  Cylinder a 138.3 g/l in Long Bore  Increase D
read param
tme=700    gen=120    nsk=20    lib=4    npg=5000    nfb=8000
flx=yes    fdn=yes    plt=yes   run=yes  tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt   sct=1
'Fuel
mix=1
     35138 3.5437E-04
      8016 3.3183E-02
      1001 6.6367E-02
'Lead
mix=2
     82000  3.3130E-02
'Water
mix=3
      8016  3.3428E-02
      1001  6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="U235   Cylinder    Long Bore    Cask"
cylinder    1  1       4.3099    101.6000    0.0000
cylinder    3  1       4.3100    101.6000    0.0000
            orig       0.0000      0.0001
cylinder    2  1      24.8600    129.2938   -27.6938
            orig       0.0000      0.0001
cylinder    3  1      54.8600    159.2938   -57.6938
            orig       0.0000      0.0001
end geom
end data
end
=kenova
369 g U235  Cylinder a 62.3 g/l in Long Bore  Increase D
read param
tme=700    gen=120    nsk=20    lib=4    npg=5000    nfb=8000
flx=yes    fdn=yes    plt=yes   run=yes  tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt   sct=1
'Fuel
mix=1
      3562 1.5962E-04
      8016  3.3316E-02
      1001  6.6636E-02
'Lead
mix=2
     82000  3.3130E-02
'Water

      8016  3.3428E-02
      1001  6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="U235   Cylinder    Long Bore    Cask"
cylinder    1  1       4.3099    101.6000    0.0000
cylinder    3  1       4.3100    101.6000    0.0000
            orig       0.0000      0.0001
cylinder    2  1      24.8600    129.2938   -27.6938
            orig       0.0000      0.0001
cylinder    3  1      54.8600    159.2938   -57.6938
            orig       0.0000      0.0001
end geom
end data
end
=kenova
326 g U235  Cylinder a 55.0 g/l in Long Bore  Increase D
read param
tme=700    gen=120    nsk=20    lib=4    npg=5000    nfb=8000
flx=yes    fdn=yes    plt=yes   run=yes  tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt   sct=1
'Fuel
mix=1
      3555 1.4092E-04
      8016  3.3331E-02
      1001  6.6662E-02
'Lead
mix=2
     82000  3.3130E-02
'Water
mix=3
      8016  3.3428E-02
      1001  6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="U235   Cylinder    Long Bore    Cask"
cylinder    1  1       4.3099    101.5999    0.0000
cylinder    3  1       4.3100    101.6000    0.0000
            orig       0.0000      0.0001
cylinder    2  1      24.8600    129.2938   -27.6938
            orig       0.0000      0.0001
cylinder    3  1      54.8600    159.2938   -57.6938
            orig       0.0000      0.0001
end geom
end data
end
```

Input File for ^{235}U Scrap in the PRTR Graphite Cask as given in Table 3

```
=nitawl
0$$          82         2         3         4        18
             19         9        15        20
1$$         500         7         0         0         0
              0         0         3         0         0
              0         0
t
2$$       92235    -35185     -3583     -3555
          82000      1001      8016
3**       35195       293         2    4.6274    0.0000
            0.0 4.7297E-04        1    1.0079 2.8555E+03
              1   15.9994 2.5923E+02       1     1.000
           3583       293         2    4.6274    0.0000
            0.0 2.1291E-04        1    1.0079 6.3776E+03
              1   15.9994 5.7898E+02       1         1
           3555       293         2    4.6274    0.0000
            0.0 1.4092E-04        1    1.0079 9.6503E+03
              1   15.9994 8.7610E+02       1     1.000
4**       f293
t
end
```

```
=kenova
820 g U235  Cylinder a 184.6 g/l i PRTR Graph Increase D
read param
tme=700     gen=120    nsk=20     lib=4      npg=5000   nfb=8000
flx=yes     fdn=yes    plt=yes    run=yes    tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt   sct=1
'Fuel
mix=1
      35185 4.7297E-04
       8016 3.3102E-02
       1001 6.6203E-02
'Lead
mix=2
      82000 3.3130E-02
'Water
mix=3
       8016 3.3428E-02
       1001 6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="U235   Cylinder   PRTR Graphi Cask"
cylinder    1 1        4.6274     66.0400    0.0000
cylinder    3 1        4.6275     66.0400    0.0000
            orig       0.0000     0.0001
cylinder    2 1        19.7800    84.0500    -18.0100
            orig       0.0000     0.0001
cylinder    3 1        49.7800    114.0500   -48.0100
            orig       0.0000     0.0001
end geom
end data
end
=kenova
369 g U235  Cylinder a 83.1 g/l in PRTR Graph Increase D
read param
tme=700     gen=120    nsk=20     lib=4      npg=5000   nfb=8000
flx=yes     fdn=yes    plt=yes    run=yes    tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt   sct=1
'Fuel
mix=1
       3583 2.1291E-04
       8016 3.3281E-02
       1001 6.6562E-02
'Lead
mix=2
      82000 3.3130E-02
'Water
mix=3
       8016 3.3428E-02
       1001 6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="U235   Cylinder   PRTR Graphi Cask"
cylinder    1 1        4.6274     66.0400    0.0000
cylinder    3 1        4.6275     66.0400    0.0000
            orig       0.0000     0.0001
cylinder    2 1        19.7800    84.0500    -18.0100
            orig       0.0000     0.0001
cylinder    3 1        49.7800    114.0500   -48.0100
            orig       0.0000     0.0001
end geom
end data
end
=kenova
244 g U235  Cylinder a 55.0 g/l in PRTR Graph Increase D
read param
tme=700     gen=120    nsk=20     lib=4      npg=5000   nfb=8000
flx=yes     fdn=yes    plt=yes    run=yes    tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt   sct=1
'Fuel
mix=1
       3555 1.4092E-04
       8016 3.3331E-02
       1001 6.6662E-02
'Lead
mix=2
      82000 3.3130E-02
'Water
mix=3
       8016 3.3428E-02
       1001 6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="U235   Cylinder   PRTR Graphi Cask"
cylinder    1 1        4.6274     66.0399    0.0000
cylinder    3 1        4.6275     66.0400    0.0000
            orig       0.0000     0.0001
cylinder    2 1        19.7800    84.0500    -18.0100
            orig       0.0000     0.0001
cylinder    3 1        49.7800    114.0500   -48.0100
            orig       0.0000     0.0001
end geom
end data
end
```

Input File for ^{235}U Scrap in the One Ton Sample Cask as given in Table 3

```
=nitawl
0$$             82          2          3          4         18
                19          9         15         20
1$$            500          7          0          0          0
                 0          0          3          0          0
                 0          0
t
2$$          92235     -35392     -35176      -3555
             82000       1001       8016
3**          35392        293          2     4.3099     0.0000
               0.0 1.0036E-03          1     1.0079 1.3308E+03
                 1    15.9994 1.2082E+02          1      1.000
             35176        293          2     4.3099     0.0000
               0.0 4.5170E-04          1     1.0079 2.9912E+03
                 1    15.9994 2.7156E+02          1          1
              3555        293          2     4.3099     0.0000
               0.0 1.4092E-04          1     1.0079 9.6503E+03
                 1    15.9994 8.7610E+02          1      1.000
4**        f293
t
end
=kenova
820 g U235  Cylinder a 391.7 g/l in One Ton    Increase D
read param
tme=700     gen=120    nsk=20     lib=4      npg=5000   nfb=8000
fix=yes     fdn=yes    plt=yes    run=yes    tba=60.0
end param
'**********
'* MIXTURES
'**********
```

```
read mixt   sct=1
'Fuel
mix=1
      35392 1.0036E-03
       8016  3.2735E-02
       1001  6.5471E-02
'Lead
mix=2
     82000  3.3130E-02
'Water
mix=3
       8016  3.3428E-02
       1001  6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="U235    Cylinder    One Ton     Cask"
cylinder     1  1          4.3099     35.8775     0.0000
cylinder     3  1          4.3100     35.8775     0.0000
             orig          0.0000      0.0001
cylinder     2  1         22.3200     57.2213   -21.3438
             orig          0.0000      0.0001
cylinder     3  1         52.3200     87.2213   -51.3438
             orig          0.0000      0.0001
end geom
end data
end
=kenova
369 g U235  Cylinder a 176.3 g/l in One Ton    Increase D
read param
tme=700      gen=120     nsk=20      lib=4       npg=5000    nfb=8000
flx=yes      fdn=yes     plt=yes     run=yes     tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt   sct=1
'Fuel
mix=1
      35176 4.5170E-04
       8016  3.3116E-02
       1001  6.6233E-02
'Lead
mix=2
     82000  3.3130E-02
'Water
mix=3
       8016  3.3428E-02
       1001  6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="U235    Cylinder    One Ton     Cask"
cylinder     1  1          4.3099     35.8775     0.0000
cylinder     3  1          4.3100     35.8775     0.0000
             orig          0.0000      0.0001
cylinder     2  1         22.3200     57.2213   -21.3438
             orig          0.0000      0.0001
cylinder     3  1         52.3200     87.2213   -51.3438
             orig          0.0000      0.0001
end geom
end data
end
=kenova
115 g U235  Cylinder a 55.0 g/l in One Ton    Increase D
read param
tme=700      gen=120     nsk=20      lib=4       npg=5000    nfb=8000
fix=yes      fdn=yes     plt=yes     run=yes     tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt   sct=1
'Fuel
mix=1
       3555 1.4092E-04
       8016  3.3331E-02
       1001  6.6662E-02
'Lead
mix=2
     82000  3.3130E-02
'Water
mix=3
       8016  3.3428E-02
       1001  6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="U235    Cylinder    One Ton     Cask"
cylinder     1  1          4.3099     35.8771     0.0000
cylinder     3  1          4.3100     35.8775     0.0000
             orig          0.0000      0.0001
cylinder     2  1         22.3200     57.2213   -21.3438
             orig          0.0000      0.0001
cylinder     3  1         52.3200     87.2213   -51.3438
             orig          0.0000      0.0001
end geom
end data
end
```

Input File for ^{239}Pu Scrap in the Large Bore Cask as given in Table 3

```
=nitawl
0$$              82           2           3           4          18
                 19           9          15          20
1$$             500           7           0           0           0
                  0           0           3           0           0
                  0           0
t
2$$           94239       -3979       -3934       -3932
              82000        1001        8016
3**            3979         293           2      5.5799      0.0000
                0.0  1.9904E-04           1      1.0079  6.8249E+03
                  1     15.9994  6.1959E+02           1           1
               3934         293           2      5.5799      0.0000
                0.0  8.6408E-05           1      1.0079  1.5757E+04
                  1     15.9994  1.4305E+03           1           1
               3932         293           2      5.5799      0.0000
                0.0  8.0614E-05           1      1.0079  1.6891E+04
                  1     15.9994  1.5335E+03           1           1
4**          f293
t
end
=kenova
530 g Pu     Cylinder a 79.0 g/l in Large Bore Increase D
read param
tme=700      gen=120     nsk=20      lib=4       npg=5000    nfb=8000
flx=yes      fdn=yes     plt=yes     run=yes     tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt   sct=1
'Fuel
mix=1
       3979 1.9904E-04
       8016  3.3295E-02
       1001  6.6589E-02
'Lead
mix=2
      82000  3.3130E-02
'Water
```

```
mix=3
     8016  3.3428E-02
     1001  6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="Pu      Cylinder    Large Bore  Cask"
cylinder  1  1        5.5799     68.5800    0.0000
cylinder  3  1        5.5800     68.5800    0.0000
          orig        0.0000      0.0001
cylinder  2  1       26.7650     95.4800  -26.9000
          orig        0.0000      0.0001
cylinder  3  1       56.7650    125.4800  -56.9000
          orig        0.0000      0.0001
end geom
end data
end
=kenova
230 g Pu   Cylinder a 34.3 g/l in Large Bore Increase D
read param
tme=700    gen=120    nsk=20     lib=4     npg=5000    nfb=8000
flx=yes    fdn=yes    plt=yes    run=yes   tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt   sct=1
'Fuel
mix=1
     3934 8.6408E-05
     8016  3.3370E-02
     1001  6.6740E-02
'Lead
mix=2
    82000  3.3130E-02
'Water
mix=3
     8016  3.3428E-02
     1001  6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="Pu      Cylinder    Large Bore  Cask"
cylinder  1  1        5.5799     68.5800    0.0000
cylinder  3  1        5.5800     68.5800    0.0000
          orig        0.0000      0.0001
cylinder  2  1       26.7650     95.4800  -26.9000
          orig        0.0000      0.0001
cylinder  3  1       56.7650    125.4800  -56.9000
          orig        0.0000      0.0001
end geom
end data
end
=kenova
215 g Pu   Cylinder a 32.0 g/l in Large Bore Increase D
read param
tme=700    gen=120    nsk=20     lib=4     npg=5000    nfb=8000
flx=yes    fdn=yes    plt=yes    run=yes   tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt   sct=1
'Fuel
mix=1
     3932 8.0614E-05
     8016  3.3374E-02
     1001  6.6748E-02
'Lead
mix=2
    82000  3.3130E-02
'Water
mix=3
     8016  3.3428E-02
     1001  6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="Pu      Cylinder    Large Bore  Cask"
cylinder  1  1        5.5799     68.5800    0.0000
cylinder  3  1        5.5800     68.5800    0.0000
          orig        0.0000      0.0001
cylinder  2  1       26.7650     95.4800  -26.9000
          orig        0.0000      0.0001
cylinder  3  1       56.7650    125.4800  -56.9000
          orig        0.0000      0.0001
end geom
end data
end
```

Input File for ^{239}Pu Scrap in the Long Bore Cask as given in Table 3

```
=nitawl
0$$              82          2          3          4          18
                 19          9         15         20
1$$             500          7          0          0           0
                  0          0          3          0           0
                  0          0
t
2$$           94239      -3989      -3939      -3932
              82000       1001       8016
3**            3989        293          2     4.3099      0.0000
                0.0 2.2521E-04          1     1.0079  6.0285E+0[illegible]
                  1    15.9994 5.4730E+02          1           1
               3939        293          2     4.3099      0.0000
                0.0 9.7744E-05          1     1.0079  1.3926E+04
                  1    15.9994 1.2643E+03          1           1
               3932        293          2     4.3099      0.0000
                0.0 8.0614E-05          1     1.0079  1.6891E+04
                  1    15.9994 1.5335E+03          1           1
4**        f293
t
end
=kenova
530 g Pu   Cylinder a 89.4 g/l in Long Bore  Increase D
read param
tme=700    gen=120    nsk=20     lib=4     npg=5000    nfb=8000
flx=yes    fdn=yes    plt=yes    run=yes   tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt   sct=1
'Fuel
mix=1
     3989 2.2521E-04
     8016  3.3277E-02
     1001  6.6554E-02
'Lead
mix=2
    82000  3.3130E-02
'Water
mix=3
     8016  3.3428E-02
     1001  6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="Pu      Cylinder    Long Bore   Cask"
```

```
cylinder    1  1        4.3099     101.6000     0.0000
cylinder    3  1        4.3100     101.6000     0.0000
            orig        0.0000       0.0001
cylinder    2  1        24.8600    129.2938    -27.6938
            orig        0.0000       0.0001
cylinder    3  1        54.86      159.2938    -57.6938
            orig        0.0000       0.0001
end geom
end data
end
=kenova
230 g Pu    Cylinder a 38.8 g/l in Long Bore  Increase D
read param
tme=700     gen=120     nsk=20      lib=4       npg=5000    nfb=8000
flx=yes     fdn=yes     plt=yes     run=yes     tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt   sct=1
'Fuel
mix=1
      3939 9.7744E-05
      8016  3.3363E-02
      1001  6.6725E-02
'Lead
mix=2
     82000  3.3130E-02
'Water
mix=3
      8016  3.3428E-02
      1001  6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="Pu     Cylinder    Long Bore   Cask"
cylinder    1  1        4.3099     101.6000     0.0000
cylinder    3  1        4.3100     101.6000     0.0000
            orig        0.0000       0.0001
cylinder    2  1        24.8600    129.2938    -27.6938
            orig        0.0000       0.0001
cylinder    3  1        54.86      159.2938    -57.6938
            orig        0.0000       0.0001
end geom
end data
end
=kenova
190 g Pu    Cylinder a 32.0 g/l in Long Bore  Increase D
read param
tme=700     gen=120     nsk=20      lib=4       npg=5000    nfb=8000
flx=yes     fdn=yes     plt=yes     run=yes     tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt   sct=1
'Fuel
mix=1
      3932 8.0614E-05
      8016  3.3374E-02
      1001  6.6748E-02
'Lead
mix=2
     82000  3.3130E-02
[illegible]
      8016  3.3428E-02
      1001  6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
```

```
read geom
unit 1
com="Pu     Cylinder    Long Bore   Cask"
cylinder    1  1        4.3099     101.6000     0.0000
cylinder    3  1        4.3100     101.6000     0.0000
            orig        0.0000       0.0001
cylinder    2  1        24.8600    129.2938    -27.6938
            orig        0.0000       0.0001
cylinder    3  1        54.86      159.2938    -57.6938
            orig        0.0000       0.0001
end geom
end data
end
```

Input File for 239Pu Scrap in the PRTR Graphite Cask as given in Table 3

```
=nitawl
0$$               82           2           3           4          18
                  19           9          15          20
1$$              500           7           0           0           0
                   0           0           3           0           0
                   0           0
t
2$$            94239      -39119       -3952       -3932
               82000        1001        8016
3**            39119         293           2      4.6274      0.0000
                 0.0  3.0079E-04           1      1.0079  4.5069E+03
                   1     15.9994  4.0916E+02           1           1
                3952         293           2      4.6274      0.0000
                 0.0  1.3049E-04           1      1.0079  1.0424E+04
                   1     15.9994  9.4636E+02           1           1
                3932         293           2      4.6274      0.0000
                 0.0  8.0614E-05           1      1.0079  1.6891E+04
                   1     15.9994  1.5335E+03           1           1
4**         f293
t
end
=kenova
530 g Pu    Cylinder a 119.4 g/l i PRTR Graph Increase D
read param
tme=700     gen=120     nsk=20      lib=4       npg=5000    nfb=8000
flx=yes     fdn=yes     plt=yes     run=yes     tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt   sct=1
'Fuel
mix=1
     39119 3.0079E-04
      8016  3.3227E-02
      1001  6.6453E-02
'Lead
mix=2
     82000  3.3130E-02
'Water
mix=3
      8016  3.3428E-02
      1001  6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="Pu     Cylinder    PRTR Graphi Cask"
cylinder    1  1        4.6274      66.0400     0.0000
cylinder    3  1        4.6275      66.0400     0.0000
            orig        0.0000       0.0001
cylinder    2  1        19.7800     84.0500    -18.0100
            orig        0.0000       0.0001
cylinder    3  1        49.7800    114.0500    -48.0100
            orig        0.0000       0.0001
end geom
end data
```

```
end
=kenova
230 g Pu     Cylinder a 51.8 g/l in PRTR Graph Increase D
read param
tme=700      gen=120     nsk=20      lib=4       npg=5000    nfb=8000
flx=yes      fdn=yes     plt=yes     run=yes     tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt    sct=1
'Fuel
mix=1
      3952 1.3049E-04
      8016  3.3341E-02
      1001  6.6681E-02
'Lead
mix=2
     82000  3.3130E-02
'Water
mix=3
      8016  3.3428E-02
      1001  6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="Pu      Cylinder     PRTR Graphi Cask"
cylinder     1  1         4.6274     66.0400     0.0000
cylinder     3  1         4.6275     66.0400     0.0000
             orig         0.0000      0.0001
cylinder     2  1        19.7800     84.0500   -18.0100
             orig         0.0000      0.0001
cylinder     3  1        49.7800    114.0500   -48.0100
             orig         0.0000      0.0001
end geom
end data
end
=kenova
142 g Pu     Cylinder a 32.0 g/l in PRTR Graph Increase D
read param
tme=700      gen=120     nsk=20      lib=4       npg=5000    nfb=8000
flx=yes      fdn=yes     plt=yes     run=yes     tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt    sct=1
'Fuel
mix=1
      3932 8.0614E-05
      8016  3.3374E-02
      1001  6.6748E-02
'Lead
mix=2
     82000  3.3130E-02
'Water
mix=3
      8016  3.3428E-02
      1001  6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="Pu      Cylinder     PRTR Graphi Cask"
cylinder     1  1         4.6274     66.0400     0.0000
cylinder     3  1         4.6275     66.0400     0.0000
             orig         0.0000      0.0001
cylinder     2  1        19.7800     84.0500   -18.0100
             orig         0.0000      0.0001
cylinder     3  1        49.7800    114.0500   -48.0100
```

```
             orig           0.0000      0.0001
end geom
end data
end
```

Input File for 239Pu Scrap in the One Ton Sample Cask as given in Table 3

```
=nitawl
0$$             82          2          3          4         18
                19          9         15         20
1$$            500          7          0          0          0
                 0          0          3          0          0
                 0          0
t
2$$          94239     -39253     -39110      -3932
             82000       1001       8016
3**          39253        293          2     4.3099     0.0000
               0.0 6.3785E-04          1     1.0079 2.1109E+03
                 1    15.9994 1.9163E+02          1          1
             39110        293          2     4.3099     0.0000
               0.0 2.7711E-04          1     1.0079 4.8944E+03
                 1    15.9994 4.4434E+02          1          1
              3932        293          2     4.3099     0.0000
               0.0 8.0614E-05          1     1.0079 1.6891E+04
                 1    15.9994 1.5335E+03          1          1
4**          f293
t
end
=kenova
530 g Pu     Cylinder a 253.2 g/l i One Ton     Increase D
read param
tme=700      gen=120     nsk=20      lib=4       npg=5000    nfb=8000
flx=yes      fdn=yes     plt=yes     run=yes     tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt    sct=1
'Fuel
mix=1
     39253 6.3785E-04
      8016 3.3001E-02
      1001 6.6001E-02
'Lead
mix=2
     82000  3.3130E-02
'Water
mix=3
      8016 3.3428E-02
      1001 6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="Pu      Cylinder   One Ton     Cask"
cylinder     1  1         4.3099     35.8775     0.0000
cylinder     3  1         4.3100     35.8775     0.0000
             orig         0.0000      0.0001
cylinder     2  1        22.3200     57.2213   -21.3438
             orig         0.0000      0.0001
cylinder     3  1        52.320      87.2213   -51.3438
             orig         0.0000      0.0001
end geom
end data
end
=kenova
230 g Pu     Cylinder a 110.0 g/l i One Ton     Increase D
read param
tme=700      gen=120     nsk=20      lib=4       npg=5000    nfb=5000
flx=yes      fdn=yes     plt=yes     run=yes     tba=60.0
end param
'**********
'* MIXTURES
```

```
'**********
read mixt   sct=1

     39110 2.7711E-04
      8016 3.3242E-02
      1001 6.6485E-02
'Lead
mix=2
     82000  3.3130E-02
'Water
mix=3
      8016  3.3428E-02
      1001  6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="Pu    Cylinder   One Ton     Cask"
cylinder   1  1        4.3099      35.8775     0.0000
cylinder   3  1        4.3100      35.8775     0.0000
           orig        0.0000      0.0001
cylinder   2  1       22.3200      57.2213   -21.3438
           orig        0.0000      0.0001
cylinder   3  1       52.320      87.2213    -51.3438
           orig        0.0000      0.0001
end geom
end data
end
=kenova
67 g Pu    Cylinder a 32.0 g/l in One Ton    Increase D
read param
tme=700    gen=120    nsk=20     lib=4      npg=5000    nfb=8000
flx=yes    fdn=yes    plt=yes    run=yes    tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt   sct=1
'Fuel
mix=1
      3932 8.0614E-05
      8016 3.3374E-02
      1001 6.6748E-02
'Lead
mix=2
     82000  3.3130E-02
'Water
mix=3
      8016  3.3428E-02
      1001  6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="Pu    Cylinder   One Ton     Cask"
cylinder   1  1        4.3099      35.8775     0.0000
cylinder   3  1        4.3100      35.8775     0.0000
           orig        0.0000      0.0001
cylinder   2  1       22.3200      57.2213   -21.3438
           orig        0.0000      0.0001
cylinder   3  1       52.320      87.2213    -51.3438
           orig        0.0000      0.0001
end geom
end data
end
```

Input File for 239Pu in the Large Bore Cask with Increased Lead Reflection as given after Table 3

```
=nitawl
0$$             82          2          3          4          18
                19          9         15         20
1$$            500          5          0          0           0
                 0          0          1          0           0
                 0          0
t
2$$          94239      -3934
             82000       1001       8016
3**           3934        293          2     5.5799      0.0000
               0.0 8.6408E-05          1     1.0079  1.5757E+04
                 1    15.9994 1.4305E+03          1           1
4**       f293
t
end
=kenova
230 g Pu Cylinder a 34.3 g/l in Large Bore Increase Lead Thickness to
12.4"
read param
tme=700    gen=120    nsk=20     lib=4      npg=5000    nfb=8000
flx=yes    fdn=yes    plt=yes    run=yes    tba=60.0
end param
'**********
'* MIXTURES
'**********
read mixt   sct=1
'Fuel
mix=1
      3934 8.6408E-05
      8016 3.3370E-02
      1001 6.6740E-02
'Lead
mix=2
     82000  3.3130E-02
'Water
mix=3
      8016  3.3428E-02
      1001  6.6856E-02
end mixt
'**********
'* GEOMETRY
'**********
read geom
unit 1
com="Pu Cylinder Large Bore Cask with 12.4 inch Lead"

cylinder   1  1         5.5799     68.5800     0.0000
cylinder   3  1         5.5800     68.5800     0.0000
           orig         0.0000      0.0001
cylinder   2  1        37.0760     95.4800   -26.9000
           orig         0.0000      0.0001
cylinder   3  1        67.0760    125.4800   -56.9000
           orig         0.0000      0.0001
end geom
end data
end
```

Input File for 239Pu in the 5 l Cask with 8" Lead Reflector as given in Table 4

```
=nitawl
0$$          82          2          3          4          18
             19          9         15         20
1$$         500          8          0          0           0
              0          0          3          0           0
              0          0
t
2$$        8016       1001      94239     -94092      -94032
         -94046      28000      82000
3**       94092        293          3    10.6060      0.0000
           0.00 2.3176E-04          1     1.0079  5.8574E-03
              1    15.9994 5.3176E+02          1       1.000
          94046        293          3    10.6060      0.0000
           0.00 1.1588E-04          1     1.0079  1.1742E+04
              1    15.9994 1.0660E+03          1       1.000
          94032        293          3    11.9719      0.0000
           0.00 8.0614E-05          1     1.0079  1.8891E+04
              1    15.9994 1.8335E+03          1       1.000
```

```
4**   f293
t
end
=kenova
Normal Conditions 230 g 5L Pu sphere 8" lead refl + FWR
read param
 tme=200.0 lib=4  flx=yes fdn=yes  npg=5000
 gen=120 tba=60.0 nsk=20  nub=yes  nfb=8000
end param
read geom
 sphere  1 1 10.608
 sphere  2 1 30.928
 cuboid  3 1 6p72.0
end geom
read mixt
'PU ISOTOPICS
  mix=1 94046 1.1588E-04  8016 3.3350E-02  1001 6.6701E-02
'WATER ISOTOPICS
  mix=3  8016 3.3428E-02  1001 6.6856E-02
'LEAD
  mix=2 82000 3.3133E-02
sct=1 end mixt
end data
end
=kenova
Loss of Mass 460 G 5L Pu sphere 8" lead refl + FWR
read param
 tme=200.0 lib=4  flx=yes fdn=yes  npg=5000
 gen=120 tba=60.0 nsk=20  nub=yes  nfb=8000
end param
read geom
 sphere  1 1 10.608
 sphere  2 1 30.928
 cuboid  3 1 6p72.0
end geom
read mixt
'PU ISOTOPICS
  mix=1 94092 2.3176E-04  8016 3.3273E-02  1001 6.6546E-02
'WATER ISOTOPICS
  mix=3  8016 3.3428E-02  1001 6.6856E-02
'LEAD
  mix=2 82000 3.3133E-02
sct=1 end mixt
end data
end
=kenova
Loss of Refl 230 g 5L Pu sphere 12" lead refl + FWR
read param
 tme=200.0 lib=4  flx=yes fdn=yes  npg=5000
 gen=120 tba=60.0 nsk=20  nub=yes  nfb=8000
end param
read geom
 sphere  1 1 10.608
 sphere  2 1 41.088
 cuboid  3 1 6p82.0
end geom
read mixt
'PU ISOTOPICS
  mix=1 94046 1.1588E-04  8016 3.3350E-02  1001 6.6701E-02
'WATER ISOTOPICS
  mix=3  8016 3.3428E-02  1001 6.6856E-02
'LEAD
  mix=2 82000 3.3133E-02
sct=1 end mixt
end data
end
=kenova
Loss of Volume 230 g 7L Pu sphere 8"lead refl + FWR
read param
 tme=200.0 lib=4  flx=yes fdn=yes  npg=5000
 gen=120 tba=50.0 nsk=20  nub=yes  nfb=8000
end param
read geom
 sphere  1 1 11.9719
 sphere  2 1 32.2919
 cuboid  3 1 6p73.0
end geom
read mixt
'PU ISOTOPICS
  mix=1 94032 8.0614E-05  8016 3.3374E-02  1001 6.6748E-02
'WATER ISOTOPICS
  mix=3  8016 3.3428E-02  1001 6.6856E-02
'LEAD
  mix=2 82000 3.3133E-02
sct=1 end mixt
end data
end
```

Input File for ²³⁵U in the 5 l Cask with 8" Lead Reflector as given in Table 4

```
=nitawl
0$$         62          2          3          4         18
            19          9         15         20
1$$        500          7          0          0          0
             0          0          3          0          0
             0          0
t
2$$       8016       1001      92235     -92738     -92369
        -92007      82000
3**      92738        293          3    10.6080     0.0000
           0.0 3.7817E-04          1     1.0079 3.5783E+03
             1    15.9994 3.2466E+02          1      1.000
         92369        293          3    10.6080     0.0000
           0.0 1.8909E-04          1     1.0079 7.1848E+03
             1    15.9994 6.5227E+02          1      1.000
         92007        293          3    11.7000     0.0000
           0.0 1.4092E-04          1     1.0079 9.6503E+03
             1    15.9994 8.7610E+02          1      1.000
4**   f293
t
end
=kenova
Normal Condition 369 g 5L U235 73.8 g/l sphere with 8" lead refl +
FWR
read param tme=150.0 lib=4  nsk=20 gen=120 npg=5000
          nub=yes   flx=yes fdn=yes tba=60.0 nfb=8000 end param
read geometry
sphere  1 1 10.608
sphere  2 1 30.928
cuboid  3 1 6p72.0
end geom
read mixt
'FUEL
mix=1 92369 1.8909E-04  8016 3.3298E-02  1001 6.6595E-02
'WATER ISOTOPICS
mix=3  8016 3.3428E-02  1001 6.6856E-02
'LEAD
mix=2 82000 3.3133E-02
end data
end
=kenova
Loss of Mass 738 g 5L U235 147.6 g/L sphere with 8" lead refl + FWR
read param tme=150.0 lib=4  nsk=20 gen=120 npg=5000
          nub=yes   flx=yes fdn=yes tba=60.0 nfb=8000 end param
read geometry
sphere  1 1 10.608
sphere  2 1 30.928
cuboid  3 1 6P72.0
end geom
read mixt
'FUEL
mix=1 92738 3.7817E-04  8016 3.3167E-02  1001 6.6334E-02
'WATER ISOTOPICS
mix=3  8016 3.3428E-02  1001 6.6856E-02
'LEAD
mix=2 82000 3.3133E-02
end data
end
=kenova
Loss of Refl 369 g 5L U235 73.8 g/l sphere with 12" lead refl + FWR
```

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```
read param tme=150.0 lib=4  nsk=20 gen=120 npg=5000
          nub=yes   flx=yes fdn=yes tba=60.0 nfb=8000 end param
r  geometry
    e  1 1 10.608
sphere  2 1 41.088
cuboid  3 1 6p82.0
end geom
read mixt
'FUEL
mix=1 92369 1.8909E-04  8016 3.3298E-02  1001 6.6595E-02
'WATER ISOTOPICS
mix=3  8016 3.3428E-02  1001 6.6856E-02
'LEAD
mix=2 82000 3.3133E-02
end data
end
=kenova
Loss of Volume 369 g 6.71L U235 55 g/L sphere with 8" lead refl + FXR
read param tme=150.0 lib=4  nsk=20 gen=120 npg=5000
          nub=yes   flx=yes fdn=yes tba=60.0 nfb=8000 end param
read geometry
sphere  1 1 11.7000
sphere  2 1 32.0200
cuboid  3 1 6p63.0
end geom
read mixt
'FUEL
mix=1 92007 1.4092E-04  8016 3.3331E-02  1001 6.6662E-02
'WATER ISOTOPICS
mix=3  8016 3.3428E-02  1001 6.6856E-02
'LEAD
mix=2 82000 3.3133E-02
end data
end
```

Appendix B Input Files for Benchmark Cases given in Table 5

Input File for $Pu(NO_3)_4$ Sphere at 26.3 g Pu/l with Thin Steel Shell and Full Water Reflection

Input File for $Pu(NO_3)_4$ Sphere at 34.3 g Pu/l with Thin Steel Shell

Input File for $Pu(NO_3)_4$ Sphere at 35.5 g Pu/l with 4" Concrete Shell

Input File for $Pu(NO_3)_4$ Sphere at 32.8 g Pu/l with 4" Concrete Shell

Input File for $Pu(NO_3)_4$ Sphere at 29.6 g Pu/l with 10" Concrete Shell

Input File for 4x4 array of 93.2 wt% Enriched Uranyl Nitrate Solution at 67.28 gU/l with concrete reflection

```
=nitawl
0$$ 82   2   3   4  18
 19  20   9  15
1$$   500  17   0   0   0
  0   0   6   0   0
  0   0
t
2$$  92235 92234  92236  92238   14000
  26000   7014   6012   8016   1001
  20000  22000  11023  12000  13027
  19000 16000
3** 92234 293    2    10.5600 0.9502
 0.0  1.7693E-06   1 1.0079   7.5125E+05
  1   16.1609   7.4984E+04   1   1.000
 92235 293    2    10.5600 0.9502
 0.0  1.6061E-04   1 1.0079   8.2758E+03
  1   15.9415   8.1445E+02   1   1.000
 92236 293    2    10.5600 0.9502
 0.0  7.4495E-07   1 1.0079   1.7843E+06
  1   16.1622   1.7811E+05   1   1.000
 92238 293    2 .  10.5500 0.9502
 0.0  9.1432E-06   1 1.0079   1.4537E+05
  1   16.1517   1.4502E+04   1   1.000
 26000 293    1    25.4000 0.0000
 0.0  2.5278E-04   1 1.0079   8.3939E+02
  1   16.7297   8.9763E+02   1   1.000
 11023 293    1    25.4000 0.0000
 0.0  3.8303E-04   1 1.0079   5.5395E+02
  1   16.8578   5.9671E+02   1   1.000
4** f293
t
end
=kenova ROT53 4x4 array of UN solution w/o sleeve (67.28 gU/l-21.12
cm diam cyl)
read param   gen=120   nsk=20  npg=5000   nfb=5000
tme=700  fdn=yes   plt=yes   run=yes    tba=60.0
flx=yes   lib=4  nub=yes
end param
read mixt
'***************
'* MIXTURES *
'***************
mix=1
'Fuel
   92234    1.7693E-06
   92235    1.6061E-04
   92236    7.4495E-07
   92238    9.1432E-06
 8016    3.4149E-02
 7014    4.2162E-04
 1001    6.5156E-02
mix=2
'Al tank
   13027    5.9469E-02
mix=3
'Concrete
   12000    7.1285E-04
   13027    1.1241E-03
   20000    8.0213E-03
   26000    2.5278E-04
   19000    4.8976E-04
   14000    7.7139E-03
 1001    1.0401E-02
   11023    3.8303E-04
 8016    4.2362E-02
 6012    6.4237E-03
 7014    1.9956E-05
   16000    6.2809E-05
   22000    2.9192E-05
end mixt
'***************
'* GEOMETRY  *
'***************
read geom
unit 1
com="Sphere  U235 with gU/l-21.12 cm   diam cyl) "
  cylinder 1  1    0.505  0.00       -0.32
  cylinder 2  1    10.56  0.00       -0.32
  cylinder 1  1    10.56       27.15      -0.32
  cylinder 0  1    10.56       119.1      -0.32
  cylinder 2  1    10.96       119.1      -0.32
   cuboid 0  1   15.24  -15.24   15.24  -15.24   123.445 -0.32
unit 2
  cylinder 1  1     0.505      25.40      0.00
  cylinder 2  1     0.635      25.40      0.00
   cuboid 3  1   15.24  -15.24   15.24  -15.24     25.4  0.0
unit 3
  cylinder 1  1     0.505      5.00  0.00
  cylinder 2  1     0.635      5.00  0.00
   cuboid 0  1   15.24  -15.24   15.24  -15.24     5.0  0.0
unit 4
  cylinder 1  1     1.14  0.00  -0.32
  cylinder 2  1    10.56  0.00      -0.32
  cylinder 1  1    10.56       27.15      -0.32
  cylinder 0  1    10.56       119.1      -0.32
  cylinder 2  1    10.96       119.1      -0.32
   cuboid 0  1   15.24  -15.24   15.24  -15.24   123.445 -0.32
unit 5
  cylinder 1  1     1.140      25.40      0.00
  cylinder 2  1     1.270      25.40      0.00
   cuboid 3  1   15.24  -15.24   15.24  -15.24     25.4  0.0
unit 6
  cylinder 1  1     1.140      5.00  0.00
  cylinder 2  1     1.270      5.00  0.00
   cuboid 0  1   15.24  -15.24   15.24  -15.24     5.0  0.0
unit 7     array=1      0.0 0.0 0.0
unit 8     array=2      0.0 0.0 0.0
unit 9     array=3      0.0 0.0 0.0
unit 10
    cuboid 0  1    121.92  0.0 0.14  0.0  5.0   0.0
    cuboid 3  1    121.92  0.0 0.14  0.0  30.4  0.0
    cuboid 0  1    121.92  0.0 0.14  0.0 154.165 0.0
unit 11
    cuboid 0  1     25.7  0.0  122.2 0.0  5.0   0.0
    cuboid 3  1     25.7  0.0  122.2 0.0  30.4  0.0
    cuboid 0  1     25.7  0.0  122.2 0.0 31.035 0.0
    cuboid 3  1     25.7  0.0  122.2 0.0 154.165 0.0
unit 12
    cuboid 0  1    173.32  0.0 25.7  0.0  5.0   0.0
    cuboid 3  1    173.32  0.0 25.7  0.0  30.4  0.0
    cuboid 0  1    173.32  0.0 25.7  0.0 31.035 0.0
    cuboid 3  1    173.32  0.0 25.7  0.0 154.165 0.0
unit 13     array=4      0.0 0.0 0.0
unit 14     array=5      0.0 0.0 0.0
global unit 15  array=6      0.0 0.0 0.0
reflector  0  1     0.0 0.0     0.0 0.0 0.635 0.0 1.0
reflector  3  1     0.0 0.0     0.0 0.0 25.4 0.0 1.0
end geom
'***************
'*   ARRAY   *
'***************
read array
ara=1      nux=1 nuy=1     nuz=3  fill     3 2 1      end fill
```

```
ara=2     nux=1 nuy=1    nuz=3  fill    6 5 4     end fill
ara=3     nux=4 nuy=4    nuz=1 fill 7 7 7 7
      7 8 7 7
      7 8 7 7
      7 7 7 7   end fill
ara=4     nux=1 nuy=3    nuz=1 fill 10 9 10    end fill
ara=5     nux=3 nuy=1    nuz=1 fill 11 13 11   end fill
ara=6     nux=1 nuy=3    nuz=1 fill 12 14 12   end fill
end array
read plot
ttl='Plot' nch=' *!.'
xul=0  xlr=125  yul=71.46  ylr=71.46  zul=166 zlr=-5
uax=1 wdn=-1    nax=130 ndn=80  lpi=10     pic=mix end
end plot
end data
end
-
Input File for 2x2 array of 93.2 wt% Enriched Uranyl Nitrate Solution
at 76.09 gU/l with concrete reflection
=nitawl
0$$  82  2  3  4      18
   19      20  9       15
1$$      500      17  0  0  0
     0  0  6  0  0
     0  0
t
2$$     92235  92234  92236   92238    14000
  26000    7014    6012    8016    1001
  20000   22000   11023   12000   13027
  19000  16000
3**    92234      293  2 10.5600  0.9502
    0.0  2.0009E-06  1  1.0079    6.6236E+05
     1 16.1816   6.6870E+04  1    1.000
  92235      293  2 10.5600  0.9502
    0.0  1.8164E-04  1  1.0079   7.2963E+03
     1 15.9352   7.2503E+02  1    1.000
  92236      293  2 10.5600  0.9502
    0.0  8.4250E-07  1  1.0079   1.5731E+06
     1 16.1829   1.5883E+05  1    1.000
  92238      293  2 10.5600  0.9502
    0.0  1.0341E-05  1  1.0079   1.2816E+05
     1 16.1712   1.2930E+04  1    1.000
  26000      293  1  25.400  0.0000
    0.0  2.5276E-04  1  1.0079   8.3939E+02
     1 16.7297   8.9763E+02  1    1.000
  11023      293  1  25.400  0.0000
    0.0  3.8303E-04  1  1.0079   5.5395E+02
     1 16.8578   5.9671E+02  1    1.000
4**   f293
t
end
=kenova
ROT54 2x2 array w/o sleeve (76.09  gU/l-21.12 cm  diam cyl)
read param    gen=120   nsk=20    npg=5000  nfb=8000
tme=700   fdn=yes   plt=yes   run=yes   tba=60.0
flx=yes   lib=4     nub=yes
end param
read mixt
'*************
'* MIXTURES *
'*************
mix=1
'Fuel
   92234     2.0009E-06
   92235     1.8164E-04
   92236     8.4250E-07
   92238     1.0341E-05
    8016     3.4249E-02
    7014     4.7215E-04
    1001     6.4966E-02
mix=2
'Al tank
   13027     5.9469E-02
mix=3
'Concrete
   12000     7.1685E-04
   13027     1.1241E-03
   20000     8.0213E-03
   26000     2.5278E-04
   19000     4.8976E-04
   14000     7.7139E-03
    1001     1.0401E-02
   11023     3.8303E-04
    8016     4.2362E-02
    6012     6.4237E-03
    7014     1.9958E-05
   16000     8.2809E-05
   22000     2.9192E-05
end mixt
'*************
'* GEOMETRY  *
'*************
read geom
unit 1
 cylinder 1  1     0.505      0.00     -0.32
 cylinder 2  1     10.55      0.00     -0.32
 cylinder 1  1     10.56     62.34     -0.32
 cylinder 0  1     10.56     119.1     -0.32
 cylinder 2  1     10.96     119.1     -0.32
   cuboid 0  1     15.24  -15.24  15.24  -15.24  123.445 -0.32
unit 2
 cylinder 1  1     0.505     25.40      0.00
 cylinder 2  1     0.635     25.40      0.00
   cuboid 3  1     15.24  -15.24  15.24  -15.24    25.4  0.0
unit 3
 cylinder 1  1     0.505      5.00      0.00
 cylinder 2  1     0.635      5.00      0.00
   cuboid 0  1     15.24  -15.24  15.24  -15.24     5.0  0.0
unit 4
 cylinder 1  1      1.14      0.00     -0.32
 cylinder 2  1     10.55      0.00     -0.32
 cylinder 1  1     10.56     62.34     -0.32
 cylinder 0  1     10.56     119.1     -0.32
 cylinder 2  1     10.96     119.1     -0.32
   cuboid 0  1     15.24  -15.24  15.24  -15.24  123.445 -0.32
unit 5
 cylinder 1  1     1.140     25.40      0.00
 cylinder 2  1     1.270     25.40      0.00
   cuboid 3  1     15.24  -15.24  15.24  -15.24    25.4  0.0
unit 6
 cylinder 1  1     1.140      5.00      0.00
 cylinder 2  1     1.270      5.00      0.00
   cuboid 0  1     15.24  -15.24  15.24  -15.24     5.0  0.0
unit 7    array=1     0.0 0.0 0.0
unit 8    array=2     0.0 0.0 0.0
unit 9    array=3     0.0 0.0 0.0
unit 10
   cuboid 0  1   30.48  0.0      60.96 0.0  5.0   0.0
   cuboid 3  1   30.48  0.0      60.96 0.0 30.4  0.0
   cuboid 0  1   30.48  0.0      60.96 0.0      154.165 0.0
unit 11
   cuboid 0  1  121.92  0.0      30.62 0.0  5.0   0.0
   cuboid 3  1  121.92  0.0      30.62 0.0 30.4  0.0
   cuboid 0  1  121.92  0.0      30.62 0.0     154.165 0.0
unit 12
   cuboid 0  1   25.7  0.0 122.2  0.0 5.0   0.0
   cuboid 3  1   25.7  0.0 122.2  0.0      30.4  0.0
   cuboid 0  1   25.7  0.0 122.2  0.0     31.035 0.0
   cuboid 3  1   25.7  0.0 122.2  0.0    154.165 0.0
unit 13
   cuboid 0  1  173.32  0.0      25.7  0.0  5.0   0.0
   cuboid 3  1  173.32  0.0      25.7  0.0 30.4  0.0
   cuboid 0  1  173.32  0.0      25.7  0.0 31.035 0.0
   cuboid 3  1  173.32  0.0      25.7  0.0     154.165 0.0
unit 14   array=4     0.0 0.0 0.0
unit 15   array=5     0.0 0.0 0.0
unit 16   array=6     0.0 0.0 0.0
global unit 17 array=7     0.0 0.0 0.0
reflector 0  1     0.0 0.0   0.0 0.0      0.635 0.0 1.0
reflector 3  1     0.0 0.0   0.0 0.0      25.4 0.0 1.0
```

```
end geom
'*************
'*   ARRAY   *
'*************
read array
ara=1     nux=1 nuy=1     nuz=3  fill     3 2 1      end fill
ara=2     nux=1 nuy=1     nuz=3  fill     6 5 4      end fill
ara=3     nux=2 nuy=2     nuz=1 fill      8 7 8 7    end fill
ara=4     nux=3 nuy=1     nuz=1 fill      10 9 10    end fill
ara=5     nux=1 nuy=3     nuz=1 fill      11 14 11   end fill
ara=6     nux=3 nuy=1     nuz=1 fill      12 15 12   end fill
ara=7     nux=1 nuy=3     nuz=1 fill      13 16 13   end fill
end array
read plot
ttl='Plot'     nch=' *!.'     pic=mix
xul=25. xlr=73 yul=71.46 ylr=71.46 zul=166 zlr=-1
uax=1 wdn=-1    nax=130    ndn=80 lpi=10  end
end plot
end data
end
-
Input File for 4x4 array of 93.2 wt% Enriched Uranyl Nitrate Solution
at 360.37 gU/l with concrete reflection
=nitawl
0$$  82  2  3  4       18
     19       20  9       15
1$$  500       23  0  0  0
      0  0       10  0  0
      0  0
t
2$$     92235  92234   92236   92238    14000
   26000 -26001     6012    8016     1001
   20000   22000   11023   12000   13027
   19000  16000   15031   25055   42000
    7014  24000   28000
3**      92234       293  2  8.3800  0.6576
     0.0  9.4767E-06  1  1.0079   1.2499E+05
      1 16.7021   1.8007E+04  1   1.000
  92235      293  2  8.3800  0.6576
     0.0  8.6027E-04  1  1.0079   1.3769E+03
      1 15.7583   1.8678E+02  1   1.000
  92236      293  2  8.3800  0.6576
     0.0  3.9902E-06  1  1.0079   2.9685E+05
      1 16.7073   4.2781E+04  1   1.000
  92238      293  2  8.3800  0.6576
     0.0  4.8974E-05  1  1.0079   2.4186E+04
      1 16.6623   3.4759E+03  1   1.000
  26000      293  1 25.4000  0.0000
     0.0  2.5278E-04  1  1.0079   8.3939E+02
      1 16.7297   8.9763E+02  1   1.000
  11023      293  1 25.4000  0.0000
     0.0  3.8303E-04  1  1.0079   5.5395E+02
      1 16.8578   5.9671E+02  1   1.000
  26001      293  1  0.3100  0.0000
     0.0  5.9852E-02  1   58.69   2.2046E+00
      1 48.1197   4.0995E-02  1   1.000
  25055      293  1  0.3100  0.0000
     0.0  1.1209E-03  1  55.847   6.0872E+02
      1 54.2180   3.6440E-02  1   1.000
  24000      293  1  0.3100  0.0000
     0.0  1.6985E-02  1  55.847   4.0171E+01
      1 55.4800   3.5621E-02  1   1.000
  28000      293  1  0.3100  0.0000
     0.0  7.5400E-03  1  55.847   9.0492E+01
      1 48.1197   4.0995E-02  1   1.000
4**    f293
t
end
=kenova
ROT61 4x4 array UN solution w/sleeve (360.37 gU/l-16.12 cm diam cyl)
read param gen=120     nsk=20     npg=5000 nfb=8000
tme=700    fdn=yes     plt=yes    run=yes  tba=50.0
flx=yes    lib=4  nub=yes
end param
read mixt
'**************
'* MIXTURES *
'**************
mix=1
'Fuel
    92234 9.4767E-06
    92235 8.6027E-04
    92236 3.9902E-06
    92238 4.8974E-05
     8016 3.7295E-02
     7014 2.1977E-03
     1001 5.8064E-02
mix=2
'Al tank
    13027 5.9469E-02
mix=3
'Steel Sleeve
    26001 5.9852E-02
    24000 1.6985E-02
    28000 7.5400E-03
     6012 2.6231E-04
    14000 1.3768E-03
    15031 3.8530E-05
    16000 2.8282E-05
    25055 1.1209E-03
    42000 8.9563E-06
mix=4
'Concrete
    12000 7.1885E-04
    13027 1.1241E-03
    20000 8.0213E-03
    26000 2.5278E-04
    19000 4.8976E-04
    14000 7.7139E-03
     1001 1.0401E-02
    11023 3.8303E-04
     8016 4.2362E-02
     6012 6.4237E-03
     7014 1.9958E-05
    16000 8.2809E-05
    22000 2.9192E-05
end mixt
'**************
'* GEOMETRY  *
'**************
read geom
unit 1
  cylinder 1  1      0.505  0.00        -0.32
  cylinder 2  1       8.06  0.00        -0.32
  cylinder 1  1       8.06        32.32        -0.32
  cylinder 0  1       8.06        119.1        -0.32
  cylinder 2  1       8.38        119.1        -0.32
  cylinder 0  1       8.38        121.68       -0.32
  cylinder 3  1       8.69        121.68       -0.32
    cuboid 0  1   15.24  -15.24   15.24  -15.24   123.445 -0.32
unit 2
  cylinder 1  1      0.505        25.40        0.00
  cylinder 2  1      0.635        25.40        0.00
    cuboid 4  1   15.24  -15.24   15.24  -15.24     25.4  0.0
unit 3
  cylinder 1  1      0.505        5.00  0.00
  cylinder 2  1      0.635        5.00  0.00
    cuboid 0  1   15.24  -15.24   15.24  -15.24     5.0  0.0
unit 4
  cylinder 1  1       1.14  0.00  -0.32
  cylinder 2  1       8.06  0.00        -0.32
  cylinder 1  1       8.06        32.32        -0.32
  cylinder 0  1       8.06        119.1        -0.32
  cylinder 2  1       8.38        119.1        -0.32
  cylinder 0  1       8.38        121.68       -0.32
  cylinder 3  1       8.69        121.68       -0.32
    cuboid 0  1   15.24  -15.24   15.24  -15.24   123.445 -0.32
unit 5
  cylinder 1  1      1.140        25.40        0.00
  cylinder 2  1      1.270        25.40        0.00
```

```
   cuboid 4  1   15.24  -15.24   15.24  -15.24     25.4  0.0
unit 6
  cylinder 1  1        1.140         5.00  0.00
  cylinder 2  1        1.270         5.00  0.00
   cuboid 0  1   15.24  -15.24   15.24  -15.24      5.0   0.0
unit 7     array=1       0.0 0.0 0.0
unit 8     array=2       0.0 0.0 0.0
unit 9     array=3       0.0 0.0 0.0
unit 10
   cuboid 0  1     121.92  0.0 0.14  0.0  5.0   0.0
   cuboid 4  1     121.92  0.0 0.14  0.0  30.4  0.0
   cuboid 0  1     121.92  0.0 0.14  0.0 154.165 0.0
unit 11
   cuboid 0  1      25.7  0.0  122.2 0.0  5.0   0.0
   cuboid 4  1      25.7  0.0  122.2 0.0  30.4  0.0
   cuboid 0  1      25.7  0.0  122.2 0.0 31.035 0.0
   cuboid 4  1      25.7  0.0  122.2 0.0 154.165 0.0
unit 12
   cuboid 0  1     173.32  0.0 25.7  0.0  5.0   0.0
   cuboid 4  1     173.32  0.0 25.7  0.0  30.4  0.0
   cuboid 0  1     173.32  0.0 25.7  0.0 31.035 0.0
   cuboid 4  1     173.32  0.0 25.7  0.0 154.165 0.0
unit 13     array=4       0.0 0.0 0.0
unit 14     array=5       0.0 0.0-0.0
global unit 15  array=6       0.0 0.0 0.0
reflector  0  1     0.0 0.0     0.0 0.0 0.635 0.0 1.0
reflector  4  1     0.0 0.0     0.0 0.0 25.4 0.0 1.0
end geom
'**************
'*   ARRAY   *
'**************
read array
ara=1        nux=1 nuy=1       nuz=3  fill     3 2 1        end fill
ara=2        nux=1 nuy=1       nuz=3  fill     6 5 4        end fill
ara=3        nux=4 nuy=4       nuz=1 fill 7 7 7 7
                                          7 8 7 7
                                          7 8 7 7
                                          7 7 7 7    end fill
ara=4        nux=1 nuy=3       nuz=1 fill 10 9 10     end fill
ara=5        nux=3 nuy=1       nuz=1 fill 11 13 11    end fill
ara=6        nux=1 nuy=3       nuz=1 fill 12 14 12    end fill
end array
read plot
ttl='Plot' nch=' *!.' pic=mix
xul=0. xlr=150. yul=71.46  ylr=71.46  zul=165 zlr=-3
uax=1 wdn=-1      nax=130      ndn=60 lpi=10    end
end plot
end data
end
```

Input File for 4.31 wt% Optimum Moderated UO_2 Rods with Lead Reflector at Various Distances

```
=nitawl
0$$    82              2              3              4             18
           19         20              9             15
1$$    500            21              0              0              0
            0          0              5              0              0
            0          0
t
2$$  92235         92238          13027          82000           8016
         1001      29000         -29001          25000         -26001
        14000      16000          24000          20000           7014
        25055      12000          17000          22000           6012
        48000
3**    92235          293             .2         0.6325         0.0409
          0.0 1.0124E-03               1        15.9994     1.6960E+02
            1   238.0508   2.3237E-02                 1          1.000
        92238          293              2         0.6325         0.0409
          0.0 2.2193E-02               1        15.9994     7.7459E+00
            1   235.0439   5.3372E-01                 1          1.000
        26001          293              2        0.70735         0.0000
      0.64135  2.0305E-04               1       26.98154     3.9906E-02
            1    30.4624   2.3202E-01                 1          1.000
        29001          293              2        0.70735         0.0000
      0.64135  1.0197E-04               1       26.98154     7.9463E-02
            1    34.0419   6.1400E+01                 1          1.000
        24000          293              2        0.70735         0.0000
      0.64135  1.0904E-04               1       26.98154     7.4309E+02
            1    35.0863   6.0131E+01                 1          1.000
4**         f293
t
end
=kenova
4.31 wt% UO2 rods P=2.54 cm (Opt Mod) lead reflector @ 0.00 in
read param
tme=700       gen=120       nsk=20       lib=4          npg=5000
flx=yes       fdn=yes       tba=60.0     nub=yes        nfb=8000
run=yes       end param
'*******************
'* MIXTURES *
'*******************
read mixt     sct=1
'Fuel
mix=1
          92235 1.0124E-03
          92238 2.2193E-02
           8016 4.6411E-02
'Clad
mix=2
          13027 5.7878E-02
          14000 2.3072E-04
          26001 2.0305E-04
          29001 1.0197E-04
          25055 4.4230E-05
          12000 7.9981E-04
          24000 1.0904E-04
          22000 5.0729E-05
'Water
mix=3
           8016 3.3428E-02
           1001 6.6856E-02
          17000 5.1298E-07
          26000 3.2350E-10
          82000 1.4532E-11
          48000 3.2144E-11
           7014 4.0792E-09
'Lead
mix=4
          82000 3.2771E-02
          29000 1.3909E-04
'Rubber End Caps
mix=5
           6012 3.8416E-02
           1001 5.1304E-02
          20000 2.2627E-03
          16000 4.2183E-04
           8016 1.0989E-02
          14000 8.4975E-05
end mixt
'*******************
'* GEOMETRY  *
'*******************.
read geom
unit 1
com="Single Fuel Pin"
     cylinder 1  1                 0.63245        91.44           0
     cylinder 0  1                 0.64135        91.44           0
     cylinder 2  1                 0.70735        91.44           0
     cylinder 5  1                 0.70735        93.98       -2.54
       cuboid 3  1        1.270 -1.270 1.270 -1.270   93.98  -2.54
unit 2    array 1                  -10.16        -16.51       -2.54
com="13 x 5 array of pins"
unit 3
com="Critical Separation  - Water Gap"
       cuboid 3  1          2p10.160     2p10.310       93.98  -2.54
global unit 4   array 2  0 0 0
'Inner shell for lead
       cuboid 3  1        20.320 0.00  152.15 -11.85 107.42 -15.98
'Outer shell to fill with lead
       cuboid 4  1        30.62 -10.20 152.15 -11.85 107.42 -15.98
```

```
'Water tank
     cuboid 3  1          50.82 -30.50 170.80 -30.50 121.94 -30.50
end geom
'
read array
ara=1 nux=8 nuy=13 nuz=1        fill 104r1 t  end fill
ara=2 nux=1 nuy=5  nuz=1         fill 2 3 2 3 2 t end fill
end array
end data
end
=kenova
4.31 wt% UO2 rods P=2.54 cm (Opt Mod) lead reflector @ 0.25 in
read param
tme=700     gen=120     nsk=20      lib=4       npg=5000
flx=yes     fdn=yes     tba=60.0    nub=yes     nfb=8000
run=yes      end param
'*******************
'* MIXTURES *
'*******************
read mixt    sct=1
'Fuel
mix=1
       92235 1.0124E-03
       92238 2.2193E-02
        8016 4.6411E-02
'Clad
mix=2
       13027 5.7878E-02
       14000 2.3072E-04
       26001 2.0305E-04
       29001 1.0197E-04
       25055 4.4230E-05
       12000 7.9981E-04
       24000 1.0904E-04
       22000 5.0729E-05
'Water
mix=3
        8016 3.3428E-02
        1001 6.6856E-02
       17000 5.1298E-07
       26000 3.2350E-10
       82000 1.4532E-11
       48000 3.2144E-11
        7014 4.0792E-09
'Lead
mix=4
       82000 3.2771E-02
       29000 1.3909E-04
'Rubber End Caps
mix=5
        6012 3.8415E-02
        1001 5.1304E-02
       20000 2.2627E-03
       16000 4.2183E-04
        8016 1.0989E-02
       14000 8.4975E-05
end mixt
'*******************
'* GEOMETRY  *
'*******************
read geom
unit 1
com="Single Fuel Pin"
   cylinder 1  1                0.63245       91.44            0
   cylinder 0  1                0.64135       91.44            0
   cylinder 2  1                0.70735       91.44            0
   cylinder 5  1                0.70735       93.98        -2.54
     cuboid 3  1         1.270 -1.270 1.270 -1.270   93.98  -2.54
unit 2    array 1                -10.16       -16.51        -2.54
com="13 x 8 array of pins"
unit 3
com="Critical Separation  - Water Gap"
     cuboid 3  1           2p10.160    2p10.390    93.98  -2.54
global unit 4   array 2  0 0 0
'Inner shell for lead
```

```
     cuboid 3  1          20.960 -0.66 152.31 -11.69 107.42 -15.98
'Outer shell to fill with lead
     cuboid 4  1          31.18 -10.86 152.31 -11.69 107.42 -15.98
'Water tank
     cuboid 3  1          50.82 -30.50 171.12 -30.50 121.94 -30.50
end geom
'
read array
ara=1 nux=8 nuy=13 nuz=1        fill 104r1 t  end fill
ara=2 nux=1 nuy=5  nuz=1         fill 2 3 2 3 2 t end fill
end array
end data
end
=kenova
4.31 wt% UO2 rods P=2.54 cm (Opt Mod) lead reflector @ 0.52 in
read param
tme=700     gen=120     nsk=20      lib=4       npg=5000
flx=yes     fdn=yes     tba=60.0    nub=yes     nfb=8000
run=yes      end param
'*******************
'* MIXTURES *
'*******************
read mixt    sct=1
'Fuel
mix=1
       92235 1.0124E-03
       92238 2.2193E-02
        8016 4.6411E-02
'Clad
mix=2
       13027 5.7878E-02
       14000 2.3072E-04
       26001 2.0305E-04
       29001 1.0197E-04
       25055 4.4230E-05
       12000 7.9981E-04
       24000 1.0904E-04
       22000 5.0729E-05
'Water
mix=3
        8016 3.3428E-02
        1001 6.6856E-02
       17000 5.1298E-07
       26000 3.2350E-10
       82000 1.4532E-11
       48000 3.2144E-11
        7014 4.0792E-09
'Lead
mix=4
       82000 3.2771E-02
       29000 1.3909E-04
'Rubber End Caps
mix=5
        6012 3.8415E-02
        1001 5.1304E-02
       20000 2.2627E-03
       16000 4.2183E-04
        8016 1.0989E-02
       14000 8.4975E-05
end mixt
'*******************
'* GEOMETRY  *
'*******************
read geom
unit 1
com="Single Fuel Pin"
   cylinder 1  1                0.63245       91.44            0
   cylinder 0  1                0.64135       91.44            0
   cylinder 2  1                0.70735       91.44            0
   cylinder 5  1                0.70735       93.98        -2.54
     cuboid 3  1         1.270 -1.270 1.270 -1.270   93.98  -2.54
unit 2    array 1                -10.16       -16.51        -2.54
com="13 x 8 array of pins"
unit 3
com="Critical Separation  - Water Gap"
```

```
'Water tank
    cuboid 3  1         50.82 -30.50 170.80 -30.50 121.94 -30.50
end geom
'
read array
ara=1 nux=8 nuy=13 nuz=1        fill 104r1 t  end fill
ara=2 nux=1 nuy=5  nuz=1         fill 2 3 2 3 2 t end fill
end array
end data
end
=kenova
4.31 wt% UO2 rods P=2.54 cm (Opt Mod) lead reflector @ 0.26 in
read param
tme=700      gen=120      nsk=20       lib=4        npg=5000
flx=yes      fdn=yes      tba=60.0     nub=yes      nfb=8000
run=yes        end param
'*******************
'* MIXTURES *
'*******************
read mixt     sct=1
'Fuel
mix=1
        92235 1.0124E-03
        92238 2.2193E-02
         8016 4.6411E-02
'Clad
mix=2
        13027 5.7878E-02
        14000 2.3072E-04
        26001 2.0305E-04
        29001 1.0197E-04
        25055 4.4230E-05
        12000 7.9981E-04
        24000 1.0904E-04
        22000 5.0729E-05
'Water
mix=3
         8016 3.3428E-02
         1001 6.6856E-02
        17000 5.1298E-07
        26000 3.2350E-10
        82000 1.4532E-11
        48000 3.2144E-11
         7014 4.0792E-09
'Lead
mix=4
        82000 3.2771E-02
        29000 1.3909E-04
'Rubber End Caps
mix=5
         6012 3.8415E-02
         1001 5.1304E-02
        20000 2.2627E-03
        16000 4.2183E-04
         8016 1.0989E-02
        14000 8.4975E-05
end mixt
'*******************
'* GEOMETRY  *
'*******************
read geom
unit 1
com="Single Fuel Pin"
    cylinder 1  1               0.63245       91.44           0
    cylinder 0  1               0.64135       91.44           0
    cylinder 2  1               0.70735       91.44           0
    cylinder 5  1               0.70735       93.93       -2.54
      cuboid 3  1          1.270 -1.270 1.270 -1.270  93.93  -2.54
unit 2    array 1                -10.16        -16.51       -2.54
com="13 x 8 array of pins"
unit 3
com="Critical Separation  - Water Gap"
      cuboid 3  1           2p10.160     2p10.390     93.93  -2.54
global unit 4   array 2  0 0 0
'Inner shell for lead
      cuboid 3  1         20.960 -0.66 152.31 -11.69 107.42 -15.98
'Outer shell to fill with lead
      cuboid 4  1         31.18 -10.86 152.31 -11.69 107.42 -15.98
'Water tank
      cuboid 3  1         50.82 -30.50 171.12 -30.50 121.94 -30.50
end geom
'
read array
ara=1 nux=8 nuy=13 nuz=1        fill 104r1 t  end fill
ara=2 nux=1 nuy=5  nuz=1          fill 2 3 2 3 2 t end fill
end array
end data
end
=kenova
4.31 wt% UO2 rods P=2.54 cm (Opt Mod) lead reflector @ 0.52 in
read param
tme=700      gen=120      nsk=20       lib=4        npg=5000
flx=yes      fdn=yes      tba=60.0     nub=yes      nfb=8000
run=yes        end param
'*******************
'* MIXTURES *
'*******************
read mixt     sct=1
'Fuel
mix=1
        92235 1.0124E-03
        92238 2.2193E-02
         8016 4.6411E-02
'Clad
mix=2
        13027 5.7878E-02
        14000 2.3072E-04
        26001 2.0305E-04
        29001 1.0197E-04
        25055 4.4230E-05
        12000 7.9981E-04
        24000 1.0904E-04
        22000 5.0729E-05
'Water
mix=3
         8016 3.3428E-02
         1001 6.6856E-02
        17000 5.1298E-07
        26000 3.2350E-10
        82000 1.4532E-11
        48000 3.2144E-11
         7014 4.0792E-09
'Lead
mix=4
        82000 3.2771E-02
        29000 1.3909E-04
'Rubber End Caps
mix=5
         6012 3.8415E-02
         1001 5.1304E-02
        20000 2.2627E-03
        16000 4.2183E-04
         8016 1.0989E-02
        14000 8.4975E-05
end mixt
'*******************
'* GEOMETRY  *
'*******************
read geom
unit 1
com="Single Fuel Pin"
    cylinder 1  1               0.63245       91.44           0
    cylinder 0  1               0.64135       91.44           (
    cylinder 2  1               0.70735       91.44           (
    cylinder 5  1               0.70735       93.98       -2.54
      cuboid 3  1          1.270 -1.270 1.270 -1.270  93.96  -2.54
unit 2    array 1                -10.16        -16.51       -2.54
com="13 x 8 array of pins"
unit 3
com="Critical Separation  - Water Gap"
```

```
     cuboid 3  1          2p10.160      2p9.520      93.98  -2.54
global unit 4   array 2  0 0 0
'Inner shell for lead
     cuboid 3  1          21.641 -1.32 150.57 -13.43 107.42 -15.98
'Outer shell to fill with lead
     cuboid 4  1          31.84 -11.52 150.57 -13.43 107.42 -15.98
'Water tank
     cuboid 3  1          50.82 -30.50 167.64 -30.50 121.94 -30.50
end geom
'
read array
ara=1 nux=8 nuy=13 nuz=1       fill 104r1 t  end fill
ara=2 nux=1 nuy=5  nuz=1        fill 2 3 2 3 2 t end fill
end array
end data
end
=kenova
4.31 wt% UO2 rods P=2.54 cm (Opt Mod) lead reflector @ 2.13 in
read param
tme=700      gen=120     nsk=20      lib=4      npg=5000
flx=yes      fdn=yes     tba=60.0    nub=yes    nfb=8000
run=yes      end param
'******************
'* MIXTURES *
'******************
read mixt    sct=1
'Fuel
mix=1
       92235 1.0124E-03
       92238 2.2193E-02
        8016 4.6411E-02
'Clad
mix=2
       13027 5.7878E-02
       14000 2.3072E-04
       26001 2.0305E-04
       29001 1.0197E-04
       25055 4.4230E-05
       12000 7.9981E-04
       24000 1.0904E-04
       22000 5.0729E-05
'Water
mix=3
        8016 3.3428E-02
        1001 6.6856E-02
       17000 5.1298E-07
       26000 3.2350E-10
       82000 1.4532E-11
       48000 3.2144E-11
        7014 4.0792E-09
'Lead
mix=4
       82000 3.2771E-02
       29000 1.3909E-04
'Rubber End Caps
mix=5
        6012 3.8415E-02
        1001 5.1304E-02
       20000 2.2627E-03
       16000 4.2183E-04
        8016 1.0989E-02
       14000 8.4975E-05
end mixt
'******************
'* GEOMETRY  *
'******************
read geom
     1
'    Single Fuel Pin"
   cylinder 1  1              0.63245       91.44            0
   cylinder 0  1              0.64135       91.44            0
   cylinder 2  1              0.70735       91.44            0
   cylinder 5  1              0.70735       93.98        -2.54
     cuboid 3  1        1.270 -1.270 1.270 -1.270   93.98  -2.54
unit 2    array 1            -10.16        -16.51        -2.54
com="13 x 8 array of pins"
unit 3
com="Critical Separation  - Water Gap"
     cuboid 3  1          2p10.160      2p5.150      93.98  -2.54
global unit 4   array 2  0 0 0
'Inner shell for lead
     cuboid 3  1          25.725 -5.41 141.83 -22.17 107.42 -15.98
'Outer shell to fill with lead
     cuboid 4  1          35.93 -15.61 141.83 -22.17 107.42 -15.98
'Water tank
     cuboid 3  1          50.82 -30.50 150.16 -30.50 121.94 -30.50
end geom
'
read array
ara=1 nux=8 nuy=13 nuz=1       fill 104r1 t  end fill
ara=2 nux=1 nuy=5  nuz=1        fill 2 3 2 3 2 t end fill
end array
end data
end
=kenova
4.31 wt% UO2 rods P=2.54 cm (Opt Mod) without lead reflector
read param
tme=700      gen=120     nsk=20      lib=4      npg=5000
flx=yes      fdn=yes     tba=60.0    nub=yes    nfb=8000
run=yes      end param
'******************
'* MIXTURES *
'******************
read mixt    sct=1
'Fuel
mix=1
       92235 1.0124E-03
       92238 2.2193E-02
        8016 4.6411E-02
'Clad
mix=2
       13027 5.7878E-02
       14000 2.3072E-04
       26001 2.0305E-04
       29001 1.0197E-04
       25055 4.4230E-05
       12000 7.9981E-04
       24000 1.0904E-04
       22000 5.0729E-05
'Water
mix=3
        8016 3.3428E-02
        1001 6.6856E-02
       17000 5.1298E-07
       26000 3.2350E-10
       82000 1.4532E-11
       48000 3.2144E-11
        7014 4.0792E-09
'Lead
mix=4
       82000 3.2771E-02
       29000 1.3909E-04
'Rubber End Caps
mix=5
        6012 3.8415E-02
        1001 5.1304E-02
       20000 2.2627E-03
       16000 4.2183E-04
        8016 1.0989E-02
       14000 8.4975E-05
end mixt
'******************
'* GEOMETRY  *
'******************
read geom
unit 1
com="Single Fuel Pin"
   cylinder 1  1              0.63245       91.44            0
   cylinder 0  1              0.64135       91.44            0
   cylinder 2  1              0.70735       91.44            0
```

```
   cylinder 5  1              0.70735      93.98        -2.54
     cuboid 3  1      1.270 -1.270 1.270 -1.270   93.98  -2.54
unit 2    array 1               -10.16       -16.51       -2.54
com="13 x 8 array of pins"
unit 3
com="Critical Separation  - Water Gap"
     cuboid 3  1         2p10.160      2p4.120     93.98  -2.54
global unit 4   array 2  0 0 0
'Water tank
     cuboid 3  1        50.82 -30.50 146.04 -30.50 121.94 -30.50
end geom
'
read array
ara=1 nux=8 nuy=13 nuz=1       fill 104r1 t  end fill
ara=2 nux=1 nuy=5  nuz=1        fill 2 3 2 3 2 t end fill
end array
end data
end
```

Input File for 4.31 wt% Undermoderated UO_2 Rods with Lead Reflector at Various Distances

```
=nitawl
0$$            82         2         3         4        18
               19         9        15        20
1$$           500        24         0         0         0
                0         0         2         0         0
                0         0
t
2$$         92234     25055     92235      -235      8016
            92236     24304     92238      -238      1001
            26304     29000     42000     28304     14000
            13027     12000      5010      5011     24000
            26000     28000     40302     82000
3**           235    293.16         2   0.63245  0.18049496
              0.0 0.0010104         1   15.9994 171.4236421
                1 238.049392 232.5850528        1         1
              238    293.16         2   0.63245  0.18049495
              0.0   0.02216         1   15.9994 7.816175451
                1 235.043971 0.536340131        1         1
4**       f293.16
t
end
=keno5
SIMULATED SHIPPING CONTAINER EXP. - 4.31 WT% FUEL LEAD REFL (npg=5000)
read parameters
tme=290.0 tba=60.0 gen=120 npg=5000 lib=4
flx=yes fdn=yes nub=yes pwt=yes
plt=yes run=yes nsk=20
end parameters
'
' ***********************************
' *         SETUP MIXTURES          *
' ***********************************
'
read mixt  sct=1
' FUEL ISOTOPICS
mix= 1
    92234  5.1843E-06
      235  1.0104E-03
    92236  5.1403E-06
      238  2.2160E-02
     8016  4.6762E-02
' CLAD ISOTOPICS
mix= 2
    13027  5.8075E-02
    12000  5.3487E-04
    14000  4.6300E-04
    24000  1.0942E-04
    25055  4.4381E-05
    26000  2.0374E-04
    29000  1.0233E-04
' MODERATOR ISOTOPICS
mix= 3
     8016  3.3359E-02
     1001  6.6737E-02
' LEAD WALL ISOTOPICS
mix= 4
     82000  3.2771E-02
     29000  3.9239E-04
end mixt
'
' ***********************************
' *         SETUP GEOMETRY          *
' *                                 *
' *        12X16 PIN LATTICE        *
' ***********************************
'
read geometry
'
'
unit  1
com=" UNIT PIN CELL "
cylinder  1 1   0.63245  92.075  0.0
cylinder  0 1   0.64135  92.075  0.0
cylinder  2 1   0.70735  92.075  0.0
cuboid    3 1   0.946  -0.946   0.946  -0.946  92.075  0.0
'
'
unit 2 array 1  -11.352  -15.136   0.0
com=" 12X16 PIN ARRAY (ASSEMBLY)"
cuboid 3 1 11.35201 -11.35201 15.13601 -15.13601 92.075 0.0
'
'
unit 3
com=" CRITICAL SEPARATION WATER GAP "
cuboid    3 1 11.35201  -11.35201  8.87  -8.87  92.075  0.0
'
'
global unit 4 array 2   0.0  0.0  0.0
com=" CRITICAL ARRAY GEOMETRY (3 ASSEMBLIES) "
'INNER CUBOID SHELL FOR LEAD
cuboid 3 1 22.70402 -0.00002 145.148 -18.852 105.56 -17.84
'OUTER CUBOID SHELL TO FILL W/LEAD
cuboid 4 1 32.90402 -10.20002 145.148 -18.852 105.56 -17.84
'CUBOID OF WATER TANK
cuboid 3 1 53.20401 -30.501 170.878 -54.122 107.275 -17.84
end geometry
'
'
read array
ara=1 nux=12 nuy=16 nuz=1 fill 192r1 t end fill
ara=2 nux=1 nuy=5  nuz=1  fill 2 3 2 3 2 t end fill
end array
read start nst=1 end start
'
' ***********************************
' *         PLOT GEOMETRY           *
' ***********************************
'
read plot
'
ttl=' XY PIN CELL BY MATERIAL'
nch=' o:-'
xul=0.0 xlr=1.892 yul=1.892 ylr=0.0 zul=50.0 zlr=50.0
uax=1.0 vdn=-1.0 nax=80 lpi=10 pic=mat   end
'
ttl=' XY SECTION OF 12x16 ASSEMBLY BY MATERIAL'
nch=' oo-'
xul=0.0 xlr=22.704 yul=30.272 ylr=0.0 zul=50.0 zlr=50.0
uax=1.0 vdn=-1.0 nax=100 lpi=10 pic=mat   end
'
ttl=' XY SECTION OF CRITICAL ARRAY BY MATERIAL'
nch=' oo-*'
xul=-15.0 xlr=35.0 yul=140.0 ylr=-5.0 zul=50.0 zlr=50.0
uax=1.0 vdn=-1.0 nax=100 lpi=10 pic=mat   end
'
ttl=' XZ SECTION OF CRITICAL ARRAY BY MATERIAL'
nch=' oo-*'
xul=-15.0 xlr=35.0 yul=1.27 ylr=1.27 zul=50.0 zlr=-10.0
uax=1.0 wdn=-1.0 nax=100 lpi=10 pic=mat   end
```

```
end plot
end data
end

Simulated shipping container exp - 4.31 wt% fuel lead refl (npg=5000)
read parameters
tme=290.0 tba=60.0 gen=120 nsk=20 npg=5000 lib=4
fix=yes fdn=yes nub=yes pwt=yes
plt=yes run=yes
end parameters
'
' ************************************
' *        setup mixtures            *
' ************************************
'
read mixt  sct=1
' fuel isotopics
mix= 1
     92234  5.1843e-06
       235  1.0104e-03
     92236  5.1403e-06
       238  2.2160e-02
      8016  4.6762e-02
' clad isotopics
mix= 2
     13027  5.8075e-02
     12000  5.3487e-04
     14000  4.6300e-04
     24000  1.0942e-04
     25055  4.4381e-05
     26000  2.0374e-04
     29000  1.0233e-04
' moderator isotopics
mix= 3
      8016  3.3369e-02
      1001  6.6737e-02
' lead wall isotopics
mix= 4
     82000  3.2771e-02
     29000  3.9239e-04
end mixt
'
' ************************************
' *        setup geometry            *
' *                                  *
' *       12x16 pin lattice          *
' ************************************
'
read geometry
'
'
unit  1
com=" unit pin cell "
cylinder  1 1   0.63245  92.075  0.0
cylinder  0 1   0.64135  92.075  0.0
cylinder  2 1   0.70735  92.075  0.0
cuboid    3 1   0.946  -0.946   0.946  -0.946  92.075  0.0
'
'
unit 2 array 1  -11.352  -15.136   0.0
com=" 12x16 pin array (assembly)"
cuboid 3 1 11.35201 -11.35201 15.13601 -15.13601 92.075 0.0
'
'
unit 3
com=" critical separation water gap "
cuboid    3 1 11.35201  -11.35201  8.715 -8.715 92.075  0.0


global unit 4 array 2   0.0  0.0  0.0
com=" critical array geometry (3 assemblies) "
'inner cuboid shell for lead
cuboid 3 1 24.66   -1.956   145.148 -16.652 105.56 -17.84
'outer cuboid shell to fill w/lead
cuboid 4 1 34.66  -12.156   145.148 -16.652 105.56 -17.84
'cuboid of water tank
cuboid 3 1 53.20401 -30.501 170.878 -54.122  107.275 -17.84
end geometry
'
'
read array
ara=1 nux=12 nuy=16 nuz=1 fill 192r1 t end fill
ara=2 nux=1 nuy=5  nuz=1  fill 2 3 2 3 2 t end fill
end array
read start nst=1 end start
'
' ************************************
' *        plot geometry             *
' ************************************
'
read plot
'
ttl=' xy pin cell by material'
nch=' o:-'
xul=0.0 xlr=1.892 yul=1.892 ylr=0.0 zul=50.0 zlr=50.0
uax=1.0 vdn=-1.0 nax=80 lpi=10 pic=mat   end
'
ttl=' xy section of 12x16 assembly by material'
nch=' oo-'
xul=0.0 xlr=22.704 yul=30.272 ylr=0.0 zul=50.0 zlr=50.0
uax=1.0 vdn=-1.0 nax=100 lpi=10 pic=mat   end
'
ttl=' xy section of critical array by material'
nch=' oo-*'
xul=-15.0 xlr=35.0 yul=140.0 ylr=-5.0 zul=50.0 zlr=50.0
uax=1.0 vdn=-1.0 nax=100 lpi=10 pic=mat   end
'
ttl=' xz section of critical array by material'
nch=' oo-*'
xul=-15.0 xlr=35.0 yul=1.27 ylr=1.27 zul=50.0 zlr=-10.0
uax=1.0 wdn=-1.0 nax=100 lpi=10 pic=mat   end
end plot
end data
end
=kenc5
Simulated shipping container exp -4.31wt% fuel lead refl @3 cm (5000)
read parameters
tme=290.0 tba=60.0 gen=120 nsk=20 npg=5000 lib=4
flx=yes fdn=yes nub=yes pwt=yes
plt=yes run=yes
end parameters
'
' ************************************
' *        setup mixtures            *
' ************************************
'
read mixt  sct=1
' fuel isotopics
mix= 1
     92234  5.1843e-06
       235  1.0104e-03
     92236  5.1403e-06
       238  2.2160e-02
      8016  4.6762e-02
' clad isotopics
mix= 2
     13027  5.8075e-02
     12000  5.3487e-04
     14000  4.6300e-04
     24000  1.0942e-04
     25055  4.4381e-05
     26000  2.0374e-04
     29000  1.0233e-04
' moderator isotopics
mix= 3
      8016  3.3369e-02
      1001  6.6737e-02
' lead wall isotopics
mix= 4
     82000  3.2771e-02
```

```
    29000  3.9239e-04
end mixt
'
'  ***********************************
'  *         setup geometry          *
'  *                                 *
'  *        12x16 pin lattice        *
'  ***********************************
'
read geometry
'
'
unit  1
com=" unit pin cell "
cylinder  1 1   0.63245  92.075  0.0
cylinder  0 1   0.64135  92.075  0.0
cylinder  2 1   0.70735  92.075  0.0
cuboid    3 1   0.946  -0.946   0.946  -0.946  92.075  0.0
'
'
unit 2 array 1  -11.352  -15.136   0.0
com=" 12x16 pin array (assembly)"
cuboid 3 1 11.35201 -11.35201 15.13601 -15.13601 92.075 0.0
'
'
unit 3
com=" critical separation water gap "
cuboid    3 1 11.35201  -11.35201  8.125 -8.125 92.075  0.0
'
'
global unit 4 array 2   0.0  0.0  0.0
com=" critical array geometry (3 assemblies) "
'inner cuboid shell for lead
cuboid 3 1 25.704   -3.0   145.148 -18.852 105.56 -17.84
'outer cuboid shell to fill w/lead
cuboid 4 1 35.904  -13.2   145.148 -18.852 105.56 -17.84
'cuboid of water tank
cuboid 3 1 53.20401 -30.501 170.878 -54.122  107.275 -17.84
end geometry
'
'
read array
ara=1 nux=12 nuy=16 nuz=1 fill 192r1 t end fill
ara=2 nux=1 nuy=5  nuz=1  fill 2 3 2 3 2 t end fill
end array
read start nst=1 end start
'
'  ***********************************
'  *         plot geometry           *
'  ***********************************
'
read plot
'
ttl=' xy pin cell by material'
nch=' o:-'
xul=0.0 xlr=1.892 yul=1.892 ylr=0.0 zul=50.0 zlr=50.0
uax=1.0 vdn=-1.0 nax=80 lpi=10 pic=mat   end
'
ttl=' xy section of 12x16 assembly by material'
nch=' oo-'
xul=0.0 xlr=22.704 yul=30.272 ylr=0.0 zul=50.0 zlr=50.0
uax=1.0 vdn=-1.0 nax=100 lpi=10 pic=mat   end
'
ttl=' xy section of critical array by material'
nch=' oo-*'
xul=-15.0 xlr=35.0 yul=140.0 ylr=-5.0 zul=50.0 zlr=50.0
uax=1.0 vdn=-1.0 nax=100 lpi=10 pic=mat   end
'
ttl=' xz section of critical array by material'
nch=' oo-*'
xul=-15.0 xlr=35.0 yul=1.27 ylr=1.27 zul=50.0 zlr=-10.0
uax=1.0 wdn=-1.0 nax=100 lpi=10 pic=mat   end
end plot
end data
end
```

```
=keno5
Simulated shipping container exp - 4.31 wt% fuel lead refl (npg=5000)
read parameters
tme=290.0 tba=60.0 gen=120 nsk=20 npg=5000 lib=4
flx=yes fdn=yes nub=yes pwt=yes
plt=yes run=yes
end parameters
'
'  ***********************************
'  *         setup mixtures          *
'  ***********************************
'
read mixt  sct=1
' fuel isotopics
mix= 1
     92234  5.1843e-06
       235  1.0104e-03
     92236  5.1403e-06
       238  2.2160e-02
      8016  4.5762e-02
' clad isotopics
mix= 2
     13027  5.8075e-02
     12000  5.3487e-04
     14000  4.6300e-04
     24000  1.0942e-04
     25055  4.4381e-05
     26000  2.0374e-04
     29000  1.0233e-04
' moderator isotopics
mix= 3
      8016  3.3369e-02
      1001  6.6737e-02
' lead wall isotopics
mix= 4
     82000  3.2771e-02
     29000  3.9239e-04
end mixt
'
'  ***********************************
'  *         setup geometry          *
'  *                                 *
'  *        12x16 pin lattice        *
'  ***********************************
'
read geometry
'
'
unit  1
com=" unit pin cell "
cylinder  1 1   0.63245  92.075  0.0
cylinder  0 1   0.64135  92.075  0.0
cylinder  2 1   0.70735  92.075  0.0
cuboid    3 1   0.946  -0.946   0.946  -0.946  92.075  0.0
'
'
unit 2 array 1  -11.352  -15.136   0.0
com=" 12x16 pin array (assembly)"
cuboid 3 1 11.35201 -11.35201 15.13601 -15.13601 92.075 0.0
'
'
unit 3
com=" critical separation water gap "
cuboid    3 1 11.35201  -11.35201  7.175 -7.175 92.075  0.0
'
'
global unit 4 array 2   0.0  0.0  0.0
com=" critical array geometry (3 assemblies) "
'inner cuboid shell for lead
cuboid 3 1 28.109   -5.405   145.148 -18.852 105.56 -17.84
'outer cuboid shell to fill w/lead
cuboid 4 1 38.309  -15.605   145.148 -18.852 105.56 -17.84
'cuboid of water tank
cuboid 3 1 53.20401 -30.501 170.878 -54.122  107.275 -17.84
end geometry
```

```
'
'
re  array
a   nux=12 nuy=16 nuz=1 fill 192r1 t end fill
ara 2 nux=1 nuy=5  nuz=1  fill 2 3 2 3 2 t end fill
end array
read start nst=1 end start
'
' ************************************
' *         plot geometry            *
' ************************************
'
read plot
'
ttl=' xy pin cell by material'
nch=' o:-'
xul=0.0 xlr=1.892 yul=1.892 ylr=0.0 zul=50.0 zlr=50.0
uax=1.0 vdn=-1.0 nax=80 lpi=10 pic=mat   end
'
ttl=' xy section of 12x16 assembly by material'
nch=' oo-'
xul=0.0 xlr=22.704 yul=30.272 ylr=0.0 zul=50.0 zlr=50.0
uax=1.0 vdn=-1.0 nax=100 lpi=10 pic=mat   end
'
ttl=' xy section of critical array by material'
nch=' oo-*'
xul=-15.0 xlr=35.0 yul=140.0 ylr=-5.0 zul=50.0 zlr=50.0
uax=1.0 vdn=-1.0 nax=100 lpi=10 pic=mat   end
'
ttl=' xz section of critical array by material'
nch=' oo-*'
xul=-15.0 xlr=35.0 yul=1.27 ylr=1.27 zul=50.0 zlr=-10.0
uax=1.0 wdn=-1.0 nax=100 lpi=10 pic=mat   end
end plot
end data
e
=k  
Simulated shipping container exp - 4.31 wt% fuel water refl
(npg=5000)
read parameters
tme=290.0 tba=60.0 gen=120 npg=5000 lib=4
flx=yes fdn=yes nub=yes pwt=yes
plt=yes run=yes nsk=20
end parameters
'
' ************************************
' *         setup mixtures           *
' ************************************
'
read mixt  sct=1
' fuel isotopics
mix= 1
    92234  5.1843e-06
      235  1.0104e-03
    92236  5.1403e-06
      238  2.2160e-02
     8016  4.6762e-02
' clad isotopics
mix= 2
    13027  5.8075e-02
    12000  5.3487e-04
    14000  4.6300e-04
    24000  1.0942e-04
    25055  4.4381e-05
    26000  2.0374e-04
    29000  1.0233e-04
' moderator isotopics
m
     8016  3.3369e-02
     1001  6.6737e-02
end mixt
'
' ************************************
' *         setup geometry           *
' *                                  *
' *         12x16 pin lattice        *
' ************************************
'
read geometry
'
'
unit  1
com=" unit pin cell "
cylinder  1 1   0.63245  92.075  0.0
cylinder  0 1   0.64135  92.075  0.0
cylinder  2 1   0.70735  92.075  0.0
cuboid    3 1   0.946  -0.946   0.946  -0.946  92.075  0.0
'
'
unit 2 array 1  -11.352  -15.136  0.0
com=" 12x16 pin array (assembly)"
cuboid 3 1 11.35201 -11.35201 15.13601 -15.13601 92.075 0.0
'
'
unit 3
com=" critical separation water gap "
cuboid    3 1 11.352  -11.352   6.485  -6.485  92.075  0.0
'
'
global unit 4 array 2   0.0  0.0  0.0
com=" critical array geometry (3 assemblies) "
cuboid 3 1 53.20401 -30.501 147.25603 -30.503 107.275 -17.84
end geometry
'
'
read array
ara=1 nux=12 nuy=16 nuz=1 fill 192r1 t end fill
ara=2 nux=1 nuy=5  nuz=1  fill 2 3 2 3 2 t end fill
end array
read start nst=1 end start
'
' ************************************
' *         plot geometry            *
' ************************************
'
read plot
'
ttl=' xy pin cell by material'
nch=' o:-'
xul=0.0 xlr=1.892 yul=1.892 ylr=0.0 zul=50.0 zlr=50.0
uax=1.0 vdn=-1.0 nax=80 lpi=10 pic=mat   end
'
ttl=' xy section of 12x16 assembly by material'
nch=' oo-'
xul=0.0 xlr=22.704 yul=30.272 ylr=0.0 zul=50.0 zlr=50.0
uax=1.0 vdn=-1.0 nax=100 lpi=10 pic=mat   end
'
ttl=' xy section of critical array by material'
nch=' oo-'
xul=-5.0 xlr=25.0 yul=140.0 ylr=-5.0 zul=50.0 zlr=50.0
uax=1.0 vdn=-1.0 nax=100 lpi=10 pic=mat   end
'
ttl=' xz section of critical array by material'
nch=' oo-'
xul=-5.0 xlr=25.0 yul=1.27 ylr=1.27 zul=100.0 zlr=-10.0
uax=1.0 wdn=-1.0 nax=100 lpi=10 pic=mat   end
end plot
end data
end
```

Input File for 2.35 wt% Optimum Moderated UO_2 Rods with Lead Reflector at Various Distances

```
=nitawl
0$$    82       2        3        4      18
         19      20        9       15
1$$    500      17        0        0       0
  0        0        5        0        0
  0        0
t
2$$  92235   92238   13027  14000  25055
```

```
    29000 -29001   12000    24000
    48000   26000  -26001  22000
     8016    1001   17000   82000
3**  92235    293       2  0.5588 0.0897
      0.0   4.8828E-04      1 15.9994   3.1135E+02
 1      238.0508    4.3490E+02        1  1.000
   92238     293       2  0.5588 0.0897
      0.0   2.0033E-02      1 15.9994   7.5886E+00
 1      235.0439    2.8517E-01        1  1.000
   26001     293       2  0.6350 0.0000
  0.5588    2.0305E-04      1        26.98154   3.9906E+02
 1 30.4624     2.3202E+01       1  1.000
   29001     293       2  0.6350 0.0000
  0.5588    1.0197E-04      1        26.98154   7.9463E+02
 1 34.0419     6.1400E+01       1  1.000
   24000     293       2  0.6350 0.0000
  0.5588    1.0904E-04      1        26.98154   7.4309E+02
 1 35.0863     6.0131E+01       1  1.000
4**  f293
t
end             =kenova
2.35 wt%  UO2 rods       with lead      reflector at  0.00 in
read param
tme=700    gen=120 nsk=20  npg=5000      nfb=8000
flx=yes    fdn=yes plt=yes run=yes tba=60.0
nub=yes    lib=4
end param
'***************
'* MIXTURES *
'***************
read mixt  sct=1
'Fuel
mix=1
     92235   4.8828E-04
    92238   2.0033E-02
     8016   4.1043E-02
'Clad
mix=2
    13027    5.7878E-02
    14000    2.3072E-04
    26001    2.0305E-04
    29001    1.0197E-04
    25055    4.4230E-05
    12000    7.9981E-04
    24000    1.0904E-04
    22000    5.0729E-05
'Water
mix=3
     8016    3.3427E-02
     1001    6.6854E-02
    17000    1.0095E-06
    26000    3.2350E-10
    82000    3.8609E-10
    48000    5.3798E-11
'Lead
mix=4
    82000    3.2771E-02
    29000    1.3909E-04
end mixt
'***************
'* GEOMETRY  *
'***************
read geom
unit 1
'Fuel
  cylinder 1  1    0.5588   91.44      0
'Al Clad
  cylinder 2  1     0.635   91.44      0
'Al End Plugs
  cylinder 2  1     0.635   96.52  -1.27
    cuboid 3  1     1.016 -1.016  1.016 -1.016 96.52  -1.27
unit 2      array 1       -16.256 -19.304       0
unit 3
com="Crit  Separation"
    cuboid 3  1    2p16.256   2p5.920     96.52  -1.27
```

```
global unit 4     array 2 0 0 0
'Inner shell lea
    cuboid 3  1     32.512 0.00    153.75 -10.25 109.33 -14.0
'Outer shell of
    cuboid 4  1     42.71 -10.20   153.75 -10.25 109.33 -14.0
'Water tank
    cuboid 3  1     63.01 -30.50   174.00 -30.50 121.94 -30.5
end geom

read array
ara=1 nux=16      nuy=19  nuz=1 fill     304r1 t end fill
ara=2 nux=1       nuy=5   nuz=1 fill     2 3 2 3 2 t   end fill
end array
read start nst=1   end start
end data
end                  =kenova
2.35 wt%  UO2 rods      with lead      reflector at  0.26 in
read param
tme=700    gen=120 nsk=20  npg=5000      nfb=8000
flx=yes    fdn=yes plt=yes run=yes tba=60.0
nub=yes    lib=4
end param
'***************
'* MIXTURES *
'***************
read mixt  sct=1
'Fuel
mix=1
     92235   4.8828E-04
    92238    2.0033E-02
     8016    4.1043E-02
'Clad
mix=2
    13027    5.7878E-02
    14000    2.3072E-04
    26001    2.0305E-04
    29001    1.0197E-04
    25055    4.4230E-05
    12000    7.9981E-04
    24000    1.0904E-04
    22000    5.0729E-05
'Water
mix=3
     8016    3.3427E-02
     1001    6.6854E-02
    17000    1.0095E-06
    26000    3.2350E-10
    82000    3.8609E-10
    48000    5.3798E-11
'Lead
mix=4
    82000    3.2771E-02
    29000    1.3909E-04
end mixt
'***************
'* GEOMETRY  *
'***************
read geom
unit 1
'Fuel
  cylinder 1  1     0.5588   91.44      0
'Al Clad
  cylinder 2  1      0.635   91.44      0
'Al End Plugs
  cylinder 2  1      0.635   96.52  -1.27
    cuboid 3  1     1.016 -1.016  1.016 -1.016 96.52  -1.27
unit 2      array 1       -16.256 -19.304       0
unit 3
com="Crit  Separation"
    cuboid 3  1     2p16.256   2p5.860     96.52  -1.27
global unit 4     array 2 0 0 0
'Inner shell lea
    cuboid 3  1     33.172 -0.65  153.63 -10.37 109.33 -14.0
'Outer shell of
    cuboid 4  1     43.37 -10.86  153.63 -10.37 109.33 -14.0
```

```
'Water tank
   cuboid 3  1    63.01 -30.50  173.76 -30.50 121.94 -30.5
end geom

read array
ara=1 nux=15     nuy=19  nuz=1 fill    304r1 t end fill
ara=2 nux=1      nuy=5   nuz=1 fill    2 3 2 3 2 t   end fill
end array
read start nst=1   end start
end data
end
=kenova
2.35 wt%  UO2 rods      with lead     reflector at  1.03 in
read param
tme=700    gen=120 nsk=20  npg=5000      nfb=6000
flx=yes    fdn=yes plt=yes run=yes tba=60.0
nub=yes    lib=4
end param
'***************
'* MIXTURES *
'***************
read mixt  sct=1
'Fuel
mix=1
    92235   4.8828E-04
   92238    2.0033E-02
    8016    4.1043E-02
'Clad
mix=2
   13027    5.7878E-02
   14000    2.3072E-04
   26001    2.0305E-04
   29001    1.0197E-04
   25055    4.4230E-05
   12000    7.9981E-04
   24000    1.0904E-04
   22000    5.0729E-05
'Water
mix=3
    8016    3.3427E-02
    1001    6.6854E-02
   17000    1.0095E-06
   26000    3.2350E-10
   82000    3.8609E-10
   48000    5.3798E-11
'Lead
mix=4
   82000    3.2771E-02
   29000    1.3909E-04
end mixt
'***************
'* GEOMETRY  *
'***************
read geom
unit 1
'Fuel
  cylinder 1  1    0.5588   91.44      0
'Al Clad
  cylinder 2  1     0.635   91.44      0
'Al End Plugs
  cylinder 2  1     0.635   96.52  -1.27
    cuboid 3  1     1.016 -1.016  1.016 -1.016 96.52  -1.27
unit 2      array 1       -16.256 -19.304     0
unit 3
com="Crit  Separation"
    cuboid 3  1    2p16.256   2p5.625    96.52  -1.27
global unit 4    array 2 0 0 0
     shell lea
    cuboid 3  1    35.128 -2.62  151.16 -12.84 109.33 -14.0
'Outer shell of
    cuboid 4  1    45.33 -12.82  151.16 -12.84 109.33 -14.0
'Water tank
    cuboid 3  1    63.01 -30.50  168.82 -30.50 121.94 -30.5
end geom

read array
ara=1 nux=16     nuy=19  nuz=1 fill    304r1 t end fill
ara=2 nux=1      nuy=5   nuz=1 fill    2 3 2 3 2 t   end fill
end array
read start nst=1   end start
end data
end             =kenova
2.35 wt%  UO2 rods      without lead  reflector
read param
tme=700    gen=120 nsk=20  npg=5000      nfb=8000
flx=yes    fdn=yes plt=yes run=yes tba=60.0
nub=yes    lib=4
end param
'***************
'* MIXTURES *
'***************
read mixt  sct=1
'Fuel
mix=1
    92235   4.8828E-04
   92238    2.0033E-02
    8016    4.1043E-02
'Clad
mix=2
   13027    5.7878E-02
   14000    2.3072E-04
   26001    2.0305E-04
   29001    1.0197E-04
   25055    4.4230E-05
   12000    7.9981E-04
   24000    1.0904E-04
   22000    5.0729E-05
'Water
mix=3
    8016    3.3427E-02
    1001    6.6854E-02
   17000    1.0095E-06
   26000    3.2350E-10
   82000    3.8609E-10
   48000    5.3798E-11
'Lead
mix=4
   82000    3.2771E-02
   29000    1.3909E-04
end mixt
'***************
'* GEOMETRY  *
'***************
read geom
unit 1
'Fuel
  cylinder 1  1    0.5588   91.44      0
'Al Clad
  cylinder 2  1     0.635   91.44      0
'Al End Plugs
  cylinder 2  1     0.635   96.52  -1.27
    cuboid 3  1     1.016 -1.016  1.016 -1.016 96.52  -1.27
unit 2      array 1       -16.256 -19.304      0
unit 3
com="Crit  Separation"
    cuboid 3  1    2p16.256   2p4.155    96.52  -1.27
global unit 4    array 2 0 0 0
'Water tank
    cuboid 3  1    63.01 -30.50  162.94 -30.50 121.94 -30.5
end geom

read array
ara=1 nux=16     nuy=19  nuz=1 fill    304r1 t end fill
ara=2 nux=1      nuy=5   nuz=1 fill    2 3 2 3 2 t   end fill
end array
read start nst=1   end start
end data
end
```

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Input File for 2.35 wt% Undermoderated UO_2 Rods with Lead Reflector at Various Distances

```
=nitawl
0$$   82       2        3        4        18
      19       20       9        15
1$$   500      17       0        0        0
      0        0        5        0        0
      0        0
t
2$$   92235    92238    13027    14000    25055
      29000    -29001   12000    24000
      48000    26000    -26001   22000
      8016     1001     17000    82000
3**   92235    293      2        0.5588   0.2098
      0.0 4.8828E-04    1        15.9994  3.1135E+02
      1   238.0508  4.3490E+02   1        1.000
      92238    293      2        0.5588   0.2098
      0.0 2.0033E-02    1        15.9994  7.5686E+00
      1   236.0439  2.8517E-01   1        1.000
      26001    293      2        0.6350   0.0000
      0.5588  2.0305E-04   1     26.98154 3.9906E+02
      1   30.4624   2.3202E+01   1        1.000
      29001    293      2        0.6350   0.0000
      0.5588  1.0197E-04   1     26.98154 7.9463E+02
      1   34.0419   6.1400E+01   1        1.000
      24000    293      2        0.6350   0.0000
      0.5588  1.0904E-04   1     26.98154 7.4309E+02
      1   35.0863   6.0131E+01   1        1.000
4**      f293
t
end
=kenova
2.35 wt% UO2 Rods P=1.684 (Undermod)   lead reflector @ 0.00
read param
tme=700    gen=120    nsk=20    tba=60.0    npg=5000
flx=yes    fdn=yes    nub=yes   lib=4       nfb=8000
end param
'******************
'* MIXTURES *
'******************
read mixt    sct=1
'Fuel
mix=1
        92235 4.8828E-04
        92238 2.0033E-02
         8016 4.1043E-02
'Clad
mix=2
        13027 5.7878E-02
        14000 2.3072E-04
        26001 2.0305E-04
        29001 1.0197E-04
        25055 4.4230E-05
        12000 7.9981E-04
        24000 1.0904E-04
        22000 5.0729E-05
'Water
mix=3
         8016 3.3427E-02
         1001 6.6854E-02
        17000 8.4931E-08
        26000 2.5680E-07
        82000 1.4532E-11
        48000 5.3573E-12
'Lead
mix=4
        82000 3.2771E-02
        29000 1.3909E-04
end mixt
'******************
'* GEOMETRY *
'******************
read geom
unit 1
'Fuel
   cylinder 1  1           0.5588     91.44      0
'Al Clad
   cylinder 2  1           0.635      91.44      0
'Al End Plugs
   cylinder 2  1           0.635      96.52     -1.27
     cuboid 3  1         4p0.842      96.52     -1.27
unit 2 array 1            -15.156    -19.366    -1.27
com="Center Cluster"
unit 3 array 2            -15.156    -16.84     -1.27
com="End Cluster"
unit 4
com="Critical Separation - Water Gap"
     cuboid 3  1     2p15.156    2p5.030    96.52 -1.27
global unit 5 array 3    0 0 0
'Inner shell lead
     cuboid 3  1     30.312 0.00  145.11 -18.89 109.33 -14.08
'Outer shell of lead
     cuboid 4  1     40.51 -10.20 145.11 -18.89 109.33 -14.08
'Water tank
     cuboid 3  1     60.81 -30.50 156.71 -30.50 127.02 -30.50
end geom
read array
ara=1 nux=18 nuy=23 nuz=1     fill 414r1 t end fill
ara=2 nux=18 nuy=20 nuz=1     fill 360r1 t end fill
ara=3 nux=1   nuy=5    nuz=1     fill 3 4 2 4 3 t end fill
end array
end data
end
=kenova
2.35 wt% UO2 Rods P=1.684 (Undermod)   lead reflector @ 0.26
read param
tme=700    gen=120    nsk=20    tba=60.0    npg=5000
flx=yes    fdn=yes    nub=yes   lib=4       nfb=8000
end param
'******************
'* MIXTURES *
'******************
read mixt    sct=1
'Fuel
mix=1
        92235 4.8828E-04
        92238 2.0033E-02
         8016 4.1043E-02
'Clad
mix=2
        13027 5.7878E-02
        14000 2.3072E-04
        26001 2.0305E-04
        29001 1.0197E-04
        25055 4.4230E-05
        12000 7.9981E-04
        24000 1.0904E-04
        22000 5.0729E-05
'Water
mix=3
         8016 3.3427E-02
         1001 6.6854E-02
        17000 8.4931E-08
        26000 2.5680E-07
        82000 1.4532E-11
        48000 5.3573E-12
'Lead
mix=4
        82000 3.2771E-02
        29000 1.3909E-04
end mixt
'******************
'* GEOMETRY *
'******************
read geom
unit 1
'Fuel
   cylinder 1  1           0.5588     91.44      0
'Al Clad
```

```
   cylinder 2  1                0.635      91.44          0
'Al End Plugs
   cylinder 2  1                0.635      96.52      -1.27
     cuboid 3  1              4p0.842      96.52      -1.27
unit 2 array 1                -15.156    -19.366      -1.27
com="Center Cluster"
unit 3 array 2                -15.156     -16.84      -1.27
com="End Cluster"
unit 4
com="Critical Separation - Water Gap"
     cuboid 3  1        2p15.156       2p5.055      96.52 -1.27
global unit 5 array 3   0 0 0
'Inner shell lead
     cuboid 3  1        30.972 -0.66 145.16 -18.84 109.33 -14.08
'Outer shell of lead
     cuboid 4  1        41.17 -10.85 145.16 -18.84 109.33 -14.08
'Water tank
     cuboid 3  1        60.81 -30.50 156.81 -30.50 127.02 -30.50
end geom
'
read array
ara=1 nux=18 nuy=23 nuz=1     fill 414r1 t end fill
ara=2 nux=18 nuy=20 nuz=1     fill 360r1 t end fill
ara=3 nux=1   nuy=5    nuz=1    fill 3 4 2 4 3 t end fill
end array
end data
end
=kenova
2.35 wt% UO2 Rods P=1.684 (Undermod)   lead reflector @ 1.29
read param
tme=700     gen=120     nsk=20     tba=60.0     npg=5000
flx=yes     fdn=yes     nub=yes    lib=4        nfb=8000
end param
'*******************
'* MIXTURES *
'*******************
read mixt    sct=1
'Fuel
mix=1
       92235 4.8828E-04
       92238 2.0033E-02
        8016 4.1043E-02
'Clad
mix=2
       13027 5.7878E-02
       14000 2.3072E-04
       26001 2.0305E-04
       29001 1.0197E-04
       25055 4.4230E-05
       12000 7.9981E-04
       24000 1.0904E-04
       22000 5.0729E-05
'Water
mix=3
        8016 3.3427E-02
        1001 6.6854E-02
       17000 8.4931E-08
       26000 2.5880E-07
       82000 1.4532E-11
       48000 5.3573E-12
'Lead
mix=4
       82000 3.2771E-02
       29000 1.3909E-04
end mixt
'*******************
'* GEOMETRY  *
'*******************
read geom
unit 1
'Fuel
   cylinder 1  1                0.5588     91.44          0
'Al Clad
   cylinder 2  1                0.635      91.44          0
'Al End Plugs
```

```
   cylinder 2  1                0.635      96.52      -1.27
     cuboid 3  1              4p0.842      96.52      -1.27
unit 2 array 1                -15.156    -19.366      -1.27
com="Center Cluster"
unit 3 array 2                -15.156     -16.84      -1.27
com="End Cluster"
unit 4
com="Critical Separation - Water Gap"
     cuboid 3  1        2p15.156       2p4.250      96.52 -1.27
global unit 5 array 3   0 0 0
'Inner shell lead
     cuboid 3  1        33.588 -3.28 143.55 -20.45 109.33 -14.08
'Outer shell of lead
     cuboid 4  1        43.79 -13.48 143.55 -20.45 109.33 -14.08
'Water tank
     cuboid 3  1        60.81 -30.50 153.59 -30.50 127.02 -30.50
end geom
'
read array
ara=1 nux=18 nuy=23 nuz=1     fill 414r1 t end fill
ara=2 nux=18 nuy=20 nuz=1     fill 360r1 t end fill
ara=3 nux=1   nuy=5    nuz=1    fill 3 4 2 4 3 t end fill
end array
end data
end
=kenova
2.35 wt% UO2 Rods P=1.684 (Undermod)   without lead reflector
read param
tme=700     gen=120     nsk=20     tba=60.0     npg=5000
flx=yes     fdn=yes     nub=yes    lib=4        nfb=8000
end param
'*******************
'* MIXTURES *
'*******************
read mixt    sct=1
'Fuel
mix=1
       92235 4.8828E-04
       92238 2.0033E-02
        8016 4.1043E-02
'Clad
mix=2
       13027 5.7878E-02
       14000 2.3072E-04
       26001 2.0305E-04
       29001 1.0197E-04
       25055 4.4230E-05
       12000 7.9981E-04
       24000 1.0904E-04
       22000 5.0729E-05
'Water
mix=3
        8016 3.3427E-02
        1001 6.6854E-02
       17000 8.4931E-08
       26000 2.5880E-07
       82000 1.4532E-11
       48000 5.3573E-12
'Lead
mix=4
       82000 3.2771E-02
       29000 1.3909E-04
end mixt
'*******************
'* GEOMETRY  *
'*******************
read geom
unit 1
'Fuel
   cylinder 1  1                0.5588     91.44          0
'Al Clad
   cylinder 2  1                0.635      91.44          0
'Al End Plugs
   cylinder 2  1                0.635      96.52      -1.27
     cuboid 3  1              4p0.842      96.52      -1.27
```

```
unit 2 array 1                 -15.156      -19.366        -1.27
com="Center Cluster"
unit 3 array 2                 -15.156      -16.84         -1.27
com="End Cluster"
unit 4
com="Critical Separation - Water Gap"
    cuboid 3  1          2p15.156       2p3.295      96.52 -1.27
global unit 5 array 3    0 0 0
'Water tank
    cuboid 3  1          60.81 -30.50 149.77 -30.50 127.02 -30.50
end geom
'
read array
ara=1 nux=18 nuy=23 nuz=1     fill 414r1 t end fill
ara=2 nux=18 nuy=20 nuz=1     fill 360r1 t end fill
ara=3 nux=1   nuy=5    nuz=1     fill 3 4 2 4 3 t end fill
end array
end data
end
```

Appendix B Input Files for Benchmarks used for the Statistical Analysis of the Calculations in this Basis Memo

Input File for 239Pu Water Reflected Critical Mass as given in Table 5.

```
=nitawl
0$$  82  2 3 4 18 19 9 15 20
1$$  500 12 0 0 0 0 0 9 0 0 0 0
t
2$$    94239   -23901   -23902   -23903   -23904
         -23905   -23906   -23908   -23911
         -23914
     1001    8016
3**    23901     293      3    17.540    0.000
      0.0  6.1468E-5     1    1.0079   2.2161E4
       1   15.9994  2.0119E3     1      1.000
     23902     293      3   15.700    0.000
      0.0  8.3637E-5     1    1.0079   1.6280E4
       1   15.9994  1.4780E3     1      1.000
     23903     293      3   15.130    0.000
      0.0  9.7240E-5     1    1.0079   1.3999E4
       1   15.9994  1.2708E3     1      1.000
     23904     293      3   15.100    0.000
      0.0  9.7492E-5     1    1.0079   1.3962E4
       1   15.9994  1.2676E3     1      1.000
     23905     293      3   14.370    0.000
      0.0  1.1966E-4     1    1.0079   1.1371E4
       1   15.9994  1.0323E3     1      1.000
     23906     293      3   13.230    0.000
      0.0  1.8390E-4     1    1.0079   7.3891E3
       1   15.9994  6.7081E2     1      1.000
     23908     293      3   12.640    0.000
      0.0  2.5192E-4     1    1.0079   5.3867E3
       1   15.9994  4.8903E2     1      1.000
     23911     293      3   12.210    0.000
      0.0  7.4316E-4     1    1.0079   1.8080E3
       1   15.9994  1.6414E2     1      1.000
     23914     293      3    8.390    0.000
      0.0  1.0480E-2     1    1.0079   1.0288E2
       1   15.9994  9.340100     1      1.000
4**    F293
end
=keno5
pu 24.4g/l sphere with water reflector (npg=5000)
read param tme=200.0 lib=4 nsk=20 gen=120 flx=yes
fdn=yes npg=5000 nub=yes tba=60.0 end param
read geometry sphere 1 1 17.54
sphere 2 1 48.02
cuboid 0 1 6P48.05
end geom
read mixt mix=1 23901 6.1468-5 8016 3.3387-2 1001 6.6774-2
mix=2 8016 3.34558-2 1001 6.69116-2 sct=1 end mixt
end data                                              end
```

Input File for 239Pu with a Thin Steel Shell and Full Water Reflection as given in Table 5.

```
=nitawl
0$$    82     2     3     4     18
       19     9    15    20
1$$    500    12     0     0     0
       0      0     2     0     0
       0      0
t
2$$    8016    7014    1001
     24000   28000   26000   -26001
     94238   94239   94240   94241   94242
3**    94239   299.8      3  17.7800   0.0000
      0.0 6.6004E-05      1  1.0079 2.0092E-04
       1  15.8772 2.0505E+03    1    1.000
     26001   299.8      3  17.9070   0.000
      0.0   0.0618      1   58.69    2.312
       1  51.9960 1.1546E-00      1    1.000
4**  F299.8
t
end
keno5
J BENCHMARK 4 SPHERE WITH STEEL SHELL AND WATER REFLECTOR
(npg=5000)    read param tme=200.0 lib=4 nsk=20 gen=120 flx=yes
fdn=yes nub=yes npg=5000 tba=60.0 end param
read geometry sphere 1 1 17.78
sphere 2 1 17.907
sphere 3 1 46.000
cuboid 0 1 6P46.100
end geom
read mixt mix=1 94239 6.6004-5 94240 3.5692-7
7014 7.5114-4 8016 3.4514-2 1001 6.5006-2 26000 1.5457-6
mix=2 26001 6.175E-2 24000 1.658-2 28000 8.158-3
mix=3 8016 3.332-2 1001 6.663-2 sct=1 end mixt
end data                                              end
```

Input File for 239Pu with a Thin Steel Shell and No Water Reflection as given in Table 5.

```
=nitawl
0$$     82      2      3      4      18
        19      9     15     20
1$$    500     12      0      0      0
        0      0      3      0      0
        0      0
t
2$$    8016    7014    1001    26000   -26001
     24000   28000
     94238   94239   94240   94241   94242
3**    94239   299.8     3  19.3180   0.0000
      0.0 8.2232E-05     1   1.0079 1.6254E+04
       1  15.8987 1.6340E-03     1    1.000
     94240   299.8     3  19.3180   0.0000
      0.0 3.9521E-06     1   1.0079 3.3992E+05
       1  16.0003 3.4396E+04     1    1.000
     26001   299.8     3  19.4400   0.0000
      0.0 6.3310E-02     1   58.69 1.7995E+00
       1  51.9960 1.1234E+00     1    1.000
4**  f299.8
t
end
=keno5
PU BENCHMARK 4 SPHERE WITH STEEL REFLECTOR (npg=5000)
read param tme=200.0 lib=4 nsk=20 gen=120 flx=yes
fdn=yes npg=5000 nub=yes tba=60.0 end param
read geometry sphere 1 1 19.318
sphere 2 1 19.44
cuboid 0 1 6P19.5
end geom
read mixt mix=1 94239 8.2232-5 94240 3.9521-6 94241 2.6356-7
94242 5.3567-9 7014 6.4132-4 8016 3.4536-2 1001 6.5520-2 26000 6.965-7
mix=2 26001 6.331E-2 24000 1.654-2 28000 6.51-3 sct=1 end mixt
end data                                              end
```

Input File for 239Pu with a thin Steel Shell plus a 4" Concrete Shell as given in Table 5.

```
=nitawl
0$$     82      2      3      4      18
        19      9     15     20
1$$    500     20      0      0      0
        0      0      6      0      0
        0      0
t
2$$    8016    7014    1001    24000   28000
     94238   94239   94240   94241   94242
     26000   -26001  -26002   12000   13027
     20000   19000   25055   14000   11023
3**    94239    296      3  17.8700   0.0000
      0.0 8.5060E-05     1   1.0079 1.4673E+04
       1  15.7040 1.8144E+03     1    1.000
     94240    296      3  17.8700   0.0000
      0.0 4.0700E-06     1   1.0079 3.0665E+05
       1  15.7945 3.8144E+04     1    1.000
     26001    296      3  17.9820   0.0000
      0.0 6.3310E-02     1   58.69 1.7995E+00
       1  51.9960 1.1234E+00     1    1.000
     26002    296 3.0000E+00  28.142   0.0000
      0.0  0.0013      1   1.0079   264.045
       1  18.0027 1.6293E-02     1    1.000
     25055    296 3.0000E-00  28.142   0.0000
      0.0 2.7560E-05     1   1.0079 12857.329
       1  18.8550 8.4872E-03     1    1.000
     11023    296 3.0000E-00  28.142   0.0000
      0.0 1.1450E-04     1   1.0079  3094.742
       1  18.8523 2.0401E-03     1    1.000
4**  f296
t
end
=keno5
PU BENCHMARK 21 SPHERE WITH STEEL SHELL AND CONCRETE REFLECTOR
```

```
(5000)
read param tme=200.0 lib=4 nsk=20 gen=120 flx=yes
fdn=yes npg=5000 nub=yes tba=60.0 end param
read geometry sphere 1 1 17.87
sphere 2 1 17.982
sphere 3 1 28.142
cuboid 0 1 6P28.2
end geom
read mixt
'PU ISOTOPICS
mix=1 94239 8.506-5 94240 4.070-6 94241 2.7-7
94242 6.0-9 7014 2.098-3 8016 3.601-2 1001 6.118-2 26000 7.3-7
'STEEL VESSEL ISOTOPICS
mix=2 26001 6.331E-2 24000 1.654-2 28000 6.51-3
'CONCRETE ISOTOPICS
mix=3 12000 7.62-4 13027 3.353-3 20000 2.609-3 26002 1.342-3
19000 4.358-4 25055 2.756-5 14000 1.293-2 1001 1.737-2
11023 1.145-4 8016 4.529-2 sct=1 end mixt
end data                                          end
```

Input File for ^{239}Pu with a 4" Concrete Shell as given in Table 5.

```
=nitawl
0$$    82     2     3     4     18
             19     9    15     20
1$$    500    16    0     0     0
        0     0     6     0     0
        0     0
t
2$$    8016    7014    1001    94239    94240
     26000   -26001   12000    13027    20000
     19000    25055   14000    11023    24000
     28000
3**    94239    298     3  17.7800   0.0000
      0.0 7.8828E-05    1   1.0079 1.6419E-04
       1  15.8238 1.7975E+03    1     1.000
     94240     298     3  17.7800   0.0000
      0.0 3.7851E-06    1   1.0079 3.4195E+05
       1  15.9157 3.7659E+04    1     1.000
     26000     298     3 17.89176   0.0000
      0.0 6.3310E-02    1    58.69    1.799
       1  51.9960 1.1234E+00    1     1.000
     26001     298     3 28.05176   0.0000
      0.0 1.3417E-03    1   1.0079 2.6444E+02
       1  17.6042 1.5657E+02    1     1.000
     25055     298     3 28.05176   0.0000
      0.0 2.7673E-05    1   1.0079 1.2821E+04
       1  18.4810 8.1422E+03    1     1.000
     11023     298     3 28.05176   0.0000
      0.0 1.1417E-04    1   1.0079 3.1077E+03
       1  18.4778 1.9708E+03    1     1.000
4** f298
t
end
=keno5
PU SPHERE WITH STEEL SHELL AND 4" CONCRETE REFLECTOR (npg=5000)
read param tme=200.0 lib=4 nsk=20 tba=60.0 gen=120 flx=yes
fdn=yes plt=yes nub=yes run=yes npg=5000 end param
read geometry sphere 1 1 17.78
sphere 2 1 17.8918
sphere 3 1 28.05
cuboid 0 1 6P28.1
end geom
read mixt
'PU ISOTOPICS
mix=1 94239 7.883-5
94240 3.785-6
7014 1.146-3
8016 3.516-2
1001 6.345-2
'STEEL VESSEL ISOTOPICS
mix=2 26000 6.331E-2
24000 1.654-2
28000 6.51-3
'CONCRETE ISOTOPICS
mix=3
12000 7.619-4
13027 3.353-3
20000 2.609-3
26001 1.342-3
19000 4.357-4
25055 2.767-5
14000 1.293-2
1001 1.739-2
11023 1.142-4
8016 4.53-2
sct=1 end mixt
read plot
ttl='XY SECTION THROUGH CENTER OF SPHERE'
nch=' O-*'
xul=-45.0 xlr=45.0 yul=45.0 ylr=-45.0 zul=0.0 zlr=0.0
uax=1.0 vdn=-1.0 nax=80.0 lpi=10.0 pic=mat end plot
end data                                          end
```

Input File for ^{239}Pu with a 10" Concrete Shell as given in Table 5.

```
=nitawl
0$$    82     2     3     4     18
      19     9    15     20
1$$    500    16    0     0     0
        0     0     6     0     0
        0     0
t
2$$    8016    7014    1001    94239    94240
     26000   -26001   12000    13027    20000
     19000    25055   14000    11023    28000
     24000
3**    94239    298     3  17.7800   0.0000
      0.0 7.1137E-05    1   1.0079 1.7945E+04
       1  15.8213 1.9691E+03    1     1.000
     94240     298     3  17.7800   0.0000
      0.0 3.4158E-06    1   1.0079 3.7373E+05
       1  15.9052 4.1233E+04    1     1.000
     26000     298     3 17.89176   0.0000
      0.0 6.3310E-02    1    58.69  1.7995E+00
       1  51.9960 1.1234E+00    1     1.000
     26001     298     3 43.29176   0.0000
      0.0 1.3417E-03    1   1.0079 2.6444E+02
       1  17.6042 1.5657E+02    1     1.000
     25055     298     3 43.29176   0.0000
      0.0 2.7673E-05    1   1.0079 1.2821E+04
       1  18.4810 8.1422E+03    1     1.000
     11023     298     3 43.29176   0.0000
      0.0 1.1417E-04    1   1.0079 3.1077E+03
       1  18.4778 1.9708E+03    1     1.000
4** f298
t
end
=keno5
PU SPHERE WITH STEEL SHELL AND 10" CONCRETE REFLECTOR (npg=5000)
read param tme=200.0 lib=4 nsk=20 tba=60.0 gen=120 flx=yes
fdn=yes plt=yes nub=yes run=yes npg=5000 end param
read geometry sphere 1 1 17.78
sphere 2 1 17.8918
sphere 3 1 43.29
cuboid 0 1 6P44.0
end geom
read mixt
'PU ISOTOPICS
mix=1 94239 7.114-5
94240 3.416-6
7014 1.146-3
8016 3.473-2
1001 6.258-2
'STEEL VESSEL ISOTOPICS
mix=2 26000 6.331E-2
24000 1.654-2
28000 6.51-3
'CONCRETE ISOTOPICS
mix=3
12000 7.619-4
13027 3.353-3
20000 2.609-3
26001 1.342-3
19000 4.357-4
25055 2.767-5
14000 1.293-2
1001 1.739-2
11023 1.142-4
8016 4.53-2
sct=1 end mixt
read plot
ttl='XY SECTION THROUGH CENTER OF SPHERE'
nch=' O-*'
xul=-45.0 xlr=45.0 yul=45.0 ylr=-45.0 zul=0.0 zlr=0.0
uax=1.0 vdn=-1.0 nax=80.0 lpi=10.0 pic=mat end plot
```

```
end data                                         end
```

Input File for a 4x4 Concrete Reflected Array of 93.2 wt% Enriched Uranyl Nitrate at 67.28 g/l as given in Table 5.

```
=nitawl
0$$  82  2  3  4  18
     19  20  9  15
1$$  500  17  0  0  0
      0  0  6  0  0
      0  0
t
2$$  92235    92234    92236    92238    14000
     26000    7014     6012     8016     1001
     20000    22000    11023    12000    13027
     19000    16000
3** 92234 293  2   10.5600   0.9502
     0.0 1.7693E-06  1   1.0079  7.5125E+05
     1   16.1609  7.4984E+04  1   1.000
   92235 293  2   10.5600   0.9502
     0.0 1.6061E-04  1   1.0079  8.2758E+03
     1   15.9415  8.1445E+02  1   1.000
   92236 293  2   10.5600   0.9502
     0.0 7.4495E-07  1   1.0079  1.7843E+06
     1   16.1622  1.7811E+05  1   1.000
   92238 293  2   10.5600   0.9502
     0.0 9.1432E-06  1   1.0079  1.4537E+05
     1   16.1517  1.4502E+04  1   1.000
   26000 293  1   25.4000   0.0000
     0.0 2.5278E-04  1   1.0079  8.3939E+02
     1   16.7297  8.9763E+02  1   1.000
   11023 293  1   25.4000   0.0000
     0.0 3.8303E-04  1   1.0079  5.5395E+02
     1   16.8578  5.9671E+02  1   1.000
4**  f293
t
end
=kenova
ROT53 4x4 array of UN solution w/o sleeve (67.28 gU/l-21.12 cm diam cyl)
read param   gen=120     nsk=20  npg=5000    nfb=8000
xe=700       fdn=yes     plt=yes     run=yes     tba=60.0
flx=yes      lib=4  nub=yes
end param
read mixt
'**************
'* MIXTURES *
'**************
mix=1
'Fuel
      92234    1.7693E-06
      92235    1.6061E-04
      92236    7.4495E-07
      92238    9.1432E-06
  8016    3.4149E-02
  7014    4.2162E-04
  1001    6.5156E-02
mix=2
'Al tank
      13027    5.9469E-02
mix=3
'Concrete
      12000    7.1885E-04
      13027    1.1241E-03
      20000    8.0213E-03
      26000    2.5278E-04
      19000    4.8976E-04
      14000    7.7139E-03
  1001    1.0401E-02
      11023    3.8303E-04
  8016    4.2362E-02
  6012    6.4257E-03
  7014    1.9958E-05
      16000    8.2809E-05
      22000    2.9192E-05
end mixt
'**************
'* GEOMETRY *
'**************
read geom
unit 1
com="Sphere   U235 with     gU/l-21.12 cm  diam cyl)
    cylinder 1  1     0.505   0.00  -0.32
    cylinder 2  1     10.56   0.00  -0.32
    cylinder 1  1     10.56  27.15  -0.32
    cylinder 0  1     10.56  119.1  -0.32
    cylinder 2  1     10.96  119.1  -0.32
     cuboid 0  1   15.24 -15.24  15.24 -15.24  123.445 -0.32
unit 2
    cylinder 1  1     0.505  25.40  0.00
    cylinder 2  1     0.635  25.40  0.00
     cuboid 3  1   15.24 -15.24  15.24 -15.24   25.4  0.0
unit 3
    cylinder 1  1     0.505  5.00   0.00
    cylinder 2  1     0.635  5.00   0.00
     cuboid 0  1   15.24 -15.24  15.24 -15.24   5.0  0.0
unit 4
    cylinder 1  1     1.14   0.00  -0.32
    cylinder 2  1     10.56  0.00  -0.32
    cylinder 1  1     10.56  27.15  -0.32
    cylinder 0  1     10.56  119.1  -0.32
    cylinder 2  1     10.96  119.1  -0.32
     cuboid 0  1   15.24 -15.24  15.24 -15.24  123.445 -0.32
unit 5
    cylinder 1  1     1.140  25.40  0.00
    cylinder 2  1     1.270  25.40  0.00
     cuboid 3  1   15.24 -15.24  15.24 -15.24   25.4  0.0
unit 6
    cylinder 1  1     1.140  5.00   0.00
    cylinder 2  1     1.270  5.00   0.00
     cuboid 0  1   15.24 -15.24  15.24 -15:24   5.0  0.0
unit 7  array=1  0.0 0.0 0.0
unit 8  array=2  0.0 0.0 0.0
unit 9  array=3  0.0 0.0 0.0
unit 10
     cuboid 0  1    121.92  0.0    0.14  0.0     5.0  0.0
     cuboid 3  1    121.92  0.0    0.14  0.0    30.4  0.0
     cuboid 0  1    121.92  0.0    0.14  0.0   154.165 0.0
unit 11
     cuboid 0  1    25.7  0.0     122.2 0.0     5.0  0.0
     cuboid 3  1    25.7  0.0     122.2 0.0    30.4  0.0
     cuboid 0  1    25.7  0.0     122.2 0.0    31.035 0.0
     cuboid 3  1    25.7  0.0     122.2 0.0   154.165 0.0
unit 12
     cuboid 0  1    173.32  0.0    25.7  0.0     5.0  0.0
     cuboid 3  1    173.32  0.0    25.7  0.0    30.4  0.0
     cuboid 0  1    173.32  0.0    25.7  0.0    31.035 0.0
     cuboid 3  1    173.32  0.0    25.7  0.0   154.165 0.0
unit 13      array=4  0.0 0.0 0.0
unit 14      array=5  0.0 0.0 0.0
global unit 15  array=6  0.0 0.0 0.0
reflector    0  1     0.0 0.0      0.0 0.0     0.635 0.0 1.0
reflector    3  1     0.0 0.0      0.0 0.0     25.4 0.0 1.0
end geom
'**************
'*  ARRAY  *
'**************
read array
ara=1  nux=1 nuy=1     nuz=3  fill    3 2 1   end fill
ara=2  nux=1 nuy=1     nuz=3  fill    6 5 4   end fill
ara=3  nux=4 nuy=4     nuz=1  fill    7 7 7 7
         7 8 7 7
         7 8 7 7
         7 7 7 7        end fill
ara=4  nux=1 nuy=3     nuz=1  fill    10 9 10       end fill
ara=5  nux=3 nuy=1     nuz=1  fill    11 13 11      end fill
ara=6  nux=1 nuy=3     nuz=1  fill    12 14 12      end fill
end array
read plot
ttl='Plot'    nch=' *!.'
xul=0  xlr=125  yul=71.46     ylr=71.46      zul=166  zlr=-5
uax=1  wdn=-1   nax=130  ndn=80  lpi=10  pic=mix  end
end plot
end data
end
```

Input File for a 2x2 Concrete Reflected Array of 93.2 wt% Enriched Uranyl Nitrate at 76.09 g/l as given in Table 5.

```
=nitawl
0$$  82  2  3  4  18
     19  20  9  15
1$$  500  17  0  0  0
      0  0  6  0  0
      0  0
t
2$$  92235    92234    92236    92238    14000
```

```
  26000     7014     6012     8016     1001
  20000     22000    11023    12000    13027
  19000     16000
3**     92234 293  2   10.5600    0.9502
   0.0 2.0009E-06  1     1.0079  6.6236E+05
    1   16.1816  6.6870E-04  1      1.000
  92235 293  2    10.5600    0.9502
   0.0 1.8164E-04  1     1.0079  7.2963E+03
    1   15.9352  7.2503E-02  1      1.000
  92236 293  2    10.5600    0.9502
   0.0 8.4250E-07  1     1.0079  1.5731E+06
    1   16.1829  1.5883E+05  1      1.000
  92238 293  2    10.5600    0.9502
   0.0 1.0341E-05  1     1.0079  1.2816E+05
    1   16.1712  1.2930E-04  1      1.000
  26000 293  1     25.400    0.0000
   0.0 2.5278E-04  1     1.0079  8.3939E-02
    1   16.7297  8.9763E-02  1      1.000
  11023 293  1     25.400    0.0000
   0.0 3.8303E-04  1     1.0079  5.5395E+02
    1   16.8578  5.9671E+02  1      1.000
4**  f293
t
end
=kenova
ROT54 2x2     array w/o     sleeve (76.09 gU/l-21.12 cm diam cyl)
read param    gen=120     nsk=20      npg=5000     nfb=8000
tme=700       fdn=yes     plt=yes     run=yes      tba=60.0
flx=yes       lib=4 nub=yes
end param
read mixt
'*************
'* MIXTURES *
'*************
mix=1
'Fuel
     92234   2.0009E-06
     92235   1.8164E-04
     92236   8.4250E-07
     92238   1.0341E-05
      8016   3.4248E-02
      7014   4.7215E-04
      1001   6.4966E-02
mix=2
'Al tank
     13027   5.9469E-02
mix=3
'Concrete
     12000   7.1885E-04
     13027   1.1241E-03
     20000   8.0213E-03
     26000   2.5278E-04
     19000   4.8976E-04
     14000   7.7139E-03
      1001   1.0401E-02
     11023   3.8303E-04
      8016   4.2362E-02
      6012   6.4237E-03
      7014   1.9958E-05
     16000   8.2809E-05
     22000   2.9192E-05
end mixt
'*************
'* GEOMETRY *
'*************
read geom
unit 1
   cylinder 1  1     0.505  0.00  -0.32
   cylinder 2  1     10.56  0.00  -0.32
   cylinder 1  1     10.56  62.34  -0.32
   cylinder 0  1     10.56  119.1  -0.32
   cylinder 2  1     10.96  119.1  -0.32
     cuboid 0  1   15.24  -15.24  15.24  -15.24  123.445 -0.32
unit 2
   cylinder 1  1     0.505  25.40  0.00
   cylinder 2  1     0.635  25.40  0.00
     cuboid 3  1   15.24  -15.24  15.24  -15.24   25.4  0.0
unit 3
   cylinder 1  1     0.505   5.00  0.00
   cylinder 2  1     0.635   5.00  0.00
     cuboid 0  1   15.24  -15.24  15.24  -15.24    5.0  0.0
unit 4
   cylinder 1  1     1.14  0.00  -0.32
   cylinder 2  1     10.56  0.00  -0.32
   cylinder 1  1     10.56  62.34  -0.32
   cylinder 0  1     10.56  119.1  -0.32
   cylinder 2  1     10.96  119.1  -0.32
     cuboid 0  1   15.24  -15.24  15.24  -15.24  123.445 -0.32
unit 5
   cylinder 1  1     1.140  25.40   0.00
   cylinder 2  1     1.270  25.40   0.00
     cuboid 3  1   15.24  -15.24  15.24  -15.24   25.4  0.0
unit 6
   cylinder 1  1     1.140   5.00   0.00
   cylinder 2  1     1.270   5.00   0.00
     cuboid 0  1   15.24  -15.24  15.24  -15.24    5.0  0.0
unit 7      array=1       0.0 0.0 0.0
unit 8      array=2       0.0 0.0 0.0
unit 9      array=3       0.0 0.0 0.0
unit 10
     cuboid 0  1    30.48  0.0    60.96 0.0     5.0  0.0
     cuboid 3  1    30.48  0.0    60.96 0.0    30.4  0.0
     cuboid 0  1    30.48  0.0    60.96 0.0   154.165 0.0
unit 11
     cuboid 0  1   121.92  0.0    30.62 0.0     5.0  0.0
     cuboid 3  1   121.92  0.0    30.62 0.0    30.4  0.0
     cuboid 0  1   121.92  0.0    30.62 0.0   154.165 0.0
unit 12
     cuboid 0  1    25.7  0.0    122.2  0.0     5.0  0.0
     cuboid 3  1    25.7  0.0    122.2  0.0    30.4  0.0
     cuboid 0  1    25.7  0.0    122.2  0.0   31.035 0.0
     cuboid 3  1    25.7  0.0    122.2  0.0   154.165 0.0
unit 13
     cuboid 0  1   173.32  0.0    25.7  0.0     5.0  0.0
     cuboid 3  1   173.32  0.0    25.7  0.0    30.4  0.0
     cuboid 0  1   173.32  0.0    25.7  0.0   31.035 0.0
     cuboid 3  1   173.32  0.0    25.7  0.0   154.165 0.0
unit 14     array=4       0.0 0.0 0.0
unit 15     array=5       0.0 0.0 0.0
unit 16     array=6       0.0 0.0 0.0
global unit 17 array=7      0.0 0.0 0.0
reflector   0  1    0.0 0.0     0.0 0.0    0.635 0.0 1.0
reflector   3  1    0.0 0.0     0.0 0.0    25.4 0.0 1.0
end geom
'*************
'* ARRAY *
'*************
read array
ara=1  nux=1 nuy=1   nuz=3  fill   3 2 1  end fill
ara=2  nux=1 nuy=1   nuz=3  fill   6 5 4  end fill
ara=3  nux=2 nuy=2   nuz=1  fill   8 7 8 7     end fill
ara=4  nux=3 nuy=1   nuz=1  fill   10 9 10     end fill
ara=5  nux=1 nuy=3   nuz=1  fill   11 14 11    end fill
ara=6  nux=3 nuy=1   nuz=1  fill   12 15 12    end fill
ara=7  nux=1 nuy=3   nuz=1  fill   13 16 13    end fill
end array
read plot
ttl='Plot'  nch=' *1.'  pic=mix
xul=25. xlr=73 yul=71.46    ylr=71.46    zul=166 zlr=-1
uax=1 wdn=-1  nax=130      ndn=80 lpi=10  end
end plot
end data
end
-
```

Input File for a 4x4 Concrete Reflected Array of 93.2 wt% Enriched Uranyl Nitrate at 360.37 g/l as given in Table 5.

```
=nitawl
0$$    82   2   3   4   18
      19  20   9  15
1$$   500  23   0   0   0
       0   0  10   0   0
       0   0
t
2$$  92235     92234     92236     92238      14000
    26000    -26001  6012      8016       1001
    20000     22000      11023      12000      13027
    19000     16000      15031      25055      42000
     7014     24000      28000
3**  92234  293   2     8.3800     0.6576
     0.0  9.4767E-06   1     1.0079  1.2499E+05
      1    16.7021  1.8007E-04   1      1.000
   92235  293   2     8.3800     0.6576
     0.0  8.6027E-04   1     1.0079  1.3769E-03
      1    15.7553  1.8678E-02   1      1.000
```

```
  92236 293  2   8.3800   0.6576
   0.0 3.9902E-06  1   1.0079 2.9685E+05
   1   16.7073 4.2781E-04  1   1.000
  92238 293  2   8.3800   0.6576
   0.0 4.8974E-05  1   1.0079 2.4186E-04
   1   16.6623 3.4759E-03  1   1.000
  26000 293  1   25.4000   0.0000
   0.0 2.5278E-04  1   1.0079 8.3939E+02
   1   16.7297 8.9763E+02  1   1.000
  11023 293  1   25.4000   0.0000
   0.0 3.8303E-04  1   1.0079 5.5395E-02
   1   16.8578 5.9671E+02  1   1.000
  26001 293  1   0.3100  0.0000
   0.0 5.9852E-02  1   58.69 2.2046E+00
   1   48.1197 4.0995E-02  1   1.000
  25055 293  1   0.3100   0.0000
   0.0 1.1209E-03  1   55.847 6.0872E+02
   1   54.2180 3.6440E-02  1   1.000
  24000 293  1   0.3100   0.0000
   0.0 1.6985E-02  1   55.847 4.0171E+01
   1   55.4800 3.5621E-02  1   1.000
  28000 293  1   0.3100   0.0000
   0.0 7.5400E-03  1   55.847 9.0492E+01
   1   48.1197 4.0995E-02  1   1.000
4**  f293
t
end
=kenova
ROT61 4x4 array UN solution w/sleeve (360.37 gU/l-16.12 cm diam cyl)
read param   gen=120  nsk=20 npg=5000   nfb=8000
tme=700      fdn=yes  plt=yes   run=yes   tba=60.0
fix=yes      lib=4    nub=yes
end param
read mixt
'*************
'* MIXTURES *
'*************
 mix=1
 'fuel
    92234   9.4767E-06
    92235   8.6027E-04
    92236   3.9902E-06
    92238   4.8974E-05
  8016   3.7295E-02
  7014   2.1977E-03
  1001   5.8064E-02
mix=2
'Al tank
    13027   5.9469E-02
mix=3
'Steel Sleeve
    26001   5.9852E-02
    24000   1.6985E-02
    28000   7.5400E-03
  6012   2.6231E-04
    14000   1.3768E-03
    15031   3.8530E-05
    16000   2.8282E-05
    25055   1.1209E-03
    42000   8.9563E-06
mix=4
'Concrete
    12000   7.1885E-04
    13027   1.1241E-03
    20000   8.0213E-03
    26000   2.5278E-04
    19000   4.8976E-04
    14000   7.7139E-03
  1001   1.0401E-02
    11023   3.8303E-04
  8016   4.2562E-02
  6012   6.4257E-03
  7014   1.9558E-05
    16000   8.2809E-05
    22000   2.9192E-05
  d mixt
'************
'* GEOMETRY *
'*************
read geom
unit 1
    cylinder 1  1    0.505   0.00  -0.32
    cylinder 2  1    8.06  0.00  -0.32
    cylinder 1  1    8.06  32.32  -0.32
    cylinder 0  1    8.06  119.1  -0.32
    cylinder 2  1    8.38  119.1  -0.32
    cylinder 0  1    8.38  121.68 -0.32
    cylinder 3  1    8.69  121.68 -0.32
     cuboid 0  1   15.24 -15.24  15.24 -15.24  123.445 -0.32
unit 2
    cylinder 1  1    0.505  25.40  0.00
    cylinder 2  1    0.635  25.40  0.00
     cuboid 4  1   15.24 -15.24  15.24 -15.24   25.4  0.0
unit 3
    cylinder 1  1    0.505  5.00   0.00
    cylinder 2  1    0.635  5.00   0.00
     cuboid 0  1   15.24 -15.24  15.24 -15.24   5.0  0.0
unit 4
    cylinder 1  1    1.14   0.00  -0.32
    cylinder 2  1    8.06   0.00  -0.32
    cylinder 1  1    8.06  32.32  -0.32
    cylinder 0  1    8.06  119.1  -0.32
    cylinder 2  1    8.38  119.1  -0.32
    cylinder 0  1    8.38  121.68 -0.32
    cylinder 3  1    8.69  121.68 -0.32
     cuboid 0  1   15.24 -15.24  15.24 -15.24  123.445 -0.32
unit 5
    cylinder 1  1    1.140  25.40  0.00
    cylinder 2  1    1.270  25.40  0.00
     cuboid 4  1   15.24 -15.24  15.24 -15.24   25.4  0.0
unit 6
    cylinder 1  1    1.140  5.00   0.00
    cylinder 2  1    1.270  5.00   0.00
     cuboid 0  1   15.24 -15.24  15.24 -15.24   5.0  0.0
unit 7  array=1  0.0 0.0 0.0
unit 8  array=2  0.0 0.0 0.0
unit 9  array=3  0.0 0.0 0.0
unit 10
     cuboid 0  1    121.92 0.0    0.14 0.0     5.0  0.0
     cuboid 4  1    121.92 0.0    0.14 0.0    30.4  0.0
     cuboid 0  1    121.92 0.0    0.14 0.0   154.165 0.0
unit 11
     cuboid 0  1    25.7  0.0    122.2 0.0    5.0  0.0
     cuboid 4  1    25.7  0.0    122.2 0.0   30.4  0.0
     cuboid 0  1    25.7  0.0    122.2 0.0   31.035 0.0
     cuboid 4  1    25.7  0.0    122.2 0.0   154.165 0.0
unit 12
     cuboid 0  1   173.32 0.0    25.7  0.0    5.0  0.0
     cuboid 4  1   173.32 0.0    25.7  0.0   30.4  0.0
     cuboid 0  1   173.32 0.0    25.7  0.0   31.035 0.0
     cuboid 4  1   173.32 0.0    25.7  0.0   154.165 0.0
unit 13      array=4  0.0 0.0 0.0
unit 14      array=5  0.0 0.0 0.0
global unit 15  array=6  0.0 0.0 0.0
reflector    0  1   0.0 0.0     0.0 0.0    0.635 0.0 1.0
reflector    4  1   0.0 0.0     0.0 0.0    25.4 0.0 1.0
end geom
'*************
'*  ARRAY  *
'*************
read array
ara=1  nux=1 nuy=1   nuz=3  fill   3 2 1  end fill
ara=2  nux=1 nuy=1   nuz=3  fill   6 5 4  end fill
ara=3  nux=4 nuy=4   nuz=1  fill   7 7 7 7
     7 8 7 7
     7 8 7 7
     7 7 7 7      end fill
ara=4  nux=1 nuy=3   nuz=1 fill    10 9 10      end fill
ara=5  nux=3 nuy=1   nuz=1 fill    11 13 11     end fill
ara=6  nux=1 nuy=3   nuz=1 fill    12 14 12     end fill
end array
read plot
ttl='Plot'   nch=' *1.'   pic=mix
xul=0. xlr=150. yul=71.46    ylr=71.46    zul=166 zlr=-3
uax=1 wdn=-1   nax=130       ndn=80 lpi=10. end
end plot
end data
end
-
```

Input File for 4.31 wt% Enriched Undermoderated UO_2 Fuel Rods with a Lead Wall Reflector as given in Table 5.

```
=nitawl
0SS  82        2        3        4        18
     19        20       9        15
```

```
1$$ 500       19       0       0       0
     0       0       5       0       0
     0       0
t
2$$ 92235     92238    13027    82000    8016
    1001     29000   -29001    26000   -26001
    14000    16000    24000    20000
    25055    12000    17000    22000    6012
3** 92235      293      2    0.6325   0.1801
    0.0  1.0124E-03      1   15.9994  1.6980E+02
     1  238.0508  2.3237E-02      1    1.000
    92238      293      2   0.6325    0.1801
    0.0  2.2193E-02      1   15.9994  7.7459E+00
     1  235.0439  5.3372E-01      1    1.000
    26001      293      2   0.6985    0.0000
   0.6325  2.0305E-04      1   26.98154  3.9906E+02
     1   30.4624  2.3202E-01      1    1.000
    29001      293      2   0.6985    0.0000
   0.6325  1.0197E-04      1   26.98154  7.9463E+02
     1   34.0419  6.1400E-01      1    1.000
    24000      293      2   0.6985    0.0000
   0.6325  1.0904E-04      1   26.98154  7.4309E-02
     1   35.0863  6.0131E-01      1    1.000
4**     f293
t
end
=kenova
4.31 wt%   UO2 rods   with lead   reflector at 0.00 in
read param
tme=700   gen=120   nsk=20   lib=4   npg=5000
flx=yes   fdn=yes   tba=60.0   nub=yes   nfb=8000
end param
'******************
'* MIXTURES *
'******************
read mixt   sct=1
'Fuel
mix=1
    92235  1.0124E-03
    92238  2.2193E-02
     8016  4.6411E-02
'Clad
mix=2
    13027  5.7878E-02
    14000  2.3072E-04
    26001  2.0305E-04
    29001  1.0197E-04
    25055  4.4230E-05
    12000  7.9981E-04
    24000  1.0904E-04
    22000  6.1944E-05
'Water
mix=3
     8016  3.3427E-02
     1001  6.6855E-02
    17000  8.4931E-08
    26000  2.5880E-07
'Lead
mix=4
    82000  3.2771E-02
    29000  1.3909E-04
'Rubber   End Caps
mix=5
     6012  3.8415E-02
     1001  5.1304E-02
    20000  2.2627E-03
    14000  4.2183E-04
     8016  1.0989E-02
    16000  8.4975E-05
end mixt
'******************
'* GEOMETRY *
'******************
read geom
unit 1
  cylinder 1  1        0.63245     91.44      0
  cylinder 3  1        0.64135     91.44      0
  cylinder 2  1        0.70735     91.44      0
  cylinder 5  1        0.70735     93.98    -2.54
    cuboid 3  1     0.946 -0.946 0.946 -0.946 93.98 -2.54
unit 2   array 1        -15.136    -11.352      0
unit 3
com="Crit   Separation"
    cuboid 3  1       15.136 -15.136 8.870 -8.870 93.98 -2.54
global unit 4   array 2   0 0 0
'Inner shell for lead
    cuboid 3  1       30.272 0.00  145.15 -18.85 109.96 -13.44
'Outer shell to fill    w/lead
    cuboid 4  1       40.47 -10.20  145.15 -18.85 109.96 -13.44
'Water tank
    cuboid 3  1       60.77 -30.50  156.80 -30.50 121.94 -30.50
end geom
'
read array
ara=1 nux=16 nuy=12     nuz=1 fill   192r1 t     end fill
ara=2 nux=1  nuy=5      nuz=1 fill   2 3 2 3 2 t  end fill
end array
end data
end
=kenova
4.31 wt%   UO2 rods   with lead   reflector at 0.26 in
read param
tme=700   gen=120   nsk=20   lib=4   npg=5000
flx=yes   fdn=yes   tba=60.0   nub=yes   nfb=8000
end param
'******************
'* MIXTURES *
'******************
read mixt   sct=1
'Fuel
mix=1
    92235  1.0124E-03
    92238  2.2193E-02
     8016  4.6411E-02
'Clad
mix=2
    13027  5.7878E-02
    14000  2.3072E-04
    26001  2.0305E-04
    29001  1.0197E-04
    25055  4.4230E-05
    12000  7.9981E-04
    24000  1.0904E-04
    22000  6.1944E-05
'Water
mix=3
     8016  3.3427E-02
     1001  6.6855E-02
    17000  8.4931E-08
    26000  2.5880E-07
'Lead
mix=4
    82000  3.2771E-02
    29000  1.3909E-04
'Rubber   End Caps
mix=5
     6012  3.8415E-02
     1001  5.1304E-02
    20000  2.2627E-03
    14000  4.2183E-04
     8016  1.0989E-02
    16000  8.4975E-05
end mixt
'******************
'* GEOMETRY *
'******************
read geom
unit 1
  cylinder 1  1        0.63245     91.44      0
  cylinder 3  1        0.64135     91.44      0
  cylinder 2  1        0.70735     91.44      0
  cylinder 5  1        0.70735     93.98    -2.54
    cuboid 3  1     0.946 -0.946 0.946 -0.946 93.98 -2.54
unit 2   array 1        -15.136    -11.352      0
unit 3
com="Crit   Separation"
    cuboid 3  1       15.136 -15.136 9.090 -9.090 93.98 -2.54
global unit 4   array 2   0 0 0
'Inner shell for lead
    cuboid 3  1       30.932 -0.66  145.59 -18.41 109.96 -13.44
'Outer shell to fill    w/lead
    cuboid 4  1       40.47 -10.20  145.59 -18.41 109.96 -13.44
'Water tank
    cuboid 3  1       60.77 -30.50  157.68 -30.50 121.94 -30.50
```

```
end geom

read array
ara=1 nux=16 nuy=12      nuz=1 fill  192r1 t     end fill
ara=2 nux=1  nuy=5       nuz=1 fill  2 3 2 3 2 t  end fill
end array
end data
end
=kenova
4.31 wt%   UO2 rods    with lead    reflector at 0.77 in
read param
tme=700    gen=120    nsk=20     lib=4      npg=5000
flx=yes    fdn=yes    tba=60.0   nub=yes    nfb=8000
end param
'******************
'* MIXTURES *
'******************
read mixt   sct=1
'Fuel
mix=1
     92235  1.0124E-03
     92238  2.2193E-02
      8016  4.6411E-02
'Clad
mix=2
     13027  5.7878E-02
     14000  2.3072E-04
     26001  2.0305E-04
     29001  1.0197E-04
     25055  4.4230E-05
     12000  7.9981E-04
     24000  1.0904E-04
     22000  6.1944E-05
'Water
mix=3
      8016  3.3427E-02
      1001  6.6855E-02
     17000  8.4931E-08
     26000  2.5880E-07
'Lead
mix=4
     82000  3.2771E-02
     29000  1.3909E-04
'Rubber     End Caps
mix=5
      6012  3.8415E-02
      1001  5.1304E-02
     20000  2.2627E-03
     14000  4.2183E-04
      8016  1.0989E-02
     16000  8.4975E-05
end mixt
'******************
'* GEOMETRY  *
'******************
read geom
unit 1
  cylinder 1  1          0.63245      91.44        0
  cylinder 3  1          0.64135      91.44        0
  cylinder 2  1          0.70735      91.44        0
  cylinder 5  1          0.70735      93.98       -2.54
    cuboid 3  1       0.946 -0.946 0.946 -0.946 93.98 -2.54
unit 2   array 1         -15.136      -11.352       0
unit 3
com="Crit   Separation"
    cuboid 3  1       15.136 -15.136 8.715 -8.715  93.98 -2.54
global unit 4   array 2   0 0 0
'Inner shell for lead
    cuboid 3  1       32.228 -1.96  144.84 -19.16 109.96 -13.44
'Outer shell to fill    w/lead
    cuboid 4  1       40.47 -10.20  144.84 -19.16 109.96 -13.44
'Water tank
    cuboid 3  1       60.77 -30.50  156.18 -30.50 121.94 -30.50
end geom

read array
ara=1 nux=16 nuy=12      nuz=1 fill  192r1 t     end fill
ara=2 nux=1  nuy=5       nuz=1 fill  2 3 2 3 2 t  end fill
end array
end data
end
=kenova
4.31 wt%   UO2 rods    with lead    reflector at 1.97 in
read param
tme=700    gen=120    nsk=20     lib=4      npg=5000
flx=yes    fdn=yes    tba=60.0   nub=yes    nfb=8000
end param
'******************
'* MIXTURES *
'******************
read mixt   sct=1
'Fuel
mix=1
     92235  1.0124E-03
     92238  2.2193E-02
      8016  4.6411E-02
'Clad
mix=2
     13027  5.7878E-02
     14000  2.3072E-04
     26001  2.0305E-04
     29001  1.0197E-04
     25055  4.4230E-05
     12000  7.9981E-04
     24000  1.0904E-04
     22000  6.1944E-05
'Water
mix=3
      8016  3.3427E-02
      1001  6.6855E-02
     17000  8.4931E-08
     26000  2.5880E-07
'Lead
mix=4
     82000  3.2771E-02
     29000  1.3909E-04
'Rubber     End Caps
mix=5
      6012  3.8415E-02
      1001  5.1304E-02
     20000  2.2627E-03
     14000  4.2183E-04
      8016  1.0989E-02
     16000  8.4975E-05
end mixt
'******************
'* GEOMETRY  *
'******************
read geom
unit 1
  cylinder 1  1          0.63245      91.44        0
  cylinder 3  1          0.64135      91.44        0
  cylinder 2  1          0.70735      91.44        0
  cylinder 5  1          0.70735      93.98       -2.54
    cuboid 3  1       0.946 -0.946 0.946 -0.946 93.98 -2.54
unit 2   array 1         -15.136      -11.352       0
unit 3
com="Crit   Separation"
    cuboid 3  1       15.136 -15.136 7.175 -7.175  93.98 -2.54
global unit 4   array 2   0 0 0
'Inner shell for lead
    cuboid 3  1       35.273 -5.00  141.76 -22.24 109.96 -13.44
'Outer shell to fill    w/lead
    cuboid 4  1       40.47 -10.20  141.76 -22.24 109.96 -13.44
'Water tank
    cuboid 3  1       60.77 -30.50  150.02 -30.50 121.94 -30.50
end geom

read array
ara=1 nux=16 nuy=12      nuz=1 fill  192r1 t     end fill
ara=2 nux=1  nuy=5       nuz=1 fill  2 3 2 3 2 t  end fill
end array
end data
end
=kenova
4.31 wt%   UO2 rods    without lead  reflector
read param
tme=700    gen=120    nsk=20     lib=4      npg=5000
flx=yes    fdn=yes    tba=60.0   nub=yes    nfb=8000
end param
'******************
'* MIXTURES *
'******************
read mixt   sct=1
```

```
'Fuel
mix=1
     92235  1.0124E-03
     92238  2.2193E-02
      8016  4.6411E-02
'Clad
mix=2
     13027  5.7878E-02
     14000  2.3072E-04
     26001  2.0305E-04
     29001  1.0197E-04
     25055  4.4230E-05
     12000  7.9981E-04
     24000  1.0904E-04
     22000  6.1944E-05
'Water
mix=3
      8016  3.3427E-02
      1001  6.6855E-02
     17000  8.4931E-08
     26000  2.5880E-07
'Lead
mix=4
     82000  3.2771E-02
     29000  1.3909E-04
'Rubber     End Caps
mix=5
      6012  3.8415E-02
      1001  5.1304E-02
     20000  2.2627E-03
     14000  4.2183E-04
      8016  1.0989E-02
     16000  8.4975E-05
end mixt
'*******************
'* GEOMETRY  *
'*******************
read geom
unit 1
   cylinder 1  1          0.63245     91.44      0
   cylinder 3  1          0.64135     91.44      0
   cylinder 2  1          0.70735     91.44      0
   cylinder 5  1          0.70735     93.98     -2.54
     cuboid 3  1      0.946 -0.946  0.946 -0.946  93.98  -2.54
unit 2   array 1         -15.136     -11.352     0
unit 3
com="Crit   Separation"
   cuboid 3  1      15.136 -15.136 6.485 -6.485  93.98  -2.54
global unit 4  array 2   0 0 0
'Water tank
   cuboid 3  1      60.77 -30.50  147.26 -30.50  121.94 -30.50
end geom
'
read array
ara=1 nux=16 nuy=12       nuz=1 fill   192r1 t      end fill
ara=2 nux=1  nuy=5        nuz=1 fill   2 3 2 3 2 t  end fill
end array
end data
end
```

Input File for 4.31 wt% Enriched Optimum Moderated UO_2 Fuel Rods with a Lead Wall Reflector as given in Table 5.

```
=nitawl
0$$  82         2        3        4        18
      19       20        9       15
1$$  500       21        0        0         0
       0        0        5        0         0
       0        0
t
2$$ 92235      92238     13027     82000      8016
     1001      29000    -29001     26000    -26001
    14000      16000     24000     20000      7014
    25055      12000     17000     22000      6012
    48000
3** 92235       293        2    0.6325     0.0409
     0.0 1.0124E-03        1   15.9994   1.6980E-02
      1  238.0508  2.3237E-02        1       1.000
    92238       293        2    0.6325     0.0409
     0.0 2.2193E-02        1   15.9994   7.7459E-00
      1  235.0439  5.3372E-01        1       1.000
    26001       293        2   0.70735     0.0000
   0.64135  2.0305E-04        1   26.98154   3.9906E-02
      1  30.4624  2.3202E+01        1       1.000
    29001       293        2   0.70735     0.0000
   0.64135  1.0197E-04        1   26.98154   7.9463E-02
      1  34.0419  6.1400E+01        1       1.000
    24000       293        2   0.70735     0.0000
   0.64135  1.0904E-04        1   26.98154   7.4309E-02
      1  35.0863  6.0131E-01        1       1.000
4**      f293
t
end
=kenova
4.31 wt% UO2 rods P=2.54 cm (Opt Mod) lead reflector @ 0.00 in
read param
tme=700    gen=120   nsk=20     lib=4     npg=5000
flx=yes    fdn=yes   tba=60.0   nub=yes   nfb=8000.
run=yes     end param
'*******************
'* MIXTURES *
'*******************
read mixt   scr=1
'Fuel
mix=1
     92235 1.0124E-03
     92238 2.2193E-02
      8016 4.6411E-02
'Clad
mix=2
     13027 5.7878E-02
     14000 2.3072E-04
     26001 2.0305E-04
     29001 1.0197E-04
     25055 4.4230E-05
     12000 7.9981E-04
     24000 1.0904E-04
     22000 5.0729E-05
'Water
mix=3
      8016 3.3428E-02
      1001 6.6856E-02
     17000 5.1298E-07
     26000 3.2350E-10
     82000 1.4532E-11
     48000 3.2144E-11
      7014 4.0792E-09
'Lead
mix=4
     82000 3.2771E-02
     29000 1.3909E-04
'Rubber End Caps
mix=5
      6012 3.8415E-02
      1001 5.1304E-02
     20000 2.2627E-03
     16000 4.2183E-04
      8016 1.0989E-02
     14000 8.4975E-05
end mixt
'*******************
'* GEOMETRY  *
'*******************
read geom
unit 1
com="Single Fuel Pin"
   cylinder 1  1          0.63245     91.44      0
   cylinder 0  1          0.64135     91.44      0
   cylinder 2  1          0.70735     91.44      0
   cylinder 5  1          0.70735     93.98     -2.54
     cuboid 3  1      1.270 -1.270 1.270 -1.270  93.98  -2.54
unit 2   array 1          -10.16     -16.51     -2.54
com="13 x 8 array of pins"
unit 3
com="Critical Separation  - Water Gap"
     cuboid 3  1        2p10.160   2p10.310   93.98  -2.54
global unit 4  array 2  0 0 0
'Inner shell for lead
     cuboid 3  1      20.320 0.00  152.15 -11.85 107.42 -15.98
'Outer shell to fill with lead
     cuboid 4  1      30.52 -10.20 152.15 -11.85 107.42 -15.98
'Water tank
     cuboid 3  1      50.82 -30.50 170.80 -30.50 121.94 -30.50
end geom
'
```

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```
read array
ra=1 nux=8 nuy=13 nuz=1     fill 104r1 t  end fill
ara=2 nux=1 nuy=5  nuz=1    fill 2 3 2 3 2 t end fill
end array
end data
end
=kenova
4.31 wt% UO2 rods P=2.54 cm (Opt Mod) lead reflector @ 0.26 in
read param
tme=700    gen=120    nsk=20    lib=4     npg=5000
flx=yes    fdn=yes   tba=60.0   nub=yes   nfb=8000
run=yes    end param
'******************
'* MIXTURES *
'******************
read mixt   sct=1
'Fuel
mix=1
    92235 1.0124E-03
    92238 2.2193E-02
     8016 4.6411E-02
'Clad
mix=2
    13027 5.7878E-02
    14000 2.3072E-04
    26001 2.0305E-04
    29001 1.0197E-04
    25055 4.4230E-05
    12000 7.9981E-04
    24000 1.0904E-04
    22000 5.0729E-05
'Water
mix=3
     8016 3.3428E-02
     1001 6.6856E-02
    17000 5.1298E-07
    26000 3.2350E-10
    82000 1.4532E-11
    48000 3.2144E-11
     7014 4.0792E-09
'Lead
mix=4
    82000 3.2771E-02
    29000 1.3909E-04
'Rubber End Caps
mix=5
     6012 3.8415E-02
     1001 5.1304E-02
    20000 2.2627E-03
    16000 4.2183E-04
     8016 1.0989E-02
    14000 8.4975E-05
end mixt
'******************
'* GEOMETRY *
'******************
read geom
unit 1
com="Single Fuel Pin"
  cylinder 1  1         0.63245     91.44        0
  cylinder 0  1         0.64135     91.44        0
  cylinder 2  1         0.70735     91.44        0
  cylinder 5  1         0.70735     93.98      -2.54
    cuboid 3  1   1.270 -1.270 1.270 -1.270  93.98 -2.54
unit 2   array 1        -10.16     -16.51     -2.54
com="13 x 8 array of pins"
unit 3
com="Critical Separation  - Water Gap"
    cuboid 3  1      2p10.160    2p10.390    93.98 -2.54
global unit 4  array 2  0 0 0
'Inner shell for lead
    cuboid 3  1    20.980 -0.66 152.31 -11.69 107.42 -15.98
'Outer shell to fill with lead
    cuboid 4  1    31.18 -10.86 152.31 -11.69 107.42 -15.98
'Water tank
    cuboid 3  1    50.82 -30.50 171.12 -30.50 121.94 -30.50
end geom

read array
ara=1 nux=8 nuy=13 nuz=1    fill 104r1 t  end fill
ara=2 nux=1 nuy=5  nuz=1    fill 2 3 2 3 2 t end fill
end array
```

```
end data
end
=kenova
4.31 wt% UO2 rods P=2.54 cm (Opt Mod) lead reflector @ 0.52 in
read param
tme=700    gen=120    nsk=20    lib=4     npg=5000
flx=yes    fdn=yes   tba=60.0   nub=yes   nfb=8000
run=yes    end param
'******************
'* MIXTURES *
'******************
read mixt   sct=1
'Fuel
mix=1
    92235 1.0124E-03
    92238 2.2193E-02
     8016 4.6411E-02
'Clad
mix=2
    13027 5.7878E-02
    14000 2.3072E-04
    26001 2.0305E-04
    29001 1.0197E-04
    25055 4.4230E-05
    12000 7.9981E-04
    24000 1.0904E-04
    22000 5.0729E-05
'Water
mix=3
     8016 3.3428E-02
     1001 6.6856E-02
    17000 5.1298E-07
    26000 3.2350E-10
    82000 1.4532E-11
    48000 3.2144E-11
     7014 4.0792E-09
'Lead
mix=4
    82000 3.2771E-02
    29000 1.3909E-04
'Rubber End Caps
mix=5
     6012 3.8415E-02
     1001 5.1304E-02
    20000 2.2627E-03
    16000 4.2183E-04
     8016 1.0989E-02
    14000 8.4975E-05
end mixt
'******************
'* GEOMETRY *
'******************
read geom
unit 1
com="Single Fuel Pin"
  cylinder 1  1         0.63245     91.44        0
  cylinder 0  1         0.64135     91.44        0
  cylinder 2  1         0.70735     91.44        0
  cylinder 5  1         0.70735     93.98      -2.54
    cuboid 3  1   1.270 -1.270 1.270 -1.270  93.98 -2.54
unit 2   array 1        -10.16     -16.51     -2.54
com="13 x 8 array of pins"
unit 3
com="Critical Separation  - Water Gap"
    cuboid 3  1      2p10.160    2p9.520    93.98 -2.54
global unit 4  array 2  0 0 0
'Inner shell for lead
    cuboid 3  1    21.641 -1.32 150.57 -13.43 107.42 -15.98
'Outer shell to fill with lead
    cuboid 4  1    31.84 -11.52 150.57 -13.43 107.42 -15.98
'Water tank
    cuboid 3  1    50.82 -30.50 167.64 -30.50 121.94 -30.50
end geom

read array
ara=1 nux=8 nuy=13 nuz=1    fill 104r1 t  end fill
ara=2 nux=1 nuy=5  nuz=1    fill 2 3 2 3 2 t end fill
end array
end data
end
=kenova
4.31 wt% UO2 rods P=2.54 cm (Opt Mod) lead reflector @ 2.13 in
```

```
read param
tme=700   gen=120   nsk=20    lib=4     npg=5000
flx=yes.  fdn=yes   tba=60.0  nub=yes   nfb=8000
run=yes   end param
'******************
'* MIXTURES *
'******************
read mixt   sct=1
'Fuel
mix=1
     92235 1.0124E-03
     92238 2.2193E-02
      8016 4.6411E-02
'Clad
mix=2
     13027 5.7878E-02
     14000 2.3072E-04
     26001 2.0305E-04
     29001 1.0197E-04
     25055 4.4230E-05
     12000 7.9981E-04
     24000 1.0904E-04
     22000 5.0729E-05
'Water
mix=3
      8016 3.3428E-02
      1001 6.6856E-02
     17000 5.1298E-07
     26000 3.2350E-10
     82000 1.4532E-11
     48000 3.2144E-11
      7014 4.0792E-09
'Lead
mix=4
     82000 3.2771E-02
     29000 1.3909E-04
'Rubber End Caps
mix=5
      6012 3.8415E-02
      1001 5.1304E-02
     20000 2.2627E-03
     16000 4.2183E-04
      8016 1.0989E-02
     14000 8.4975E-05
end mixt
'******************
'* GEOMETRY *
'******************
read geom
unit 1
com="Single Fuel Pin"
   cylinder 1  1       0.63245     91.44      0
   cylinder 0  1       0.64135     91.44      0
   cylinder 2  1       0.70735     91.44      0
   cylinder 5  1       0.70735     93.98     -2.54
    cuboid 3  1     1.270 -1.270 1.270 -1.270  93.98 -2.54
unit 2   array 1        -10.16      -16.51        -2.54
com="13 x 8 array of pins"
unit 3
com="Critical Separation - Water Gap"
    cuboid 3  1      2p10.160     2p5.150     93.98 -2.54
global unit 4   array 2  0 0 0
'Inner shell for lead
    cuboid 3  1      25.725 -5.41 141.83 -22.17 107.42 -15.98
'Outer shell to fill with lead
    cuboid 4  1      35.93 -15.61 141.83 -22.17 107.42 -15.98
'Water tank
    cuboid 3  1      50.82 -30.50 150.16 -30.50 121.94 -30.50
end geom
'.
read array
ara=1 nux=8 nuy=13 nuz=1      fill 104r1 t  end fill
ara=2 nux=1 nuy=5  nuz=1      fill 2 3 2 3 2 t end fill
end array
end data
end
=kenova
4.31 wt% UO2 rods P=2.54 cm (Opt Mod) without lead reflector
read param
tme=700   gen=120   nsk=20    lib=4     npg=5000
flx=yes   fdn=yes   tba=60.0  nub=yes   nfb=8000
run=yes   end param
```

```
'******************
'* MIXTURES *
'******************
read mixt   sct=1
'Fuel
mix=1
     92235 1.0124E-03
     92238 2.2193E-02
      8016 4.6411E-02
'Clad
mix=2
     13027 5.7878E-02
     14000 2.3072E-04
     26001 2.0305E-04
     29001 1.0197E-04
     25055 4.4230E-05
     12000 7.9981E-04
     24000 1.0904E-04
     22000 5.0729E-05
'Water
mix=3
      8016 3.3428E-02
      1001 6.6856E-02
     17000 5.1298E-07
     26000 3.2350E-10
     82000 1.4532E-11
     48000 3.2144E-11
      7014 4.0792E-09
'Lead
mix=4
     82000 3.2771E-02
     29000 1.3909E-04
'Rubber End Caps
mix=5
      6012 3.8415E-02
      1001 5.1304E-02
     20000 2.2627E-03
     16000 4.2183E-04
      8016 1.0989E-02
     14000 8.4975E-05
end mixt
'******************
'* GEOMETRY *
'******************
read geom
unit 1
com="Single Fuel Pin"
   cylinder 1  1       0.63245     91.44      0
   cylinder 0  1       0.64135     91.44      0
   cylinder 2  1       0.70735     91.44      0
   cylinder 5  1       0.70735     93.98     -2.54
    cuboid 3  1     1.270 -1.270 1.270 -1.270  93.98 -2.54
unit 2   array 1        -10.16      -16.51        -2.54
com="13 x 8 array of pins"
unit 3
com="Critical Separation - Water Gap"
    cuboid 3  1      2p10.160     2p4.120     93.98 -2.54
global unit 4   array 2  0 0 0
'Water tank
    cuboid 3  1      50.82 -30.50 146.04 -30.50 121.94 -30.50
end geom
'
read array
ara=1 nux=8 nuy=13 nuz=1      fill 104r1 t  end fill
ara=2 nux=1 nuy=5  nuz=1      fill 2 3 2 3 2 t end fill
end array
end data
end
```

Input File for 2.35 wt% Enriched Undermoderated UO_2 Fuel Rods with a Lead Wall Reflector as given in Table 5.

```
=nitawl
0$$   82       2       3       4       18
      19      20       9      15
1$$  500      17      .0       0        0
       0       0       5       0        0
       0       0
t
2$$   92235    92238    13027    14000    25055
      29000   -29001    12000    24000
      48000    26000   -26001    22000
       8016     1001    17000    82000
```

```
3**   92235     293       2    0.5588     0.2098
    0.0 4.8828E-04        1    15.9994  3.1135E-02
      1  238.0508  4.3490E+02       1       1.000
   92238     293       2    0.5588     0.2098
    0.0 2.0033E-02        1    15.9994  7.5886E-00
      1  235.0439  2.8517E-01       1       1.000
   26001     293       2    0.6350     0.0000
   0.5588 2.0305E-04       1   26.98154   3.9906E-02
      1  30.4624  2.3202E-01       1       1.000
   29001     293       2    0.6350     0.0000
   0.5588 1.0197E-04       1   26.98154   7.9463E+02
      1  34.0419  6.1400E+01       1       1.000
   24000     293       2    0.6350     0.0000
   0.5588 1.0904E-04       1   26.98154   7.4309E+02
      1  35.0863  6.0131E+01       1       1.000
4**      f293
t
end
=kenova
2.35 wt% UO2 Rods P=1.684 (Undermod)  lead reflector @ 0.00
read param
tme=700    gen=120   nsk=20     tba=60.0   npg=5000
flx=yes    fdn=yes   nub=yes    lib=4      nfb=8000
end param
'******************
'* MIXTURES *
'******************
read mixt   sct=1
'Fuel
mix=1
   92235 4.8828E-04
   92238 2.0033E-02
    8016 4.1043E-02
'Clad
mix=2
   13027 5.7878E-02
   14000 2.3072E-04
   26001 2.0305E-04
   29001 1.0197E-04
   25055 4.4230E-05
   12000 7.9981E-04
   24000 1.0904E-04
   22000 5.0729E-05
'Water
mix=3
    8016 3.3427E-02
    1001 6.6854E-02
   17000 8.4931E-08
   26000 2.5880E-07
   82000 1.4532E-11
   48000 5.3573E-12
'Lead
mix=4
   82000 3.2771E-02
   29000 1.3909E-04
end mixt
'******************
'* GEOMETRY *
'******************
read geom
unit 1
'Fuel
  cylinder 1  1         0.5588      91.44        0
'Al Clad
  cylinder 2  1         0.635       91.44        0
'Al End Plugs
  cylinder 2  1         0.635       96.52       -1.27
    cuboid 3  1       4p0.842       96.52       -1.27
unit 2 array 1         -15.156     -19.366      -1.27
com="Center Cluster"
unit 3 array 2         -15.156     -16.84       -1.27
com="End Cluster"
unit 4
com="Critical Separation - Water Gap"
    cuboid 3  1     2p15.156     2p5.030     96.52 -1.27
lobal unit 5 array 3   0 0 0
.nner shell lead
    cuboid 3  1      30.312 0.00  145.11 -18.89 109.33 -14.08
'Outer shell of lead
    cuboid 4  1      40.51 -10.20 145.11 -18.89 109.33 -14.08
'Water tank
    cuboid 3  1      60.81 -30.50 156.71 -30.50 127.02 -30.50
end geom

read array
ara=1 nux=18 nuy=23 nuz=1    fill 414r1 t end fill
ara=2 nux=18 nuy=20 nuz=1    fill 360r1 t end fill
ara=3 nux=1  nuy=5  nuz=1    fill 3 4 2 4 3 t end fill
end array
end data
end
=kenova
2.35 wt% UO2 Rods P=1.684 (Undermod)  lead reflector @ 0.26
read param
tme=700    gen=120   nsk=20     tba=60.0   npg=5000
flx=yes    fdn=yes   nub=yes    lib=4      nfb=8000
end param
'******************
'* MIXTURES *
'******************
read mixt   sct=1
'Fuel
mix=1
   92235 4.8828E-04
   92238 2.0033E-02
    8016 4.1043E-02
'Clad
mix=2
   13027 5.7878E-02
   14000 2.3072E-04
   26001 2.0305E-04
   29001 1.0197E-04
   25055 4.4230E-05
   12000 7.9981E-04
   24000 1.0904E-04
   22000 5.0729E-05
'Water
mix=3
    8016 3.3427E-02
    1001 6.6854E-02
   17000 8.4931E-08
   26000 2.5880E-07
   82000 1.4532E-11
   48000 5.3573E-12
'Lead
mix=4
   82000 3.2771E-02
   29000 1.3909E-04
end mixt
'******************
'* GEOMETRY *
'******************
read geom
unit 1
'Fuel
  cylinder 1  1         0.5588      91.44        0
'Al Clad
  cylinder 2  1         0.635       91.44        0
'Al End Plugs
  cylinder 2  1         0.635       96.52       -1.27
    cuboid 3  1       4p0.842       96.52       -1.27
unit 2 array 1         -15.156     -19.366      -1.27
com="Center Cluster"
unit 3 array 2         -15.156     -16.84       -1.27
com="End Cluster"
unit 4
com="Critical Separation - Water Gap"
    cuboid 3  1     2p15.156     2p5.055     96.52 -1.27
global unit 5 array 3   0 0 0
'Inner shell lead
    cuboid 3  1      30.972 -0.66 145.16 -18.84 109.33 -14.08
'Outer shell of lead
    cuboid 4  1      41.17 -10.86 145.16 -18.84 109.33 -14.08
'Water tank
    cuboid 3  1      60.81 -30.50 156.81 -30.50 127.02 -30.50
end geom

read array
ara=1 nux=18 nuy=23 nuz=1    fill 414r1 t end fill
ara=2 nux=18 nuy=20 nuz=1    fill 360r1 t end fill
ara=3 nux=1  nuy=5  nuz=1    fill 3 4 2 4 3 t end fill
end array
end data
end
```

```
=kenova
2.35 wt% UO2 Rods P=1.684 (Undermod)  lead reflector @ 1.29
read param
tme=700   gen=120   nsk=20    tba=60.0   npg=5000
flx=yes   fdn=yes   nub=yes   lib=4      nfb=8000
end param
'******************
'* MIXTURES *
'******************
read mixt   sct=1
'Fuel
mix=1
    92235 4.8828E-04
    92238 2.0033E-02
     8016 4.1043E-02
'Clad
mix=2
    13027 5.7878E-02
    14000 2.3072E-04
    26001 2.0305E-04
    29001 1.0197E-04
    25055 4.4230E-05
    12000 7.9981E-04
    24000 1.0904E-04
    22000 5.0729E-05
'Water
mix=3
     8016 3.3427E-02
     1001 6.6854E-02
    17000 8.4931E-08
    26000 2.5880E-07
    82000 1.4532E-11
    48000 5.3573E-12
'Lead
mix=4
    82000 3.2771E-02
    29000 1.3909E-04
end mixt
'******************
'* GEOMETRY *
'******************
read geom
unit 1
'Fuel
  cylinder 1  1         0.5588     91.44       0
'Al Clad
  cylinder 2  1         0.635      91.44       0
'Al End Plugs
  cylinder 2  1         0.635      96.52      -1.27
    cuboid 3  1       4p0.842      96.52      -1.27
unit 2 array 1         -15.156    -19.366     -1.27
com="Center Cluster"
unit 3 array 2         -15.156    -16.84      -1.27
com="End Cluster"
unit 4
com="Critical Separation - Water Gap"
    cuboid 3  1     2p15.156     2p4.250     96.52 -1.27
global unit 5 array 3   0 0 0
'Inner shell lead
    cuboid 3  1     33.588 -3.28 143.55 -20.45 109.33 -14.08
'Outer shell of lead
    cuboid 4  1     43.79 -13.48 143.55 -20.45 109.33 -14.08
'Water tank
    cuboid 3  1     60.81 -30.50 153.59 -30.50 127.02 -30.50
end geom
'
read array
ara=1 nux=18 nuy=23 nuz=1    fill 414r1 t end fill
ara=2 nux=18 nuy=20 nuz=1    fill 360r1 t end fill
ara=3 nux=1  nuy=5  nuz=1    fill 3 4 2 4 3 t end fill
end array
end data
end
=kenova
2.35 wt% UO2 Rods P=1.684 (Undermod)  without lead reflector
read param
tme=700   gen=120   nsk=20    tba=60.0   npg=5000
flx=yes   fdn=yes   nub=yes   lib=4      nfb=8000
end param
'******************
'* MIXTURES *
'******************
read mixt   sct=1
'Fuel
mix=1
    92235 4.8828E-04
    92238 2.0033E-02
     8016 4.1043E-02
'Clad
mix=2
    13027 5.7878E-02
    14000 2.3072E-04
    26001 2.0305E-04
    29001 1.0197E-04
    25055 4.4230E-05
    12000 7.9981E-04
    24000 1.0904E-04
    22000 5.0729E-05
'Water
mix=3
     8016 3.3427E-02
     1001 6.6854E-02
    17000 8.4931E-08
    26000 2.5880E-07
    82000 1.4532E-11
    48000 5.3573E-12
'Lead
mix=4
    82000 3.2771E-02
    29000 1.3909E-04
end mixt
'******************
'* GEOMETRY *
'******************
read geom
unit 1
'Fuel
  cylinder 1  1         0.5588     91.44       0
'Al Clad
  cylinder 2  1         0.635      91.44       0
'Al End Plugs
  cylinder 2  1         0.635      96.52      -1.27
    cuboid 3  1       4p0.842      96.52      -1.27
unit 2 array 1         -15.156    -19.366     -1.27
com="Center Cluster"
unit 3 array 2         -15.156    -16.84      -1.27
com="End Cluster"
unit 4
com="Critical Separation - Water Gap"
    cuboid 3  1     2p15.156     2p3.295     96.52 -1.27
global unit 5 array 3   0 0 0
'Water tank
    cuboid 3  1     60.81 -30.50 149.77 -30.50 127.02 -30.50
end geom
'
read array
ara=1 nux=18 nuy=23 nuz=1    fill 414r1 t end fill
ara=2 nux=18 nuy=20 nuz=1    fill 360r1 t end fill
ara=3 nux=1  nuy=5  nuz=1    fill 3 4 2 4 3 t end fill
end array
end data
end
```

Input File for 2.35 wt% Enriched Optimum Moderated UO_2 Fuel Rods with a Lead Wall Reflector as given in Table 5.

```
=nitawl
0$$     82      2       3       4       18
        19     20       9      15
1$$    500     17       0       0       0
         0      0       5       0       0
         0      0
t
2$$    92235    92238    13027    14000    25055
       29000   -29001    12000    24000
       48000    26000   -26001    22000
        8016     1001    17000    82000
3**    92235     293       2     0.5588    0.0897
       0.0  4.8828E-04     1    15.9994   3.1135E-02
        1   238.0508  4.3490E-02     1     1.000
      92238     293       2     0.5588    0.0897
       0.0  2.0033E-02     1    15.9994   7.5886E-00
        1   235.0439  2.8517E-01     1     1.000
      26001     293       2     0.6350    0.0000
      0.5588  2.0305E-04     1    26.98154  5.9906E-02
```

```
      1    30.4624   2.3202E-01       1      1.000
   29001       293        2      0.6350    0.0000
   0.5588  1.0197E-04        1    26.98154  7.9463E-02
      1    34.0419   6.1400E-01       1      1.000
   24000       293        2      0.6350    0.0000
   0.5588  1.0904E-04        1    26.98154  7.4309E-02
      1    35.0863   6.0131E-01       1      1.000
4**        f293
t
end
=kenova
2.35 wt%     UO2 rods    with lead    reflector at 0.00 in
read param
tme=700     gen=120    nsk=20    npg=5000    nfb=8000
flx=yes     fdn=yes    plt=yes   run=yes     tba=60.0
nub=yes     lib=4
end param
'***************
'* MIXTURES *
'***************
read mixt    sct=1
'Fuel
mix=1
     92235  4.8828E-04
     92238  2.0033E-02
      8016  4.1043E-02
'Clad
mix=2
     13027  5.7878E-02
     14000  2.3072E-04
     26001  2.0305E-04
     29001  1.0197E-04
     25055  4.4230E-05
     12000  7.9981E-04
     24000  1.0904E-04
     22000  5.0729E-05
'Water
mix=3
      8016  3.3427E-02
      1001  6.6854E-02
     17000  1.0095E-06
     26000  3.2350E-10
     82000  3.8609E-10
     48000  5.3798E-11
'Lead
mix=4
     82000  3.2771E-02
     29000  1.3909E-04
end mixt
'***************
'* GEOMETRY *
'***************
read geom
unit 1
'Fuel
     cylinder 1  1          0.5588      91.44       0
'Al Clad
     cylinder 2  1          0.635       91.44       0
'Al End Plugs
     cylinder 2  1          0.635       96.52      -1.27
       cuboid 3  1      1.016 -1.016  1.016 -1.016 96.52  -1.27
unit 2        array 1      -16.256     -19.304       0
unit 3
com="Crit      Separation"
       cuboid 3  1      2p16.256       2p6.920   96.52  -1.27
global unit 4   array 2     0 0 0
'Inner shell lea
       cuboid 3  1      32.512 0.00  153.75 -10.25 109.33 -14.0
'Outer shell of
       cuboid 4  1      42.71 -10.20  153.75 -10.25 109.33 -14.0
'Water tank
       cuboid 3  1      63.01 -30.50  174.00 -30.50 121.94 -30.5
end geom
'
read array
ara=1 nux=16    nuy=19      nuz=1 fill   304r1 t      end fill
ara=2 nux=1     nuy=5       nuz=1 fill   2 3 2 3 2 t  end fill
end array
read start     nst=1        end start
end data
end
=kenova
2.35 wt%     UO2 rods    with lead    reflector at 0.26 in
read param
tme=700     gen=120    nsk=20    npg=5000    nfb=8000
flx=yes     fdn=yes    plt=yes   run=yes     tba=60.0
nub=yes     lib=4
end param
'***************
'* MIXTURES *
'***************
read mixt    sct=1
'Fuel
mix=1
     92235  4.8828E-04
     92238  2.0033E-02
      8016  4.1043E-02
'Clad
mix=2
     13027  5.7878E-02
     14000  2.3072E-04
     26001  2.0305E-04
     29001  1.0197E-04
     25055  4.4230E-05
     12000  7.9981E-04
     24000  1.0904E-04
     22000  5.0729E-05
'Water
mix=3
      8016  3.3427E-02
      1001  6.6854E-02
     17000  1.0095E-06
     26000  3.2350E-10
     82000  3.8609E-10
     48000  5.3798E-11
'Lead
mix=4
     82000  3.2771E-02
     29000  1.3909E-04
end mixt
'***************
'* GEOMETRY *
'***************
read geom
unit 1
'Fuel
     cylinder 1  1.         0.5588      91.44       0
'Al Clad
     cylinder 2  1.         0.635       91.44       0
'Al End Plugs
     cylinder 2  1          0.635       96.52      -1.27
       cuboid 3  1      1.016 -1.016  1.016 -1.016 96.52  -1.27
unit 2        array 1      -16.256     -19.304       0
unit 3
com="Crit      Separation"
       cuboid 3  1      2p16.256       2p6.860   96.52  -1.27
global unit 4   array 2     0 0 0
'Inner shell lea
       cuboid 3  1      33.172 -0.66  153.63 -10.37 109.33 -14.0
'Outer shell of
       cuboid 4  1      43.37 -10.86  153.63 -10.37 109.33 -14.0
'Water tank
       cuboid 3  1      63.01 -30.50  173.76 -30.50 121.94 -30.5
end geom
'
read array
ara=1 nux=16    nuy=19      nuz=1 fill   304r1 t      end fill
ara=2 nux=1     nuy=5       nuz=1 fill   2 3 2 3 2 t  end fill
end array
read start     nst=1        end start
end data
end
=kenova
2.35 wt%     UO2 rods    with lead    reflector at 1.03 in
read param
tme=700     gen=120    nsk=20    npg=5000    nfb=8000
flx=yes     fdn=yes    plt=yes   run=yes     tba=60.0
nub=yes     lib=4
end param
'***************
'* MIXTURES *
'***************
read mixt    sct=1
'Fuel
```

```
mix=1
     92235  4.8828E-04
     92238  2.0033E-02
      8016  4.1043E-02
'Clad
mix=2
     13027  5.7878E-02
     14000  2.3072E-04
     26001  2.0305E-04
     29001  1.0197E-04
     25055  4.4230E-05
     12000  7.9981E-04
     24000  1.0904E-04
     22000  5.0729E-05
'Water
mix=3
      8016  3.3427E-02
      1001  6.6854E-02
     17000  1.0095E-06
     26000  3.2350E-10
     82000  3.8609E-10
     48000  5.3798E-11
'Lead
mix=4
     82000  3.2771E-02
     29000  1.3909E-04
end mixt
'***************
'* GEOMETRY *
'***************
read geom
unit 1
'Fuel
    cylinder 1 1        0.5588    91.44    0
'Al Clad
    cylinder 2 1        0.635     91.44    0
'Al End Plugs
    cylinder 2 1        0.635     96.52    -1.27
    cuboid 3 1      1.016 -1.016 1.016 -1.016 96.52 -1.27
unit 2     array 1      -16.256   -19.304  0
unit 3
com="Crit    Separation"
    cuboid 3 1      2p16.256     2p5.625  96.52 -1.27
global unit 4  array 2    0 0 0
'Inner shell lea
    cuboid 3 1      35.128 -2.62 151.16 -12.84 109.33 -14.0
'Outer shell of
    cuboid 4 1      45.33 -12.82 151.16 -12.84 109.33 -14.0
'Water tank
    cuboid 3 1      63.01 -30.50 168.82 -30.50 121.94 -30.5
end geom
'
read array
ara=1 nux=16   nuy=19     nuz=1 fill  304r1 t     end fill
ara=2 nux=1    nuy=5      nuz=1 fill  2 3 2 3 2 t  end fill
end array
read start     nst=1      end start
end data
end
=kenova
2.35 wt%     UO2 rods     without lead reflector
read param
tme=700      gen=120     nsk=20     npg=5000    nfb=8000
flx=yes      fdn=yes     plt=yes    run=yes     tba=60.0
nub=yes      lib=4
end param
'***************
'* MIXTURES *
'***************
read mixt     sct=1
'Fuel
mix=1
     92235  4.8828E-04
     92238  2.0033E-02
      8016  4.1043E-02
'Clad
mix=2
     13027  5.7878E-02
     14000  2.3072E-04
     26001  2.0305E-04
     29001  1.0197E-04
     25055  4.4230E-05
     12000  7.9981E-04
     24000  1.0904E-04
     22000  5.0729E-05
'Water
mix=3
      8016  3.3427E-02
      1001  6.6854E-02
     17000  1.0095E-06
     26000  3.2350E-10
     82000  3.8609E-10
     48000  5.3798E-11
'Lead
mix=4
     82000  3.2771E-02
     29000  1.3909E-04
end mixt
'***************
'* GEOMETRY *
'***************
read geom
unit 1
'Fuel
    cylinder 1 1        0.5588    91.44    0
'Al Clad
    cylinder 2 1        0.635     91.44    0
'Al End Plugs
    cylinder 2 1        0.635     96.52    -1.27
    cuboid 3 1      1.016 -1.016 1.016 -1.016 96.52 -1.27
unit 2     array 1      -16.256   -19.304  0
unit 3
com="Crit    Separation"
    cuboid 3 1      2p16.256     2p4.155  96.52 -1.27
global unit 4  array 2    0 0 0
'Water tank
    cuboid 3 1      63.01 -30.50 162.94 -30.50 121.94 -30.5
end geom
'
read array
ara=1 nux=16   nuy=19     nuz=1 fill  304r1 t     end fill
ara=2 nux=1    nuy=5      nuz=1 fill  2 3 2 3 2 t  end fill
end array
read start     nst=1      end start
end data
end
```

7.0 STRUCTURAL EVALUATION

7.1 INTRODUCTION

The PRTR Graphite Cask, or Radiometallurgy Cask 27, is an onsite, intra-area packaging for transporting Type B radioactive material within the 300 Area of the Hanford Site. This section of the document defines and evaluates the NTC structural requirements for intra-area transport of this package. Structural performance of the package is evaluated only for NTC; accident conditions are evaluated in the risk and dose consequence section of this document.

7.2 STRUCTURAL EVALUATION OF PACKAGE

7.2.1 Package Structural Description

The PRTR Graphite Cask is fundamentally a right circular cylinder of lead and stainless steel composite construction. The lead is sandwiched between outer and inner stainless steel tubular shells. At each end of the cask is a thick circular plate that is welded to both inner and outer shells, which encapsulates the lead. At the top, closure of the inner cavity is provided by a bolted blind flange with an attached shield plug of composite lead-stainless steel construction. The cask is equipped with a manually actuated, rotating, shielded drum door, which provides closure at the bottom end. None of the end closures are sealed. A handling yoke is provided on the cask and welded to the outer shell. Attached to the yoke is a lifting bail, which can be locked into position for lifting and handling of the cask. Support plates are welded to the outer bottom housing to provide support during transport.

The cask is constructed of welded 304 stainless steel. Shielding is provided by lead, which is poured after fabrication of the stainless steel body and internal components.

7.2.2 Chemical and Galvanic Reactions

At the operating temperatures, no chemical or galvanic interaction of the materials will occur. The lead is encapsulated in the stainless steel; consequently, there are no agents to generate chemical or galvanic reactions. In addition, stainless steel forms a natural oxide layer, which provides protection from most corrosive agents (i.e., water) under the normal operating temperatures.

7.2.3 Sizes of Package and Cavity

The outside dimensions of the cask are 36.0 cm (14.0 in.) in diameter by 99.0 cm (39.0 in.) in length. Dimensions of the inner cavity are 7.94 cm (3.13 in.) in diameter by 63.5 cm (25.0 in.) in length.

7.2.4 Weight

The PRTR Graphite Cask has an empty weight of 1,089 kg (2,400 lb) and a maximum gross weight of 1,202 kg (2,650 lb).

7.2.5 Tamper- Indicating Devices

Due to the weight of the cask closures and the intra-area shipment of this cask, no tamper indicating devices are provided.

7.2.6 Positive Closure

Positive closure of the cask is provided by the bolted blind end flanges. The top end blind flange is secured with four, No. 10 hex head screws. At the bottom end the flange is closed off with a rotating shielded drum door.

7.2.7 Lifting and Tiedown Devices

No tiedown devices are provided on the cask. For lifting and handling, yokes on each side of the cask with a rotating bail are provided. The yokes are recessed into the outer housing and reinforced with welded plates. The bail is equipped with bearings that are pressed onto the yoke. As shown in the Part B, Section 7.5, the yoke and the lifting attachments meet the requirements of the *Hanford Site Hoisting and Rigging Manual* (RL 1993).

7.3 NORMAL TRANSPORT CONDITIONS

7.3.1 Conditions To Be Evaluated

Onsite structural performance of the package is assessed for Hanford Site normal conditions in this section. The onsite conditions evaluated for are hot and cold temperature extremes, reduced and increased external pressure, vibration, water spray, compression, inertial loading, and penetration. The package structural response with solar insolation is evaluated for the onsite hot ambient temperature extreme of 46 °C (115 °F [Fadeff 1992]) and without for the cold ambient temperature extreme of -33 °C (-27 °F [Fadeff 1992]). Reduced and increased external pressure structural response is evaluated for a Hanford Site maximum barometric pressure range of 0.94 atm (13.81 psi) to 1.01 atm (14.85 psi). Vibrational loading response of the package is evaluated for the parameters established in ANSI N14.23 (ANSI 1980). In the case of water spray, package response is evaluated for in-leakage of water at ambient temperatures and pressures. The package structural response to compression is evaluated for compressive loads resulting from anticipated stacking onto the package. Because there are no in-transient load transfers, structural response of the package to inertial loads is evaluated for rough transport of the package based on ANSI N14.23 shock loading parameters. Penetration structural response is idealized as a loading from a steel rod 3.2 cm (1.25 in.) in diameter with a rounded end weighing 6.0 kg (13.0 lb) dropping onto the package from a height of 1.0 m (40.0 in.). These loads are to be applied independently and nonsequentially.

7.3.2 Acceptance Criteria

The criteria for acceptable performance of the package are based on all major critical components of the package remaining structurally functional, the contents remaining contained, and only superficial damage of noncritical components being incurred during NTC. To meet the criteria for NTC, the analytical tests are to assume, as a worst case, the package is intermittently subjected to the above loading conditions during normal transport operations. Performances of the package in meeting these criteria are demonstrated by either positive margins of safety based on material yield strength or package loadings that are within acceptable limits of the component/materials used in the package.

7.3.3 Hot and Cold Evaluation

Based on the thermal evaluation from Part B, Section 8.0, for a worst-case heat source of 5.65 W with solar insolation under Hanford Site conditions, the maximum internal component temperature of the cask is 79 °C (175 °F). Considering the materials of construction (lead and stainless steel), no material degradation or appreciable reduction in yield strength will occur. Under these conditions the external temperature of the cask is 78 °C (172 °F). Consequently, structural performance of the package is not affected by the Hanford Site hot temperature extreme. Following the thermal analysis, the radiological payload activity was reduced, resulting in a heat loading of 2.92 W. Because the heat loading is less than that previously analyzed, the conclusions remain the same.

Evaluation of cold temperature package performance shows that because the primary structural material of construction is stainless steel, no extremely cold weather shipping restrictions are required. Austenitic stainless steel is not susceptible to low-temperature brittle fracture. Consequently, with an onsite, low, extremely cold temperature of -33 °C (-27 °F), no degradation cask of performance will occur.

7.3.4 Reduced and Increased External Pressure

Because the cask is not sealed, reduced or increased external pressure is not a concern.

7.3.5 Vibration

Vibration of the package is not a concern because the shipment occurs only 12 times a year for a distance of less than 1.61 km (1.0 mi). Based on a speed of 24 km/h (15 mi/h) for a distance of 1.61 km (1.0 mi), 12 times a year, at a loading frequency of 2 Hz (ANSI 1980), this equates to approximately 6,000 cycles per year. Relative to the loading on the materials and the material fatigue strengths, vibrational loading on this cask is not significant.

7.3.6 Water Spray

Because the package is not sealed, in-leakage of water into the cask cavity is a concern. Consequently, all payloads must be shipped in sealed containers. Prior to and after transport, the cask must be inspected for any in-leakage of water into the cask cavity.

7.3.7 Compression

The package is shipped as an exclusive-use shipment, and stacking on the package is prohibited. Consequently, package compression is not a concern.

7.3.8 Inertial Loading

During normal transport of this package, no in-transit load transfers are involved. Consequently, normal condition inertial loads would arise from rough transport shock loads of 3.5*g*s vertical to the plane of travel and 2.3*g*s in the direction of travel (ANSI 1980).

In the case of the rough transport, shock loads of the conveyance are evaluated as intermittent in nature and applied as a single pulse to the package. Because the duration of the shock load is of such long duration (greater than three times the natural frequency of the system), it is applied as a quasi-static load, and the package is evaluated by classical linear elastic methods. To ensure component and material loading are within the elastic range, the allowable stresses are established on the basis of the maximum shear stress theory of failure. The weld allowable loading is established on base material yield strength with a joint efficiency reduction factor based on the American Society of Mechanical Engineers *Boiler and Pressure Vessel Code*, Section VIII (ASME 1992).

Evaluation of rough transport loads on the package presented in Part B, Section 7.5, shows that the package remains fully functional, maintains structural integrity, and maintains the contents. In the evaluation, package performance is analyzed for both vertical and longitudinal loadings. In both cases the evaluation shows the induced stresses on the package are below the allowable stresses.

7.3.9 Penetration

The evaluation presented in Part B, Section 7.5, shows the exposed surfaces of the package cannot be penetrated by a 6.0-kg (13.0-lb) object dropped from 1.0 m (40.0 in.). Results of the evaluation show that only superficial marring of the exposed stainless steel surfaces results from dropping the object.

7.3.10 Conclusions

The results of these evaluations show the package is acceptable for transport on the Hanford Site under NTC. Due to the possibility of in-leakage of water into the cask cavity, proper protection and sealing of the payload and cask internals are required.

7.4 REFERENCES

ANSI, 1980, *American National Standard Design Basis for Resistance to Shock and Vibration of Radioactive Material Packages Greater than One Ton in Truck Transport*, DRAFT, ANSI N14.23, American National Standards Institute, New York, New York.

ASME, 1992, *Boiler and Pressure Vessel Code*, Section VIII, Division 1, American Society of Mechanical Engineers, New York, New York.

Fadeff, J. G., 1992, *Environmental Conditions for On-site Hazardous Materials Packages*, WHC-SD-TP-RPT-004, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

RL, 1993, *Hanford Site Hoisting and Rigging Manual*, DOE/RL-92-36, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

7.5 APPENDIX: STRUCTURAL ANALYSIS

ENGINEERING SAFETY EVALUATION

Subject: PRTR Cask NTC Structural Evaluation & Puncture Threshold		Page: 1 of 11
Originator: S. S. Shiraga		Date: 05/19/97
Checker: R. J. Smith		Date: 05/25/97

I. Objective:

The objective of this evaluation is to evaluate the PRTR cask performance relative to the Normal Transport Conditions outlined within Section 7 of this Safety Evaluation Packaging (SEP). Also this evaluation determines adequacy of lifting system and the equivalent steel thickness of the cask for determination of the puncture failure threshold.

II. References:

ANSI, 1992, ANSI N14.23, *Draft American National Standard Design Basis for Resistance to Shock and Vibration of Radioactive Material Packages Greater than One Ton in Truck Transport*, American National Standard Institute, New York, New York.

ASME, 1995, *Boiler and Pressure Vessel Code*, Section II, Part D, American Society of Mechanical Engineers, New York, New York.

Roark, R. J., 1965, *Formulas for Stress and Strain*, Fourth Edition, McGraw-Hill Book Company, New York, New York.

Blodgett, O. W., 1966, *Design of Welded Structures*, The James F. Lincoln Arc Welding Foundation, Cleveland, Ohio.

Roark, R. J., Young, W. C., 1983, *Formulas for Stress and Strain*, Fifth Edition, McGraw-Hill Book Company, New York, New York.

ASME, 1992, *Boiler and Pressure Vessel Code*, Section VIII, Division 1, American Society of Mechanical Engineers, New York, New York.

Rinehart, J. S., and Pearson, J., 1954, *Behavior of Metals Under Impulsive Loads*, American Society of Metals, Cleveland, Ohio.

ANSI, 1993, ANSI N14.6, *American National Standard for Radioactive Materials-Special Lifting Devices for Shipping Containers Weighing 10 000 Pounds (4500 kg) or More*, American National Standard Institute, New York, New York.

ORNL, 1970, *Cask Designer's Guide*, ORNL-NISC-68, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Mathcad Plus 5, 1994, *User's Guide*, Math Soft Inc., Cambridge, Massachusetts.

III. Results and Conclusions:

This evaluation shows that the PRTR cask will meet normal transport conditions (NTC) and lifting loads as specified in Section 7 of this SEP. The evaluation shows the inertial loadings on the cask from rough transport are well below the material yield. Consequently, rough transport will not result in any permanent deformation of the package. The results demonstrate that the cask will not sustain any damage during NTC and remain fully functional.

Also, within this evaluation, the equivalent steel thickness of the package is determined. Based on empirical data (Rinehart, 1954) the equivalent steel thickness of the cask body is 2.6 inches.

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IV. Evaluation:

Normal Transport Conditions Evaluation of PRTR Cask:

Determination of inertial loading for NTC:

During normal transport of this package no in-transit load transfers are involved. Consequently, normal condition inertial loads arise from rough transport shock loads. Rough transport loads are derived from ANSI N14.23 (ANSI, 1980). Rough transport shock loads for this package are defined as a vertical 3.5 g and longitudinal (in direction of travel) 2.3 g shock load to the package. Lateral load of 1.6 g is neglected, as it is bounded by the vertical and longitudinal loads. Assume the shock is a single pulse applied to the package as a quasi-static load. Acceptance criteria is the package remain fully functional after the event, i. e., no plastic deformation of components.

Empty weight of package: $W_p := 2400 \cdot lbf$ Maximum weight of payload: $W_{pay} := 250 \cdot lbf$

Gross weight of package: $W_t := W_p + W_{pay}$

Inertial loadings: Vertical: $g_v := 3.5$ Longitudinal: $g_l := 2.3$

Material parameters (ASME, 1995):

Assume cask shells are constructed of 304L stainless steel (SA 240, Class 2) at 200 °F:

Yield strength: $s_{ysst} := 21.3 \cdot ksi$ Poisson's Ratio: $\nu_{sst} := 0.31$

Elastic modulus: $E_{sst} := 27.6 \cdot 10^6 \cdot psi$

Allowable stress for NTC on sst components based on maximum shear stress: $s_{asst} := \frac{2}{3} \cdot s_{ysst}$

Assumed cask bolts are constructed of SA193 Type B8 (Class 2) at 200 °F:

Yield strength: $s_{yb} := 27.5 \cdot ksi$

Allowable stress for NTC bolts based on ASME criteria: $s_{ab} := \frac{2}{3} \cdot s_{yb}$

Assume lead properties at 250 °F:

Yield strength: $s_{ypb} := 8 \cdot ksi$ Poisson's ratio: $\nu_{pb} := 0.4$

Elastic modulus: $E_{pb} := 2 \cdot 10^6 \cdot psi$

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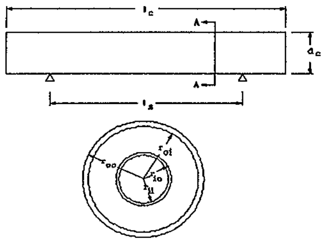
Geometric parameters of package:

Idealize the package as a composite beam with of concentric cylinders of stainless steel and lead.



Section A–A

Length of cask: $l_c := 39.625\,in$

Diameter of cask: $d_c := 14 \cdot in$

Length between supports: $l_s := l_c - 2 \cdot (2.5 \cdot in)$

Outer shell wall thickness: $t_{os} := 0.250\,in$

Outer shell outside radius: $r_{oo} := \frac{d_c}{2}$

Outer shell inside radius: $r_{oi} := r_{oo} - t_{os}$

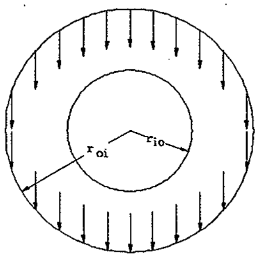
Inner shell outside radius: $r_{io} := \frac{3.375\,in}{2}$

Inner shell inside radius: $r_{ii} := \frac{3.125\,in}{2}$

Inner shell wall thickness: $t_{is} := r_{io} - r_{ii}$ $\quad t_{is} = 0.12 \cdot in$

End plate thickness: $t_{ep} := 0.5 \cdot in$ $\quad$ End plate weld leg: $w_{leg} := 0.1875\,in$

Determine deflection of lead, assuming the lead is unbonded to the stainless steel walls:



Density of lead: $\rho_{pb} := 710 \cdot \frac{lbf}{ft^3}$

Idealize as ring supporting it's own weight. Use Roark, 1965, case 18, page 176.

Weight per linear inch of lead:

$$w_{pb} := \rho_{pb} \cdot \left[\pi \cdot \left(r_{oi}^2 - r_{io}^2\right)\right] \qquad w_{pb} = 55 \cdot \frac{lbf}{in}$$

Moment of inertia of the section:

$$I_{pb} := \pi \cdot \frac{r_{oi}^4 - r_{io}^4}{4} \qquad I_{pb} = 1624 \cdot in^4$$

Nominal radius: $r_{pb} := \frac{r_{oi} + r_{io}}{2}$

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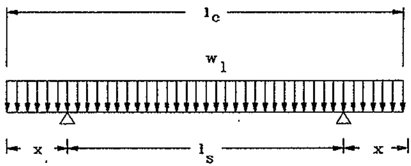
Diametrial compression of lead: $\Delta_y := -\frac{g_v \cdot w_{pb} \cdot r_{pb}^4}{E_{pb} \cdot I_{pb}} \cdot (0.4674)$ $\Delta_y = -8.8 \cdot 10^{-6} \cdot in$

This is negligible, consequently no significant load on inner shell.

Determine Loading on Cask Body due to Bending:

Since cask is shipped in the horizontal, setting on two support plates, idealize as simply supported beam with uniform loading which over hangs each end (Blodgett, 1966).



Assumed uniform load: $w_l := \frac{g_v \cdot W_t}{l_c}$ $w_l = 234 \cdot \frac{lbf}{in}$ Over hang distance: $x := \frac{l_c - l_s}{2}$ $x = 2.5 \cdot in$

Reaction loads at supports: $F_r := w_l \left(x + \frac{l_s}{2}\right)$ $F_r = 4638 \cdot lbf$

Maximum moment at center: $M_c := \frac{w_l}{8} \cdot \left(l_s^2 - 4 \cdot x^2\right)$ $M_c = 34346 \cdot lbf \cdot in$

Moment at supports: $M_s := \frac{w_l \cdot x^2}{2}$ $M_s = 731 \cdot lbf \cdot in$

Maximum load and moment at supports.

Determine composite moment of inertia:

Moment of inertia about center (neutral axis) of cross section:

Outer shell: $I_{os} := \pi \cdot \left(\frac{r_{oo}^4 - r_{oi}^4}{4}\right)$ Inner shell: $I_{is} := \pi \cdot \left(\frac{r_{io}^4 - r_{ii}^4}{4}\right)$

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Composite moment of inertia: $EI := E_{sst} \cdot I_{os} + E_{pb} \cdot I_{pb} + E_{sst} \cdot I_{is}$

Determine composite area:

Outer shell: $A_{os} := \pi \cdot \left(r_{oo}^2 - r_{oi}^2\right)$ Inner shell: $A_{is} := \pi \cdot \left(r_{io}^2 - r_{ii}^2\right)$

Lead shielding: $A_{pb} := \pi \cdot \left(r_{oi}^2 - r_{io}^2\right)$

Composite area factor: $AE := A_{os} \cdot E_{sst} + A_{pb} \cdot E_{pb} + A_{is} \cdot E_{sst}$

Bending stress in outer shell at maximum moment: $\sigma_{bos} := \frac{M_s \cdot E_{sst} \cdot r_{oo}}{EI}$ $\sigma_{bos} = 13.67 \cdot psi$

Bending stress in inner shell at maximum moment: $\sigma_{bis} := \frac{M_s \cdot E_{sst} \cdot r_{io}}{EI}$ $\sigma_{bis} = 3.29 \cdot psi$

Bending stress in lead shielding at maximum moment: $\sigma_{bpb} := \frac{M_s \cdot E_{pb} \cdot r_{oi}}{EI}$ $\sigma_{bpb} = 0.95 \cdot psi$

Maximum shear stress in outer shell: $\tau_{sos} := \frac{F_r \cdot E_{sst}}{AE}$ $\tau_{sos} = 0.21 \cdot ksi$

Maximum shear stress in inner shell: $\tau_{sis} := \frac{F_r \cdot E_{sst}}{AE}$ $\tau_{sis} = 0.21 \cdot ksi$

Maximum shear stress in shielding: $\tau_{pb} := \frac{F_r \cdot E_{pb}}{AE}$ $\tau_{pb} = 0.02 \cdot ksi$

Since stresses are not significant, package is demonstrated to meet acceptance criteria for vertical loading.

Determine worst case end load:

Assume as a worst case entire weight of cask is inertially loaded onto the end plate, weakest component is the weld. Also assume the plate thickness is uniform and that of the thinnest section.

Idealize as a plate with a center hole, clamped and fixed at outer and inner edges, loaded with a uniformly distributed load (Roark, 1983, Table 24, 2h).

For determination of moments redefine: $r_{io} := \frac{5.5 \cdot in}{2} - 0.188 in$

Inertial load on end plate assume uniformly distributed: $w_{pl} := \frac{g_r \cdot W_t}{\pi \cdot \left(r_{oi}^2 - r_{io}^2\right)}$ $w_{pl} = 50 \cdot psi$

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Plate factors:

$$C2 := \frac{1}{4}\left[1 - \left(\frac{r_{io}}{r_{oi}}\right)^2 \cdot \left(1 + 2\cdot\ln\left(\frac{r_{oi}}{r_{io}}\right)\right)\right] \qquad C3 := \frac{r_{io}}{4\cdot r_{oi}}\cdot\left[\left[\left(\frac{r_{io}}{r_{oi}}\right)^2 + 1\right]\cdot\ln\left(\frac{r_{oi}}{r_{io}}\right) + \left(\frac{r_{io}}{r_{oi}}\right)^2 - 1\right]$$

$$C5 := \frac{1}{2}\cdot\left[1 - \left(\frac{r_{io}}{r_{oi}}\right)^2\right] \qquad C6 := \frac{r_{io}}{4\cdot r_{oi}}\cdot\left[\left(\frac{r_{io}}{r_{oi}}\right)^2 - 1 + 2\cdot\ln\left(\frac{r_{oi}}{r_{io}}\right)\right]$$

$$C8 := \frac{1}{2}\left[1 + \nu_{sst} + \left(1 - \nu_{sst}\right)\cdot\left(\frac{r_{io}}{r_{oi}}\right)^2\right] \qquad C9 := \left(\frac{r_{io}}{r_{oi}}\right)\cdot\left[\frac{1+\nu_{sst}}{2}\cdot\ln\left(\frac{r_{oi}}{r_{io}}\right) + \left(\frac{1-\nu_{sst}}{4}\right)\cdot\left[1 - \left(\frac{r_{io}}{r_{oi}}\right)^2\right]\right]$$

$$L11 := \frac{1}{64}\left[1 + 4\cdot\left(\frac{r_{io}}{r_{oi}}\right)^2 - 5\cdot\left(\frac{r_{io}}{r_{oi}}\right)^4 - 4\cdot\left(\frac{r_{io}}{r_{oi}}\right)^2\cdot\left[2 + \left(\frac{r_{io}}{r_{oi}}\right)^2\right]\cdot\ln\left(\frac{r_{oi}}{r_{io}}\right)\right] \qquad L14 := \frac{1}{16}\left[1 - \left(\frac{r_{io}}{r_{oi}}\right)^4 - 4\cdot\left(\frac{r_{io}}{r_{oi}}\right)^2\cdot\ln\left(\frac{r_{oi}}{r_{io}}\right)\right]$$

$$L17 := \frac{1}{4}\left[1 - \left(\frac{1-\nu_{sst}}{4}\right)\cdot\left[1 - \left(\frac{r_{io}}{r_{oi}}\right)^4\right] - \left(\frac{r_{io}}{r_{oi}}\right)^2\cdot\left[1 + \left(1+\nu_{sst}\right)\cdot\ln\left(\frac{r_{oi}}{r_{io}}\right)\right]\right]$$

Axial load on inner weld: $f_{iw} := w_{pl}\cdot r_{oi}\cdot\left(\frac{C2\cdot L14 - C5\cdot L11}{C2\cdot C6 - C3\cdot C5}\right)$ $\qquad f_{iw} = 144\cdot\frac{lbf}{in}$

Axial load on outer weld: $f_{ow} := f_{iw}\cdot\left(\frac{r_{io}}{r_{oi}}\right) - \frac{w_{pl}}{2\cdot r_{oi}}\cdot\left(r_{oi}^2 - r_{io}^2\right)$ $\qquad f_{ow} = -89\cdot\frac{lbf}{in}$

Moment on inner weld: $M_{iw} := -w_{pl}\cdot r_{oi}^2\cdot\left(\frac{C3\cdot L14 - C6\cdot L11}{C2\cdot C6 - C3\cdot C5}\right)$ $\qquad M_{iw} = -94\cdot lbf$

Moment on outer weld: $M_{ow} := M_{iw}\cdot C8 + f_{iw}\cdot r_{oi}\cdot C9 - w_{pl}\cdot r_{oi}^2\cdot L17$ $\qquad M_{ow} = -63\cdot lbf$

Axial load from moment on inner weld: $f_{biw} := \frac{\left|M_{iw}\right|}{r_{io}}$ $\qquad f_{biw} = 37\cdot\frac{lbf}{in}$

Axial load from moment on outer weld: $f_{bow} := \frac{M_{ow}}{r_{oi}}$ $\qquad f_{bow} = -9\cdot\frac{lbf}{in}$

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Total load on inner weld: $f_{tiw} := f_{iw} + f_{biw}$ $f_{tiw} = 181 \cdot \frac{lbf}{in}$

Total load on outer weld: $f_{tow} := |f_{ow}| + f_{bow}$ $f_{tow} = 80 \cdot \frac{lbf}{in}$

Determine allowable on welds:

Assuming base material strengths and ASME joint efficiency factors:

Length of inner weld: $w_{in} := 0.1875 in$ Leg length of outer weld: $w_{out} := 0.1875 in$

ASME joint efficiency (ASME, 1992) factor assuming no inspection:. $eff := 0.60$

Allowable on inner weld: $f_{iall} := 0.707 s_{ysst} \cdot w_{in} \cdot eff$ $f_{iall} = 1694 \cdot \frac{lbf}{in}$

Allowable on outer weld: $f_{oall} := 0.707 s_{ysst} \cdot w_{out} \cdot eff$ $f_{oall} = 1694 \cdot \frac{lbf}{in}$

Margin of safety on inner weld: $MS_{iw} := \frac{f_{iall}}{f_{tiw}} - 1$ $MS_{iw} = 8.38$

Margin of safety on outer weld: $MS_{ow} := \frac{f_{oall}}{|f_{tow}|} - 1$ $MS_{ow} = 20.26$

Determine end loading of top end closure bolts:

Assume payload is restrained in cavity by dunnage and bears against the top and bottom closures. Worst case loading would occur at the top closure, since it has the fewest number of bolts. Loading results from shield plug and payload.

Weight of shield plug, ignore inner plumbing:

Plate diameter: $d_{spl} := 8.75 in$ Plate thickness: $t_{pl} := 0.375 in$

Shell OD: $od_{sh} := 5.25 in$ Wall thickness: $t_{sh} := 0.250 in$ Inner plate thickness: $t_{ipl} := 0.25 in$

Inner shell ID: $id_{ish} := od_{sh} - 2 \cdot t_{sh}$ Length: $l_{sh} := 5.00 in - t_{ipl}$

Lead length: $l_{pb} := l_{sh}$ Stainless steel density: $\rho_{sst} := 0.29 \frac{lbf}{in^3}$

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Weight of stainless steel:

$$w_{sst} := \rho_{sst} \cdot \left[\pi \cdot \frac{d_{spl}^{2}}{4} \cdot t_{pl} + \pi \cdot \left(\frac{od_{sh}^{2} - id_{ish}^{2}}{4} \right) \cdot l_{sh} + \pi \cdot \frac{od_{sh}^{2}}{4} \cdot t_{ipl} \right] \qquad w_{sst} = 14 \cdot lbf$$

Weight of lead: $w_{pb} := \rho_{pb} \cdot \frac{id_{ish}^{2}}{4} \cdot l_{pb}$ $\qquad w_{pb} = 11 \cdot lbf$

Total plug weight: $w_{plug} := w_{sst} + w_{pb}$ $\qquad w_{plug} = 25 \cdot lbf$

Assume bolts are uniformly loaded:

Nominal diameter of bolts: $d_b := 0.25 \cdot in$ Lead: $l_b := \frac{20}{in}$

Tensile stress area: $A_s := 0.7854 \left(d_b - \frac{0.9743}{l_b} \right)^2$ Number of bolts: $n_{bolt} := 4$

Assume preload torque for bolts is: $T_{pre} := 30 \cdot lbf \cdot in$ $\qquad T_{pre} = 2.5 \cdot ft \cdot lbf$

Assume nut friction factor: $\mu_n := 0.2$

Preload force per bolt: $F_{pre} := \frac{T_{pre}}{d_b \cdot \mu_n}$ $\qquad F_{pre} = 600 \cdot lbf$

Total load on top closure bolts: $F_{cl} := n_{bolt} \cdot F_{pre} + g_l \cdot (w_{plug} + W_{pay})$ $\qquad F_{cl} = 1769 \cdot lbf$ ☜

Tensile stress on bolts: $\sigma_{ten} := \frac{F_{cl}}{n_{bolt} \cdot A_s}$ $\qquad \sigma_{ten} = 13.89 \cdot ksi$ ☜

Margin of safety: $MS_{bolt} := \frac{s_{ab}}{\sigma_{ten}} - 1$ $\qquad MS_{bolt} = 0.32$ ☜

Therefore OK, since margin of safety is positive.

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Lifting Evaluation:

Determine if the cask lifting yoke meets the 3 to 1 requirements of Hanford Hoisting & Rigging Manual:

Idealize lifting yoke as a short beam uniformly loaded cantilever:

Length of yoke: $l_y := 0.9375 \cdot in$ Diameter of yoke: $d_y := 1.5739 \cdot in$

Load on yoke: $F_{load} := \frac{W_t}{2}$ Dynamic load factor: $DLF := 1.25$

Cross sectional area: $A_y := \pi \cdot \frac{d_y^2}{4}$ Moment of inertia: $I_y := \pi \cdot \frac{d_y^4}{64}$

Maximum bending stress at end: $\sigma_{yb} := \left(\frac{DLF \cdot F_{load} \cdot l_y}{I_y} \cdot \frac{d_y}{2} \right)$ $\sigma_{yb} = 4.06 \cdot ksi$

Maximum shear stress: $\tau_{max} := \frac{4}{3} \cdot \frac{DLF \cdot F_{load}}{A_y}$ $\tau_{max} = 1.14 \cdot ksi$

Loads are well under yield strength of material.

Determine if lifting bracket meets requirements of Hanford Hoisting & Rigging Manual:

Cask attachment brackets at yoke:

Edge distance: $d_{edge} := 3.5 \cdot in - \frac{d_y}{2}$ Side edge distances: $d_{side} := \frac{4.25 \cdot in - d_y}{2}$

Bracket thickness: $t_{brac} := 1 \cdot in$

Shear tear out of bracket: $\sigma_{bto} := \frac{DLF \cdot F_{load}}{d_{side} \cdot t_{brac}}$ $\sigma_{bto} = 1.24 \cdot ksi$

Tensile stress on bracket: $\sigma_{bten} := \frac{DLF \cdot F_{load}}{2 \cdot t_{brac} \cdot d_{side}}$ $\sigma_{bten} = 0.62 \cdot ksi$

Lifting bail:

Bail thickness: $t_{bail} := 1 \cdot in$ Minimum edge distance: $d_{min} := (5.25 - 3.5) \cdot in$

Assumed diameter of hook: $d_{hook} := 1 \cdot in$

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Shear tear out of bail: $\sigma_{bailto} := \frac{DLF \cdot F_{load}}{2 \cdot d_{min} \cdot t_{bail}}$ $\sigma_{bailto} = 0.47 \cdot ksi$

Loads are well under yield strength of material.

Check of bolts holding bail and cask yoke brackets together.

Nominal diameter: $d_b := 0.625 in$ Lead: $l_b := \frac{11}{in}$ Number of bolts per leg: $n_b := 3$

Yield strength of PH-18-8 bolt (assumed same as 304 stainless steel):

Tensile stress area of screw: $A_s := 0.7854\left(d_b - \frac{0.9743}{l_b}\right)^2$

Determine If Sufficient Thread Engagement Is Available (Industrial Press, 1992):

Available thread depth: $L_{avail} := 1.5 \cdot in$ Number of threads per in: $n_t := l_b$

Minimum tensile strength of bolt: $s_{bolt} := \frac{DLF \cdot F_{load}}{n_b \cdot A_s}$ $s_{bolt} = 2 \cdot ksi$

Maximum minor diameter of internal thread: $K_{nmax} := 0.546 in$

Minimum pitch diameter of external thread: $E_{smin} := 0.5561 \cdot in$

Minimum engagement length since materials are the same:

$$L_e := \frac{2 \cdot A_s}{\pi \cdot K_{nmax} \cdot \left[\frac{1}{2} + 0.57735 n_t \cdot \left(E_{smin} - K_{nmax}\right)\right]} \qquad L_e = 0.47 \cdot in$$

Since Lavail>Le, there is sufficient thread engagement and bolt strength.

NTC Penetration of Package:

Mass of projectile: $m_p := 6 \cdot kg$ Height of drop: $h_{dr} := 1 \cdot m$ Hemispherical end diameter: $d_{hemi} := 3.2 \cdot cm$

Evaluate package penetration by empirical methods (Rhinehart and Pearson, 1954):

Velocity of projectile: $v_o := \sqrt{2 \cdot g \cdot h_{dr}}$ $v_o = 14.5 \cdot \frac{ft}{sec}$

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Assuming the test rod is a hard unyielding object, at this velocity (< 10,000 ft/sec), the force that acts on the projectile is proportional to the cross sectional area and is essentially constant during penetration.

Cross sectional area of projectile: $A_p := \pi \cdot \frac{d_{hemi}^2}{4}$ $A_p = 1.25 \cdot in^2$

Volume of material displaced per unit of energy constant (Rhinehart and Pearson, 1954, page 202, Table 12-1):

For steel: $K_s := 0.26 \cdot 10^{-4} \cdot \frac{in^3}{ft \cdot lbf}$

Depth of penetration into steel: $s_{sp} := \frac{1}{2} \cdot m_p \cdot v_o^2 \cdot \frac{K_s}{A_p}$ $s_{sp} = 0.001 \cdot in$

The penetration depth is not significant, therefore no penetration of package.

PRTR Cask Puncture Failure Thresholds, Equivalent Steel Thickness:

Equivalent Thickness of lead to steel (Rinehart, 1954): $f_{equ} := 2.3$

ID of Outer Shell: $id_{o3} := 13.5 \cdot in$ Outer Shell Wall Thickness: $t_{ow3} := 0.25 \cdot in$

OD of Inner Shell: $od_{i3} := 3.375 \cdot in$ ID of Inner Shell: $id_{i3} := 3.125 \cdot in$

Inner Shell Wall Thickness: $t_{iw3} := \frac{od_{i3} - id_{i3}}{2}$ $t_{iw3} = 0.125 \cdot in$

Lead Thickness: $t_{pb3} := \frac{id_{o3} - od_{i3}}{2}$ $t_{pb3} = 5.06 \cdot in$

Total Equivalent thickness of steel: $t_{eq3} := t_{ow3} + t_{iw3} + \frac{t_{pb3}}{f_{equ}}$ $t_{eq3} = 2.6 \cdot in$

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8.0 THERMAL EVALUATION

8.1 INTRODUCTION

The PRTR Graphite Cask is an onsite, intra-area packaging for transporting Type B radioactive material within the 300 Area of the Hanford Site. This section of the document defines and evaluates the NTC structural requirements for intra-area transport of this package. Thermal performance of the package is evaluated only for NTC; accident conditions are evaluated in the risk and dose consequence section of this document.

8.2 THERMAL EVALUATION OF PACKAGE

8.2.1 Package Description

The PRTR Graphite Cask is fundamentally a right circular cylinder of lead and stainless steel composite construction. The lead is sandwiched between outer and inner stainless steel tubular shells. At each end of the cask is a thick circular plate that is welded to both inner and outer shells, which encapsulates the lead. At the top, closure of the inner cavity is provided by a bolted blind flange with an attached shield plug of composite lead-stainless steel construction. The cask is equipped with a manually actuated, sliding trap door, which provides closure at the bottom end. None of the end closures are sealed. A handling yoke is provided on the cask and welded to the outer shell. In addition, support plates are welded to the outer housing of the cask to provide support during transport and lifting attachment anchors for handling.

The cask is constructed of welded 304L stainless steel. Shielding is provided by lead, which is poured after fabrication of the stainless steel body and internal components.

8.3 NORMAL TRANSPORT CONDITIONS THERMAL EVALUATION

8.3.1 Conditions To Be Evaluated

Thermal performance of the package is assessed for Hanford Site NTC in this section. The package is evaluated for the worst-case Hanford Site thermal loading condition of a still-air ambient temperature of 46 °C (115 °F [Fadeff 1992]) with decay heat sources with and without solar insolation. Because of the variability of the payloads, the heat sources are assumed to be tightly packed in the cask cavity and against the inside wall of the cask.

8.3.2 Acceptance Criteria

The criterion for acceptable performance of the package is the accessible surface of the package in still air at 46 °C (115 °F) and in the shade is not to exceed 82 °C (182 °F). This is based on this package being transported as an exclusive-use shipment.

8.3.3 Thermal Evaluation and Conclusions

For this evaluation the worst-case decay heat source is assumed to generate a total heat load of 5.65 W. Based on the variable geometries of the payloads, the configuration of the heat source is assumed to be uniformly distributed over the length of the cask cavity and fitted tightly up against the inside wall of the cavity. This provides a conservative estimate of the cask temperature, but it does not provide a conservative estimate of the temperature load to the payload. This evaluation bounds temperatures for the cask, but does not provide any estimation of payload temperatures. Temperature-sensitive payloads must be evaluated on a case-by-case basis to determine the temperature parameters within the cask.

Results of this evaluation show the cask component temperatures under solar insolation are below 99 °C (211 °F) for the structural evaluation. The results also show the cask meets the NTC exterior surface temperature requirement of 82 °C (182 °F) in the shade for exclusive-use shipments. Table B2-2 shows a heat loading of 2.92 W resulting from a reduced payload. Because the heat loading is less than the previously analyzed heat loading, the thermal evaluation conclusion remains the same.

8.4 REFERENCE

Fadeff, J. G., 1992, *Environmental Conditions for On-site Hazardous Materials Packages*, WHC-SD-TP-RPT-004, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

8.5 APPENDIX: PRTR GRAPHITE CASK NTC THERMAL EVALUATION

ENGINEERING SAFETY EVALUATION

Subject:	PRTR Cask Normal Transport Conditions Thermal Evaluation	Page: 1 of 5
Originator:	S. S. Shiraga	Date: 05/20/97
Checker:	S. R. Crow	Date: 05/25/97

I. Objective:

The objective of this evaluation is determine the cask component temperatures under solar insolation for the structural evaluation and the exterior temperature in the shade as specified in Section 8 of this Safety Evaluation for Packaging (SEP).

II. References:

Irwin, J. J., 1995, WHC-SD-TP-RPT-005, Rev. 1, *Thermal Analysis Methods for Safety Analysis Reports for Packaging*, Westinghouse Hanford Company, Richland, Wash.

ORNL, 1970, *Cask Designer's Guide*, ORNL-NISC-68, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Mathcad Plus 5, 1994, *User's Guide*, Math Soft Inc., Cambridge, Massachusetts.

WHC, 1980, Drawing No. H-3-13699, Rev. 7, *PRTR Graphite Sample Cask Assy.*, Westinghouse Hanford Company, Richland, Washington.

III. Results and Conclusions:

The results also show the cask meets the normal transport conditions (NTC) exterior temperature requirement of 182 °F in the shade for exclusive use shipments. Because of the variability of the payloads, the heat sources are assumed to be tightly packed in the cask cavity and against the inside wall of the cask. This provides a conservative estimate of the peak temperatures subjected to the cask, but it does not provide a conservative estimate of the payload temperatures. Temperature sensitive payloads must be evaluated on a case by case basis to verify payload stability and integrity.

ENGINEERING SAFETY EVALUATION

Subject: PRTR Cask Normal Transport Conditions Thermal Evaluation — Page: 2 of 5
Originator: S. S. Shiraga — Date: 05/20/97
Checker: S. R. Crow — Date: 05/25/97

IV. Evaluation:

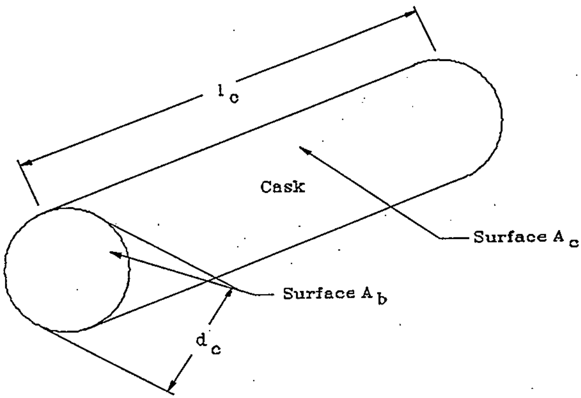
Normal Transport Conditions (NTC) Thermal Evaluation:

Determine temperature of outer shell with and without solar insolation:

Evaluate as steady state heat transfer for a horizontal cylinder with flat plate ends (Irwin, 1995):

Free convection coefficient for a horizontal cylinder: $k_{hc} := 0.27 \cdot \frac{BTU}{hr \cdot ft^2}$

Free convection coefficient for a vertical plate: $k_{vp} := 0.29 \cdot \frac{BTU}{hr \cdot ft^2}$



Length of cylinder: $l_c := 39 \cdot in$ Diameter of plate: $d_c := 14 \cdot in$

Surface area of cylinder: $A_c := \pi \cdot l_c \cdot d_c$ Surface area of plate: $A_b := \frac{\pi}{4} \cdot d_c^2$

Convection coefficients:

$$hd_1 := \frac{k_{hc} \cdot A_c \cdot R^{-\frac{1}{4}}}{\left(\frac{l_c}{ft}\right)^{-\frac{1}{4}}} \qquad hd_2 := \frac{k_{vp} \cdot 2 \cdot A_b \cdot R^{-\frac{1}{4}}}{\left(\frac{d_c}{ft}\right)^{-\frac{1}{4}}}$$

ENGINEERING SAFETY EVALUATION

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Radient heating constant:

Stefan-Boltzman's natural constant: $\sigma_{sb} := 0.1714 10^{-8} \cdot \frac{BTU}{hr \cdot ft^2 \cdot R^4}$

Emissivity of stainless steel: $\varepsilon_s := 0.32$

Radiation coefficients $K_1 := \sigma_{sb} \cdot \varepsilon_s \cdot A_c$ $K_2 := \sigma_{sb} \cdot \varepsilon_s \cdot 2 \cdot A_b$

Solar heat loading (Irwin, 1995), hourly average loading based on a 12 hr period:

Curved surfaces: $Q_{s1} := 314 \cdot \frac{watt}{m^2}$ $Q_{s1} = 99.54 \cdot \frac{BTU}{hr \cdot ft^2}$

Non-vertical surfaces, flat surfaces: $Q_s := \frac{Q_{s1}}{2}$ $Q_s = 49.77 \cdot \frac{BTU}{hr \cdot ft^2}$

Internal heat load: $q_{int} := 5.65 \cdot watt$

Assumed solar absorptivity: $\alpha_{sol} := 0.57$

Solar heat load: $q_{sol} := \alpha_{sol} \cdot \left(Q_s \cdot \frac{A_b}{2} + Q_{s1} \cdot A_c \right)$

Total heat load: $q_{tot} := q_{sol} + q_{int}$ $q_{tot} = 710 \cdot \frac{BTU}{hr}$

Outside ambient temperature is 115 °F and in Rankine: $T_o := (115 + 459.7) \cdot R$

Using conservation of energy: $q_{in} - q_{out} = 0$

Then by substitution: $q_{tot} - q_{rad} - q_{con} = 0$ or

$$q_{tot} - K_1 \cdot \left(T_f^4 - T_o^4 \right) - K_2 \cdot \left(T_f^4 - T_o^4 \right) - hd_1 \cdot \left(T_f - T_o \right)^{\frac{1}{4}} - hd_2 \cdot \left(T_f - T_o \right)^{\frac{1}{4}} = 0$$

ENGINEERING SAFETY EVALUATION

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Solve for T_f which the temperature at the surface using MathCad roots of equation solution:

$$T_{f1} := \mathrm{root}\left[q_{tot} - K_1 \cdot \left(T_f^4 - T_o^4\right) - K_2 \cdot \left(T_f^4 - T_o^4\right) - hd_1 \cdot \left(T_f - T_o\right)^{\frac{1}{4}} - hd_2 \cdot \left(T_f - T_o\right)^{\frac{1}{4}}, T_f\right]$$

External surface temperature in sun:

Temperature in °F: $T_{ff} := \left|\frac{T_{f1} - 459.7R}{R}\right|$ $T_{ff} = 208$

Temperature in Shade:

Total shaded heat load: $q_{stot} := q_{int}$

Solve for T_f which the temperature at the surface using MathCad roots of equation solution:

$$T_{f2} := \mathrm{root}\left[q_{stot} - K_1 \cdot \left(T_f^4 - T_o^4\right) - K_2 \cdot \left(T_f^4 - T_o^4\right) - hd_1 \cdot \left(T_f - T_o\right)^{\frac{1}{4}} - hd_2 \cdot \left(T_f - T_o\right)^{\frac{1}{4}}, T_f\right]$$

External surface temperature in shate: $T_{f2} = 577 \cdot R$

Temperature in °F: $T_{ff2} := \left|\frac{T_{f2} - 459.7R}{R}\right|$ $T_{ff2} = 117$

With this simplified model determine temperature of inner shell with solar insolation:

Assume as one-dimensional heat transfer and internal heat source is against inside shell wall, no gap.

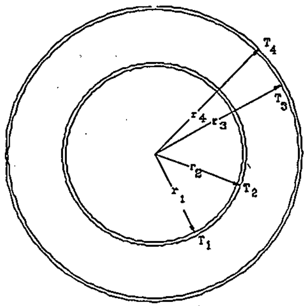
$$q_{tot} = \frac{2 \cdot \pi \cdot l_c \cdot \left(T_1 - T_4\right)}{\frac{\ln\left(\frac{r_2}{r_1}\right)}{k_{sst}} + \frac{\ln\left(\frac{r_3}{r_2}\right)}{k_{pb}} + \frac{\ln\left(\frac{r_4}{r_3}\right)}{k_{sst}}}$$

ENGINEERING SAFETY EVALUATION

Subject: PRTR Cask Normal Transport Conditions Thermal Evaluation — Page: 5 of 5

Originator: S. S. Shiraga — Date: 05/20/97

Checker: S. R. Crow — Date: 05/25/97



Inner shell inside radius: $r_1 := \frac{3.125\,in}{2}$

Inner shell outside radius: $r_2 := \frac{3.375\,in}{2}$

Outer shell inside radius: $r_3 := \frac{13.5\,in}{2}$

Outer shell outside radius: $r_4 := \frac{d_c}{2}$

Outer shell temperature, for full solar insolation:

$$T_4 := T_{ff}$$

Thermal properties of materials:

Conductivity (Irwin, 1995):

Lead at 212°F: $k_{pb} := 0.000447 \frac{BTU}{sec \cdot in}$ — 304L stainless steel at 200°F: $k_{sst} := 0.000215 \frac{BTU}{sec \cdot in}$

Solve heat transfer equation for inner temperature:

$$T_1 := \frac{q_{tot} + 2\cdot\pi\cdot\frac{l_c}{\left[\frac{\ln\left(\frac{r_2}{r_1}\right)}{k_{sst}} + \frac{\ln\left(\frac{r_3}{r_2}\right)}{k_{pb}} + \frac{\ln\left(\frac{r_4}{r_3}\right)}{k_{sst}}\right]}\cdot T_4}{2\cdot\pi\cdot l_c}\cdot\left[\frac{\ln\left(\frac{r_2}{r_1}\right)}{k_{sst}} + \frac{\ln\left(\frac{r_3}{r_2}\right)}{k_{pb}} + \frac{\ln\left(\frac{r_4}{r_3}\right)}{k_{sst}}\right]$$

Inside temperature of inner shell (°F): $T_1 = 211$ ☜

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9.0 PRESSURE AND GAS GENERATION EVALUATION

Only dry contents are authorized for the PRTR Graphite Cask. Therefore, there are no pressure or gas generation concerns.

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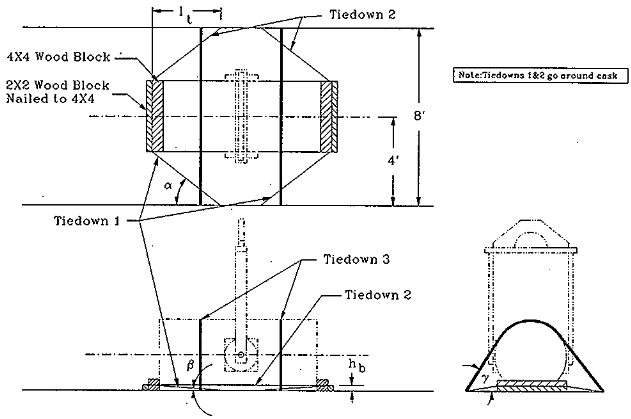
10.0 TIEDOWN EVALUATION

10.1 SYSTEM DESIGN

The PRTR Graphite Cask shall be centered and placed horizontally on the bed of the trailer for shipment. The long axis of the cask is centered along the long axis of the trailer. In accordance with the regulations, the tiedowns must have an aggregate working capacity of one-half the cask weight.

The package is to be secured in accordance with DOT regulations (49 CFR 393.100). The cask is to be secured to the trailer by two sets of tiedowns as shown in Figure 10-1. One set acts as chocks to block and brace the cask from horizontal movement. The other set acts as vertical restraints. There are two 4x4 wood blocks placed at each end of the cask. These 4x4 blocks have a 2x2 nailed to the side at the bottom to form landings for the tiedowns. Each of the chocking tiedowns is looped around the cask from opposite sides of the trailer and attached to the trailer. The chocking tiedowns lay on the landing and bear against the wood blocks when drawn tight. The vertical restraint tiedowns are placed over the cask on each side of the lifting yoke. These tiedowns are then attached to the trailer on opposite sides and drawn tight.

Figure 10-1. Cask Tiedown Configuration.



10.2 ATTACHMENTS, RATINGS, AND REQUIREMENTS

Each tiedown and trailer attachment point must have a minimum working strength of 11,120 N (2,500 lb). The 2x2 wood blocks must be nailed to the 4x4 wood blocks with a minimum of three 10 d nails. The length of the blocks is specified as the same as the diameter of the cask to within a tolerance of 0.32 cm (⅛ in.).

10.3 REFERENCE

49 CFR 393.100, 1997, "Parts and Accessories Necessary for Safe Operation," *Code of Federal Regulations*, as amended.

10.4 APPENDIX: ENGINEERING SAFETY EVALUATION

WMNW

ENGINEERING SAFETY EVALUATION

Subject: 327 PRTR Cask Tiedown Evaluation		Page 1 of 3
Preparer: S. S. Shiraga	[signature]	Date 07/21/97
Checker: P. C. Ferrell	Pat C. Ferrell	Date 8/5/97
Section Chief: S. S. Shiraga	[signature]	Date 8/5/97

1.0 OBJECTIVE

The objective of this evaluation is to determine the capacity and configuration of the tiedown system for the 327 PRTR Cask. The tiedowns are specified to the requirements of 49 CFR 393.100.

2.0 REFERENCES

49 CFR 393.100, 1995, "Protection Against Falling Cargo," Subpart I, *Code of Federal Regulations*, as amended.

3.0 ASSUMPTIONS, RESULTS, AND CONCLUSIONS

As defined in this document, shipment of the 327 PRTR cask within the 300 Area is authorized under a risk based assessment. Consequently, the tiedown system must be an engineered system to ensure that the package remains on the conveyance during all normal non-accident conditions. Since the shipment is only within the 300 Area, the system is specified based on the requirements of 49 CFR 393.100.

As shown in the evaluation, the cask is assumed to be centered on a standard flat bed trailer and the lifting yoke placed in the vertical position. The system consists of two 4X4 wood blocks with 2X2 wood blocks nailed to them, forming an "L" shape. These "L" shaped blocks span the width of the cask and are placed at each end. Two cables or chains are looped around the cask and blocks from each side and drawn tight. The cables or chains rest on the landing formed by the "L" shape of the blocks. This forms the blocking and bracing to restrain longitudinal and lateral loads. Placed over the cask on each side of the lifting yoke are two tiedown straps, cables, or chains to provide vertical restraint. The minimum specified working strength of the tiedowns is 2,500 lb. The wood blocks are to be constructed from standard commercial grade lumber. The 2X2 blocks are to be nailed to the 4X4 blocks with a minimum of three 10 d nails.

ENGINEERING SAFETY EVALUATION

WMNW

Subject: 327 PRTR Cask Tiedown Evaluation	Page 2 of 3
Preparer: S. S. Shiraga *SSS*	Date 07/21/97
Checker: P. C. Ferrell *PCF*	Date *8/5/97*
Section Chief: S. S. Shiraga *SSS*	Date *8/5/97*

4.0 EVALUATION

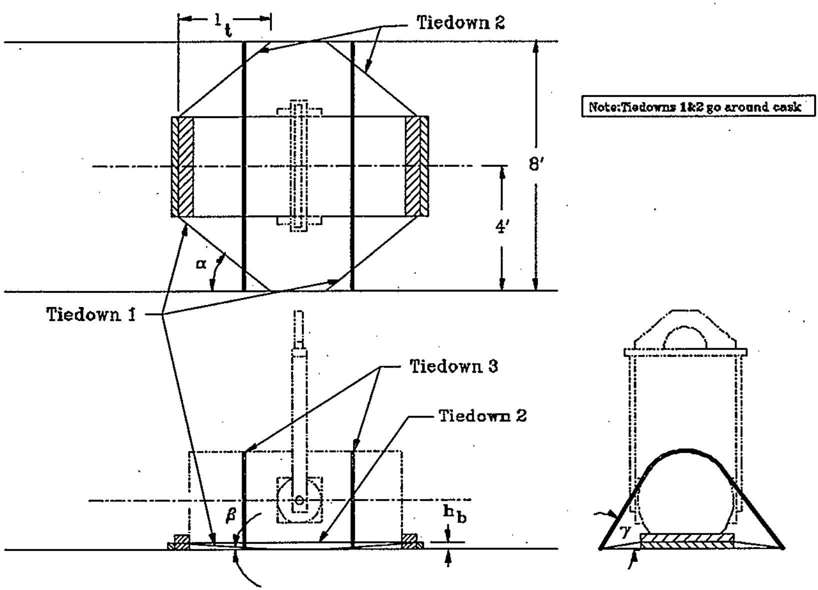
PRTR Cask Tiedown Evaluation:

OD of cask: $od_{cask} := 14 \cdot in$ Length of cask: $l_{cask} := 39.625 in$

Gross weight of cask: $w_{cask} := 2650 lbf$ DOT inertial load factor: $g_{dot} := 0.5$

Chain height from deck: $h_b := 1.5 \cdot in$ Length to trailer attachment: $l_t := 15 \cdot in$

Load on tiedowns: $F_{ch} := g_{dot} \cdot w_{cask}$ $F_{ch} = 1325 \cdot lbf$



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ENGINEERING SAFETY EVALUATION

Subject: 327 PRTR Cask Tiedown Evaluation — Page 3 of 3
Preparer: S. S. Shiraga [signature] — Date 07/21/97
Checker: P. C. Ferrell [signature] — Date 8/5/97
Section Chief: S. S. Shiraga [signature] — Date 8/5/97

Angle off horizontal: $\alpha := \operatorname{atan}\left[\dfrac{48\cdot in - \dfrac{od_{cask}}{2}}{l_t}\right]$ $\alpha = 69.9\cdot deg$

Angle off vertical: $\beta := \operatorname{atan}\left(\dfrac{h_b\cdot\cos(\alpha)}{l_t}\right)$ $\beta = 2\cdot deg$

Determine chocking tiedowns:

Tension on lateral chain only one tiedown acting: $T_{lat} := \dfrac{F_{ch}}{\sin(\alpha)\cdot\cos(\beta)}$ $T_{lat} = 1412\cdot lbf$

Tension on longitudinal chain, two tiedowns acting: $T_{long} := \dfrac{F_{ch}}{2\cdot(\cos(\alpha)\cdot\cos(\beta))}$ $T_{long} = 1929\cdot lbf$

Determine tiedowns:

Vertical tiedown angle: $\gamma := \operatorname{atan}\left(\dfrac{od_{cask}}{4\cdot ft}\right)$ $\gamma = 16.3\cdot deg$

Tension in vertical tiedowns: $T_{ver} := \dfrac{F_{ch}}{2\cdot\sin(\gamma)}$ $T_{ver} = 2366\cdot lbf$

Based on above, minimum working load of all tiedowns is specified as 2,500 lb.

WMNW-PE-001/2

DISTRIBUTION SHEET

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Distribution	Packaging Engineering	Page 1 of 1
		Date Sept. 24, 1997
Project Title/Work Order Safety Evaluation for Packaging (Onsite) Plutonium Recycle Test Reactor Graphite Cask (HNF-SD-TP-SEP-063, Rev. 0)		EDT No. 621885
		ECN No. N/A

Name	MSIN	Text With All Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only
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