ENGINEERING CHANGE NOTICE

Page 1 of 10

1. ECN 646743

Proj. ECN

2. ECN Category (mark one)	3. Originator's Name, Organization, MSIN, and Telephone No.	4. USQ Required?	5. Date
Supplemental [] Direct Revision [X] Change ECN [] Temporary [] Standby [] Supersedure [] Cancel/Void []	JC McCoy/WMNW Eng/H1-15/373-0170	[X] Yes [] No	2/22/99
	6. Project Title/No./Work Order No.	7. Bldg./Sys./Fac. No.	8. Approval Designator
	772028/131 CACN/COA 102297/E100	NA	SQ
	9. Document Numbers Changed by this ECN (includes sheet no. and rev.)	10. Related ECN No(s).	11. Related PO No.
	WHC-SD-TP-SARP-001, Rev. 1-B	NA	NA

12a. Modification Work	12b. Work Package No.	12c. Modification Work Complete	12d. Restored to Original Condition (Temp. or Standby ECN only)
[] Yes (fill out Blk. 12b) [X] No (NA Blks. 12b, 12c, 12d)	NA	NA Design Authority/Cog. Engineer Signature & Date	NA Design Authority/Cog. Engineer Signature & Date

13a. Description of Change   13b. Design Baseline Document? [] Yes [X] No

This revision evaluates two new packaging configurations, the Steel Pig and the Light-Duty Utility Arm sampler (LDUA), for the Sample Pig Transport System.

14a. Justification (mark one)

Criteria Change	[X]	Design Improvement	[]	Environmental	[]	Facility Deactivation	[]
As-Found	[]	Facilitate Const	[]	Const. Error/Omission	[]	Design Error/Omission	[]

14b. Justification Details

The Steel Pig was added to the Sample Pig Transport System because the Tank Waste Remediation System (TWRS) requires a packaging for 500 mL samples with higher dose rates than could be shipped in the Safesend configuration. The LDUA sampler configuration was added to allow TWRS more flexibility in sample transport than the current Doorstop Sample Carrier configuration allows.

Design verification of this change was performed, and the change(s) were found not to adversely impact the underlying safety bases and parameters of the package.

Verification performed by: R. J. Smith

*See attached USQ (TF-98-1151, Rev. 1)

15. Distribution (include name, MSIN, and no. of copies)

Copy controlled.

RELEASE STAMP

MAR 16 1999

DATE: STA: 15 HANFORD RELEASE ID: 20

A-7900-013-2 (05/96) GEF095

ENGINEERING CHANGE NOTICE	Page 2 of 10	1. ECN (use no. from pg. 1) 646743

16. Design Verification Required	17. Cost Impact				18. Schedule Impact (days)	
	ENGINEERING		CONSTRUCTION			
[X] Yes	Additional	[NA] $	Additional	[NA] $	Improvement	[NA]
[] No	Savings	[NA] $	Savings	[NA] $	Delay	[NA]

19. *Change Impact Review:* Indicate the related documents (other than the engineering documents identified on Side 1) that will be affected by the change described in Block 13. Enter the affected document number in Block 20.

SDD/DD	[]	Seismic/Stress Analysis	[]	Tank Calibration Manual	[]
Functional Design Criteria	[]	Stress/Design Report	[]	Health Physics Procedure	[]
Operating Specification	[]	Interface Control Drawing	[]	Spares Multiple Unit Listing	[]
Criticality Specification	[]	Calibration Procedure	[]	Test Procedures/Specification	[]
Conceptual Design Report	[]	Installation Procedure	[]	Component Index	[]
Equipment Spec.	[]	Maintenance Procedure	[]	ASME Coded Item	[]
Const. Spec.	[]	Engineering Procedure	[]	Human Factor Consideration	[]
Procurement Spec.	[]	Operating Instruction	[]	Computer Software	[]
Vendor Information	[]	Operating Procedure	[X]	Electric Circuit Schedule	[]
OM Manual	[]	Operational Safety Requirement	[]	ICRS Procedure	[]
FSAR/SAR	[]	IEFD Drawing	[]	Process Control Manual/Plan	[]
Safety Equipment List	[]	Cell Arrangement Drawing	[]	Process Flow Chart	[]
Radiation Work Permit	[]	Essential Material Specification	[]	Purchase Requisition	[]
Environmental Impact Statement	[]	Fac. Proc. Samp. Schedule	[]	Tickler File	[]
Environmental Report	[]	Inspection Plan	[]		[]
Environmental Permit	[]	Inventory Adjustment Request	[]		[]

20. Other Affected Documents: *(NOTE: Documents listed below will not be revised by this ECN.)* Signatures below indicate that the signing organization has been notified of other affected documents listed below.

Document Number/Revision	Document Number/Revision	Document Number Revision
The operating procedures for the Sample Pig, LDUA, and related equipment are the responsibility of TWRS to identify and revise as necessary. WMNW shall review the procedures as required by HNF-PRO-154 and HNF-PRO-163.		

21. Approvals

	Signature	Date		Signature	Date
Design Authority:	GP Janicek	3/10/99	Design Agent:		
Cog. Eng.:	JC McCoy	2/22/99	PE		
Cog. Mgr.:	JG Field*	2/22/99	QA		
QA:	MR Turner*	2/22/99	Safety		
Safety:	T Romano*	2/22/99	Design		
Environ.			Environ.		
Other	Independent Reviewer: RJ Smith*	2/22/99	Other		
	CA Esvelt	2-25-99			
	JS Schofield	2/26/99			

DEPARTMENT OF ENERGY

Signature or a Control Number that tracks the Approval Signature

ADDITIONAL

*Safety Review Board Members

TANK WASTE REMEDIATION SYSTEM (TWRS) UNREVIEWED SAFETY QUESTION (USQ) SCREENING/DETERMINATION FORM	Page 1 of 8
	USQ Tracking Number TF-98-1151
	Rev 1

AREA: [] East [] West [X] General

FACILITY: [] SST [] DST [] AWF [X] Other: CPO Shipping

ECN number(s): # 646743
Work Package number(s): N/A

PCA number(s): N/A
Other document number(s): N/A

TITLE: REVISION OF HNF-SD-TP-SARP-001, REVISION 1-B TO 2 PER ECN # 646743

Description of the Proposed Activity, Reportable Occurrence, or PIAB:

The proposed activity is the revision to HNF-SD-SARP-001 (SARP-001), *Sample Pig Transport System Safety Analysis Report for Packaging (Onsite),* by ECN # 646743. Revision 1 of this USQS includes the use of the Doorstop paint can as the secondary containment container in the sample pig transport system for LUDA sampling only.

Introduction:

The SARP-001 provides the analysis and evaluation necessary to demonstrate that the sample pig transport system meets the onsite transportation safety requirements of HNF-PRO-154, *Responsibilities and Procedures, for all hazardous Material* and HNF-PRO-157, *Radioactive Material/Waste Shipments.*

However, when taking waste samples (using an approved sampling device for use in the sample pig transport shipping container system from Hanford's tank farms) the bounding document for work in Tank Farms is HNF-SD-WM-BIO-001, *Tank Waste Remediation System Basis for Interim Operation,* (BIO).

ECN # 646743 updates the SARP-001 to incorporate the use of a modified PAS-1 Pig, referred to as the Steel Pig in the SARP, or the paint can (for LUDA sampling only) with the sample pig transport shipping container system. The sample pig transport shipping container system parameters were re-evaluated to ensure that the Steel Pig and the paint can (normally used with the Doorstop shipping container system) used with the sample pig transport shipping container system meets the onsite transport safety requirements of HNF-PRO-154 and HNF-PRO-157.

The maximum source term used in the re-evaluation for the Steel Pig was sample volume of 500 ml. The radionuclide inventory was scaled from the 125 ml worst case inventory in the SARP. The maximum source term used in the re-evaluation for the paint can was sample volume of 125 ml for LUDA sampling only.

The SARP-001 revision now includes the following as approved secondary containment containers to be used with the sample pig transport shipping container system:

1) Sample Pig
2) SAFESEND
3) Steel Pig

TANK WASTE REMEDIATION SYSTEM (TWRS) UNREVIEWED SAFETY QUESTION (USQ) SCREENING/DETERMINATION FORM	Page 2 of 8
	USQ Tracking Number TF-98-1151
	Rev 1

4) Paint Can (normally used with the Doorstop shipping container system)(LUDA sampling only)

Scope:

The scope of this USQS is to determine if the changes made by ECN # 646743 to SARP-001, for shipping and transporting tank farm waste samples using the Steel Pig or the Doorstop paint can (LUDA samples only) with the sample pig transport shipping container system, comply with the requirements set forth in the tank farms Authorization Basis.

Authorization Basis:

The Authorization Basis (AB) for work in tank farms is given in Wagoner 1997. This letter lists all the applicable Authorization Basis documents for TWRS. The two major AB documents are:

1) Basis for Interim Operation (BIO), and
2) The associated Technical Specification Requirements (TSR)

There is no specific applicability to waste tank sample shipments located in the BIO. However, Section 5.3.2.23.1 (High Wind) Part A, the accident scenario for sample cask transport vehicle crash states, " The containers are transported using WHC-SD-TP-SARP-002, *Safety Analysis Report for Packaging (Onsite) Onsite Transport Cask,* as the Authorization Basis for the onsite transport cask or WHC-SD-TP-SARP-001, *Sample Pig Transport System Safety Analysis Report for Packaging (Onsite),* for pigs... Because the safety analysis reports for packaging provide the Authorization Basis for cask and pig transport, their transport is not considered further in this BIO." This last statement would also imply that HNF-SD-TP-SARP-023, *Safety Analysis Report for Doorstop System* would be considered the Authorization Basis for Doorstops.

DOE-9501704B letter, *"Cancellation of RLID 5480.3, Safety Requirements for the Packaging and Transportation of Hazardous Materials, Hazardous Substances, and Hazardous Wastes; and RL 5480.1 Change 1, Chapter III, Safety Requirements for the Packaging of Fissile and Other Radioactive Materials"*, (dated March 29, 1995), stated that for onsite transfers of hazardous materials, each contractor must establish company policy for preparing, packaging, and transferring hazardous materials that will not present a hazard to the health and safety of the workers, the public, and the environment. HNF-PRO-154, *Responsibilities and Procedures, for all Hazardous Material* and HNF-PRO-157, *Radioactive Material/Waste Shipments* provides onsite packaging requirements for the Hanford Site. HNF-SD-TP-SARP-023, WHC-SD-TP-SARP-001 and WHC-SD-TP-SARP-002 provides the analyses and evaluation necessary to demonstrate that the shipping containers meet the performance requirements stated in HNF-PRO-154, HNF-PRO-157, and U.S. Department of Transportation (DOT) requirements.

The DOE-9501704B letter also states that the company policy shall be consistent with existing DOE and reauthorized RL Orders and statutory requirements for onsite operations. Contractors may elect to use U.S. Department of Transportation (DOT) approved or DOE/Nuclear Regulatory Commission certified containers for onsite transfers or established defensible safety bases for containers that do not meet offsite shipping regulations.

TANK WASTE REMEDIATION SYSTEM (TWRS) UNREVIEWED SAFETY QUESTION (USQ) SCREENING/DETERMINATION FORM	Page 3 of 8
	USQ Tracking Number TF-98-1151
	Rev 1

References:

1) HNF-SD-WM-BIO-001, Rev. 1-A, *Tank Waste Remediation System Basis Forinterim Operation,* January, 1998.

2) HNF-SD-WM-TSR-006, Rev. O-Q, *Tank Waste Remediation System Technical Safety Requirements,* January, 1998.

3) HNF-PRO-154, *Responsibilities and Procedures for all Hazardous Materials*

4) HNF-PRO-157, *Radioactive Materials/Waste Shipments*

5) DOE-RL Letter, A.R. Valdez to President/WHC et. Al., *Correspondence Number 9501704B; Cancellation of RLID 5480.3, Safety Requirements for the Packaging and Transportation of Hazardous Materials, Hazardous Substances, and Hazardous Wastes; and RL 5480.1 Change 1, Chapter III, Safety Requirements for the Packaging of Fissile and Other Radioactive Materials,* March 29, 1995.

6) Wagoner 1997, DOE-RL Letter 97-SCD-186, J. D. Wagoner to H. J. Hatch, FDH, *Contract Number DE-AC06-96RL13200 – Approval of Tank Waste Remediation System (TWRS) Basis for Interim Operation (BIO) Readiness and Authorization Basis (AB) Approval,* September 12, 1997.

Conclusion:

The changes made to SARP-001 by ECN # 646743 that affect the tank farm waste sample shipments and transportation using the pig shipping container system is within the bounds of the Authorization Basis.

USQ SCREENING:

A. Does the Proposed Activity represent a change to the facility as described in the Authorization Basis?

[X] No [] Yes [] N/A

Basis:
DOE Order 5480.21, Chapter 2, #2, "*Changes*" defines what is not considered a change to the facility as follows:

(a) The change does not add, delete, or convert an automatic or manual feature of the SSC.
(b) The change does not introduce a new system interactions.
(c) The change does not alter the seismic qualifications, environmental qualification or quality group classification of the SSC.
(d) The change replaces a component with equipment equivalent to that of the old component.

The proposed activity does not violate any of these criteria and is therefore not a change to the facility as described in the Authorization Basis (AB). No new system interactions are involved. The SARP change does not represent a change to any TWRS facility. The sample volume sizes brought out in the SARP are applicable to the grab sampling activities. The BIO describes the grab sampling activities, but does not dictate a sample volume size to be used or how the sample is to be transported. Therefore, the sample size and method of transporting the sample in the pig shipping container system does not affect the BIO. The taking of waste samples, packaging and shipping the Steel Pig or the Doorstop pain can with the sample pig transport shipping container system per the SARP does not add waste to the tank or change the tank waste composition.

B. Does the Proposed Activity represent a change to procedures as described in the Authorization Basis?

[X] No [] Yes [] N/A

Basis:
DOE Order 5480.21 defines changes in the procedures as follows:

"*3. Changes in the Procedures as Described in Safety Analysis.*

a. There are three types of procedures changes to be considered. First, if a procedure is not contained or described in the safety analyses, it would not require USQ evaluation to be performed before a change can be implemented. Second, changes to procedures simply listed, and not outlined, summarized, or described in the safety analyses, do not require evaluation in accordance with this Order in the outline, summary, or description in the safety analyses are impacted.

b. Procedures are not limited to those items specifically identified as procedures types (e.g., operating, chemistry, system, test, surveillance, and emergency plan) but could include anything described in the safety analyses that defines or describes activities or controls over the conduct of work. If changes to these activities or controls are made, such changes qualify as changes to procedures as described in the safety analyses, and the changes must be evaluated.

c. In instances when procedural modifications are implementing operational changes, such as set point changes, while the procedure itself may not meet the requirement for evaluation, in accordance with this Order, the operational change should be evaluated to assure it does not impact the authorization basis limits or supporting safety analyses."

The proposed activity does not impact the safety basis limits or represent a change to the procedures as described in the Authorization Basis documents. The proposed activity does not create any new procedures nor does it affect any existing procedures.

TANK WASTE REMEDIATION SYSTEM (TWRS) UNREVIEWED SAFETY QUESTION (USQ) SCREENING/DETERMINATION FORM	Page 5 of 8
	USQ Tracking Number TF-98-1151
	Rev 1

C. Does the test or experiment represent a test or experiment not described in the Authorization Basis?

[] No [] Yes [X] N/A

Basis: The proposed change is not a test or experiment.

D. Does the Proposed Activity or Reportable Occurrence impact any TSRs or other Authorization Basis controls?

[X] No [] Yes [] N/A

Basis:
There are currently no applicable OSRs, IOSRs, or any CIP within TWRS and this portion of the screening still has not been modified within HNF-IP-0842 or applicable HNF-PRO document. However, this question is intended to address any AB level control, whether it is from the TSR document or other AB document. Applicable TWRS BIO/TSR controls for using the steel pig or the Doorstop paint can with the sample pig transport shipping container system are within the boundaries of the TWRS facilities are:

a) AC 5.10.2.b Ignition Controls (Vehicle Controls) which controls the vehicle used within the tank farms.
b) AC 5.10.2c Flammable Gas Ignition Controls which controls the material of construction of equipment to be of spark-resistant material, or shall be rendered incapable of sparking with sufficient energy to combust hydrogen, or evaluated to be incapable of sparking with sufficient energy to combust hydrogen under the applied conditions.
c) AC 5.16 Dome Loading Controls which limits the weight of equipment on the tank.

The SARP changes do not affect these controls. Therefore, the proposed change does not affect any AB level control.

E. Does the Reportable Occurrence or PIAB involve analytical errors, omissions, and/or deficiencies in the Authorization Basis?

[] No [] Yes [X] N/A

Basis: The proposed change is not a Reportable Occurrence or PIAB

TANK WASTE REMEDIATION SYSTEM (TWRS) **UNREVIEWED SAFETY QUESTION (USQ)** **SCREENING/DETERMINATION FORM**	Page 6 of 8
	USQ Tracking Number TF-98-1151
	Rev 1

USQ SCREENER:

R. G. Brown
Print Name

[signature] 1/21/99
Signature Date

USQ EVALUATOR:

C. A. Esvelt
Print Name

[signature] 1-21-99
Signature Date

USQ DETERMINATION:

1. Could the Proposed Activity, Reportable Occurrence, or PIAB significantly increase the frequency of occurrence of an accident previously evaluated in the Authorization Basis?

   [] No [] Yes/Maybe

   Basis:

2. Could the Proposed Activity, Reportable Occurrence, or PIAB increase the consequences of an accident previously evaluated in the Authorization Basis?

   [] No [] Yes/Maybe

   Basis:

3. Could the Proposed Activity, Reportable Occurrence, or PIAB significantly increase the frequency of occurrence of a malfunction of equipment important to safety previously evaluated in the Authorization Basis?

   [] No [] Yes/Maybe

   Basis:

4. Could the Proposed Activity, Reportable Occurrence, or PIAB increase the consequences of a malfunction of equipment important to safety previously evaluated in the Authorization Basis?

   [] No [] Yes/Maybe

   Basis:

TANK WASTE REMEDIATION SYSTEM (TWRS) UNREVIEWED SAFETY QUESTION (USQ) SCREENING/DETERMINATION FORM	Page 7 of 8
	USQ Tracking Number TF-98-1151
	Rev 1

5. Could the Proposed Activity, Reportable Occurrence, or PIAB create the possibility of an accident of a different type than any previously evaluated in the Authorization Basis?

   [] No [] Yes/Maybe

   Basis:

6. Could the Proposed Activity, Reportable Occurrence, or PIAB create the possibility of a malfunction of equipment important to safety of a different type than any previously evaluated in the Authorization Basis?

   [] No [] Yes/Maybe

   Basis:

7. Could the Proposed Activity, Reportable Occurrence, or PIAB reduce the margin of safety for any TSR or other Authorization Basis control?

   [] No [] Yes/Maybe

   Basis:

8. Does the Proposed Activity, Reportable Occurrence, or PIAB require a new or revised TSR or other Authorization Basis control?

   [] No [] Yes/Maybe

   Basis:

USQ EVALUATOR:

Print Name

Signature

Date

USQ CORE EVALUATOR:

Print Name

Signature

Date

TANK WASTE REMEDIATION SYSTEM (TWRS) UNREVIEWED SAFETY QUESTION (USQ) SCREENING/DETERMINATION FORM	Page 8 of 8
	USQ Tracking Number TF-98-1151
	Rev 1

PRC CONCURRENCE (as required):

Meeting number/date:

PRC Chairperson, Print Name

PRC Chairperson, Signature

Date

Safety Analysis Report for Packaging (Onsite) Sample Pig Transport System

J. C. McCoy
Waste Management federal Services, Inc., Northwest Operations
for Fluor Daniel Hanford, Inc., Richland, WA 99352
U.S. Department of Energy Contract DE-AC06-96RL13200

EDT/ECN: ECN 646743 UC: 513
Org Code: 74900 Task Order: GS080003
CACN/COA: 102297/EL00 Project/Crosswalk: 772028/128
B&R Code: EW3120074 Total Pages: ~~313~~ 312

Key Words: SARP, Type B, fissile excepted, interarea, Safesend, Steel Pig, Light-Duty Utility Arm, LDUA

Abstract: This Safety Analysis Report for Packaging (SARP) provides a technical evaluation of the Sample Pig Transport System as compared to the requirements of the U.S. Department of Energy, Richland Operations Office (RL) Order 5480.1, Change 1, Chapter III.

The evaluation concludes that the package is acceptable for the onsite transport of Type B, fissile excepted radioactive materials when used in accordance with this document.

Janis Aardal 3-16-99
Release Approval Date

Approved for Public Release

RECORD OF REVISION	(1) Document Number HNF-SD-TP-SARP-001	Page 3

(2) Title
Sample Pig Shipping Container Safety Analysis Report for Packaging (Onsite)

CHANGE CONTROL RECORD

(3) Revision	(4) Description of Change - Replace, Add, and Delete Pages	Authorized for Release	
		(5) Cog. Engr.	(6) Cog. Mgr. Date
	(7)		
2 RS	Revision to (1) evaluate two new packaging configurations, the Steel Pig and Light-Duty Utility Arm sampler, for the Sample Pig Transport System and (2) convert document to Word. Replace entire document. Per ECN 646743.	JC McCoy [signature]	JG Field [signature] 3-12-99

LIST OF EFFECTIVE PAGES

Page	Revision	Comment
	2	ECN
	2	SD Cover
	2	ROR
	2	LOEP
iii - xii	2	TOC
A1-1 - A1-2	2	
A2-1 - A2-6	2	
A3-1 - A3-4	2	
A4-1 - A4-4	2	
A5-1 - A5-6	2	
A6-1 - A6-4	2	
A7-1 - A7-6	2	
A8-1 - A8-2	2	
A9-1 - A9-2	2	
A10-1 - A10-12	2	
B1-1 - B1-4	2	
B2-1 - B2-16	2	
B3-1 - B3-2	2	
B4-1 - B4-14	2	
B5-1 - B5-26	2	
B6-1 - B6-2	2	
B7-1 - B7-60	2	
B8-1 - B8-86	2	
B9-1 - B9-30	2	
B10-1 - B10-11	2	

CONTENTS

PART A: PACKAGE DESCRIPTION AND OPERATIONS

CONTENTS (cont.)

CONTENTS (cont.)

PART B: PACKAGE EVALUATION

CONTENTS (cont.)

CONTENTS (cont.)

CONTENTS (cont.)

LIST OF FIGURES

LIST OF FIGURES (cont.)

LIST OF TABLES

LIST OF TABLES (cont.)

LIST OF TABLES (cont.)

LIST OF TERMS

AISC	American Institute of Steel Construction
ALARA	as low as reasonably achievable
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
AWS	American Welding Society
BIO	Basis for Interim Operation (Tank Waste Remediation System)
BBI	Best-Basis Inventory
CFR	*Code of Federal Regulations*
Ci	curie
Ci/L	curies per liter
cm	centimeter
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
ft	feet
in.	inch
kg	kilogram
lb	pound
LDUA	Light-Duty Utility Arm
LFL	lower flammability limit
m	meter
mL	milliliter
mrem/h	millirem per hour
mSv/h	millisievert per hour
NRC	U.S. Nuclear Regulatory Commission
NuPac	Nuclear Packaging, Incorporated
OD	*outside diameter*
OTC	Onsite Transfer Cask
oz	ounce
QA	quality assurance
QC	Quality Control
QL	Quality Level
SARP	Safety Analysis Report for Packaging
SS	stainless steel
THI	Transportation Hazard Indicator
TOC	total organic carbon
USQ	unresolved safety question
WHC	Westinghouse Hanford Company

SAFETY ANALYSIS REPORT FOR PACKAGING (ONSITE) SAMPLE PIG TRANSPORT SYSTEM

PART A: PACKAGE DESCRIPTION AND OPERATIONS

1.0 INTRODUCTION

1.1 GENERAL INFORMATION

The Sample Pig Transport System includes a multi-component packaging system consisting of a Type B certified N-55 overpack; U.S. Department of Transportation (DOT) Specification 17C or 17H or a specification UN1A2 208 L (55-gal) drum; Sample Pig Shipping Container; and one of four payload container configurations. These include (1) a lead-shielded sample carrier known as the Sample Pig, (2) a steel-shielded sample carrier known as the Steel Pig, (3) the Light-Duty Utility Arm (LDUA) Sampler, or (4) Safesend[1]. The Sample Pig Transport System is used to transport samples to onsite laboratories for evaluation.

This Safety Analysis Report for Packaging (SARP) provides the analyses and evaluation necessary to demonstrate that the Sample Pig Transport System meets the requirements of HNF-PRO-154, *Responsibilities and Procedures for all Hazardous Material*; HNF-PRO-157, *Radioactive Material/Waste Shipments*; HNF-PRO-163, Documentation and Record Keeping; and HNF-PRO-166, *Transportation Safety Training Requirements*. Through evaluation herein, the packaging has been shown to meet the Transportation Hazard Indicator (THI) 3 performance requirements. Evaluation by testing, analysis, and initial leak testing per American National Standards Institute (ANSI) N14.5 (ANSI 1987) demonstrate packaging performance and safety.

The scope of this SARP includes evaluating the package design and demonstrating that it meets onsite packaging requirements. This SARP also establishes operational, acceptance, maintenance, and quality assurance (QA) guidelines to ensure that the method of transport for the Sample Pig Transport System is performed in accordance with HNF-PRO-154 and HNF-PRO-157.

1.2 SYSTEM DESCRIPTION

The Sample Pig Transport System is designed to transport Type B radioactive material on the Hanford Site in accordance with the onsite packaging requirements and HNF-PRO-154 and HNF-PRO-157. The Sample Pig Transport System is a reusable package for shipments of solid, liquid, slurry, or sludge samples.

---

[1]Safesend is a trademark of the 3M Corporation.

The system (Figure A2-1) utilizes an existing certified packaging (N-55 overpack) with an internal containment system (Sample Pig Shipping Container). The N-55 Overpack System (overpack with 208 L [55-gal] drum inside) provides fire and impact resistance per Title 10 *Code of Federal Regulations* Part 71 (10 CFR 71). The Sample Pig Shipping Container is retained inside of the 208 L (55-gal) drum using fiberboard spacers. A Sample Pig, Steel Pig, LDUA Sampler, or Safesend, with the tank waste sample inside, is loaded into the Sample Pig Shipping Container.

Two N-55 overpacks may be placed on the transport vehicle. A tiedown fixture is affixed to the top of the overpack, and straps are used to tie down the package to the transporter.

1.3 REVIEW AND UPDATE CYCLES

This SARP is subject to periodic reviews and updates. The reviews shall be performed every five years to ensure that all SARP evaluations and other included information meet new or revised regulatory and/or company requirements. The first complete review and update of the Sample Pig Transport System SARP will be approximately September 2001. Review shall be through the formal process per Part A, Section 7.6.

2.0 PACKAGING SYSTEM

2.1 CONFIGURATION AND DIMENSIONS

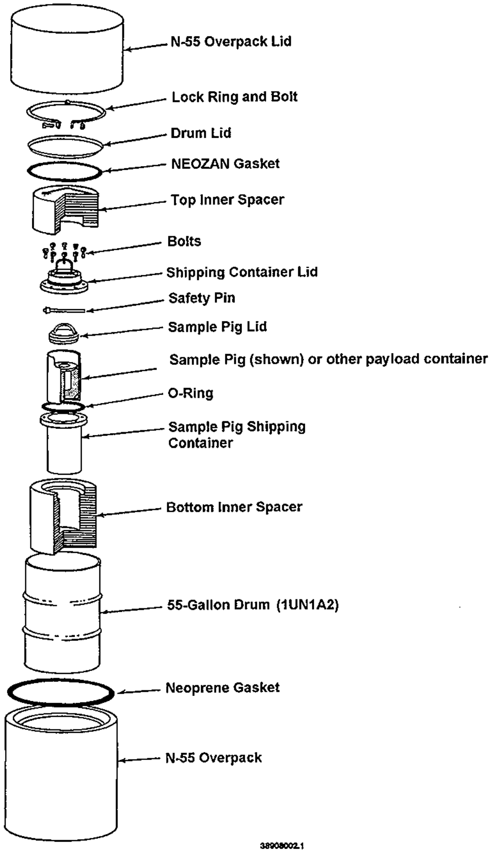
The packaging system consists of an N-55 overpack; a DOT specification 208 L (55-gal) drum with foam inner spacers; a Sample Pig Shipping Container; and a Sample Pig (Figure A1-1), Steel Pig, LDUA Sampler, or Safesend. The N-55 overpack is a right circular cylinder 122 cm (48 in.) high by 81 cm (32 in.) in diameter with an 89-cm- (35-in.-) high by 61-cm- (24-in.-) diameter cavity. The 208 L (55-gal) drum is 89 cm (35 in.) high by 61 cm (24 in.) in diameter and fits snugly into the N-55 overpack. The Sample Pig Shipping Container (Figure A2-2) is 34.93 cm (13¾ in.) tall by 20 cm (8 in.) in diameter and fits snugly into the cavity created by the drum's inner spacer. The Sample Pig Shipping Container holds either a Sample Pig, a Steel Pig, an LDUA Sampler, or a Safesend, which carries the tank waste sample. The Sample Pig is lead-shielded and approximately 31.12 cm (12.25 in.) tall by 15 cm (6 in.) in diameter and transports a 125 mL (4-oz) sample. The Steel Pig is 26.67 cm (10.5 in.) tall by 16.83 cm (6.625 in.) in diameter and transports up to 0.5 L (16.9-oz) samples. The LDUA Sampler contains a 68 ml (2.3-oz) sample in a stainless steel (SS) clamshell and is placed in a metal can with 1 cm of lead shielding for transport. The Safesend is approximately 31.75 cm (12.50 in.) tall by 20.27 cm (7.98 in.) in diameter and can transport up to 1 L (34-oz) samples. However, the Safesend has no shielding for samples larger than 0.25 L.

2.2 MATERIALS OF CONSTRUCTION

The structural materials of the Sample Pig Transport System are as follows:

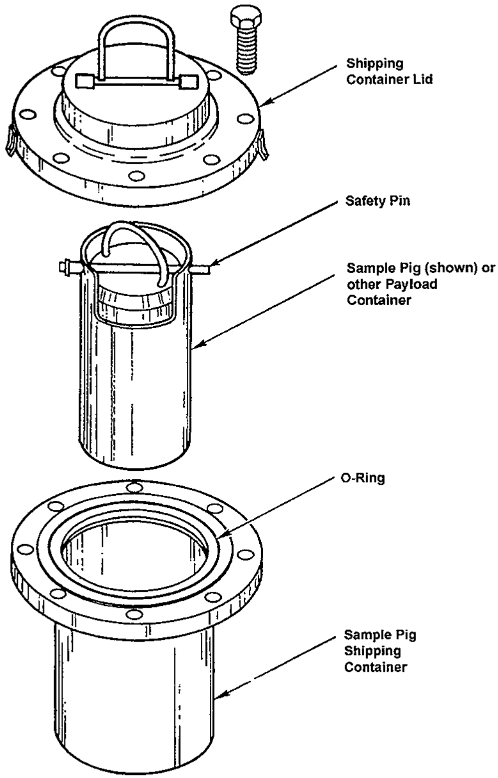
- *Overpack shell*: 20-gage galvanized steel outer shell and fiberglass inner shell
- *Overpack foam*: 3 lb/ft^3 polyurethane foam
- *208 L (55-gal)*: galvanized carbon steel
- *Sample Pig Shipping Container*: Schedule 40 American Society for Testing and Materials (ASTM) A312 Type 304L SS seamless pipe and an ASTM A182 Grade F Type 304L SS pipe flange
- *Sample Pig Shipping Container lid*: ASTM A182 Grade F 304L SS pipe flange with a schedule 40 ASTM A312 304L SS pipe welded to it and an ASTM A240 304L SS plate welded on top
- *Sample Pig Shipping Container lid bolts*: ¾ in. hex head ASTM A193 Grade B8 304 SS bolts
- *Sample Pig*: Schedule 40 ASTM A312 304L SS seamless pipe shell with 4.8 cm (1.9 in.) of poured lead shielding. Quick-release safety pin holds lid in place

Figure A2-1. Sample Pig Transport System.



[1] Safesend is a trademark of the 3M Corporation.

Figure A2-2. Sample Pig Shipping Container With Sample Pig.



[1] Safesend is a trademark of the 3M Corporation.

- *Sample Pig lid*: Schedule 80 ASTM A312 304L SS seamless pipe with 11-gage ASTM 240 SS sheet covering each end
- *Steel Pig and LDUA Sampler*: ASTM A312 Type 304 SS
- *Safesend (or equivalent container)*: molded polyethylene.

Other Materials utilized are:

- Parker 2-375 Neoprene[2] 45-Durometer Sample Pig Shipping Container O-ring, or 9.475 in. ± 0.055 inside diameter (ID), 9.895 in. outside diameter (OD) Neoprene 45-Durometer O-ring
- Neoprene overpack gasket
- Drum gasket as specified by drum manufacturer.

2.3 MECHANICAL PROPERTIES OF MATERIAL

The mechanical material properties for the Sample Pig Transport System are presented in Part B, Section 7.2.2.

2.4 DESIGN AND FABRICATION METHODS

Design of the Sample Pig Transport System meets American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section VIII (ASME 1992), requirements.

Fabrication of the N-55 overpack was in accordance with the Nuclear Packaging, Incorporated (NuPac) QA program which is a 10 CFR 71, Subpart H approved program. The Quality Level (QL) of the overpack requires American Welding Society (AWS) welds and performance of those welds by ASME, Section IX, certified welders. The 208 L (55-gal) drum is fabricated in accordance with the requirements detailed in 49 CFR 178.

Maintenance required for QL B-3 components is found in Table A8-2.The Sample Pig Shipping Container was fabricated in accordance with a NQA-1 program and meets ASME (1992), requirements. The Sample Pig Shipping Container is a leak testable container that meets the ANSI N14.5 (ANSI 1987) leak rate requirements.

The Sample Pig, Steel Pig, LDUA Sampler (including the overpack can), and Safesend container are supplied as general service items. The quality requirements for these items are discussed in more detail in Part A, Section 7.0.

[2]Neoprene is a trademark of E. I. du Pont de Nemours and Company.

2.5 WEIGHTS AND CENTER OF GRAVITY

The weight of the empty Sample Pig Transport System is 261 kg (575 lb). The maximum authorized gross weight of the packaging system is 272 kg (600 lb). The weight of the contents *shall not exceed 11 kg (25 lb). The center of gravity is located 57.9 cm (22.8 in.) from the* bottom on the package centerline.

2.6 CONTAINMENT BOUNDARY

The Sample Pig Shipping Container provides the containment boundary. It meets the definition of leaktight given in ANSI N14.5 (ANSI 1987). The 208 L (55-gal) drum provides a secondary containment boundary with its gasket and bolted lid. For a complete description of the containment system, refer to Part B, Section 4.0.

2.7 CAVITY SIZE

The internal cavity of the Sample Pig Shipping Container is 20.27 cm (7.98 in.) in diameter by 33.66 cm (13.25 in.) high.

2.8 HEAT DISSIPATION

No special devices are used for the transfer or dissipation of heat. Refer to Part B, Section 8.0, for the thermal evaluation of the Sample Pig Transport System. Maximum allowable decay heat is 3 W. The maximum internal pressure of the Sample Pig Transport System shall not exceed 5.8 psig.

2.9 SHIELDING

Lead and steel are the primary shielding materials. The Sample Pig has approximately 4.8 cm (1.9 in.) of lead on each side of its cavity. The Steel Pig has approximately 3.81 cm (1.5 in.) to 4.127 cm (1.625 in.) of SS surrounding its cavity. The LDUA Sampler is unshielded, but is surrounded by approximately 1 cm (0.4 in.) of lead shielding when packaged inside the metal can for transport. Refer to Part B, Section 5.0, for the shielding evaluation. Shielding is also provided inside of the Safesend by SS pigs for sample sizes less than 0.25 L.

2.10 LIFTING DEVICES

Lifting devices are a structural part of the package. Four reinforced lifting locations are provided on the N-55 overpack. There are also lifting bails integral to the Sample Pig and the Sample Pig Shipping Container, and the Steel Pig is equipped with a 1.27 cm (0.5-in.) eyebolt with 13 UNC threads for lifting. The LDUA Sampler and the Safesend are not equipped with any special lifting devices. Refer to Part B, Section 7.0, for greater detail on the lifting devices.

2.11 TIEDOWN DEVICES

There are no tiedown devices or attachment points that are a structural part of the packaging. A tiedown assembly is utilized to attach the packages to the transport vehicle and is evaluated in Part B, Section 10.0.

3.0 PACKAGE CONTENTS

3.1 GENERAL DESCRIPTION

The Sample Pig Transport System is used to transport liquid or solid tank waste that has not been fully characterized. The samples may be shipped in volumes of 0.125 L, 0.5 L, and 1 L. Note that although the LDUA Sampler has a volume of 0.068 L, it is conservatively modeled as a 0.125 L sample throughout this SARP. A bounding source term has been developed to minimize the need for reevaluation of the source term when additional tank waste characterization data becomes available in the future. The source term was developed from the worst-case source terms shown in the Basis for Interim Operations data in WHC-SD-WM-SARR-016 (Van Keuren 1996), AZ-102 characterization data shown in WHC-SD-WM-ER-411 (WHC 1997), and AX-104 characterization data shown in HNF-SD-WM-ER-675 (Lambert and Hendrickson 1997). The resulting source term was used to determine the shielding parameters for each sample size as shown in Part B, Section 5.0. The worst-case 0.125 L source term can be transported in the Sample Pig (or LDUA Sampler, as appropriate). *Samples up to 0.5 L may be transported in the Steel Pig. Samples up to 1 L may* be transported in the Safesend. However, due to the lack of shielding in the Safesend, these samples can only be transported with reduced concentrations of strong gamma- and beta-emitting radionuclides. The source terms for each volume are shown in Table A3-1.

The heat generation rates for the 0.125 L sample in the Sample Pig (or LDUA Sampler, as appropriate) is 0.063 W. The heat generation rate for the 0.5 L sample in the Steel Pig is 0.25 W. The heat generation rate for the 0.5 L and 1 L sample volumes in the Safesend are 0.116 W and 0.121 W (Part B, Section 9.0). Each sample size is a fissile excepted, Type B, non-highway route controlled quantity (Part B, Section 2.0).

3.2 CONTENTS RESTRICTIONS

3.2.1 Radioactive Materials

The source term is limited to that shown in Table A3-1 for each sample size. Note that the source term is limited for each isotope, not the total number of curies per sample size.

3.2.2 Nonradioactive Materials

Nonradioactive materials are (1) aqueous solutions or solid mixtures of oxides, nitrites, nitrates, phosphates, sulfates, fluorides, chlorides, tricalcium aluminate or (2) organic compounds or extraction liquids.

Table A3-1. Source Terms for 0.125 L, 0.5 L, and 1 L Volumes of Tank Waste in the Sample Pig Transport System. (2 sheets total)

Isotope	0.125 L in Sample Pig or LDUA Sampler decayed 4 years (Ci)	0.5 L in Steel Pig decayed 4 years (Ci)	0.5 L in Safesend[a] decayed 4 years (Ci)	1 L in Safesend decayed 4 years (Ci)
^{3}H	4.46 E-03	1.78 E-02	1.78 E-02	3.57 E-02
^{14}C	2.89 E-06	1.16 E-05	1.16 E-05	2.31 E-05
^{59}Ni	1.47 E-05	5.88 E-05	5.88 E-05	1.18 E-04
^{60}Co[b]	9.69 E-04	3.88 E-03	1.74 E-03	1.71 E-03
^{63}Ni	1.44 E-03	5.76 E-03	5.76 E-03	1.15 E-02
^{79}Se	1.39 E-05	5.56 E-05	5.56 E-05	1.11 E-04
^{90}Sr[b]	8.82 E+00	3.53 E+01	1.59 E+01	1.56 E+01
^{90}Y[b]	8.82 E+00	3.53 E+01	1.59 E+01	1.56 E+01
^{93}Zr	6.43 E-05	2.57 E-04	2.57 E-04	5.14 E-04
^{93m}Nb	5.06 E-05	2.02 E-04	2.02 E-04	4.05 E-04
^{99}Tc	4.05 E-02	1.62 E-01	1.62 E-01	3.24 E-01
^{106}Ru[b]	1.90 E-03	7.60 E-03	3.41 E-03	3.37 E-03
^{106}Rh[b]	1.90 E-03	7.60 E-03	3.41 E-03	3.37 E-03
^{113m}Cd	3.80 E-04	1.52 E-03	1.52 E-03	3.04 E-03
^{125}Sb[b]	1.28 E-02	5.12 E-02	2.30 E-02	2.27 E-02
^{125m}Te	3.12 E-03	1.25 E-02	1.25 E-02	2.50 E-02
^{126}Sn	2.18 E-05	8.72 E-05	8.72 E-05	1.74 E-04
^{126}Sb	3.05 E-06	1.22 E-05	1.22 E-05	2.44 E-05
^{126m}Sb	2.18 E-05	8.72 E-05	8.72 E-05	1.74 E-04
^{129}I	2.16 E-05	8.64 E-05	8.64 E-05	1.73 E-04
^{134}Cs[b]	4.09 E-03	1.64 E-02	7.31 E-03	7.28 E-03
^{137}Cs[b]	3.11 E-01	1.24 E+00	5.56 E-01	5.53 E-01
^{137m}Ba[b]	2.94 E-01	1.18 E+00	5.26 E-01	5.23 E-01
^{147}Pm	4.24 E-05	1.70 E-04	1.70 E-04	3.39 E-04
^{151}Sm	5.04 E-02	2.02 E-01	2.02 E-01	4.03 E-01
^{152}Eu	4.39 E-05	1.76 E-04	1.76 E-04	3.51 E-04
^{154}Eu[b]	2.72 E-02	1.09 E-01	4.87 E-02	4.84 E-02
^{155}Eu	1.41 E-02	5.64 E-02	5.64 E-02	1.13 E-01
^{231}Pa	1.13 E-08	4.52 E-08	4.52 E-08	9.04 E-08

Table A3-1. Source Terms for 0.125 L, 0.5 L, and 1 L Volumes of Tank Waste in the Sample Pig Transport System. (2 sheets total)

Isotope	0.125 L in Sample Pig or LDUA Sampler decayed 4 years (Ci)	0.5 L in Steel Pig decayed 4 years (Ci)	0.5 L in Safesend[a] decayed 4 years (Ci)	1 L in Safesend decayed 4 years (Ci)
^{231}Th	3.35 E-08	1.34 E-07	1.34 E-07	2.68 E-07
^{233}Pa	3.35 E-03	1.34 E-02	1.34 E-02	2.68 E-02
^{234m}Pa	5.83 E-07	2.33 E-06	2.33 E-06	4.66 E-06
^{234}Th	5.83 E-07	2.33 E-06	2.33 E-06	4.66 E-06
^{233}U	6.16 E-08	2.46 E-07	2.46 E-07	4.93 E-07
^{234}U	8.57 E-07	3.43 E-06	3.43 E-06	6.86 E-06
^{235}U	3.35 E-08	1.34 E-07	1.34 E-07	2.68 E-07
^{236}U	7.00 E-08	2.80 E-07	2.80 E-07	5.60 E-07
^{237}U	2.54 E-07	1.02 E-06	1.02 E-06	2.03 E-06
^{238}U	5.83 E-07	2.33 E-06	2.33 E-06	4.66 E-06
^{237}Np	3.35 E-03	1.34 E-02	1.34 E-02	2.68 E-02
^{239}Np	1.68 E-06	6.72 E-06	6.72 E-06	1.34 E-05
^{238}Pu	6.12 E-04	2.45 E-03	2.45 E-03	4.90 E-03
^{239}Pu	5.30 E-03	2.12 E-02	2.12 E-02	4.24 E-02
^{240}Pu	1.40 E-03	5.60 E-03	5.60 E-03	1.12 E-02
^{241}Pu	1.06 E-02	4.24 E-02	4.24 E-02	8.48 E-02
^{242}Pu	1.29 E-08	5.16 E-08	5.16 E-08	1.03 E-07
^{241}Am	3.71 E-02	1.48 E-01	1.48 E-01	2.97 E-01
^{243}Am	1.68 E-06	6.72 E-06	6.72 E-06	1.34 E-05
^{242}Cm	8.50 E-09	3.40 E-08	3.40 E-08	6.80 E-08
^{243}Cm	6.11 E-07	2.44 E-06	2.44 E-06	4.89 E-06
^{244}Cm	1.77 E-04	7.08 E-04	7.08 E-04	1.42 E-03

NOTE: Isotopes with activities below 1×10^{-9} Ci are not reported.
[a]Safesend is a trademark of the 3M Corporation.
[b]These isotopes or their daughters contribute significantly to the dose on the surface of the Safesend package.

LDUA = Light-Duty Utility Arm.

This page intentionally left blank.

4.0 TRANSPORT SYSTEM

4.1 TRANSPORTER

The Sample Pig Transport System is transported by an exclusive-use vehicle. Transfer of the Sample Pig Transport System is restricted to trucks 1C392 and 1C393. Other vehicles may be authorized to transfer the Sample Pig Transport System, provided it is shown that they (1) have equivalent gross vehicle weight limits, tiedown frames, and overhead hoist capacities and heights and (2) are generally similar to the previously mentioned vehicles.

4.2 TIEDOWN SYSTEM

The tiedown system for the Sample Pig Transport System is shown in Figure A4-1. The tiedown strap assembly shall have a minimum tensile strength of 907 kg (2,000 lb). An analysis and discussion of the tiedown system are provided in Part B, Section 10.0.

4.3 SPECIAL TRANSFER REQUIREMENTS

4.3.1 Routing and Access Control

For interarea transport (transport between the 200 Areas and 300 Area), the transfer route shall be controlled to preclude public access during the transfer. There are no intra-area transfer restrictions.

4.3.2 Radiological Limitations

The radiation levels shall not exceed the following limits: 10 mSv/h (1,000 mrem/h) on the exterior surface of the N-55 overpack, 2 mSv/h (200 mrem/h) at a vertical plane from the edge of the transport vehicle, 0.1 mSv/h (10 mrem/h) at 2 m (7 ft) from the vehicle edge, and 0.02 mSv/h (2 mrem/h) at any normally occupied space (driver location), unless the worker is a qualified Hanford Site radiological worker, in which case the limit is 0.05 mSv/h (5 mrem/h).

Removable contamination on external surfaces of the Sample Pig Transport System shall not exceed Table A4-1.

4.3.3 Time Restrictions

Gas generation concerns limit the time the Sample Pig Shipping Container can remain sealed without approaching explosive limits. The seal times (also referred to as shipping windows) are shown in Table A4-2.

Figure A4-1. Tiedown Configuration.

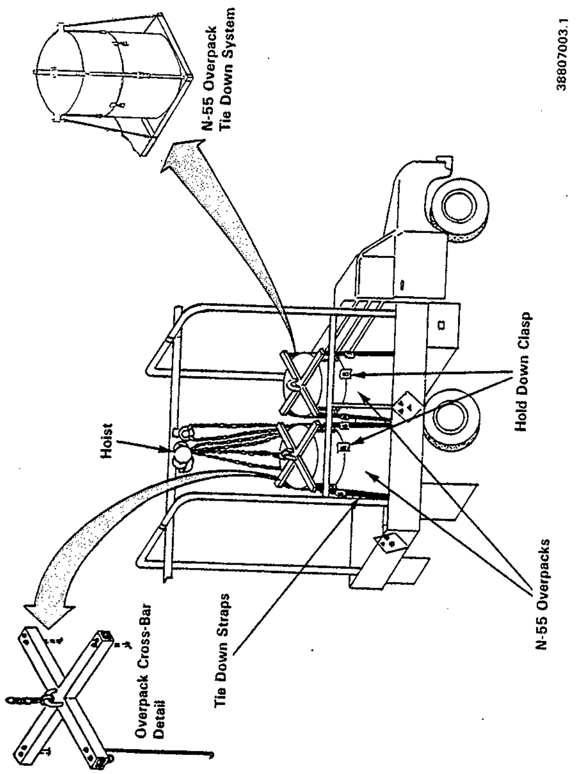


Table A4-1. External Package Contamination Limits.

Contaminant	Maximum permissible limits	
	μCi/cm^2	dpm/cm^2
Beta-gamma emitting radionuclides; all radionuclides with half-lives less than ten days; natural uranium; natural thorium; uranium-235; uranium-238; thorium-232; thorium-228 and thorium-230 when contained in ores or physical concentrates	10^{-5}	22
All other alpha emitting radionuclides	10^{-6}	2.2

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

Table A4-2. Shipping Windows.

Sample configuration	0.125 L Sample Pig	0.125 L LDUA	0.5 L Steel Pig	0.5 L Safesend*	1 L Safesend
Void volume (cc)	4972	7409	3709	1903	1400
Total hydrogen generation rate (cc/h)	0.128	0.128	0.516	0.327	0.494
Shipping window (hours[days])	485 (20.2)	723 (30.1)	89 (3.7)	72 (3)	35 (1.46)

*Safesend is a trademark of the 3M Corporation.
LDUA = Light-Duty Utility Arm.

4.3.4 Speed Limitations

There are no special restrictions. Posted speed limits shall be followed.

4.3.5 Environmental Conditions

Transport shall not take place under icy conditions unless roads have been plowed and sanded, or when visibility is seriously impaired by fog, rain, snow, or dust (less than one mile visibility).

4.3.6 Frequency of Use and Mileage Limitations

The Sample Pig Shipping Container is reusable and with proper maintenance can be used until inspections identify unacceptable conditions caused by normal wear.

4.3.7 Escort and Emergency Response

There are no specific escort requirements for transport of the Sample Pig Transport System. All emergency response notification is the responsibility of the shipper. The typical fire department response time onsite is 15 minutes.

4.3.8 Exclusive Use

The transport vehicle shall not carry any other packagings containing hazardous material during Sample Pig Shipping Container transfer.

5.0 ACCEPTANCE OF PACKAGING FOR USE

5.1 NEW PACKAGING

All newly fabricated Sample Pig Transport System components shall be inspected and tested per the following requirements prior to use in the field. The Sample Pig Transport System is a THI 3 package per HNF-PRO-154. The Sample Pig Transport System contents dose consequence is covered by the Onsite Transfer Cask (OTC) SARP (WHC-SD-TP-SARP-002, Rev. 1-C) dose consequence (Part B, Section 4.0). The Sample Pig Transport System easily meets the failure threshold requirements of a THI 3 package as detailed in WHC-SD-TP-SARP-002, Rev. 1-C, because it meets 10 CFR 71 performance requirements.

5.1.1 Acceptance Requirements

Fabrication acceptance requirements for the Sample Pig Transport System are based upon the THI and QL of the component to be inspected or tested. QL A-3 and B-3 components or activities, as defined in Part A, Section 7.0, are important to safety and require proper documentation if they are not inspected or tested as required by this section.

5.1.2 Inspection and Testing

The following inspections and testing shall be performed on newly fabricated Sample Pig Transport System components. The inspections are based on the QL of the component. QL A-3 components are considered important to safety, and the inspections and testing shall be documented and maintained per Part A, Section 5.1.3. QL A-3 testing and inspection requirements are listed in Table A5-1.

QL B-3 components fabrication inspections and tests are required to be performed as shown in Table A5-2. QL B-3 components are considered important to safety, and the inspections and testing shall be documented and maintained per Part A, Section 5.1.3.

Table A5-1. Quality Level A-3 Fabrication Testing and Inspections

Component test/inspection	Acceptance requirements
Sample Pig Shipping Container, seal, and bolts visual inspection	Meets all the materials and fabrication requirements of the drawings (Part B, Section 9.2).
Sample Pig Transport System assembly test	Each component is placed inside the respective component and closes and functions properly (i.e., Sample Pig , Steel Pig , Light-Duty Utility Arm Sampler, or Safesend* inside the Sample Pig Shipping Container, inside the 208 L [55-gal] drum, inside the N-55 overpack).
Lead shielding 100% lead gamma scan	No deficiencies that would reduce the effective shielding thickness by 10% or more.
Sample Pig Shipping Container leak test	Meets ANSI N14.5 (ANSI 1987) leaktight leak rate of 1 x 10^{-70} atm, cc/s.
Sample Pig Shipping Container closure bolts	Does not exhibit headmarks published in U.S. Department of Energy Bulletin No. DOE/EH-0266 (DOE 1992).

Safesend is a trademark of the 3M Corporation.
ANSI = American National Standards Institute.
ANSI, 1987, *American National Standard for Radioactive Materials - Leakage Tests on Packages for Shipment*, ANSI N14.5 American National Standards Institute, Inc., New York, New York.
DOE, 1992, *DOE Quality Alert*, Bulletin DOE/EH-0266, Issue No. 92-4, U.S. Department of Energy, Washington, D.C.

Table A5-2. Quality Level B-3 Fabrication Inspections and Tests

Component inspection/test	Acceptance requirements
Lifting fixture load test	*Hanford Site Hoisting and Rigging Manual* (RL 1993).
208 L (55-gal) drum visual inspection	Per N-55 overpack SARP drawing and requirements or requirements of 49 CFR 173 for reusable drums (UN1A2).
N-55 overpack visual inspection	Per N-55 overpack SARP drawings and requirements.
Lifting fixture visual inspection	Meet material and fabrication requirements.

SARP = Safety analysis report for packaging.
49 CFR 173, "Shippers--General Requirements for Shipments and Packagings," *Code of Federal Regulations*, as amended.
RL, 1993, *Hanford Site Hoisting and Rigging Manual*, DOE/RL-92-36, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

QL C-3 component fabrication inspections and tests are required to be performed as shown in Table A5-3. QL C-3 activities are not considered important to safety.

Table A5-3. Quality Level C-3 Fabrication Tests and Inspections.

Component inspection/test	Acceptance requirements
Sample Pig, Light-Duty Utility Arm Sampler, or Steel Pig visual inspection	Drawing material and fabrication requirements.
Safesend*	Quality control green tag for use.
Tiedown straps	Meets purchase requisition requirements.
Overpack gasket	Meets N-55 overpack drawing requirements.

*Safesend is a trademark of the 3M Corporation.

5.1.3 Documentation

All inspections shall be documented in procedures and/or inspection checklists and verified by Quality Control (QC). The documentation shall be maintained for the life of the package or five years, whichever is longer.

5.2 PACKAGING FOR REUSE

The following applies to the Sample Pig Transport System components that have previously been used to transport radioactive materials.

5.2.1 Acceptance Requirements

Acceptance requirements for the re-use of the Sample Pig Transport System are based upon the THI and QL of the component to be inspected or tested. QL A-3 activities are considered important to safety, and the inspections and testing shall be documented and maintained per Part A, Section 5.2.3. QL A-3 components or activities, as defined in Part A, Section 7.0, are important to safety and require proper documentation if they are not inspected or tested as required by this section.

5.2.2 Inspection and Testing

Each of the following inspections shall be performed prior to re-use of any or all of the Sample Pig Transport System components. The inspections are based on the QL of the component. QL A-3 component inspections are listed in Table A5-4.

Table A5-4. Quality Level A-3 Component Inspections

Component/inspection	Acceptance criteria
Sample Pig Shipping Container cleaned and decontaminated	Table A4-1 limits.
Sample Pig Shipping Container visual inspection	No weld degradation, dents, or damage to the container greater than 1.27 cm (0.5 in.) in depth that could affect the containment of the packaging are present.
Sample Pig Shipping Container O-ring visual inspection	Replace if signs of aging, cracking, hardening, or stretching are present.
Sample Pig Shipping Container closure lid Bolts visual inspection	Replace if signs of rust (excluding stains), galled threads, suspect head markings, or cracks are present.
Sample Pig Shipping Container seal surface	No scratches or damage that would affect containment are present.

QL B-3 component inspections are listed in Table A5-5. QL B-3 activities are considered important to safety, and the inspections and testing shall be documented and maintained per Part A, Section 5.2.3.

Table A5-5. Quality Level B-3 Component Inspections.

Component inspection	Acceptance requirements
N-55 overpack decontamination and Visual inspection	Table A4-1 decontamination limits and no signs of weld degradation, loss of rivets, large dents (greater than ¼ of each overpack half), or visible foam.
208 L (55-gal) drum decontamination and Visual inspection	Table A4-1 decontamination limits, no signs of weld degradation or dents in the drum that prevent proper closure of the lid.
Lifting fixtures visual inspection	No signs of weld degradation.

QL C-3 component inspections are listed in Table A5-6. QL C-3 activities are not considered important to safety.

Table A5-6. Quality Level C-3 Component Inspections.

Component inspection	Acceptance requirements
N-55 overpack gasket visual inspection	Replace if signs of aging, cracking, hardening, or stretching are present.
Tiedown straps visual inspection	Replace if signs of fraying or breaking are present.
Safesend* visual inspection	Replace if there are signs the container will not close properly; the absorbent shows discoloration, indicating a spill inside the container; or the container is excessively damaged. The Safesend is not limited to eight uses when used with the Sample Pig Transport System.
Sample Pig or Steel Pig visual inspection	Replace if excessive weld degradation or closure latch degradation is present.

*Safesend is a trademark of the 3M Corporation.

5.2.3 Documentation

All inspections shall be documented in procedures and/or inspection checklists and the document periodically reviewed by QA/QC. The documentation shall be maintained for the life of the package or five years, whichever is longer.

This page intentionally left blank.

6.0 OPERATING PROCEDURES

6.1 GENERAL REQUIREMENTS

The following are recommended guidelines for the use of the packaging. Prior to use, specific operating procedures shall be written by the user and approved by Packaging Engineering. Items or activities labeled as QL A-3 and B-3 shall be considered "Important to Safety" and shall be followed as written in this SARP. Modifications of QL A-3 and B-3 steps will require an engineering change notice and unresolved safety question (USQ) screening. Prior to loading, the shipper shall verify that the source term to be shipped does not exceed the worst-case source term shown in Part A, Section 3.0. If the source term is expected to exceed these values, the organization responsible for this SARP must be contacted to evaluate the source term with respect to the requirements shown in this SARP (particularly dose rate and gas generation parameters).

6.2 LOADING THE PACKAGE

1. Verify that the packaging is in unimpaired physical condition before each use. No obvious breaches (e.g., broken welds, punctures, lid distortions) shall be present. (QL B-3)

2. Place samples inside a Sample Pig (a 0.125 L sample), a Steel Pig (0.5 L or smaller sample), or a Safesend (0.5 or 1 L sample). Remove a packaging label from the side of the Safesend, if present. LDUA Samplers are placed in a plastic bag and the bag is sealed (twisted and taped closure [horsetail]). (QL C-3)

   NOTE: The Safesend is not limited to 8 uses when used with the Sample Pig Transport System. However, if all the labels are removed, the Safesend cannot be used with the Hedgehog system for offsite transport.

3. Close the appropriate sample carrier as follows. (QL C-3)

   a. Position the lid of the Sample Pig in place, and install the locking safety pin.

   b. Position the Steel Pig lid on the studs, and install the lock washers and nuts.

   c. Install the Safesend lid, and tighten until the lock engages.

   d. Place the bagged LDUA Sampler in a metal can and close the lid. The can may be a slip lid, food pack, or paint can, but not a rolled seam can. Rolled seam cans are impervious to gas which may be generated by the sample.

4. Lower the sample container into the Sample Pig Shipping Container cavity. (QL C-3)

5. If desired for liquid samples, place inert absorbent material, capable of absorbing twice the amount of material being shipped, around the sample container. (QL C-3)

   NOTE: The Safesend already includes absorbent in its packaging structure.

6. Wipe the O-rings, flange grooves, and mating surfaces of the Sample Pig Shipping Container with a lint-free cloth. (QL A-3)

7. Lubricate the O-rings with Apiezon[3] Type N lubricant. The lubricating material should be applied sparingly. Install the O-rings. (QL B-3)

8. Place the lid of the Sample Pig Shipping Container onto the O-ring flange, being careful not to scratch the mating surfaces of the flanges with the guide pins or to nick the O-rings. (QL A-3)

9. Place the hex head nuts in position on the Sample Pig Shipping Container and tighten to 20 ± 5 ft·lb. (QL A-3) A tamper-indicating seal may be placed on the Sample Pig Shipping Container if desired. (QL C-3)

10. Position the bottom section of the inner spacer inside the 208 L (55-gal) drum. (QL C-3)

11. If the 208 L (55-gal) drum is not already in the N-55 overpack, place it inside the bottom half of the overpack. (QL C-3)

12. Using a hoist, lower the sealed Sample Pig Shipping Container into the 208 L (55-gal) drum. (QL C-3)

13. Position the top section of the inner spacer over the Sample Pig Shipping Container. (QL C-3)

14. Place the 208 L (55-gal) drum lid, including a gasket, and the lock ring and bolt on the drum. (QL B-3)

15. Torque the lock ring and bolt to 40 ft·lb ± 5 ft·lb while hammer tapping the lock ring with a rubber or leather mallet to ensure an adequate seal. (QL B-3)

16. Position the top half of the N-55 overpack on the bottom half. (QL C-3)

17. Secure the top half of the N-55 overpack to the bottom half by fastening the four toggle clamps (barrel pins). This shall be done by adjusting the "T" bar on the clamps such that the clamps may be closed with minimum force. Reopen the clamps and rotate the "T" bar on all four clamps two full 360° turns clockwise. Then close the clamps. (QL C-3)

---

[3]Apiezon is a trademark of Biddle Instruments.

18. Verify that radiation dose rates do not exceed the following limits: 10 mSv/h (1,000 mrem/h) on the exterior surface of the N-55 overpack, 2 mSv/h (200 mrem/h) at a vertical plane projected from the vehicle edge, 0.1 mSv/h (10 mrem/h) at 2 m (7 ft) from the vehicle edge, and 0.02 mSv/h (2 mrem/h) at any normally occupied space (driver location), unless the worker is a qualified Hanford Site radiological worker in which case the limits is 0.05 mSv/h (5 mrem/h). If these dose rates are exceeded in practice, supplemental shielding shall be installed to reduce the dose rate to the driver to below acceptable limits. ALARA practices or supplemental shielding will be required to limit exposure to the public and workers at the edge of the vehicle and at 2 m from the vehicle.

    NOTE: As shown in Part B, Section 5.0, the maximum dose rates to the driver may be exceeded for several of the worst-case source configurations. These are the 0.125 L sample in the Sample Pig (nonradiological worker only), the LDUA Sampler, and the 0.5 L and 1 L samples in the Safesend. The dose rate limits at the edge of the vehicle and at 2 m may be exceeded for the worst-case 0.5 L and 1 L samples in the Safesend.

19. Removable contamination on external surfaces of the Sample Pig Transport System shall not exceed Table A4-1 values. (QL A-3)

20. Install a tamper-indicating seal on the N-55 overpack if a seal was not placed on the Sample Pig Shipping Container in step 9. (QL C-3)

21. If it is not already in place, attach the lifting and tiedown yoke to the top of the N-55 overpack and place the package on the transporter. Carefully tension the straps between the yoke and the transporter frame to ensure even tension on all four straps. (QL B-3)

NOTE: Ensure that the time restrictions in Part A, Section 4.3.3, are followed.

6.3 UNLOADING PACKAGE

1. Survey the N-55 overpack prior to opening to ensure removable contamination on external surfaces of the N-55 overpack does not exceed Table A4-1 limits. (QL A-3)

2. Verify the integrity of the tamper-indicating seal on the N-55 overpack. (QL B-3)

3. Remove the tiedowns and unlock the toggle clamps on the N-55 overpack. (QL C-3)

4. Remove top half of the N-55 overpack. (QL C-3)

5. Remove the 208 L (55-gal) drum lid and the top inner spacer. (QL C-3)

6. Survey the 208 L (55-gal) drum lid and top inner spacer prior to removing the Sample Pig Shipping Container to ensure a contamination spread will not occur while removing the shipping container. (QL A-3)

7. Remove the Sample Pig Shipping Container from the drum using a hoist. (QL A-3)

NOTE: The Sample Pig Shipping Container and Sample Pig shall be removed from the overpack intact.

8. Survey the Sample Pig Shipping Container to ensure removable contamination on external surfaces of the Sample Pig Shipping Container does not exceed Table A4-1 limits. (QL A-3)

9. Carefully open the Sample Pig Shipping Container, and remove the sample carrier. The remainder of the unpackaging steps will be addressed in appropriate operational procedures. (QL C-3)

CAUTION: THE SAMPLE PIG SHIPPING CONTAINER MAY BE PRESSURIZED DUE TO HYDROGEN GAS BUILDUP.

6.4 EMPTY PACKAGE (PACKAGING

Empty packages shall be prepared for transport per 49 CFR 173.428 (1995 version) under the conditions that the smearable internal contamination levels and the smearable external contaminations levels are acceptable per 49 CFR 173.443 (see Table A4-1). Otherwise, the package shall be reassembled and transported per Part A, Sections 6.2 and 6.3.

7.0 QA REQUIREMENTS

7.1 INTRODUCTION

This section describes the QA requirements for the procurement, fabrication, operation, and maintenance of the Sample Pig Transport System. The design and fabrication of the N-55 overpack was performed by NuPac following their 10 CFR 71, Subpart H, certification and those guidelines similar to those detailed below. The Sample Pig Transport System components fabricated by the Westinghouse Hanford Company (WHC) were programmatically controlled by WHC-CM-4-2, *Quality Assurance Manual*. The format and requirements for procurement and use of new packagings or components, including fabrication, operation, and maintenance, are controlled by HNF-MP-599, *Project Hanford Quality Assurance Program Description*, and HNF-PRO-154.

7.2 GENERAL REQUIREMENTS

These requirements apply to activities, such as packaging, fabrication, repair, operation, and maintenance, that could affect the quality of the Sample Pig Transport System and associated hardware. The overall Sample Pig Transport System is classified per the HNF-PRO-154 as a THI 3. The THI-3 evaluation of this payload is detailed in the OTC SARP, WHC-SD-TP-SARP-002, Rev. 1-C. Note that although the volume allowed in the Sample Pig exceeds that of the OTC, 1 L versus 0.5 L, the evaluation demonstrates that well over 1 L of the source material is within the THI-3 limits. Therefore, the analysis in WHC-SD-TP-SARP-002, Rev. 1-C, bounds the source in the Sample Pig.

THI 3 packaging systems defined in HNF-PRO-154 represent the third highest level of hazard for the contents. A packaging system assigned this level must be capable of mitigating a release less than 0.5 rem and greater than 0.01 rem beyond the Hanford Site boundaries from either a normal or accident condition of transport.

Each THI contains a QL designator consisting of two parts, an alphanumeric designator with a numerical designator. The alphanumeric designator assigns the fabrication, testing, use, maintenance standards, and quality requirements for each item, component, or activity of the packaging system. The numeric designator following the letter is the THI number of the packaging system. The following are definitions and requirements for each Sample Pig Transport System item, component, or activity.

Quality Level A-3: Critical impact on safety and associated functional requirements: items or components whose failure or malfunction could directly result in an unacceptable condition of containment or confinement, shielding, or nuclear criticality.

This QL refers to the Sample Pig Shipping Container containment boundary and shielding. The requirements for fabrication, operations, and maintenance shall comply with the requirements of the following: AWS, international or national standards, or WHC operational and maintenance requirements with minimum fabrication leak test requirements of 10^{-4} atm cc/s, air.

Material required to be on hand for fabrication are ASTM or military specification materials with certificates of conformance from the Sellers.

Any procurement of items shall be from a supplier with an approved QA program in accordance with, or equivalent to, appropriate Basic Requirements and Supplements of ASME NQA-1. QA procurement clauses shall be imposed, as applicable, to ensure product quality. Specific requirements are to be developed by the Packaging QA engineer and the Packaging Engineering cognizant engineer.

Quality Level B-3: Major impact on safety and associated functional requirements: items or components whose failure or malfunction could indirectly result in an unacceptable condition of containment or confinement, shielding, or nuclear criticality. An unsafe condition could result only if the failure of this item or subsystem occurred in conjunction with the failure of other items or subsystem in A-3 or this level.

This QL refers to the N-55 overpack 208 L (55-gal) drum closure and lifting fixtures. The requirements for fabrication, operation, and maintenance shall comply with the requirements of the following: American Institute of Steel Construction (AISC), AWS, international or national standards, or WHC operational and maintenance requirements with fabrication leakage rate requirements of 10^{-1} atm cc/s, air.

Materials for fabrication require only the Seller's certificate of compliance.

Quality Level C-3: Minor impact on safety and associated functional requirements: items or components whose failure or malfunction would not reduce packaging effectiveness and would not result in an unacceptable condition of containment or confinement, shielding, or nuclear criticality, regardless of other failure in A-3, B-3, or this level.

This QL refers to the N-55 overpack gasket, tiedown system, Safesend, Sample Pig, Steel Pig, LDUA Sampler, and all content containers. The requirements for fabrication, operation, and maintenance shall comply with the following: AISC, AWS, international or national standards, Project Hanford Management System, or Seller's prepared requirements media.

Each cognizant engineer involved with procurement, fabrication, use, or maintenance of the Sample Pig Transport System components is responsible for ensuring that the assigned tasks are performed in accordance with controlling plans and procedures, which must, in turn, conform to the requirements of these QA requirements. Quality requirements for tasks are determined and documented in the plans and procedures used by the involved organizations.

Documentation and review requirements are based upon the QL of each component or activity. Changes or discoveries of noncompliance for all QL A-3 and B-3 components and activities shall be reviewed by the USQ screening process to ensure the quality and safety of the change or discovery. Changes to the SARP safety bases (contents, shielding, structural, containment, criticality) will require USQ 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 work. Quality achievement is to be verified by persons or organizations not directly responsible for performing the work.

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

- Follow current requirements of this SARP, HNF-PRO-154, and HNF-MP-599
- Provide instructions for implementing QA requirements.

The Director, QA, is responsible for establishing and administering the Project Hanford Management Contract QA program as stated in HNF-MP-599.

7.4 QA ACTIVITIES

7.4.1 Design Control

All engineering change notices (ECNs) to the packaging shall be approved by Packaging Engineering.

7.4.2 Procurement and Fabrication Control

Procurement and fabrication of Sample Pig Transport System components shall be documented and controlled based on the QL of the component (see Table A7-1). Requirements of HNF-MP-599 shall be followed as required by the QL and Packaging QA engineer.

Table A7-1. Procurement and Fabrication Quality Levels.

Component	Quality level
N-55 overpack	B-3
208 L (55-gal) drum	B-3
Sample Pig Shipping Container	A-3
Sample Pig Shipping Container gasket	A-3
Lifting attachments	B-3
Overpack gasket	C-3
208 L (55-gal) drum gasket	B-3
Sample Pig, Light-Duty Utility Arm Sampler, or Steel Pig	C-3
Content containers	C-3
Tiedown attachments	C-3
Safesend*	C-3

*Safesend is a trademark of the 3M Corporation.

7.4.3 Control of Operation/Processes

Processes affecting the quality of package items or services shall be controlled by instructions, procedures, drawings, checklists, or other appropriate means. These means shall ensure that process parameters are controlled with defined limits and that specified environmental conditions are maintained. Methods for defining how process controls will be applied are defined in HNF-MP-599.

7.4.4 Control of Inspection and Testing

Fabrication and acceptance inspections shall be performed to the following guidelines.

7.4.4.1 Inspection Personnel. Inspection for acceptance of items fabricated onsite shall be performed by QC personnel from Operations. Items fabricated by offsite suppliers will be inspected by QC personnel from Acquisitions Verification Services.

7.4.4.2 In-Process Inspection. Fabrication and acceptance inspections, detailed in Part A, Section 5.0, are performed by QC personnel from operations.

7.4.5 Control of Operations and Maintenance

Loading/unloading procedures shall be written by the user with appropriate reference to this SARP and will be used to ensure adequate loading, operation, and maintenance of packaging. The loading/unloading procedure identifies actions required by loading personnel to safely and properly load the Sample Pig Transport System per this SARP. The loading/unloading procedures shall also identify which steps, as defined in this SARP (Part A, Section 6.0), are important to safety.

Quality Assurance verification shall be included for each QL A-3 and B-3 maintenance activity as described in Part A, Sections 8.2, regardless of assigned QL.

7.4.6 Test Control

These requirements apply to activities associated with the testing of the Sample Pig Transport System and associated hardware involving QL A-3 or designated B-3 items. Testing shall be performed and documented per HNF-MP-599.

Tests required to verify conformance of package components to this SARP's requirements and to demonstrate satisfactory performance for service shall be planned, performed, and documented. Characteristics to be tested and test methods to be employed shall be specified. Test results shall be documented, and their conformance with acceptance criteria shall be evaluated.

7.4.7 Control of Measuring and Test Equipment

The requirements for measuring and test equipment, contained in HNF-MP-599 and HNF-PRO-490, *Control of Measuring and Test Equipment and Nondata Test Equipment*, apply to all equipment used to determine acceptability of Sample Pig Transport System items, components, or activities, regardless of the assigned QL.

7.4.8 Control of Nonconforming Items

Identification, documentation, evaluation, and disposition of nonconforming items and activities shall be accomplished per HNF-MP-599 and HNF-PRO-298, *Nonconforming Item Reporting and Control*, regardless of the assigned QL.

Items procured or fabricated for the Sample Pig Transport System or use in the package shall be QC inspected by Acquisitions Verification Services prior to use for compliance with the purchase order, specification, and/or fabrication drawing. The cognizant engineer, with QA concurrence, shall define the acceptance criteria.

7.4.9 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 HNF-MP-599 and HNF-PRO-052, *Corrective Action Management*.

7.4.10 QA Records and Document Control

Records that furnish documentary evidence of quality shall be specified, prepared, and maintained per HNF-MP-599 and HNF-PRO-222, *Quality Assurance Records*. All documents used to perform and/or verify items activities are controlled. Controlled documents include (but are not limited to) the following: drawings, specifications, purchase orders, plans and procedures to inspect and test, Project Hanford Management Contract reports, quality verification reports, nonconformance reports, corrective action reports, the SARP, and operational and maintenance procedures.

7.4.11 Audits

The internal and external audit process is guided by and shall be in accordance with HNF-MP-599.

7.5 SARP CONTROL SYSTEM

This SARP is a copy controlled supporting document to ensure that only up-to-date approved versions are used for transport. Any changes made to this SARP will be by engineering change notices, which are distributed to users through the Copy Control System and incorporated into the SARP.

Any review comment records produced during the initial release or subsequent changes will be on file with the organization responsible for this SARP, currently the Engineering group of Waste Management Federal Services, Inc., Northwest Operations.

8.0 MAINTENANCE

8.1 GENERAL REQUIREMENTS

A maintenance program shall be followed to ensure the integrity of the N-55 overpacks, 208 L (55-gal), and Sample Pig Shipping Containers. Gaskets, toggle clamps, and other components necessary for the safe and easy operation of the packaging shall be given regular inspection and be repaired or replaced as necessary.

8.2 INSPECTION AND VERIFICATION SCHEDULES

Maintenance frequency and acceptance requirements are based upon the THI and the QL of the component or activity. QL A-3 and B-3 components or activities are considered important to safety. Should the maintenance not be performed for QL A-3 and/or B-3 components, proper safety and QA review, and documentation are required.

Maintenance required for QL A-3 components is listed in Table A8-1.

Table A8-1. Quality Level A-3 Maintenance Requirements.

Component/activity	Frequency	Acceptance requirements
Sample Pig Shipping Container leak test	Annually	ANSI N14.5 (ANSI 1987) 1 x 10^{-7} atm cc/s
Sample Pig Shipping Container O-ring replacement	Annually	N/A
Sample Pig Shipping Container O-ring seating surface visual inspection	Annually	No scratches or damage that would affect containment are present
Sample Pig Shipping Container closure bolts replacement	Annually	Replace if signs of degradation are present and check for headmarks matching those listed in U.S. Department of Energy Bulletin No. DOE/EH-0266 (DOE 1992).
Sample Pig Shipping Container visual inspection	Annually	Exterior structural welds do not have visible cracks. Exterior not damaged in area of closure bolts or gasket such that containment would be jeopardized. Exterior has no flaws, punctures, or dents in excess of 0.635 cm (¼ in.)

ANSI = American National Standards Institute.

ANSI, 1987, *American National Standard for Radioactive Materials - Leakage Tests on Packages for Shipment*, ANSI N14.5 American National Standards Institute, Inc., New York, New York.

DOE, 1992, *DOE Quality Alert*, Bulletin DOE/EH-0266, Issue No. 92-4, U.S. Department of Energy, Washington, D.C.

Maintenance required for QL B-3 components is found in Table A8-2.

Table A8-2. Quality Level B-3 Maintenance Requirements.

Component activity	Frequency	Acceptance requirements
208 L (55-gal) drum gasket replacement	Annually	Size and material as specified by the drum manufacturer.
N-55 overpack gasket replacement	Annually	Neoprene gasket material 0.635 cm (¼ in.) to 1.27 cm (½ in.) thick.

Maintenance required for QL C-3 components is listed in Table A8-3.

Table A8-3. Quality Level C-3 Maintenance Requirements.

Component	Frequency	Acceptance requirements
Tiedown straps visual inspection	Annually	Replace if frayed or worn.
Sample Pig, Light-Duty Utility Arm Sampler, or Steel Pig visual inspection	Every 2 years	Replace if signs of significant degradation in container.
Safesend* visual inspection	Annually	Replace if signs of significant degradation in container (eight use requirement does not apply).
N-55 overpack toggle clamps functional inspection lubricate and visually inspect	Annually	Replace if clamps are bent or damaged to the extent that proper latching would be impaired.

*Safesend is a trademark of the 3M Corporation.

8.3 DOCUMENTATION

Maintenance from Part A, Section 8.2 shall be documented in procedures and/or inspection checklists and verified by QA/QC. Records of inspection and maintenance for the Sample Pig Transport System shall be retained for the life of the packaging system or five years, whichever is longer.

9.0 REFERENCES

10 CFR 71, "Packaging and Transportation of Radioactive Material," *Code of Federal Regulations*, as amended.

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

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

ANSI, 1987, *American National Standard for Radioactive Materials - Leakage Tests on Packages for Shipment*, ANSI N14.5 American National Standards Institute, Inc., New York, New York.

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

DOE, 1992, *DOE Quality Alert*, Bulletin DOE/EH-0266, Issue No. 92-4, U.S. Department of Energy, Washington, D.C.

HNF-MP-599, *Project Hanford Quality Assurance Program Description*, Fluor Daniel Hanford, Inc., Richland, Washington.

HNF-PRO-052, *Corrective Action Management*, Fluor Daniel Hanford, Inc., Richland, Washington.

HNF-PRO-154, *Responsibilities and Procedures for all Hazardous Material*, Fluor Daniel Hanford, Inc., Richland, Washington.

HNF-PRO-157, *Radioactive Material/Waste Shipments*, Fluor Daniel Hanford, Inc., Richland, Washington.

HNF-PRO-163, *Documentation and Record Keeping*, Fluor Daniel Hanford, Inc., Richland, Washington.

HNF-PRO-166, *Transportation Safety Training Requirements*, Fluor Daniel Hanford, Inc., Richland, Washington.

HNF-PRO-222, *Quality Assurance Records*, Fluor Daniel Hanford, Inc., Richland, Washington.

HNF-PRO-298, *Control of Measuring and Test Equipment and Nondata Test Equipment*, Fluor Daniel Hanford, Inc., Richland, Washington.

HNF-PRO-490, *Nonconforming Item Reporting and Control*, Fluor Daniel Hanford, Inc., Richland, Washington.

Lambert, S. L., and D. W. Hendrickson, 1997, *Preliminary Tank Characterization Report for Single-Shell Tank 241-AX-104: Best Basis Inventory*, HNF-SD-WM-ER-675, Rev. 0, prepared by SGN Eurisys Services Corporation for Fluor Daniel Hanford, Inc., Richland, Washington.

NuPac, 1987, *Application for NRC Certificate of Compliance Authorizing Shipment of Nuclear Materials in NuPac Model N-55 Packaging*, Nuclear Packaging Inc., Federal Way, Washington.

RL, 1993, *Hanford Site Hoisting and Rigging Manual*, DOE/RL-92-36, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Van Keuren, J. C., 1996, *Tank Waste Compositions and Atmospheric Dispersion Coefficients for Use in Safety Analysis Consequence Assessments* WHC-SD-WM-SARR-016, Rev. 2, Westinghouse Hanford Company, Richland, Washington.

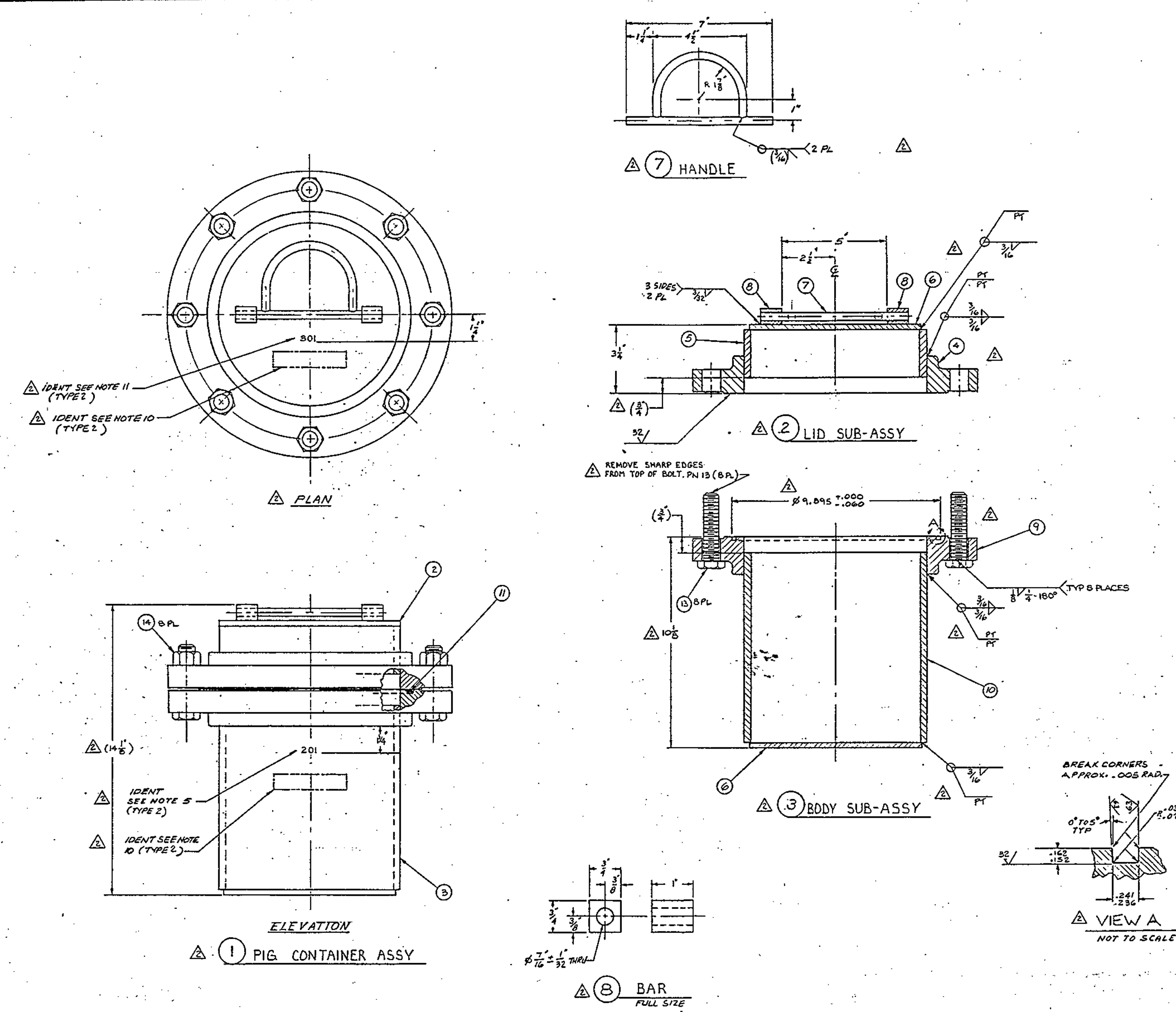
WHC-SD-TP-SARP-002, *Safety Analysis Report for Packaging (Onsite) Onsite Transfer Cask*, Rev. 1-C, Westinghouse Hanford Company, Richland, Washington.

WHC, 1997, *Tank Characterization Report for Double-Shell Tank 241-AZ-102*, WHC-SD-WM-ER-411, Rev. 0-B, Westinghouse Hanford Company, Richland, Washington.

10.0 APPENDIX

10.1 DRAWINGS

This page intentionally left blank.



IMP LVL	QTY			PART NO.	DESCRIPTION	MATERIAL OR REF.
2			X	1	PIG CONTAINER ASSEMBLY	
2		X	1	2	LID SUB-ASSEMBLY	
2	X		1	3	BODY SUB-ASSEMBLY	
3		1		4	FLANGE 8"-150# R.F. SLIP-ON	ASTM A182 F 304L SST
3		1		5	PIPE-8" SCH 40S × 2 1/4 L —SEAMLESS	ASTM A312 GR TP 304L SST
3	1	1		6	PLATE-Ø 8 1/8 × 1/4 THK	ASTM A240 304L SST
3		1		7	HANDLE-ROD-Ø 3/8" × LENGTH AS REQ'D	ASTM A276 304L SST
3		2		8	BAR - 3/4 × 3/4 × 1" L	ASTM A276 304L SST
3	1			9	FLANGE, SLIP-ON, R.F. - 8", 150# (MODIFIED)	ASTM A182 F 304L SST
3	1			10	PIPE-8" SCH 40 × 9 1/8" L —SEAMLESS	ASTM A312 GR TP 304L SST
3			1	11	O-RING 9 1/2 I.D × 9 7/8 O.D × 3/16	PARKER 2-375 40 DURO-NEOPRENE
		~~4~~		~~12~~	~~STRIP 3/4 × 1/8 × 1 1/4 LG~~	~~ASTM A240 304L SST~~
3	8			13	BOLT, HEX HD 3/4-10UNC-2A × 3 1/2" L	ASTM A193 GR B8 304 SST
3			8	14	NUT, HEX - 3/4"-10UNC-2B	ASTM A194 GR 8F 303 SST

GENERAL NOTES

1. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES
2. 125/ FINISH ON WORKED SURFACES.
3. HELIUM LEAK TEST TO A MINIMUM LEAK TIGHTNESS OF $1.96 \times 10^{-7} cm^3/s$ PER ANSI N14.5. LUBRICATE O-RING WITH BIDDLE INSTRUMENTS "APIEZON N" HIGH-VACUUM GREASE PER MANUFACTURER'S INSTRUCTIONS.
4. ~~CERTIFICATIONS OF MATERIAL REQUIRED. (PT'S 4, 5, 6, 9, 10)~~
5. IDENTIFICATION PER HS-BS-0015 TYPE 2 (DIE-STAMPING). START WITH 201 AND NUMBER EACH ADDITIONAL BODY PN 3 IN CONSECUTIVE ORDER WITH (201, 202, 203 ETC.) USE CHARACTER SIZE OF 1/4".
6. BOLTS ARE TO BE SNUG TIGHT (5-10 FT-LBS) SO THAT FLANGES SEAT METAL TO METAL.
7. ~~O-RING IS TO BE LUBRICATED BEFORE EACH USE OF THE CONTAINER.~~
8. ~~WELD AND INSPECT STAINLESS STEEL STRUCTURAL COMPONENTS PER HS-V-SS-0073. VT WELDS AT FINAL PASS AND PT DESIGNATED WELDS AT FINAL PASS. DOCUMENT PER APPROVED INSPECTION PLAN. QUALIFY ASME SECT. IX~~
9. UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ON: DECIMALS, ANGLES ±0° 30′, FRACTIONS ±1/16. ~~DO NOT SCALE PRINT~~
10. IDENTIFY SUB-ASSEMBLIES 2 AND 3 PER HS-BS-0015, TYPE 2 (DIE STAMPING), WITH DRAWING NUMBER PART NUMBER, AND DRAWING REVISION NUMBER IN LOCATIONS INDICATED. USE CHARACTER SIZE OF 1/4".
11. IDENTIFICATION PER HS-BS-0015, TYPE 2. (DIE STAMPING): START WITH 301 AND NUMBER EACH ADDITIONAL LID PN 2 IN CONSECUTIVE ORDER WITH (301, 302, 303 ETC.). USE CHARACTER SIZE OF 1/4".
12. ALL PARTS AND MATERIAL SHALL BE AS SPECIFIED OR COGNIZANT ENGINEER APPROVED EQUAL.

DWG NO.	DRAWING TITLE
H-2-74449	INNER DRUM ASSEMBLY

DRAWING TRACEABILITY LIST

REFERENCE DRAWINGS: H-2-74449 INNER DRUM ASSY

NEXT USED ON H-2-74449

REV. NO.	DESCRIPTION
2	ECN-105873, 105867 REVISION PER
1	INCORPORATED FCN 1082, 50779

COMMENT PRT ISSUE NO. 2-5-24-78 CHECK PRT. ISSUE NO. 4-8-28-78 DRAWING STATUS D.I.-B-0015

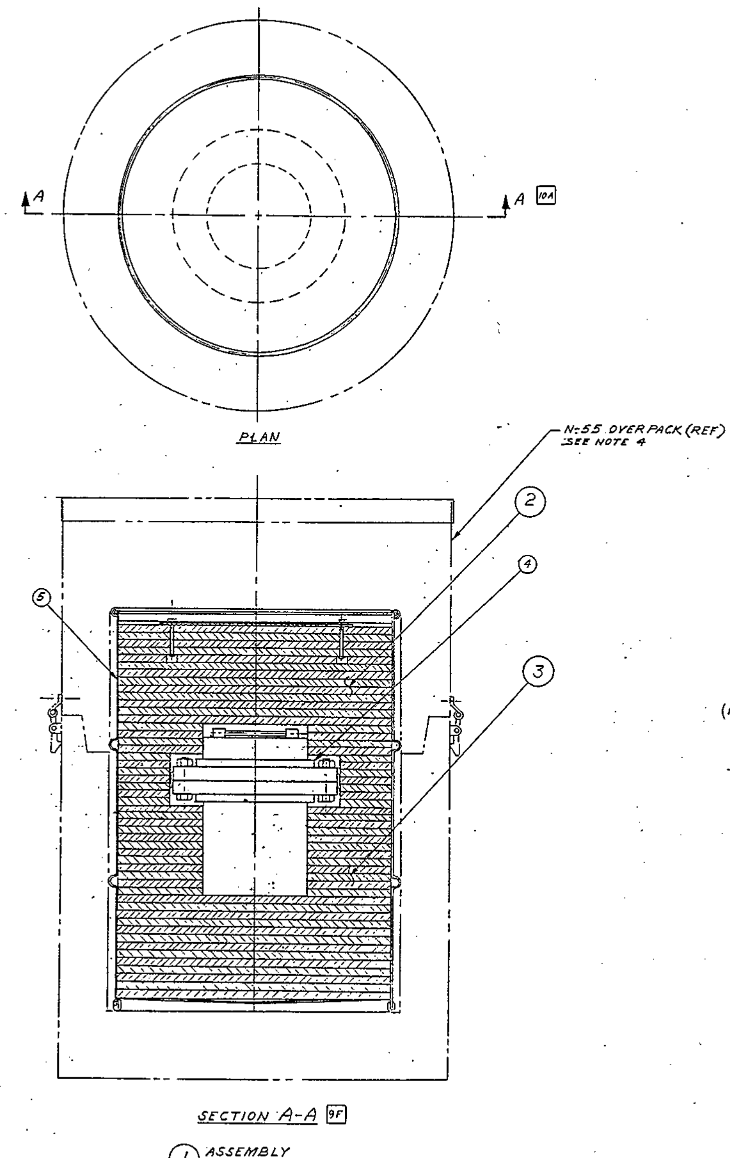
U. S. Department of Energy
Richland Operations Office
Rockwell Hanford Operations
Richland, Washington 99352

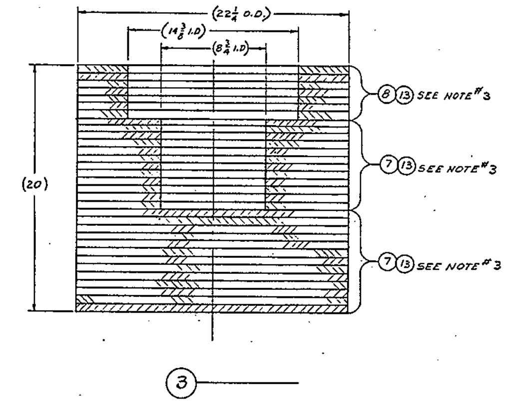
PIG SHIPPING CONTAINER

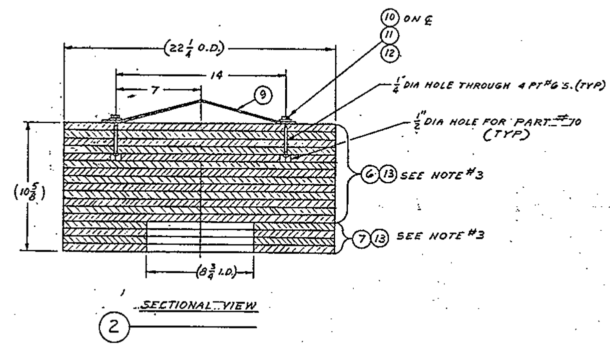
DRAWN F. Janek · J.P. STREHLOW · SCALE 1/2 & SHOWN · BLDG NO. 221-B · INDEX NO. 3902 · CLASSIFICATION NONE · NOT REQ'D · DRAWING NO. H-2-74448 · SHEET 1 OF 1 · LAST REV. 2

A10-3/4

QTY			PART NO	DESCRIPTION	MATL OR REF
		X	1	OVERPACK ASSEMBLY	
	X	1	2	TOP INNER SPACER ASSY	
X		1	3	BOTTOM INNER SPACER ASSY	
		1	4	PIG SHIPPING CONTAINER	H-2-74448
		1	5	55 GAL. DRUM	SEE NOTE 2
13	13		6	22 1/4 DIA × 5/8 THK DISK	JOHNS MANVILLE CEILING TILE; FIRE DIKE #400
12	4		7	22 1/4 O.D. × 8 3/4 I.D. × 5/8 THK RING	
7			8	22 1/4 O.D. × 14 3/8 I.D. × 5/8 THK RING	
	1		9	LUGGAGE STRAP 1" WIDTH × 20" LG	McMASTER-CARR #9588K19
	2		10	CARRIAGE BOLT 1/4-20UNC-2A × 3 1/2 LG	C.STL ASTM-A307GR.A
	2		11	HEX NUT 1/4-20UNC-2B	C.STL ASTM-A307GR.A
	2		12	PLAIN WASHER NOM. SIZE 1/4 - 1" O.D.	C.STL. COM'L
A/R	A/R		13	FLEXIBLE DECK ADHESIVE	B.F. GOODRICH, C4-108







NOTES:-

1. MARK DRUM WITH DRAWING NO., 1" LETTERS 3" DOWN FROM TOP. PAINT ALL NUMBERS WITH AMERCOAT NO. 33 OR APPROVED EQUAL. APPLIED PER MANUFACTURERS RECOMMENDATIONS.
2. CODE OF FEDERAL REGULATIONS TITLE 49 PART 178.118 SPEC 17H STL DRUM.
3. PARTS #6 & 7 IN ASSY #2 AND PARTS #10, 11 & 12 IN ASSY #3 TO BE GLUED TOGETHER USING PART # (13)
4. N-55 OVER-PACK AND TIE DOWN ARE EXISTING AND MOUNTED ON TRANSPORT TRUCK. SEE DRAWING H-2-73010. TO TRANSPORT THE PIG SAMPLER, REPLACE THE DRUM ASSEMBLY INSIDE THE N-55 OVER-PACK SHOWN ON DRAWING H-2-73010 WITH THE DRUM ASSEMBLY SHOWN ON THIS DRAWING.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ON:
DECIMALS — ANGLES ± 30' — FRACTIONS ± 1/16
DO NOT SCALE PRINT

QUALITY ASSURANCE LEVEL II

U.S. Department of Energy
Richland Operations Office
Rockwell Hanford Operations
Richland, Washington 99352

INNER DRUM ASSEMBLY

J.P. STREKLON

SCALE: 1"=1' & SHOWN — 221-B — 3902

NONE — NOT REQ'D — H-2-74449 — 0

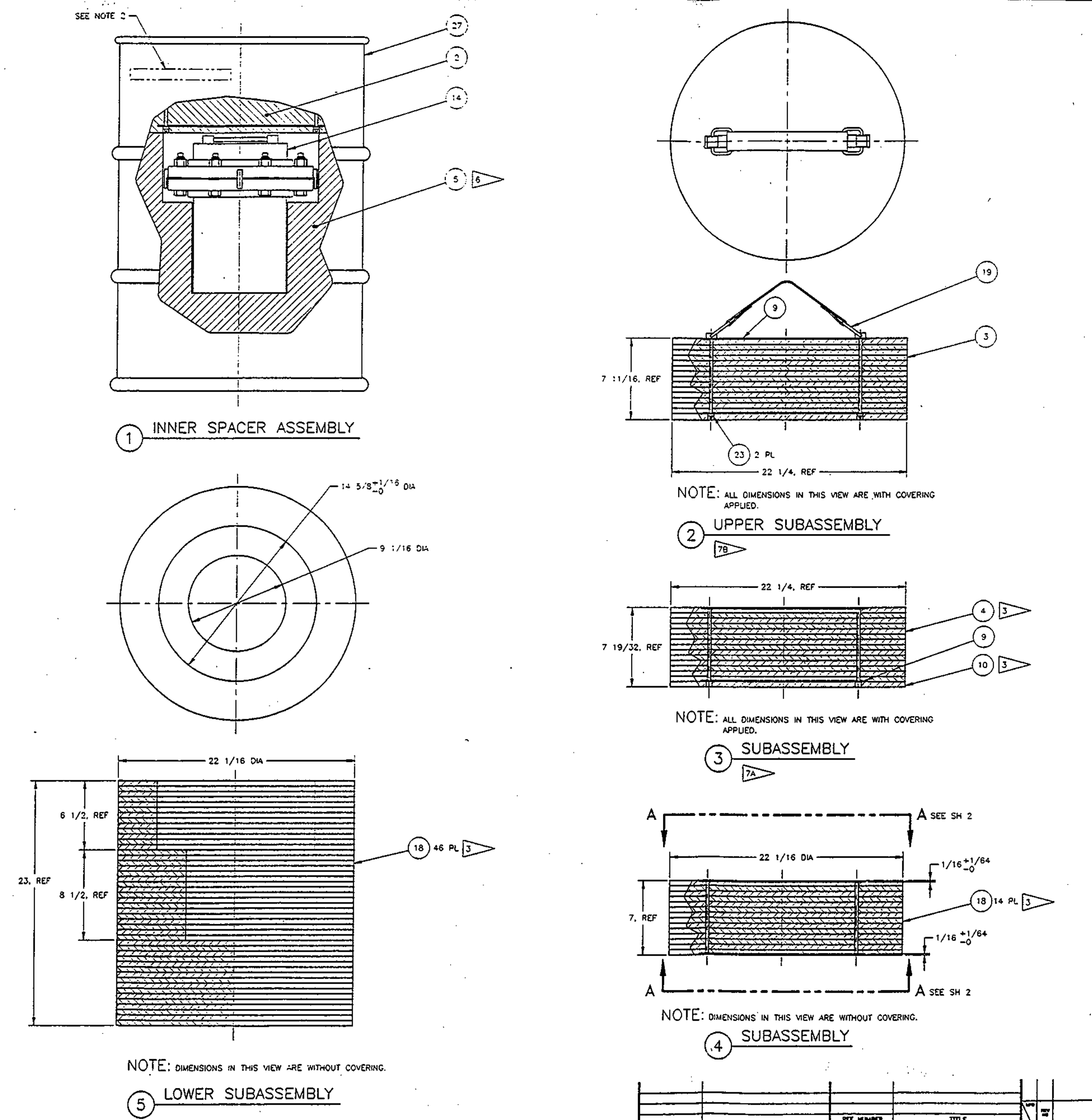
H-2-74448 PIG SHIPPING CONTAINER

REFERENCE DRAWINGS

NEXT USED ON H-2-73010

COMMENT PRT ISSUE NO. 2-5-21-78 — CHECK PRT. ISSUE NO. 5-8-28-78

DRAWING STATUS D.I.-B-0015



PARTS/MATERIAL LIST

QTY REQD -050	-040	-030	-020	-010	PART/DASH NUMBER	NOMENCLATURE/DESCRIPTION	MATERIAL/REFERENCE	SHEET	ITEM NO
				X	-010	ASSEMBLY, INNER SPACER		1	1
			X	1	-020	SUBASSEMBLY, UPPER		1	2
		X	1		-030	SUBASSEMBLY		1	3
	X	1			-040	SUBASSEMBLY		1	4
X				1	-050	SUBASSEMBLY, LOWER		1	5
									6
									7
									8
		1	1		-001	PLATE, SHEET, .063 THK	ASTM B209 6061-T6 AL	2	9
		1			-002	DISK, BOTTOM, BOARD, WOOD FIBER, 1/2 THK MINIMUM DENSITY 17 1/4, LB/FT3	WOOD FIBER IND.	2	10
									11
									12
									13
				1	H-2-824299-1	PIG CONTAINER ASSEMBLY			14
									15
									16
									17
46	14					BOARD, WOOD FIBER, 1/2 THK MINIMUM DENSITY 17 1/4, LB/FT3	WOOD FIBER IND.		18
			1		DC LMC100355-85	SLING	LIFT-IT		19
									20
									21
									22
			2			NUT, HEX 1/4-28 UNF-2B	ASTM A320, GR B8, SST		23
									24
									25
									26
				1		DRUM, 55 GALLON	SEE NOTE 5		27

GENERAL NOTES: (UNLESS OTHERWISE SPECIFIED)

1. DIMENSIONING AND TOLERANCING IN FRACTIONS ARE GENERAL DIMENSIONS. DIMENSIONS ARE IN INCHES. TOLERANCES: FRACTIONAL: ±1/16
2. IDENTIFY ITEM 27 WITH DRAWING NUMBER, PART NUMBER AND REVISION NUMBER PER HS-BS-0015, TYPE 8, WITH 1 INCH HIGH, BLACK CHARACTERS 3 INCHES DOWN FROM TOP.
3. JOIN ITEMS WITH ELMER'S CARPENTER'S WOOD GLUE (ALIPHATIC RESIN) PER MANUFACTURER'S INSTRUCTIONS.
4. EXTERNAL SURFACES SHALL BE SMOOTH, INTERNAL CAVITY SURFACES SHALL BE AS SMOOTH AS PRACTICABLE.
5. CODE OF FEDERAL REGULATIONS TITLE 49 PART 178.118 SPEC 17-H STEEL DRUM.
6. FIBERGLASS COVERING: COVER ALL SURFACES WITH GLASS MAT/POLYESTER RESIN. MAXIMUM THICKNESS 3/32 INCH PER SURFACE. MINIMUM THICKNESS 1/16 INCH PER SURFACE. COLOR WHITE, USING GEL COAT.
7. FIBERGLASS COVERING:
   A. WITH TWO FURNISHED $1/4^{+1/32}_{-0}$ DIA METAL DOWELS INSTALLED. COATED WITH A RELEASE AGENT. COVER ITEM 3 (SUBASSEMBLY), TOP SURFACE AND OUTSIDE DIAMETER, WITH GLASS MAT/ POLYESTER RESIN. MAXIMUM THICKNESS 3/32 INCH PER SURFACE. MINIMUM THICKNESS 1/16 PER SURFACE. COLOR WHITE, USING GEL COAT. CURE AS REQUIRED AFTER COATING AND REMOVE METAL DOWELS.
   B. INSTALL ITEM 19 (SLING). FASTEN WITH ITEM 23 (NUT), 2 PLACES. FILL THE COUNTER BORES (3/4 DIA NOMINAL HOLES) THRU BOTTOM SURFACE WITH RESIN TO HOLD ITEM 23 (NUT), 2 PLACES, IN PLACE. FINISH COVERING ITEM 3 (ASSY) BOTTOM WITH GLASS MAT/POLYESTER RESIN. MAXIMUM THICKNESS 3/32 INCH PER SURFACE. MINIMUM THICKNESS 1/16 INCH PER SURFACE. COLOR WHITE, USING GEL COAT.

OFFICIAL RELEASE BY WHC DATE DEC 15 1994

DWG NO	TITLE	REF NUMBER	TITLE
DRAWING TRACEABILITY LIST		NEXT USED ON	H-2-824299

REVISIONS — CADFILE R824691A — CADCODE DOS-6.0:ACD2:12:SS

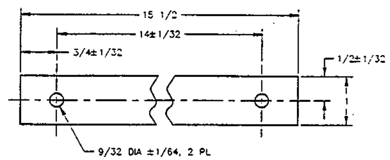
DRAWN HA CHRISTY 12/14/94
RW BARKER 12/14/94

U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
Westinghouse Hanford Company

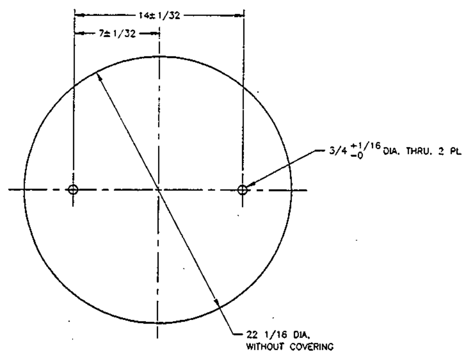
INNER SPACER ASSEMBLY

F 2704HV 3902 H-2-824691 0
SCALE 1/4 — 604907 — SHEET 1 of 2

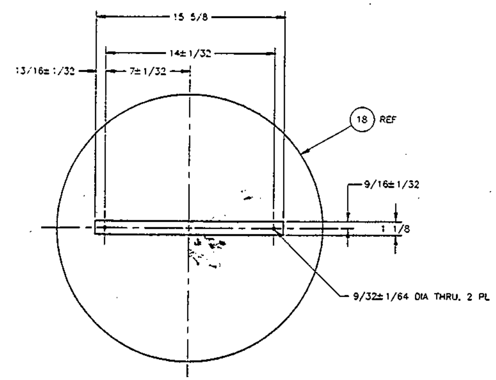
A10-7/8



(9) PLATE
SCALE: 1/1



(10) BOTTOM DISC
SCALE: 1/4



VIEW A–A SEE SH 1
2 PL
SCALE: 1/4

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1

OFFICIAL RELEASE BY WHC
DATE DEC 15 1994

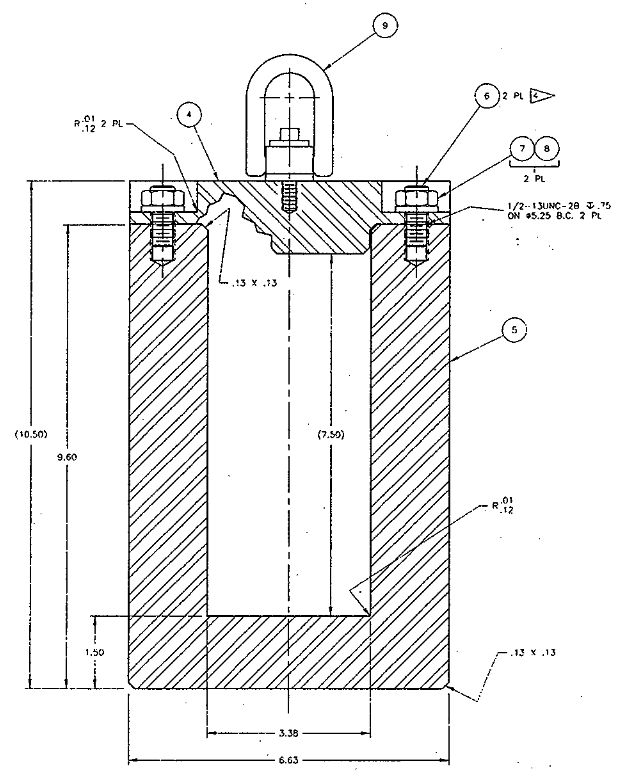
DRAWN WA CHRISTY 12/14/94
RW BARKER 12/14/94

U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
Westinghouse Hanford Company

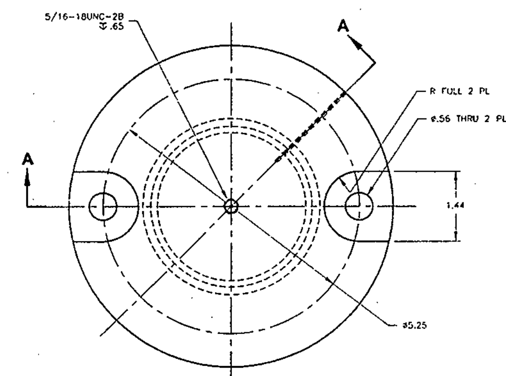
INNER SPACER ASSEMBLY

F 2704HV 3902 H-2-824691 0
SCALE SHOWN SHEET 2

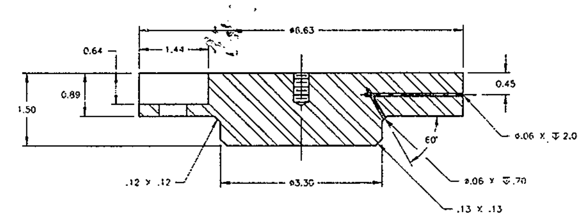
DRAWING TRACEABILITY LIST
NEXT USED ON
REFERENCES
REVISIONS
CADFILE 98246918
CADCODE DOS:6.0:ACD2:12:SS



1 CARRIER ASSEMBLY



4 LID



SECTION A–A

PARTS / MATERIAL LIST

QTY REQD -020	QTY REQD -010	PART/DASH NUMBER	DESCRIPTION	MATERIAL/REFERENCE	SHT	ITEM NO
	X	-010	CARRIER ASSEMBLY		1	1
						2
						3
	1	-001	LID	ASTM A240 OR A276 TYPE 304 SST		4
	1	-002	BODY	ASTM A276 TYPE 304 SST		5
	2	-003	STUD, 1/2-13UNC-2A X 1.5 LG	ASTM A307, GR B		6
	2	-004	NUT, HEX, JAM, 1/2-13UNC-2B	SST ANY GRADE		7
	2	-005	WASHER, LOCK, 1/2 HELICAL SPRING	SST ANY GRADE		8
	1	1016887	HOIST RING 5/16-18UNC-2A X .59 L	CROSBY		9
						10
						11
						12

GENERAL NOTES: (UNLESS OTHERWISE SPECIFIED)

1. ALL DIMENSIONS ARE IN INCHES. DIMENSIONING AND TOLERANCING PER ASME Y14.5M-94. TOLERANCES: FRACTIONAL = ±1/8", ANGULAR = ±1° DECIMAL .X = ±.1, .XX = ±.03, .XXX = ±.005.
2. BREAK ALL SHARP EDGES AND REMOVE ALL BURRS.
3. ALL MACHINED SURFACES SHALL HAVE A 125 RMS OR BETTER FINISH, UNLESS NOTED OTHERWISE. SAND BLAST WITH SILICA MEDIA ON ALL SURFACES AFTER ESTABLISHED SURFACE FINISH (ITEMS 4 & 5 ONLY).

4 TO PREVENT STUDS FROM TURNING, APPLY LOCKTITE® 262 (OR EQUIVALENT) PER MANUFACTURER'S INSTRUCTIONS.

REV NO	DESCRIPTION	REV BY DATE	CHK BY DATE	DPSC APVD DATE	ENGR

REVISIONS

PROPRIETARY
[X] NON-PROPRIETARY

DO NOT SCALE PRINT
DIMENSIONS ARE IN INCHES UNLESS NOTED

WASTE MANAGEMENT FEDERAL SERVICES NORTHWEST OPERATIONS

PROJECT NO. 782028 / 128

CAD FILE ID. EF001A
DTF NO. 01126

THIS DRAWING IS THE PROPERTY OF WASTE MANAGEMENT FEDERAL SERVICES NORTHWEST OPERATIONS. IT IS LOANED UPON THE CONDITION THAT IT IS NOT TO BE REPRODUCED, COPIED OR LOANED TO OTHERS WITHOUT WRITTEN PERMISSION OF WASTE MANAGEMENT FEDERAL SERVICES NORTHWEST OPERATIONS AND IS TO BE RETURNED UPON REQUEST.

DRAWN BY BD FLANAGAN 12/10/98
CHECKED BY RJ SMITH 12/10/98
ENGINEER JC MCCOY 12/11/98

SAMPLE PIG TRANSPORT SYSTEM STEEL SAMPLE CARRIER

SIZE F | DRAWING NUMBER E-F-001 | REV. 0

SCALE 1:1 | WT. N/A | SHEET 1 OF 1

A10-11/12

PART B: PACKAGE EVALUATION

1.0 INTRODUCTION

1.1 SAFETY EVALUATION METHODOLOGY

The safety of the Sample Pig Transport System has been shown, by drop testing and analysis, to meet the intent of Title 10 *Code of Federal Regulations* Part 71 (10 CFR 71), Type B packaging regulations.

1.2 EVALUATION SUMMARY AND CONCLUSIONS

This evaluation compares the packaging's structural, thermal, containment, shielding, and criticality design features with the performance criteria found in the 10 CFR 71 Type B packaging requirements. The criteria for design acceptance of a 10 CFR 71 Type B packaging are met for the Sample Pig Transport System containing either liquid or solid contents.

1.2.1 Contents

The allowable contents of the Sample Pig Transport System are shown in Part B, Section 2.0. Four different payload configurations are authorized as detailed in Part A, Sections 2.0 and 3.0. These configurations are the Light-Duty Utility Arm (LDUA) Sampler, a 0.068 ml sampler conservatively modeled as a 0.125 L sample; the 0.125 L sample in the lead-shielded Sample Pig; samples up to 0.5 L in the steel-shielded Steel Pig; and samples up to 1 L in the Safesend.[1] However, due to the lack of shielding in the Safesend, these samples can only be transported with reduced concentrations of strong gamma- and beta-emitting radionuclides Note, sample sizes smaller that those evaluated may be transported in each configuration without further evaluation. This is provided the same controls are used for the smaller samples.

1.2.2 Radiological Risk

A radiological risk evaluation (Part B, Section 3.0) is not performed for the Sample Pig Transport System because it has been demonstrated to meet the performance requirements of U.S. Department of Transportation (DOT)/ U.S. Nuclear Regulatory Commission (NRC) for Type B packagings.

[1]Safesend is a trademark of the 3M Corporation.

1.2.3 Containment

Containment is provided by the Sample Pig Shipping Container. Additional containment is provided by the 55-gallon (1UN1A2) drum and the N-55 overpack. The containment boundary meets the requirements of American National Standards Institute (ANSI) N14.5 (ANSI 1987) with a leakage rate of less than or equal to 1×10^{-7} std cm^3.

Containment (Part B, Section 4.0) is maintained throughout normal conditions of transport and hypothetical accident conditions as demonstrated by testing and analysis.

1.2.4 Shielding

Shielding is provided by the stainless steel (SS) Sample Pig Shipping Container. Additional shielding is provided by the lead in the Sample Pig, a 1 cm lead sheet in the can used with the LDUA Sampler, or the SS in the Steel Pig, depending on the shipping configuration. However, note that the Safesend has no shielding and cannot be used to transport the full worst-case source concentration of strong gamma and beta emitters in 0.5 L and 1 L volumes.

1.2.5 Criticality

A criticality evaluation (Part B, Section 6.0) is not required for the Sample Pig Transport System since the contents are limited to fissile excepted quantities.

1.2.6 Structural

It was determined through testing and analysis (Part B, Section 7.0) that the Sample Pig Transport System meets 10 CFR 71 Normal Conditions of Transport and Hypothetical Accident Conditions design criteria.

The drop testing performed (WHC 1995) demonstrates minor damage will occur from a 9 m (30 ft) or 1.2 m (4 ft) drop. A conservative evaluation determined that the Sample Pig Transport System could observe a maximum of 188*g*'s during a side drop. This was determined based on the crush of the N-55 overpack from that scenario. The containment of the Sample Pig Shipping Container is not compromised due to this maximum *g*-loading as shown by analysis and leak testing after the drop testing (Part B, Section 7.0). In addition, the increase in dose rate on the surface of the N-55 does not exceed the accident dose rate limit (Part B, Section 5.0).

1.2.7 Thermal

The heat generation rates are 0.626 W for the 0.125 L sample in the Sample Pig or sampler, 0.25 W for the 0.5 L sample in the Steel Pig, and 0.116 W and 0.121 W for the 0.5 L and 1 L samples in the Safesend. This low thermal generation rate from the payload does not impose any significant heat into the thermal calculations. The calculations performed assumed a worst-case 3 W payload and demonstrates both during normal and accident conditions the Sample Pig Transport System is not adversely affected.

1.2.8 Gas Generation

A gas generation study is provided in Part B, Section 9.0. The gas generation rates result in hold times (the maximum time the Sample Pig Shipping Container or Safesend can remain sealed) shown in Table B1-1 below. The shipping windows shown assume that any plastic bags containing the samples are closed with a twist-and-tape method (horsetail) unless a vent is provided.

Table B1-1. Shipping Windows.

Sample configuration	0.125 L Sample Pig	0.125 L Light-Duty Utility Arm	0.5 L Steel Pig	0.5 L Safesend*	1 L Safesend
Void volume (cc)	4972	7409	3709	1903	1400
Total hydrogen generation rate (cc/h)	0.128	0.128	0.516	0.327	0.494
Shipping window (hours [days])	485 (20.5)	723 (30.1)	89 (3.7)	72 (3)	35 (1.46)

*Safesend is a trademark of the 3M Corporation.

1.2.9 Tiedown System

The tiedown system when evaluated against the current 0.5*g* to working load limit meets the requirements of 49 CFR 393 with positive margins of safety. There are no tiedown devices that are a structural part of the package. Therefore, 49 CFR 173 tiedown requirements are not required to be met.

1.3 REFERENCES

10 CFR 71, "Packaging and Transportation of Radioactive Material," *Code of Federal Regulations*, as amended.

49 CFR 173, "Transportation," *Code of Federal Regulations*, as amended.

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

ANSI, 1987, *American National Standard for Radioactive Materials - Leakage Tests on Packages for Shipment*, ANSI N14.5, American National Standards Institute, New York, New York.

NRC, 1987, *Certificate of Compliance for the NuPac Model N-55 Overpack*, COC Number 9070, Docket Number 71-9070, U.S. Nuclear Regulatory Commission, Washington, D.C.

WHC, 1995, *Pig Shipping Container Test Report*, WHC-SD-TP-TR-002, Westinghouse Hanford Company, Richland, Washington.

2.0 CONTENTS EVALUATION

2.1 CHARACTERIZATION

The Sample Pig Transport System is used to transport liquid or solid tank waste that has not been fully characterized. The samples may be shipped in volumes of 0.125 L, 0.5 L, and 1 L. A bounding source term has been developed to minimize the need for reevaluation of the source term when additional tank waste characterization data become available in the future. The following discusses the procedure used to establish the bounding source term.

Table B2-1 shows the highest activity inventory for each radionuclide using the data in Tables B2.7-1 through B2.7-3 for a 0.125 L sample volume. Three data sources were evaluated to establish bounding radionuclide activities for transport in the Sample Pig Transport System. WHC-SD-WM-SARR-016, Rev. 2 (WHC 1996), contains worst-case radionuclide activity concentrations for solid and liquid tank waste, which were developed using all of the tank waste characterization data available at the time. Table B2.7-1 in Part B, Section 2.7, lists the worst-case activity concentrations from WHC (1996) and the radioactive inventory in a 0.125 L sample using the highest activity concentrations from either the solid or liquid tank waste. The second source of data was the Best-Basis Inventory for Tank AZ-102 contained in WHC-SD-WM-ER-411 (WHC 1997). Table B2.7-2 in Part B, Section 2.7, lists the best basis source term for 0.125 L of AZ-102 waste using the characterization data from Appendix E of WHC (1997). The third source of data was the Best-Basis Inventory for Tank AX-104 contained in HNF-SD-WM-ER-675 (Lambert and Hendrickson 1997). Table B2.7-3 in Part B, Section 2.7, lists the best basis source term for 0.125 L of AX-104 waste using the characterization data from Appendix D of Lambert and Hendrickson (1997). Note that all three sources of data are valid for the year 1994.

Table B2-1 also contains the inventory after decaying the highest activity inventory for 4 years from 1994 to 1998 using the ORIGEN-S (WMNW 1998) computer code. The ORIGEN-S input file is attached at Part B, Section 2.7.2. The worst-case inventory decayed 4 years (see Table B2-1) was then used to determine the maximum dose rate on the surface of the Sample Pig Transport System for each packaging configuration. This bounding inventory is used for all the analyses in this safety analysis report for packaging (SARP). Note that isotopes with activities below 1×10^{-9} Ci are not reported.

The following summarizes the assumptions made in the development of the worst-case source term.

1. The density of the sludge is 1.49 g/cm^3 (Table 4-2, WHC [1997]).

2. The AZ-102 sludge volume is assumed to be 329,000 L (Appendix E, WHC [1997]). Approximately 12% of the ^{137}Cs is entrained in the AZ-102 sludge (Table 4-2, WHC [1997]). All other radionuclides are entrained in the sludge.

Table B2-1. Worst-Case Inventories for 0.125 L of Tank Waste. (2 sheets total)

Isotope	0.125 L of worst-case BIO (Ci)	0.125 L of AZ-102 waste (Ci)	0.125 L of AX-104 waste (Ci)	0.125 L of maximum (Ci)*	Source of maximum	0.125 L decayed 4 years (Ci)
^{3}H		5.58 E-03	1.60 E-05	5.58E-03	AZ-102	4.46E-03
^{14}C	7.78 E-07	3.15 E-07	2.98 E-06	2.98E-06	AX-104	2.98E-06
^{59}Ni		4.10 E-06	1.47 E-05	1.47E-05	AX-104	1.47E-05
^{60}Co	1.64 E-03	1.30 E-03	1.64 E-03	1.64E-03	BIO	9.69E-04
^{63}Ni		4.75 E-04	1.48 E-03	1.48E-03	AX-104	1.44E-03
^{79}Se	5.75 E-08	8.68 E-06	1.39 E-05	1.39E-05	AX-104	1.39E-05
^{90}Sr	9.73 E+00	1.41 E+00	7.45 E+00	9.73E+00	BIO	8.82E+00
^{90}Y	9.73 E+00	1.41 E+00	7.45 E+00	9.73 E+00	BIO	8.82 E+00
^{93}Zr		4.23 E-05	6.43 E-05	6.43 E-05	AX-104	6.43 E-05
^{93m}Nb		1.65 E-05	4.80 E-05	4.80 E-05	AX-104	5.06 E-05
^{99}Tc	4.05 E-02	2.28 E-04	2.11 E-05	4.05 E-02	BIO	4.05 E-02
^{106}Ru	2.44 E-07	2.90 E-02	4.73 E-08	2.90 E-02	AZ-102	1.90 E-03
^{106}Rh						1.90 E-03
^{113m}Cd		4.63E -04	2.75 E-04	4.63 E-04	AZ-102	3.80 E-04
^{125}Sb	6.11 E-04	3.53 E-02	1.34 E-03	3.53 E-02	AZ-102	1.28 E-02
^{125m}Te						3.12 E-03
^{126}Sn		1.35 E-05	2.18 E-05	2.18 E-05	AX-104	2.18 E-05
^{126}Sb						3.05 E-06
^{126m}Sb						2.18 E-05
^{129}I	2.16 E-05	5.78 E-07	4.05 E-08	2.16 E-05	BIO	2.16 E-05
^{134}Cs	3.19 E-05	1.57 E-02	9.78 E-07	1.57 E-02	AZ-102	4.09 E-03
^{137}Cs	3.41 E-01	1.97 E-01	1.54 E-01	3.41 E-01	BIO	3.11 E-01
^{137m}Ba	3.23 E-01	1.86 E-01	1.45 E-01	3.23 E-01	BIO	2.94 E-01
^{144}Ce	1.14 E-09			1.14 E-09	BIO	
^{147}Pm	1.22 E-04			1.22 E-04	BIO	4.24 E-05
^{151}Sm		3.05 E-02	5.20 E-02	5.20 E-02	AX-104	5.04 E-02
^{152}Eu		5.40 E-05	1.59 E-05	5.40 E-05	AZ-102	4.39 E-05
^{154}Eu	3.75 E-02	8.78 E-03	8.83 E-03	3.75 E-02	BIO	2.72 E-02
^{155}Eu	1.98 E-04	2.55 E-02	8.43 E-03	2.55 E-02	AZ-102	1.41 E-02
^{226}Ra		3.23 E-11	9.25 E-10	9.25 E-10	AX-104	
^{227}Ac		1.82 E-10		1.82 E-10	AZ-102	
^{228}Ra		2.65 E-15	8.35 E-15	8.35 E-15	AX-104	
^{229}Th		2.58 E-13	1.31 E-12	1.31 E-12	AX-104	
^{231}Pa		6.85 E-10	1.13 E-08	1.13 E-08	AX-104	1.13 E-08
^{231}Th						3.35 E-08
^{232}Th		3.58 E-15	7.55 E-16	3.58 E-15	AZ-102	

Table B2-1. Worst-Case Inventories for 0.125 L of Tank Waste. (2 sheets total)

Isotope	0.125 L of worst-case BIO (Ci)	0.125 L of AZ-102 waste (Ci)	0.125 L of AX-104 waste (Ci)	0.125 L of maximum (Ci)*	Source of maximum	0.125 L decayed 4 years (Ci)
^{234}Th						5.83 E-07
^{233}Pa						3.35 E-03
^{234m}Pa						5.83 E-07
^{232}U		2.78 E-10	1.05 E-12	2.78 E-10	AZ-102	
^{233}U		1.37 E-10	2.47 E-14	1.37 E-10	AZ-102	6.16 E-08
^{234}U		8.50 E-07	1.27 E-08	8.50 E-07	AZ-102	8.57 E-07
^{235}U		3.35 E-08	5.38 E-10	3.35 E-08	AZ-102	3.35 E-08
^{236}U		7.00 E-08	3.53 E-10	7.00 E-08	AZ-102	7.00 E-08
^{237}U						2.54 E-07
^{238}U		5.83 E-07	1.27 E-08	5.83 E-07	AZ-102	5.83 E-07
^{237}NP	3.35 E-03	4.45 E-06	4.48 E-08	3.35 E-03	BIO	3.35 E-03
^{239}Np						1.68 E-06
^{238}Pu	6.32 E-04	6.88 E-05	1.18 E-05	6.32 E-04	BIO	6.12 E-04
^{239}Pu	5.30 E-03	4.75 E-04	1.65 E-03	5.30 E-03	BIO	5.30 E-03
^{240}Pu		1.41 E-04	5.80 E-05	1.41 E-04	BIO	1.40 E-03
^{241}Pu	1.29 E-02	6.50 E-03	8.40 E-04	1.29 E-02	BIO	1.06 E-02
^{242}Pu		1.29 E-08	4.73 E-09	1.29 E-08	AZ-102	1.29 E-08
^{241}Am	3.73 E-02	1.43 E-02	4.80 E-04	3.73 E-02	BIO	3.71 E-02
^{243}Am		1.68 E-06	1.46 E-08	1.68 E-06	AZ-102	1.68 E-06
^{242}Cm	6.72 E-10	4.25 E-06	4.38 E-07	4.25 E-06	AZ-102	8.50 E-09
^{243}Cm		6.73 E-07	3.35 E-08	6.73 E-07	AZ-102	6.11 E-07
^{244}Cm	2.06 E-04	1.49 E-05	1.03 E-06	2.06 E-04	BIO	1.77 E-04

*Note that isotopes with activities below 1×10^{-9} Ci are not reported.
BIO = Basis for Interim Operation (Tank Waste Remediation System) (FDH 1997).
FDH, 1997, *Tank Waste Remediation System Basis for Interim Operation*, HNF-SD-WM-BIO-001, Rev. 0, prepared by DE&S Hanford, Inc., for Fluor Daniel Hanford, Inc., Richland, Washington.

3. Tank AX-104 contains a total of 26,500 L of waste (Appendix D, LMHC [1997]). The activity of each radionuclide was assumed to be homogeneously distributed throughout the total tank waste volume.

4. The sampler volume is 125 mL. The other volumes will be scaled from the 125 mL sample.

5. Beta particles originating in the source do not directly contribute to the dose rate outside the containers because of the shielding provided. The bremsstrahlung radiation produced by beta particles decelerating in the source are accounted for in the shielding evaluation, Part B, Section 5.0.

Table B2-2 contains the calculations used to determine the number of A_2s in the Sample Pig for 0.125 L of the worst-case inventory decayed 4 years. The radioactive inventory contains 12.18 A_2s; therefore, the package contains Type B quantities of radioactive material (Part B, Section 9.0). The payload is not a highway route controlled quantity since the total payload is less than 27,000 Ci or 3,000 A_2s (49 CFR 173.403). The total heat load for the radioactive inventory is 0.0626 W for the 0.125 L sample.

Table B2-2. A_2s for 0.125 L of the Worst-Case Tank Waste Decayed 4 Years. (2 sheets total)

Isotope	Activity		A_2s	Sum of fractional A_2s
	Bq	Ci	Ci	
^{3}H	1.65 E+08	4.46 E-03	1.08 E+03	4.13 E-06
^{14}C	1.07 E+05	2.89 E-06	5.41 E+01	5.34 E-08
^{59}Ni	5.44 E+05	1.47 E-05	1.08 E+03	1.36 E-08
^{60}Co	3.59 E+07	9.69 E-04	1.08 E+01	8.97 E-05
^{63}Ni	5.33 E+07	1.44 E-03	8.11 E+02	1.78 E-06
^{79}Se	5.14 E+05	1.39 E-05	5.41 E+01	2.57 E-07
^{90}Sr	3.29 E+11	8.82 E+00	2.70 E+00	3.49 E+00
^{90}Y*	3.29 E+11	8.82 E+00	0	0
^{93}Zr	2.38 E+06	6.43 E-05	5.41 E+00	1.19 E-05
^{93m}Nb	1.87 E+06	5.06 E-05	1.62 E+02	3.12 E-07
^{99}Tc	1.50 E+09	4.05 E-02	2.43 E+01	1.67 E-03
^{106}Ru	7.03 E+07	1.90 E-03	5.41 E+00	3.51 E-04
^{106}Rh*	7.03 E+07	1.90 E-03	0	0
^{113m}Cd	1.41 E+07	3.80 E-04	2.43 E+00	1.56 E-04
^{125}Sb	4.74 E+08	1.28 E-02	2.43 E+01	5.27 E-04
^{125m}Te	1.15 E+08	3.12 E-03	2.43 E+02	1.28 E-05
^{126}Sn	8.07 E+05	2.18 E-05	8.11 E+00	2.69 E-06
^{126}Sb	1.13 E+05	3.05 E-06	1.08 E+01	2.82 E-07
^{126m}Sb*	8.07 E+05	2.18 E-05	0	0
^{129}I	7.99 E+05	2.16 E-05	Unlimited	0

Table B2-2. A_2s for 0.125 L of the Worst-Case Tank Waste Decayed 4 Years. (2 sheets total)

Isotope	Activity		A_2s	Sum of fractional A_2s
	Bq	Ci	Ci	
^{134}Cs	1.51 E+08	4.09 E-03	1.35 E+01	3.03 E-04
^{137}Cs	1.15 E+10	3.11 E-01	1.35 E+01	2.30 E-02
^{137m}Ba*	1.09 E+10	2.94 E-01	0	0
^{147}Pm	1.57 E+06	4.24 E-05	2.43 E+01	1.74 E-06
^{151}Sm	1.86 E+09	5.04 E-02	1.08 E+02	4.67 E-04
^{152}Eu	1.62 E+06	4.39 E-05	2.43 E+01	1.81 E-06
^{154}Eu	1.01 E+08	2.72 E-02	1.35 E+01	2.01 E-03
^{155}Eu	5.22 E+08	1.41 E-02	5.41 E+01	2.61 E-04
^{231}Pa	4.18 E+02	1.13 E-08	1.62 E-03	6.98 E-06
^{231}Th*	1.24 E+03	3.35 E-08	0	0
^{233}Pa	1.24 E+08	3.35 E-03	2.43 E+01	1.38 E-04
^{234}Pa*	2.80 E+01	7.58 E-10	0	0
^{234m}Pa*	2.16 E+04	5.83 E-07	0	0
^{234}Th	2.16 E+04	5.83 E-07	5.41 E+00	1.08 E-07
^{233}U	2.28 E+03	6.16 E-08	2.70 E-02	2.28 E-06
^{234}U	3.17 E+04	8.57 E-07	2.70 E-02	3.17 E-05
^{235}U	1.31 E+03	3.53 E-08	Unlimited	0
^{236}U	2.59 E+03	7.00 E-08	2.70 E-02	2.59 E-06
^{237}U	9.40 E+03	2.54 E-07	0	0
^{238}U	2.16 E+04	5.83 E-07	Unlimited	0
^{237}NP	1.24 E+08	3.35 E-03	5.41 E-03	6.19 E-01
^{239}Np	6.22 E+04	1.68 E-06	0	0
^{238}Pu	2.26 E+07	6.12 E-04	5.41 E-03	1.13 E-01
^{239}Pu	1.96 E+08	5.30 E-03	5.41 E-03	9.80 E-01
^{240}Pu	5.18 E+07	1.40 E-03	5.41 E-03	2.59 E-01
^{241}Pu	3.92 E+08	1.06 E-02	2.70 E-01	3.93 E-02
^{242}Pu	4.77 E+02	1.29 E-08	5.41 E-03	2.38 E-06
^{241}Am	1.37 E+09	3.71 E-02	5.41 E-03	6.86 E+00
^{243}Am	6.22 E+04	1.68 E-06	5.41 E-03	3.11 E-04
^{242}Cm	3.15 E+02	8.50 E-09	2.70 E-01	3.15 E-08
^{243}Cm	2.26 E+04	6.11 E-07	8.11 E-03	7.53 E-05
^{244}Cm	6.55 E+06	1.77 E-04	1.08 E-02	1.64 E-02
Total	6.83 E+11	1.85 E+01	Sum of A_2s	12.18

*Daughter isotope, no A_2 value.

The source term for each volume is shown in Table B2-3. The source terms for 0.5 L and 1 L sample volumes in the Safesend are limited as shown in Table B2-3 due to shielding considerations (Part B, Section 5.0). The Steel Pig has sufficient shielding to accommodate the full worst-case source term in a 0.5 L sample. Therefore, for the 0.5 L sample, all activities and A_2 fractions are four times those given in Table B2-2. The 0.5 L sample in the Steel Pig and the 0.5 L and 1 L volumes in the Safesend are also Type B and non-highway route controlled quantities of material. The sum of fractional A_2s for the 0.5 L sample in the Steel Pig is 48.72. The sum of fractional A_2 values for the 0.5 and 1 L samples in the Safesend is 41.411 and 76.961, respectively.

Table B2-3. Source Terms for 0.125 L, 0.5 L, and 1 L Volumes of Tank Waste in the Sample Pig Transport System. (2 sheets total)

Isotope	0.125 L in Sample Pig or LDUA decayed 4 years (Ci)	0.5 L in Steel Pig decayed 4 years (Ci)	0.5 L in Safesend decayed 4 years (Ci)	1 L in Safesend decayed 4 years (Ci)
^{3}H	4.46 E-03	1.78 E-02	1.78 E-02	3.57 E-02
^{14}C	2.89 E-06	1.16 E-05	1.16 E-05	2.31 E-05
^{59}Ni	1.47 E-05	5.88 E-05	5.88 E-05	1.18 E-04
$^{60}Co^{b}$	9.69 E-04	3.88 E-03	1.74 E-03	1.71 E-03
^{63}Ni	1.44 E-03	5.76 E-03	5.76 E-03	1.15 E-02
^{79}Se	1.39 E-05	5.56 E-05	5.56 E-05	1.11 E-04
$^{90}Sr^{b}$	8.82 E+00	3.53 E+01	1.59 E+01	1.56 E+01
$^{90}Y^{b}$	8.82 E+00	3.53 E+01	1.59 E+01	1.56 E+01
^{93}Zr	6.43 E-05	2.57 E-04	2.57 E-04	5.14 E-04
^{93m}Nb	5.06 E-05	2.02 E-04	2.02 E-04	4.05 E-04
^{99}Tc	4.05 E-02	1.62 E-01	1.62 E-01	3.24 E-01
$^{106}Ru^{b}$	1.90 E-03	7.60 E-03	3.41 E-03	3.37 E-03
$^{106}Rh^{b}$	1.90 E-03	7.60 E-03	3.41 E-03	3.37 E-03
^{113m}Cd	3.80 E-04	1.52 E-03	1.52 E-03	3.04 E-03
$^{125}Sb^{b}$	1.28 E-02	5.12 E-02	2.30 E-02	2.27 E-02
^{125m}Te	3.12 E-03	1.25 E-02	1.25 E-02	2.50 E-02
^{126}Sn	2.18 E-05	8.72 E-05	8.72 E-05	1.74 E-04
^{126}Sb	3.05 E-06	1.22 E-05	1.22 E-05	2.44 E-05
^{126m}Sb	2.18 E-05	8.72 E-05	8.72 E-05	1.74 E-04
^{129}I	2.16 E-05	8.64 E-05	8.64 E-05	1.73 E-04
$^{134}Cs^{b}$	4.09 E-03	1.64 E-02	7.31 E-03	7.28 E-03
$^{137}Cs^{b}$	3.11 E-01	1.24 E+00	5.56 E-01	5.53 E-01
$^{137m}Ba^{b}$	2.94 E-01	1.18 E+00	5.26 E-01	5.23 E-01
^{147}Pm	4.24 E-05	1.70 E-04	1.70 E-04	3.39 E-04
^{151}Sm	5.04 E-02	2.02 E-01	2.02 E-01	4.03 E-01

Table B2-3. Source Terms for 0.125 L, 0.5 L, and 1 L Volumes of Tank Waste in the Sample Pig Transport System. (2 sheets total)

Isotope	0.125 L in Sample Pig or LDUA decayed 4 years (Ci)	0.5 L in Steel Pig decayed 4 years (Ci)	0.5 L in Safesend decayed 4 years (Ci)	1 L in Safesend decayed 4 years (Ci)
^{152}Eu	4.39 E-05	1.76 E-04	1.76 E-04	3.51 E-04
$^{154}Eu^{b}$	2.72 E-02	1.09 E-01	4.87 E-02	4.84 E-02
^{155}Eu	1.41 E-02	5.64 E-02	5.64 E-02	1.13 E-01
^{231}Pa	1.13 E-08	4.52 E-08	4.52 E-08	9.04 E-08
^{231}Th	3.35 E-08	1.34 E-07	1.34 E-07	2.68 E-07
^{233}Pa	3.35 E-03	1.34 E-02	1.34 E-02	2.68 E-02
^{234m}Pa	5.83 E-07	2.33 E-06	2.33 E-06	4.66 E-06
^{234}Th	5.83 E-07	2.33 E-06	2.33 E-06	4.66 E-06
^{233}U	6.16 E-08	2.46 E-07	2.46 E-07	4.93 E-07
^{234}U	8.57 E-07	3.43 E-06	3.43 E-06	6.86 E-06
^{235}U	3.35 E-08	1.34 E-07	1.34 E-07	2.68 E-07
^{236}U	7.00 E-08	2.80 E-07	2.80 E-07	5.60 E-07
^{237}U	2.54 E-07	1.02 E-06	1.02 E-06	2.03 E-06
^{238}U	5.83 E-07	2.33 E-06	2.33 E-06	4.66 E-06
^{237}Np	3.35 E-03	1.34 E-02	1.34 E-02	2.68 E-02
^{239}Np	1.68 E-06	6.72 E-06	6.72 E-06	1.34 E-05
^{238}Pu	6.12 E-04	2.45 E-03	2.45 E-03	4.90 E-03
^{239}Pu	5.30 E-03	2.12 E-02	2.12 E-02	4.24 E-02
^{240}Pu	1.40 E-04	5.60 E-04	5.60 E-04	1.12 E-03
^{241}Pu	1.06 E-02	4.24 E-02	4.24 E-02	8.48 E-02
^{242}Pu	1.29 E-08	5.16 E-08	5.16 E-08	1.03 E-07
^{241}Am	3.71 E-02	1.48 E-01	1.48 E-01	2.97 E-01
^{243}Am	1.68 E-06	6.72 E-06	6.72 E-06	1.34 E-05
^{242}Cm	8.50 E-09	3.40 E-08	3.40 E-08	6.80 E-08
^{243}Cm	6.11 E-07	2.44 E-06	2.44 E-06	4.89 E-06
^{244}Cm	1.77 E-04	7.08 E-04	7.08 E-04	1.42 E-03

[a]Note that isotopes with activities below 1×10^{-9} Ci are not reported.

[b]These isotopes or their daughters contribute significantly to the dose on the surface of the Safesend package.

2.2 FISSILE MATERIAL CONTENT

Table B2-4 contains the calculations to determine the fissile content of the 0.125 L Sample Pig or LDUA configuration. The activities for the radionuclides identified as fissile in 49 CFR 173.403 (^{233}U, ^{235}U, ^{238}Pu, ^{239}Pu, and ^{241}Pu) are included along with their specific activities from 49 CFR 173.435.

The quantity (g) of each fissile radionuclide is listed in Table B2-4. These values were calculated by dividing the maximum radionuclide activity (Ci) by its specific activity (Ci/g). Table B2-4 shows that the total quantity of fissile material contained in the 0.125 L sample volume is 0.1 g. Since the total quantity of fissile material is less than 15 g, the sample is fissile excepted per 49 CFR 173.453(a), and no further analysis is required to address criticality concerns.

Table B2-4. Sample Pig Transport System Fissile Material Inventory for 0.125 L Sample Volume.

Isotope	Activity		Specific activity Ci/g	Quantity g
	Bq	Ci		
^{233}U	2.28 E+03	6.16 E-08	9.70 E-03	6.35 E-06
^{235}U	1.24 E+03	3.35 E-08	2.20 E-06	1.52 E-02
^{238}Pu	2.26 E+07	6.12 E-04	1.70 E+01	3.60 E-05
^{239}Pu	1.96 E+08	5.30 E-03	6.20 E-02	8.55 E-02
^{241}Pu	3.92 E+08	1.06 E-02	1.00 E+02	1.06 E-04
			Total	1.01 E-01

The 0.5 L (both configurations) and 1 L sample source terms are 4 and 8 times the activity of the 0.125 L sample, except for strong beta and gamma emitters as indicated in Table B2-3 in the Safesend. Therefore, the fissile material quantities in the 0.5 L and 1 L sample volumes are 0.4 g and 0.8 g, respectively, which are also fissile-excepted quantities.

2.3 RESTRICTIONS

The Sample Pig Transport System is limited to the source term shown in Table B2-3 for sample volumes of 0.125 L (LDUA and Sample Pig), 0.5 L (Steel Pig and Safesend), and 1 L. Note that the 0.5 L and 1 L sources in the Safesend are limited by shielding considerations.

The maximum dose rate on the surface of the N-55 overpack is 10 mSv/h (1,000 mrem/h). The radiation dose rate on the package surface may not be exceeded; otherwise, either the samples must be repackaged or additional evaluation will be required. The source term and sample configurations shown in Table B2-3 will result in a dose rate that is at or below this limit. The dose rate limit for the vehicle driver is 0.05 mSv/h (5 mrem/h) if the driver is a qualified Hanford Site radiological worker. If the driver is not a qualified radiological worker, the allowable dose rate is reduced to 0.02 mSv/h (2 mrem/h). The radiation dose rate at the driver's position may not be exceeded; however, supplemental shielding may be used, and repackaging is not required. If the dose rate at the edge of the vehicle or at 2 m from the vehicle is exceeded, as low as reasonably achievable (ALARA) practices will be used to limit the exposure to the public and workers. This may include the use of supplemental shielding.

2.4 SIZE AND WEIGHT

The maximum weight of the Sample Pig Shipping Container contents (sample and container) is 95 kg (209 lb).

2.5 CONCLUSIONS

The worst-case source term has been evaluated as a payload for the Sample Pig Transport System. The results indicate that the worst-case source term may be transported in the 0.125 L shielded Sample Pig or LDUA Sampler and the 0.5 L Steel Pig configurations. The 0.5 and 1 L sample sizes may be shipped in the Safesend, but are limited to the radionuclide inventories shown in Table B2-3. Supplemental shielding may be required to limit the dose rate to the driver and at 2 m from the vehicle if the worst-case source term is transported. Due to gas generation considerations, the maximum time a sample can be sealed is 723 hours in the LDUA, 485 hours in the lead-shielded Sample Pig, 89 hours in the Steel Pig, and 72 hours for the 0.5 L sample and 35 hours for the 1 L sample in the Safesend.

2.6 REFERENCES

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

FDH, 1997, *Tank Waste Remediation System Basis for Interim Operation*, HNF-SD-WM-BIO-001, Rev. 0, prepared by DE&S Hanford, Inc., for Fluor Daniel Hanford, Inc., Richland, Washington.

Lambert, S. L., and D. W. Hendrickson, 1997, *Preliminary Tank Characterization Report for Single-Shell Tank 241-AX-104: Best-Basis Inventory*, HNF-SD-WM-ER-675, Rev. 0, prepared by SGN Eurisys Services Corporation for Fluor Daniel Hanford, Inc., Richland, Washington.

WHC, 1997, *Tank Characterization Report for Double-Shell Tank 241-AZ-102*, WHC-SD-WM-ER-411, Rev. 0-B, Westinghouse Hanford Company, Richland, Washington.

WHC, 1996, *Tank Waste Compositions and Atmospheric Dispersion Coefficients for Use in Safety Analysis Consequence Assessments*, WHC-SD-WM-SARR-016, Rev. 2, Westinghouse Hanford Company, Richland, Washington.

WMNW, 1998, *WMNW Computer Program Verification for SCALE 4.3*, EBU-SQA-001, Rev. 0-A, Waste Management Federal Services, Inc., Northwest Operations, Richland, Washington.

2.7 APPENDICES

2.7.1 Tank Waste Characterization Data Used for Source Term Generation

Table B2.7-1. BIO Worst-Case Activity Concentrations.

Isotope	ALL liquids Bq/L	All solids Bq/L	Max liquids and solids Bq/L	0.125 L inventory Ci
^{14}C	2.30 E+05	1.60 E+05	2.30 E+05	7.78E-07
^{60}Co	9.53 E+06	4.85 E+08	4.85 E+08	1.64E-03
^{79}Se	0.0000	1.70 E+04	1.70 E+04	5.75E-08
^{90}Sr	1.05 E+10	2.88 E+12	2.88 E+12	9.73E+00
^{90}Y	1.05 E+10	2.88 E+12	2.88 E+12	9.73E+00
^{99}Tc	1.70 E+07	1.20 E+10	1.20 E+10	4.05E-02
^{106}Ru	9.93 E+02	7.22 E+04	7.22 E+04	2.44E-07
^{125}Sb	3.42 E+04	1.81 E+08	1.81 E+08	6.13E-04
^{129}I	2.00 E+04	6.40 E+06	6.40 E+06	2.16E-05
^{134}Cs	6.11 E+06	9.44 E+06	9.44 E+06	3.20E-05
^{137}Cs	8.84 E+10	1.01 E+11	1.01 E+11	3.40E-01
^{144}Ce	9.05 E+00	3.37 E+02	3.37 E+02	1.14E-09
^{147}Pm	3.60 E+07	0.0000	3.60 E+07	1.22E-04
^{154}Eu	2.35 E+09	1.11 E+10	1.11 E+10	3.75E-02
^{155}Eu	5.87 E+07	5.01 E+06	5.87 E+07	1.98E-04
^{237}Np	2.30 E+05	9.92 E+08	9.92 E+08	3.35E-03
^{238}Pu	1.78 E+06	1.87 E+08	1.87 E+08	6.33E-04
^{239}Pu	3.62 E+07	1.57 E+09	1.57 E+09	5.30E-03
^{241}Pu	2.57 E+08	3.81 E+09	3.81 E+09	1.29E-02
^{241}Am	4.23 E+07	1.10 E+10	1.10 E+10	3.73E-02
^{242}Cm	1.13 E+01	1.99 E+02	1.99 E+02	6.73E-10
^{244}Cm	4.23 E+05	6.08 E+07	6.08 E+07	2.06E-04

Source: WHC, 1996, *Tank Waste Compositions and Atmospheric Dispersion Coefficients for Use in Safety Analysis Consequence Assessments*, WHC-SD-WM-SARR-016, Rev. 2, Westinghouse Hanford Company, Richland, Washington.

Note: 1 Ci = 3.7×10^{10} Bq.

BIO = Basis for Interim Operation (Tank Waste Remediation System) (FDH 1997).

FDH, 1997, *Tank Waste Remediation System Basis for Interim Operation*, HNF-SD-WM-BIO-001, Rev. 0, prepared by DE&S Hanford, Inc., for Fluor Daniel Hanford, Inc., Richland, Washington.

Table B2.7-2. AZ-102 Best-Basis Inventory (BBI).

Isotope	AZ-102 BBI in tank, Ci	AZ-102 BBI in sludge, Ci*	0.125 L of AZ-102 sludge, Ci**	Isotope	AZ-102 BBI in tank, Ci	AZ-102 BBI in sludge, Ci*	0.125 L of AZ-102 sludge, Ci**
^{3}H	1.47 E+04	1.47 E+04	5.58 E-03	^{226}Ra	8.50 E-05	8.50 E-05	3.23 E-11
^{14}C	8.30 E-01	8.30 E-01	3.15 E-07	^{227}Ac	4.80 E-04	4.80 E-04	1.82 E-10
^{59}Ni	1.08 E+01	1.08 E+01	4.10 E-06	^{228}Ra	7.00 E-09	7.00 E-09	2.65 E-15
^{60}Co	3.42 E+03	3.42 E+03	1.30 E-03	^{229}Th	6.80 E-07	6.80 E-07	2.58 E-13
^{63}Ni	1.25 E+03	1.25 E+03	4.75 E-04	^{231}Pa	1.80 E-03	1.80 E-03	6.85 E-10
^{79}Se	2.28 E+01	2.28 E+01	8.68 E-06	^{232}Th	9.39 E-09	9.39 E-09	3.58 E-15
^{90}Sr	3.70 E+06	3.70 E+06	1.41 E+00	^{232}U	7.30 E-04	7.30 E-04	2.78 E-10
^{90}Y	3.70 E+06	3.70 E+06	1.41 E+00	^{233}U	3.60 E-04	3.60 E-04	1.37 E-10
^{93}Zr	1.11 E+02	1.11 E+02	4.23 E-05	^{234}U	2.24 E+00	2.24 E+00	8.50 E-07
^{93m}Nb	4.33 E+01	4.33 E+01	1.65 E-05	^{235}U	8.83 E-02	8.83 E-02	3.35 E-08
^{99}Tc	5.99 E+02	5.99 E+02	2.28 E-04	^{236}U	1.84 E-01	1.84 E-01	7.00 E-08
^{106}Ru	7.62 E+04	7.62 E+04	2.90 E-02	^{237}Np	1.17 E+01	1.17 E+01	4.45 E-06
^{113m}Cd	1.22 E+03	1.22 E+03	4.63 E-04	^{238}Pu	1.81 E+02	1.81 E+02	6.88 E-05
^{125}Sb	9.27 E+04	9.27 E+04	3.53 E-02	^{238}U	1.53 E+00	1.53 E+00	5.83 E-07
^{126}Sn	3.54 E+01	3.54 E+01	1.35 E-05	^{239}Pu	1.25 E+03	1.25 E+03	4.75 E-04
^{129}I	1.52 E+00	1.52 E+00	5.78 E-07	^{240}Pu	3.72 E+02	3.72 E+02	1.41 E-04
^{134}Cs	4.12 E+04	4.12 E+04	1.57 E-02	^{241}Am	3.77 E+04	3.77 E+04	1.43 E-02
^{137}Cs	4.32 E+06	5.18 E+05	1.97 E-01	^{241}Pu	1.71 E+04	1.71 E+04	6.50 E-03
^{137m}Ba	4.09 E+06	4.90 E+05	1.86 E-01	^{242}Pu	3.40 E-02	3.40 E-02	1.29 E-08
^{151}Sm	8.02 E+04	8.02 E+04	3.05 E-02	^{242}Cm	1.12 E+01	1.12 E+01	4.25 E-06
^{152}Eu	1.42 E+02	1.42 E+02	5.40 E-05	^{243}Am	4.42 E+00	4.42 E+00	1.68 E-06
^{154}Eu	2.31 E+04	2.31 E+04	8.78 E-03	^{243}Cm	1.77 E+00	1.77 E+00	6.73 E-07
^{155}Eu	6.69 E+04	6.69 E+04	2.55 E-02	^{244}Cm	3.93 E+01	3.93 E+01	1.49 E-05

Source: WHC, 1997, *Tank Characterization Report for Double-Shell Tank 241-AZ-102*, WHC-SD-WM-ER-411, Rev. 0-B, Westinghouse Hanford Company, Richland, Washington.

Note: 1 Ci = 3.7×10^{10} Bq.

*Tank AZ-102 contains a total of 329,00 L of waste. It is assumed that 12% of the ^{137}Cs activity is contained in the sludge and the remainder is in the supernate.

**The activity of each isotope is determined by dividing the inventory in the sludge by the sludge volume (329,000 L) and then multiplying by 0.125 L.

Table B2.7-3. AX-104 Inventory.

Isotope	AX-104 Best-Basis Inventory in Tank, Ci	0.125 L of AX-104 Waste Ci*	Isotope	AX-104 Best-Basis Inventory in Tank, Ci	0.125 L of AX-104 Waste Ci*
^{3}H	3.38 E+00	1.60 E-05	^{226}Ra	1.96 E-04	9.25 E-10
^{14}C	6.30 E-01	2.89 E-06	^{228}Ra	1.77 E-09	8.35 E-15
^{59}Ni	3.12 E+00	1.47 E-05	^{229}Th	2.77 E-07	1.31 E-12
^{60}Co	3.47 E+02	1.64 E-03	^{231}Pa	2.40 E-03	1.13 E-08
^{63}Ni	3.13 E+02	1.48 E-03	^{232}Th	1.60 E-10	7.55 E-16
^{79}Se	2.95 E+00	1.39 E-05	^{232}U	2.22 E-07	1.05 E-12
^{90}Sr	1.58 E+06	7.45 E+00	^{233}U	5.24 E-09	2.47 E-14
^{90}Y	1.58 E+06	7.45 E+00	^{234}U	2.70 E-03	1.27 E-08
^{93m}Nb	1.02 E+01	4.80 E-05	^{235}U	1.14 E-04	5.38 E-10
^{93}Zr	1.36 E+01	6.43 E-05	^{236}U	7.47 E-05	3.53 E-10
^{99}Tc	4.47 E+00	2.11 E-05	^{237}Np	9.50 E-03	4.48 E-08
^{106}Ru	1.00 E-02	4.73 E-08	^{238}Pu	2.50 E+00	1.18 E-05
^{113m}Cd	5.82 E+01	2.75 E-04	^{238}U	2.70 E-03	1.27 E-08
^{125}Sb	2.83 E+02	1.34 E-03	^{239}Pu	3.50 E+02	1.65 E-03
^{126}Sn	4.61 E+00	2.18 E-05	^{240}Pu	1.23 E+01	5.80 E-05
^{129}I	8.60 E-03	4.05 E-08	^{241}Am	1.02 E+02	4.80 E-04
^{134}Cs	2.07 E-01	9.78 E-07	^{241}Pu	1.78 E+02	8.40 E-04
^{137}Cs	3.26 E+04	1.54 E-01	^{242}Cm	9.29 E-02	4.38 E-07
^{137m}Ba	3.07 E+04	1.45 E-01	^{242}Pu	1.00 E-03	4.73 E-09
^{151}Sm	1.10 E+04	5.20 E-02	^{243}Am	3.10 E-03	1.46 E-08
^{152}Eu	3.36 E+00	1.59 E-05	^{243}Cm	7.10 E-03	3.35 E-08
^{154}Eu	1.87 E+03	8.83 E-03	^{244}Cm	2.19 E-01	1.03 E-06
^{155}Eu	1.79 E+03	8.43 E-03			

Source: LMHC, 1997, Preliminary *Tank Characterization Report for Single-Shell Tank 241-AX-104: Best-Basis Inventory*, HNF-SD-WM-ER-675, Rev. 0, prepared by Lockheed martin Hanford Corporation for Fluor Daniel Hanford, Inc., Richland, Washington.

Note: 1 Ci = 3.7×10^{10} Bq.

*Tank AX-104 contains a total of 26,500 L of waste. The activity of each isotope is determined by dividing the inventory in the sludge by the sludge volume (26,500 L) and then multiplying by 0.125 L.

2.7.2 ORIGEN-S Input File

```
#ORIGENS
0$$ A11 71 E T
DECAY CASE
3$$ 21 1 1 238 A16 4 A33 44 E T
35$$ 0 T
54$$ A8 1 E
56$$ A2 5 A6 1 A10 0 A13 48 A14 5 A15 3 E
57** 0 E T
DOORSTOP
CI
60** .3 1 2 3 4
61** F.000001
65$$
'GRAM-ATOMS GRAMS CURIES WATTS-ALL WATTS-GAMMA
   3Z  1 0 0  1 0 0   3Z   3Z   6Z
   3Z  1 0 0  1 0 0   3Z   3Z   6Z
   3Z  1 0 0  1 0 0   3Z   3Z   6Z
81$$ 2 0 24 1 E
82$$ 0 0 0 0 2
83** 2.E+7    1.4E+7    1.2E+7    1.E+7     8.E+6
 7.5E+6    7.E+6     6.5E+6    6.E+6     5.5E+6
 5.E+6     4.5E+6    4.E+6     3.5E+6    3.E+6
 2.5E+6    2.349999E+6 2.149999E+6 2.E+6    1.799999E+6
 1.659999E+6 1.569999E+6 1.5E+6    1.439999E+6 1.329999E+6
 1.199999E+6 1.E+6     7.999999E+5 6.999999E+5 5.999999E+5
 5.119999E+5 5.099999E+5 4.499999E+5 3.999999E+5 2.999999E+5
 1.999999E+5 1.499999E+5 9.999994E+4 7.499994E+4 6.999994E+4
 6.E+4     4.5E+4    3.E+4     2.E+4     9.999996E+3
84** 2.E+7    1.733299E+7 1.5683E+7  1.455E+7   1.384E+7
 1.284E+7   1.E+7     8.1873E+6  6.434E+6   4.8E+6
 4.304E+6   3.E+6     2.479E+6   2.354E+6   1.85E+6
 1.5E+6    1.4E+6    1.356E+6   1.317E+6   1.25E+6
 1.2E+6    1.1E+6    1.01E+6    9.2E+5    9.E+5
 8.75E+5   8.611E+5   8.2E+5    7.5E+5    6.79E+5
 6.7E+5    6.E+5     5.73E+5    5.5E+5    4.9952E+5
 4.7E+5    4.4E+5    4.2E+5    4.E+5     3.3E+5
 2.7E+5    2.E+5     1.5E+5    1.283E+5   1.E+5
 8.5E+4    8.2E+4    7.5E+4    7.3E+4    6.E+4
 5.2E+4    5.E+4     4.5E+4    3.E+4     2.5E+4
 1.7E+4    1.3E+4    9.5E+3    8.03E+3   6.E+3
 3.9E+3    3.74E+3   3.E+3     2.58E+3   2.29E+3
 2.2E+3    1.8E+3    1.55E+3   1.5E+3    1.15E+3
 9.5E+2    6.83E+2   6.7E+2    5.5E+2    3.05E+2
 2.85E+2   2.4E+2    2.1E+2    2.075E+2   1.925E+2
 1.86E+2   1.22E+2   1.19E+2   1.15E+2   1.08E+2
 1.E+2     9.E+1     8.2E+1    8.E+1     7.6E+1
 7.2E+1    6.75E+1   6.5E+1    6.1E+1    5.9E+1
 5.339999E+1 5.2E+1    5.059999E+1 4.92E+1   4.829999E+1
 4.7E+1    4.52E+1   4.4E+1    4.239999E+1 4.1E+1
 3.959999E+1 3.909999E+1 3.8E+1    3.7E+1    3.55E+1
 3.459999E+1 3.375E+1   3.325E+1   3.175E+1   3.125E+1
 3.E+1     2.75E+1   2.5E+1    2.25E+1   2.1E+1
 2.E+1     1.9E+1    1.85E+1   1.7E+1    1.6E+1
```

```
1.51E+1    1.44E+1    1.375E+1   1.29E+1    1.19E+1
1.15E+1    1.E+1      9.099999E+0 8.099999E+0 7.15E+0
7.E+0      6.75E+0    6.5E+0     6.25E+0    6.E+0
5.4E+0     5.E+0      4.75E+0    4.E+0      3.73E+0
3.5E+0     3.15E+0    3.049999E+0 3.E+0     2.969999E+0
2.87E+0    2.77E+0    2.669999E+0 2.57E+0   2.469999E+0
2.379999E+0 2.299999E+0 2.209999E+0 2.12E+0  2.E+0
1.94E+0    1.86E+0    1.77E+0    1.679999E+0 1.589999E+0
1.5E+0     1.45E+0    1.4E+0     1.349999E+0 1.299999E+0
1.25E+0    1.224999E+0 1.2E+0    1.174999E+0 1.15E+0
1.139999E+0 1.129999E+0 1.12E+0  1.11E+0    1.099999E+0
1.089999E+0 1.08E+0   1.07E+0    1.059999E+0 1.049999E+0
1.04E+0    1.03E+0    1.02E+0    1.009999E+0 1.E+0
9.75E-1    9.5E-1     9.25E-1    9.E-1      8.5E-1
8.E-1      7.5E-1     7.E-1      6.5E-1     6.25E-1
6.E-1      5.5E-1     5.E-1      4.5E-1     4.E-1
3.75E-1    3.5E-1     3.25E-1    3.E-1      2.75E-1
2.5E-1     2.25E-1    2.E-1      1.75E-1    1.5E-1
1.25E-1    9.999996E-2 8.999997E-2 7.999998E-2 6.999999E-2
6.E-2      5.E-2      4.E-2      3.E-2      2.53E-2
9.999998E-3 7.499997E-3 4.999999E-3 3.999997E-3 3.E-3
2.5E-3     2.E-3      1.5E-3     1.2E-3     9.999999E-4
7.499999E-4 4.999998E-4 9.999999E-5 1.E-5
73$$   10030  60140  280590 270600 280630 340790 380900
 390900 400930 410931 430990 441060 481131 511250 501260
 531290 551340 551370 561371 581440 611470 621510 631520
 631540 631550 882260 892270 882280 902290 912310 902320
 922320 922330 922340 922350 922360 922380 932370 942380
 942390 942400 942410 942420 952410 952430 962420 962430
 962440
74**    5.58E-03 2.98E-06 1.47E-05 1.64E-03 1.48E-03 1.39E-5
 9.73    9.73    6.43E-05 4.80E-5 4.05E-02 2.90E-02 4.63E-04
 3.53E-02 2.18E-05 2.16E-05 1.57E-02 3.41E-01 3.23E-01 1.15E-09
 1.22E-04 5.20E-02 5.40E-05 3.75E-02 2.55E-02 9.25E-10 1.82E-10
 8.35E-15 1.31E-12 1.13E-08 3.58E-15 2.78E-10 1.37E-10 8.5E-07
 3.35E-8  7.0E-8   5.83E-07 3.35E-3 6.32E-4  5.30E-3  1.4E-4
 1.29E-2  1.29E-08 3.73E-02 1.68E-06 4.25E-06 6.73E-07 2.06E-04
75$$  3 3 1 1 1 3 3 3 3 3 3 3 3 3 3 3 3 3 3
 3 3 3 3 3 3 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
 2 2 2 2 2 2 2 2 T
DOORSTOP TIMESTEP 5
56$$ 0 0 A10 5 E T
56$$ F0 T
END
```

CHECKLIST FOR CHECKING OF ANALYSIS/CALCULATIONS

Document Number/Revision: HNF-SD-TP-SARP-001

Document Title: Safety Analysis Report for Packaging (Onsite) Sample Pig Transport System

Scope of Review: Contents Evaluation (Section 2.0), Shielding Evaluation (Section 5), Criticality Evaluation (Section 6)

Yes	No	N/A	
[x]	[ ]	[ ]	Problem completely defined.
[x]	[ ]	[ ]	Appropriate analytical method used.
[x]	[ ]	[ ]	Necessary assumptions are appropriate and explicitly stated.
[x]	[ ]	[ ]	Computer codes and data files documented.
[x]	[ ]	[ ]	Data used in calculations explicitly stated in document.
[ ]	[ ]	[x]	Sources of non-standard formula/data are referenced and the correctness of the reference verified.
[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.
[x]	[ ]	[ ]	Code run streams correct and consistent with analysis documentation.
[x]	[ ]	[ ]	Code output consistent with input and with results reported in analysis documentation.
[x]	[ ]	[ ]	Acceptability limits on analytical results applicable and supported. Limits checked against sources.
[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.

I have checked the analysis/calculation and it is complete and accurate to the best of my knowledge.

Engineer/Checker A. V. Savino [signature] Date 8/12/98

NOTE: Any hand calculations, notes or summaries generated as part of this check should be signed, dated, and attached to this checklist. Material should be labeled and recorded so that it is intelligible to a technically qualified third party.

WMNW-PE-006

3.0 RADIOLOGICAL RISK EVALUATION

3.1 INTRODUCTION

A radiological risk evaluation is not required for the Sample Pig Transport System since it is shown to meet the performance standards of the DOT/NRC regulations.

This page intentionally left blank.

4.0 CONTAINMENT EVALUATION

4.1 INTRODUCTION

The Sample Pig Transport System meets the leaktight criteria of ANSI N14.5 (ANSI 1987) and maintains containment of the payload through normal conditions of transport and hypothetical accident conditions. Leakrate calculations were performed per ANSI N14.5 (ANSI 1987) to determine the required leakrates based on the payload. As shown in Part B, Section 4.6.2.1, the allowable leakrate is much greater than leaktight. Therefore, there is a significant amount of conservatism in the design of the Sample Pig Transport System for maintaining containment of the payload.

The Sample Pig Shipping Container utilizes a Viton[2] containment gasket and has been proven by leak testing after the drop, and bolt analyses, that containment will be maintained through all normal and accident conditions of transport.

4.2 CONTAINMENT SOURCE SPECIFICATION

The containment source is based on the worst case, all solid, source term from all waste tanks (Part B, Section 2.0). The Sample Pig Transport System is used for transporting liquid tank samples and therefore, this source term conservatively represents the payload.

4.3 NORMAL TRANSFER CONDITIONS

4.3.1 Conditions to be Evaluated

The conditions to be evaluated for normal conditions include: hot and cold environmental conditions, pressurization, the 1.2 m (4 ft) drop onto an unyielding surface, and vibration normally incident to transport. The 1.2 m (4 ft) drop is enveloped by the 9 m (30 ft) drop and therefore the calculations referred to are the 9 m (30 ft) drop calculations. The evaluations will consider the loading affects on the containment boundary of the Sample Pig Shipping Container from these scenarios.

4.3.2 Containment Acceptance Criteria

Containment is maintained during normal conditions of transport. Therefore, the acceptance criteria is leaktight. The stresses are evaluated and compared with American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section VIII

[2]Viton is a trademark of E. I. du Pont de Nemours and Company.

allowables to demonstrate containment has been maintained per the analysis. After drop testing, the package was also leak tested to a leak rate criteria of 1 x 10^{-7} atm cc/sec, air.

4.3.3 Containment Model

The containment model used for the environmental conditions, pressurization, drop, and bolt vibration consists of the Sample Pig Shipping Container as leaktested and transported. Three drop orientations are evaluated and the worst case *g*-loading is taken to evaluate the bolt prying and non-prying load stresses. The bolt vibration model assumes the Sample Pig Shipping Container is in the N-55 overpack in transport.

4.3.4 Containment Calculations

The drop is performed in three orientations for the 9 m (30 ft) drop (enveloping case) and the results of the worst case *g*-loading on the containment bolts is evaluated (Part B, Section 7.6.1.5. An evaluation was performed to develop this worst case *g*-loading from the actual crush observed after the drop tests (Part B, Section 7.6.1.4). The bolt vibration evaluates the stresses associated with the conservative ANSI N14.23 shock loads (Part B, Section 7.6.1.6).

4.4 ACCIDENT CONDITIONS

4.4.1 Conditions to be Evaluated

The accident condition evaluation reviews hot and cold environmental conditions, pressurization, and the affects to the Sample Pig Shipping System containment boundary from the 9 m (30 ft) drop onto an unyielding surface.

4.4.2 Containment Acceptance Criteria

The allowable leak rate for accident conditions based on the incredible 1000 mL (34 oz) source term is 7.22 x 10^{-2} atm cc/sec, air (Part B, Section 4.7.1). It is demonstrated by testing and analysis that the Sample Pig Shipping Container maintains containment (1.0 x 10^{-7} atm cc/sec, air) subsequent to the 9 m (30 ft) drop.

Bolt stresses are calculated per NUREG/CR-6007 (LLNL 1993) and evaluated per ASME B&PV Code, Section VIII (ASME 1992) allowables to determine if containment is maintained.

4.4.3 Containment Model

The containment model used for the drop and bolt analysis consists of the Sample Pig Shipping Container as leaktested and transported. The Sample Pig Transport System is dropped 9 m (30 ft) in three orientations (side, end, center of gravity over corner) onto a hard, unyielding surface (WHC 1995). The bolt loads experienced by the deceleration are evaluated per NUREG/CR-6007 (LLNL 1993).

4.4.4 Containment Calculations

The drop is performed in three orientations for the 9 m (30 ft) drop (WHC 1995) and the containment bolts are evaluated (Part B, Section 7.6.1.5) to determine the stresses imposed by a 190*g* deceleration loading. The worst case deceleration is 188*g*'s during the side drop. Stresses due to internal pressure are added to this evaluation for a combined stress case.

As demonstrated by leak testing the Sample Pig Shipping Container after the 9 m (30 ft) drop, containment is maintained. The leak rate maintained is 1×10^{-7} atm, cc/sec and as demonstrated by the leak rate calculations, only 7.22×10^{-2} is required to be maintained.

The bolt evaluation demonstrates a margin of safety against bolt failure of 1.74 using a *g*-loading of 190*g*'s.

4.5 CONTAINMENT EVALUATIONS AND CONCLUSIONS

The Sample Pig Shipping container has been demonstrated both by 9 m (30 ft) drop testing, closure bolt analysis, and closure bolt vibration analysis to maintain containment during normal and accident conditions.

A N-55 overpack loaded with a Sample Pig Shipping Container was drop tested 9 m (30 ft) onto an unyielding surface. Leak testing subsequent to several drop tests demonstrated the Sample Pig Shipping Container maintained containment ($< 1 \times 10^{-7}$ cc/sec). Additional confirmatory analyses were performed by conservatively determining the *g*-loading receive during the actual testing by the amount of crush measured (Part B, Section 7.6.1.4). This *g*-loading was then used to analyze the closure bolts per NUREG/CR-6007 (LLNL 1993). Positive margins of safety in reference to ASME, Section VIII (ASME 1992) shear and tension allowable demonstrate that the closure bolts will maintain containment during the 9 m (30 ft) drop. Normal vibration loads per ANSI N14.23 also were evaluated and positive margins of safety against fatigue (9.5), peak shock (1), and shear (8.3), demonstrate containment is also maintained through vibration loadings normally incident to transport.

4.5.1 Environmental Conditions

The Sample Pig Shipping Container closure lid (containment vessel) consists of an 8 in. SS pipe flange with a Parker 45-Durometer Neoprene[3] O-ring. The Neoprene material temperature range is -54 °C (-65 °F) to 149 °C (300 °F) The SS material easily meets the requirements of -40 °C (-40 °F) to 37.77 °C (100 °F) and the Hanford Site conditions -32.77 °C (-27 °F) to 46.11 °C (115 °F).

4.6 REFERENCES

10 CFR 71, 1988, "Packaging and Transportation of Radioactive Material," *Code of Federal Regulations*, as amended.

49 CFR 173, 1987, "Transportation," *Code of Federal Regulations*, as amended.

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

ANSI, 1987, *American National Standard for Radioactive Materials - Leakage Tests on Packages for Shipment*, ANSI N14.5, American National Standards Institute, New York, New York.

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

LLNL, 1993, *Stress Analysis of Closure Bolts for Shipping Casks*, NUREG/CR-6007, Lawrence Livermore National Laboratory, Livermore, California, January 1993.

[3]Neoprene is a trademark of E. I. du Pont de Nemours and Company.

4.7 APPENDIX

4.7.1 Leak Rate Analyses

PACTEC
Packaging Technology, Inc.

Document No. AEBOA4-01
Page 1 of 17

Title Leakage Rate Calculations per ANSI N14.5 *Revision* 0 *Date* 8/7/96

Customer Westinghouse Hanford Company (WHC) *Work Order* AEBOA04

Introduction: WHC has requested that PacTec perform leakage rate calculations for the On-Site Transfer Cask (OTC), Sample Pig, and Doorstop (DST) per *American National Standard for Radioactive Materials - Leakage Tests on Packages for Shipment, ANSI N14.5.* The radioactive material which is transported in these packages is both solid and liquid. Table 1.0 provides the isotopic inventory in Curies/liter for each configuration (provided by WHC) to be used in the calculations:

References: (1) On-Site Transfer Cask (OTC) Safety Analysis Report for Packaging, Westinghouse Hanford Co., WHC-TP-SARP-002.

(2) Sample Pig Transport System Safety Analysis Report for Packaging, Westinghouse Hanford Co., WHC-TP-SARP-001

Revision	Preparer	Reviewer	Program Manager
0	Gary L. Clark [signature] 08/07/96	Steven A. Porter [signature] 8/15/96	[signature] 8/15/96

Packaging Technology, Inc., 4507-D Pacific Highway East, Tacoma WA 98424-2633 ☎(206)922-1450 (206)922-1445

PacTec Calculation Sheet

Title Leakage Rate Calculations per ANSI N14.5 *Revision* 0 *Date* 8/7/96

Table 1.0 Radioisotopic Inventory for Leakage Rate Calculations (Ci/liter)
(Source: Westinghouse Hanford Co.)

Isotope	All Liquid	All Solid	SST Liquid	SST Solid	DST Liquid	DST Solid
C-14	6.2E-06	4.3E-06	2.7E-06	3.2E-06	6.2E-06	4.3E-06
Co-60	2.6E-04	1.3E-02	2.6E-04	1.1E-02	1.9E-04	4.1E-04
Se-79	0.0	4.6E-07	0.0	4.6E-07	0.0	0.0
Sr-90	3.0E-01	7.8E+01	3.0E-01	4.3E+01	1.2E-01	1.4
Y-90	3.0E-01	7.8E+01	3.0E-01	4.3E+01	1.2E-01	1.4
Tc-99	4.6E-04	3.2E-01	4.6E-04	3.2E-01	3.0E-04	1.7E-03
Ru-106	2.7E-08	1.9E-06	2.7E-08	1.9E-06	0.0	0.0
Rh-106*	2.7E-08	1.9E-06	2.7E-08	1.9E-06	0.0	0.0
Sb-125	9.2E-07	4.9E-03	9.2E-07	4.9E-03	0.0	0.0
I-129**	5.4E-07	1.7E-04	2.7E-07	1.7E-04	5.4E-07	5.4E-07
Cs-134	1.6E-04	2.5E-04	3.2E-06	3.8E-05	1.6E-04	2.5E-04
Cs-137	2.4	2.7	5.9E-01	2.7	1.6	1.6
Ba-137m	2.2	2.6	5.6E-01	2.6	1.5	1.5
Ce-144	2.5E-10	9.2E-09	2.5E-10	9.2E-09	0.0	0.0
Pr-144*	2.5E-10	9.2E-09	2.5E-10	9.2E-09	0.0	0.0
Pm-147	9.7E-04	0.0	0.0	0.0	9.7E-04	0.0
Eu-154	6.5E-02	3.0E-01	6.5E-02	1.6E-01	1.1E-03	8.1E-03
Eu-155	1.6E-03	1.4E-04	1.6E-03	1.4E-04	0.0	0.0
Np-237	6.2E-06	2.7E-02	0.0	8.1E-04	6.2E-06	2.2E-05
Pu-238	4.9E-05	5.1E-03	2.5E-06	5.1E-03	4.9E-05	1.9E-03
Pu-239	9.7E-04	4.3E-02	9.7E-04	1.2E-02	2.1E-04	4.3E-02
Pu-240	9.7E-04	4.3E-02	9.7E-04	1.2E-02	2.1E-04	4.3E-02
Pu-241	7.0E-03	1.0E-01	7.0E-03	8.6E-02	4.9E-04	1.0E-01
Am-241	1.1E-03	3.0E-01	1.1E-03	6.2E-03	9.2E-04	7.3E-02
Cm-242	3.0E-10	5.4E-09	0.0	0.0	3.0E-10	0.0
Cm-244	1.1E-05	1.6E-03	1.1E-05	6.2E-05	3.2E-06	4.3E-04
Totals	5.3	160	1.8	92	3.4	6.2

* No A_2 values are specified for these isotopes in 10 CFR 71 and therefore, will be ignored.
** The A_2 value is unlimited for I-129; therefore, a value of 1.0×10^8 will be assumed.

The allowable leakage rates for both the normal and hypothetical accident conditions of transport are specified in 10 CFR §71.51, *Additional requirements for Type B packages.* These leakage rates are as follows:

Normal Condition of Transport (NCT) Allowable: $R_N = 2.778 \times 10^{-10} (A_2)$, *Ci/sec*

Hypothetical Accident Condition (HAC) Allowable: $R_A = 1.653 \times 10^{-6} (A_2)$, *Ci/sec*

Since all of the package configurations to be evaluated involve a mixture of isotopes, the value of A_2 must be computed in accordance with Appendix A of 10 CFR 71 for each configuration.

PacTec Calculation Sheet Page 10 of 17

Title Leakage Rate Calculations per ANSI N14.5 *Revision* 0 *Date* 8/7/96

Sample Pig All Liquid

The Sample Pig is assumed to be better than leaktight for all normal conditions. For HAC, the total waste volume of 1,000 ml is assumed to have the potential to leak. Therefore, the total Curies for each isotope for the Sample Pig is equal to the All Liquid case listed in Table 1.0, and are listed in Table 4.0.

Table 4.0 Sample Pig All Liquid Case

Isotope	Total Curies	HAC Releasable Curies	*f(i)*	A_2 (Ci)	*f(i)/A_2*
C-14	6.20E-06	6.40E-06	1.18E-06	54.1	2.17E-08
Co-60	2.60E-04	2.60E-04	4.93E-05	10.8	4.57E-06
Sr-90	3.00E-01	3.00E-01	5.69E-02	2.7	2.11E-02
Y-90	3.00E-01	3.00E-01	5.69E-02	5.41	1.05E-02
Tc-99	4.60E-04	4.60E-04	8.73E-05	24.3	3.59E-06
Ru-106	2.70E-08	2.70E-08	5.12E-09	5.41	9.47E-10
Sb-125	9.20E-07	9.20E-07	1.75E-07	24.3	7.18E-09
I-129	5.40E-07	5.40E-07	1.02E-07	1.00E+08	1.02E-15
Cs-134	1.60E-04	1.60E-04	3.04E-05	13.5	2.25E-06
Cs-137	2.40E+00	2.40E+00	4.55E-01	13.5	3.37E-02
Ba-137m	2.20E+00	2.20E+00	4.17E-01	24.3	1.72E-02
Ce-144	2.50E-10	2.50E-10	4.74E-11	5.41	8.77E-12
Pm-147	9.70E-04	9.70E-04	1.84E-04	24.3	7.57E-06
Eu-154	6.50E-02	6.50E-02	1.23E-02	13.5	9.13E-04
Eu-155	1.60E-03	1.60E-03	3.04E-04	54.1	5.61E-06
Np-237	6.20E-06	6.20E-06	1.18E-06	5.41E-03	2.17E-04
Pu-238	4.90E-05	4.90E-05	9.30E-06	5.41E-03	1.72E-03
Pu-239	9.70E-04	9.70E-04	1.84E-04	5.41E-03	3.40E-02
Pu-240	9.70E-04	9.70E-04	1.84E-04	5.41E-03	3.40E-02
Pu-241	7.00E-05	7.00E-05	1.33E-05	0.27	4.92E-05
Am-241	1.10E-03	1.10E-03	2.09E-04	5.41E-03	3.86E-02
Cm-242	3.00E-10	3.00E-10	5.69E-11	0.27	2.11E-10
Cm-244	1.10E-05	1.10E-05	2.09E-06	1.08E-02	1.93E-04
Totals	5.27E+00	5.27E+00	-	-	5.20E+00

The total Curie content for the Sample Pig All Liquid case is equal to the sum of each isotope or 5.27 Ci. The resultant A_2 value for the mixture is 5.20 Ci. For HAC, all of the liquid content is releasable (5.27 Ci). Solving for the same values as for the Sample Pig All Liquid case (HAC only):

$$R_A = 8.58 \times 10^{-6}\ Ci/sec$$

Packaging Technology, Inc., 4507-D Pacific Highway East, Tacoma WA 98424-2633 ☎(206)922-1450 (206)922-1445

$$C_A = 5.20 \times 10^{-3}\ Ci/ml$$

$$L_A = 1.65 \times 10^{-3}\ ml/sec,\ water$$

Per §7.6.5.4.3 of WHC-SD-TP-SARP-001 (Sample Pig SARP), this leakage rate is for the mixture at a temperature of 220 °F (378 °K) and a pressure of 19.9 psia (1.357 atm abs). For testing purposes, this liquid leakage rate needs to be converted to an equivalent air leakage rate. Converting liquid leakage rate to an equivalent air leakage rate is accomplished per Appendix B of ANSI N14.5. Having a known leakage rate, a leakage hole diameter "D" is computed using Equations B14 and B3 of ANSI N14.5.

The Sample Pig is fitted with a Parker O-ring #2-375 which has a cross-sectional diameter of 0.275 in. (0.6985 cm). The leakpath length "a" will be assumed to be this diameter. Since the temperature is above the boiling point for water at atmospheric pressure (212 °F), the viscosity for water at 212 °F will be used, i.e., $\mu_{212\,°F}$ = 0.284 cP. The equivalent hole diameter is computed from the following:

$$L = F_C\,(P_u - P_d) \qquad \text{(Eq. B14)}$$

$$F_c = 2.49 \times 10^{6}\,(D^4)/(a\,\mu) \qquad \text{(Eq. B3)}$$

where; L = 1.65×10^{-3} cc/sec

P_u = 1.357 atm abs

P_d = 1.00 atm abs

Solving these equations results in the equivalent diameter D of 4.4×10^{-3} cm. Since the pressure ratio ($[1.357]^{-1}$ = 0.737) is greater than the critical pressure ratio for air (0.528), the flow will be unchoked. To convert to air leakage for this diameter, the correct expressions for unchoked flow are Equations B2, B3, and B4 of ANSI N14.5:

$$L = (F_c + F_M)(P_u - P_d) \qquad \text{(Eq. B2)}$$

$$F_c = 2.49 \times 10^{6}\,(D^4)\,/\,(a\,\mu) \qquad \text{(Eq. B3)}$$

$$F_M = 3.81 \times 10^{3}\,(D)^3\,(T/M)^{1/2}\,/\,(a\,P_a) \qquad \text{(Eq. B4)}$$

where; P_u = 1.357 atm abs

P_a = 1.00 atm abs

M_{air} = 29

T = 378 °K (220 °F)

PacTec Calculation Sheet

Title Leakage Rate Calculations per ANSI N14.5 *Revision* 0 *Date* 8/7/96

$$\mu_{air} = 0.022 \text{ cP}$$

$$a = 0.6985 \text{ cm}$$

$$D = 4.4 \times 10^{-3} \text{ cm}$$

Solving Equation B2, the calculated maximum HAC leakage rate, L_A, is 0.0224 cc/sec, air at a temperature of 220 °F and a pressure of 19.9 psia. Solving the same equations at STP conditions (77 °F/298 °K, μ_{air} = 0.0181 cP, ΔP = 1 atm, and assuming unchoked flow), the maximum permissible leakage rate will be 0.0737 cc/sec, air. As with the OTC cases, the leakage rate for testing the Sample Pig All Liquid configuration must be less than this value. Therefore, the recommended leakage rate is:

$$L_{Pig-liquid} = 1.0 \times 10^{-2} \text{ cc/sec, air } (2.3 \times 10^{-2} \text{ cc/sec, helium})$$

PacTec Calculation Sheet

Title Leakage Rate Calculations per ANSI N14.5 *Revision* 0 *Date* 8/7/96

Sample Pig All Solid

The Sample Pig is assumed to be better than leaktight for all normal conditions. For HAC, the total waste volume of 1,000 cc is assumed to have the potential to leak. Therefore, the total Curies for each isotope for the Sample Pig is equal to the All Solid case listed in Table 1.0, and are listed in Table 5.0.

Table 5.0 Sample Pig All Solid Case

Isotope	Total Curies	HAC Releasable Curies	*f(i)*	A_2 (Ci)	*f(i)/A₂*
C-14	4.30E-06	4.30E-06	2.65E-08	54.1	4.89E-10
Co-60	1.30E-02	1.30E-02	8.00E-05	10.8	7.41E-06
Se-79	4.60E-07	4.60E-07	2.83E-09	54.1	5.23E-11
Sr-90	7.80E+01	7.80E+01	4.80E-01	2.7	1.78E-01
Y-90	7.80E+01	7.80E+01	4.80E-01	5.41	8.87E-02
Tc-99	3.20E-01	3.20E-01	1.97E-03	24.3	8.11E-05
Ru-106	1.90E-06	1.90E-06	1.17E-08	5.41	2.16E-09
Sb-125	4.90E-03	4.90E-03	3.02E-05	24.3	1.24E-06
I-129	1.70E-04	1.70E-04	1.05E-06	1.00E+08	1.05E-14
Cs-134	2.50E-04	2.50E-04	1.54E-06	13.5	1.14E-07
Cs-137	2.70E+00	2.70E+00	1.66E-02	13.5	1.23E-03
Ba-137m	2.60E+00	2.60E+00	1.60E-02	24.3	6.59E-04
Ce-144	9.20E-09	9.20E-09	5.66E-11	5.41	1.05E-11
Eu-154	3.00E-01	3.00E-01	1.85E-03	13.5	1.37E-04
Eu-155	1.40E-04	1.40E-04	8.62E-07	54.1	1.59E-08
Np-237	2.70E-02	2.70E-02	1.66E-04	5.41E-03	3.07E-02
Pu-238	5.10E-03	5.10E-03	3.14E-05	5.41E-03	5.80E-03
Pu-239	4.30E-02	4.30E-02	2.65E-04	5.41E-03	4.89E-02
Pu-240	4.30E-02	4.30E-02	2.65E-04	5.41E-03	4.89E-02
Pu-241	1.00E-01	1.00E-01	6.16E-04	0.27	2.28E-03
Am-241	3.00E-01	3.00E-01	1.85E-03	5.41E-03	3.41E-01
Cm-242	5.40E-09	5.40E-09	3.32E-11	0.27	1.23E-10
Cm-244	1.60E-03	1.60E-03	9.85E-06	1.08E-02	9.12E-04
Totals	1.62E+02	5.27E+00	-	-	1.34E+00

The total Curie content for the Sample Pig All Solid case is equal to the sum of each isotope or 162.46 Ci. The resultant A_2 value for the mixture is 1.3376 Ci. For HAC, all of the solid content is releasable (162 Ci). Solving for the same values as for the Sample Pig All Liquid case (HAC only) yields:

$$R_A = 2.21 \times 10^{-6}\ Ci/cc$$

Packaging Technology, Inc., 4507-D Pacific Highway East, Tacoma WA 98424-2633 ☎(206)922-1450 (206)922-1445

$$C_A = 1.62 \times 10^{-1}\ Ci/cc$$

$$L_A = 1.36 \times 10^{-5}\ cc/sec,\ air$$

Per §7.6.5.4.3 of WHC-SD-TP-SARP-001 (Sample Pig SARP), this leakage rate is for the mixture at a temperature of 220 °F (378 °K) and a pressure of 19.9 psia (1.357 atm abs). To correlate at standard temperature and pressure (STP), it must be determined whether the flow is choked or unchoked flow. This is accomplished by determining if the pressure ratio is equal to or less than the critical pressure ratio, r_c. which is equal to 0.528 for air. For this case, the pressure ratio is $(1.357)^{-1}$ or 0.74. Since this ratio is greater than 0.528, the flow will be unchoked. Therefore, the correct expressions to be utilized are Equations B2, B3, and B4 of ANSI N14.5 to determine an equivalent hole diameter. With this hole diameter, the leakage rate at STP conditions can be determined.

As before, the leakpath length "a" will be assumed to be the Parker O-ring diameter, 0.6985 cm. The equivalent hole diameter is computed from the following:

$$L = (F_c + F_M)(P_u - P_d) \qquad \text{(Eq. B2)}$$

$$F_c = 2.49 \times 10^6\ (D^4)/(a\ \mu) \qquad \text{(Eq. B3)}$$

$$F_M = 3.81 \times 10^3\ (D)^3\ (T/M)^{1/2} / (a\ P_a) \qquad \text{(Eq. B4)}$$

where; $L = 1.36 \times 10^{-5}$ cc/sec, air

$P_u = 1.357$ atm abs

$P_a = P_d = 1.00$ atm abs

$M_{air} = 29$

T = 378 °K (220 °F)

$\mu_{air} = 0.022$ cP

a = 0.6985 cm

Solving these equations results in the equivalent diameter "D" of 6.68×10^{-4} cm. Solving the same equations with this diameter at STP conditions (77 °F/298 °K, $\mu_{air} = 0.0181$ cP, $\Delta P = 1$ atm, and assuming unchoked flow), the maximum permissible leakage rate will be 4.4×10^{-5} cc/sec, air. As with the OTC cases, the leakage rate for testing the Sample Pig All Solid configuration must be less than this value. Therefore, the recommended leakage rate is:

$$L_{Pig\text{-}solid} = 1.0 \times 10^{-5}\ cc/sec,\ air\ (2.3 \times 10^{-5}\ cc/sec,\ helium)$$

Leakage Rate Calculations per ANSI N14.5

Isotope	Total Curies	HAC Releasable Curies	*f(i)*	A2 (Ci)	*f(i)/A2*
C-14	6.20E-06	6.40E-06	1.18E-06	54.1	2.17E-08
Co-60	2.60E-04	2.60E-04	4.93E-05	10.8	4.57E-06
Sr-90	3.00E-01	3.00E-01	5.69E-02	2.7	2.11E-02
Y-90	3.00E-01	3.00E-01	5.69E-02	5.41	1.05E-02
Tc-99	4.60E-04	4.60E-04	8.73E-05	24.3	3.59E-06
Ru-106	2.70E-08	2.70E-08	5.12E-09	5.41	9.47E-10
Sb-125	9.20E-07	9.20E-07	1.75E-07	24.3	7.18E-09
I-129	5.40E-07	5.40E-07	1.02E-07	1.00E+08	1.02E-15
Cs-134	1.60E-04	1.60E-04	3.04E-05	13.5	2.25E-06
Cs-137	2.40E+00	2.40E+00	4.55E-01	13.5	3.37E-02
Ba-137m	2.20E+00	2.20E+00	4.17E-01	24.3	1.72E-02
Ce-144	2.50E-10	2.50E-10	4.74E-11	5.41	8.77E-12
Pm-147	9.70E-04	9.70E-04	1.84E-04	24.3	7.57E-06
Eu-154	6.50E-02	6.50E-02	1.23E-02	13.5	9.13E-04
Eu-155	1.60E-03	1.60E-03	3.04E-04	54.1	5.61E-06
Np-237	6.20E-06	6.20E-06	1.18E-06	5.41E-03	2.17E-04
Pu-238	4.90E-05	4.90E-05	9.30E-06	5.41E-03	1.72E-03
Pu-239	9.70E-04	9.70E-04	1.84E-04	5.41E-03	3.40E-02
Pu-240	9.70E-04	9.70E-04	1.84E-04	5.41E-03	3.40E-02
Pu-241	7.00E-05	7.00E-05	1.33E-05	0.27	4.92E-05
Am-241	1.10E-03	1.10E-03	2.09E-04	5.41E-03	3.86E-02
Cm-242	3.00E-10	3.00E-10	5.69E-11	0.27	2.11E-10
Cm-244	1.10E-05	1.10E-05	2.09E-06	1.08E-02	1.93E-04

Total Curies 5.27 5.27
A2 = 5.2029 Value for Mixture (Ci)
Release Fraction = NA for normal conditions
Powder Release Percentage: NA
Release Percentage of Total Volume = 100
0.00 Releasable Volume for Normal Conditions (ml)
1000.00 Releasable Volume for Accident Conditions (ml)

<u>ANSI N14.5-1987 Leakage Rate Terms (w/o Temperature/Pressure Correction)</u>

Rn =	1.45E-09	Normal Condition Allowable Release Rate (Ci/sec)
Ra =	8.58E-06	Accident Condition Allowable Release Rate (Ci/sec)
Cn =	0.00E+00	Normal Condition Activity per Volume (Ci/ml)
Ca =	5.20E-03	Accident Condition Activity per Volume (Ci/ml)
Ln =	NA	Normal Condition Maximum Permissible Leakage Rate (ml/sec, water)
La =	1.65E-03	Accident Condition Maximum Permissible Leakage Rate (ml/sec, water)

Leakage Rate Calculations per ANSI N14.5

Isotope	Total Curies	HAC Releasable Curies	*f(i)*	A2 (Ci)	*f(i)/A2*
C-14	4.30E-06	4.30E-06	2.65E-08	54.1	4.89E-10
Co-60	1.30E-02	1.30E-02	8.00E-05	10.8	7.41E-06
Se-79	4.60E-07	4.60E-07	2.83E-09	54.1	5.23E-11
Sr-90	7.80E+01	7.80E+01	4.80E-01	2.7	1.78E-01
Y-90	7.80E+01	7.80E+01	4.80E-01	5.41	8.87E-02
Tc-99	3.20E-01	3.20E-01	1.97E-03	24.3	8.11E-05
Ru-106	1.90E-06	1.90E-06	1.17E-08	5.41	2.16E-09
Sb-125	4.90E-03	4.90E-03	3.02E-05	24.3	1.24E-06
I-129	1.70E-04	1.70E-04	1.05E-06	1.00E+08	1.05E-14
Cs-134	2.50E-04	2.50E-04	1.54E-06	13.5	1.14E-07
Cs-137	2.70E+00	2.70E+00	1.66E-02	13.5	1.23E-03
Ba-137m	2.60E+00	2.60E+00	1.60E-02	24.3	6.59E-04
Ce-144	9.20E-09	9.20E-09	5.66E-11	5.41	1.05E-11
Eu-154	3.00E-01	3.00E-01	1.85E-03	13.5	1.37E-04
Eu-155	1.40E-04	1.40E-04	8.62E-07	54.1	1.59E-08
Np-237	2.70E-02	2.70E-02	1.66E-04	5.41E-03	3.07E-02
Pu-238	5.10E-03	5.10E-03	3.14E-05	5.41E-03	5.80E-03
Pu-239	4.30E-02	4.30E-02	2.65E-04	5.41E-03	4.89E-02
Pu-240	4.30E-02	4.30E-02	2.65E-04	5.41E-03	4.89E-02
Pu-241	1.00E-01	1.00E-01	6.16E-04	0.27	2.28E-03
Am-241	3.00E-01	3.00E-01	1.85E-03	5.41E-03	3.41E-01
Cm-242	5.40E-09	5.40E-09	3.32E-11	0.27	1.23E-10
Cm-244	1.60E-03	1.60E-03	9.85E-06	1.08E-02	9.12E-04

Total Curies 162.46 162.46
A2 = 1.3376 **Value for Mixture (Ci)**
Release Fraction = NA for normal conditions
Powder Release Percentage: NA
Release Percentage of Total Volume = 100
0.00 Releasable Volume for Normal Conditions (cc)
1000.00 Releasable Volume for Accident Conditions (cc)

ANSI N14.5-1987 Leakage Rate Terms (w/o Temperature/Pressure Correction)

Rn =	3.72E-10	Normal Condition Allowable Release Rate (Ci/sec)
Ra =	2.21E-06	Accident Condition Allowable Release Rate (Ci/sec)
Cn =	0.00E+00	Normal Condition Activity per Volume (Ci/cc)
Ca =	1.62E-01	Accident Condition Activity per Volume (Ci/cc)
Ln =	NA	Normal Condition Maximum Permissible Leakage Rate (cc/sec, air)
La =	1.36E-05	Accident Condition Maximum Permissible Leakage Rate (cc/sec, air)

This page intentionally left blank.

5.0 SHIELDING EVALUATION

5.1 INTRODUCTION

This shielding evaluation supports the shipment of tank waste samples in the Sample Pig Shipping Container. The Sample Pig Shipping Container will transport liquid and solid samples taken from the Hanford Site underground storage tanks. The sample sizes that may be shipped are 0.125 L in the Sample Pig or LDUA Sampler, 0.5 L samples in the Steel Pig, and 0.5 L or 1.0 L in the Safesend. The Sample Pig, LDUA Sampler (packed in a metal can), Steel Pig, or the Safesend is loaded into the Sample Pig Shipping Container, which is placed in a 208 L (55-gal) drum. The drum is then placed inside a N-55 overpack. A maximum of two overpacks may be loaded on the truck at any one time.

The dose rate limits for transport are 10 mSv/h (1,000 mrem/h) at the surface of the N-55, 2 mSv/h (200 mrem/h) at the surface of the transport vehicle, 0.1 mSv/h (10 mrem/h) at 2 m from the vehicle surface, and 2 mrem at the driver's position. If the driver is a qualified Hanford Radiological worker, the maximum dose rate at the driver's position is 0.05 mSv/h (5 mrem/h). If the radiation dose rate on the package surface is exceeded, the samples must be repackaged; otherwise, additional evaluation will be required. The radiation dose rate at the driver's position may not be exceeded. Supplemental shielding may be used, and repackaging is not required. If the dose rate at the edge of the vehicle or at 2 m from the vehicle is exceeded, ALARA practices will be used to limit the exposure to the public and workers; this may include the use of supplemental shielding.

The shielding evaluation was conducted using the worst-case source term as shown in Table B2-1 and repeated in the 0.125 L column of Table B5-1. The other entries in Table B5-1 show the source terms for a 0.5 L sample in the Steel Pig or 0.5 L and 1 L samples in the Safesend. Due to the lack of shielding for the 0.5 L and 1.0 L samples packaged in the Safesend, the gamma and strong beta-emitting radionuclides, which contribute to the dose rate outside the package, were iterated to determine the quantity that would produce a surface dose rate of 10 mSv/h (1,000 mrem/h) on the N-55. When in the Steel Pig, the 0.5 L sample can be accommodated with the worst-case source term, without iteration on the strong beta and gamma emitters, because dose rates on the surface of the N-55 are less than 10 mSv/h (1,000 mrem/h).

5.2 DIRECT RADIATION SOURCE SPECIFICATION

5.2.1 Gamma Source

The maximum source term for each sample configuration is shown in Table B5-1. As shown in Part B, Section 5.4, this source term meets the transportation dose rate limits at the surface of the N-55 overpack. Due to the lack of shielding for the 0.5 L and 1.0 L samples when shipped in the Safesend carrier, the source term was iterated to determine the maximum source that could be transported and meet the surface dose rate limit. The evaluation done in Part B, Section 5.4, resulted in the source term shown in Table B5-1. Only the strong gamma- and beta-emitting radionuclides were iterated because only these contribute to the dose rate outside the package. When in the Steel Pig, the 0.5 L sample can be accommodated with the worst-case source term, without iteration on the strong beta and gamma emitters, and meet the surface dose rate limit.

Table B5-1. Source Terms for 0.125 L, 0.5 L, and 1 L Volumes of Tank Waste in the Sample Pig Transport System. (2 sheets total)

Isotope	0.125 L in Sample Pig or LDUA Sampler decayed 4 years (Ci)	0.5 L in Steel Pig decayed 4 years (Ci)	0.5 L in Safesend decayed 4 years (Ci)	1 L in Safesend decayed 4 years (Ci)
^{3}H	4.46 E-03	1.78 E-02	1.78 E-02	3.57 E-02
^{14}C	2.89 E-06	1.16 E-05	1.16 E-05	2.31 E-05
^{59}Ni	1.47 E-05	5.88 E-05	5.88 E-05	1.18 E-04
$^{60}Co^{b}$	9.69 E-04	3.88 E-03	1.74 E-03	1.71 E-03
^{63}Ni	1.44 E-03	5.76 E-03	5.76 E-03	1.15 E-02
^{79}Se	1.39 E-05	5.56 E-05	5.56 E-05	1.11 E-04
$^{90}Sr^{b}$	8.82 E+00	3.53 E+01	1.59 E+01	1.56 E+01
$^{90}Y^{b}$	8.82 E+00	3.53 E+01	1.59 E+01	1.56 E+01
^{93}Zr	6.43 E-05	2.57 E-04	2.57 E-04	5.14 E-04
^{93m}Nb	5.06 E-05	2.02 E-04	2.02 E-04	4.05 E-04
^{99}Tc	4.05 E-02	1.62 E-01	1.62 E-01	3.24 E-01
$^{106}Ru^{b}$	1.90 E-03	7.60 E-03	3.41 E-03	3.37 E-03
$^{106}Rh^{b}$	1.90 E-03	7.60 E-03	3.41 E-03	3.37 E-03
^{113m}Cd	3.80 E-04	1.52 E-03	1.52 E-03	3.04 E-03
$^{125}Sb^{b}$	1.28 E-02	5.12 E-02	2.30 E-02	2.27 E-02
^{125m}Te	3.12 E-03	1.25 E-02	1.25 E-02	2.50 E-02
^{126}Sn	2.18 E-05	8.72 E-05	8.72 E-05	1.74 E-04
^{126}Sb	3.05 E-06	1.22 E-05	1.22 E-05	2.44 E-05
^{126m}Sb	2.18 E-05	8.72 E-05	8.72 E-05	1.74 E-04
^{129}I	2.16 E-05	8.64 E-05	8.64 E-05	1.73 E-04
$^{134}Cs^{b}$	4.09 E-03	1.64 E-02	7.31 E-03	7.28 E-03
$^{137}Cs^{b}$	3.11 E-01	1.24 E+00	5.56 E-01	5.53 E-01
$^{137m}Ba^{b}$	2.94 E-01	1.18 E+00	5.26 E-01	5.23 E-01
^{147}Pm	4.24 E-05	1.70 E-04	1.70 E-04	3.39 E-04
^{151}Sm	5.04 E-02	2.02 E-01	2.02 E-01	4.03 E-01
^{152}Eu	4.39 E-05	1.76 E-04	1.76 E-04	3.51 E-04
$^{154}Eu^{b}$	2.72 E-02	1.09 E-01	4.87 E-02	4.84 E-02
^{155}Eu	1.41 E-02	5.64 E-02	5.64 E-02	1.13 E-01
^{231}Pa	1.13 E-08	4.52 E-08	4.52 E-08	9.04 E-08

Table B5-1. Source Terms for 0.125 L, 0.5 L, and 1 L Volumes of Tank Waste in the Sample Pig Transport System. (2 sheets total)

Isotope	0.125 L in Sample Pig or LDUA decayed 4 years (Ci)	0.5 L in Steel Pig decayed 4 years (Ci)	0.5 L in Safesend decayed 4 years (Ci)	1 L in Safesend decayed 4 years (Ci)
^{231}Th	3.35 E-08	1.34 E-07	1.34 E-07	2.68 E-07
^{233}Pa	3.35 E-03	1.34 E-02	1.34 E-02	2.68 E-02
^{234m}Pa	5.83 E-07	2.33 E-06	2.33 E-06	4.66 E-06
^{234}Th	5.83 E-07	2.33 E-06	2.33 E-06	4.66 E-06
^{233}U	6.16 E-08	2.46 E-07	2.46 E-07	4.93 E-07
^{234}U	8.57 E-07	3.43 E-06	3.43 E-06	6.86 E-06
^{235}U	3.35 E-08	1.34 E-07	1.34 E-07	2.68 E-07
^{236}U	7.00 E-08	2.80 E-07	2.80 E-07	5.60 E-07
^{237}U	2.54 E-07	1.02 E-06	1.02 E-06	2.03 E-06
^{238}U	5.83 E-07	2.33 E-06	2.33 E-06	4.66 E-06
^{237}Np	3.35 E-03	1.34 E-02	1.34 E-02	2.68 E-02
^{239}Np	1.68 E-06	6.72 E-06	6.72 E-06	1.34 E-05
^{238}Pu	6.12 E-04	2.45 E-03	2.45 E-03	4.90 E-03
^{239}Pu	5.30 E-03	2.12 E-02	2.12 E-02	4.24 E-02
^{240}Pu	1.40 E-04	5.60 E-04	5.60 E-04	1.12 E-03
^{241}Pu	1.06 E-02	4.24 E-02	4.24 E-02	8.48 E-02
^{242}Pu	1.29 E-08	5.16 E-08	5.16 E-08	1.03 E-07
^{241}Am	3.71 E-02	1.48 E-01	1.48 E-01	2.97 E-01
^{243}Am	1.68 E-06	6.72 E-06	6.72 E-06	1.34 E-05
^{242}Cm	8.50 E-09	3.40 E-08	3.40 E-08	6.80 E-08
^{243}Cm	6.11 E-07	2.44 E-06	2.44 E-06	4.89 E-06
^{244}Cm	1.77 E-04	7.08 E-04	7.08 E-04	1.42 E-03

[a]Note that isotopes with activities below 1 x 10^{-9} Ci are not reported.

[b]These isotopes or their daughters contribute significantly to the dose on the surface of the Safesend package.

5.2.2 Beta Source

The beta source leads to an insignificant dose rate outside of the overpack because of the shielding provided by the shipping container. This shielding is described in Part B, Section 5.4.3. The bremsstrahlung radiation produced by the deceleration of the beta particles in the source is accounted for in the photon emission rates calculated using the ORIGEN-S computer code (Part B, Section 2.0).

5.2.3 Neutron Source

The neutron dose rate for the 0.125 L sample size was estimated using the methods described in Nelson (1996) and was found to be insignificant compared to the gamma dose rate, even for larger samples. Therefore, the neutron dose rates are not reported.

5.3 SUMMARY OF SHIELDING PROPERTIES OF MATERIALS

The shielding attenuation properties for the bulk materials used in this analysis were obtained from the ISO-PC data library (Rittmann 1995). A description of the configuration and densities of the shielding materials used in the calculational models is given in Part B, Section 5.4.3.

5.4 NORMAL CONDITIONS OF TRANSPORT

5.4.1 Conditions to be Evaluated

Dose rates will be evaluated at the overpack surface, at the vehicle surface, which in this case is the side or back of the truck, and at 2 m (7 ft) from the vehicle surface. Dose rates will also be calculated at 15 cm (6 in.) from the front end of the truck bed, which is the approximate distance to the nearest normally occupied space, i.e., the driver.

5.4.2 Acceptance Criteria

Transportation safety specifies a maximum of 10 mSv/h (1,000 mrem/h) on any surface of the overpack, 2 mSv/h (200 mrem/h) at the vehicle surface, 0.1 mSv/h (10 mrem/h) at 2 m (7 ft) from the vehicle surface, and 0.05 mSv/h (5 mrem/h) in any normally occupied space for radiological workers, or 0.02 mSv/h (2 mrem/h) in any normally occupied space for nonradiological workers.

5.4.3 Shielding Model

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 (ANSI/ANS 1991). Simplified radial and axial models of the Sample Pig Shipping Container were used since ISO-PC limits the number of shields to five, whereas there are greater than five shield layers in both the radial and axial directions.

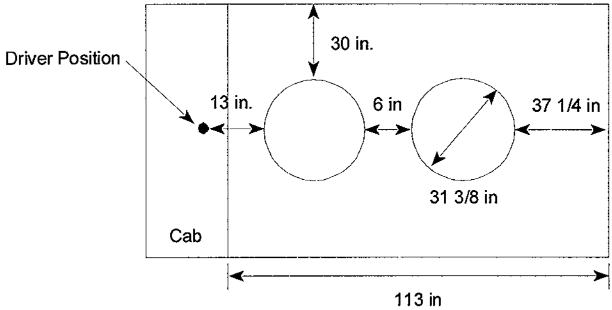
5.4.3.1 0.125 L Sample. Two configurations are modeled, the lead-shielded Sample Pig and the LDUA Sampler.

In the Sample Pig, the 0.125 L sample bottle has an outside diameter (OD) of approximately 5.24 cm (2.06 in.) and a height of 12.5 cm (4.9 in.). The source was modeled as a cylinder with an OD of 5.24 cm (2.06 in.) and a height of 5.8 cm (2.3 in. [which is equivalent to a volume of 0.125 L]). The sample is placed in a lead-lined shielding pig, which is then placed into the Sample Pig Shipping Container, the 208 L (55-gal) drum, and the N-55 overpack.

The 0.125 L LDUA Sampler configuration was modeled as a cylinder with an equal diameter and length of 5.4193 cm (2.1336 in.) such that the volume is 0.125 L (125 cm^3). The sampler is sealed in a plastic bag, placed in a paint can, and surrounded by a 1 cm-thick lead shield. The plastic bag and paint can are ignored in the ISO-PC shielding model, and the source cylinder is directly surrounded by 1 cm of lead. The LDUA Sampler with its 1 cm-thick shield is centered within the 10.136 cm (3.99 in.) inner radius Sample Pig Container. There is an air annulus of thickness 6.4264 cm (2.5301 in.) between the shield wall and the inner wall of the Sample Pig Container. The base of the lead shield surrounding the sample is taken to be 5.27 cm above the bottom of the Sample Pig Container, corresponding to the same thickness of fiber subassembly used when the Safesend is packaged in this container. This results in a more conservative dose rate estimate at the top of the overpack than assuming the lead shield rests on the bottom of the Sample Pig Container.

A maximum of two overpacks containing these 125 mL samples may be loaded on the truck at any one time (see Figure B5-1). The overpacks are vertically oriented on the truck and are spaced apart by 15 cm (6 in.). The distance from the centerline of the overpacks to the side of the truck is 116.8 cm (3 ft, 10 in.), and the distance from the overpack centerline to the back of the truck is 145.8 cm (4 ft, 9.4 in.). Therefore, the vehicle surface will be defined as the side of the truck in this analysis. The maximum dose rate at the side of the truck (vehicle surface) will occur between the front and rear overpacks when two overpacks are loaded on the truck. The distance from an overpack to a person located on the side of the truck at the midpoint between the front and rear overpacks is 125.5 cm (4 ft, 1.4 in.). The ISO-PC dose rate estimate at the side of the truck will account for the dose contributions from both overpacks. The driver is located 33 cm (13 in.) from the overpack that is located on the front end of the truck bed.

Figure B5-1. Simplified Sketch of Shipping Container Transport Vehicle. (Not to Scale)



5.4.3.2 0.5 L Sample in Safesend. The 0.5 L sample was modeled as a cylinder with an OD of 10.3 cm (4.1 in.) and a height of 6.0 cm (2.4 in.). The actual 0.5 L bottle has an OD of 9.1 cm (3.6 in.), but the difference between the model and the actual bottle is negligible. The sample bottle is placed into the Safesend, which is placed in the Sample Pig Shipping Container. The rest of the packaging is the same as described in Part B, Section 5.4.3.1.

5.4.3.3 1 L Sample. The 1 L sample bottle was modeled as a cylinder with an OD of 10.3 cm (4.1 in.) and a height of 12.0 cm (4.7 in.). The sample bottle is placed into the Safesend which is placed in the Sample Pig Shipping Container. The rest of the packaging is the same as described in Part B, Section 5.4.3.1.

5.4.3.4 0.5 L Sample in the Steel Pig. The 0.5 L sample with the worst-case radionuclide mixture (four times the 0.125 L sample content) was modeled as a cylinder with a diameter of 8.57 cm (3.375 in.) and a height of 8.66 cm (3.41 in.). The Steel Pig has an OD of 16.83 cm (6.625 in.). The Steel Pig is placed inside the Sample Pig Shipping Container, and there is a 1.72 cm (0.678-in.) air gap between the outer surface of the carrier and the inner surface of the container. The rest of the packaging is the same as described in Part B, Section 5.4.3.1. To simplify the model and reduce the number of radial zones, the steel wall of the Sample Pig Shipping Container is combined with the Steel Pig wall, and the air gap is combined with the zone occupied by the wood fiber assembly (also modeled as an air zone).

Tables B5-2 through B5-11 summarize the radial and axial ISO-PC models.

Table B5-2. Sample Pig Shipping Container Overpack Radial Geometry and Material Composition for the 0.125 L Worst-Case LDUA Sampler With 1 cm Lead Shield.

Zone (material)	Zone outer radius cm (in.)	Zone thickness cm (in.)	Zone material density (g/cc)	ISO-PC zone thickness (cm)
Source (water)	2.7096 (1.0668)	2.7096 (1.0668)	1.49	2.7096 (1.0668)
Shield (lead)	3.7096 (1.4605)	1.000 (0.3937)	11.34	1.000 (0.3937)
Gap (air)	10.136 (3.99)	6.4264 (2.5301)	1.22E-3	NA[b]
Sample Pig Shipping Container (steel)	10.954 (4.313)	0.818 (0.322)	7.86	NA[a]
Subassembly[c] (wood fiber)	28.575 (11.250)	17.621 (6.937)	1.22 E-3	25.821[b] (10.17)
208 L (55-gal) (steel)	28.706 (11.302)	0.131 (0.052)	7.86	0.949[a] (0.3736)
Gap (air)	30.480 (12.000)	1.774 (0.698)	1.22 E-3	NA[b]
N-55 (polyurethane)	39.745 (15.648)	9.265 (3.648)	0.0481	9.265 (3.648)
N-55 (steel)	39.846 (15.687)	0.101 (0.040)	7.86	0.101 (0.040)

[a]The steel wall thicknesses of 0.818 cm (0.322 in.) and 0.131 cm (0.052 in.) were combined to produce a single 0.949 cm (0.3736-in.) zone of steel.

[b]Since ISO-PC is limited to a total of six zones (one source plus five shield zones), the air gaps 6.4264 cm (2.5301 in.), 17.621 cm (6.937 in.), and 1.774 cm (0.698 in.) were combined to produce a single 25.821 cm (10.17-in.) zone of air (the wood fiber subassembly was modeled as an air gap).

[c]The shielding afforded by the subassembly was ignored. This zone was modeled as air.

LDUA = Light-Duty Utility Arm.

Table B5-3. Sample Pig Shipping Container Overpack Top Axial Geometry and Material Composition for the 0.125 L Worst-Case LDUA Sampler With 1 cm Lead Shield.

Zone (material)	Zone thickness cm (in.)	Zone material density (g/cc)	ISO-PC zone thickness cm (in.)
Source (water)	5.4193 (2.134)	1.49	5.4193 (2.134)
Shield (lead)	1.00 (0.394)	11.34	1.00 (0.394)
Gap (air)	21.601 (8.504)	1.22 E-3	21.601 (8.504)
Sample Pig container lid (steel)	0.635 (0.250)	7.86	0.635 (0.250)
Subassembly[c] (wood fiber)	32.728 (12.885)	1.22E-3	NA[a]
Drum lid (steel)	0.161 (0.063)	7.86	NA[b]
N-55[c] (polyurethane)	17.78 (7.00)	1.22E-3	50.508[a] (19.885)
N-55 lid (steel)	0.101 (0.040)	7.86	0.262[b] (0.103)

[a]The air zones of 32.728 cm (12.885 in.)and 17.78 cm (7.00 in.) were combined to produce a single 50.508 cm (19-885 in.) zone of air.

[b]The steel lid thicknesses of 0.161 cm (0.063 in.) and 0.101 cm (0.040 in.) were combined to produce a single 0.262 cm (0.103-in.) zone of steel.

[c]The shielding afforded by the subassembly and polyurethane was ignored. These zones were modeled as air.

LDUA = Light-Duty Utility Arm.

Table B5-4. Sample Pig Shipping Container Overpack Radial Geometry and Material Composition for the 0.125 L Sample Size in the Sample Pig.

Zone (material)	Zone outer radius, cm (in.)	Zone thickness cm (in.)	Zone material density (g/cc)	ISO-PC zone thickness, cm (in.)
Source (water)	2.619 (1.031)	2.619 (1.031)	1.49	2.619 (1.031)
Sample Pig inner sleeve (steel)	2.858 (1.125)	0.239 (0.094)	7.86	NA[a]
Shield Pig (lead)	7.938 (3.125)	5.080 (2.000)	11.34	5.080 (2.000)
Shield Pig outer layer (steel)	8.414 (3.313)	0.476 (0.187)	7.86	1.664[a] (0.655)
Gap (air)	10.136 (3.991)	1.722 (0.678)	1.22 E-3	21.117[b] (8.314)
Sample Pig Shipping Container (steel)	10.954 (4.313)	0.818 (0.322)	7.86	NA[a]
Subassembly[c] (wood fiber)	28.575 (11.250)	17.621 (6.937)	1.22 E-3	NA[b]
208 L (55-gal) (steel)	28.706 (11.302)	0.131 (0.052)	7.86	NA[a]
Gap (air)	30.480 (12.000)	1.774 (0.698)	1.22 E-3	NA[b]
N-55 (polyurethane)	39.745 (15.648)	9.266 (3.648)	0.0481	9.266 (3.648)
N-55 (steel)	39.846 (15.687)	0.101 (0.040)	7.86	0.101 (0.040)

[a]Since ISO-PC is limited to a total of six zones (one source plus five shield zones), the steel wall thicknesses of 0.239 cm (0.94 in.), 0.476 cm (0.187 in.), 0.818 cm (0.322 in.), and 0.131 cm (0.052 in.) were combined to produce a single 1.664 cm (0.655-in.) zone of steel.

[b]The air gaps (1.722 cm [0.678 in.], 17.621 cm [6.938 in.], and 1.774 cm [0.698]) were combined to produce a single 21.117 cm [8.314-in.] zone of air.

[c]The shielding afforded by the Safesend and the subassembly was ignored. These zones were modeled as air.

Table B5-5. Sample Pig Shipping Container Overpack Top Axial Geometry and Material Composiiton for 0.125 L Sample in the Sample Pig.

Zone (material)	Zone thickness cm (in.)	Zone material density (g/cc)	ISO-PC zone thickness cm (in.)
Source (water)	5.800 (2.283)	1.49	5.800 (2.283)
Bottom of shield Pig cover (steel)	0.318 (0.125)	7.86	1.271[a] (0.500)
Shield Pig (lead)	5.080 (2.000)	11.34	5.080 (2.000)
Top of shield Pig cover (steel)	0.318 (0.125)	7.86	NA[a]
Gap (air)	17.465 (6.876)	1.22 E-3	50.193[b] (19.761)
Sample Pig Shipping Container top (steel)	0.635 (0.250)	7.86	NA[a]
Subassembly[b] (wood fiber)	32.728 (12.885)	1.22 E-3	NA[b]
Drum lid (steel)	0.161 (0.063)	7.86	NA[c]
N-55 (polyurethane)	17.78 (7.00)	0.0481	17.78 (7.00)
N-55 Lid (steel)	0.101 (0.040)	7.86	0.262[c] (0.103)

[a]Since ISO-PC is limited to a total of six zones, the steel layers (0.318 cm [0.125 in.], 0.318 cm [0.125 in.], and 0.635 cm [0.250 in.]) were combined into a single 1.271 cm (0.500-in.) zone of steel.

[b]Since the subassembly was modeled as air, the air zone of 17.465 cm (6.876 in.) the subassembly zone thickness of 32.728 cm (12.885 in.) were combined to produce a single 50.193 cm (19.761-in.) zone of air.

[c]The Pig bottom thickness of 0.635 cm (0.250 in.) was combined with the drum bottom thickness of 0.131 cm (0.052 in.) to produce a single 0.766 cm (0.302-in.) zone of steel.

Table B5-6. Sample Pig Shipping Container Overpack Bottom Axial Geometry and Material Composition for 0.125 L Sample in the Sample Pig

Zone (material)	Zone thickness cm (in.)	Zone material Density (g/cc)	ISO-PC zone Thickness, cm (in.)
Source (water)	5.800 (2.283)	1.49	5.800 (2.283)
Bottom of Inner Sleeve (steel)	0.238 (0.094)	7.86	NA[a]
Shield pig (lead)	4.763 (1.875)	11.34	4.763 (1.875)
Shield Pig bottom (steel)	0.305 (0.120)	7.86	1.178[a] (0.464)
Sample Pig Shipping Container bottom (steel)	0.635 (0.250)	7.86	NA[a]
Subassembly[b] (wood fiber)	20.32 (8.00)	1.22 E-3	20.32 (8.00)
Drum bottom (steel)	0.131 (0.333)	7.86	NA[c]
N-55 (polyurethane)	14.0 (5.5)	0.0481	14.0 (5.5)
N-55 bottom (steel)	0.101 (0.040)	7.86	0.232[c] (0.091)

[a]Since ISO-PC is limited to a total of six zones, the steel layers (0.238 cm [0.094 in.], 0.305 cm [0.120 in.], and 0.635 cm [0.250 in.]) were combined into a single 1.178 cm (0.464-in.) zone of steel.

[b]The shielding afforded by the subassembly was ignored. This zone was modeled as air.

[c]The 208 L (55-gal) drum bottom thickness of 0.131 cm (0.052 in.) was combined with the N-55 bottom thickness of 0.101 cm (0.040 in.) to produce a single 0.232 cm (0.091-in.) zone of steel.

Table B5-7. Sample Pig Shipping Container Overpack Radial Geometry and Material Composition for the 0.5 L Worst-Case Sample in Steel Pig

Zone (material)	Zone outer radius cm (in.)	Zone thickness cm (in.)	Zone material density (g/cc)	ISO-PC zone thickness, cm (in.)
Source (water)	4.2863 (1.6875)	4.2863 (1.6875)	1.49	4.2863 (1.6875)
Steel Pig (steel)	10.136 (3.991)	4.1275 (1.625)	1.22 E-3	4.9445[a] (1.947)
Gap (air)	10.136 (3.99)	1.7222 (0.678)	1.22E-3	NA[b]
Sample Pig Shipping Container (steel)	10.954 (4.313)	0.818 (0.322)	7.86	NA[a]
Subassembly[c] (wood fiber)	28.575 (11.250)	17.621 (6.937)	1.22 E-3	21.12[b] (8.31)
208 L (55-gal) (steel)	28.706 (11.302)	0.131 (0.052)	7.86	0.131 (0.052)
Gap (air)	30.480 (12.000)	1.774 (0.698)	1.22 E-3	NA[b]
N-55 (polyurethane)	39.745 (15.648)	9.266 (3.648)	0.0481	9.266 (3.648)
N-55 (steel)	39.846 (15.687)	0.101 (0.040)	7.86	0.101 (0.040)

[a]The steel wall thicknesses of 4.986 cm (1.963 in.) and 4.1275 cm (1.625 in.) were combined to produce a single 4.9445 cm (1.947 in.) zone of steel.

[b]Since ISO-PC is limited to a total of six zones (one source plus five shield zones), the air gaps 1.7222 cm (0.678 in.), 17.621 cm (6.937 in.), and 1.774 cm (0.698 in.) were combined to produce a single 21.12 cm (8.31-in.) zone of air (the wood fiber subassembly was modeled as an air gap).

[c]The shielding afforded by the subassembly was ignored. This zone was modeled as air.

Table B5-8. Sample Pig Shipping Container Overpack Top Axial Geometry and Material Composition for 0.5 L Worst-Case Sample in Steel Pig

Zone (material)	Zone thickness cm (in.)	Zone material density (g/cc)	ISO-PC zone thickness, cm (in.)
Source (water)	8.66 (2.20)	1.49	8.66 (2.20)
Gap (air)	10.39 (4.09)	1.22 E-3	16.55[d] (6.52)
Steel Pig lid (steel)	3.81 (1.50)	7.86	4.445[a] (1.75)
Gap (air)	6.16 (2.425)	1.22 E-3	NA[d]
Sample Pig Shipping Container top (steel)	0.635 (0.250)	7.86	NA[a]
Subassembly[c] (wood fiber)	32.728 (12.885)	1.22 E-3	32.728 (12.885)
Drum lid (steel)	0.161 (0.063)	7.86	NA[b]
N-55 (polyurethane)	17.78 (7.00)	0.0481	17.78 (7.00)
N-55 lid (steel)	0.101 (0.040)	7.86	0.262[b] (0.103)

[a]The steel lid thicknesses of 3.81 cm (1.50 in.) and 0.635 cm (0.250 in.) were combined to produce a single 4.445 cm (1.75-in.) zone of steel.

[b]The steel lid thicknesses of 0.161 cm (0.063 in.) and 0.101 cm (0.040 in.) were combined to produce a single 0.262 cm (0.103-in.) zone of steel.

[c]The shielding afforded by the subassembly was ignored. This zone was modeled as air.

[d]The air gaps of thicknesses 10.39 cm (4.09 in.) and 6.16 cm (2.425 in.) were combined to produce a single 16.55 cm (6.52-in.) zone of air.

Table B5-9. Sample Pig Shipping Container Overpack Radial Geometry and Material Composition for the 0.5 L and 1.0 L Sample Sizes in the Safesend.

Zone (material)	Zone outer radius, cm (in.)	Zone thickness cm (in.)	Zone material Density (g/cc)	ISO-PC zone thickness, cm (in.)
Source (water)	5.150 (2.028)	5.150 (2.028)	1.49	5.150 (2.028)
Safesend[a] (foam)	10.136 (3.991)	4.986 (1.963)	1.22 E-3	22.607[b] (8.900)
Sample Pig Shipping Container (steel)	10.954 (4.313)	0.818 (0.322)	7.86	0.949[c] (0.374)
Subassembly[a] (wood fiber)	28.575 (11.250)	17.621 (6.937)	1.22 E-3	NA[b]
208 L (55-gal) (steel)	28.706 (11.302)	0.131 (0.052)	7.86	NA[c]
Gap (air)	30.480 (12.000)	1.774 (0.698)	1.22 E-3	1.774 (0.698)
N-55 (polyurethane)	39.745 (15.648)	9.266 (3.648)	0.0481	9.266 (3.648)
N-55 (steel)	39.846 (15.687)	0.101 (0.040)	7.86	0.101 (0.040)

[a]The shielding afforded by the Safesend and the subassembly was ignored. These zones were modeled as air.

[b]Since ISO-PC is limited to a total of six zones (one source plus five shield zones), the small air gaps (4.986 cm [1.963 in.] and 17.621 cm [6.937 in.]) were combined to produce a single 22.607 cm (8.900-in.) zone of air.

[c]The steel wall thicknesses of 0.818 cm (0.322 in.) and 0.131 cm (0.052 in.) were combined to produce a single 0.949 cm (0.374-in.) zone of steel.

Table B5-10. Sample Pig Shipping Container Overpack Top Axial Geometry and Material Composition for 0.5 L and 1.0 L Samples in the Safesend

Zone (material)	Zone thickness cm (in.)	Zone material density (g/cc)	ISO-PC zone thickness, cm (in.)
Source (water) (0.5 L)	6.0 (2.4)	1.49	6.0 (2.4)
Source (water) (1.0 L)	12.0 (4.7)	1.49	12.0 (4.7)
Safesend/void (air) (0.5 L)	23.02 (9.06)	1.22 E-3	23.02 (9.06)
Safesend/void (air) (1.0 L)	17.02[a] (6.70)	1.22 E-3	17.02[a] (6.70)
Sample Pig Shipping Container top (steel)	0.635 (0.250)	7.86	0.796[b] (0.3130
Subassembly[c] (wood fiber)	32.728 (12.885)	1.22 E-3	32.728 (12.885)
Drum lid (steel)	0.161 (0.063)	7.86	NA[b]
N-55 (polyurethane)	17.78 (7.00)	1.22 E-3	17.78 (7.00)
N-55 lid (steel)	0.101 (0.040)	7.86	0.101 (0.040)

[a]The value in parenthesis is the air zone thickness for the 500 mL [17-oz] case.

[b]Since ISO-PC is limited to a total of six zones, the Sample Pig Shipping Container top and drum lid steel layers (0.635 cm [0.250 in.] and 0.161 cm [0.063 in.]) were combined into a single 0.796 cm (0.313-in.) zone of steel.

[c]The shielding afforded by the subassembly was ignored. This zone was modeled as air.

Table B5-11. Sample Pig Shipping Container Overpack Bottom Axial Geometry and Material Composition for 0.5 L and 1 L Samples.

Zone (material)	Zone thickness cm (in.)	Zone material Density (g/cc)	ISO-PC zone thickness, cm (in.)
Source (water) (0.5 L)	6.0 (2.4)	1.49	6.0 (2.4)
Source (water) (1.0 L)	12.0[a] (4.7)	1.49	12.0[a] (4.7)
Safesend[b] (air)	5.27 (2.07)	1.22 E-3	5.27 (2.07)
Sample Pig Shipping Container Bottom (steel)	0.635 (0.250)	7.86	0.766[c] (0.302)
Subassembly[b] (wood fiber)	20.32 (8.00)	1.22 E-3	20.32 (8.00)
Drum bottom (steel)	0.131 (0.052)	7.86	NA[c]
N-55 (polyurethane)	14.0 (5.5)	1.22 E-3	14.0 (5.5)
N-55 bottom (steel)	0.101 (0.040)	7.86	0.101 (0.040)

[a]The value in parenthesis is the source zone thickness for the 500 mL (17-oz) case.

[b]The shielding afforded by the subassembly was ignored. This zone was modeled as air.

[c]Since ISO-PC is limited to a total of six zones, the Sample Pig Shipping Container bottom and drum bottom steel layers (0.635 cm [0.250 in.] and 0.131 cm [0.052 in.]) were combined into a single 0.766 m (0.302-in.) zone of steel.

5.4.4 Shielding Calculations

Table B5-12 summarizes the gamma dose rate estimates from ISO-PC for various distances from the N-55 overpack for each of the three cases. Note that the source term was iterated for the 0.5 L and 1.0 L samples in the Safesend carrier to result in a dose rate on the

N-55 surface of 10 mSv/h (1,000 mrem/h). Due to the lack of shielding in the Safesend, the maximum source term cannot be shipped in the 0.5 L and 1.0 L sample sizes in the Safesend. The maximum source term can, however, be shipped in the 0.5 L sample size when carried in the Steel Pig because the overpack surface dose rates are less than 1,000 rem/h.

Table B5-12. Dose Rates Outside the Sample Pig Transport System, mSv/h (mrem/h).

Detector location		0.125 L LDUA Sampler	0.125 L sample in Sample Pig	0.5 L Steel Pig	0.5 L sample in Safesend	1.0 L sample in Safesend
Overpack surface	Side	2.81 (281)	0.08 (8)	4.44 (444)	10 (1,000)	9.98 (998)
	Top	0.9 (89.5)	0.03 (3)	1.51 (151)	2.81 (281)	2.78 (278)
	Bottom	NA	0.12 (12)	NA	9.59 (959)	7.26 (726)
Vehicle surface[a]		0.03 (29.7)	1.7 E-02 (1.7)	0.93 (93.4)	2.1 (210)	2.1 (210)
2 m from vehicle surface		4.5E-02 (4.48)	3.0 E-03 (0.3)	0.14 (14.1)	0.32 (32)	0.32 (32)
Driver location[b]		0.88 (88)	0.03 (3)	1.39 (139.1)	3.13 (313)	3.12 (312)

1 Sievert = 100 rem.
[a]Dose rate at the limiting location on the side of the truck bed.
[b]Driver located 33 cm (13 in.) from the overpack on the front end of the truck bed.

5.5 ACCIDENT CONDITIONS

5.5.1 Conditions To Be Evaluated

Testing was performed on the N-55 overpack, and it was found that the overpack lid maintained its integrity even after a 9 m (30-ft) drop test. The structural analysis indicates that the Sample Pig Transport System also maintains its integrity after the drop. Therefore, there is no credible scenario that could occur during onsite shipment of the N-55 that would result in the loss of the lid or the loss of any shielding provided by the N-55, 208-L (55-gal) drum, or Sample Pig Shipping Container. However, the N-55 overpack experienced permanent deformation from each of the three drop tests (end, side, and corner). The deformation resulted from some of the material of the spacer assembly being crushed during impact. This deformation will cause a slight decrease in the distance from the source to the overpack surface, which, in turn, will cause a slight increase in the dose rates. Figure 7.6.1.4-1 shows the amount of damage resulting from each of the drop tests. The side drop, which resulted in approximately 5.08 cm (2 in.) of damage to the N-55, will cause the greatest dose rate increase. Because the maximum dose rate during normal conditions occurs on the side of the overpack, the dose rates at the side of the overpack will also be limiting after the drop tests.

5.5.2 Acceptance Criteria

The external dose rate from a single package shall not exceed 10 mSv/h (1000 mrem/h) at 1 m from the surface under accident conditions as directed by the onsite transportation safety program.

5.5.3 Shielding Model

The maximum dose rate at the vehicle surface during normal transfer conditions is 10 mSv/h (1,000 mrem/h) for the worst-case source term. The location of the maximum vehicle surface dose rate is 125 cm from the surface of the overpack, and since two overpacks contribute to the dose rate at that location, the dose rate from a single overpack is 1.05 mSv/h (105.3 mrem/h). The radial dose at approximately 1 m from the overpack is decreasing at a rate slightly greater than 1/r, where r is the distance. Therefore, the dose rate at 1 m is conservatively estimated to be 1.32 mSv/h (132 mrem/h = 105.3 mrem/h x 1.25 m/1 m). For the side drop case the distance from the overpack will decrease by 5.08 cm (2 in.), which corresponds to a distance of 0.95 m from the overpack. The dose rate at 0.95 m, which corresponds to 1 m from the damaged package, is conservatively estimated to be 1.39 mSv/h (139 mrem/h) = 132 mrem/h x 1.00 m/0.95 m), which is far below the 10-mSv/h (1000-mrem/h) limit at 1 m from the surface under accident conditions.

5.6 SHIELDING EVALUATION AND CONCLUSIONS

The worst case-source term was used as derived in Part B, Section 2.0, for the 125 mL sample size. However, the lack of shielding in the Safesend, when used for the 0.5 and 1.0 L samples, required that the strong gamma- and beta-emitting radionuclides be restricted to the amount that would produce a surface dose rate of 10 mSv/h (1,000) mrem/h or less on the surface of the N-55 overpack. The resulting source term is shown in Table B5-1. As shown in Table B5-13, the surface dose rate limit of 10 mSv/h (1,000 mrem/h) is met for all sources and conditions evaluated. However, some dose rate limits are exceeded. The maximum dose to the driver for the 0.125 L sample in the Sample Pig is exceeded only if the driver is not a qualified Hanford radiological worker when transporting the worst-case source term; otherwise, all other limits are met for this sample size. The dose rate limit to the driver is exceeded for the 0.125 L sample in the LDUA Sampler, but all other limits are met. The dose rate limit to the driver at 2 m from the vehicle is exceeded for a 0.5 L sample in the Steel Pig. The dose rate limits to the driver, at the edge of the vehicle and at 2 m from the vehicle, are exceeded for the 0.5 L and 1 L sample in the Safesend. If these sources (shown in Table B5-1) are encountered in practice, supplemental shielding will be required for the driver, and ALARA practices or supplemental shielding will be required to limit exposure to the public and workers.

Table B5- 13. Comparison of Maximum Dose Rates, mSv/h (mrem/h), With Dose Rate Limits.

Detector location	Limit	0.125 L LDUA Sampler	0.125 L sample	0.5 L sample in the Steel Pig	0.5 L sample in the Safesend	1.0 L sample in the Safesend
Overpack surface	2 (200)	2.81 (281)	0.08 (8)	4.44 (444)	10.0 (1000)	9.98 (998)
Vehicle surface[a]	2 (200)	0.03 (29.7)	1.7 E-02 (1.7)	1.51 (151)	2.1[c] (210)	2.1[c] (210)
2 m from vehicle surface	0.1 (10)	4.5E-02 (4.48)	3.0E-03 (0.3)	0.93 (93.4)	0.32[c] (32)	0.32[c] (32)
Driver location[b]	0.05 (5)	0.88 (88)	0.03 (3)	1.39 (139.1)	3.13[c] (313)	3.12[c] (312)

1 Sievert = 100 rem.

[a]Dose rate at the limiting location on the side of the truck bed.

[b]Driver located 33 cm (13 in.) from the overpack on the front end of the truck bed. The 5 mrem/h limit applies to a qualified radiological worker. If the driver is a nonradiological worker, the dose rate limit is 2 mrem/h.

[c]Additional shielding and/or ALARA controls will be used to reduce the dose rates below the required limits (see Part A, Section 6.0).

ALARA = as low as reasonably achievable.

5.7 REFERENCES

ANSI/ANS, 1991, *Neutron and Gamma-ray Fluence-to-Dose Factors*, ANSI/ANS-6.1.1-1991, American National Standards Institute/American Nuclear Society, New York, New York.

Nelson, J. V., 1996, *Estimation of Neutron Dose Rates from Nuclear Waste Packages*, (internal memo to 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.

5.8 APPENDICES: ISO-PC INPUT FILES

5.8.1 0.125 L Sample

```
0      2  PIG - 125 mL
Cylindrical Source Geom - Dose Rate at 1 cm
&Input Next= 1, ISpec= 3, IGeom= 7, ICONC=0, SFACT= 1, DUNIT=1,
 NTheta= 30, NPsi= 30, NShld= 6, JBuf= 6, OPTION=1,
 Slth= 5.8,
 Y= 2.9,
 T(1)= 2.619,
 T(2)= 5.080,
 T(3)= 1.664,
 T(4)= 21.117,
 T(5)= 9.266,
 T(6)= 0.101,
 X= 40.85,
 WEIGHT(451) =  2.89E-06 ,
 WEIGHT(472) =  9.69E-04 ,
 WEIGHT( 27) =  1.39E-05 ,
 WEIGHT( 82) =  8.82E+00 ,
 WEIGHT( 84) =  8.82E+00 ,
 WEIGHT(102) =  6.43E-05 ,
 WEIGHT(103) =  5.06E-05 ,
 WEIGHT(141) =  4.05E-02 ,
 WEIGHT(170) =  1.90E-03 ,
 WEIGHT(172) =  1.90E-03 ,
 WEIGHT(206) =  3.80E-04 ,
 WEIGHT(269) =  1.28E-02 ,
 WEIGHT(270) =  3.12E-03 ,
 WEIGHT(272) =  2.18E-05 ,
 WEIGHT(274) =  3.05E-06 ,
 WEIGHT(273) =  2.18E-05 ,
 WEIGHT(290) =  2.16E-05 ,
 WEIGHT(319) =  4.09E-03 ,
 WEIGHT(335) =  3.11E-01 ,
 WEIGHT(336) =  2.94E-01 ,
 WEIGHT(388) =  4.24E-05 ,
 WEIGHT(403) =  5.04E-02 ,
 WEIGHT(408) =  4.39E-05 ,
 WEIGHT(415) =  2.72E-02 ,
 WEIGHT(418) =  1.41E-02 ,
 WEIGHT(371) =  1.13E-08 ,
 WEIGHT(450) =  3.35E-08 ,
 WEIGHT(490) =  3.35E-03 ,
 WEIGHT(533) =  5.83E-07 ,
 WEIGHT(530) =  5.83E-07 ,
 WEIGHT(519) =  6.16E-08 ,
 WEIGHT(520) =  8.57E-07 ,
 WEIGHT(476) =  3.35E-08 ,
 WEIGHT(398) =  7.00E-08 ,
 WEIGHT(491) =  2.54E-07 ,
 WEIGHT(526) =  5.83E-07 ,
 WEIGHT(502) =  3.35E-03 ,
 WEIGHT(503) =  1.68E-06 ,
 WEIGHT(492) =  6.12E-04 ,
 WEIGHT(493) =  5.30E-03 ,
 WEIGHT(494) =  1.40E-04 ,
 WEIGHT(495) =  1.06E-02 ,
```

```
 WEIGHT(497) =  1.29E-08 ,
 WEIGHT(496) =  3.71E-02 ,
 WEIGHT(505) =  1.68E-06 ,
 WEIGHT(504) =  8.50E-09 ,
 WEIGHT(506) =  6.11E-07 ,
 WEIGHT(500) =  1.77E-04 , &
 Water  1  1.49
 Lead  14        11.34
 Iron   9              7.86
 Air    3                     0.00122
 Poly-C 6                              0.0481
 lIron  9                                     7.86
Vehicle Surface - Side of the Truck at 1.25 m - Between 2 Overpacks
&Input Next= 4, X = 125.37 &
2 m from Vehicle Surf - Side of the Truck - 3.196 m - Between 2 Overpacks
&Input Next= 4, X = 319.6 &
Driver Location - 0.729 m from Overpack - Overpacks in Front
&Input Next= 4, X = 72.866 &
Cylindrical Source Geom - Dose Rate at 1 cm from top
&Input Next= 1, IGeom= 9, ICONC=0,
 Slth= 2.619,
 T(1)= 5.8,
 T(2)= 1.271,
 T(3)= 5.08,
 T(4)= 50.193,
 T(5)= 17.78,
 T(6)= 0.262,
 X= 81.386, &
 Water  1  1.49
 Iron   9       7.86
 Lead  14              11.34
 Air    3                     0.00122
 Poly-C 6                              0.0481
 lIron  9                                     7.86
Cylindrical Source Geom - Dose Rate at 1 cm from bottom
&Input Next= 1, OPTION=0,
 Slth= 2.619,
 T(1)= 5.8,
 T(2)= 4.763,
 T(3)= 1.178,
 T(4)= 20.32,
 T(5)= 14.0 ,
 T(6)= 0.232,
 X= 47.293, &
 Water  1  1.49
 Lead  14        11.34
 Iron   9              7.86
 Air    3                     0.00122
 Poly-C 6                              0.0481
 lIron  9                                     7.86
&Input Next= 6 &
```

5.8.2 0.5 L Sample in Safesend

```
0      2  PIG 0.5 L SAMPLE
Cylindrical Source Geom - Dose Rate at 1 cm from side
&Input Next= 1 , ISpec= 3, IGeom= 7, ICONC=0, SFACT= 1, DUNIT=1,
 NTheta= 30, NPsi= 30, NShld= 6, JBuf= 6, OPTION=1,
 Slth= 12.0,
 Y= 6.00 ,
```

```
 T(1)= 5.15,
 T(2)= 22.607,
 T(3)= 0.949,
 T(4)= 1.774,
 T(5)= 9.266,
 T(6)= 0.101,
 X= 40.85,
WEIGHT(451) =  1.16E-05,
WEIGHT(472) =  1.74E-03,
WEIGHT( 27) =  5.56E-05,
WEIGHT( 82) =  1.59E+01,
WEIGHT( 84) =  1.59E+01,
WEIGHT(102) =  2.57E-04,
WEIGHT(103) =  2.02E-04,
WEIGHT(141) =  1.62E-01,
WEIGHT(170) =  3.41E-03,
WEIGHT(172) =  3.41E-03,
WEIGHT(206) =  1.52E-03,
WEIGHT(269) =  2.30E-02,
WEIGHT(270) =  1.25E-02,
WEIGHT(272) =  8.72E-05,
WEIGHT(274) =  1.22E-05,
WEIGHT(273) =  8.72E-05,
WEIGHT(290) =  8.64E-05,
WEIGHT(319) =  7.310E-03,
WEIGHT(335) =  5.56E-01,
WEIGHT(336) =  5.26E-01,
WEIGHT(388) =  1.70E-04,
WEIGHT(403) =  2.02E-01,
WEIGHT(408) =  1.76E-04,
WEIGHT(415) =  4.87E-02,
WEIGHT(418) =  5.64E-02,
WEIGHT(371) =  4.52E-08,
WEIGHT(450) =  1.34E-07,
WEIGHT(490) =  1.34E-02,
WEIGHT(533) =  2.33E-06,
WEIGHT(530) =  2.33E-06,
WEIGHT(519) =  2.46E-07,
WEIGHT(520) =  3.43E-06,
WEIGHT(476) =  1.34E-07,
WEIGHT(398) =  2.80E-07,
WEIGHT(491) =  1.02E-06,
WEIGHT(526) =  2.33E-06,
WEIGHT(502) =  1.34E-02,
WEIGHT(503) =  6.72E-06,
WEIGHT(492) =  2.45E-03,
WEIGHT(493) =  2.12E-02,
WEIGHT(494) =  5.60E-04,
WEIGHT(495) =  4.24E-02,
WEIGHT(497) =  5.16E-08,
WEIGHT(496) =  1.48E-01,
WEIGHT(505) =  6.72E-06,
WEIGHT(504) =  3.40E-08,
WEIGHT(506) =  2.44E-06,
WEIGHT(500) =  7.08E-04, &
 Water  1  1.49
 Air    3       0.00122
 Iron   9              7.86
 Air    3                     0.00122
 Poly-C 6                            0.0481
 IIron  9                                   7.86
Vehicle Surface - Side of the Truck at 1.25 m - Between 2 Overpacks
```

```
&Input Next= 4, X = 125.37 &
2 m from Vehicle Surf - Side of the Truck - 3.196 m - Between 2 Overpacks
&Input Next= 4, X = 319.6 &
Driver Location - 0.729 m from Overpack - Overpacks in Front
&Input Next= 4, X = 72.866 &
Cylindrical Source Geom - Dose Rate at 1 cm from top
&Input Next= 1, IGeom= 9,
 Slth= 5.15,
 T(1)= 6.0,
 T(2)= 26.02,
 T(3)= 0.796,
 T(4)= 32.728,
 T(5)= 17.78,
 T(6)= 0.101,
 X= 84.425, &
 Water  1  1.49
 Air    3       0.00122
 Iron   9               7.86
 Air    3                       0.00122
 Poly-C 6                               0.048
1Iron   9                                       7.86
Cylindrical Source Geom - Dose Rate at 1 cm from bottom
&Input Next= 1 ,
 Slth= 5.15,
 T(1)= 6.0,
 T(2)= 5.27,
 T(3)= 0.766,
 T(4)= 20.32,
 T(5)= 14.0 ,
 T(6)= 0.101,
 X= 47.457, &
 Water  1  1.49
 Air    3       0.00122
 Iron   9               7.86
 Air    3                       0.00122
 Poly-C 6                               0.0481
1Iron   9                                       7.86
End of Input
&Input Next= 6 &
```

5.8.3 1.0 L Sample in Safesend

```
0     2  PIG 1 L SAMPLE
Cylindrical Source Geom - Dose Rate at 1 cm from side
&Input Next= 1 , ISpec= 3, IGeom= 7, ICONC=0, SFACT= 1, DUNIT=1,
 NTheta= 30, NPsi= 30, NShld= 6, JBuf= 6, OPTION=1,
 Slth= 12.0,
 Y= 6.00 ,
 T(1)= 5.15,
 T(2)= 22.607,
 T(3)= 0.949,
 T(4)= 1.774,
 T(5)= 9.266,
 T(6)= 0.101,
 X= 40.85,
 WEIGHT(451) =   2.31E-05,
 WEIGHT(472) =   1.71E-03,
 WEIGHT( 27) =  1.11E-04,
 WEIGHT( 82) =  1.56E+01,
 WEIGHT( 84) =  1.56E+01,
```

```
WEIGHT(102) =   5.14E-04,
WEIGHT(103) =   4.05E-04,
WEIGHT(141) =   3.24E-01,
WEIGHT(170) =   3.37E-03,
WEIGHT(172) =   3.37E-03,
WEIGHT(206) =   3.04E-03,
WEIGHT(269) =   2.27E-02,
WEIGHT(270) =   2.50E-02,
WEIGHT(272) =   1.74E-04,
WEIGHT(274) =   2.44E-05,
WEIGHT(273) =   1.74E-04,
WEIGHT(290) =   1.73E-04,
WEIGHT(319) =   7.28E-03,
WEIGHT(335) =   5.53E-01,
WEIGHT(336) =   5.23E-01,
WEIGHT(388) =   3.39E-04,
WEIGHT(403) =   4.03E-01,
WEIGHT(408) =   3.51E-04,
WEIGHT(415) =   4.84E-02,
WEIGHT(418) =   1.13E-01,
WEIGHT(371) =   9.04E-08,
WEIGHT(450) =   2.68E-07,
WEIGHT(490) =   2.68E-02,
WEIGHT(533) =   4.66E-06,
WEIGHT(530) =   4.66E-06,
WEIGHT(519) =   4.93E-07,
WEIGHT(520) =   6.86E-06,
WEIGHT(476) =   2.68E-07,
WEIGHT(398) =   5.60E-07,
WEIGHT(491) =   2.03E-06,
WEIGHT(526) =   4.66E-06,
WEIGHT(502) =   2.68E-02,
WEIGHT(503) =   1.34E-05,
WEIGHT(492) =   4.90E-03,
WEIGHT(493) =   4.24E-02,
WEIGHT(494) =   1.12E-03,
WEIGHT(495) =   8.48E-02,
WEIGHT(497) =   1.03E-07,
WEIGHT(496) =   2.97E-01,
WEIGHT(505) =   1.34E-05,
WEIGHT(504) =   6.80E-08,
WEIGHT(506) =   4.89E-06,
WEIGHT(500) =   1.42E-03, &
Water  1  1.49
Air    3       0.00122
Iron   9              7.86
Air    3                     0.00122
Poly-C 6                            0.0481
1Iron  9                                   7.86
Vehicle Surface - Side of the Truck at 1.25 m - Between 2 Overpacks
&Input Next= 4, X = 125.37 &
2 m from Vehicle Surf - Side of the Truck - 3.196 m - Between 2 Overpacks
&Input Next= 4, X = 319.6 &
Driver Location - 0.729 m from Overpack - Overpacks in Front
&Input Next= 4, X = 72.866 &
Cylindrical Source Geom - Dose Rate at 1 cm from top
&Input Next= 1, IGeom= 9,
 Slth= 5.15,
 T(1)= 12.0,
 T(2)= 17.02,
 T(3)= 0.796,
 T(4)= 32.728,
```

```
 T(5)= 17.78,
 T(6)= 0.101,
 X= 81.425, &
 Water  1  1.49
 Air    3        0.00122
 Iron   9                 7.86
 Air    3                           0.00122
 Poly-C 6                                 0.048
1Iron   9                                     7.86
Cylindrical Source Geom - Dose Rate at 1 cm from bottom
&Input Next= 1 ,
 Slth= 5.15,
 T(1)= 12.0,
 T(2)= 5.27,
 T(3)= 0.766,
 T(4)= 20.32,
 T(5)= 14.0 ,
 T(6)= 0.101,
 X= 53.457, &
 Water  1  1.49
 Air    3        0.00122
 Iron   9                 7.86
 Air    3                           0.00122
 Poly-C 6                                 0.0481
1Iron   9                                     7.86
End of Input
&Input Next= 6 &
```

5.8.4 0.5 L Sample in Steel Pig (Activity Four Times 0.125 L Sample), Radial Model

```
0      2  Steel Pig in Pig Container with 500 ml Sample
Cylindrical Source Geom - Dose Rate at 1 cm
&Input Next= 1, ISpec= 3, IGeom= 7, ICONC=0, SFACT= 4, DUNIT=1,
 NTheta= 30, NPsi= 30, NShld= 6, JBuf= 6, OPTION=1,
 Slth= 8.66,
 Y= 4.33,
 T(1)= 4.286,
 T(2)= 4.946,
 T(3)= 21.117,
 T(4)= 0.131,
 T(5)= 9.266,
 T(6)= 0.101,
 X= 40.85,
 WEIGHT(451) =  2.89E-06 ,
 WEIGHT(472) =  9.69E-04 ,
 WEIGHT( 27) =  1.39E-05 ,
 WEIGHT( 82) =  8.82E+00 ,
 WEIGHT( 84) =  8.82E+00 ,
 WEIGHT(102) =  6.43E-05 ,
 WEIGHT(103) =  5.06E-05 ,
 WEIGHT(141) =  4.05E-02 ,
 WEIGHT(170) =  1.90E-03 ,
 WEIGHT(172) =  1.90E-03 ,
 WEIGHT(206) =  3.80E-04 ,
 WEIGHT(269) =  1.28E-02 ,
 WEIGHT(270) =  3.12E-03 ,
 WEIGHT(272) =  2.18E-05 ,
 WEIGHT(274) =  3.05E-06 ,
 WEIGHT(273) =  2.18E-05 ,
 WEIGHT(290) =  2.16E-05 ,
```

```
 WEIGHT(319) =  4.09E-03 ,
 WEIGHT(335) =  3.11E-01 ,
 WEIGHT(336) =  2.94E-01 ,
 WEIGHT(388) =  4.24E-05 ,
 WEIGHT(403) =  5.04E-02 ,
 WEIGHT(408) =  4.39E-05 ,
 WEIGHT(415) =  2.72E-02 ,
 WEIGHT(418) =  1.41E-02 ,
 WEIGHT(371) =  1.13E-08 ,
 WEIGHT(450) =  3.35E-08 ,
 WEIGHT(490) =  3.35E-03 ,
 WEIGHT(533) =  5.83E-07 ,
 WEIGHT(530) =  5.83E-07 ,
 WEIGHT(519) =  6.16E-08 ,
 WEIGHT(520) =  8.57E-07 ,
 WEIGHT(476) =  3.35E-08 ,
 WEIGHT(398) =  7.00E-08 ,
 WEIGHT(491) =  2.54E-07 ,
 WEIGHT(526) =  5.83E-07 ,
 WEIGHT(502) =  3.35E-03 ,
 WEIGHT(503) =  1.68E-06 ,
 WEIGHT(492) =  6.12E-04 ,
 WEIGHT(493) =  5.30E-03 ,
 WEIGHT(494) =  1.40E-04 ,
 WEIGHT(495) =  1.06E-02 ,
 WEIGHT(497) =  1.29E-08 ,
 WEIGHT(496) =  3.71E-02 ,
 WEIGHT(505) =  1.68E-06 ,
 WEIGHT(504) =  8.50E-09 ,
 WEIGHT(506) =  6.11E-07 ,
 WEIGHT(500) =  1.77E-04 , &
 Water  1  1.49
 Iron   9        7.86
 Air    3              0.00122
 Iron   9                      7.86
 Poly-C 6                                0.0481
 1Iron  9                                          7.86
Vehicle Surface - Side of the Truck at 1.25 m - Between 2 Overpacks
&Input Next= 4, X = 125.37 &
2 m from Vehicle Surf - Side of the Truck - 3.196 m - Between 2 Overpacks
&Input Next= 4, X = 319.6 &
Driver Location - 0.729 m from Overpack - Overpacks in Front
&Input Next= 4, X = 72.866 &
End of Input
&Input Next= 6 &
```

5.8.5 0.5 L Sample in Steel Pig, Axial Model

```
0      2  Steel Pig with 500 ml Sample
Cylindrical Source Geom - Dose Rate at 1 cm above top
&Input Next= 1, ISpec= 3, IGeom= 9, ICONC=0, SFACT= 4, DUNIT=1,
 NTheta= 30, NPsi= 30, NShld= 6, JBuf= 6, OPTION=1,
 Slth= 4.286,
 T(1)= 8.66,
 T(2)= 16.55,
 T(3)= 4.445,
 T(4)= 32.728,
 T(5)= 17.78,
 T(6)= 0.262,
 X= 81.425,
```

```
WEIGHT(451) = 2.89E-06 ,
WEIGHT(472) = 9.69E-04 ,
WEIGHT( 27) = 1.39E-05 ,
WEIGHT( 82) = 8.82E+00 ,
WEIGHT( 84) = 8.82E+00 ,
WEIGHT(102) = 6.43E-05 ,
WEIGHT(103) = 5.06E-05 ,
WEIGHT(141) = 4.05E-02 ,
WEIGHT(170) = 1.90E-03 ,
WEIGHT(172) = 1.90E-03 ,
WEIGHT(206) = 3.80E-04 ,
WEIGHT(269) = 1.28E-02 ,
WEIGHT(270) = 3.12E-03 ,
WEIGHT(272) = 2.18E-05 ,
WEIGHT(274) = 3.05E-06 ,
WEIGHT(273) = 2.18E-05 ,
WEIGHT(290) = 2.16E-05 ,
WEIGHT(319) = 4.09E-03 ,
WEIGHT(335) = 3.11E-01 ,
WEIGHT(336) = 2.94E-01 ,
WEIGHT(388) = 4.24E-05 ,
WEIGHT(403) = 5.04E-02 ,
WEIGHT(408) = 4.39E-05 ,
WEIGHT(415) = 2.72E-02 ,
WEIGHT(418) = 1.41E-02 ,
WEIGHT(371) = 1.13E-08 ,
WEIGHT(450) = 3.35E-08 ,
WEIGHT(490) = 3.35E-03 ,
WEIGHT(533) = 5.83E-07 ,
WEIGHT(530) = 5.83E-07 ,
WEIGHT(519) = 6.16E-08 ,
WEIGHT(520) = 8.57E-07 ,
WEIGHT(476) = 3.35E-08 ,
WEIGHT(398) = 7.00E-08 ,
WEIGHT(491) = 2.54E-07 ,
WEIGHT(526) = 5.83E-07 ,
WEIGHT(502) = 3.35E-03 ,
WEIGHT(503) = 1.68E-06 ,
WEIGHT(492) = 6.12E-04 ,
WEIGHT(493) = 5.30E-03 ,
WEIGHT(494) = 1.40E-04 ,
WEIGHT(495) = 1.06E-02 ,
WEIGHT(497) = 1.29E-08 ,
WEIGHT(496) = 3.71E-02 ,
WEIGHT(505) = 1.68E-06 ,
WEIGHT(504) = 8.50E-09 ,
WEIGHT(506) = 6.11E-07 ,
WEIGHT(500) = 1.77E-04 , &
Water  1  1.49
Air    3       0.00122
Iron   3             7.86
Air    3                    0.00122
Poly-C 6                            0.0481
1Iron  9                                   7.86
End of Input
&Input Next= 6 &
```

5.8.6 LDUA Sampler, Radial Model

```
0     2 LDUA in Pig Container with 125 ml Sample
Cylindrical Source Geom - Dose Rate at side
&Input Next= 1, ISpec= 3, IGeom= 7, ICONC=0, SFACT= 1, DUNIT=1,
 NTheta= 30, NPsi= 30, NShld= 6, JBuf= 6, OPTION=1,
 Slth= 5.4193,
 Y= 2.7097,
 T(1)= 2.7096,
 T(2)= 1.00,
 T(3)= 25.821,
 T(4)= 0.949,
 T(5)= 9.266,
 T(6)= 0.101,
 X= 40.85,
 WEIGHT(451) =  2.89E-06 ,
 WEIGHT(472) =  9.69E-04 ,
 WEIGHT( 27) =  1.39E-05 ,
 WEIGHT( 82) =  8.82E+00 ,
 WEIGHT( 84) =  8.82E+00 ,
 WEIGHT(102) =  6.43E-05 ,
 WEIGHT(103) =  5.06E-05 ,
 WEIGHT(141) =  4.05E-02 ,
 WEIGHT(170) =  1.90E-03 ,
 WEIGHT(172) =  1.90E-03 ,
 WEIGHT(206) =  3.80E-04 ,
 WEIGHT(269) =  1.28E-02 ,
 WEIGHT(270) =  3.12E-03 ,
 WEIGHT(272) =  2.18E-05 ,
 WEIGHT(274) =  3.05E-06 ,
 WEIGHT(273) =  2.18E-05 ,
 WEIGHT(290) =  2.16E-05 ,
 WEIGHT(319) =  4.09E-03 ,
 WEIGHT(335) =  3.11E-01 ,
 WEIGHT(336) =  2.94E-01 ,
 WEIGHT(388) =  4.24E-05 ,
 WEIGHT(403) =  5.04E-02 ,
 WEIGHT(408) =  4.39E-05 ,
 WEIGHT(415) =  2.72E-02 ,
 WEIGHT(418) =  1.41E-02 ,
 WEIGHT(371) =  1.13E-08 ,
 WEIGHT(450) =  3.35E-08 ,
 WEIGHT(490) =  3.35E-03 ,
 WEIGHT(533) =  5.83E-07 ,
 WEIGHT(530) =  5.83E-07 ,
 WEIGHT(519) =  6.16E-08 ,
 WEIGHT(520) =  8.57E-07 ,
 WEIGHT(476) =  3.35E-08 ,
 WEIGHT(398) =  7.00E-08 ,
 WEIGHT(491) =  2.54E-07 ,
 WEIGHT(526) =  5.83E-07 ,
 WEIGHT(502) =  3.35E-03 ,
 WEIGHT(503) =  1.68E-06 ,
 WEIGHT(492) =  6.12E-04 ,
 WEIGHT(493) =  5.30E-03 ,
 WEIGHT(494) =  1.40E-04 ,
 WEIGHT(495) =  1.06E-02 ,
 WEIGHT(497) =  1.29E-08 ,
 WEIGHT(496) =  3.71E-02 ,
 WEIGHT(505) =  1.68E-06 ,
 WEIGHT(504) =  8.50E-09 ,
```

WEIGHT(506) = 6.11E-07 ,
WEIGHT(500) = 1.77E-04 , &
Water 1 1.49
Lead 14 11.34
Air 3 0.00122
Iron 9 7.86
Poly-C 6 0.0481
IIron 9 7.86
Vehicle Surface - Side of the Truck at 1.25 m - Between 2 Overpacks
&Input Next= 4, X = 125.37 &
2 m from Vehicle Surf - Side of the Truck - 3.196 m - Between 2 Overpacks
&Input Next= 4, X = 319.6 &
Driver Location - 0.729 m from Overpack - Overpacks in Front
&Input Next= 4, X = 72.866 &
End of Input
&Input Next= 6 &

5.8.7 LDUA Sampler, Axial Model

0 2 LDUA in Pig Container with 125 ml Sample
Cylindrical Source Geom - Dose Rate at 1 cm above top
&Input Next= 1, ISpec= 3, IGeom= 9, ICONC=0, SFACT= 1, DUNIT=1,
NTheta= 30, NPsi= 30, NShld= 6, JBuf= 6, OPTION=1,
Slth= 2.7096,
T(1)= 5.4193,
T(2)= 1.00,
T(3)= 21.6007,
T(4)=0.635,
T(5)=50.508,
T(6)= 0.262,
X= 80.425,
WEIGHT(451) = 2.89E-06 ,
WEIGHT(472) = 9.69E-04 ,
WEIGHT(27) = 1.39E-05 ,
WEIGHT(82) = 8.82E+00 ,
WEIGHT(84) = 8.82E+00 ,
WEIGHT(102) = 6.43E-05 ,
WEIGHT(103) = 5.06E-05 ,
WEIGHT(141) = 4.05E-02 ,
WEIGHT(170) = 1.90E-03 ,
WEIGHT(172) = 1.90E-03 ,
WEIGHT(206) = 3.80E-04 ,
WEIGHT(269) = 1.28E-02 ,
WEIGHT(270) = 3.12E-03 ,
WEIGHT(272) = 2.18E-05 ,
WEIGHT(274) = 3.05E-06 ,
WEIGHT(273) = 2.18E-05 ,
WEIGHT(290) = 2.16E-05 ,
WEIGHT(319) = 4.09E-03 ,
WEIGHT(335) = 3.11E-01 ,
WEIGHT(336) = 2.94E-01 ,
WEIGHT(388) = 4.24E-05 ,
WEIGHT(403) = 5.04E-02 ,
WEIGHT(408) = 4.39E-05 ,
WEIGHT(415) = 2.72E-02 ,
WEIGHT(418) = 1.41E-02 ,
WEIGHT(371) = 1.13E-08 ,
WEIGHT(450) = 3.35E-08 ,
WEIGHT(490) = 3.35E-03 ,
WEIGHT(533) = 5.83E-07 ,

```
WEIGHT(530) =  5.83E-07 ,
WEIGHT(519) =  6.16E-08 ,
WEIGHT(520) =  8.57E-07 ,
WEIGHT(476) =  3.35E-08 ,
WEIGHT(398) =  7.00E-08 ,
WEIGHT(491) =  2.54E-07 ,
WEIGHT(526) =  5.83E-07 ,
WEIGHT(502) =  3.35E-03 ,
WEIGHT(503) =  1.68E-06 ,
WEIGHT(492) =  6.12E-04 ,
WEIGHT(493) =  5.30E-03 ,
WEIGHT(494) =  1.40E-04 ,
WEIGHT(495) =  1.06E-02 ,
WEIGHT(497) =  1.29E-08 ,
WEIGHT(496) =  3.71E-02 ,
WEIGHT(505) =  1.68E-06 ,
WEIGHT(504) =  8.50E-09 ,
WEIGHT(506) =  6.11E-07 ,
WEIGHT(500) =  1.77E-04 , &
Water  1  1.49
Lead  14        11.34
Air    3              0.00122
Iron   9                       7.86
Air    3                                  0.00122
1Iron  9                                             7.86
End of Input
&Input Next= 6 &
```

CHECKLIST FOR CHECKING OF ANALYSIS/CALCULATIONS

Document Number/Revision: HNF-SD-TP-SARP-001

Document Title: Shielding Evaluations for Steel Pig and LDUA Sampler

Yes	No	N/A	
[X]	[ ]	[ ]	Problem completely defined.
[X]	[ ]	[ ]	Appropriate analytical method used.
[X]	[ ]	[ ]	Necessary assumptions are appropriate and explicitly stated.
[X]	[ ]	[ ]	Computer codes and data files documented.
[X]	[ ]	[ ]	Data used in calculations explicitly stated in document.
[X]	[ ]	[ ]	Sources of non-standard formula/data are referenced and the correctness of the reference verified.
[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.
[X]	[ ]	[ ]	Code run streams correct and consistent with analysis documentation.
[X]	[ ]	[ ]	Code output consistent with input and with results reported in analysis documentation.
[X]	[ ]	[ ]	Acceptability limits on analytical results applicable and supported. Limits checked against sources.
[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.

I have checked the analysis/calculation and it is complete and accurate to the best of my knowledge.

Engineer/Checker John C. McCoy Date 1/15/99

NOTE: Any hand calculations, notes or summaries generated as part of this check should be signed, dated, and attached to this checklist. Material should be labeled and recorded so that it is intelligible to a technically qualified third party.

WMNW-PE-006

6.0 CRITICALITY EVALUATION

6.1 DISCUSSION AND RESULTS

Table B6-1 shows that the total quantity of fissile material contained in the 0.125 L sample volume is 0.1 g. Because the total quantity of fissile material is less than 15 g, the sample is fissile excepted per 49 CFR 173.453(a), and no further analysis is required to address criticality concerns.

Table B6-1. Sample Pig Transport System Fissile Material Inventory for 0.125 L Sample Volume.

Isotope	Activity		Specific activity Ci/g	Quantity g
	Bq	Ci		
^{233}U	2.28 E+03	6.16 E-08	9.70 E-03	6.35 E-06
^{235}U	1.24 E+03	3.35 E-08	2.20 E-06	1.52 E-02
^{238}Pu	2.26 E+07	6.12 E-04	1.70 E+01	3.60 E-05
^{239}Pu	1.96 E+08	5.30 E-03	6.20 E-02	8.55 E-02
^{241}Pu	3.92 E+08	1.06 E-02	1.00 E+02	1.06 E-04
			Total	1.01 E-01

The 0.5 L and 1 L sample source terms are four and eight times the activity of the 0.125 L sample, except for strong beta and gamma emitters, as indicated in Table B2-3, when shipped in the Safesend. Therefore, the fissile material quantities in the 0.5 L and 1 L sample volumes are 0.4 g and 0.8 g, respectively, which are also fissile-excepted quantities (Part B, Section 9.0).

6.2 REFERENCE

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

CHECKLIST FOR CHECKING OF ANALYSIS/CALCULATIONS

Document Number/Revision: HNF-SD-TP-SARP-001

Document Title: Safety Analysis Report for Packaging (Onsite) Sample Pig Transport System
Section: Criticality Evaluation (Section 6.0)

Yes	No	N/A	
[x]	[ ]	[ ]	Problem completely defined.
[x]	[ ]	[ ]	Appropriate analytical method used.
[x]	[ ]	[ ]	Necessary assumptions are appropriate and explicitly stated.
[]	[ ]	[x]	Computer codes and data files documented.
[x]	[ ]	[ ]	Data used in calculations explicitly stated in document.
[ ]	[ ]	[x]	Sources of non-standard formula/data are referenced and the correctness of the reference verified.
[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.
[ ]	[ ]	[x]	Code run streams correct and consistent with analysis documentation.
[ ]	[ ]	[x]	Code output consistent with input and with results reported in analysis documentation.
[ ]	[ ]	[x]	Acceptability limits on analytical results applicable and supported. Limits checked against sources.
[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.

I have checked the analysis/calculation and it is complete and accurate to the best of my knowledge.

Engineer/Checker Anthony V. Savino [signature] Date 1/15/99

NOTE: Any hand calculations, notes or summaries generated as part of this check should be signed, dated, and attached to this checklist. Material should be labeled and recorded so that it is intelligible to a technically qualified third party.

WMNW-PE-006

7.0 STRUCTURAL EVALUATION

7.1 INTRODUCTION

This section presents the structural analysis of the Sample Pig Shipping Container System and all associated lifting attachments. Tiedown assemblies are discussed in Part B, Section 10.0, because they are not a structural part of the package. This section demonstrates the Sample Pig Shipping Container System meets the intent of 10 CFR 71 requirements based on the analyses herein and drop testing performed on the package (WHC 1995).

7.2 STRUCTURAL EVALUATION OF PACKAGE

7.2.1 Structural Design and Features

As discussed in Part A, Section 2.0, the Sample Pig Shipping Container consists of multiple packagings. Of those multiple packagings two constitute a Type B NRC-certified packaging (USA/9070/B(U)), the 208 L (55-gal) (UN1A2) drum and N-55 overpack. The inner container is an onsite container used to transport onsite tank waste samples.

The primary containment for the Sample Pig Transport System is the Sample Pig Shipping Container. The 208 L (55-gal) (UN1A2) drum is considered secondary confinement in this system. The N-55 overpack acts as an impact limiter in the Sample Pig Transport System. The foam inner spacer around the Sample Pig Shipping Container inside of the 208 L (55-gal) (UN1A2) drum, provides additional cushioning.

The Sample Pig has a lead lid with a locking safety pin. The Steel Pig is a SS shielded pig with a bolted lid. The Sample Pig Shipping Container is sealed with a Neoprene O-ring and the lid is bolted with eight hex-head SS bolts. The 208 L (55-gal) (UN1A2) drum is sealed with a gasket and a bolted lock ring is tightened around the outside of the drum lid. The N-55 overpack has a Neoprene gasket at the stepped joint between the upper and lower section of the overpack. Four toggle clamps on the outside of the N-55 overpack connect the upper and lower sections.

7.2.2 Mechanical Properties of Materials

Mechanical properties of the materials are detailed in Table B7-1.

Table B7-1. Mechanical Properties of Materials.

Material description	Temperature °C (°F)	Yield S_y MPa (ksi)	Ultimate S_u MPa (ksi)	Allowable S_m MPa (ksi)
Galvanized steel	38 (100) 93 (200) 149 (300)	248 (36)	414 (60)	110 (16) 110 (16) 110 (16)
ASTM A312 304L SS pipe	38 (100) 93 (200) 149 (300)	172 (25) 148 (21.4) 132 (19.2)	483 (70) 456 (66.2) 420 (60.9)	115 (16.7) 115 (16.7) 115 (16.7)
ASTM A182 Grade F 304L SS pipe flange	38 (100) 93 (200) 149 (300)	172 (25) 148 (21.4) 132 (19.2)	448 (65) 424 (61.5) 390 (56.5)	115 (16.7) 115 (16.7) 115 (16.7)
ASTM A240 304L SS plate	38 (100) 93 (200) 149 (300)	172 (25) 147 (21.3) 132 (19.1)	483 (70) 456 (66.2) 420 (60.9)	115 (16.7) 115 (16.7) 115 (16.7)
ASTM A193 Grade B8 304 SS bolting material	38 (100) 93 (200) 149 (300)	207 (30)	517 (75)	69 (10) 8.3 (57) 7.5 (52)

ASTM = American Society for Testing and Materials
SS = stainless steel

7.2.3 Chemical and Galvanic Reactions

The materials of fabrication for the containment vessel, Sample Pig Shipping Container (i.e., SS, lead, and Viton) will not cause significant chemical, galvanic, or other reactions with each other or with the contents.

7.2.4 Size of Package and Cavity

The overall size of the package is detailed in Part A, Section 2.0. The size of the contents cavity is the cavity of the Sample Pig Shipping Container, which is 20.27 cm (7.98 in.) inside diameter (ID) by 33.34 cm (13.125 in.) high.

7.2.5 Weights and Centers of Gravity

The approximate weight of each component of the Sample Pig Transport System are as shown in Table B7-2.

Table B7-2. Sample Pig Transport System Weights.

Packaging component	Weight, kg (lb)
N-55 overpack	90.9 (200)
208 L (55-gal) (UN1A2) drum (with foam spacer)	79.6 (175)
Sample Pig Shipping Container	45.5 (100)
Sample Pig*	45.5 (100)
Total	261.4 (575)

*The Steel Pig weight of 38.6 kg (85 lb) is bounded by the weight of the Sample Pig.

The center of gravity located at the center of the packaging system in the X direction and 58.42 cm (23 in.) from the bottom in the Y direction. See Part B, Section 7.6.1.1 for the calculation.

7.2.6 Tamper-Indicating Feature

The N-55 overpack tamper-indicating feature is evidence tape which is placed over the joint between the top and bottom overpack shells. When intact, the tape provides evidence that the package has not been opened by unauthorized persons.

7.2.7 Positive Closure

The Sample Pig Transport System must have a positive fastening device which cannot be inadvertently opened [10 CFR 71.43(c)]. The Sample Pig Shipping Container has a bolted lid with eight 1.3 cm (0.5-in.) bolts torqued to 27.12 N-m (20 ft-lb). The 208 L (55-gal) drum lid has a locking ring bolt that is torqued to 54.23 N-m (40 ft-lb). The N-55 overpack is securely closed with four toggle clamps.

7.2.8 Lifting and Tiedown Devices

The four lifting locations on the N-55 overpack have previously been approved for a gross weight of 341 kg (750 lb) (NuPac 1987). The Sample Pig Transport System authorized gross weight 273 kg (600 lb) is lower; therefore, the lifting locations meet the 10 CFR 71.45(a) requirement.

The Lifting and Tiedown Yoke Arrangement Drawing (H-2-99129, Part A, Section 9.2) have been shown to meet this requirement for the purposes of lifting the package onto and off the transporter (Part B, Section 7.6.1.2).

There are no tiedown devices that are a structural part of the package.

7.2.9 Brittle Fracture

The Sample Pig, Steel Pig, and Sample Pig Shipping Container are made of austenitic SS and lead. The steel remains ductile at -40 °C (-40 °F) (10 CFR 71.71[c][2]). The bolts are carbon steel and less than 3 cm (1 in.) in diameter, so brittle fracture of the bolts is not a concern at these temperatures as stated in ASME Section III Division 1, Subsection NB-2311 (a)(2). Lead is not susceptible to brittle fracture at this temperature. The O-ring for the Sample Pig Shipping Container is fabricated of Neoprene, which has a performance temperature range of -55 °C (-67 °F) through 140 °C (284 °F).

7.3 NORMAL TRANSFER CONDITIONS

7.3.1 Conditions to be Evaluated

Normal conditions of transport per 10 CFR 71 list conditions to be evaluated and their acceptance criteria. The following conditions evaluated are scenarios and tests to simulate the affects normal conditions of transport have on the package.

- Free drop from 1.2 m (4 ft) onto an unyielding surface in an orientation as to cause maximum damage.
- Vibration normally incident to transportation.
- The application of a uniform load of five times the package weight, in the orientation of transport.
- Penetration of a 6 kg (13 lb), 3.2 cm (1.25 in.) diameter rod 101.6 cm (40 in.) onto the package.
- The application of water spray that simulates rainfall of approximately 5.08 cm (2 in.) per hour for a least one hour.

The above loading cases must be applied with both hot and cold environmental conditions and in combination with the increased and decreased external pressurization.

7.3.2 Acceptance Criteria

Under the normal conditions of transport listed above, it must be demonstrated that the Sample Pig Shipping Container maintains containment and shielding of the tank waste sample.

Criteria based on the NRC Regulatory Guides requires the Sample Pig Shipping Container stresses to remain elastic, with adequate safety margins. The allowable stresses were determine for the ASME B&PV Code, Section II.

7.3.3 Structural Model

Conservative, classical methods of analysis were used to evaluate the stresses induced in the Sample Pig Shipping Container during normal conditions of transport. Classical modelling techniques were also used in conjunction with the analytical methods. Free body diagrams and text, throughout the analyses (Part B, Section 7.6.1) explain how each type of loading was modeled and evaluated. CASKDROP models (PacTec) were used to determine the g-loading based on the crush from the 9 m (30 ft) drop testing. Although, the 9 m (30 ft) drop is accident conditions, it is a worst case drop and therefore is used to demonstrate the 1.2 m (4 ft) requirement is met.

7.3.4 Initial Conditions

The Sample Pig Shipping System was evaluated per 10 CFR 71 conditions (NuPac 1987) and Hanford Site Conditions (Part B, Section 8.0) The initial condition stresses due to thermal loading are added to the normal conditions of transport conditions.

Per 10 CFR 71, the initial conditions for normal conditions of transport for analysis are defined as ambient temperatures between -40 °C (-40 °F) and 37.3 °C (100 °F). Hanford ambient temperatures are between and -32.7 °C (-27 °F) and 46.11 °F (115 °F). The initial internal pressure within the containment system must be considered to be the maximum normal operating pressure, unless a lower internal pressure consistent with the ambient temperature considered to precede and follow the test is more unfavorable.

7.3.4.1 Environmental Heat Loading.

7.3.4.1.1 Hot. The "hot" heat loading required to be evaluated for onsite packages is at 46.1 °C (115 F), in still air with solar insolation.

The maximum Sample Pig Shipping Container temperature due to insolation and decay heat is 87.22 °C (189 °F). Stresses in the wall of the Sample Pig Shipping Container are negligible due to this temperature rise.

7.3.4.1.2 Cold. The "cold" heat loading required to be evaluated for onsite package is at -32.77 °C (-27 °F), in still air and shade.

The temperatures of the Sample Pig Shipping Container will reach the -32.77 °C (-27 °F) during steady state for this conditions. Stresses due to this temperature are also negligible in the Sample Pig Shipping Container.

7.3.4.2 Maximum Pressure Stresses. Calculations and testing were performed to determine resulting stresses encountered on the endplate, cylinder wall, welds, and flange bolts of the Sample Pig Shipping Container when subjected to a reduced external pressure of 3.5 psa absolute (Part B, Section 7.6.1.3). All results of calculations show a large margin of safety over the allowable limits. This is a bounding case between the reduced and increased external pressure.

7.3.5 Structural Evaluations and Conclusions

7.3.5.1 Free Drop. The Sample Pig Transport System was dropped from a height of 30 ft in several orientations onto a hard unyielding surface (WHC 1995). After the package was dropped, the Sample Pig Shipping Container was leak tested (WHC 1995) and met the requirements for leaktight given in ANSI N14.5 of 1×10^{-7} standard cc/s. By meeting the requirements for leaktight following a 9 m (30 ft) drop, the container satisfies the requirements for normal conditions of transport (1.2 m [4 ft] drop).

7.3.5.2 Vibration. The N-55 overpack is certified by the NRC, showing that it can withstand vibrations under normal conditions. An evaluation of the closure bolts for normal conditions of transport vibration was performed (Part B, Section 7.6.1.6) to demonstrate there is no lid slippage or bolt fatigue that occurs during transport. Therefore, the Sample Pig Shipping System satisfies the normal vibration requirements.

7.3.5.3 Compression. The N-55 overpack will support a uniformly distributed load, equal to five times its fully loaded weight, or 1,701 kg (3,750 lb), without generating stress in any packaging material in excess of its yield strength (NuPac 1987). Five times the allowable weight of the Sample Pig Transport System is 1,361 kg (3,000 lb). Therefore this requirement is met.

7.3.5.4 Penetration. A 6 kg (13 lb) rod dropped from a height of 102 cm (40 in.) has negligible effect on the N-55 overpack (NuPac 1987).

7.3.5.5 Water Spray. The surface of the overpack is galvanized steel and will not be adversely affected by water. There are no places on the overpack where water could collect, freeze and potentially damage the overpack. The N-55 overpack is certified under the NRC to provide protection for this requirement.

7.4 ACCIDENT CONDITIONS

7.4.1 Conditions to be Evaluated

Hypothetical accident conditions per 10 CFR 71 list conditions to be evaluated and their acceptance criteria. For hypothetical accident conditions the evaluation is based on the sequential loading scenarios listed below:

- Free drop from 9 m (30 ft) onto an unyielding surface with the package oriented in such a to cause the worst damage.
- Puncture drop of the package 101 cm (40 in.) onto a 15.24 cm (6 in.) diameter bar.
- Exposure of the package to a 801.67 °C (1475 °F) fire for 30 minutes.

The above loading cases must be applied with the previous evaluated initial condition stresses.

7.4.2 Acceptance Criteria

Under the hypothetical accident conditions listed above, it must be demonstrated that the Sample Pig Shipping System maintain containment and shielding of the tank waste.

Criteria taken from the NRC Regulatory Guides requires the Sample Pig Shipping Container stresses not to exceed the allowables in the area of containment closures. Stress allowables used are from ASME B&PV Code Section II.

Leak testing after drop testing must meet a leak rate of 1.36×10^{-5} cc/sec, air or less.

7.4.3 Structural Model

Classical modeling techniques were for the bolt evaluations and the CASKDROP (PacTec) finite element modeling program was used for the *g*-loading evaluation.

7.4.4 Initial Conditions

Initial conditions required for hypothetical accident conditions per 10 CFR 71 are identical to those required by normal conditions of transport.

7.4.4.1 Heat Loading. The heat loading during the impact scenarios also coincides with the normal conditions of transport. Stresses related to the fire temperature loading on the package is negligible (Part B, Section 7.4.5). The fire accident condition temperatures do not affect the material nor add any additional stresses to evaluate.

7.4.4.2 Maximum Pressure Stresses. The maximum pressure stresses are the same as the maximum pressure stresses for normal conditions of transport.

7.4.5 Structural Evaluation and Conclusions

The Sample Pig Shipping System has been demonstrated by drop testing and verification analysis to maintain containment after hypothetical accident conditions.

7.4.5.1 Free Drop. The Sample Pig Transport System was dropped 9 m (30 ft) in several orientations onto a hard unyielding surface. The overpack received only superficial damage. The Sample Pig Shipping Container (primary containment vessel) received no damage, maintained its contents and successfully passed a leak test following the drop (WHC 1995). The leak rate was 1×10^{-7} cc/sec which is 2 orders of magnitude lower than the required leak rate of 1.36×10^{-5} cc/sec, air.

An evaluation was performed to determine the *g*-loading from this 9 m (30 ft) drop (Part B, Section 7.6.1.4). This *g*-loading was then used to evaluate the affects the drop has on the closure bolts (Part B, Section 7.6.1.5).

7.4.5.2 Puncture. The N-55 overpack successfully passed the puncture test when tested by Nuclear Packaging for certification of Type B solids (NuPac 1987). Effects to the Sample Pig Shipping Container for liquids would be negligible, and less severe than caused by the 9 m (30 ft) drop.

7.4.5.3 Thermal. The ability of the package to retain its contents and provide adequate shielding through the hypothetical accident thermal event is demonstrated in Part B, Section 8.0. The maximum temperature that the Sample Pig Shipping Container reaches, which occurs 12 hours after the fire is extinguished, is 81.11 °C (178 °F). This temperature is lower than the 87.22 °C (189 °F) that the Sample Pig Shipping Container (containment boundary) reaches during normal conditions, therefore, the stresses will be less.

7.4.5.4 Immersion - Fissile Material. Authorized contents for the Sample Pig Transport System include only fissile-excepted materials, therefore this immersion does not apply.

7.4.5.5 Immersion - All Packages. Water immersion has no effect on the Overpack, therefore it will have no effect on the packaging system (NuPac 1987).

7.5 REFERENCES

10 CFR 71, "Packaging and Transportation of Radioactive Material," *Code of Federal Regulations*, as amended.

49 CFR 173, "Transportation," *Code of Federal Regulations*, as amended.

ANSI, 1987, *American National Standard for Radioactive Materials - Leakage Tests on Packages for Shipment*, ANSI N14.5, American National Standards Institute, New York, New York.

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

NRC, 1987, *Certificate of Compliance for the NuPac Model N-55 Overpack,* CoC Number 9070, Docket Number 71-9070, U.S. Nuclear Regulatory Commission, Washington, D.C.

NuPac, 1987, *Application for NRC Certificate of Compliance Authorizing Shipment of Nuclear Materials in NuPac Model N-55 Packaging,* Nuclear Packaging, Incorporated, Federal Way, Washington.

7.6 APPENDICES

7.6.1 Design Calculations

7.6.1.1 Weights and Center of Gravity Calculation. The design weight and vertical center of gravity location of the Sample Pig Transport System are shown below. The Sample Pig configuration consist of a Sample Pig Container carried inside an internal spacer assembly. This assembly is contained in the 208 L (55-gal) (UN1A2) drum which is the inner portion of the N-55 overpack system. Figure B7.6.1.1-1 gives the general arrangement of the package configuration with associated dimensions. Table B7.6.1.1-1 contains detailed weight and dimensional data from which the package center of gravity was calculated. The center of gravity dimension, Y_{CG} becomes:

$$Y_{CG} = 23.0 \text{ in.}$$

For the loading conditions to be evaluated, the weight of the tiedown frame must also be included in the center of gravity determination because the acceleration experienced by the N-55 will be experienced by the frame.

The frame is made up of 3 x 2 rectangular structural tubing (0.64 cm [0.25 in.] wall thickness) with four J bolts and four eye bolts attached to the frame ends. Total weight of the tiedown frame is approximately 27 kg (60 lb) with its center of gravity 1.5 in. above the bottom of the frame beams. Themoment to be added to the above calculations is (48 in. + 1.5 in.) (60 lb) = 2,970 in-lb. The vertical center of gravity dimension Y_{CG}, when the frame is included in the calculation becomes:

$$Y_{CG} = 23.86 \text{ in.}$$

Figure B7.6.1.1-1. Sample Pig Arrangement.

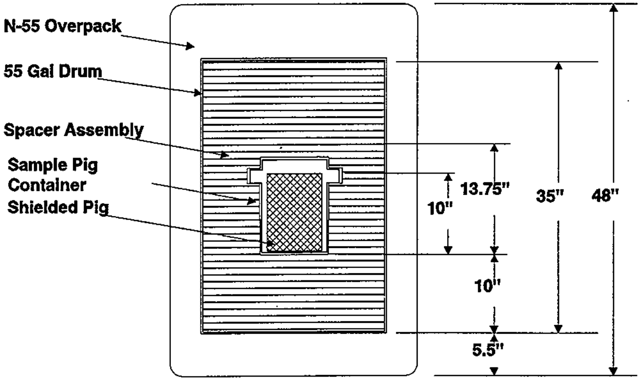


Table B7.6.1.1-1. Vertical Center of Gravity Location, Sample Pig Transport System.

Component	Weight (lb)	Distance from base (in.)	Moment
N-55 overpack	200.0	24.0	4800.0
17H 208 L (55-gal) (UN1A2) drum	55.0	23.0	1265.0
Spacer assembly	120.0	23.0	2760.0
Sample Pig Container	100.0	22.9	2290.0
Sample Pig with contents	125.0	21.0	2625.0
Totals	600.0	-----	13740.0
Center of gravity dimension (in.)			23.0

7.6.1.2 Lifting Analysis. The N-55 package containing the Sample Pig Transport System is lifted onto its transport vehicle by a lift assembly. The lifting portions of the assembly include the frame and J-bolts which are used to lift the upper half of the overpack. The lifting loads and stresses are determined below.

7.6.1.2.1 Lifting Devices. The tiedown frame can be used to lift the assembled N-55 package when loading or unloading the transport vehicle. The frame is attached to the N-55 lifting lugs by four J-bolts which bolt to the ends of the frame. However, the J-bolts are used only to lift the top of the overpack during loading and unloading operations. The maximum load on each J-bolt is 100/2 = 27.73 kg (50 lb). A loaded package could be lifted using straight rods with clevis ends in place of the J-bolts. The following analysis shows that the frame assembly is adequate to lift a loaded overpack.

The lifting load is conservatively assumed to be carried by two of the four bolt and clevis assemblies. The load per bolt is then

$$W_b = \frac{800}{2} = 181.82\ kg\ (400\ lb)$$

This load is carried through the frame arms to the lifting U bolt welded to the center of the frame.

The lifting induced stresses are calculated below and are to be compared with manufacturer s working load limits for lifting hardware. These are normally 1/5 of breaking loads. For the tiedown frame the working load limit is considered to be the lesser of 1/3 of material yield stress or 1/5 of material ultimate stress. A Safety Margin, SM, will be calculated to evaluate all stress calculations against the above allowables.

$$SM = lesser\ of:\ \frac{0.2\,F_U}{f}\ \ or\ \ \frac{0.33\,F_Y}{f}$$

The frame is constructed of 3 x 2 structural tubing using A500 Grade B steel. Wall thickness of the tubing is 0.64 cm (0.25 in.). Material yield stress, F_y, is 290 MPa (42,000 psi) and ultimate stress, F_u, is 400 MPa (58,000 psi). A-36 steel is used for other parts of the tiedown assembly. F_y is 248 MPa (36,000 psi) and F_u is 400 MPa (58,000 psi).

Based on the loads given above and the loading geometry, the lifting load is considered to be the worst case for the tiedown frame. Lifting analyses for individual portions of the tiedown frame are given below.

7.6.1.2.2 J-bolt. The J-bolts are constructed of A-36 ½-in.-diameter rod. The J bend at the end of the bolt has an inside radius of ½ in. The load per rod, W_R, is assumed to be a maximum of 23 kg (50 lb) as shown above. The J-bolts are not used to lift a loaded overpack. Calculating the tensile stress in the bolt, the minimum tensile area of the bolt is 0.9155 cm^2 (0.1419 in^2) at the threaded portion of the bolt (½ in.-13UNC).

$$f_t = \frac{W_R}{A} = \frac{50}{0.1419} = 2.4 \ MPa \ (352 \ psi)$$

$$SM = \frac{11{,}600}{352} = 16.46$$

NOTE: The straight bolt which could replace the J-bolt for lifting the loaded assembly would be the same diameter as the J-bolt. Since it would experience a 182 kg (400 lb) load rather than a 23 kg (50 lb) load, its Safety Margin would be 1/8 that of the J-bolt or 2.06.

The N-55 lifting lug is assumed to load the rod at the center of the curved portion of the "J." This results in a moment which can be assumed constant along the length of the bolt including the threaded portion (if any) below the nut and washer on the top surface of the frame. This is because the bolt hangs from the nut and passes through a hole in the lower frame which is considerably larger than the bolt diameter. The moment arm from the center of the lifting lug to the centerline of the bolt is

$$L_m = 0.5 + \frac{0.5}{2} = 1.9 \ cm \ (0.75 \ in.)$$

The section modulus of the bolt at the threaded area is

$$S = \frac{\pi d^3}{32} = \frac{\pi (0.425)^3}{32} = 0.123 \ cm^3 \ (0.0075 \ in^3)$$

where d is based on the tensile area given above.

The bending stress becomes:

$$S_b = \frac{M_b}{S} = \frac{50(0.75)}{0.0075} = 34 \ MPa \ (5{,}000 \ psi)$$

Combining the tensile stress with the tensile portion of the bending stress results in a total tensile stress of:

$$eS_T = S_t + S_b = 352 + 5{,}000 = 36 \ MPa \ (5{,}352 \ psi)$$

If the moment can be shown not to reach the threaded portion of the bolt, the highest stress area of the bolt is at the transition from the curved J to the straight shank of the bolt. The tensile area of the bolt at this location is 2.74 cm^2 (0.425 in^2) giving a tensile stress of:

$$f_t = \frac{W_R}{A} = \frac{50}{0.1963} = 1.8 \ MPa \ (255 \ psi)$$

Conservatively using a correction factor for curved beams from *Formulas for Stress and Strain* (Roark and Young 1975), Table 16, Case 2 with R/c = 0.75/0.25 =3.0, k_i = 1.332 the bending stress becomes:

$$S_b = k_i \frac{M_b}{S} = 1.332 \frac{50\,(0.75)}{0.0123} = 28 \ \ MPa\,(4{,}061\ psi)$$

Combining the tensile stress with the tensile portion of the bending stress results in a total tensile stress of:

$$S_T = S_t + S_b = 255 + 4{,}061 = 30 \ \ MPa\,(4{,}316\ psi)$$

Minimum Safety Margin from the two calculations shown above:

$$SM = \frac{\frac{58{,}000}{5}}{5{,}352} = 2.17$$

Therefore, the J-Bolts meet 1/5 of S_u by having a positive safety margin.

The J-Bolts are also evaluated as shown in Section 7.6.1.2.7 to meet the *Hanford Site Hoisting and Rigging Manual* (RL 1993).

7.6.1.2.3 Frame. The lifting load is carried from the frame ends where the bolts attach to the center lifting bail as shown in Figure B7.6.1.2-1 below. The maximum moment in the frame is:

$$M_F = W_R\, l_f = 400(16.5) = 746 \ \ N\text{-}m\,(6{,}600\ in\text{-}lb)$$

The structural tubing has a section modulus, S_x, of 9.48 cm^3 (1.47 in^3). The maximum bending stress is then:

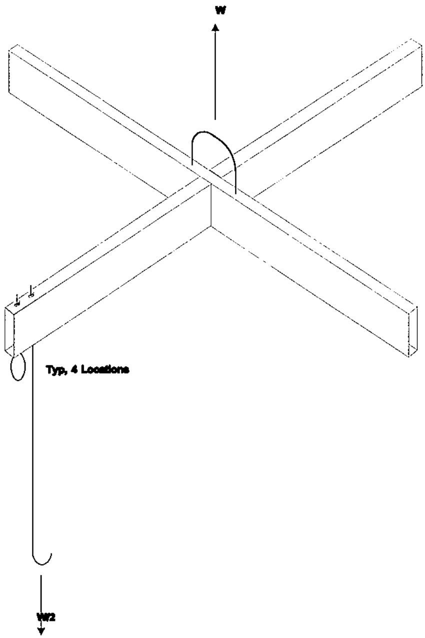
$$f_b = \frac{M_F}{S_Y} = \frac{6{,}600}{1.47} = 31 \ \ MPa\,(4{,}490\ psi)$$

$$SM = \frac{11{,}600}{4{,}490} = 2.58$$

Therefore, the frame meets 1/5 S_u by having a positive safety margin.

7.6.1.2.4. Lifting Bail. The lifting bail is a U-bolt constructed of 3/4 in. rod with an inside diameter of 2 in. The radius of the centerline of the bail, R, is then 1.375 in. The U-bolt material is A-36 steel.

Figure B7.6.1.2-1. Tiedown Frame.



The U-bolt can be considered as of a chain link with a central stud joining the two sides of the link. This configuration is analyzed by *Practical Stress Analysis in Engineering Design* (Blake 1960). The maximum bending moment occurs at the point of loading.

$$M_0 = \frac{WRC_1}{2}$$

Where C_1 is a function of the ratio L/R.

$$C_1 = \frac{(k+2)[k^3 + 6k^2 + 12k(4-\pi) + 48(\pi - 3)]}{k^4 + 4\pi k^3 + 48k^2 + 24\pi k + 24(\pi^2 - 8)}$$

where k = L/R.

Substituting k = 2.5/1.375 = 1.818 gives C_1 = 0.459 and thus the maximum moment becomes:

$$M_0 = \frac{800(1.375)(0.459)}{2} = 28.5\ N\text{-}m\ (252.5\ in\text{-}lb)$$

Similarly, a tensile load, H, is produced at the point of loading

$$H = \frac{WC_2}{2}$$

where C_2 is given by:

$$C_2 = \frac{12(k+2)[(\pi-2)k+2(4-\pi)]}{k^4+4\pi k^3+48k^2+24\pi k+24(\pi^2-8)}$$

Substituting gives $C_2 = 0.407$ and the tensile load becomes:

$$H = \frac{800(0.407)}{2} = 724\ N\ (162.8\ lb)$$

At the point of loading, on the outer surface the maximum tensile stress is due to both the tensile loading, H, and the moment, M_0. The stress due to H is:

$$S_t = \frac{H}{A} = \frac{162.8}{0.442} = 2.5\ MPa\ (368.5\ psi)$$

The bending stress can be calculated for a curved beam using *Formulas for Stress and Strain* (Roark and Young 1975) Table 16, Case 2 with R/c = 3.67. The correction factor for the inner surface is by interpolation, $k_i = 1.24$. The section modulus of the bail is:

$$S_x = \frac{\pi\ d^3}{32} = 0.678\ cm^3\ (0.0414\ in^3)$$

The bending stress on the inner surface of bail (compressive) is:

$$f_b = k_i \frac{M_b}{S} = 1.24 \frac{252.5}{0.0414} = 52\ MPa\ (7{,}560\ psi)$$

The sum of the tensile stress and the compressive bending stress is:

$$S_T = S_t + S_b = 369 + -7{,}560 = -49.6\ MPa\ (-7{,}191\ psi)$$

The tensile stress in one of the bail legs is:

$$f_t = \frac{(0.5\,W_b)}{A_W} = \frac{400}{\pi(0.375)^2} = 6.2\ MPa\ (905psi)$$

The maximum moment in the bail leg is at the frame connection and can be calculated using Eq 29.11b of *Practical Stress Analysis in Engineering Design* (Blake 1960).

$$M = M_0 - \frac{WR}{2} + H(R+x) = 252.5 - \frac{800\,(1.375)}{2} + 162.8\,(1.375+1.25) = 15\ N\text{-}m\ (130\ in\text{-}lb)$$

Bending stress is:

$$f_b = \frac{M_b}{S} = \frac{130}{0.0414} = 21.6\ MPa\ (3{,}136\ \ psi)$$

Combining the tensile portion of the bending stress and the stress due to the tensile load:

$$f_b + f_t = 3{,}136 + 905 = 28\ MPa\ (4{,}041\ \ psi)$$

From above the maximum stress in the bail occurs at the point of loading. The Safety Margin is:

$$SM = \frac{\frac{58{,}000}{5}}{7{,}191} = 1.61$$

Therefore, the bail meets the requirements.

7.6.1.2.5 Frame Welds. Two opposing frame arms are welded to the tube section which forms the other two arms. The attaching welds are continued completely around the attaching tube section. Assume the weld forms a 5.0 cm x 7.6 cm (2 in. x 3 in.) box section with a wall thickness of 0.48 cm (3/16 in.). Treating the weld as a line the effective section modulus of the weld is:

$$S_w = bd + \frac{d^2}{3} = (2.1875)(2.8125) + \frac{(2.8125)^2}{3} = 56.7\ cm^2\ (8.789\ in^2)$$

where b and d are the width and height of the section at the centerline of the weld line. The effective shear area of the weld is:

$$A_w = 2bd = 2(2.1875)(2.8125) = 61.74\ cm^2\ (9.57\ \ in^2)$$

Using a bending moment of 746 N-m (6,600 in-lb) and a shear load of 1,779 N (400 lb), the weld loading becomes:

$$f_w = \left[\left(\frac{400}{9.57} \right)^2 + \left(\frac{6,600}{8.789} \right)^2 \right]^{0.5} = 132\ kN/m\ (752\ \ lb/in)$$

The allowable weld load for a 0.48 cm (3/16 in.) weld is:

$$\tau_w = (0.6)(0.1875)(.707)\left(\frac{58,000}{5} \right) = 161\ kN/m\ (923\ \ lb/in)$$

$$SM = \frac{923}{752} = 1.23$$

The lifting bail is welded to the top surface of the frame using to 0.64 cm (1/4 in.) fillet welds around the base of each leg of the bail. The bail is constructed of 1.9 cm (3/4 in.) A-36 rod. The weld length around one of the legs is:

$$l_w = 0.75\,\pi = 6\ cm\ (2.36\ \ in.)$$

The weld load is:

$$f_w = \frac{0.5\,W_b}{l_w} = \frac{430}{2.36} = 32\ kN/m\ (182.2\ \ lb/in)$$

The allowable weld load is:

$$\tau_w = (0.6)(0.25)(0.707)\left(\frac{58,000}{5} \right) = 215\ kN/m\ (1,230\ \ lb/in)$$

$$SM = \frac{1,230}{182.2} = 6.75$$

7.6.1.2.6 References.

Blake, Alexander, 1960, *Practical Stress Analysis in Engineering Design*, Second Edition, Marcel Dekker, Inc., New York, New York.

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

Roark, R. J., and W. C. Young, 1975, *Formulas for Stress and Strain*, Fifth Edition, McGraw Hill Book Company, New York, New York.

7.6.1.3 Reduced External and Increased External Pressure Analyses.

ENGINEERING SAFETY EVALUATION

Subject Reduced External Pressure - Pig Shipping Container Page 1 of 13
Originator M. D. Clements *Mary D. Clements* Date 8/29/96
Checker S. S. Shiraga *[signature]* Date 8/29/96

I. **Objective:**

The purpose of this analysis is to evaluate the stresses in the Pig Shipping Container due to decreased external pressurization.

II. **References:**

10 CFR 71, "Packaging and Transportation of Radioactive Materials," *Code of Federal Regulations*, as amended.

ASME, 1992a, *Boiler and Pressure Vessel Code*, Section III, Subsection NB American Society of Mechanical Engineers, New York, New York.

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

III. **Results and Conclusions:**

The Pig Shipping Container is evaluated per ASME B&PV Code, Section III (ASME 1992a), internal pressurization. The material properties and allowable stresses are also from ASME B&PV Code, Section VIII (ASME 1992b). Stresses in the wall of the container and at each end are evaluated. The areas evaluated are at the discontinuity between the wall of the container, and the flange and bottom plate.

Large positive margins of safety demonstrate that the Pig Shipping Container can easily withstand reduced external pressurization per 10 CFR 71. This stress is also added to the bolt drop stress analysis. These stresses are larger than the increased external pressure and therefore envelop the pressurization stresses.

ENGINEERING SAFETY EVALUATION

Subject Reduced External Pressure - Pig Shipping Container Page 2 of 13
Originator M. D. Clements [signature] Date 8/29/96
Checker S. S. Shiraga [signature] Date 8/21/96

IV. Evaluation:

Internal pressure of Pig Shipping Container:

Pressure differential: Assume atmospheric pressure of 14.7 psi and subtract the reduced external pressure of 3.5 psi. Therefore, the pressure differential and internal pressure is 11.2 psi. This is the worst case pressure loading as required by 10 CFR 71.

$p = 11.2$ psi

The Pig Shipping Container is ASTM A312 304L stainless steel schedule 40 seamless pipe with the following material properties per the ASME B&PV Code Section VIII (ASME 1992b).

Stress allowable at operating temperature range (70-300 °F): $S_a = 16{,}700$ psi

ksi = 1000 psi

Modulus of Elasticity: $E = 29{,}000$ ksi Poisson's ratio: $\nu = 0.3$

The variables to be used in this analysis are defined as followed in reference to the Pig Shipping Container Figure 1.

Outside radius of 8 in. Schedule 40 pipe: $r_o = \frac{8.625}{2}\ in.$ $r_o = 4.313\ in.$

Wall thickness of 8 in. Schedule 40 pipe: $t_c = 0.322$ in.

Thickness of bottom plate: $t_p = 0.25$ in.

Inside radius: $r_i = r_o - t_c$ $r_i = 3.99$ in.

Distance from top of container to evaluation point (weld joint): - $x = 0$ in.

Ratio of outside radius to inside radius: $Y = \frac{r_o}{r_i}$

Ratio of outside radius to intermediate radius: $Z = \frac{r_o}{r_i + \frac{1}{2} t_c}$

Length of container: $L = 10.125 + 3.25 = 13.375$ in.

Constants: $D = \frac{E\, t_c^3}{12\,(1 - \nu^2)}$ $\beta = \left[\frac{3\,(1 - \nu^2)}{\left(r_i + \frac{t_c}{2}\right)^2 t_c^2} \right]^{\frac{1}{4}}$

ENGINEERING SAFETY EVALUATION

Subject Reduced External Pressure - Pig Shipping Container Page 3 of 13
Originator M. D. Clements [signature] Date 6/20/96
Checker S. S. Shiraga [signature] Date 8/25/96

$$F_{11} = \frac{\cosh(\beta\ x)\sin(\beta\ x) - \sinh(\beta\ x)\cos(\beta\ x)}{2}$$

$$F_{12} = \sinh(\beta\ x)\sin(\beta\ x)$$

$$F_{13} = \frac{\cosh(\beta\ x)\sin(\beta\ x) + \sinh(\beta\ x)\cos(\beta\ x)}{2}$$

$$F_{14} = \cosh(\beta\ x)\cos(\beta\ x)$$

$$f_1 = e^{-\beta\ x}\cos(\beta\ x)$$

$$f_2 = e^{-\beta\ x}(\cos(\beta\ x) - \sin(\beta\ x))$$

$$f_3 = e^{-\beta\ x}(\cos(\beta\ x) + \sin(\beta\ x))$$

$$f_4 = e^{-\beta\ x}\sin(\beta\ x)$$

$$B_{11} = \frac{\sinh(2\ \beta\ L) - \sin(2\ \beta\ L)}{2\ (\sinh(\beta\ L)^2 - \sin(\beta\ L)^2)}$$

$$B_{12} = \frac{\cosh(\beta\ 2\ L) - \cos(2\ \beta\ L)}{2\ (\sinh(\beta\ L)^2 - \sin(\beta\ L)^2)}$$

$$B_{22} = \frac{\sinh(2\ \beta\ L) + \sin(2\ \beta\ L)}{2\ (\sinh(\beta\ L)^2 - \sin(\beta\ L)^2)}$$

$$G_{11} = -(\cos(\beta\ L)\sin(\beta\ L) - \sinh(\beta\ L)\cos(\beta\ L))$$

$$G_{12} = \frac{-2\sinh(\beta\ L)\sin(\beta\ L)}{(\sinh(\beta\ L)^2 - \sin(\beta\ L)^2)}$$

$$G_{22} = \frac{-2\ (\cosh(\beta\ L)\sin(\beta\ L) + \sinh(\beta\ L)\cos(\beta\ L))}{(\sinh(\beta\ L)^2 - \sin(\beta\ L)^2)}$$

$$f = \frac{t_c}{r_o}$$

$$F_1 = \frac{3\ (1 - \nu)\ (2 - f^2)\ (1 - f)^2\ (8 - f\ (4 - f)\ (1 - \nu))}{16\ (2 - f)}$$

ENGINEERING SAFETY EVALUATION

Subject Reduced External Pressure - Pig Shipping Container Page 4 of 13
Originator M. D. Clements MDC Date 8/29/96
Checker S. S. Shiraga SSS Date 8/29/96

$$F_2 = \frac{3}{8}(1-f)^2\left[(1-\nu)(2-f^2)+4(1+\nu)\left(1+2\ln\left(\frac{2-f}{2-2f}\right)\right)\right]$$

$$F_3 = \frac{3}{8}(1-\nu)(2-f)(8-f(4-f)(1-\nu))$$

Evaluate stress in cylinder wall:
Primary membrane stress in wall due to internal pressure:

$$S = \left(\frac{p\ r_i}{t_c}\right) + \left(\frac{p}{2}\right) \qquad S = 144.4\ psi$$

Principle stresses developed at any point in the wall of the pipe due to internal pressure is:

Inside surface (primary membrane):

Tangential stress: $\sigma_1 = \frac{p(1+Z^2)}{(Y^2-1)}$ $\sigma_1 = 139\ psi$

Longitudinal stress: $\sigma_2 = \frac{p}{(Y^2-1)}$ $\sigma_2 = 67\ psi$

Radial stress: $\sigma_3 = \frac{p(1-Z^2)}{(Y^2-1)}$ $\sigma_3 = -5\ psi$

Outside surface (primary membrane):

$Z = 1$

Tangential stress: $\sigma_{1o} = \frac{p(1+Z^2)}{(Y^2-1)}$ $\sigma_{1o} = 133\ psi$

Longitudinal stress: $\sigma_{2o} = \frac{p}{(Y^2-1)}$ $\sigma_{2o} = 67\ psi$

Radial stress: $\sigma_{3o} = \frac{p(1-Z^2)}{(Y^2-1)}$ $\sigma_{3o} = 0\ psi$

Primary plus secondary stress in cylindrical shell: $S_s = \frac{2\ p\ Y^2}{(Y^2-1)}$ $S_s = 156\ psi$

ENGINEERING SAFETY EVALUATION

Subject Reduced External Pressure - Pig Shipping Container Page 5 of 13
Originator M. D. Clements Date 8/29/96
Checker S. S. Shiraga Date 8/29/96

Total stress intensities in pipe wall evaluation due to internal pressure:

Primary membrane (inside surface) (outside surface)

Longitudinal: $\sigma_{lc} = |S + \sigma_2|$ $\sigma_{lco} = \sigma_{2o}$

Tangential: $\sigma_{tc} = \sigma_1$ $\sigma_{tco} = \sigma_{1o}$

Radial: $\sigma_{rc} = \sigma_3$ $\sigma_{rco} = \sigma_{3o}$

Secondary (inside surface maximum):

Longitudinal: $S_{lc} = S_s$

Stress intensities (inside):

$SI_{12} = |\sigma_{lc} - \sigma_{tc}|$ $SI_{12} = 72$ psi

$SI_{23} = |\sigma_{tc} - \sigma_{rc}|$ $SI_{23} = 144$ psi

$SI_{34} = |\sigma_{rc} - \sigma_{lc}|$ $SI_{34} = 216$ psi

Stress intensities (outside):

$SI_{12o} = |\sigma_{lco} - \sigma_{tco}|$ $SI_{12o} = 67$ psi

$SI_{23o} = |\sigma_{tco} - \sigma_{rco}|$ $SI_{23o} = 133$ psi

$SI_{34o} = |\sigma_{rco} - \sigma_{lco}|$ $SI_{34o} = 67$ psi

Margin of safety in cylinder due to primary membrane stresses:

$$MS_{pc} = \frac{S_a}{SI_{34}} - 1 \qquad MS_{pc} = 76$$

Margin of safety in cylinder due to primary and secondary stresses:

$$MS_{sc} = \frac{3\ S_a}{SI_{34} + S_s} - 1 \qquad MS_{sc} = 134$$

ENGINEERING SAFETY EVALUATION

Subject Reduced External Pressure - Pig Shipping Container Page 6 of 13
Originator M. D. Clements Date 8/29/96
Checker S. S. Shiraga Date 8/28/96

Evaluate discontinuity stresses at junctions:

Displacements in the flat head due to pressure: $\theta_o = \dfrac{F_1}{E\left(\dfrac{t_p}{r_o}\right)^3} p$ $\omega_p = -\left(\dfrac{t_p}{2}\right)\theta_o$

Radial displacement, angular displacement, bending moment, and shear force at weld joint of pipe and flange per ASME Section III (equivalent to ASME Section VIII) Article A-2000 and A-6000.

MathCAD function for solution of simultaneous linear equations.

Given:

$$\frac{-2\,F_3}{3\,E\left(\dfrac{t_c}{r_i}\right)} Q_o + \frac{F_3}{E\,r_i\left(\dfrac{t_c}{r_i}\right)^2} M_o + \omega_p = \left(\frac{B_{11}}{2\,\beta^3 D}\right) Q_o + \left(\frac{B_{12}}{2\,\beta^2 D}\right) M_o + \left(\frac{G_{11}}{2\,\beta^3 D}\right) Q_l + \left(\frac{G_{12}}{2\,\beta^2 D}\right) M_l$$

$$\frac{F_3}{E\,r_i\left(\dfrac{t_c}{r_i}\right)^2} Q_o - \frac{2\,F_3}{E\,r_i^2\left(\dfrac{t_c}{r_i}\right)^3} M_o + \theta_o = -\left[\frac{B_{12}}{2\,\beta^2 D} Q_o + \left(\frac{B_{22}}{2\,\beta\,D}\right) M_o + \left(\frac{G_{12}}{2\,\beta^2 D}\right) Q_l + \left(\frac{G_{22}}{2\,\beta\,D}\right) M_l\right]$$

$$\frac{-2\,F_3}{3\,E\left(\dfrac{t_c}{r_i}\right)} Q_l + \frac{F_3}{E\,r_i\left(\dfrac{t_c}{r_i}\right)^2} M_l + \omega_p = \left(\frac{G_{11}}{2\,\beta^3 D}\right) Q_o + \left(\frac{G_{12}}{2\,\beta^2 D}\right) M_o + \left(\frac{B_{11}}{2\,\beta^3 D}\right) Q_l + \left(\frac{B_{12}}{2\,\beta^2 D}\right) M_l$$

$$\frac{F_3}{E\,r_i\left(\dfrac{t_c}{r_i}\right)^2} Q_l - \frac{2\,F_3}{E\,r_i^2\left(\dfrac{t_c}{r_i}\right)^3} M_l + \theta_o = \left(\frac{G_{12}}{2\,\beta^2 D}\right) Q_o + \left(\frac{G_{22}}{2\,\beta\,D}\right) M_o + \left(\frac{B_{12}}{2\,\beta^2 D}\right) Q_l + \left(\frac{B_{22}}{2\,\beta\,D}\right) M_l$$

Q_o = -0.003 lb/ft Q_l = -0.003 lb/ft

M_o = 66 lb M_l = 48 lb

ENGINEERING SAFETY EVALUATION

Subject Reduced External Pressure - Pig Shipping Container Page 7 of 13
Originator M. D. Clements Date 8/29/96
Checker S. S. Shiraga Date 8/29/96

$$\omega_o = \left(\frac{B_{11}}{2\ \beta^3\ D}\right) Q_o + \left(\frac{B_{12}}{2\ \beta^2\ D}\right) M_o + \left(\frac{G_{11}}{2\ \beta^3\ D}\right) Q_l + \left(\frac{G_{12}}{2\ \beta^2\ D}\right) M_l$$

$$\omega_o = 1.2 \cdot 10^{-4}\ in.$$

$$\Theta_o = -\left[\left(\frac{B_{12}}{2\ \beta^2\ D}\right) Q_o + \left(\frac{B_{22}}{\beta\ D}\right) M_o + \left(\frac{G_{12}}{2\ \beta^2\ D}\right) Q_l + \left(\frac{G_{22}}{2\ \beta\ D}\right) M_l\right]$$

$$\Theta_o = -6.7 \cdot 10^{-4}\ rad$$

$$\omega_l = \left(\frac{G_{11}}{2\ \beta^3\ D}\right) Q_o + \left(\frac{G_{12}}{2\ \beta^2\ D}\right) M_o + \left(\frac{B_{11}}{2\ \beta^3\ D}\right) Q_l + \left(\frac{B_{12}}{2\ \beta^2\ D}\right) M_l$$

$$\omega_l = 2.6 \cdot 10^{-5}\ in.$$

$$\Theta_l = \left(\frac{G_{12}}{2\ \beta^2\ D}\right) Q_o + \left(\frac{G_{22}}{2\ \beta\ D}\right) M_o + \left(\frac{B_{12}}{2\ \beta^2\ D}\right) Q_l + \left(\frac{B_{22}}{\beta\ D}\right) M_l$$

$$\Theta_l = 4.9 \cdot 10^{-4}\ rad$$

Determine discontinuity stresses at each juncture.

Juncture O inside surface: $\sigma_{ol} = 6\ \frac{M_o}{t_c^2}$ $\quad \sigma_{ol} = 3{,}799\ psi$

$$\sigma_{ot} = \frac{E\ \omega_o}{\left(r_i + \frac{t_c}{2}\right)} + \frac{6\ \nu\ M_o}{t_c^2} \qquad \sigma_{ot} = 1{,}967\ psi$$

Juncture O outside surface: $\sigma_{ool} = \frac{-6\ M_o}{t_c^2}$ $\quad \sigma_{ool} = -3{,}799\ psi$

$$\sigma_{oot} = \frac{E\ \omega_o}{\left(r_i + \frac{t_c}{2}\right)} - \frac{6\ \nu\ M_o}{t_c^2} \qquad \sigma_{oot} = -313\ psi$$

ENGINEERING SAFETY EVALUATION

Subject Reduced External Pressure - Pig Shipping Container Page 8 of 13
Originator M. D. Clements Date 8/29/96
Checker S. S. Shiraga Date 8/28/96

Juncture L inside surface: $\sigma_{ll} = \dfrac{6\ M_l}{t_c^2}$ $\sigma_{ll} = 2{,}773\ psi$

$$\sigma_{lt} = \frac{E\ \omega_l}{\left(r_l + \dfrac{t_c}{2}\right)} + \frac{6\ \nu\ M_l}{t_c^2} \qquad \sigma_{lt} = 1{,}011\ psi$$

Juncture L outside surface: $\sigma_{lol} = \dfrac{-6\ M_l}{t_c^2}$ $\sigma_{lol} = -2{,}773\ psi$

$$\sigma_{lot} = \frac{E\ \omega_l}{\left(r_l + \dfrac{t_c}{2}\right)} + \frac{6\ \nu\ M_l}{t_c^2} \qquad \sigma_{lot} = -653\ psi$$

Combination of primary and secondary stresses at both junctures O and L inside and outside surfaces:

Juncture O inside surface:

Longitudinal: $\sigma_1 = \sigma_2 + \sigma_{ol}$

Tangential: $\sigma_t = \sigma_1 + \sigma_{ot}$

Radial: $\sigma_r = \sigma_3$

Juncture O outside surface:

Longitudinal: $\sigma_{lo} = \sigma_{2o} + \sigma_{ool}$

Tangential: $\sigma_{to} = \sigma_{lo} + \sigma_{oot}$

Radial: $\sigma_{ro} = \sigma_{3o}$

Junction L inside surface:

Longitudinal: $\sigma_{lL} = \sigma_2 + \sigma_{ll}$

Tangential: $\sigma_{tL} = \sigma_1 + \sigma_{lt}$

Radial: $\sigma_{rL} = \sigma_3$

ENGINEERING SAFETY EVALUATION

Subject Reduced External Pressure - Pig Shipping Container Page 9 of 13
Originator M. D. Clements *MDC* Date 8/29/96
Checker S. S. Shiraga *SSS* Date 8/28/96

Junction L outside surface:

Longitudinal: $\sigma_{loL} = \sigma_{2o} + \sigma_{lot}$

Tangential: $\sigma_{toL} = \sigma_{1o} + \sigma_{lot}$

Radial: $\sigma_{roL} = \sigma_{3o}$

Stress intensities at Junction O inside surface:

$SI_1 = |\sigma_1 - \sigma_t|$ $SI_1 = 1{,}760$ psi

$SI_2 = |\sigma_t - \sigma_r|$ $SI_2 = 2{,}111$ psi

$SI_3 = |\sigma_r - \sigma_1|$ $SI_3 = 3{,}871$ psi

Margin of safety at Junction O inside surface:

$$MS_{oi} = \frac{3\ S_a}{SI_3} - 1 \qquad MS_{oi} = 12$$

Stress intensities at Junction O outside surface:

$SI_4 = |\sigma_{lo} - \sigma_{to}|$ $SI_4 = 3{,}553$ psi

$SI_5 = |\sigma_{to} - \sigma_{ro}|$ $SI_5 = 179$ psi

$SI_6 = |\sigma_{ro} - \sigma_{lo}|$ $SI_6 = 3{,}732$ psi

Margin of safety at Junction O outside surface:

$$MS_{oo} = \frac{3\ S_a}{SI_6} - 1 \qquad MS_{oo} = 12$$

Stress intensities at Junction L inside surface:

$SI_7 = |\sigma_{lL} - \sigma_{tL}|$ $SI_7 = 1{,}690$ psi

$SI_8 = |\sigma_{tL} - \sigma_{rL}|$ $SI_8 = 1{,}155$ psi

$SI_9 = |\sigma_{rL} - \sigma_{lL}|$ $SI_9 = 2{,}845$ psi

Margin of safety at Junction L inside surface:

$$MS_{li} = \frac{3\ S_a}{SI_9} - 1 \qquad MS_{li} = 16$$

ENGINEERING SAFETY EVALUATION

Subject Reduced External Pressure - Pig Shipping Container Page 10 of 13
Originator M. D. Clements [signature] Date 8/29/96
Checker S. S. Shiraga [signature] Date 8/29/96

Stress intensities at Junction L outside surface:

$SI_{10} = |\sigma_{loL} - \sigma_{toL}|$ $SI_{10} = 2{,}187$ psi

$SI_{11} = |\sigma_{toL} - \sigma_{roL}|$ $SI_{11} = 519$ psi

$SI_{12} = |\sigma_{roL} - \sigma_{loL}|$ $SI_{12} = 2{,}706$ psi

Margin of safety at Junction L outside surface:

$$MS_{lo} = \frac{3\ S_a}{SI_{12}} - 1 \qquad MS_{lo} = 17$$

Evaluate stress in flat head (closure lid and bottom): $x = \frac{t_p}{2}$

Primary membrane: $\sigma_{hl} = \left(x - \frac{t_p}{2}\right)\frac{p}{t_p}$ $\sigma_{hl} = 0\ psi$

Therefore, all primary membrane stresses = 0 psi

Primary bending:

Tangential: $$\sigma_{ht} = \frac{x\ p}{t_p\left(\frac{t_p}{r_o}\right)^2}\left[F_2 - \frac{3\ (1 + 3\ \nu)\left(\frac{r_o}{2}\right)^2}{4\ r_o^2}\right] \qquad \sigma_{ht} = 3{,}156\ psi$$

Radial: $$\sigma_{hr} = \frac{x\ p}{t_p\left(\frac{t_p}{r_o}\right)^2}\left[F_2 - \frac{3\ (3 - \nu)\left(\frac{r_o}{2}\right)^2}{4\ r_o^2}\right] \qquad \sigma_{hr} = 2{,}906\ psi$$

Primary stress intensities:

$SI_{lt} = |\sigma_{hl} - \sigma_{ht}|$ $SI_{lt} = 3{,}156$ psi

$SI_{tr} = |\sigma_{ht} - \sigma_{hr}|$ $SI_{tr} = 250$ psi

$SI_{rl} = |\sigma_{hr} - \sigma_{hl}|$ $SI_{rl} = 2{,}906$ psi

ENGINEERING SAFETY EVALUATION

Subject Reduced External Pressure - Pig Shipping Container Page 11 of 13
Originator M. D. Clements *MDC* Date 8/29/96
Checker S. S. Shiraga *SSS* Date 8/29/96

Margin of safety primary membrane plus bending:

$$MS_{pb} = \frac{1.5\ S_a}{SI_{lt}} - 1 \qquad MS_{pb} = 7.$$

Evaluate flange junctions per Roark Fourth Edition (page 302, Case 13).

Cross sectional area of flange:

$R_o = 9\ 11/16$ in. $\qquad R_i = 8.625$ in. $\qquad t_f = R_o - R_i$

$A = R_o \cdot t_f \qquad c = 1.75$ in. $\qquad R_2 = r_o - ½\ t_c$

$$\lambda = \left(\frac{3\ (1 - \nu^2)}{R_2^2\ t_2^2}\right)^{\frac{1}{4}}$$

$$M_o = \left(\frac{P}{2\ \lambda^2}\right) \frac{A}{A + t_c\ c + \frac{2\ t_c}{\lambda}} \qquad M_o = 5\ \frac{in}{in}\ lbf$$

Maximum longitudinal bending secondary stress at edge of flange:

$$\sigma_{bf} = \frac{-6\ M_o}{t_c^2} \qquad \sigma_{bf} = -284\ psi$$

Maximum shear load: $V_o = 2\ M_o\ \lambda \qquad V_o = 10.9\ \frac{lbf}{in}$

Maximum hoop secondary radial stress:

$$\sigma_h = \frac{-2\ V_o}{t_c}\ \lambda\ R_2 \qquad \sigma_h = -312\ psi$$

$$\sigma_{h2} = \frac{2\ M_o}{t_c}\ \lambda^2\ R_2 \qquad \sigma_{h2} = 156\ psi$$

Total hoop stress: $\sigma_{hoop} = \sigma_h + \sigma_{h2}$

ENGINEERING SAFETY EVALUATION

Subject Reduced External Pressure - Pig Shipping Container Page 12 of 13
Originator M. D. Clements Date 8/29/96
Checker S. S. Shiraga Date 8/27/96

Maximum longitudinal secondary stress:

$$\sigma_1 = \frac{1.9332\ V_o}{\lambda\ t_c^2} \qquad \sigma_1 = 183\ psi$$

$$\sigma_{12} = -\left(\frac{6\ M_o}{t_c^2}\right) \qquad \sigma_{12} = -284\ psi$$

Total longitudinal stress: $\sigma_{long} = \sigma_1 + \sigma_{12}$

Total secondary tangential stress: $\sigma_{tang} = 0$ psi

Shear primary tangential stress: $\sigma_s = \frac{V_o}{t_c} \qquad \sigma_s = 34\ psi$

Total primary tangential stress: $\sigma_T = \sigma_s + \sigma_{tc}$

Primary longitudinal stress: $S = \sigma_{lc}$

Primary hoop stress: $H = \sigma_{rc}$

Primary stress intensities:

$SI_{12} = |S - \sigma_s|$ $\qquad SI_{12} = 177$ psi

$SI_{23} = |\sigma_s - H|$ $\qquad SI_{23} = 39$ psi

$SI_{31} = |H - S|$ $\qquad SI_{31} = 216$ psi

Margin of safety for primary stress: $MS_p = \frac{S_a}{SI_{31}} - 1 \qquad MS_p = 76.18$

Secondary stress intensities:

$SIs_{12} = |\sigma_{tang} - \sigma_{long}|$ $\qquad SIs_{12} = 101$ psi

$SIs_{23} = |\sigma_{long} - \sigma_{hoop}|$ $\qquad SIs_{23} = 55$ psi

$SIs_{31} = |\sigma_{hoop} - \sigma_{tang}|$ $\qquad SIs_{31} = 156$ psi

ENGINEERING SAFETY EVALUATION

Subject Reduced External Pressure - Pig Shipping Container Page 13 of 13
Originator M. D. Clements [signature] Date 8/29/96
Checker S. S. Shiraga [signature] Date 8/29/96

Margin of safety for secondary plus primary stresses:

$$MS_s = \frac{3\ S_a}{SI_{31} + SIs_{31}} - 1 \qquad MS_s = 133.45$$

Therefore, the Pig Shipping Container has sufficient margins of safety for the reduced external pressure loading. Also, the increased external pressure creates a lower stress of 3.5 psi on the container and therefore, the container will withstand those stresses also.

7.6.1.4 Drop *g*-loading Evaluation. The Sample Pig Shipping Container is carried inside a DOT 17H 208 L (55-gal) (UN1A2) drum, which, in turn, is contained inside an N-55 overpack. The overpack is used to carry radioactive payloads that can be contained in the 208 L (55-gal) (UN1A2) drum and result in an assembly gross weight less than 273 kg (600 lb). The N-55 provides both impact and fire protection because of its layer of foam, which completely surrounds the 208 L (55-gal) (UN1A2) drum.

The Sample Pig Shipping Container is a shielded container roughly 23 cm (9 in.) in diameter by 33 cm (13 in.) long. The lid/container interface consists of a bolted flange with a sealing O-ring. This container is considered to be the containment boundary. The Sample Pig Shipping Container is surrounded by a drum spacer assembly made of layers of a Celotex[4]-like material.

The N-55 has been successfully drop tested as part of its certification process (NuPac 1987). In these tests, a 208 L (55-gal) (UN1A2) drum containing sand was used for the payload which resulted in an assembly weight of 341 kg (750 lb). The tests produced minimal damage to the 208 L (55-gal) (UN1A2) drum. The lid seal remained intact as shown by a post drop leak test. The second test considered was conducted recently to demonstrate the ability of the Sample Pig Transport System to meet the 10 CFR 71 requirements. The Sample Pig Transport System is similar to the Doorstop System in that both payloads are carried in a 208 L (55-gal) drum contained in an N-55 Overpack. In addition both payloads are positioned inside the drum by a spacer assembly constructed of crushable material. The test consisted of three drops at different orientations from a height of 9 m (30 ft). The drop orientations were as follows.

- *End Drop.* The centerline of the overpack is vertical at the instant of impact on the overpack end.
- *Side Drop.* The centerline of the overpack is horizontal at the time of impact on the side of the overpack.
- *Corner Drop.* The center of gravity of the package is directly over the point of impact on the upper "corner" of the overpack. A line connecting the point of impact with the package center of gravity would be vertical at the instant of impact.

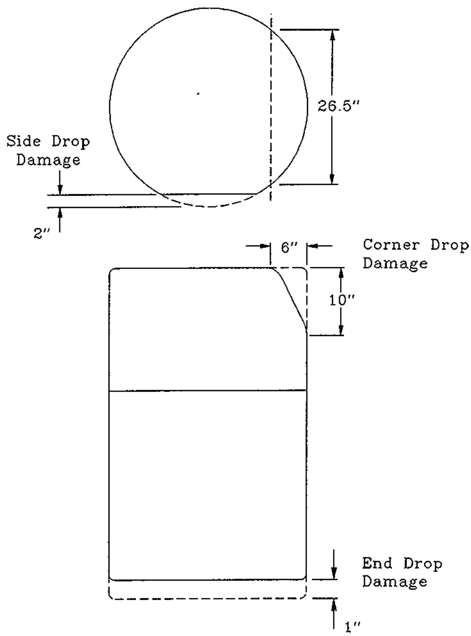
The drop test sequence resulted in no visible damage to the Sample Pig Shipping Container. In addition to the visual inspection, the container was leak tested before and after the drop test and met leak rate requirements in both tests.

The N-55 Overpack experienced permanent deformation from each of the three drops. Inspection of the spacer assembly inside the 208 L (55-gal) (UN1A2) drum showed some deformation had also occurred. This damage resulted from the Sample Pig Container crushing some of the material of the spacer assembly around it. Figure B7.6.1.4-1 below shows the magnitude of the external damage. The amount of deformation can be used to indicate the

[4]Celotex is a trademark of The Celotex Corporation.

impact loads experienced by the overpack during the deformation. This analysis is described below.

Figure B7.6.1.4-1. Sample Pig Drop Test Damage.



The Sample Pig assembly including the N-55 overpack was inspected after the drop test. Measurements were taken of the amount of deformation of the N-55. The deformation of the foam in the N-55 gives some indication of the magnitude of the deceleration experienced during each drop. The magnitude estimates were made using the PacTec computer code CASKDROP. This program is used to develop a force-deflection history of the package from the time of impact until the foam is completely crushed. The amount of energy absorbed during the foam crush is compared with the kinetic energy of the package to determine the amount of crush needed to stop the package. Since the force on the package can be calculated at each increment of deflection, a deceleration value can also be determined at each deflection step. This provides the maximum loading experienced by the package.

In the case of the N-55 with the Sample Pig payload, CASKDROP results show insufficient foam thickness is available to absorb all of the impact energy. This implies that significant damage occurs to the 208 L (55-gal) (UN1A2) drum inside the cask. However, the drop test article shows minimal damage to the drum. Therefore, the material surrounding the Sample Pig must experience significant deformation in order to absorb the energy not absorbed by the external foam. In order to provide some approximation of the inside deformation necessary to absorb this energy, a force deflection curve of the Sample Pig crushing the packing material around it was developed from experimental stress strain data (Figure B7.6.1.4-3). The amount of internal deflection could then be estimated to match the required energy absorption.

The CASKDROP analysis was conducted using the N-55 dimensions with 3.0 lb/ft^3 foam and a total gross weight of 294 kg (646 lb). The weight breakdown is as follows:

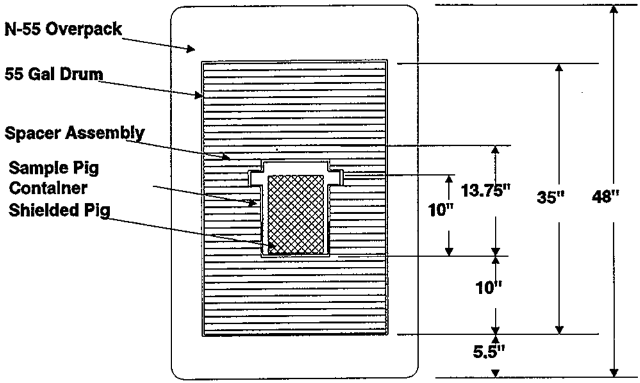
N-55 overpack	91 kg (200 lb)
208 L (55-gal) (UN1A2) drum	25 kg (55 lb)
Inner spacer (upper and lower)	61 kg (135 lb)
Sample Pig Shipping Container	49 kg (107 lb)
Shielded Pig with payload*	46 kg (102 lb)
Lifting assembly	21 kg (47 lb)
Total	294 kg (646 lb)

*The Steel Pig weight of 38.6 kg (85 lb) is bounded by the weight of the Sample Pig.

The dimensions of the package with the Sample Pig payload are shown in Figure B7.6.1.4-2.

CASKDROP runs were made for each of the three drop orientations. A summary of the results for each run is given below.

Figure B7.6.1.4-2. Sample Pig Transport System.



7.6.1.4.1 Side Drop. The side drop analysis results are shown in Table B7.6.1.4-1. Using the input parameters described above, the thickness of foam in the overpack side is insufficient to absorb the total kinetic energy of the falling package. However, an estimated deflection from the drop test described above can be used to obtain a deceleration value and an amount of kinetic energy absorbed by the crushed portion of the overpack. The measured deflection given in Figure B7.6.1.4-1 is 5.1 cm (2 in.). This is the permanent deformation resulting from the side impact. In addition to this deflection, additional elastic deflection also occurs during the impact. This is typically estimated to be approximately 45% of the permanent deflection. Combining the two deflections gives a total crush depth of approximately 7.4 cm (2.9 in.). Using the 2.9 in. deflection given above, Table B7.6.1.4-1 shows a maximum impact acceleration of 151*g*'s with a corresponding 14.3 kN-m (126,804 in-lb) of energy absorbed. This indicates approximately 53% of the total kinetic energy of the package is absorbed by the overpack foam. An indication of sensitivity to the elastic deflection percentage can be gained by using a different value. If more elastic deformation occurred, say 60%, total deflection would be 8.1 cm (3.2 in.) with a resulting impact acceleration of 188.5*g*'s with 66% of the total kinetic energy of the package absorbed by the overpack. Note that even with this amount of deflection there is still a small amount of foam remaining which is not crushed.

Table B7.6.1.4-1. CASKDROP Output, Side Drop.

N-55 Type B Overpack with Sample Pig			
Impact Limiter Weight (each) -	123 lbs	Cask and Payload Weight -	400 lbs
Impact Limiter Outside Diameter -	32.0000 in	Cask Outside Diameter -	25.0000 in
Impact Limiter Overall Length -	24.0000 in	Cask Overall Length -	35.1000 in
Impact Limiter Conical Diameter -	0.0000 in	Dynamic Unloading Modulus -	1.000E+07 lbs/in
Impact Limiter Conical Length -	0.0000 in	Rad Mass Moment of Inertia -	369 lb-in-s²
Impact Limiter End Thickness -	6.5000 in	Frictional Coefficient -	0.0000
Impact Limiter Hole Diameter -	0.0000 in	Drop Height -	30.0000 ft
Impact Limiter Hole Length -	0.0000 in	Drop Angle from Horizontal -	0.0000°
Unbacked Area Threshhold Strain -	0.1000 in/in	Crush Analysis Theory -	Global
Unbacked Area Crush Stress -	87 psi	Number of Integration Incs -	20

POLYFOAM CRUSH STRESS (Axial: "‖" to rise)	
Density = 3.000 pcf Temp = 70.000 °F σ-yield = 153.2 psi Bias = 30.000%	
ε (in/in)	σ (psi)
0.000	0.0
0.100	153.2
0.200	115.8
0.300	112.2
0.400	110.2
0.500	103.6
0.600	105.6
0.650	114.9
0.700	113.0
0.750	84.9
0.800	121.1

POLYFOAM CRUSH STRESS (Radial: "⊥" to rise)	
Density = 3.000 pcf Temp = 70.000 °F σ-yield = 86.6 psi Bias = 30.000%	
ε (in/in)	σ (psi)
0.000	0.0
0.100	86.6
0.200	76.6
0.300	79.4
0.400	86.4
0.500	86.2
0.600	96.5
0.650	99.6
0.700	98.6
0.750	118.9
0.800	176.8

POLYFOAM CRUSH STRESS (Actual Data @ 0.0°)	
Density = 3.000 pcf Temp = 70.000 °F σ-yield = 86.6 psi Bias = 30.000%	
ε (in/in)	σ (psi)
0.000	0.0
0.100	86.6
0.200	76.6
0.300	79.4
0.400	86.4
0.500	86.2
0.600	96.5
0.650	99.6
0.700	98.6
0.750	118.9
0.800	176.8

DEFL (in)	MAX ε (%)	AREA (in2)	VOLUME (in3)	XBAR (in)	IMPACT FORCE (lbs)	ACCEL (g's)	I/L MOMENT (in-lbs)	STRAIN ENERGY (in-lbs)	KINETIC ENERGY (in-lbs)	SE/KE RATIO
0.100	2.86	171	11	0.00	2,837	4.4	0	142	232,625	0.00
0.200	5.71	242	32	0.00	7,697	11.9	0	669	232,689	0.00
0.300	8.57	296	59	0.00	13,163	20.4	0	1,712	232,754	0.01
0.400	11.42	341	91	0.00	18,199	28.2	0	3,280	232,818	0.01
0.500	14.28	381	127	0.00	22,090	34.2	0	5,294	232,883	0.02
0.600	17.13	417	167	0.00	24,806	38.4	0	7,639	232,948	0.03
0.700	19.99	449	211	0.00	26,739	41.4	0	10,216	233,012	0.04
0.800	22.84	480	257	0.00	28,495	44.1	0	12,978	233,077	0.06
0.900	25.70	508	307	0.00	30,431	47.1	0	15,924	233,141	0.07
1.000	28.55	535	359	0.00	32,614	50.5	0	19,077	233,206	0.08
1.100	31.41	560	413	0.00	34,972	54.1	0	22,456	233,271	0.10
1.200	34.26	584	471	0.00	37,386	57.9	0	26,074	233,335	0.11
1.300	37.12	606	530	0.00	39,774	61.6	0	29,932	233,400	0.13
1.400	39.97	628	592	0.00	42,065	65.1	0	34,024	233,464	0.15
1.500	42.83	649	656	0.00	44,201	68.4	0	38,337	233,529	0.16
1.600	45.68	670	722	0.00	46,191	71.5	0	42,857	233,594	0.18
1.700	48.54	689	790	0.00	48,116	74.5	0	47,572	233,658	0.20
1.800	51.39	708	860	0.00	50,097	77.5	0	52,483	233,723	0.22
1.900	54.25	726	931	0.00	52,236	80.9	0	57,599	233,787	0.25
2.000	57.10	744	1,005	0.00	54,542	84.4	0	62,938	233,852	0.27
2.100	59.96	761	1,080	0.00	56,964	88.2	0	68,513	233,917	0.29
2.200	62.81	777	1,157	0.00	59,408	92.0	0	74,332	233,981	0.32
2.300	65.67	793	1,236	0.00	61,684	95.5	0	80,386	234,046	0.34
2.400	68.52	809	1,316	0.00	63,664	98.6	0	86,654	234,110	0.37
2.500	71.38	824	1,398	0.00	65,750	101.8	0	93,125	234,175	0.40
2.600	74.23	839	1,481	0.00	68,729	106.4	0	99,849	234,240	0.43
2.700	77.09	854	1,565	0.00	73,534	113.8	0	106,962	234,304	0.46
2.800	79.94	868	1,652	0.00	80,518	124.6	0	114,664	234,369	0.49
2.900	82.80	882	1,739	0.00	89,173	138.0	0	123,149	234,433	0.53
3.000	85.65	895	1,828	0.00	99,062	153.3	0	132,561	234,498	0.57
3.100	88.51	909	1,918	0.00	109,976	170.2	0	143,012	234,563	0.61
3.200	91.36	922	2,010	0.00	121,794	188.5	0	154,601	234,627	0.66
3.300	94.22	934	2,103	0.00	134,373	208.0	0	167,409	234,692	0.71
3.400	97.07	947	2,197	0.00	147,662	228.6	0	181,511	234,756	0.77
3.500	99.93	959	2,292	0.00	161,611	250.2	0	196,975	234,821	0.84

7.6.1.4.2 End Drop. The end drop analysis results are shown in Table B7.6.1.4-2. For this condition, sufficient foam is present to completely absorb the kinetic energy of the entire package. In this case, the total amount of foam crushed to absorb the necessary kinetic energy is 6.9 cm (2.72 in.). The resulting impact acceleration is 157*g*'s. Note that any deflection of the spacer assembly would lessen the load experienced by the Sample Pig below this value.

If the same elastic crush assumptions used for the Side Drop case are used here, an even lower impact load results. Using an elastic plus permanent deflection of 3.8 cm (1.5 in.), (1.45*1.0 ion.), CASKDROP gives an impact of 138.2*g*'s and 113,568 ft-lb of energy absorbed.

7.6.1.4.3 Corner Drop. The corner drop analysis shows inadequate foam is present at the corners to absorb all the energy required. Using the measured deflection as a basis for determining the total impact with a 45% elastic deflection as used above, the total deflection of approximately 18.5 cm (7.3 in.) results. Note that this uses all available foam deflection. CASKDROP gives an impact of 60.3*g*'s and 105,597 ft-lb of energy absorbed. Note that a relatively low percentage of the total energy is absorbed in this case and that the impact acceleration is relatively low. This can be explained by the fact that the increase in volume of crushed foam as the deflection increases is quite low compared to the end drop or side drop cases. This is because the overpack is impacting on its corner. The actual impact in this instance did not occur at the 55° angle as determined by the overpack center of gravity and geometry. The measured crush dimensions shown in Figure B7.6.1.4-1 imply an impact angle of about 30°. The *Pig Shipping Container*

Table B7.6.1.4-2. CASKDROP Output, End Drop. (Sheet 1 of 2)

N-55 Type B Overpack with Sample Pig			
Impact Limiter Weight (each) -	123 lbs	Cask and Payload Weight -	400 lbs
Impact Limiter Outside Diameter -	32.0000 in	Cask Outside Diameter -	25.0000 in
Impact Limiter Overall Length -	24.0000 in	Cask Overall Length -	35.1000 in
Impact Limiter Conical Diameter -	0.0000 in	Dynamic Unloading Modulus -	1.000E+07 lbs/in
Impact Limiter Conical Length -	0.0000 in	Rad Mass Moment of Inertia -	369 lb-in-s²
Impact Limiter End Thickness -	6.5000 in	Frictional Coefficient -	0.0000
Impact Limiter Hole Diameter -	0.0000 in	Drop Height -	30.0000 ft
Impact Limiter Hole Length -	0.0000 in	Drop Angle from Horizontal -	90.0000°
Unbacked Area Threshhold Strain -	0.1000 in/in	Crush Analysis Theory -	Global
Unbacked Area Crush Stress -	153 psi	Number of Integration Incs -	20

POLYFOAM CRUSH STRESS (Axial: "∥" to rise)	
Density = 3.000 pcf Temp = 70.000 °F σ-yield = 153.2 psi Bias = 30.000%	
ε (in/in)	σ (psi)
0.000	0.0
0.100	153.2
0.200	115.8
0.300	112.2
0.400	110.2
0.500	103.6
0.600	105.6
0.650	114.9
0.700	113.0
0.750	84.9
0.800	121.1

POLYFOAM CRUSH STRESS (Radial: "⊥" to rise)	
Density = 3.000 pcf Temp = 70.000 °F σ-yield = 86.6 psi Bias = 30.000%	
ε (in/in)	σ (psi)
0.000	0.0
0.100	86.6
0.200	76.6
0.300	79.4
0.400	86.4
0.500	86.2
0.600	96.5
0.650	99.6
0.700	98.6
0.750	118.9
0.800	176.8

POLYFOAM CRUSH STRESS (Actual Data @ 90.0°)	
Density = 3.000 pcf Temp = 70.000 °F σ-yield = 153.2 psi Bias = 30.000%	
ε (in/in)	σ (psi)
0.000	0.0
0.100	153.2
0.200	115.8
0.300	112.2
0.400	110.2
0.500	103.6
0.600	105.6
0.650	114.9
0.700	113.0
0.750	84.9
0.800	121.1

DEFL (in)	MAX ε (%)	AREA (in2)	VOLUME (in3)	XBAR (in)	IMPACT FORCE (lbs)	ACCEL (g's)	I/L MOMENT (in-lbs)	STRAIN ENERGY (in-lbs)	KINETIC ENERGY (in-lbs)	SE/KE RATIO
0.100	1.54	804	80	0.00	18,202	28.2	0	910	232,625	0.00
0.200	3.08	804	161	0.00	35,824	55.5	0	3,611	232,689	0.02
0.300	4.62	804	241	0.00	52,286	80.9	0	8,017	232,754	0.03
0.400	6.15	804	322	0.00	67,006	103.7	0	13,982	232,818	0.06
0.500	7.69	804	402	0.00	79,405	122.9	0	21,302	232,883	0.09
0.600	9.23	804	483	0.00	88,902	137.6	0	29,717	232,948	0.13
0.700	10.77	804	563	0.00	94,947	147.0	0	38,910	233,012	0.17
0.800	12.31	804	643	0.00	97,655	151.2	0	48,540	233,077	0.21
0.900	13.85	804	724	0.00	97,813	151.4	0	58,314	233,141	0.25
1.000	15.38	804	804	0.00	96,235	149.0	0	68,016	233,206	0.29
1.100	16.92	804	885	0.00	93,735	145.1	0	77,514	233,271	0.33
1.200	18.46	804	965	0.00	91,127	141.1	0	86,758	233,335	0.37
1.300	20.00	804	1,046	0.00	89,227	138.1	0	95,775	233,400	0.41
1.400	21.54	804	1,126	0.00	88,660	137.2	0	104,670	233,464	0.45
1.500	23.08	804	1,206	0.00	89,300	138.2	0	113,568	233,529	0.49
1.600	24.62	804	1,287	0.00	90,833	140.6	0	122,574	233,594	0.52
1.700	26.15	804	1,367	0.00	92,945	143.9	0	131,763	233,658	0.56
1.800	27.69	804	1,448	0.00	95,323	147.6	0	141,176	233,723	0.60
1.900	29.23	804	1,528	0.00	97,651	151.2	0	150,825	233,787	0.65
2.000	30.77	804	1,608	0.00	99,624	154.2	0	160,689	233,852	0.69
2.100	32.31	804	1,689	0.00	101,110	156.5	0	170,726	233,917	0.73
2.200	33.85	804	1,769	0.00	102,153	158.1	0	180,889	233,981	0.77
2.300	35.38	804	1,850	0.00	102,805	159.1	0	191,137	234,046	0.82
2.400	36.92	804	1,930	0.00	103,117	159.6	0	201,433	234,110	0.86

Table B7.6.1.4-2. CASKDROP Output, End Drop. (Sheet 2 of 2)

DEFL (in)	MAX ε (%)	AREA (in2)	VOLUME (in3)	XBAR (in)	IMPACT FORCE (lbs)	ACCEL (g's)	I/L MOMENT (in-lbs)	STRAIN ENERGY (in-lbs)	KINETIC ENERGY (in-lbs)	SE/KE RATIO
2.500	38.46	804	2,011	0.00	102,624	158.9	0	211,720	234,175	0.90
2.600	40.00	804	2,091	0.00	102,076	158.0	0	221,955	234,240	0.95
2.700	41.54	804	2,171	0.00	101,523	157.2	0	232,135	234,304	0.99
2.722	41.87	804	2,189	0.00	101,405	157.0	0	234,318	234,318	1.00
2.800	43.08	804	2,252	0.00	100,980	156.3	0	244,438	234,369	1.04
2.900	44.62	804	2,332	0.00	100,456	155.5	0	254,510	234,433	1.09
3.000	46.15	804	2,413	0.00	99,958	154.7	0	264,530	234,498	1.13
3.100	47.69	804	2,493	0.00	99,492	154.0	0	274,503	234,563	1.17
3.200	49.23	804	2,574	0.00	99,068	153.4	0	284,431	234,627	1.21
3.300	50.77	804	2,654	0.00	98,691	152.8	0	294,319	234,692	1.25
3.400	52.31	804	2,734	0.00	98,393	152.3	0	304,173	234,756	1.30
3.500	53.85	804	2,815	0.00	98,223	152.0	0	314,004	234,821	1.34
3.600	55.38	804	2,895	0.00	98,231	152.1	0	323,826	234,886	1.38
3.700	56.92	804	2,976	0.00	98,468	152.4	0	333,661	234,950	1.42
3.800	58.46	804	3,056	0.00	98,986	153.2	0	343,534	235,015	1.46
3.900	60.00	804	3,137	0.00	99,833	154.5	0	353,475	235,079	1.50
4.000	61.54	804	3,217	0.00	101,031	156.4	0	363,518	235,144	1.55
4.100	63.08	804	3,297	0.00	102,466	158.6	0	373,693	235,209	1.59
4.200	64.62	804	3,378	0.00	103,995	161.0	0	384,016	235,273	1.63
4.300	66.15	804	3,458	0.00	105,421	163.2	0	394,487	235,338	1.68
4.400	67.69	804	3,539	0.00	106,055	164.2	0	405,061	235,402	1.72
4.500	69.23	804	3,619	0.00	104,964	162.5	0	415,612	235,467	1.77
4.600	70.77	804	3,700	0.00	101,282	156.8	0	425,924	235,532	1.81
4.700	72.31	804	3,780	0.00	95,833	148.3	0	435,780	235,596	1.85
4.800	73.85	804	3,860	0.00	91,130	141.1	0	445,128	235,661	1.89
4.900	75.38	804	3,941	0.00	89,747	138.9	0	454,172	235,725	1.93
5.000	76.92	804	4,021	0.00	92,933	143.9	0	463,306	235,790	1.96
5.100	78.46	804	4,102	0.00	99,364	153.8	0	472,921	235,855	2.01
5.200	80.00	804	4,182	0.00	107,416	166.3	0	483,260	235,919	2.05
5.300	81.54	804	4,263	0.00	115,737	179.2	0	494,417	235,984	2.10
5.400	83.08	804	4,343	0.00	124,058	192.0	0	506,407	236,048	2.15
5.500	84.62	804	4,423	0.00	132,379	204.9	0	519,229	236,113	2.20
5.600	86.15	804	4,504	0.00	140,700	217.8	0	532,883	236,178	2.26
5.700	87.69	804	4,584	0.00	149,021	230.7	0	547,369	236,242	2.32
5.800	89.23	804	4,665	0.00	157,342	243.6	0	562,687	236,307	2.38
5.900	90.77	804	4,745	0.00	165,664	256.4	0	578,837	236,371	2.45
6.000	92.31	804	4,825	0.00	173,985	269.3	0	595,820	236,436	2.52
6.100	93.85	804	4,906	0.00	182,306	282.2	0	613,634	236,501	2.59
6.200	95.38	804	4,986	0.00	190,627	295.1	0	632,281	236,565	2.67
6.300	96.92	804	5,067	0.00	198,948	308.0	0	651,760	236,630	2.75
6.400	98.46	804	5,147	0.00	207,269	320.9	0	672,071	236,694	2.84
6.500	100.00	804	5,228	0.00	215,591	333.7	0	693,214	236,759	2.93

Table B7.6.1.4-3. CASKDROP Output, Corner Drop. (Sheet 1 of 2)

N-55 Type B Overpack with Sample Pig			
Impact Limiter Weight (each) -	123 lbs	Cask and Payload Weight -	400 lbs
Impact Limiter Outside Diameter -	32.0000 in	Cask Outside Diameter -	25.0000 in
Impact Limiter Overall Length -	24.0000 in	Cask Overall Length -	35.1000 in
Impact Limiter Conical Diameter -	0.0000 in	Dynamic Unloading Modulus -	1.000E+07 lbs/in
Impact Limiter Conical Length -	0.0000 in	Rad Mass Moment of Inertia -	369 lb-in-s²
Impact Limiter End Thickness -	6.5000 in	Frictional Coefficient -	0.0000
Impact Limiter Hole Diameter -	0.0000 in	Drop Height -	30.0000 ft
Impact Limiter Hole Length -	0.0000 in	Drop Angle from Horizontal -	55.2000°
Unbacked Area Threshhold Strain -	0.1000 in/in	Crush Analysis Theory -	Global
Unbacked Area Crush Stress -	118 psi	Number of Integration Incs -	20

POLYFOAM CRUSH STRESS (Axial: "|" to rise)	
Density = 3.000 pcf Temp = 70.000 °F σ-yield = 153.2 psi Bias = 30.000%	
ε (in/in)	σ (psi)
0.000	0.0
0.100	153.2
0.200	115.8
0.300	112.2
0.400	110.2
0.500	103.6
0.600	105.6
0.650	114.9
0.700	113.0
0.750	84.9
0.800	121.1

POLYFOAM CRUSH STRESS (Radial: "⊥" to rise)	
Density = 3.000 pcf Temp = 70.000 °F σ-yield = 86.6 psi Bias = 30.000%	
ε (in/in)	σ (psi)
0.000	0.0
0.100	86.6
0.200	76.6
0.300	79.4
0.400	86.4
0.500	86.2
0.600	96.5
0.650	99.6
0.700	98.6
0.750	118.9
0.800	176.8

POLYFOAM CRUSH STRESS (Actual Data @ 55.2°)	
Density = 3.000 pcf Temp = 70.000 °F σ-yield = 117.7 psi Bias = 30.000%	
ε (in/in)	σ (psi)
0.000	0.0
0.100	117.7
0.200	97.2
0.300	97.5
0.400	100.4
0.500	96.9
0.600	102.4
0.650	109.2
0.700	107.7
0.750	92.6
0.800	133.1

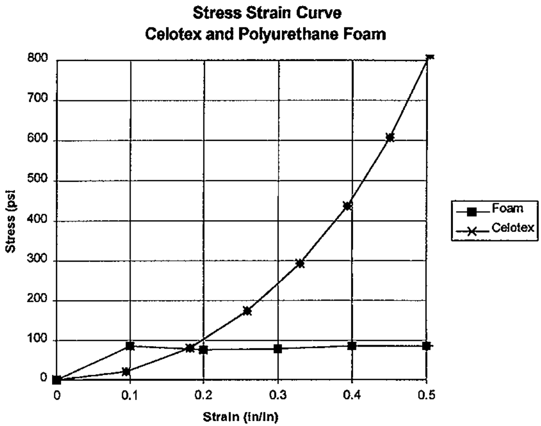
DEFL (in)	MAX ε (%)	AREA (in2)	VOLUME (in3)	XBAR (in)	IMPACT FORCE (lbs)	ACCEL (g's)	I/L MOMENT (in-lbs)	STRAIN ENERGY (in-lbs)	KINETIC ENERGY (in-lbs)	SE/KE RATIO
0.100	1.26	1	0	-0.63	5	0.0	0	0	232,625	0.00
0.200	2.52	2	0	-0.67	30	0.0	0	2	232,689	0.00
0.300	3.78	3	0	-0.71	82	0.1	0	8	232,754	0.00
0.400	5.04	5	1	-0.75	167	0.3	0	20	232,818	0.00
0.500	6.30	7	2	-0.80	287	0.4	0	43	232,883	0.00
0.600	7.56	10	2	-0.84	446	0.7	0	79	232,948	0.00
0.700	8.82	12	3	-0.88	642	1.0	0	134	233,012	0.00
0.800	10.08	15	5	-0.93	875	1.4	0	210	233,077	0.00
0.900	11.34	18	6	-0.97	1,141	1.8	0	310	233,141	0.00
1.000	12.60	21	8	-1.02	1,437	2.2	0	439	233,206	0.00
1.100	13.86	24	11	-1.07	1,757	2.7	0	599	233,271	0.00
1.200	15.13	27	13	-1.12	2,098	3.2	0	792	233,335	0.00
1.300	16.39	31	16	-1.17	2,454	3.8	0	1,019	233,400	0.00
1.400	17.65	35	19	-1.23	2,822	4.4	0	1,283	233,464	0.01
1.500	18.91	38	23	-1.29	3,197	4.9	0	1,584	233,529	0.01
1.600	20.17	42	27	-1.34	3,577	5.5	0	1,923	233,594	0.01
1.700	21.43	46	32	-1.40	3,961	6.1	0	2,300	233,658	0.01
1.800	22.70	50	36	-1.47	4,349	6.7	0	2,715	233,723	0.01
1.900	23.96	54	42	-1.53	4,740	7.3	0	3,170	233,787	0.01
2.000	25.22	58	47	-1.59	5,136	8.0	0	3,663	233,852	0.02
2.100	26.48	63	53	-1.65	5,538	8.6	0	4,197	233,917	0.02
2.200	27.74	67	60	-1.71	5,949	9.2	0	4,771	233,981	0.02
2.300	29.01	72	67	-1.78	6,368	9.9	0	5,387	234,046	0.02
2.400	30.27	76	74	-1.84	6,799	10.5	0	6,046	234,110	0.03

Table B7.6.1.4-3. CASKDROP Output, Corner Drop. (Sheet 2 of 2)

DEFL (in)	MAX e (%)	AREA (in2)	VOLUME (in3)	XBAR (in)	IMPACT FORCE (lbs)	ACCEL (g's)	I/L MOMENT (in-lbs)	STRAIN ENERGY (in-lbs)	KINETIC ENERGY (in-lbs)	SE/KE RATIO
2.500	31.53	81	82	-1.90	7,240	11.2	0	6,748	234,175	0.03
2.600	32.80	85	90	-1.95	7,693	11.9	0	7,494	234,240	0.03
2.700	34.06	90	99	-2.01	8,156	12.6	0	8,287	234,304	0.04
2.800	35.32	95	108	-2.07	8,629	13.4	0	9,126	234,369	0.04
2.900	36.59	100	118	-2.12	9,111	14.1	0	10,013	234,433	0.04
3.000	37.85	105	128	-2.18	9,602	14.9	0	10,949	234,498	0.05
3.100	39.11	110	139	-2.23	10,099	15.6	0	11,934	234,563	0.05
3.200	40.38	115	150	-2.29	10,604	16.4	0	12,969	234,627	0.06
3.300	41.64	121	162	-2.34	11,113	17.2	0	14,055	234,692	0.06
3.400	42.90	126	175	-2.40	11,629	18.0	0	15,192	234,756	0.06
3.500	44.17	131	187	-2.46	12,148	18.8	0	16,381	234,821	0.07
3.600	45.43	137	201	-2.51	12,672	19.6	0	17,622	234,886	0.08
3.700	46.70	142	215	-2.57	13,199	20.4	0	18,915	234,950	0.08
3.800	47.96	148	229	-2.62	13,726	21.2	0	20,261	235,015	0.09
3.900	49.23	153	244	-2.68	14,260	22.1	0	21,661	235,079	0.09
4.000	50.49	159	260	-2.73	14,787	22.9	0	23,113	235,144	0.10
4.100	51.75	165	276	-2.78	15,330	23.7	0	24,619	235,209	0.10
4.200	53.02	170	293	-2.84	15,860	24.6	0	26,178	235,273	0.11
4.300	54.28	176	310	-2.89	16,411	25.4	0	27,792	235,338	0.12
4.400	55.55	182	328	-2.94	16,961	26.3	0	29,460	235,402	0.13
4.500	56.82	188	347	-2.99	17,505	27.1	0	31,184	235,467	0.13
4.600	58.08	194	366	-3.04	18,056	28.0	0	32,962	235,532	0.14
4.700	59.35	200	386	-3.09	18,632	28.8	0	34,796	235,596	0.15
4.800	60.61	206	406	-3.14	19,199	29.7	0	36,688	235,661	0.16
4.900	61.88	212	427	-3.19	19,766	30.6	0	38,636	235,725	0.16
5.000	63.14	218	448	-3.24	20,370	31.5	0	40,643	235,790	0.17
5.100	64.41	224	470	-3.29	20,964	32.5	0	42,710	235,855	0.18
5.200	65.68	230	493	-3.33	21,545	33.4	0	44,835	235,919	0.19
5.300	66.94	236	516	-3.38	22,178	34.3	0	47,021	235,984	0.20
5.400	68.35	242	540	-3.43	22,811	35.3	0	49,271	236,048	0.21
5.500	69.86	249	565	-3.47	23,368	36.2	0	51,580	236,113	0.22
5.600	71.38	255	590	-3.52	23,992	37.1	0	53,948	236,178	0.23
5.700	72.91	261	616	-3.58	24,603	38.1	0	56,377	236,242	0.24
5.800	74.45	268	642	-3.62	25,170	39.0	0	58,866	236,307	0.25
5.900	76.00	274	670	-3.68	25,776	39.9	0	61,413	236,371	0.26
6.000	77.56	280	697	-3.73	26,445	40.9	0	64,024	236,436	0.27
6.100	79.14	287	726	-3.77	27,110	42.0	0	66,702	236,501	0.28
6.200	80.72	293	755	-3.81	27,855	43.1	0	69,450	236,565	0.29
6.300	82.32	300	784	-3.85	28,635	44.3	0	72,275	236,630	0.31
6.400	83.93	306	815	-3.87	29,410	45.5	0	75,177	236,694	0.32
6.500	85.54	313	846	-3.90	30,270	46.9	0	78,161	236,759	0.33
6.600	87.17	319	877	-3.93	31,180	48.3	0	81,234	236,824	0.34
6.700	88.82	326	910	-3.94	32,061	49.6	0	84,396	236,888	0.36
6.800	90.47	333	943	-3.96	33,067	51.2	0	87,652	236,953	0.37
6.900	92.14	339	976	-3.98	34,134	52.8	0	91,012	237,017	0.38
7.000	93.82	346	1,011	-3.99	35,260	54.6	0	94,482	237,082	0.40
7.100	95.51	353	1,046	-4.00	36,399	56.3	0	98,065	237,147	0.41
7.200	97.21	359	1,081	-4.00	37,647	58.3	0	101,767	237,211	0.43
7.300	98.93	366	1,117	-4.01	38,948	60.3	0	105,597	237,276	0.45

Test Report (WHC 1995) indicates that the corner drop test was changed from bottom to top corner because of damage to the N-55 base in the end drop test. Because of this, the attachment hardware was removed and a makeshift harness was used instead. This apparently did not allow sufficient control over the orientation of the package when dropped. Therefore, the deflection values measured are not the same as would occur if the overpack center of gravity were located directly over the impacted corner. With the smaller impact angle, less energy is absorb on initial impact and a large rotational moment is applied to the package causing a large secondary (slapdown) impact. (Post test photos show evidence of slapdown occurring). The deflection values derived above are perhaps somewhat lower than those actually experienced. However, the impact accelerations are quite low for this case and therefore the corner drop is not considered a limiting factor for the design.

Figure B7.6.1.4-3. Spacer Material Stress-Strain Curve.



7.6.1.4.4 Internal Spacer Assembly Analysis. As shown in Figure B7.6.1.4-2, the Sample Pig Container is contained inside the spacer assembly. The spacer assembly is constructed of Celotex boards with a density of approximately 17 lb/ft^3. A stress strain curve was obtained from ORNL and is shown in Figure B7.6.1.4-3. The force deflection curve for 3 lb/ft^3 foam used in the overpack is also shown. The foam is quite stiff through the initial portion of the curve and then shows nearly a constant crush force over a large crush range until the foam material approaches a solid mass. The force to crush the foam further becomes very large and the slope of the force deflection curve increases quickly. The Celotex shows a steadily increasing value of stress with increasing strain. The Celotex becomes stiffer than the foam at about 20% strain. The Celotex will begin to deform prior to the foam because it is softer at small strains. As the deflection increases, the increasing stiffness of the Celotex limits its deflection and thus will provide ample protection for the payload. A conservative estimate of the impact load on the Sample Pig Container is to simply use the value found for the entire assembly. Since additional deflection will occur inside the spacer assembly, the Sample Pig load will be less than that of the complete N-55 assembly.

7.6.1.4.5 References.

NuPac, 1987, *Safety Analysis Report for the NuPac N-55 Packaging*, NRC Docket No. 71-9070, Nuclear Packaging, Inc., Federal Way, Washington.

Roark, R. J. and W. C. Young, 1975, *Formulas for Stress and Strain*, Fifth Edition, McGraw Hill Book Company, New York, New York.

WHC, 1995, *Pig Shipping Container Test Report*, WHC-SD-TP-TR-002, Westinghouse Hanford Company, Richland, Washington.

Woolam, W. E., 1968, *A Study of the Dynamics of Low Energy Cushioning Materials Using Scale Models*, Journal of CELLULAR PLASTICS, New York, New York, February 1968.

7.6.1.4.6 N-55 Yoke J Hook.

ENGINEERING SAFETY EVALUATION

Subject N-55 Yoke J Hook Page 1 of 3
Originator S. S. Shiraga Date 07/19/96
Checker M. D. Clements Date 07/31/96

I. Objective:

The objective of this evaluation is to verify the performance of the N-55 lifting fixture J hooks.

II. References:

49 CFR 393.100, 1996, "Subpart I-Protection Against Shifting and Falling Cargo," *Code of Federal Regulations*, as amended.

Blodgett, O. M., 1976, *Design of Welded Structures*, The James F. Lincoln Arc Welding Foundation, Cleveland, Ohio.

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

RHO, 1978, *Transport Container Tie Down Frame*, drawing H-2-73009, Rev. 2, Rockwell Hanford Operations, Richland, Washington.

WHC, 1987, *Yoke Arrangement N-55 Lifting and Tie Down*, drawing H-2-99129, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

III. Results and Conclusions:

Results of this evaluation show the J hooks on the lifting and tiedown yoke meet the requirements of the *Hanford Site Hoisting and Rigging Manual* (DOE-RL 1993). For the hooks to meet the lifting requirements, all four hooks must be tightly drawn up against the load as specified in the operating procedures. With all four of the J hooks engaged, the minimum safety factor requirements are satisfied. Evaluation of J hook loading is based on classical elastic energy theory.

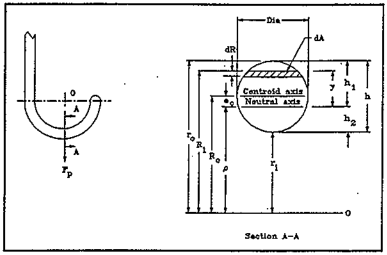
ENGINEERING SAFETY EVALUATION

Subject N-55 Yoke J Hook — Page 2 of 3
Originator S. S. Shiraga — Date 07/19/96
Checker M. D. Clements — Date 07/31/96

IV. Evaluation:

Pig and Doorstop Sampler J Hook Lift Evaluation:

Dimensions (WHC 1987; H-2-99129)



Dia = 0.5 in. $\quad r_i = 0.5$ in.

$r_o = r_i + Dia \quad h = Dia$

$$R_c = r_i + \frac{Dia}{2}$$

Derive stress equation based on elastic energy theory:

From the figure, determine the distance to the neutral axis and eccentricity by geometry:

Distance to neutral axis:

$$\rho = \frac{A}{\int_{r_i}^{r_o} \frac{1}{R_1}\, dA} = \frac{\pi h^2}{4 \int_{r_i}^{r_o} 2\pi \left[1 - \frac{2 R_1 + h}{2\sqrt{R_1^2 + R_1 h}}\right] dR_1}$$

$$\rho = \frac{h^2}{4\left[2\left(r_i + \frac{h}{2}\right) - \sqrt{4\left(r_i + \frac{h}{2}\right)^2 - h^2}\right]}$$

Eccentricity: $\quad e_c = r_i + \frac{h}{2} - \rho$

Maximum stress is at the inner fiber: $\quad \sigma_{max} = \frac{M_c h_2}{A e_c r_i}$

Weight of package: $\quad W_{pack} = 800$ lb $\qquad$ Number of J hooks: $\quad n_j = 4$

Since operating procedures specify tightening the nuts on the J hooks until tight, assume all four engaged.

Load: $\quad F_p = \frac{W_{pack}}{n_j} \qquad F_p = 200\ lb$

Moment about center of bolt from center of load: $\quad M_c = F_p \left(r_i + \frac{h}{2}\right) \qquad M_c = 150\ lb\text{-}in$

ENGINEERING SAFETY EVALUATION

Subject N-55 Yoke J Hook	Page 3 of 3
Originator S. S. Shiraga [signature]	Date 07/19/96
Checker M. D. Clements [signature]	Date 07/31/96

Maximum stress on inside fiber:

$$\sigma_{max} = \frac{4\ M_c\ \rho - r_i}{\pi\ r_i\ h^2 \left[R_c - \frac{h^2}{4\left(2\ R_c - \sqrt{4\ R_c^2 - h^2}\right)}\right]} \qquad \sigma_{max} = 16{,}282\ psi$$

Assume material is ASTM A-36 with a yield strength of: $s_y = 36$ ksi

Safety factor of each J hook: $SF = \frac{s_y}{\sigma_{max}}$ $\qquad SF = 2.21$

Since four J hooks total safety factor:

Total safety factor: $SF_{tot} = n_j\ SF$ $\qquad SF_{tot} = 8.84$

7.6.1.5 Closure Bolt Drop Analysis.

ENGINEERING SAFETY EVALUATION

Subject Pig Accident Drop Bolt Analysis		Page 1 of 6
Originator M. D. Clements	Mary D. Clements	Date 07/22/96
Checker S. S. Shiraga	[signature]	Date 08/05/96

I. Objective:

The purpose of this analysis is to determine the stresses imposed on the Pig Shipping Container due to the 30 ft drop scenario. This analysis is conservative based on assuming the Pig Shipping Container is not protected by the N-55 Overpack system. The Pig Shipping Container lid is an unprotected lid and will be evaluated per NUREG/CR-6007 (LLNL 1993) as such. The maximum *g*-load experienced by the cask is used for both the oblique and side drop cases. Only the oblique and side drop cases will be evaluated since the oblique case is the worst case stress loading on the bolts for a combination of stresses and the side drop is the worst case shear loading.

II. Reference:

LLNL, 1993, *Stress Analysis of Closure Bolts for Shipping Casks*, NUREG/CR-6007, TI 006540, Lawrence Livermore National Laboratory, Livermore, California, January 1993.

III. Results and Conclusions:

The conservative estimate from the 30 ft drop *g*-loading is 188*g*s exerted on the Pig Shipping Container. Evaluation of the prying and non-prying loads exerted on the closure bolts demonstrate that they will withstand a *g*-loading of 190*g*s without yielding. Therefore, the Pig Shipping Container will maintain containment after the 30 ft drop.

ENGINEERING SAFETY EVALUATION

Subject Pig Accident Drop Bolt Analysis — Page 2 of 6
Originator M. D. Clements — Date 07/22/96
Checker S. S. Shiraga — Date 08/05/96

IV. Evaluation:

Forces and moments generated by preload

Non-prying tensile bolt force:

Nominal diameter of bolt: $D_b = 0.75$ in.

Nut factor: $K = 0.2$

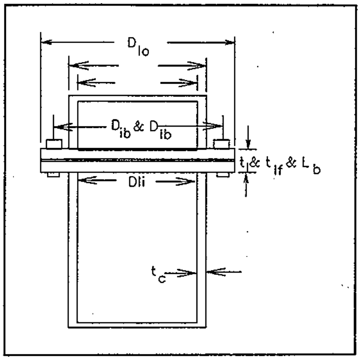
Applied torque: $Q = 20$ ft-lb

$$F_a = \frac{Q}{K\,D_b} \qquad F_a = 1.6 \cdot 10^3\ lb$$

Torsional bolt moment per bolt:

$M_t = 0.5\ Q$

$M_t = 120$ in-lb



Bolt forces generated by gasket loads are neglected due to O-ring configuration (ASME III, Appendix E)

Bolt forces/moments generated by pressure loads:

$D_{lg} = 8.7$ in. $\qquad t_l = 1.75$ in.

$N_b = 8$ $\qquad t_c = 0.322$ in.

$P_{li} = 17$ psi $\qquad P_{ci} = 17$ psi

$P_{lo} = 11.2$ psi $\qquad P_{co} = 11.2$ psi

Modulus of elasticity ASME, Section II at 200 °F:

$E_l = 27{,}600{,}000$ psi $\qquad \mu_l = 0.3$

$E_c = 27{,}600{,}000$ psi $\qquad D_{lb} = 11$ in.

Non-prying bolt force per bolt: $$F_p = \frac{\pi\, D_{lg}^2\,(P_{li} - P_{lo})}{4\,N_b} \qquad F_p = 43.1\ lb$$

ENGINEERING SAFETY EVALUATION

Subject Pig Accident Drop Bolt Analysis — Page 3 of 6

Originator M. D. Clements — Date 07/22/96

Checker S. S. Shiraga — Date 08/05/96

Shear bolt force per bolt:

$$F_{ps} = \frac{E_1\, t_1\, (P_{ci} - P_{co})\, D_{lb}^2}{2\, N_b\, E_c\, t_c\, (1 - \mu_1)} \qquad F_{ps} = 340.5\ lb$$

$$F_f = \frac{D_{lb}\,(P_{li} - P_{lo})}{4}$$

$$M_f = \frac{(P_{li} - P_{lo})\, D_{lb}^2}{32} \qquad M_f = 21.9\ lb$$

Bolt forces/moments generated by temperature loads

- Non-prying tensile bolt force negligible since bolt material and lid material both stainless steel.
- Load caused by thermal expansion difference between the closure lid and cask wall is negligible.

Load caused by temperature gradient between the inner and outer surfaces of the closure lid:

$\alpha_l = 9.9 \cdot 10^{-6}$ in/in-deg $\qquad T_{lo} = 156°$ $\qquad T_{li} = 166°$

$$M_{ft} = \frac{E_1\, \alpha_1\, t_1^2\, (T_{lo} - T_{li})}{12\,(1 - \mu_1)} \qquad M_{ft} = -996.2\ lb$$

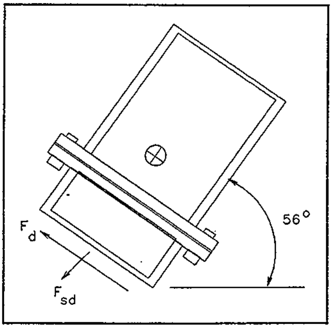
Bolt force/moment generated by impact load applied to unprotected lid (oblique drop):

$a_i = 190$ $\qquad x_i = 56°$ (angle for drop over CG)

DLF = 1 $\qquad W_c = 100$ lb

$W_{ck} = 575$ lb $\qquad W_l = 50$ lb

Width of lid: a = 3.5 in.



Weight applied to lid:

$$W_{lid} = \frac{W_{ck}}{14.8\ in.}\, a$$

$$F_d = \frac{1.34\,\sin(x_i)\, DLF\, a_i\,(W_l + W_c)}{N_b} \qquad F_d = 3.958 \cdot 10^3\ lb$$

Shear bolt force per bolt: $\qquad F_{sd} = \dfrac{\cos(x_i)\, a_i\, W_{lid}}{N_b} \qquad F_{sd} = 1.806 \cdot 10^3\ lb$

ENGINEERING SAFETY EVALUATION

Subject Pig Accident Drop Bolt Analysis — Page 4 of 6
Originator M. D. Clements — Date 07/22/96
Checker S. S. Shiraga — Date 08/05/96

Fixed edge closure force and moment:

$$F_{fd} = \frac{1.34 \sin(x_i)\, DLF\, a_i\, (W_l + W_c)}{\pi\, D_{lb}} \qquad F_{fd} = 1.099 \cdot 10^4 \, \frac{lb}{ft}$$

$$M_{fd} = \frac{1.34 \sin(x_i)\, DLF\, a_i\, (W_l + W_c)}{8\, \pi} \qquad M_{fd} = 1.26 \cdot 10^3 \, lb$$

Bolt force/moment generated by impact load applied to unprotected lid (side drop):

$x_s = 0°$

$$F_{ds} = \frac{1.34 \sin(x_s)\, DLF\, a_i\, (W_l + W_c)}{N_b} \qquad F_{ds} = 0 \, lb$$

Shear bolt force per bolt:

$$F_{sds} = \frac{\cos(x_s)\, a_i\, W_{ck}\, \frac{1}{2}}{N_b} \qquad F_{sds} = 6.828\ 10^3 \, lb$$

Fixed edge closure force and moment (not used because of low force):

$$F_{fds} = \frac{1.34 \sin(x_s)\, DLF\, a_i\, (W_l + W_c)}{\pi\, D_{lb}} \qquad F_{fds} = 0 \, \frac{lb}{ft}$$

$$M_{fds} = \frac{1.34 \sin(x_s)\, DLF\, a_i\, (W_l + W_c)}{8\, \pi} \qquad M_{fds} = 0 \, lb$$

Combine forces and moments to determine bolt stresses due to oblique and side drops:

Oblique drop: $Fa_{pt} = F_p + F_d$ $\qquad Fa_{pt} = 4.001 \cdot 10^3$ lb

$Fa_{al} = F_a$ $\qquad Fa_{al} = 1.6 \cdot 10^3$ lb

Side drop: $Fa_{pts} = F_p + F_{ds}$ $\qquad Fa_{pts} = 43.099$ lb

$Fa_c = Fa_{pt}$

Prying load combination: $Ff_c = F_f + F_{fd}$

$Mf_c = M_f + M_{ft} + M_{fd}$

ENGINEERING SAFETY EVALUATION

Subject Pig Accident Drop Bolt Analysis	Page 5 of 6
Originator M. D. Clements	Date 07/22/96
Checker S. S. Shiraga	Date 08/05/96

Determine maximum prying tensile bolt force:

$P = \frac{Fa_{pt}\ N_b}{\pi\ D_{1b}}$ $\qquad D_{lo} = 13.5$ in. $\qquad t_{lf} = t_l$

$D_{li} = 7.98$ in. $\qquad L_b = t_l \qquad B = P$

$E_{lf} = E_l \qquad E_b = E_l$

$C1 = 1$

$$C2 = \frac{8}{3\,(D_{1o} - D_{1b})^2}\left[\frac{E_1\ t_1^3}{1 - \mu_1} + \frac{(D_{1o} - D_{1i})\ E_{1f}\ t_{1f}^3}{D_{1b}}\right]\frac{L_b}{N_b\ D_b^2\ E_b}$$

$$F_{ap} = \frac{\frac{\pi\ D_{1b}}{N_b}\left[\frac{2\ Mf_c}{D_{1o} - D_{1b}} - C1\,(B - Ff_c) - C2\,(B - P)\right]}{C1 + C2} \qquad F_{ap} = 372.667\ lb$$

Total tensile bolt stresses: $\quad F_t = Fa_c + F_{ap} \qquad F_t = 4.373 \cdot 10^3$ lb

Maximum bending bolt moment:

$$K_b = \frac{N_b}{L_b}\,\frac{E_b}{D_{1b}}\,\frac{D_b^4}{64}$$

$$K1 = \frac{E_1\ t_1^3}{3\left[(1 - \mu_1^2) + (1 - \mu_1^2)\left(\frac{D_{1b}}{D_{1o}}\right)\right] D_{1b}}$$

$$M_{bb} = \left(\frac{\pi\ D_{1b}}{N_b}\right)\left(\frac{K_b}{K_b + K1}\right) Mf_c \qquad M_{bb} = 2.103\ ft\text{-}lb$$

Combine shear forces:

Oblique drop: $Fs_c = F_{ps} + F_{sd} \qquad Fs_c = 2.146 \cdot 10^3$ lb

Side drop: $Fs_{cs} = F_{ps} + F_{sds} \qquad Fs_{cs} = 7.169 \cdot 10^3$ lb

Average tensile stress caused by the tensile bolt force (F_t): $\qquad p =$ pitch

$p = 1/n \qquad n = 10$/in $\qquad D = 0.75$ in.

D_{ba} - D - 0.9743p $\qquad Sba = \frac{1.2732\ F_t}{D_{ba}^2} \qquad Sba = 1.308 \cdot 10^4\ psi$

ENGINEERING SAFETY EVALUATION

Subject Pig Accident Drop Bolt Analysis	Page 6 of 6
Originator M. D. Clements [signature]	Date 07/22/96
Checker S. S. Shiraga [signature]	Date 08/05/96

Average shear stress caused by shear bolt force (Fs_c):

$$Sbs = \frac{1.2732\ Fs_c}{D_{ba}^2} \qquad Sbs = 6.418 \cdot 10^3\ psi$$

Maximum bending stress caused by bending moment (M_{bb}):

$$Sbb = \frac{10.186\ M_{bb}}{D_{ba}^3} \qquad Sbb = 925\ psi$$

Maximum shear stress caused by torsional bolt moment:

$$Sbt = \frac{5.093\ M_t}{D_{ba}^3} \qquad Sbt = 2.2 \cdot 10^3\ psi$$

Maximum stress intensity caused by tension + shear + bending + torsion

$$SI = [(Sba + Sbb)^2 + 4\,(Sbs + Sbt)^2\,]^{0.5} \qquad SI = 2.22 \cdot 10^4\ psi$$

Determine margin of safety on bolts:

$S_y = 30{,}000$ psi $\qquad S_u = 75{,}000$ psi $\qquad S_m = 0.7\ S_u$

Tension margin of safety: $MS_t = \frac{S_y}{Sba} - 1 \qquad MS_t = 1.3$

Shear margin of safety: $MS_s = \frac{0.6\ S_y}{Sbs} - 1 \qquad MS_s = 1.8$

Tension plus shear stress ratio comparison:

$$R_t = \frac{Sba}{0.66\ S_y} \qquad R_s = \frac{Sbs}{0.6\ S_y} \qquad R_t^2 + R_s^2 = 0.56\ [< 1\ \textit{therefore OK}]$$

7.6.1.6 Closure Bolt Vibration Analysis.

ENGINEERING SAFETY EVALUATION

Subject Pig Bolt Vibration Analysis Page 1 of 8
Originator M. D. Clements *[signature]* Date 8/29/96
Checker S. S. Shiraga *[signature]* Date 8/28/96

I. Objective:

The purpose of this analysis is to determine the stresses and reaction of the Pig Shipping Container bolts to normal transport vibration.

II. References:

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

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

Industrial Press, 1980, *Machinery's Handbook*, Twenty-First Edition, Industrial Press, Inc., New York, New York.

LLNL, 1993, *Stress Analysis of Closure Bolts for Shipping Casks*, NUREG/CR-6007, TI 006540, Lawrence Livermore National Laboratory, Livermore, California, January 1993.

Roark, R. J., and W. C. Young, 1975, *Formulas for Stress and Strain*, Fifth Edition, McGraw-Hill Book Company, New York, New York.

III. Results and Conclusions:

The Pig Shipping Container closure bolts, when evaluated per NUREG/CR-6007 (LLNL 1993) for vibration, maintain positive margins of safety against bolt fatigue, lid slippage, bolt loosening, and bolt slippage. This analysis verifies that containment of the Pig Shipping Container is maintained during normal conditions of transport vibrational loadings.

ENGINEERING SAFETY EVALUATION

Subject Pig Bolt Vibration Analysis Page 2 of 8
Originator M. D. Clements Date 8/29/96
Checker S. S. Shiraga Date 8/25/96

IV. Evaluation:

Vibrational Unwinding of Bolts Under Vibrational Loads:

Based on NUREG/CR-6007, *Stress Analysis of Closure Bolts for Shipping Casks* (LLNL 1993).

Definition of Variables:

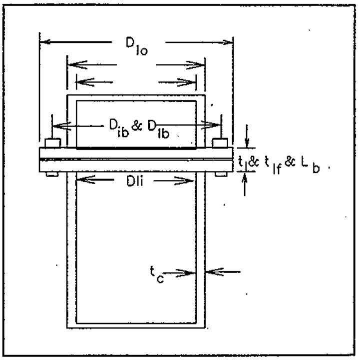
F_{ap}	is the additional tensile bolt force due to prying action of closure lid
D_b	nominal diameter of closure bolt
D_{lb}	closure lid diameter at the bolt circle
D_{li}	closure lid diameter at the inner edge
D_{lo}	closure lid diameter at the outer edge
E_b	elastic modulus of the closure bolt material
E_l	elastic modulus of the closure lid material
E_{lf}	elastic modulus of lid flange material
I_b	bolt area moment of inertia per unit length of the bolt circle
F_f	fixed-edge force of the closure lid at the bolt circle, caused by the applied load (per unit length of the bolt circle)
L_b	bolt length between the top and bottom surfaces of the closure lid at the bolt circle
M_f	fixed-edge moment of the closure lid at the bolt circle caused by the applied load (per unit length of the bolt circle)
N_b	total number of closure bolts
υ_{cl}	Poisson's ratio of the closure lid material
P_u	bolt preload per unit length of the bolt circle
t_l	thickness of the closure lid
t_{lf}	thickness of the flange of the closure lid
$P = F_f$	if $F > P$, otherwise $B = P_u$
P_{load}	preload on each bolt

B is the non-prying tensile bolt force and P_u is the bolt preload. B, P_u, F_f, and M_f are quantities per unit length of bolt circle. To convert a value per bolt to a value per unit length of bolt circle, multiply the value with the factor $[N_b/(\pi D_{lb})]$.

ENGINEERING SAFETY EVALUATION

Subject Pig Bolt Vibration Analysis Page 3 of 8
Originator M. D. Clements *MDC* Date 8/29/96
Checker S. S. Shiraga *SSS* Date 8/29/96

Defining the fixed variables:



$D_b = 0.75$ in. $D_{ib} = 11$ in.

$D_{li} = 7.98$ in. $D_{lo} = 13.5$ in.

$E_b = 29.3 \cdot 10^6$ psi $E_l = 29.3 \cdot 10^6$ psi

$E_{lf} = 29.3 \cdot 10^6$ psi $T = 20$ ft-lb

$L_b = 1.125$ in. $N_b = 8$

$\nu_{cl} = 0.3$ $K = 0.2$

$t_l = 1.125$ in. $t_{lf} = 1.125$ in.

$W_{cask} = 600$ lbf

$$P_{load} = \frac{T}{K\,D_b} \qquad P_{load} = 1.6 \times 10^3\ lb$$

$$P_u = \frac{P_{load}\,N_b}{\pi\,D_{ib}}$$

Calculated variables

Moment of inertia of bolt: $I_{bolt} = \frac{\pi\,D_b^4}{64}$

Bolt area moment of inertia per unit length of the bolt circle: $I_b = \frac{N_b\,I_{bolt}}{\pi\,D_{ib}}$

Determine load and moment at flange (Roark and Young 1975; Case 17, page 367)

For conservatism, assume total weight of lid acts at cg of lid.

Weight of lid: $F_{do} = 13.5$ in. $F_h = 1.5$ in. $F_{di} = 7.98$ in.

den = 0.29 lb/in^3 $V_{fl} = \frac{\pi}{4}\,F_h\left(F_{do}^2 - F_{di}^2\right)$

$W_{fl} = V_{fl}$ den $V_{pl} = \frac{\pi}{4}\,\frac{1}{4}\,9.8^2\ in^3$

ENGINEERING SAFETY EVALUATION

Subject Pig Bolt Vibration Analysis — Page 4 of 8
Originator M. D. Clements — Date 8/29/96
Checker S. S. Shiraga — Date 8/29/96

$$W_{pl} = V_{pl}\ den \qquad V_p = \frac{\pi}{4}\ 1.625\ (8.625^2 - 7.98^2)\ in^3$$

$$W_p = V_p\ den$$

$$W_{lid} = W_p + W_{fl} + W_{pl} \qquad W_{lid} = 49.942\ lb$$

Linear load on unsupported lid section: $w_{lid} = \frac{W_{lid}}{\pi\ D_{li}}$

Deceleration factors for shock induced vibration from ANSI N14.23 (ANSI 1992):

Vertical: $g_{ver} = 2.0$

Longitudinal: $g_{lon} = 2.3$

Lateral: $g_{lat} = 1.6$

$$g_{long} = \sqrt{g_{lon}^2 + g_{lat}^2} = 2.8$$

Since load concentration at cg, use small radius equation. (Roark and Young 1975; page 367, Case 17.

Assume small radius of: $r_o = 1$ in.

Radius of action: $r'_o = \sqrt{1.6\ r_o^2 + t_l^2} - 0.675\ t_l$

Inner radius of lid: $r_{li} = \frac{D_{li}}{2} \qquad r = r_{li}$

The force and moment at the flange ($r = r_{li}$) from Case 17 (Roark and Young 1975) is:

$$M_f = \frac{g_{ver}\ W_{lid}}{4\ \pi} \qquad M_f = 7.948\ lb$$

$$F_f = \frac{W_{lid}\ g_{ver}}{2\ \pi\ r} \qquad F_f = 47.81\ \frac{lb}{ft}$$

The non-prying loads from NUREG/CR-6007 (LLNL 1993; page 19) are:

Tensile force per bolt: $F_t = \frac{g_{ver}\ W_{lid}}{N_b}$

Moment: $M_t = \frac{g_{ver}\ W_{lid}}{8\ \pi}$

ENGINEERING SAFETY EVALUATION

Subject Pig Bolt Vibration Analysis	Page 5 of 8
Originator M. D. Clements	Date 8/29/96
Checker S. S. Shiraga	Date 8/29/96

Shear force per bolt: $F_s = \frac{g_{long} W_{lid}}{N_b}$

Since $P_u > F_f$: $B = P_u$

Equation constants, NUREG/CR-6007 (LLNL 1993; page 6):

$C_1 = 1$

$$C_2 = \left[\frac{8}{3\,(D_{lo} - D_{lb})^2}\right]\left[\frac{E_l\,t_l^3}{1 - \nu_{cl}} + \frac{(D_{lo} - D_{li})\,E_{lf}\,t_{lf}^3}{D_{lb}}\right]\left(\frac{L_b}{N_b\,D_b^2\,E_b}\right)$$

Prying bolt force:

$M_f = M_f + M_t$ and

$$F_{ap} = \left|\frac{\pi\,D_{lb}}{N_b}\left[\frac{\frac{2\,M_f}{D_{lo} - D_{lb}} - C_1\,(B - F_f) - C_2\,(B - P_u)}{C_1 + C_2}\right]\right| \qquad F_{ap} = 1,192\ lb$$

Total loosening force on bolt: $F_{tot} = F_{ap} + F_t$ $\qquad F_{tot} = 1,205$ lb

Torque required to loosen bolt:

Thread data from *Machinery's Handbook* (Industrial Press 1980).

Number of threads per inch: $n_{th} = 10$/in.

Lead on threads: $l_{th} = 1/n_{th}$

Diametrical pitch: $dp_{th} = 0.6832$ in.

Helix angle: $\alpha = atan\left(\frac{l_{th}}{\pi\,dp_{th}}\right) \qquad \alpha = 2.668°$

Assume coefficient of static friction (non-lubricated steel on steel):

$\mu = 0.1995$ $\qquad T_{los} = \frac{D_b}{2}\,P_{load}\,(\mu - \tan(\alpha))$

Torque to overcome frictional bearing force under the bolt head.

ENGINEERING SAFETY EVALUATION

Subject Pig Bolt Vibration Analysis	Page 6 of 8
Originator M. D. Clements *MDC*	Date 8/29/96
Checker S. S. Shiraga *SSS*	Date 8/29/96

Assume for a hex head cap screw effective bearing surface diameter is:

$d_{eff} = 0.7410$ in. $\qquad T_{head} = \frac{d_{eff}}{2} \mu P_{load}$

Total required torque to loosen cap screw: $\quad T_{loosen} = T_{los} + T_{head} \qquad T_{loosen} = 18\ ft\text{-}lb$

Torque generated from forces to loosen the screw:

$$T_f = \frac{D_b}{2} F_{tot} (\mu - \tan(\alpha)) \qquad T_f = 6\ ft\text{-}lb$$

Margin of safety: $\quad MS_{los} = \frac{T_{loosen}}{T_f} - 1 \qquad MS_{los} = 2$

Therefore, hex head screw will not loosen under peak vibrational longitudinal shock load. Assuming all acting at once.

Check for slippage of the bolt from peak shock loads:

Determine shear load of bolt per inch of head diameter to keep from slipping.

Assume only friction from the head of bolt to lid is generating a shear load.

Assume friction factor same as above for metal to metal: $\quad F_{si} = \frac{\mu P_{load}}{d_{eff}} \qquad F_{si} = 432\ \frac{lb}{in}$

Force per inch of lid diameter tending to move flange:

Radial moment per inch: $\quad |M_f| = 12.519$ lb

Radial bending stress on thin section of lid: $\quad \sigma_r = \frac{6\ |M_f|}{L_b^2}$

Ratio location of head, relative to the distance from the neutral axis to the surface of the lid: rat = ½

$$F_{sh} = rat\ \sigma_r\ L_b \qquad F_{sh} = 32\ \frac{lb}{in}$$

Shear force from longitudinal *g*-load: $\quad F_{shear} = \frac{\frac{1}{2} g_{load} \cdot W_{cask}}{8\ L_b}$

ENGINEERING SAFETY EVALUATION

Subject Pig Bolt Vibration Analysis Page 7 of 8
Originator M. D. Clements Date 8/29/96
Checker S. S. Shiraga Date 8/29/96

Margin of safety: $MS_{sh} = \frac{F_{si}}{F_{sh} + F_{shear}} - 1$ $MS_{sh} = 2$

Therefore, there will not be slippage of the bolt from peak shock loads.

Determine fatigue loading on bolts:

Shear forces from normal vertical vibration:

Loading parameters from ANSI N14.23 Standard (ANSI 1992) for fatigue loading.

Total vertical vibration loading of casks, assume loading of at 2 Hz:

F_{rms} is dependent upon the total weight of the package. Use Table 2 from ANSI N14.23 (ANSI 1992) based upon the total package weight of 600 lb.

$F_{rms} = 84$ lb

Linear load on thin section of lid: $f_{rms} = \frac{F_{rms}}{\pi D_{1i}}$

The non-prying loads from NUREG/CR-6007 (LLNL 1993; page 19) are:

Normal vertical shear force per bolt: $F_a = \frac{F_{rms}}{N_b}$

Total vertical shear force per bolt: $F_{vt} = F_a + F_s$

Total lateral shear force per bolt: $F_{lt} = F_s$

Therefore, the vector resultant force of the above shear forces is:

$F_{tot} = \sqrt{F_{vt}^2 + F_{lt}^2}$ $F_{tot} = 33\ lb$

Cyclic stress on bolts:

Bolt tensile stress area, ASTM F-593 (ASTM 1989; page 290):

$$A_{tb} = 0.7854 \left(D_b - \frac{0.9743}{n_{tb}}\right)^2$$

$\sigma_{tot} = \frac{F_{tot}}{A_{tb}}$ $\sigma_{tot} = 99\ psi$

ENGINEERING SAFETY EVALUATION

Subject Pig Bolt Vibration Analysis	Page 8 of 8
Originator M. D. Clements *MDC*	Date 8/29/96
Checker S. S. Shiraga *SSS*	Date 8/27/96

Stress range: $\sigma_a = \frac{\sigma_{tot}}{2}$

Mean stress on bolts: $\sigma_{stot} = \sigma_a + \frac{P_{load}}{A_{tb}}$ $\sigma_{stot} = 4,833\ psi$

Ratio of mean to range: $\frac{\sigma_a}{\sigma_{stot}} = 0.01$

Number of cycles per trip:

Assume average speed: $v_{veh} = 35$ mph

Distance of travel: $d_{travel} = 20$ mi

Frequency: $f_r = 2$ Hz

$cycl = \frac{f_r\ d_{travel}}{v_{veh}}$ $cycl = 4,114$

Alternating stress intensity for A193, Gr. B7 or B16 with the modulus of elasticity is 30 x 10^6 psi (ASME 1992; Figure I-9.1, page 207).

ksi = 1000 psi E_1 = 30,000 ksi E_{A193} = 29,300 ksi

S_{1alt} = 52,000 psi

Therefore, the alternating stress intensity form ASTM A193 is (assuming only ½ of allowable for conservatism):

$S_{A193} = \frac{E_{A193}}{E_1} S_{1alt}$ $S_{A193} = 5.079 \cdot 10^4\ psi$

The margin of safety from bolt fatigue is: $MS_f = \frac{S_{A193}}{\sigma_{stot}} - 1$ $MS_f = 9.5$

This page intentionally left blank.

8.0 THERMAL EVALUATION

8.1 INTRODUCTION

This section identifies and describes the principal thermal engineering design aspects of the Sample Pig Transport System to demonstrate compliance with the performance requirements of 10 CFR 71.

The Sample Pig Transport System is designed with a totally passive thermal system. The principal physical characteristics of the thermal system consist of an external thermal fire shield (shipping overpack) surrounding a DOT 17C 208 L (55-gal) (UN1A2) drum containing a cylindrical stainless steel shipping container. A detailed physical description can be found in Part A, Section 2.0. The overpack is a sandwich of urethane foam enclosed on the inside by a structural fiberglass shell and on the outside by a non-painted galvanized steel shell.

8.2 THERMAL SOURCE SPECIFICATION

The thermal source used for this evaluation is 3 W which is greater than the maximum possible thermal heat source as described in Part B, Section 2.0.

The highest internal decay heat for any of the payloads is 3 W. Since the internal decay heat is assumed to generate heat in the payloads themselves, rather than recognizing that a portion of the decay heat generation could occur in the shield in the form of gamma heating effects, the temperatures derived for the payload are conservative.

For this analysis, two payload configurations were studied. The first case assumed that a lead liner is used inside the payload region of the Sample Pig Transport System. This results in a maximum payload configuration of 2.90 cm (1.14 in.) diameter by 8.89 cm (3.50 in.) in length. The second case assumed that the entire volume of the payload region is used. This results in a maximum payload configuration of 5.23 cm (2.06 in.) diameter by 12.38 cm (4.875 in.) in length. For these cases the 3 W decay heat load is assumed to be evenly distributed within the respective payload volume. The payload was assumed to be organic material, wood in this analysis. Supporting calculations for the internal heat generation are in Part B, Section 8.6.5.

8.3 SUMMARY OF THERMAL PROPERTIES OF MATERIALS

Material thermal material properties used for analyses were taken from the *Thermophysical Properties of Matter Handbook* (Touloukian 1979), and the *Heat Transfer Data Book* (Fitzroy 1970). These properties are listed in Tables B8-1 through B8-10. Quadratic interpolation and linear extrapolation techniques were used to evaluate properties at temperatures not explicitly defined in the tables.

Table B8-1. Material Properties of Air.

Temperature °C (°F)	Specific heat (Btu/lbm-°F)	Conductivity (Btu/s-in-°F)	Density (lbm/in^3)
4 (40)	0.242	0.00000033	0.000041
227 (440)	0.246	0.00000055	0.000041
338 (640)	0.252	0.00000065	0.000041
671 (1240)	0.270	0.00000095	0.000041

Table B8-2. Material Properties of 304 Stainless Steel

Temperature °C (°F)	Specific heat (Btu/lbm-°F)	Conductivity (Btu/s-in-°F)	Density (lbm/in^3)
21 (70)	0.109	0.000198	0.281
38 (100)	0.111	0.000202	0.281
93 (200)	0.116	0.000215	0.281
204 (400)	0.125	0.000239	0.281
316 (600)	0.130	0.000262	0.281
427 (800)	0.135	0.000284	0.281
649 (1200)	0.140	0.000325	0.281
760 (1400)	0.145	0.000344	0.281
816 (1500)	0.149	0.000354	0.281
871 (1600)	0.151	0.000364	0.281

Normal Emissivity of 0.6 (oxidized surface).

Table B8-3. Material Properties of Lead.

Temperature °C (°F)	Specific heat (Btu/lbm-°F)	Conductivity (Btu/s-in-°F)	Density (lbm/in^3)
20 (68)	0.03	0.000470	0.41
116 (240)	0.03	0.000455	0.41
199 (390)	0.03	0.000415	0.41
310 (590)	0.03	0.000350	0.41

Normal Emissivity of 0.6 (oxidized surface).

Table B8-4. Material Properties of Carbon Steel.

Temperature °C (°F)	Specific heat (Btu/lbm-°F)	Conductivity (Btu/s-in-°F)	Density (lbm/in^3)
21 (70)	0.112	0.000741	0.284
204 (400)	0.124	0.000653	0.284
427 (800)	0.147	0.000554	0.284
593 (1100)	0.173	0.000463	0.284

Normal Emissivity of 0.9 (painted surface) or 0.3 (oxidized galvanized surface), Solar Absorptivity of 0.65 (oxidized galvanized surface per the *Heat Transfer Data Book* (Fitzroy 1970).

Table B8-5. Material Properties of Drum Payload (Wood).

Temperature °C (°F)	Specific heat (Btu/lbm-°F)	Conductivity (Btu/s-in-°F)	Density (lbm/in^3)
4 (40)	0.57	0.00000230	0.253
838 (1540)	0.57	0.00000230	0.253

Table B8-6. Material Properties of Spacer (Low Density Fiberglass).

Temperature °C (°F)	Specific heat (Btu/lbm-°F)	Conductivity (Btu/s-in-°F)	Density (lbm/in^3)
10 (50)	0.19	0.00000042	0.0025
38 (100)	0.19	0.00000048	0.0025
66 (151)	0.19	0.00000054	0.0025
838 (1540)	0.19	0.00000054	0.0025

Normal Emissivity of 0.9.

Table B8-7. Material Properties of High Density Fiberglass.

Temperature °C (°F)	Specific heat (Btu/lbm-°F)	Conductivity (Btu/s-in-°F)	Density (lbm/in^3)
-50 (-58)	0.19	0.00000167	0.090
25 (77)	0.19	0.00000224	0.090
175 (347)	0.19	0.00000336	0.090
300 (572)	0.19	0.00000280	0.090
593 (1100)	0.19	0.00000280	0.090
838 (1540)	0.19	0.00000300	0.090

Normal Emissivity of 0.9.

The material properties of the enhanced air in the two-dimensional model reflect convection as well as account for axial conduction. The properties were determined by calculation as described in Part B, Section 8.6.4. In Table B8-8, k_e/k is the ratio of the effective thermal conductivity of air over the normal conductivity of air.

Table B8-8. Material Properties of Air Enhanced by Convection

	Temperature °C °F)	Specific heat (Btu/lbm-°F)	Conductivity (Btu/s-in-°F)	Density (lbm/in^3)
For $k_e/k=5$	4 (40)	0.242	0.00000050	0.000041
	227 (440)	0.246	0.00000083	0.000041
	338 (640)	0.252	0.00000098	0.000041
	671 (1240)	0.270	0.00000143	0.000041
For $k_e/k=4.0$	4 (40)	0.242	0.00000132	0.000041
	227 (440)	0.246	0.00000220	0.000041
	338 (640)	0.252	0.00000260	0.000041
	671 (1240)	0.270	0.00000380	0.000041

Thermal conductivity for the crushable foam impact limiters was based on data from manufacturer's data sheets. The thermal models conservatively reflect a configuration in which 17.27 cm (6.8 in.) of foam has been crushed to 4.32 cm (1.7 in.). These compacted regions are assumed to have thermal properties of Polyethylene as previously used in the T-3 SARP (WHC 1991). Foam and Polyethylene properties are retained for the fire evaluation. The properties for foam and polyethylene as used in the thermal models are tabulated in Tables B8-9 and B8-10.

Table B8-9. Material Properties of Overpack Foam.

Temperature °C (°F)	Specific heat (Btu/lbm-°F)	Conductivity (Btu/s-in-°F)	Density (lbm/in^3)
21 (70)	0.17	0.00000046	0.0017
204 (400)	0.17	0.00000046	0.0017
207 (405)	0.25	0.00000490	0.0017
816 (1500)	0.25	0.00000926	0.0017

Table B8-10. Material Properties of Crushed Foam (Polyethylene).

Temperature °C (°F)	Specific heat (Btu/lbm-°F)	Conductivity (Btu/s-in-°F)	Density (lbm/in^3)
4 (40)	0.51	0.0000044	0.00668
838 (1540)	0.51	0.0000044	0.00668

8.4 THERMAL EVALUATION FOR NORMAL CONDITIONS OF TRANSPORT

8.4.1 Conditions to be Evaluated

The thermal evaluation of the Sample Pig Transport System under normal conditions of transport, as defined in 10 CFR 71, has been performed by analysis. An alternate condition for Hanford Site specific solar insolation was also analyzed. The worst-case payload configurations have been considered, as described in Part B, Section 8.2.

8.4.2 Acceptance Criteria

The Sample Pig Shipping System is required to maintain containment for the worst-case normal transfer condition thermal loads from -40 °C (-40 °F) to 46.11 °C (115 °F). The external surface temperature must be below 82.22 °C (180 °F) for handling purposes per 49 CFR 173.

8.4.3 Thermal Model

Common thermal analysis models were used for both steady-state and transient evaluation of the normal conditions of transport and transient evaluation of the hypothetical thermal accident. All of the models used for the thermal analysis were developed using the TAP-A finite difference code.

8.4.3.1 Heat Transfer Computer Code Description. The TAP-A computer code solves transient or steady-state temperature distributions using a finite difference method of solution. Multi-dimensional configurations can be analyzed using a combination of coordinates. Computations are performed with provisions for multi-material temperature dependent properties employing conduction, thermal radiation and convection. Boundary conditions may be time-dependent and convection may be to a specified flow rate in which the local heat transfer coefficient may be dependent upon time or a variable temperature difference. This code was originally developed at the Westinghouse Astronuclear Laboratory and documented in 1969 (Pierce 1969). Since then, it has been used extensively at Hanford and has completed the software quality assurance requirements for Impact Level 2 QA applications (Guzek 1990). Configuration control requirements, as outlined in WHC-CM-4-2, *Quality Assurance Manual*, Section QI 3.3, Rev. 1, have been met and the study complies with WHC-CM-6-1, *Standard Engineering Practices*, EP-2.1, Rev. 2, computer Software Configuration Management. HEATING5, a finite difference code that was developed at the Oak Ridge National Laboratory (Turner 1977), has been compared with TAP-A (Jimenez 1990) and was within about 6 percent agreement.

Part B, Section 8.6.6 contains a sample input file for the subject analysis.

8.4.3.2 General Modeling Techniques. Three modes of energy transfer were used in the analysis:

1. Conduction heat transfer within the payload and the materials of the transportation package.

2. Thermal radiation including:
   a. Heat transfer from external surfaces to the environment.
   b. Heat transfer across internal gap surfaces.
   c. Solar insolation to external surfaces.

3. Natural convection from the external surfaces of the package to still air in the environment and air gap convection within the package.

The decay heat from the payload was modeled as internal heat generation.

8.4.3.3 Solar Insolation and Thermal Radiation. The solar insolation boundary condition was modeled in accordance with guidelines provided by the NRC. This is stipulated as 800 g-cal/cm^2 for a 12 hour period for horizontal surfaces and 400 g-cal/cm^2 for vertical curved surfaces (1/2 of the horizontal). The text of 10 CFR 71 does not stipulate how this total heat load is to be applied to the drum on a transient or peak basis. The peak insolation was therefore determined using Hanford Site specific data for transient solar insolation. The *Climatology Summary for the Hanford Area* (PNL 1983) provides an experimental determination of the solar insolation at the Hanford Site based on averaged values over numerous years. The values for an average July day was chosen to give the most conservative results. These values are tabulated in Part B, Section 8.6.2. The Hanford site's maximum solar insolation is approximately 25 percent less than that stipulated in 10 CFR 71.

The solar absorption coefficient was assumed to be 0.65 for oxidized galvanized steel. This value was determined from information found in the *Heat Transfer Data Book* (Fitzroy 1970). The pertinent data from this book is reprinted in Part B, Section 8.6.2. The coefficients are multiplied by the peak solar insolation resulting in a radiative heat load boundary condition at the surface of the overpack. The emissivity coefficients of the package surfaces, external and internal, are tabulated Part B, Section 8.6.3. These values were determined from information found in the *Thermophysical Properties of Matter* (Touloukian 1979), the *Heat Transfer Data Book* (Fitzroy 1970), *Thermal Radiation Heat Transfer* (Seigel 1981), and *Heat Transfer* (Holman 1972). These coefficients are used to calculate the heat loss from the surface of the overpack to the environment by thermal radiation heat transfer and for the internal air gap heat transfer. The view factor for thermal radiation to the environment was assumed to be 1. For the internal air gaps of the package, the effective thermal emissivity of the gap surfaces are required boundary conditions. The method used to calculate these coefficients is described in Part B, Section 8.6.3.

8.4.3.4 Natural Convection. Heat is also rejected from external surfaces of the overpack to the environment by natural convection heat transfer. This mode of heat transfer depends on the temperature difference between the heat rejecting surface and the ambient air, the orientation of the heat rejecting surface, the velocity of air flowing past the surface and the thermophysical properties of air. Part B, Section 8.6.4 provides details of the calculation of the heat transfer coefficient for the convective heat transfer boundary condition. The equations for the calculations were developed from *Heat Transfer* (Holman 1972). For this analysis the air is assumed to be still (zero flow velocity) in accordance with 10 CFR 71.

For the internal air gaps, heat is transferred by a combination of conduction and convection. This mode of heat transfer depends on the temperature difference between the heat rejecting surfaces, the orientation of the heat rejecting surfaces, the gap width and the thermophysical properties of air at the mean air temperature. Part B, Section 8.6.4, provides details of the calculation of the heat transfer coefficient for the convective/conductive heat transfer boundary condition. The equations for the calculations were developed from *Heat Transfer* (Holman 1972).

8.4.3.5 2-D Model With a Payload Lead Liner. The two dimensional model of a Sample Pig Transport System is depicted in Figure B8-1 and B8-2. Figures B8-3 and B8-4 show the internal node and surface node numbers respectively. Due to the symmetry of a Sample Pig Transport System the two-dimensional model only needs to model a 1 radian section of the payload, container, spacers, and overpack.

The configuration of the model's nodes is described in the following paragraphs. Figures B8-3 and B8-4, which depict the node configuration, is not drawn to scale and only shows the relative position of nodes.

The payload region has been divided into two nodal regions, nodes 2 and 3, of equal radial width. These nodes are directly connected to lead liner nodes to model heat conduction without air gaps. The lead liner will have peak temperatures at node 1. The material properties of the payload nodes are aggregate properties meant to represent the bulk properties of an organic based payload (wood) which occupy this space. The material properties of the payload and lead are defined in Part B, Section 8.1.

The stainless steel and lead shielding container are modeled with a series of nodes in the radial and longitudinal directions. The air-filled gap separating the payload liner from the container is modeled to accommodate radiation and convective boundaries. Radiation and air convective heat transfer is also modeled between the outside surface of lead shielding and the interior surface of the Sample Pig Transport System shipping container. The lead in the shield will have peak temperatures at node 7. The material properties of the stainless steel and lead are defined in Section Part B, Section 8.1.

Figure B8-1. Sample Pig Thermal Model Configuration.

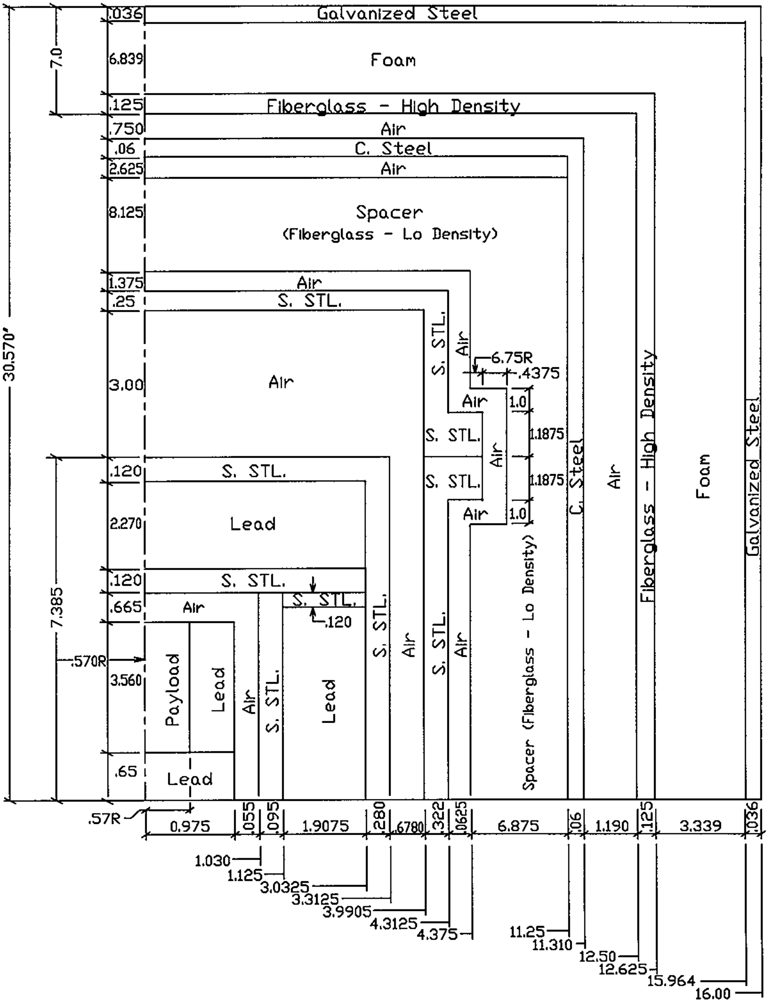


Figure B8-2. Sample Pig Thermal Model Radial Configuration.

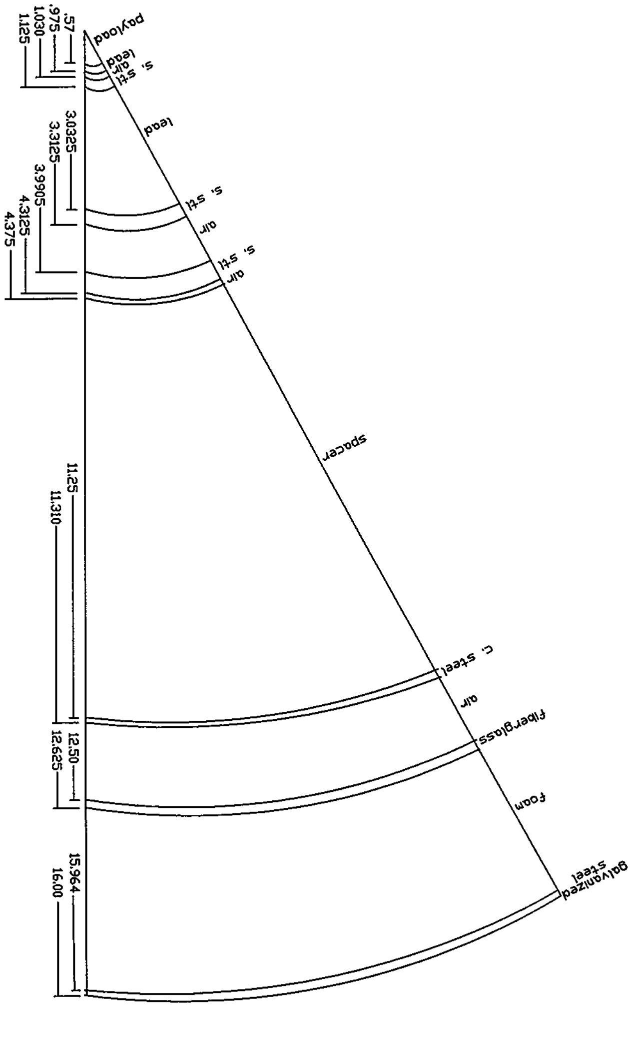


Figure B8-3. Sample Pig Thermal Model Node Network.

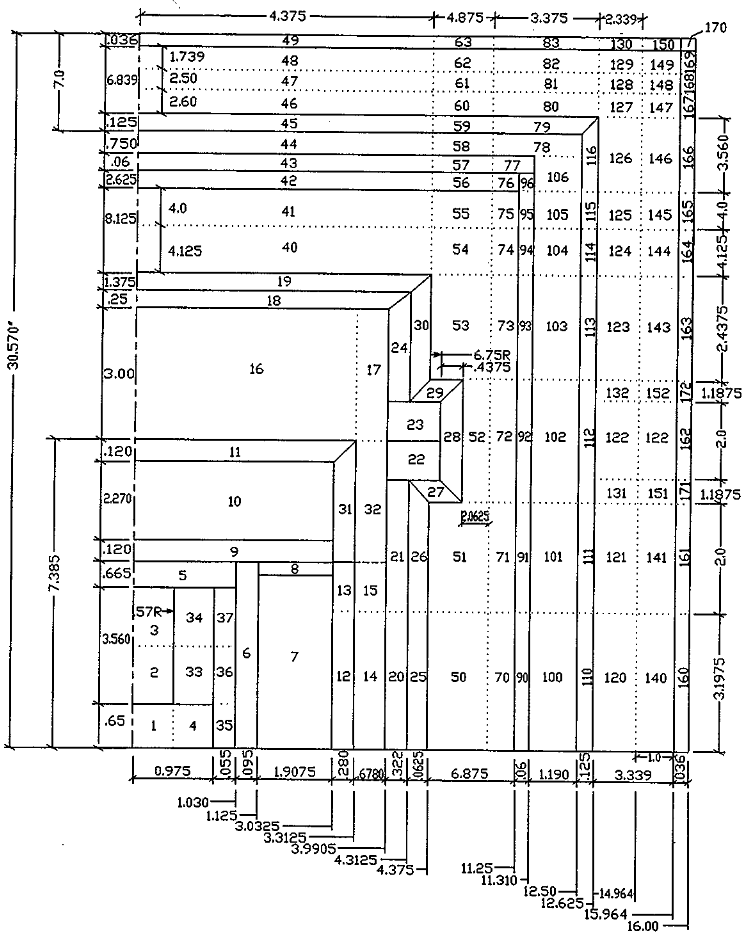
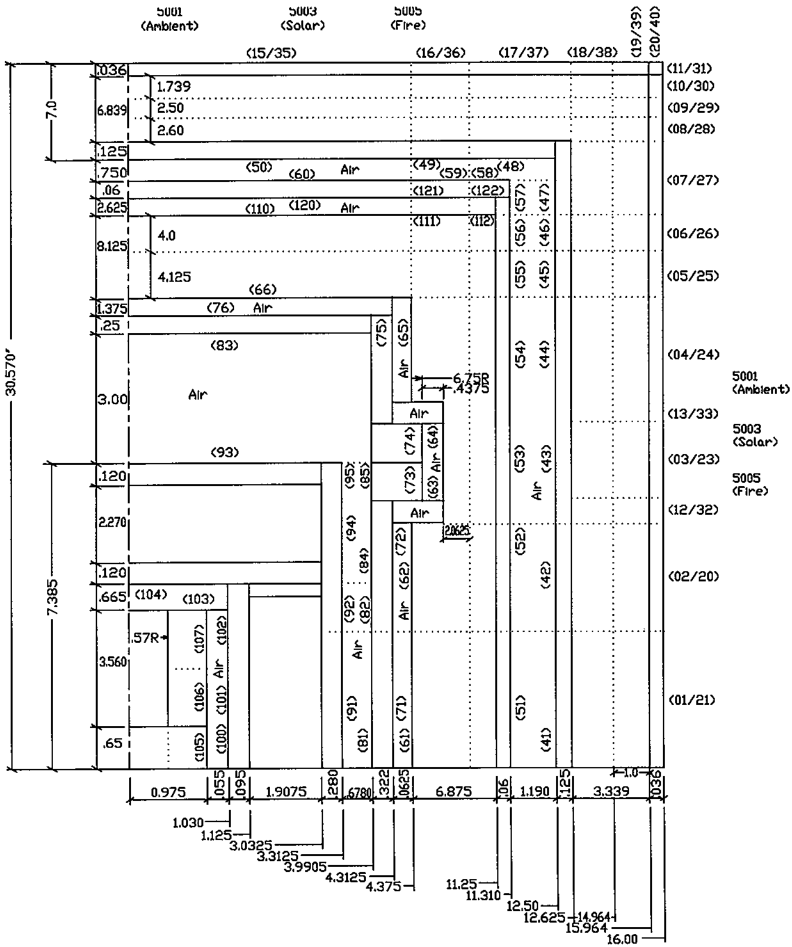


Figure B8-4. Sample Pig Thermal Model Surface Nodes.



The stainless steel payload shipping container is modeled with a series of nodes in the radial and longitudinal directions as well. The air filled gap separating the payload shipping container from the 208 L (55-gal) spacer is modeled to accommodate radiation and convective boundaries. The flanges of the container have been modelled as nodes 22 and 23. The O-ring seal at the flange was not explicitly modelled but will have peak temperatures the same as for node 22. The material properties of the stainless steel is defined in Part B, Section 8.1.

The carbon steel 208 L (55-gal) (UN1A2) drum and internal spacers are modeled with a series of nodes in the radial and longitudinal directions. The air filled gap separating the 208 L (55-gal) (UN1A2) drum and the overpack inner surface is modeled to accommodate radiation and convective boundaries. The model also accommodates an air gap between the top spacer and the drum lid. No air gaps were used between the sides of the spacers and the drum nor between individual spacer layers. The drum gasket was not explicitly modelled but will have peak temperatures the same as for node 77. The material properties of the carbon steel and spacer (low density fiberglass) are defined in Part B, Section 8.1.

The overpack with inner and outer shells and internal foam insulation are modeled with a series of nodes in the radial and longitudinal directions. The overpack outer surface is modeled to accommodate radiation and convective boundaries. No air gaps were used between the sides of the foam and the overpack liners nor between individual foam layers. The overpack gasket was not explicitly modelled but will have peak temperatures the same as for node 152. The material properties of the galvanized steel high density fiberglass and foam insulation are defined in Part B, Section 8.1.

The two-dimensional model of the package includes approximately the top half of the package. The top end of the package has been modeled to account for the overpack to be crushed down to a 4.41 cm (1.738 in.) thickness. This has been done so that fewer changes would have to be made in creating the fire accident model. For normal condition of transport the portion of the overpack which slip around the sides of the 208 L (55-gal) (UN1A2) drum have been assumed to be uncrushed. The material properties of foam have been used for the uncrushed foam regions.

Figure B8-3 shows the radial configuration of the nodes. The material used to represent each node and the nodal region dimensions are indicated on this figure. As with the previous figures, Figure B8-2 is not drawn to scale. The radial node configuration shown in Figure B8-2 comes from the center of Figure B8-1. This node configuration is slightly different at the end of the package. However, in the circumferential direction the model is only one node wide. All nodal regions of the model cover the entire 1 radian span.

The parametric case descriptions for the thermal analysis of this model are defined in Table B8-11.

8.4.3.6 Two-Dimensional Model Without a Payload Lead Liner. The two-dimensional model of a Sample Pig Transport System without a payload lead liner is also depicted in Figures B8-3 and B8-4. These figures show the internal node and surface node numbers. The difference between this model and the model with a lead liner is that the lead liner and air gap nodes have their material properties changed to that of the payload. The entire inner volume of the shielding container is assumed to be filled with payload. The payload decay heat of 3 W is also assumed to be evenly distributed within this volume. The payload transfers its heat by conduction only to the shielding container. The payload will have peak temperatures at node 1. The parametric case descriptions for the thermal analysis of this model are defined in Table B8-11.

Table B8-11. Parametric Case Description for Thermal Analysis.

Case no.	Analysis type	Payload type	Solar[1] insolation	Solar absorptivity	Thermal emissivity	Air temperature °C (°F)
1	steady state	with liner	None	NA	0.3	21-46 (70-115)
2	steady state	without liner	None	NA	0.3	21-46 (70-115)
3	steady state/ transient	with liner	PNL	0.65	0.3/0.9	21-46 (70-115)
4	steady state/ transient	without liner	PNL	0.65	0.3	21-46 (70-115)
5	steady state	with liner	10 CFR 71	0.8	0.3	21-46 (70-115)
6	steady state	without liner	10 CFR 71	0.8	0.3	21-46 (70-115)
7	Transient[2]	with liner	None	NA	0.9	38 (100)
8	Transient[3]	with liner	None	NA	0.9	38 (100)
9	Transient[2]	without liner	None	NA	0.9	38 (100)
10	Transient[4]	without liner	None	NA	0.9	38 (100)
11	transient[3]	without liner	None	NA	0.9	38 (100)

NOTE: Decay heat assumed to be 3 W for all cases.

[1]PNL, 1983, *Climatological Summary for the Hanford Area*, PNL-4622, Pacific Northwest Laboratories, Richland, Washington (month of July).

[2]Fire case with no overpack damage.

[3]Fire case with overpack damage, top and side.

[4]Fire case with overpack damage, top only.

10 CFR 71, "Packaging and Transportation of Radioactive Material," *Code of Federal Regulations*, as amended.

8.4.4 Thermal Analysis

8.4.4.2 Maximum Temperatures. Table B8-12 represents a complete set of steady-state and peak transient temperature predictions for the payload configurations that are evaluated at the prescribed ambient temperature of 37.77 °C (100 °F) and for ambient temperatures of 21.11 °C (70 °F), 32.22 °C (90 °F) and 46.11 °C (115 °F). Figures B8-5 and B8-6 (Cases 3 and 4, respectively) depict the transient response of the Sample Pig Transport System for the normal solar insolation cases at an ambient temperature of 46.11 °C (115 °F). Cases 3 and 4 were modeled with up to 8 days of solar insolation with day to night variation.

Table B8-12. Sample Pig Transport System Key Component Maximum Predicted Temperatures for Normal Transport Conditions (maximum temperatures—°F).

Case no.	Ambient	Payload	Lead shield	Shipping container[(1)]	208 L (55-gal) (UN1A2) overpack			
					Drum[(2)]	Inner	Foam	Outer
No solar load								
1A	70	173	126	117	79	81	77	71
1B	90	190	144	135	98	101	97	91
1C	100	199	153	144	108	111	107	101
1D	115	212	166	158	123	126	122	122
2A	70	149	126	117	79	81	77	71
2B	90	167	144	135	98	101	97	91
2C	100	176	153	144	108	111	107	101
2D	115	189	166	158	123	126	122	122
PNL solar load								
3D1[(3)*]	115	242	196	189	172	174	181	241
4D1[(3)*]	115	219	196	189	172	174	181	240
10 CFR 71 solar load								
5A	70	363	319	314	281	283	279	272
5B	90	397	353	346	297	301	296	287
5C[**]	100	397	353	347	304	307	302	294
5D	115	418	375	368	317	322	315	305
6A	70	366	343	335	284	287	281	272
6B	90	363	340	334	293	297	293	287
6C[**]	100	363	341	335	298	301	298	294
6D	115	366	343	338	312	313	310	305

[1]Also shipping container "O" ring
[2]Also drum gasket
[3]Transient peak temperatures
[*]Required for onsite shipment
[**]Required for offsite shipment

Figure B8-5. Sample Pig Transport System – Normal Conditions Temperature Transient Case 3.

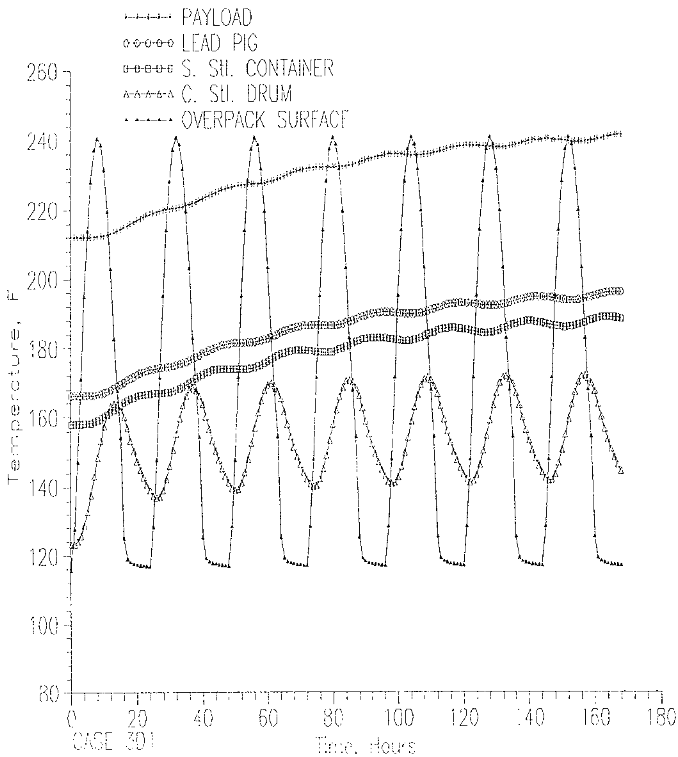
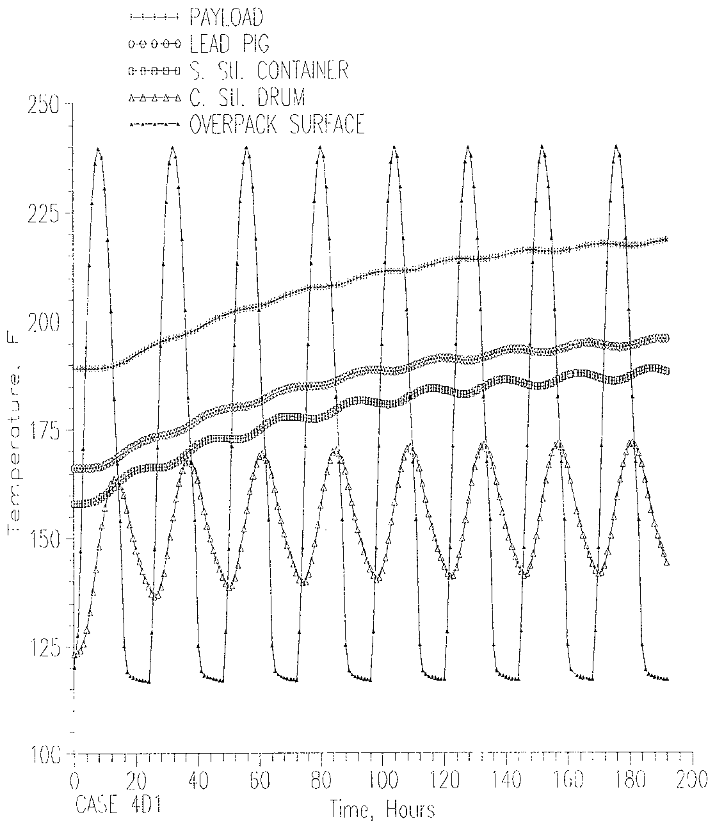


Figure B8-6. Sample Pig Transport System – Normal Conditions
Temperature Transient Case 4.



BEST AVAILABLE COPY

Please refer to Figures B8-3 and B8-4 for node identifications. These cases represent the maximum normal condition temperatures for the package, since the associated decay heat of this payload exceeds that of the other payloads. Part B, Section 8.6.7, contains detailed node temperatures.

8.4.4.2 Maximum Internal Pressures. The Sample Pig Transport System shipping container can realize an increase in its ambient pressure by way of two mechanisms. First, expansion occurs in the heating of the dry inert atmosphere from normal transport or accident conditions. Second, the payload may consist of material that might volatilize that would allow the evolved gases to escape into the container cavity and thus increase the internal pressure.

To calculate the maximum pressure, the following conservative assumptions were made:

The temperature of the dry inert atmosphere reaches the maximum hot spot temperature of the payload. The maximum payload temperature was found to be 116.66 °C (242 °F) for the peak solar case. Actual wall temperatures, such as those for node 22, stayed below 87.22 °C (189 °F) for the peak Solar case. Pressure from hydrogen gas generation (P_H) = 3378.43 Pa (0.49 psia) (Part B, Section 9.0).

If the shipping container atmosphere was then heated from 21.11 °C (70 °F) to 116.66 °C (242 °F), the resultant pressure would be:

$$P_f = (P_I + P_H)\left(\frac{T_f}{T_i}\right)$$

where:

$$T_f = (242 + 460)$$

$$T_i = (70 + 460)$$

$$P_f = \frac{(14.7 + 0.81)(242 + 460)}{(70 + 460)} = 142\ kPa\ (20.58\ lbf/\ in^2)$$

Therefore, the maximum internal pressure resulting from the normal conditions of transport condition would be:

$$P_{\max} = 142\ kPa\ (20.58\ lbf/\ in^2)(atmosphere)\ or$$
$$40.6\ kPa\ (5.9\ lbf/\ in^2)(gage)$$

8.5 THERMAL EVALUATION FOR ACCIDENT CONDITIONS

8.5.1 Conditions to be Evaluated

The thermal evaluation of the Sample Pig Transport System, for the accident conditions has been performed analytically using the thermal model described in Part B, Section 8.4.3. The most critical payload configuration has been employed for this evaluation.

8.5.2 Acceptance Criteria

Acceptance criteria to meet 10 CFR 71 requirements is that the packaging components maintain structural integrity, containment of the contents, and shielding. Onsite packaging performance requirements do not require successful fire results.

8.5.3 Package Conditions and Environment

Free-drop and puncture damage will alter the thermal behavior of the package. Specifically, free-drop damage affects the geometry of the overpack and the thermophysical properties of the foam material in the region of the damage. The parametric case descriptions for the thermal analysis of this model are defined in Table B8-2. A depiction of the thermal model node network for the hypothetical accident condition is shown in Figure B8-7. This figure shows the crushed foam at the top of the package and a local crush zone at the side of the package.

8.5.4 Thermal Model

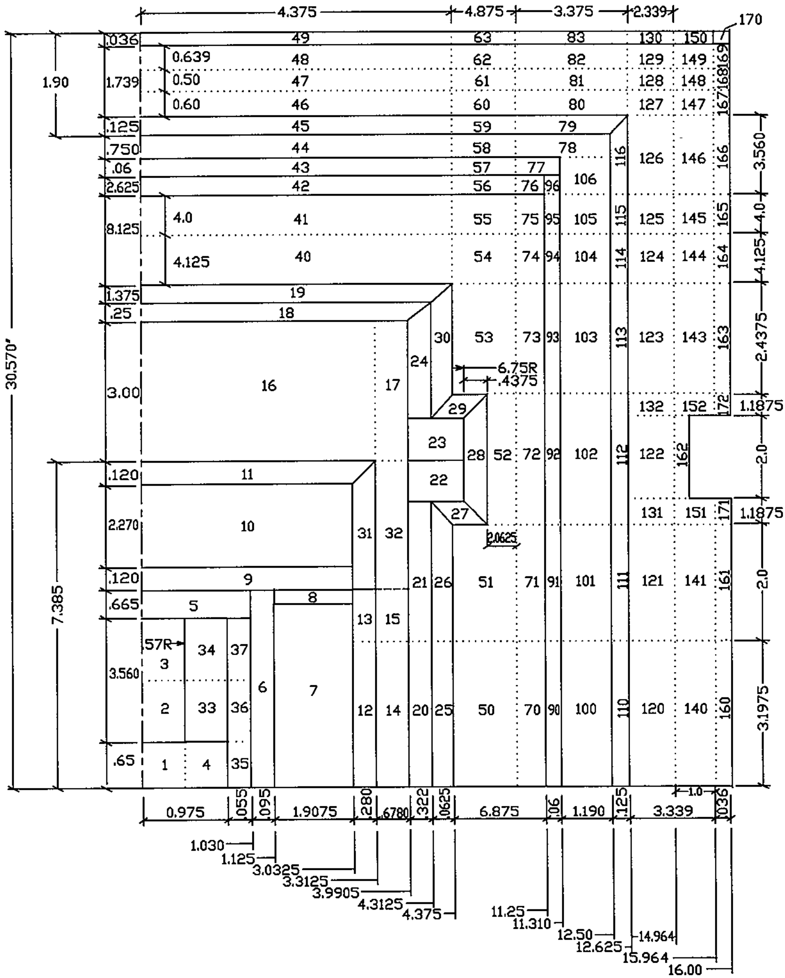
The thermal model described in Part B, Section 8.4.3, has been used for the transient analyses associated with the hypothetical thermal accident. Salient differences between the normal conditions model and the hypothetical accident model are as follows.

- The ambient environment is a prescribed constant temperature. Up to a time of 0.5 hours, this environment corresponds to a fire at 801.66 °C (1475 °F), with an emissive coefficient of 0.9. Subsequent to this time, the ambient environment drops to 37.78 °C (100 °F).

- A second node modeling the ambient environment was added to properly model the convective heat transfer from the surface of the overpack. This boundary node is kept at 801.66 °C (1475 °F) for the first half hour and dropped to 37.78 °C (100 °F) thereafter.

- Initial conditions correspond to the most critical conditions found in Part B, Section 8.2 and defined in Table B8-2.

Figure B8-7. Sample Pig Thermal Model Hypothetical Accident Node Network.



- The external convection heat transfer modes are effective throughout the accident event. No artificial cooling was included in the model. An average convective coefficient of 1 Btu/hr.-ft^2-°F was assumed for the analysis.

- The overpack foam assemblies are presumed to char at 207.22 °C (405 °F). At this temperature, the foam properties are essentially replaced by an air void of equivalent dimensions, with thermal properties as defined in Table B8-9.

8.5.5 Thermal Analysis

8.5.5.1 Maximum Temperatures. Figures B8-8 through B8-12 plot the temperature versus time response of representative thermal nodes. Representative temperature results for all nodes at selected times are presented in Table B8-13. The predicted maximum payload temperature for the hypothetical thermal accident is 104.44 °C (220 °F) at 12 hours after the fire for the payload with liner. This payload temperature has not peaked at 12 hours, when the analysis ended. For the payload without a lead liner the peak temperature is 87.77 °C (190 °F) at 12 hours after the fire and 91.11 °C (196 °F) at 24 hours after the fire. Only the case without the payload lead liner was analyzed out to 24 hours following the fire. Part B, Section 8.6.8, contains detailed node temperatures.

Table B8-13. Sample Pig Transport System Key Component Maximum Predicted Temperatures for Hypothetical Accident Conditions (maximum temperatures—°F).

	Case no.	Ambient	Payload	Lead shield	Shipping container	208 L (55-gal) (UN1A2) drum	Overpack		
							Inner	Foam	Outer
4-hour cooldown after fire	7	100	200	158	161	482	507	926	1372
	8	100	203	162	165	685	725	922	1373
	9	100	176	158	161	482	512	927	1372
	10	100	177	161	167	685	725	925	1367
	11	100	177	161	165	685	725	922	1368
12-hour cooldown after fire	8	100	220	176	171	685	725	922	1373
	10	100	193	179	178	685	725	925	1367
	11	100	190	174	171	685	725	922	1368
24-hour cooldown after fire	11	100	196	174	171	685	725	922	1368

Figure B8-8. Sample Pig Sample Package – Hypothetical Accident Temperature Transient Case 7.

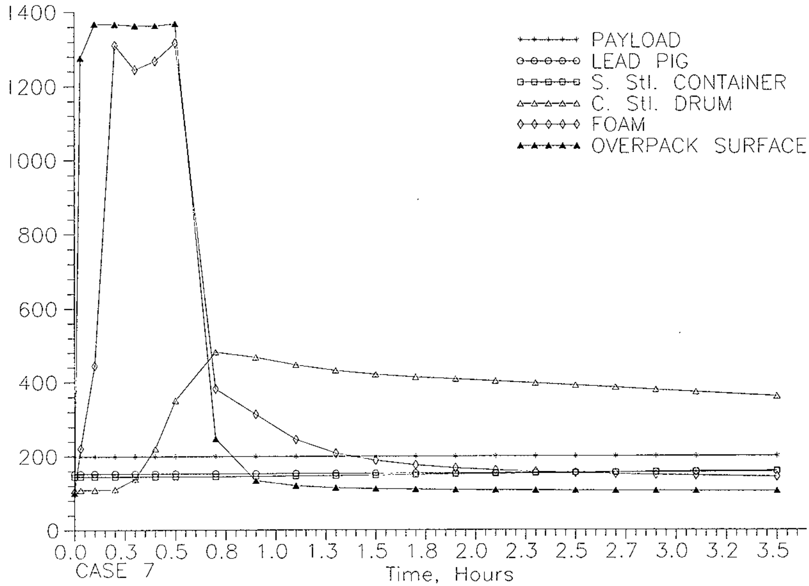


Figure B8-9. Sample Pig Sample Package - Hypothetical Accident Temperature Transient Case 8.

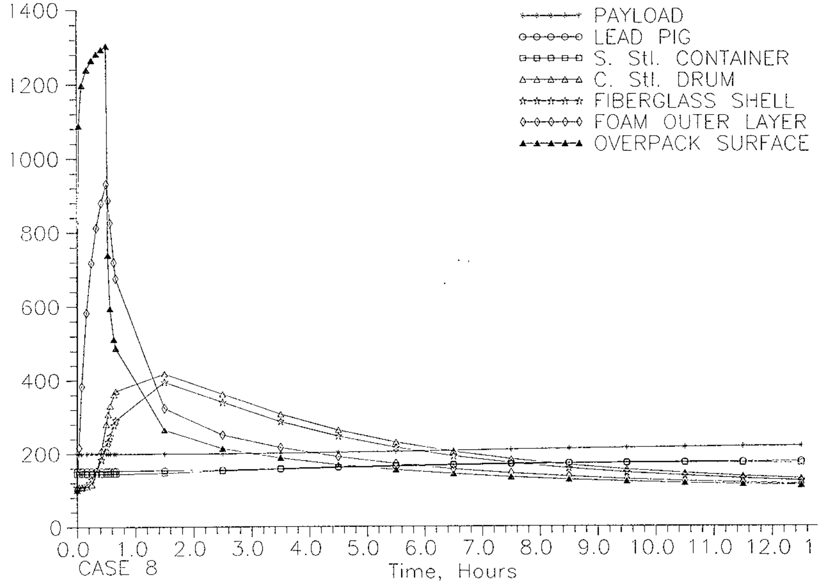
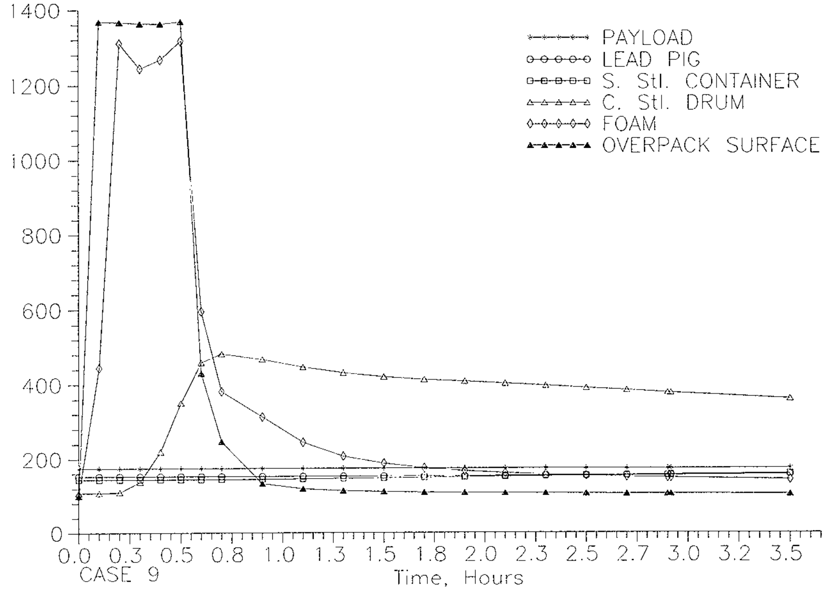


Figure B8-10. Sample Pig Transport System - Hypothetical Accident Temperature Transient Case 9.



BEST AVAILABLE COPY

Figure B8-11. Sample Pig Sample Package - Hypothetical Accident Temperature Transient Case 10.

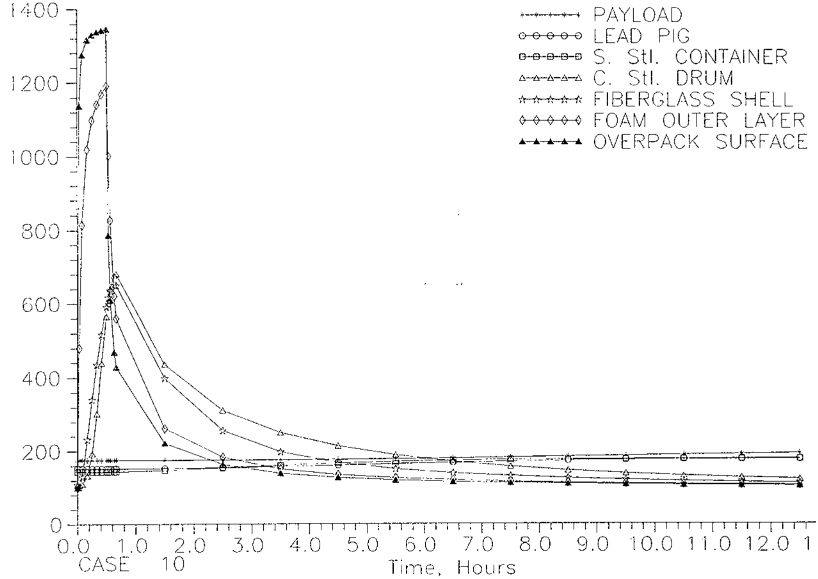
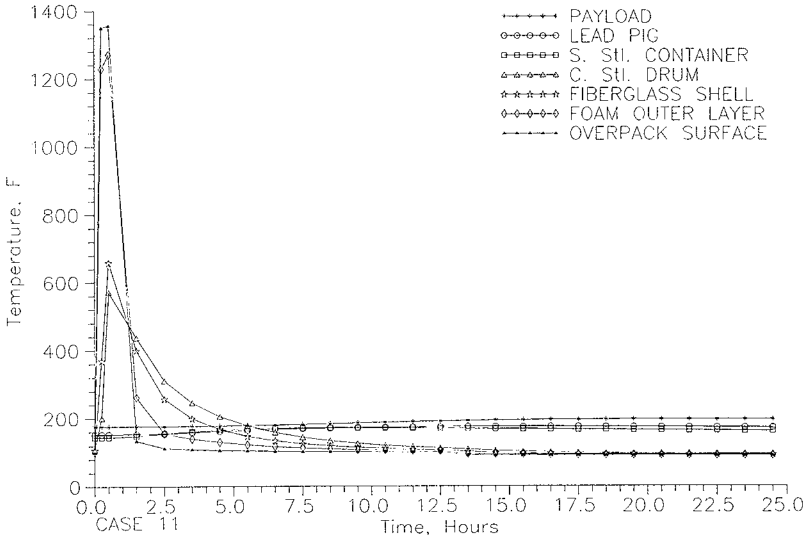


Figure B8-12. Sample Pig Sample Package - Hypothetical Accident Temperature Transient Case 11.



8.5.5.2 Maximum Internal Pressure. The Sample Pig Shipping Container can realize an increase in its ambient pressure by way of two mechanisms. First, expansion occurs in the heating of the dry inert atmosphere from normal transport or accident conditions. Second, the payload may consist of material that might volatilize that would allow the evolved gases to escape into the container cavity and thus increase the internal pressure.

To calculate the maximum pressure, the following conservative assumptions were made:

The temperature of the dry inert atmosphere reaches the maximum hot spot temperature of the payload. The maximum payload temperature was found to be 220 °F for the hypothetical accident case. Actual wall temperatures, such as those for node 22, stayed below 77.22 °C (171 °F) for the hypothetical accident case. Pressure due to hydrogen gas generation (P_H) = 3,378.43 Pa (0.49 psia) (Part B, Section 9.0).

If the shipping container atmosphere was then heated from 21.11 °C (70 °F) to 104.44 °C (220 °F), the resultant pressure would be:

$$P_f = (P_i + P_H)\left(\frac{T_f}{T_i}\right)$$

where:

$$T_f = (220 + 460) \quad and \quad T_i = (70 + 460)$$

$$P_f = \frac{(14.7 + 0.81)(220 + 460)}{(70 + 460)} = 137\ kPa\ (19.90\ lbf/\ in^2\ atm)$$

Therefore, the maximum internal pressure resulting from the hypothetical accident condition would be:

$$P_{max} = 13\ kPa\ (19.90\ lbf/\ in^2)\ (atmosphere)\ or$$
$$35.85\ kPa\ (5.2\ lbf/\ in^2)\ (gage)$$

The thermal behavior of the Sample Pig Transport System is completely compatible with the design requirements of the planned payloads. There is no prediction of lead melt, hence, no potential loss of shielding.

Three sets of data were used in the structural evaluation of the hypothetical accident conditions.

The shipping package material properties evaluated were at the following temperatures:

Shipping container	77 °C (171 °F)
Shielding lead	80 °C (176°F)
Payload	104 °C (220 °F)

The shipping container internal pressure was 35.85 kPa (5.2 lbf/in^2) (gage).

8.6 THERMAL EVALUATION AND CONCLUSIONS

Therefore, the Sample Pig Shipping System meets all 10 CFR 71 thermal requirements at onsite environmental conditions. As described and evaluated by the N-55 Safety Analysis Report (NuPac 1987), the maximum N-55 overpack temperature for normal conditions is 69 °C (157 °F). This section evaluates the Sample Pig Shipping System drum as a maximum of 78 °C (172 °F) for normal conditions. Therefore, normal conditions temperatures are less than 82 °C (180 °F). As shown by this section, the temperatures of the Sample Pig Shipping System are during accident conditions are lower than those during normal conditions. All material temperatures during the accident conditions are less than the material allowables. Therefore, the Sample Pig Shipping System meets all normal and accident thermal conditions.

8.7 REFERENCES

10 CFR 71, 1988, "Packaging and Transportation of Radioactive Material," *Code of Federal Regulations*, as amended.

49 CFR 178, 1990, "Shipping Container Specifications," *Code of Federal Regulations*, as amended.

Fitzroy, N. D. (ed), 1970, *Heat Transfer Data Book*, General Electric Company, Section 504.2.

Guzek, J. C., 1990, *TAP-A Code Notebook*, WHC-SD-FF-ER-050, Westinghouse Hanford Company, Richland, Washington.

Holman, J. P., 1972, *Heat Transfer*, McGraw-Hill Book Company, New York, New York.

Jimenez, R. F., 1990, *Thermal Analysis of Tanks 241-C-105 and 106 Using TAP-A as the Thermal Analysis Code*, WHC-SD-WM-ER-075, Westinghouse Hanford Company, Richland, Washington.

NuPac, 1987, *Application for NRC Certificate of Compliance Authorizing Shipment of Nuclear Materials in NuPac Model N-55 Packaging*, Nuclear Packaging Inc., Federal Way, Washington.

Parker, 1977, *Parker O-Ring Handbook*, 2-254, Parker Seal Group, O-Ring Division, Lexington, Kentucky.

Pierce, B. L., and H. J. Stumpf, 1969, *TAP-A Program for Computing Transient or Steady State Temperature Distributions*, WANL-TME-1872, December 1969.

PNL, 1983, *Climatological Summary for the Hanford Area*, PNL-4622, Pacific Northwest Laboratories, Richland, Washington.

Seigel, R., and J. R. Howell, 1981, *Thermal Radiation Heat Transfer*, Second Edition, McGraw-Hill Book Co., New York, New York.

Touloukian, Y. S., and C. Y. Ho, 1979, *Thermophysical Properties of Matter - The TPRC Data Series*, CINDAS/Purdue University.

Turner, W. D. et al., 1977, *Heating5 an IBM 360 Heat Conduction Program*, ORNL/CSD/TM-15, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

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

WHC-CM-6-1, *Standard Engineering Practices*, Westinghouse Hanford Company, Richland, Washington.

WHC, 1991, *T-3 Cask Safety Analysis Report for Packaging*, WHC-SD-FF-SARP-008, Westinghouse Hanford Company, Richland, Washington.

8.8 APPENDICES

8.8.1 Solar Insolation Data

Westinghouse
Hanford Company

From: Thermal Hydraulic Analysis
Phone: 6-6588 HO-33
Date: March 12, 1991
Subject: RECOMMENDED STANDARD SOLAR INSOLATION EVALUATION APPROACH

To: Thermal Hydraulic Analysis Group HO-33
Waste Characterization Analysis Group HO-34

cc: JCG/File
BAC/File
TJB/File
JJI/File
File LB

INTRODUCTION

Recently several analysts in the Thermal Hydraulic Analysis Group have been faced with evaluating the solar radiation (insolation) that could contribute to the heating of various waste storage vehicles. To ensure that a common and valid approach to this would be used, it was decided to convene a meeting of the affected analysts to reach a consensus.

A meeting was held on 3-5-91 at 10:00 AM to develop a standard approach for evaluation of solar insolation boundary conditions. The attendees were T. J. Bander, B. A. Crea, J. C. Guzek and J. J. Irwin. Their conclusions and recommendations are given below.

CONCLUSION

It was agreed by the participants that a standard and valid approach to solar insolation is desirable. A consensus was reached and the recommended method is given below.

RECOMMENDATION

The following procedure is recommended:

Use the 12-hour integrated values that are required by the Code of Federal Regulations in 10CFR 71.71(c) and an hourly heat gain distribution from the ASHRAE Handbook as Blaine has worked out in the attached Figure - 1. This basis indicates a peak hourly solar heat gain for a horizontal surface of 375.6 Btu/hr-ft^2 @24 deg-N Lat(USA Peak) and 355.8 Btu/hr-ft^2 @46 deg-N Lat(Hanford Peak). There is enough margin in the requirements set by 10CFR 71.71(c) that correction for diffuse radiation were not made to the basic ASHRAE data.

Hanford Operations and Engineering Contractor for the US Department of Energy

A reasonable assignment of peaks in adjacent curved and flat surfaces would be one-half and one-fourth of the horizontal peak respectively.

It is noteworthy that during winter months in the more northerly latitudes, a vertical surface facing south may have a higher instantaneous heating load than is given by the above approach. Analysts should judge the relevance of this fact to their evaluations.

The proposed hourly ambient temperature distribution shown in Figure - 2 was obtained from PNL Data adjusted to a 115F peak.

J. C. Guzek,
Fellow Engineer

B. A. Crea,
Software Engineer

T. J. Bander,
Software Engineer

J. J. Irwin,
Principle Engineer

Concurrence:
T. B. McCall, Manager
Thermal Hydraulic Analysis

jls

Attachments

FIGURE 1

CALCULATION OF SOLAR INSOLATION FUNCTION TO MEET THE REQUIREMENTS OF 10CFR 71.71(c) FOR TOTAL HEAT LOAD OVER A 12 HOUR PERIOD

Define the conversion factor from g-cal/cm^2 to Btu/in^2 $\qquad Qconv := .0257$

The total integrated heat incident on the cask over a 12 hour period must equal

$Qgh := 800 \cdot Qconv$	$Qgh = 20.56$	Btu/in^2 for horizontal surfaces
$Qgf := 200 \cdot Qconv$	$Qgf = 5.14$	Btu/in^2 non-horizontal flat surfaces
$Qgc := 400 \cdot Qconv$	$Qgc = 10.28$	Btu/in^2 for curved surfaces

Define a sin function as the basis of the load over a 12 hour period

$$Qrh(t, Qr, Qd) := \left[\sin\left[\pi \cdot \frac{t}{43200}\right] + Qr\right] \cdot Qd$$

- t — is time in seconds
- Qr — is the ratio of insolation at 6:00 to the value at 12:00
- Qd — is found such that the requirements of 10CFR 71.71 (c) are met

For 24 degrees N latitude on June 21 the heat gain on a horizontal surface at 6:00 AM and 6:00 PM is 17 Btu/hr-ft^2. At 12:00 noon the heat gain is 273 Btu/hr-ft^2. This latitude was chosen because it is the most northerly latitude for which data is available in the ASHRAE handbook that encompasses all of the continental US

The ratio of the initial value to the change is $\qquad Qr24 := \frac{17}{273}$

$Qd24 := .000683 \quad$ Btu/sec-in^2 $\qquad Qab24 := Qd24 \cdot Qr24$

$$Qt24 := \int_0^{43200} Qrh(t, Qr24, Qd24)\, dt \qquad Qt24 = 20.582$$

$Qsmax24 := Qab24 + Qd24 \qquad Qsmax24 \cdot 144 \cdot 3600 = 375.841 \quad$ Btu/hr-ft^2

A similar development for 46 degrees north latitude (the approximate latitude of the hanford site) gives the following set of data. It may be advantageous to use this data in certain cases. however, it must be pointed out that this data while meeting the requirements in 10CFR 71.71 (c) has a smaller margin of safety with respect to peak heating loads at lower latitudes and may cause questions with respect to the adequacy of the thermal analysis contained in a SARP for off-site shipment.

$Qd42 := .000576 \quad$ Btu/sec-in^2 $\qquad Qab42 := Qd42 \cdot Qr42 \qquad Qr42 := \frac{49}{255}$

$$Qt42 := \int_0^{43200} Qrh(t, Qr42, Qd42)\, dt \qquad Qt42 = 20.578$$

$Qsmax42 := Qab42 + Qd42 \qquad Qsmax42 \cdot 144 \cdot 3600 = 355.817 \quad$ Btu/hr-ft^2

BEST AVAILABLE COPY

FIGURE 2

TIME	AIR TEMPERATURE °F
4:00 am	75
6:00 am	74
8:00 am	85
10:00 am	97
12:00 noon	103
2:00 pm	111
4:00 pm	115
6:00 pm	113
8:00 pm	100
10:00 pm	89
12:00 midnight	82
2:00 am	78

Peak Solar Insolation per PNL (Reference 4) is 265.8 Btu/hr-ft^2

For Galvanized Steel, assume absorptivity of 0.65

$$\therefore q_r = 0.65 \times 655.8 \frac{Btu}{hr\text{-}ft^2} \times \frac{1}{3600 \frac{sec}{hr}} \times \frac{1}{144 \frac{in^2}{ft^2}} = 0.000333 \frac{Btu}{sec\text{-}in^2}$$

For TAP-A; hr = $q_r/\Delta T$ = Radiation Equipment Heat Transfer Coeficient

and $\Delta T = T_s - T_w$ = (5560 °R - T_w); T_w = Outer Surface Temperature

for T_w = 200 °F = 660 °R; ΔT = 4900 °R

$$and\ hr_{@T_w=200°F} = \frac{0.000333}{4900} = 6.8015E\text{-}8 \frac{Btu}{sec\text{-}in^2\text{-}°R}$$

hr varies slightly for other wall temperatures.

Per PNL data the solar insolation at the Hanford site for the peak summer month of July is tabulated below.

Solar Insolation For Average July Day at Hanford (1)

Hour-PST	Langleys(2)	Btu/hr-sq.ft
04-05	2.5	9.22
05-06	9.8	36.13
06-07	22.1	81.48
07-08	36.6	134.94
08-09	49.9	183.98
09-10	60.7	223.80
10-11	68.3	251.82
11-12	72.1	265.83
12-13	71.9	265.10
13-14	67.8	249.98
14-15	60.5	223.06
15-16	49.9	183.98
16-17	37.2	137.16
17-18	23.6	87.01
18-19	11.3	41.66
19-20	2.9	10.69
Sum	647.1(3)	2385.8

Notes:

(1) Per PNL-4622/UC-11, Climatological Summary for the Hanford Area, June 1983. (Reference 4)

(2) A langley is defined as 1 gram calorie per square centimeter.

(3) Total solar insolation for a 12 hour period is specified by 10CFR71 at 800 gram calorie per square centimeter.

(4) Solar Absorptivity of Galvanized steel is 0.65 (for oxidized surface) and a total normal emissivity of 0.3 (for oxidized surface) per reference 7.

8.8.2 Effective Thermal Emissivities

$$\frac{q}{A} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1}{e_1} + \frac{1}{e_2} - 1};$$ *Infinite parrallel plane(Holman equ. 8.40)*

This is of the form; $\frac{q}{A} = F_\varepsilon \cdot F_v \cdot \sigma(T_1^4 - T_2^4)$

Where F_v = View Factor = 1 (assumed)

q = Stefan - Boltzmann Const.; $0.1714X10^{-8} \frac{Btu}{hr\text{-}ft^2\text{-}°R^4}$

and F_ε = Emissivity Factor

$$\therefore F_\varepsilon = \frac{1}{\frac{1}{e_1} + \frac{1}{e_2} - 1};$$ e_1= *Emissivity of surface 1*
e_2= *Emissivity of surface 2*

For the following Emissivities having been assumed; the F_{ε}'s are:

MATERIAL	ε	MATERIAL - MATERIAL	F_ε
304 S. Stl.	.6	Lead to 304 S. Stl.	0.43
lead	.6	S. Stl. to S. Stl.	0.43
Fiberglass-L	.9	S. Stl. to Fiberglass-L	0.56
Fiberglass -H	.9	C. STL. to Fiberglass-H	0.82
C. Stl. (Painted)	.9		

8.8.3 Natural Convection Data

NATURAL CONVECTION FROM VERTICAL CYLINDERS AND HORIZONTAL PLATES

$$N_{u_d} = \frac{hd}{K_f} = c\,(Gr_f \cdot Pr_f)^m \text{ (Holman Equ. 7-25)}$$

N_{ud} = Nusselt No. for Vertical Cylinder and Horizontal Plates

h = Convective Heat Transfer Coefficient

$$Gr_f = \text{Grashof No.} = g\frac{B_f(T_w - T_\infty)\,d^3\rho_f^2}{\mu_f^2}$$

$g = 32.2\frac{ft}{sec}$ ρ_f = Density @ T_f

$B = \frac{1}{T_f(°R)}$ @ T_f μ_f = Viscosity @ T_f

K_f = Thermal conductivity @ T_f; Prf = Prandtl No. @ T_f

d = characteristics Dimension; 32.0 inches for overpack outer diameter

T_w = Wall Temperature T_∞ = Ambient Temperature

$$T_f = \frac{T_w + T_\infty}{2} = \text{film or mean temperature}$$

For Air at 1 Atmosphere:

$$\rho_f = 14.7 \times 144/(53.35 * T_f(°R))$$

$$K_f = 0.0131985 + 2.39268 \times 10^{-5}\, T_f \left[\frac{Btu}{hr\text{-}ft\text{-}°F}\right]$$

$$\mu_f = 0.0397796 + 5.93014 \times 10^{-5}\, T_f \left[\frac{Lbm}{hr\text{-}ft}\right]$$

$$Pr_f = 0.716108 - 0.000107887\, T_f$$

CONSTANTS FOR USE WITH EQN. (7-25) FOR ISOTHERMAL VERTICAL SURFACES

GEOMETRY	$Gr_f\ Pr_f$	C	m
Vertical planes and cylinders	$10^{-1} - 10^{4}$ $10^{4} - 10^{9}$ $10^{9} - 10^{13}$ $10^{9} - 10^{13}$	Use Fig. 7-7 0.59 0.021 0.10	Use Fig. 7-7 1/4 2/5 1/3
Horizontal cylinders	$0 - 10^{-5}$ $10^{-5} - 10^{4}$ $10^{4} - 10^{9}$ $10^{9} - 10^{12}$	0.4 Use Fig. 7-8 0.53 0.13	0 Use Fig. 7-8 1/4 1/3
Upper surface of heated plates or lower surface of cooled plates	$10^{5} - 2 \times 10^{7}$	0.54	1/4
Lower surface of heated plates or upper surface of cooled paltes	$3x10^{5}-3x10^{10}$	0.27	1/4
Upper surface of heated plates or lower surface of cooled plates	$2x10^{7}-3x10^{10}$	0.14	1/3

†(Reference TBD)

NATURAL CONVECTION BETWEEN ENCLOSED SURFACES

For air enclosed between two Isothermal Vertical Surfaces:

$$\frac{K_e}{K} = \begin{cases} 0.18 Gr_\delta^{\frac{1}{9}} \text{ for } 2000 < Gr_\delta < 20{,}000 & (7\text{-}37) \\ 0.065 Gr_\delta^{\frac{1}{9}} \text{ for } 20{,}000 < Gr_\delta < 1.1x10^{+7} & (7\text{-}38) \end{cases}$$

For air enclosed between two Isothermal Horizontal Spaces:

$$\frac{K_e}{K} \begin{cases} 0.195 Gr_\delta^{\frac{1}{4}} \text{ for } 10^4 < Gr_\delta < 4 X 10^5 & (7\text{-}39) \\ 0.068 Gr_\delta^{\frac{1}{3}} \text{ for } 4 X 10^5 < Gr_\delta & (7\text{-}40) \end{cases}$$

and K_e = effective thermal conductivity; $N_u = \frac{K_e}{K}$

K = thermal conductivity of air at the Mean Air Temperature

Gr_δ = Grashof No. = $\frac{\Pi^2 g \beta (T_1 - T_2) \delta^3}{\mu^2}$

δ = gap distance

L = length of surface

8.8.4 Internal Heat Generation Data

$$q_{gen} = 3\ Watts = \frac{3\ Watts}{0.2931\frac{Watts}{Btu/hr}} = 10.235\frac{Btu}{hr} X \frac{1}{3600\frac{sec}{hr}}$$

$$= 0.00284\ \frac{Btu}{sec}$$

Volume of the Payload:

Case 1: (with lead liner per H2-35369)

$$Vol. = \frac{\pi X 1.140^2}{4} * 3.560 = 3.63\ in^3$$

$$\therefore q_{gen} = \frac{0.00284}{3.63} = 0.000782\frac{Btu}{sec\text{-}in^3}$$

Case 2: (without lead liner; Pig. Container per H2-36076)

$$vol. = \frac{\pi X 2.060^2}{4} * 4.785 = 16.248 in^3$$

$$\therefore q^1_{gen} = \frac{0.00284}{16.248} = 0.000175\frac{Btu}{sec\text{-}in^3}$$

8.8.5 TAP-A Sample Pig Input Model

```
                                                                             L
  172     9  122    3   65    2   16   1   13    1    1    1                 99
PIG PACKAGE TRANSIENT (3 WATT - DIST. HEAT GEN. 100F AMBIENT TEMP. FIRE CASE 11A)
0.0          1800.     60.        .001       3.         20.       4000.       F
011.    172.530.
013001.3122.530.
01   1.            635.73     635.69     634.77     623.42     623.72     612.88TEMP
01   7.            612.75     612.56     612.54     612.43     612.38     612.70TEMP
01  13.            612.68     609.45     609.01     607.06     604.43     604.46TEMP
01  19.            602.10     606.50     605.68     604.29     604.23     604.06TEMP
01  25.            606.34     605.59     601.63     602.65     600.76     603.67TEMP
01  31.            612.35     608.54     623.40     623.22     613.99     613.99TEMP
01  37.            613.98       0.00       0.00     592.02     573.52     569.43TEMP
01  43.            568.86     568.74     568.63     566.99     564.00     561.63TEMP
01  49.            560.67     595.66     596.44     593.86     591.85     580.29TEMP
01  55.            571.07     568.92     568.59     568.47     568.36     566.67TEMP
01  61.            563.76     561.56     560.67       0.00       0.00       0.00TEMP
01  67.              0.00       0.00       0.00     575.97     576.22     577.43TEMP
01  73.            574.40     571.63     569.17     568.51     568.39     568.08TEMP
01  79.            567.90     565.65     563.01     561.35     560.70       0.00TEMP
01  85.              0.00       0.00       0.00       0.00       0.00     571.28TEMP
01  91.            571.17     570.92     570.25     569.51     568.73     568.41TEMP
01  97.              0.00       0.00       0.00     570.93     570.82     570.52TEMP
01 103.            569.94     569.23     568.48     568.07       0.00       0.00TEMP
01 109.              0.00     570.60     570.50     570.15     569.65     568.95TEMP
01 115.            568.22     567.72       0.00       0.00       0.00     566.98TEMP
01 121.            566.97     567.71     566.48     565.98     565.47     564.89TEMP
01 127.            562.91     561.78     561.06     560.77     567.10     566.98TEMP
01 133.              0.00       0.00       0.00       0.00       0.00       0.00TEMP
01 139.              0.00     562.38     562.32       0.00     562.27     562.15TEMP
01 145.            561.99     561.77     561.28     561.01     560.90     560.87TEMP
01 151.            562.30     562.36       0.00       0.00       0.00       0.00TEMP
01 157.              0.00       0.00       0.00     561.10     561.02     561.02TEMP
01 163.            561.09     561.09     561.02     560.92     560.82     560.79TEMP
01 169.            560.85     560.91     560.92     561.07
013001.            561.10     561.02     561.02     561.09     561.09     561.02TEMP
013007.            560.92     560.82     560.79     560.85     560.91     560.92TEMP
013013.            561.07     530.00     560.67     560.67     560.70     560.77TEMP
013019.            560.87     560.91     561.10     561.02     561.02     561.09TEMP
013025.            561.09     561.02     560.92     560.82     560.79     560.85TEMP
013031.            560.91     560.92     561.07     530.00     560.67     560.67TEMP
013037.            560.70     560.77     560.87     560.91     570.63     570.53TEMP
013043.            570.18     569.68     568.98     568.24     567.76     567.93TEMP
013049.            568.37     568.65     571.28     571.17     570.92     570.25TEMP
013055.            569.51     568.73     568.41     568.39     568.59     568.86TEMP
013061.            604.98     604.38     601.68     601.64     602.35     602.81TEMP
013067.            530.00     530.00     530.00     530.00     606.50     605.68TEMP
013073.            604.26     604.20     604.06     604.46     530.00     530.00TEMP
013079.            530.00     530.00     606.50     605.68     604.47     605.68TEMP
013085.            604.37     530.00     530.00     530.00     530.00     530.00TEMP
```

```
013091.         612.70    612.67    612.38    612.35    612.35    530.00TEMP
013097.         530.00    530.00    530.00    530.00    530.00    530.00TEMP
013103.         530.00    530.00    530.00    530.00    530.00    530.00TEMP
013109.         530.00    569.37    568.86    568.48    530.00    530.00TEMP
013115.         530.00    530.00    530.00    530.00    530.00    568.86TEMP
013121.         568.59    568.39
015001.     560.
015002.     5560.
015003.     560.
015004.     560.
015005.     1835.
03201.      .281                                                        304SS
03202.      .284                                                        CSTL
03203.      .41                                                         LEAD
03204.      .253                                                        PAYLOAD
03205.      .0025                                                       FGS-L
03206.      .090                                                        FGS-H
03207.      .0017                                                       FOAM
03208.      .000041                                                     AIR
03209.      .000041                                                     AIR1.5
03210.      .000041                                                     AIR4
03211.      .00668                                                      CRSH-F
04201. 1.   .109      .000198    530.      .111      .000202    560.    304SS
04201. 3.   .116      .000215    660.      .125      .000239    860.    304SS
04201. 5.   .13       .000262    1060.     .135      .000284    1260.   304SS
04201. 7.   .14       .000325    1660.     .145      .000344    1860.   304SS
04201. 9.   .149      .000354    1960.     .151      .000364    2060.   304SS
04202. 1.   .112      .000741    530.      .124      .000653    860.    CSTL
04202. 3.   .147      .000544    1260.     .173      .000463    1560.   CSTL
04203. 1.   .03       .00047     528.      .03       .000455    700.    LEAD
04203. 3.   .03       .000415    850.      .03       .000350    1560.   LEAD
04203. 5.   .03       .000350    2000.                                  LEAD
04204. 1.   .57       .0000023   500.      .57       .0000023   2000.   PAYLOAD
04205. 1.   .19       .00000042 510.       .19       .00000048 560.     FGS-L
04205. 3.   .19       .00000054 611.       .19       .00000054 2000.    FGS-L
04206. 1.   .19       .00000167 402.       .19       .00000224 537.     FGS-H
04206. 3.   .19       .00000236 807.       .19       .00000280 1032.    FGS-H
04206. 5.   .19       .00000300 2000.                                   FGS-H
04207. 1.   .17       .00000046 530.       .17       .00000046 860.     FOAM
04207. 3.   .17       .00000046 861.       .17       .00000490 865.     FOAM
04207. 5.   .17       .00000490 866.       .17       .00000926 1960.    FOAM
04208. 1.   .242      .00000033 500.       .246      .00000055 900.     AIR
04208. 3.   .252      .00000065 1100.      .27       .00000095 1700.    AIR
04209. 1.   .242      .00000050 500.       .246      .00000083 900.     AIR1.5
04209. 3.   .252      .00000098 1100.      .27       .00000143 2000.    AIR1.5
04210. 1.   .242      .00000132 500.       .246      .00000220 900.     AIR4
04210. 3.   .252      .00000260 1100.      .27       .00000380 2000.    AIR4
04211. 1.   .51       .0000044   500.      .51       .0000044   860.    CRSH-F
04211. 3.   .51       .0000044   1100.     .51       .0000044   2000.   CRSH-F
05  1.            204.    0.5700    0.2850    0.6500                    node
```

05	2.	204.	0.5700	0.2850	1.7800	node
05	3.	204.	0.5700	0.2850	1.7800	node
05	4.	204.	0.4050	0.7725	0.6500	node
05	5.	204.	1.0300	0.5150	0.6650	node
05	6.	201.	0.0950	1.0775	4.8750	node
05	7.	203.	1.9075	2.0788	4.7550	node
05	8.	201.	1.9075	2.0788	0.1200	node
05	9.	201.	3.0325	1.5163	0.1200	node
05	10.	203.	3.0325	1.5163	2.2700	node
05	11.	201.	3.3125	1.6563	0.1200	node
05	12.	201.	0.2800	3.1725	3.1975	node
05	13.	201.	0.2800	3.1725	1.6775	node
05	14.	209.	0.6780	3.6515	3.1975	node
05	15.	209.	0.6780	3.6515	1.6775	node
05	16.	210.	3.3125	1.6563	3.0000	node
05	17.	210.	0.6780	3.6515	3.0000	node
05	18.	201.	4.3125	2.1563	0.2500	node
05	19.	209.	4.3750	2.1875	1.3750	node
05	20.	201.	0.3220	4.1515	3.1975	node
05	21.	201.	0.3220	4.1515	3.0000	node
05	22.	201.	2.7595	5.3704	1.1875	node
05	23.	201.	2.7595	5.3703	1.1875	node
05	24.	201.	0.3220	4.1515	2.0625	node
05	25.	209.	0.0625	4.3438	3.1975	node
05	26.	209.	0.0625	4.3438	3.0000	node
05	27.	209.	2.8750	5.7500	1.0000	node
05	28.	209.	0.4375	6.9688	2.3750	node
05	29.	209.	2.8750	5.7500	1.0000	node
05	30.	209.	0.0625	4.3438	2.4375	node
05	31.	201.	0.2800	3.1725	2.5100	node
05	32.	209.	0.6780	3.6515	2.5100	node
05	33.	204.	0.4050	0.7725	1.7800	node
05	34.	204.	0.4050	0.7725	1.7800	node
05	35.	204.	0.0550	1.0025	0.6500	node
05	36.	204.	0.0550	1.0025	1.7800	node
05	37.	204.	0.0550	1.0025	1.7800	node
05	40.	205.	4.3750	2.1875	4.1250	node
05	41.	205.	4.3750	2.1875	4.0000	node
05	42.	210.	4.3750	2.1875	2.6250	node
05	43.	202.	4.3750	2.1875	0.0600	node
05	44.	209.	4.3750	2.1875	0.7500	node
05	45.	206.	4.3750	2.1875	0.1250	node
05	46.	211.	4.3750	2.1875	0.6000	node
05	47.	211.	4.3750	2.1875	0.5000	node
05	48.	211.	4.3750	2.1875	0.6390	node
05	49.	202.	4.3750	2.1875	0.0360	node
05	50.	205.	4.8750	6.8125	3.1975	node
05	51.	205.	4.8750	6.8125	2.0000	node
05	52.	205.	2.0625	8.2188	4.3750	node
05	53.	205.	4.8750	6.8125	2.4375	node

05	54.	205.	4.8750	6.8125	4.1250	node
05	55.	205.	4.8750	6.8125	4.0000	node
05	56.	210.	4.8750	6.8125	2.6250	node
05	57.	202.	4.8750	6.8125	0.0600	node
05	58.	209.	4.8750	6.8125	0.7500	node
05	59.	206.	4.8750	6.8125	0.1250	node
05	60.	211.	4.8750	6.8125	0.6000	node
05	61.	211.	4.8750	6.8125	0.5000	node
05	62.	211.	4.8750	6.8125	0.6390	node
05	63.	202.	4.8750	6.8125	0.0360	node
05	70.	205.	2.0000	10.2500	3.1975	node
05	71.	205.	2.0000	10.2500	2.0000	node
05	72.	205.	2.0000	10.2500	4.3750	node
05	73.	205.	2.0000	10.2500	2.4375	node
05	74.	205.	2.0000	10.2500	4.1250	node
05	75.	205.	2.0000	10.2500	4.0000	node
05	76.	210.	2.0000	10.2500	2.6250	node
05	77.	202.	2.0600	10.2800	0.0600	node
05	78.	209.	3.2500	10.8750	0.7500	node
05	79.	206.	3.3750	10.9375	0.1250	node
05	80.	211.	3.3750	10.9375	0.6000	node
05	81.	211.	3.3750	10.9375	0.5000	node
05	82.	211.	3.3750	10.9375	0.6390	node
05	83.	202.	3.3750	10.9375	0.0360	node
05	90.	202.	0.0600	11.2800	3.1975	node
05	91.	202.	0.0600	11.2800	2.0000	node
05	92.	202.	0.0600	11.2800	4.3750	node
05	93.	202.	0.0600	11.2800	2.4375	node
05	94.	202.	0.0600	11.2800	4.1250	node
05	95.	202.	0.0600	11.2800	4.0000	node
05	96.	202.	0.0600	11.2800	2.6250	node
05	100.	209.	1.1900	11.9050	3.1975	node
05	101.	209.	1.1900	11.9050	2.0000	node
05	102.	209.	1.1900	11.9050	4.3750	node
05	103.	209.	1.1900	11.9050	2.4375	node
05	104.	209.	1.1900	11.9050	4.1250	node
05	105.	209.	1.1900	11.9050	4.0000	node
05	106.	209.	1.1900	11.9050	2.6850	node
05	110.	206.	0.1250	12.5625	3.1975	node
05	111.	206.	0.1250	12.5625	2.0000	node
05	112.	206.	0.1250	12.5625	4.3750	node
05	113.	206.	0.1250	12.5625	2.4375	node
05	114.	206.	0.1250	12.5625	4.1250	node
05	115.	206.	0.1250	12.5625	4.0000	node
05	116.	206.	0.1250	12.5625	3.5600	node
05	120.	207.	2.3390	13.7945	3.1975	node
05	121.	207.	2.3390	13.7945	2.0000	node
05	122.	211.	2.3390	13.7945	2.0000	node
05	123.	207.	2.3390	13.7945	2.4375	node
05	124.	207.	2.3390	13.7945	4.1250	node

05	125.	207.	2.3390	13.7945	4.0000		node
05	126.	207.	2.3390	13.7945	3.5600		node
05	127.	211.	2.3390	13.7945	0.6000		node
05	128.	211.	2.3390	13.7945	0.5000		node
05	129.	211.	2.3390	13.7945	0.6390		node
05	130.	202.	2.3390	13.7945	0.0360		node
05	131.	207.	2.3390	13.7945	1.1875		node
05	132.	207.	2.3390	13.7945	1.1875		node
05	140.	207.	1.0000	15.4640	3.1975		node
05	141.	207.	1.0000	15.4640	2.0000		node
05	143.	207.	1.0000	15.4640	2.4375		node
05	144.	207.	1.0000	15.4640	4.1250		node
05	145.	207.	1.0000	15.4640	4.0000		node
05	146.	207.	1.0000	15.4640	3.5600		node
05	147.	211.	1.0000	15.4640	0.6000		node
05	148.	211.	1.0000	15.4640	0.5000		node
05	149.	211.	1.0000	15.4640	0.6390		node
05	150.	202.	1.0000	15.4640	0.0360		node
05	151.	207.	1.0000	15.4640	1.1875		node
05	152.	207.	1.0000	15.4640	1.1875		node
05	160.	202.	0.0360	15.9820	3.1975		node
05	161.	202.	0.0360	15.9820	2.0000		node
05	162.	202.	0.0360	15.9820	2.0000		node
05	163.	202.	0.0360	15.9820	2.4375		node
05	164.	202.	0.0360	15.9820	4.1250		node
05	165.	202.	0.0360	15.9820	4.0000		node
05	166.	202.	0.0360	15.9820	3.5600		node
05	167.	202.	0.0360	15.9820	0.6000		node
05	168.	202.	0.0360	15.9820	0.5000		node
05	169.	202.	0.0360	15.9820	0.6390		node
05	170.	202.	0.0360	15.9820	0.0360		node
05	171.	202.	0.0360	15.9820	1.1875		node
05	172.	202.	0.0360	15.9820	1.1875		node
07	1.	4.	0.3951	0.1733	0.5700	0.6500	conn
07	2.	33.	0.3951	0.1733	0.5700	1.7800	conn
07	3.	34.	0.3951	0.1733	0.5700	1.7800	conn
07	4.	35.	0.2270	0.0271	0.9750	0.6500	conn
07	5.	6.	0.7139	0.0464	1.0300	0.6650	conn
07	6.	7.	0.0485	0.6907	1.1250	4.7550	conn
07	6.	8.	2.4375	0.6907	1.1250	0.0950	conn
07	6.	35.	0.0464	0.0279	1.0300	0.6500	conn
07	6.	36.	0.0464	0.0279	1.0300	1.7800	conn
07	6.	37.	0.0464	0.0279	1.0300	1.7800	conn
07	7.	12.	1.1451	0.1369	3.0325	3.1975	conn
07	7.	13.	1.1451	0.1369	3.0325	1.6775	conn
07	8.	13.	1.1451	0.1369	3.0325	0.1200	conn
07	9.	31.	2.1020	0.1369	3.0325	0.1200	conn
07	10.	31.	2.1020	0.1369	3.0325	2.2700	conn
07	11.	31.	2.2961	1.2550	3.3125	0.1200	conn
07	12.	14.	0.1430	0.3228	3.3125	3.1975	conn

07	13.	15.	0.1430	0.3228	3.3125	1.6775	conn
07	14.	20.	0.3543	0.1578	3.9905	3.1975	conn
07	15.	21.	0.3543	0.1578	3.9905	1.6775	conn
07	16.	17.	2.2961	0.3228	3.3125	3.0000	conn
07	17.	23.	0.3543	1.1850	3.9905	1.1875	conn
07	17.	24.	0.3543	0.1578	3.9905	1.8125	conn
07	18.	24.	2.9892	1.0313	4.3125	0.2500	conn
07	19.	30.	3.0325	1.2188	4.3750	0.0625	conn
07	20.	25.	0.1641	0.0311	4.3125	3.1975	conn
07	21.	26.	0.1641	0.0311	4.3125	3.0000	conn
07	21.	32.	0.1578	0.3543	3.9905	1.3225	conn
07	22.	28.	1.5435	0.2153	6.7500	1.1875	conn
07	22.	32.	1.1850	0.3543	3.9905	1.1875	conn
07	23.	28.	1.5435	0.2153	6.7500	1.1875	conn
07	24.	30.	0.1641	0.0311	4.3125	1.0625	conn
07	25.	50.	0.0314	1.9375	4.3750	3.1975	conn
07	26.	51.	0.0314	1.9375	4.3750	2.0000	conn
07	27.	52.	1.6038	0.9637	7.1875	1.0000	conn
07	28.	52.	0.2221	0.9637	7.1875	2.3750	conn
07	29.	52.	1.6038	0.9637	7.1875	1.0000	conn
07	30.	53.	0.0314	1.9375	4.3750	2.4375	conn
07	31.	32.	0.1430	0.3228	3.3125	2.5100	conn
07	33.	36.	0.2270	0.0271	0.9750	1.7800	conn
07	34.	37.	0.2270	0.0271	0.9750	1.7800	conn
07	40.	54.	3.0325	1.9375	4.3750	4.1250	conn
07	41.	55.	3.0325	1.9375	4.3750	4.0000	conn
07	42.	56.	3.0325	1.9375	4.3750	2.6250	conn
07	43.	57.	3.0325	1.9375	4.3750	0.0600	conn
07	44.	58.	3.0325	1.9375	4.3750	0.7500	conn
07	45.	59.	3.0325	1.9375	4.3750	0.1250	conn
07	46.	60.	3.0325	1.9375	4.3750	0.6000	conn
07	47.	61.	3.0325	1.9375	4.3750	0.5000	conn
07	48.	62.	3.0325	1.9375	4.3750	0.6390	conn
07	49.	63.	3.0325	1.9375	4.3750	0.0360	conn
07	50.	70.	2.8292	0.9496	9.2500	3.1975	conn
07	51.	71.	2.8292	0.9496	9.2500	2.0000	conn
07	52.	72.	1.0934	0.9496	9.2500	4.3750	conn
07	53.	73.	2.8292	0.9496	9.2500	2.4375	conn
07	54.	74.	2.8292	0.9496	9.2500	4.1250	conn
07	55.	75.	2.8292	0.9496	9.2500	4.0000	conn
07	56.	76.	2.8292	0.9496	9.2500	2.6250	conn
07	57.	77.	2.8292	0.9766	9.2500	0.0600	conn
07	58.	78.	2.8292	1.4970	9.2500	0.7500	conn
07	59.	79.	2.8292	1.5501	9.2500	0.1250	conn
07	60.	80.	2.8292	1.5501	9.2500	0.6000	conn
07	61.	81.	2.8292	1.5501	9.2500	0.5000	conn
07	62.	82.	2.8292	1.5501	9.2500	0.6390	conn
07	63.	83.	2.8292	1.5501	9.2500	0.0360	conn
07	70.	90.	1.0473	0.0300	11.2500	3.1975	conn
07	71.	91.	1.0473	0.0300	11.2500	2.0000	conn

07	72.	92.	1.0473	0.0300	11.2500	4.3750	conn
07	73.	93.	1.0473	0.0300	11.2500	2.4375	conn
07	74.	94.	1.0473	0.0300	11.2500	4.1250	conn
07	75.	95.	1.0473	0.0300	11.2500	4.0000	conn
07	76.	96.	1.0473	0.0300	11.2500	2.6250	conn
07	77.	96.	1.0800	1.3125	11.3100	0.0600	conn
07	78.	116.	1.7408	0.0623	12.5000	0.7500	conn
07	79.	116.	1.8115	1.7800	12.6250	0.1250	conn
07	80.	127.	1.8115	1.1185	12.6250	0.6000	conn
07	81.	128.	1.8115	1.1185	12.6250	0.5000	conn
07	82.	129.	1.8115	1.1185	12.6250	0.6390	conn
07	83.	130.	1.8115	1.1185	12.6250	0.0360	conn
07	90.	100.	0.0300	0.5799	11.3100	3.1975	conn
07	91.	101.	0.0300	0.5799	11.3100	2.0000	conn
07	92.	102.	0.0300	0.5799	11.3100	4.3750	conn
07	93.	103.	0.0300	0.5799	11.3100	2.4375	conn
07	94.	104.	0.0300	0.5799	11.3100	4.1250	conn
07	95.	105.	0.0300	0.5799	11.3100	4.0000	conn
07	96.	106.	0.0300	0.5799	11.3100	2.6250	conn
07	100.	110.	0.6096	0.0623	12.5000	3.1975	conn
07	101.	111.	0.6096	0.0623	12.5000	2.0000	conn
07	102.	112.	0.6096	0.0623	12.5000	4.3750	conn
07	103.	113.	0.6096	0.0623	12.5000	2.4375	conn
07	104.	114.	0.6096	0.0623	12.5000	4.1250	conn
07	105.	115.	0.6096	0.0623	12.5000	4.0000	conn
07	106.	116.	0.6096	0.0623	12.5000	2.6850	conn
07	110.	120.	0.0627	1.1185	12.6250	3.1975	conn
07	111.	121.	0.0627	1.1185	12.6250	2.0000	conn
07	112.	122.	0.0627	1.1185	12.6250	4.3750	conn
07	112.	131.	0.0627	1.1185	12.6250	1.1875	conn
07	112.	132.	0.0627	1.1185	12.6250	1.1875	conn
07	113.	123.	0.0627	1.1185	12.6250	2.4375	conn
07	114.	124.	0.0627	1.1185	12.6250	4.1250	conn
07	115.	125.	0.0627	1.1185	12.6250	4.0000	conn
07	116.	126.	0.0627	1.1185	12.6250	3.5600	conn
07	120.	140.	1.2177	0.4918	14.9640	3.1975	conn
07	121.	141.	1.2177	0.4918	14.9640	2.0000	conn
07	122.	162.	1.2177	0.0180	14.9640	2.0000	conn
07	123.	143.	1.2177	0.4918	14.9640	2.4375	conn
07	124.	144.	1.2177	0.4918	14.9640	4.1250	conn
07	125.	145.	1.2177	0.4918	14.9640	4.0000	conn
07	126.	146.	1.2177	0.4918	14.9640	3.5600	conn
07	127.	147.	1.2177	0.4918	14.9640	0.6000	conn
07	128.	148.	1.2177	0.4918	14.9640	0.5000	conn
07	129.	149.	1.2177	0.4918	14.9640	0.6390	conn
07	130.	150.	1.2177	0.4918	14.9640	0.0360	conn
07	131.	151.	1.2177	0.4918	14.9640	1.1875	conn
07	132.	152.	1.2177	0.4918	14.9640	1.1875	conn
07	140.	160.	0.5080	0.0180	15.9640	3.1975	conn
07	141.	161.	0.5080	0.0180	15.9640	2.0000	conn

07 143.	163.	0.5080	0.0180	15.9640	2.4375	conn
07 144.	164.	0.5080	0.0180	15.9640	4.1250	conn
07 145.	165.	0.5080	0.0180	15.9640	4.0000	conn
07 146.	166.	0.5080	0.0180	15.9640	3.5600	conn
07 147.	167.	0.5080	0.0180	15.9640	0.6000	conn
07 148.	168.	0.5080	0.0180	15.9640	0.5000	conn
07 149.	169.	0.5080	0.0180	15.9640	0.6390	conn
07 150.	170.	0.5080	0.0180	15.9640	0.0360	conn
07 151.	171.	0.5080	0.0180	15.9640	1.1875	conn
07 152.	172.	0.5080	0.0180	15.9640	1.1875	conn
07 12.	3091.	0.1430	0.0000	3.3125	3.1975	conn
07 20.	3081.	0.1578	0.0000	3.3125	3.1975	conn
07 13.	3092.	0.1430	0.0000	3.3125	1.6775	conn
07 21.	3082.	0.1578	0.0000	3.3125	1.6775	conn
07 20.	3071.	0.1641	0.0000	4.3125	3.1975	conn
07 50.	3061.	1.9375	0.0000	4.3125	3.1975	conn
07 21.	3072.	0.1641	0.0000	4.3125	2.0000	conn
07 51.	3062.	1.9375	0.0000	4.3125	2.0000	conn
07 21.	3084.	0.1578	0.0000	3.3125	1.3225	conn
07 31.	3094.	0.1430	0.0000	3.3125	1.3225	conn
07 22.	3073.	1.5435	0.0000	6.7500	1.1875	conn
07 52.	3063.	0.9637	0.0000	6.7500	1.1875	conn
07 22.	3085.	1.5435	0.0000	3.3125	1.1875	conn
07 31.	3095.	0.1430	0.0000	3.3125	1.1875	conn
07 23.	3074.	1.5435	0.0000	6.7500	1.1875	conn
07 52.	3064.	0.9637	0.0000	6.7500	1.1875	conn
07 24.	3075.	0.1641	0.0000	4.3125	2.4375	conn
07 53.	3065.	1.9375	0.0000	4.3125	2.4375	conn
07 90.	3051.	0.0300	0.0000	11.3100	3.1975	conn
07 110.	3041.	0.0623	0.0000	11.3100	3.1975	conn
07 91.	3052.	0.0300	0.0000	11.3100	2.0000	conn
07 111.	3042.	0.0623	0.0000	11.3100	2.0000	conn
07 92.	3053.	0.0300	0.0000	11.3100	4.3750	conn
07 112.	3043.	0.0623	0.0000	11.3100	4.3750	conn
07 93.	3054.	0.0300	0.0000	11.3100	2.4375	conn
07 113.	3044.	0.0623	0.0000	11.3100	2.4375	conn
07 94.	3055.	0.0300	0.0000	11.3100	4.1250	conn
07 114.	3045.	0.0623	0.0000	11.3100	4.1250	conn
07 95.	3056.	0.0300	0.0000	11.3100	4.0000	conn
07 115.	3046.	0.0623	0.0000	11.3100	4.0000	conn
07 96.	3057.	0.0300	0.0000	11.3100	2.6850	conn
07 116.	3047.	0.0623	0.0000	11.3100	2.6850	conn
07 160.	3001.	0.0180	0.0000	16.0000	3.1975	conn
07 160.	3021.	0.0180	0.0000	16.0000	3.1975	conn
07 161.	3002.	0.0180	0.0000	16.0000	2.0000	conn
07 161.	3022.	0.0180	0.0000	16.0000	2.0000	conn
07 162.	3003.	0.0180	0.0000	16.0000	2.0000	conn
07 162.	3023.	0.0180	0.0000	16.0000	2.0000	conn
07 163.	3004.	0.0180	0.0000	16.0000	2.4375	conn
07 163.	3024.	0.0180	0.0000	16.0000	2.4375	conn

07	164.	3005.	0.0180	0.0000	16.0000	4.1250	conn
07	164.	3025.	0.0180	0.0000	16.0000	4.1250	conn
07	165.	3006.	0.0180	0.0000	16.0000	4.0000	conn
07	165.	3026.	0.0180	0.0000	16.0000	4.0000	conn
07	166.	3007.	0.0180	0.0000	16.0000	3.5600	conn
07	166.	3027.	0.0180	0.0000	16.0000	3.5600	conn
07	167.	3008.	0.0180	0.0000	16.0000	0.6000	conn
07	167.	3028.	0.0180	0.0000	16.0000	0.6000	conn
07	168.	3009.	0.0180	0.0000	16.0000	0.5000	conn
07	168.	3029.	0.0180	0.0000	16.0000	0.5000	conn
07	169.	3010.	0.0180	0.0000	16.0000	0.6390	conn
07	169.	3030.	0.0180	0.0000	16.0000	0.6390	conn
07	170.	3011.	0.0180	0.0000	16.0000	0.0360	conn
07	170.	3031.	0.0180	0.0000	16.0000	0.0360	conn
07	171.	3012.	0.0180	0.0000	16.0000	1.1875	conn
07	171.	3032.	0.0180	0.0000	16.0000	1.1875	conn
07	172.	3013.	0.0180	0.0000	16.0000	1.1875	conn
07	172.	3033.	0.0180	0.0000	16.0000	1.1875	conn
07	1.	2.	0.3250	0.8900	0.5700	0.2850	conn
07	2.	3.	0.8900	0.8900	0.5700	0.2850	conn
07	3.	5.	0.8900	0.3325	0.5700	0.2850	conn
07	4.	33.	0.3250	0.8900	0.4050	0.7725	conn
07	33.	34.	0.8900	0.8900	0.4050	0.7725	conn
07	5.	9.	0.3325	0.0600	1.0300	0.5150	conn
07	5.	34.	0.3250	0.8900	0.4050	0.7725	conn
07	35.	36.	0.3250	0.8900	0.0550	1.0025	conn
07	36.	37.	0.8900	0.8900	0.0550	1.0025	conn
07	7.	8.	2.3775	0.0600	1.9075	2.0788	conn
07	8.	9.	0.0600	0.0600	1.9075	2.0788	conn
07	9.	10.	0.0600	1.1350	3.0325	1.5163	conn
07	10.	11.	1.1350	0.0600	3.0325	1.5163	conn
07	11.	16.	0.0600	1.5000	3.3125	1.6563	conn
07	12.	13.	1.5988	0.8388	0.2800	3.1725	conn
07	13.	31.	0.8388	1.2550	0.2800	3.1725	conn
07	14.	15.	1.5988	0.8388	0.6780	3.6515	conn
07	15.	32.	0.8388	1.2550	0.6780	3.6515	conn
07	16.	18.	1.5000	0.1250	3.3125	1.6563	conn
07	17.	18.	1.5000	0.1250	0.6780	3.6515	conn
07	18.	19.	0.1250	0.6875	4.3125	2.1563	conn
07	19.	40.	0.6875	2.0625	4.3750	2.1875	conn
07	20.	21.	1.5988	1.5000	0.3220	4.1515	conn
07	21.	22.	1.5000	0.5938	0.3220	4.1515	conn
07	22.	23.	0.5938	0.5938	2.7595	5.2093	conn
07	22.	27.	0.5938	0.5000	2.4375	5.5313	conn
07	23.	24.	0.5938	1.0313	0.3220	4.1515	conn
07	23.	29.	0.5938	0.5000	2.4375	5.5313	conn
07	25.	26.	1.5988	1.5000	0.0625	4.3438	conn
07	26.	27.	1.5000	1.2406	0.0625	4.3438	conn
07	27.	28.	1.6038	1.1875	0.4375	6.9688	conn
07	27.	51.	0.5000	1.0000	2.8125	5.7813	conn

07	28.	29.	1.1875	1.6038	0.4375	6.9688	conn
07	29.	30.	1.2406	1.2188	0.0625	4.3438	conn
07	29.	53.	0.5000	1.2188	2.8125	5.7813	conn
07	40.	41.	2.0625	2.0000	4.3750	2.1875	conn
07	41.	42.	2.0000	1.3125	4.3750	2.1875	conn
07	42.	43.	1.3125	0.0300	4.3750	2.1875	conn
07	43.	44.	0.0300	0.3750	4.3750	2.1875	conn
07	44.	45.	0.3750	0.0625	4.3750	2.1875	conn
07	45.	46.	0.0625	0.3000	4.3750	2.1875	conn
07	46.	47.	0.3000	0.2500	4.3750	2.1875	conn
07	47.	48.	0.2500	0.3195	4.3750	2.1875	conn
07	48.	49.	0.3195	0.0180	4.3750	2.1875	conn
07	50.	51.	1.5988	1.0000	4.8750	6.8125	conn
07	51.	52.	1.0000	2.1875	4.8750	6.8125	conn
07	52.	53.	2.1875	1.2188	2.0625	8.2188	conn
07	53.	54.	1.2188	2.0625	4.8750	6.8125	conn
07	54.	55.	2.0625	2.0000	4.8750	6.8125	conn
07	55.	56.	2.0000	1.3125	4.8750	6.8125	conn
07	56.	57.	1.3125	0.0300	4.8750	6.8125	conn
07	57.	58.	0.0300	0.3750	4.8750	6.8125	conn
07	58.	59.	0.3750	0.0625	4.8750	6.8125	conn
07	59.	60.	0.0625	0.3000	4.8750	6.8125	conn
07	60.	61.	0.3000	0.2500	4.8750	6.8125	conn
07	61.	62.	0.2500	0.3195	4.8750	6.8125	conn
07	62.	63.	0.3195	0.0180	4.8750	6.8125	conn
07	70.	71.	1.5988	1.0000	2.0000	10.2500	conn
07	71.	72.	1.0000	2.1875	2.0000	10.2500	conn
07	72.	73.	2.1875	1.2188	2.0000	10.2500	conn
07	73.	74.	1.2188	2.0625	2.0000	10.2500	conn
07	74.	75.	2.0625	2.0000	2.0000	10.2500	conn
07	75.	76.	2.0000	1.3125	2.0000	10.2500	conn
07	76.	77.	1.3125	0.0300	2.0000	10.2500	conn
07	77.	78.	0.0300	0.3750	2.0600	10.2800	conn
07	78.	79.	0.3750	0.0625	3.2500	10.8750	conn
07	78.	106.	0.3750	1.3425	1.1900	11.9050	conn
07	79.	80.	0.0625	0.3000	3.3750	10.9375	conn
07	80.	81.	0.3000	0.2500	3.3750	10.9375	conn
07	81.	82.	0.2500	0.3195	3.3750	10.9375	conn
07	82.	83.	0.3195	0.0180	3.3750	10.9375	conn
07	90.	91.	1.5988	1.0000	0.0600	11.2800	conn
07	91.	92.	1.0000	2.1875	0.0600	11.2800	conn
07	92.	93.	2.1875	1.2188	0.0600	11.2800	conn
07	93.	94.	1.2188	2.0625	0.0600	11.2800	conn
07	94.	95.	2.0625	2.0000	0.0600	11.2800	conn
07	95.	96.	2.0000	1.3125	0.0600	11.2800	conn
07	100.	101.	1.5988	1.0000	1.1900	11.9050	conn
07	101.	102.	1.0000	2.1875	1.1900	11.9050	conn
07	102.	103.	2.1875	1.2188	1.1900	11.9050	conn
07	103.	104.	1.2188	2.0625	1.1900	11.9050	conn
07	104.	105.	2.0625	2.0000	1.1900	11.9050	conn

07 105.	106.	2.0000	1.3425	1.1900	11.9050	conn
07 110.	111.	1.5988	1.0000	0.1250	12.5625	conn
07 111.	112.	1.0000	2.1875	0.1250	12.5625	conn
07 112.	113.	2.1875	1.2188	0.1250	12.5625	conn
07 113.	114.	1.2188	2.0625	0.1250	12.5625	conn
07 114.	115.	2.0625	2.0000	0.1250	12.5625	conn
07 115.	116.	2.0000	1.7800	0.1250	12.5625	conn
07 120.	121.	1.5988	1.0000	2.3390	13.7945	conn
07 121.	131.	1.0000	0.5938	2.3390	13.7945	conn
07 122.	131.	1.0000	0.5938	2.3390	13.7945	conn
07 122.	132.	1.0000	0.5938	2.3390	13.7945	conn
07 123.	124.	1.2188	2.0625	2.3390	13.7945	conn
07 123.	132.	1.2188	0.5938	2.3390	13.7945	conn
07 124.	125.	2.0625	2.0000	2.3390	13.7945	conn
07 125.	126.	2.0000	1.7800	2.3390	13.7945	conn
07 126.	127.	1.7800	0.3000	2.3390	13.7945	conn
07 127.	128.	0.3000	0.2500	2.3390	13.7945	conn
07 128.	129.	0.2500	0.3195	2.3390	13.7945	conn
07 129.	130.	0.3195	0.0180	2.3390	13.7945	conn
07 140.	141.	1.5988	1.0000	1.0000	15.4640	conn
07 141.	151.	1.0000	0.5938	1.0000	15.4640	conn
07 143.	144.	1.2188	2.0625	1.0000	15.4640	conn
07 143.	152.	1.2188	0.5938	1.0000	15.4640	conn
07 144.	145.	2.0625	2.0000	1.0000	15.4640	conn
07 145.	146.	2.0000	1.7800	1.0000	15.4640	conn
07 146.	147.	1.7800	0.3000	1.0000	15.4640	conn
07 147.	148.	0.3000	0.2500	1.0000	15.4640	conn
07 148.	149.	0.2500	0.3195	1.0000	15.4640	conn
07 149.	150.	0.3195	0.0180	1.0000	15.4640	conn
07 160.	161.	1.5988	1.0000	0.0360	15.9820	conn
07 161.	171.	1.0000	0.5938	0.0360	15.9820	conn
07 162.	171.	1.0000	0.5938	0.0360	15.9820	conn
07 162.	172.	1.0000	0.5938	0.0360	15.9820	conn
07 163.	164.	1.2188	2.0625	0.0360	15.9820	conn
07 163.	172.	1.2188	0.5938	0.0360	15.9820	conn
07 164.	165.	2.0625	2.0000	0.0360	15.9820	conn
07 165.	166.	2.0000	1.7800	0.0360	15.9820	conn
07 166.	167.	1.7800	0.3000	0.0360	15.9820	conn
07 167.	168.	0.3000	0.2500	0.0360	15.9820	conn
07 168.	169.	0.2500	0.3195	0.0360	15.9820	conn
07 169.	170.	0.3195	0.0180	0.0360	15.9820	conn
07 170.	171.	0.0180	0.0180	0.0360	15.9820	conn
07 11.	3093.	0.0600	0.0000	3.0325	1.6563	conn
07 18.	3083.	0.1250	0.0000	3.0325	1.6563	conn
07 18.	3076.	0.1250	0.0000	4.3125	2.1563	conn
07 40.	3066.	2.0625	0.0000	4.3125	2.1563	conn
07 41.	3110.	2.0000	0.0000	4.3750	2.1875	conn
07 43.	3120.	0.0300	0.0000	4.3750	2.1875	conn
07 43.	3060.	0.0300	0.0000	4.3750	2.1875	conn
07 45.	3050.	0.0625	0.0000	4.3750	2.1875	conn

07 55.		3111.	2.0000	0.0000	4.8750	6.8125	conn
07 57.		3121.	0.0300	0.0000	4.8750	6.8125	conn
07 57.		3059.	0.0300	0.0000	4.8750	6.8125	conn
07 59.		3049.	0.0625	0.0000	4.8750	6.8125	conn
07 75.		3112.	2.0000	0.0000	2.0000	10.2500	conn
07 77.		3122.	0.0300	0.0000	2.0000	10.2500	conn
07 77.		3058.	0.0300	0.0000	2.0600	10.2800	conn
07 79.		3048.	0.0625	0.0000	2.0600	10.2800	conn
07 49.		3015.	0.0180	0.0000	4.3750	2.1875	conn
07 49.		3035.	0.0180	0.0000	4.3750	2.1875	conn
07 63.		3016.	0.0180	0.0000	4.8750	6.8125	conn
07 63.		3036.	0.0180	0.0000	4.8750	6.8125	conn
07 83.		3017.	0.0180	0.0000	3.3750	10.9375	conn
07 83.		3037.	0.0180	0.0000	3.3750	10.9375	conn
07 130.		3018.	0.0180	0.0000	2.3390	13.7945	conn
07 130.		3038.	0.0180	0.0000	2.3390	13.7945	conn
07 150.		3019.	0.0180	0.0000	1.0000	15.4640	conn
07 150.		3039.	0.0180	0.0000	1.0000	15.4640	conn
07 170.		3020.	0.0180	0.0000	0.0360	15.9820	conn
07 170.		3040.	0.0180	0.0000	0.0360	15.9820	conn
093041.	5010.	-1.		.82			bonn
093041.	5011.	-2.					bonn
093051.	5011.	-1.		.82			bonn
093051.	5010.	-2.					bonn
093042.	5012.	-1.		.82			bonn
093042.	5013.	-2.					bonn
093052.	5013.	-1.		.82			bonn
093052.	5012.	-2.					bonn
093043.	5014.	-1.		.82			bonn
093043.	5015.	-2.					bonn
093053.	5015.	-1.		.82			bonn
093053.	5014.	-2.					bonn
093044.	5016.	-1.		.82			bonn
093044.	5017.	-2.					bonn
093054.	5017.	-1.		.82			bonn
093054.	5016.	-2.					bonn
093045.	5018.	-1.		.82			bonn
093045.	5019.	-2.					bonn
093055.	5019.	-1.		.82			bonn
093055.	5018.	-2.					bonn
093046.	5020.	-1.		.82			bonn
093046.	5021.	-2.					bonn
093056.	5021.	-1.		.82			bonn
093056.	5020.	-2.					bonn
093047.	5022.	-1.		.82			bonn
093047.	5023.	-2.					bonn
093057.	5023.	-1.		.82			bonn
093057.	5022.	-2.					bonn
093048.	5024.	-1.		.82			bonn
093048.	5025.	-2.					bonn

093058.	5025.	-1.	.82	bonn
093058.	5024.	-2.		bonn
093049.	5026.	-1.	.82	bonn
093049.	5027.	-2.		bonn
093059.	5027.	-1.	.82	bonn
093059.	5026.	-2.		bonn
093050.	5028.	-1.	.82	bonn
093050.	5029.	-2.		bonn
093060.	5029.	-1.	.82	bonn
093060.	5028.	-2.		bonn
093061.	5030.	-1.	.56	bonn
093061.	5031.	-2.		bonn
093071.	5031.	-1.	.56	bonn
093071.	5030.	-2.		bonn
093062.	5032.	-1.	.56	bonn
093062.	5033.	-2.		bonn
093072.	5033.	-1.	.56	bonn
093072.	5032.	-2.		bonn
093063.	5034.	-1.	.56	bonn
093063.	5035.	-2.		bonn
093073.	5035.	-1.	.56	bonn
093073.	5034.	-2.		bonn
093064.	5036.	-1.	.56	bonn
093064.	5037.	-2.		bonn
093074.	5037.	-1.	.56	bonn
093074.	5036.	-2.		bonn
093065.	5038.	-1.	.56	bonn
093065.	5039.	-2.		bonn
093075.	5039.	-1.	.56	bonn
093075.	5038.	-2.		bonn
093066.	5040.	-1.	.56	bonn
093066.	5041.	-2.		bonn
093076.	5041.	-1.	.56	bonn
093076.	5040.	-2.		bonn
093081.	5042.	-1.	.43	bonn
093081.	5043.	-2.		bonn
093091.	5043.	-1.	.43	bonn
093091.	5042.	-2.		bonn
093082.	5044.	-1.	.43	bonn
093082.	5045.	-2.		bonn
093092.	5045.	-1.	.43	bonn
093092.	5044.	-2.		bonn
093083.	5046.	-1.	.43	bonn
093083.	5047.	-2.		bonn
093093.	5047.	-1.	.43	bonn
093093.	5046.	-2.		bonn
093084.	5048.	-1.	.43	bonn
093084.	5049.	-2.		bonn
093094.	5049.	-1.	.43	bonn
093094.	5048.	-2.		bonn

```
093085.      5050.    -1.                .43                                  bonn
093085.      5051.    -2.                                                     bonn
093095.      5051.    -1.                .43                                  bonn
093095.      5050.    -2.                                                     bonn
093110.      5060.    -1.                .82                                  bonn
093110.      5061.    -2.                                                     bonn
093120.      5061.    -1.                .82                                  bonn
093120.      5060.    -2.                                                     bonn
093111.      5062.    -1.                .82                                  bonn
093111.      5063.    -2.                                                     bonn
093121.      5063.    -1.                .82                                  bonn
093121.      5062.    -2.                                                     bonn
093112.      5064.    -1.                .82                                  bonn
093112.      5065.    -2.                                                     bonn
093122.      5065.    -1.                .82                                  bonn
093122.      5064.    -2.                                                     bonn
093001.3013 5005.     -1.                .90                                  bonn
093021.3033.5005.                        .0000019                             bonn
093015.3020 5005.     -1.                .90                                  bonn
093035.3040.5005.                        .0000019                             bonn
111.         120.     300.     600.      900.      1200.      1500.           prnt
121.    5.   .000175
1233.   37.  .000175
25
```

8.8.6 TAP-A Sample Pig Steady State Temperatures

PIG DRUM STEADY STATE (3 WATT - CONC. HT. GEN. 70F AMB. TEMP PEAK SUN, CASE 1A)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	325.72	2	362.00	3	363.44	4	325.67	5	324.20
6	319.60	7	319.45	8	319.22	9	319.19	10	319.08
11	319.03	12	319.41	13	319.37	14	317.63	15	317.25
16	315.85	17	314.19	18	314.39	19	312.48	20	316.01
21	315.33	22	314.12	23	314.07	24	313.94	25	315.89
26	315.26	27	311.92	28	312.82	29	311.18	30	313.64
31	319.01	32	316.80	33	326.09	34	326.35	35	322.58
36	322.79	37	322.92	40	303.09	41	285.53	42	281.85
43	281.41	44	281.35	45	281.29	46	279.30	47	275.69
48	272.83	49	271.68	50	306.20	51	307.07	52	304.83
53	302.80	54	291.79	55	283.20	56	281.28	57	281.03
58	280.97	59	280.90	60	278.88	61	275.37	62	272.73
63	271.66	70	287.67	71	287.91	72	289.10	73	286.19
74	283.61	75	281.36	76	280.79	77	280.71	78	280.53
79	280.41	80	277.65	81	274.43	82	272.42	83	271.65
90	283.37	91	283.26	92	283.00	93	282.34	94	281.62
95	280.91	96	280.65	100	283.18	101	283.06	102	282.77
103	282.16	104	281.47	105	280.77	106	280.46	110	282.98
111	282.87	112	282.54	113	281.99	114	281.29	115	280.60
116	280.23	120	278.76	121	278.78	122	279.68	123	278.25
124	277.72	125	277.25	126	276.69	127	274.27	128	272.88
129	272.00	130	271.66	131	278.96	132	278.82	140	273.35
141	273.33	142	273.49	143	273.24	144	273.11	145	272.98
146	272.81	147	272.26	148	271.93	149	271.76	150	271.71
151	273.34	152	273.36	160	271.85	161	271.80	162	271.81
163	271.84	164	271.82	165	271.80	166	271.75	167	271.69
168	271.66	169	271.69	170	271.74	171	271.74	172	271.83

PIG DRUM STEADY STATE (3 WATT - CONC. HT. GEN. 90F AMB. TEMP PEAK SUN, CASE 1B)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	359.29	2	395.58	3	397.01	4	359.24	5	357.99
6	353.52	7	353.37	8	353.20	9	353.17	10	353.02
11	352.94	12	353.30	13	353.26	14	351.04	15	350.55
16	348.76	17	346.53	18	346.86	19	344.12	20	348.99
21	348.09	22	346.44	23	346.37	24	346.19	25	348.82
26	348.00	27	343.30	28	344.61	29	342.25	30	345.76
31	352.90	32	350.00	33	359.67	34	359.93	35	356.33
36	356.54	37	356.67	40	330.31	41	304.25	42	298.77
43	298.13	44	298.05	45	297.97	46	295.64	47	291.39
48	288.04	49	286.68	50	334.83	51	336.18	52	332.99
53	329.98	54	313.73	55	300.94	56	298.06	57	297.69
58	297.61	59	297.53	60	295.15	61	291.03	62	287.92
63	286.67	70	307.83	71	308.21	72	309.99	73	305.69
74	301.84	75	298.39	76	297.49	77	297.35	78	297.13
79	296.99	80	293.73	81	289.93	82	287.57	83	286.65
90	301.59	91	301.44	92	301.09	93	300.09	94	298.98
95	297.81	96	297.35	100	301.34	101	301.19	102	300.80
103	299.86	104	298.78	105	297.64	106	297.12	110	301.10
111	300.96	112	300.53	113	299.66	114	298.58	115	297.45
116	296.85	120	295.72	121	295.74	122	296.87	123	294.96
124	294.16	125	293.41	126	292.65	127	289.75	128	288.11
129	287.07	130	286.67	131	295.97	132	295.75	140	288.82
141	288.79	142	289.00	143	288.65	144	288.45	145	288.26
146	288.04	147	287.37	148	286.99	149	286.79	150	286.73
151	288.81	152	288.82	160	286.90	161	286.85	162	286.86
163	286.89	164	286.86	165	286.83	166	286.77	167	286.70
168	286.66	169	286.71	170	286.77	171	286.77	172	286.88

PIG DRUM STEADY STATE (3 WATT - CONC. HT GEN. 100F AMBIENT TEMP PEAK SUN CASE 1C)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	359.17	2	395.43	3	396.84	4	359.10	5	357.72
6	353.28	7	353.11	8	352.84	9	352.81	10	352.67
11	352.60	12	353.06	13	353.01	14	351.05	15	350.58
16	348.87	17	346.91	18	347.18	19	344.77	20	349.22
21	348.36	22	346.84	23	346.77	24	346.61	25	349.07
26	348.28	27	344.06	28	345.22	29	343.13	30	346.23
31	352.57	32	350.01	33	359.51	34	359.75	35	356.14
36	356.34	37	356.46	40	332.62	41	309.74	42	304.95
43	304.40	44	304.33	45	304.27	46	302.17	47	298.38
48	295.38	49	294.17	50	336.61	51	337.78	52	334.93
53	332.29	54	317.97	55	306.78	56	304.28	57	303.96
58	303.90	59	303.83	60	301.71	61	298.04	62	295.27
63	294.16	70	312.61	71	312.96	72	314.55	73	310.78
74	307.42	75	304.46	76	303.71	77	303.60	78	303.41
79	303.29	80	300.42	81	297.06	82	294.96	83	294.15
90	307.07	91	306.95	92	306.67	93	305.82	94	304.89
95	303.92	96	303.57	100	306.85	101	306.73	102	306.41
103	305.62	104	304.71	105	303.77	106	303.37	110	306.65
111	306.54	112	306.18	113	305.45	114	304.54	115	303.61
116	303.14	120	302.00	121	302.02	122	303.02	123	301.36
124	300.69	125	300.07	126	299.43	127	296.89	128	295.45
129	294.54	130	294.18	131	302.23	132	302.05	140	296.03
141	296.02	142	296.20	143	295.88	144	295.71	145	295.55
146	295.36	147	294.78	148	294.46	149	294.30	150	294.26
151	296.06	152	296.04	160	294.37	161	294.34	162	294.35
163	294.35	164	294.32	165	294.29	166	294.25	167	294.18
168	294.17	169	294.23	170	294.30	171	294.30	172	294.35

PIG DRUM STEADY STATE (3 WATT - CONC. HT GEN. 115F AMBIENT TEMP PEAK SUN CASE 1D)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	380.76	2	417.01	3	418.39	4	380.69	5	379.41
6	375.03	7	374.87	8	374.64	9	374.61	10	374.45
11	374.37	12	374.80	13	374.76	14	372.70	15	372.18
16	370.35	17	368.21	18	368.53	19	365.72	20	370.77
21	369.83	22	368.14	23	368.06	24	367.87	25	370.61
26	369.74	27	364.97	28	366.29	29	363.88	30	367.44
31	374.34	32	371.58	33	381.09	34	381.32	35	377.81
36	378.01	37	378.12	40	351.30	41	323.64	42	317.79
43	317.07	44	316.94	45	316.86	46	314.48	47	310.05
48	306.52	49	305.08	50	356.30	51	357.68	52	354.41
53	351.18	54	334.17	55	320.47	56	317.35	57	316.93
58	316.83	59	316.75	60	314.20	61	309.76	62	306.42
63	305.07	70	328.57	71	328.94	72	330.73	73	326.19
74	322.03	75	318.11	76	317.00	77	316.81	78	316.58
79	316.43	80	312.83	81	308.65	82	306.06	83	305.06
90	322.14	91	321.96	92	321.55	93	320.40	94	319.09
95	317.62	96	316.92	100	321.89	101	321.72	102	321.26
103	320.19	104	318.91	105	317.45	106	316.69	110	321.63
111	321.48	112	320.98	113	319.97	114	318.69	115	317.25
116	316.41	120	315.47	121	315.49	122	316.80	123	314.59
124	313.64	125	312.69	126	311.74	127	308.48	128	306.66
129	305.53	130	305.08	131	315.75	132	315.51	140	307.55
141	307.52	142	307.76	143	307.35	144	307.12	145	306.87
146	306.60	147	305.85	148	305.43	149	305.22	150	305.16
151	307.54	152	307.55	160	305.35	161	305.29	162	305.30
163	305.33	164	305.30	165	305.25	166	305.19	167	305.11
168	305.07	169	305.13	170	305.20	171	305.21	172	305.33

PIG DRUM STEADY STATE (3 WATT DIST. HT. GEN. 70F AMB. TEMP. PEAK SUN, CASE 2A)

INTERNAL TEMPERATURES AT0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	365.58	2	365.53	3	364.62	4	353.25	5	353.54
6	342.70	7	342.55	8	342.37	9	342.34	10	342.18
11	342.09	12	342.48	13	342.44	14	340.04	15	339.49
16	337.53	17	335.11	18	335.45	19	332.55	20	337.82
21	336.81	22	335.00	23	334.93	24	334.74	25	337.64
26	336.71	27	331.68	28	333.05	29	330.56	30	334.28
31	342.05	32	338.88	33	353.24	34	353.06	35	343.82
36	343.81	37	343.80	40	318.08	41	290.79	42	285.06
43	284.37	44	284.28	45	284.19	46	281.62	47	276.93
48	273.22	49	271.72	50	322.83	51	324.21	52	320.83
53	317.70	54	300.69	55	287.32	56	284.31	57	283.91
58	283.82	59	283.73	60	281.09	61	276.53	62	273.09
63	271.71	70	294.37	71	294.78	72	296.68	73	292.21
74	288.21	75	284.63	76	283.69	77	283.55	78	283.29
79	283.14	80	279.53	81	275.32	82	272.70	83	271.68
90	287.79	91	287.66	92	287.33	93	286.32	94	285.20
95	284.01	96	283.53	100	287.51	101	287.37	102	286.99
103	286.08	104	284.98	105	283.82	106	283.27	110	287.24
111	287.12	112	286.69	113	285.84	114	284.75	115	283.60
116	282.97	120	281.45	121	281.48	122	282.74	123	280.73
124	279.91	125	279.14	126	278.32	127	275.12	128	273.30
129	272.15	130	271.70	131	281.75	132	281.55	140	274.03
141	274.00	142	274.23	143	273.87	144	273.67	145	273.47
146	273.22	147	272.48	148	272.06	149	271.84	150	271.77
151	274.02	152	274.04	160	271.96	161	271.91	162	271.92
163	271.95	164	271.93	165	271.89	166	271.83	167	271.74
168	271.70	169	271.75	170	271.81	171	271.82	172	271.94

PIG DRUM STEADY STATE (3 WATT DIST. HT. GEN. 90F AMB. TEMP. PEAK SUN, CASE 2B)

INTERNAL TEMPERATURES AT0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	363.36	2	363.31	3	362.40	4	351.04	5	351.33
6	340.50	7	340.36	8	340.16	9	340.14	10	340.00
11	339.93	12	340.30	13	340.26	14	338.30	15	337.85
16	336.24	17	334.29	18	334.56	19	332.25	20	336.49
21	335.66	22	334.20	23	334.14	24	333.99	25	336.35
26	335.58	27	331.58	28	332.66	29	330.69	30	333.63
31	339.90	32	337.34	33	351.03	34	350.84	35	341.61
36	341.61	37	341.59	40	320.74	41	298.98	42	294.39
43	293.85	44	293.77	45	293.72	46	292.25	47	289.58
48	287.48	49	286.62	50	324.65	51	325.72	52	323.04
53	320.52	54	307.03	55	296.32	56	293.90	57	293.58
58	293.51	59	293.46	60	291.96	61	289.36	62	287.40
63	286.62	70	302.25	71	302.57	72	304.06	73	300.49
74	297.27	75	294.34	76	293.55	77	293.42	78	293.26
79	293.17	80	291.10	81	288.69	82	287.19	83	286.61
90	297.09	91	296.99	92	296.73	93	295.88	94	294.94
95	293.93	96	293.49	100	296.89	101	296.79	102	296.50
103	295.71	104	294.79	105	293.80	106	293.32	110	296.72
111	296.63	112	296.31	113	295.57	114	294.66	115	293.68
116	293.15	120	292.95	121	292.96	122	293.75	123	292.33
124	291.67	125	291.04	126	290.46	127	288.59	128	287.54
129	286.89	130	286.63	131	293.12	132	292.94	140	288.13
141	288.12	142	288.26	143	287.99	144	287.82	145	287.66
146	287.50	147	287.07	148	286.83	149	286.71	150	286.68
151	288.13	152	288.12	160	286.79	161	286.76	162	286.77
163	286.77	164	286.75	165	286.72	166	286.68	167	286.64
168	286.62	169	286.66	170	286.71	171	286.71	172	286.78

PIG DRUM STEADY STATE (3 WATT DIST. HT. GEN. 100F AMB. TEMP. PEAK SUN, CASE 2C)

INTERNAL TEMPERATURES AT0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	363.49	2	363.45	3	362.55	4	351.20	5	351.55
6	340.68	7	340.55	8	340.44	9	340.42	10	340.30
11	340.24	12	340.50	13	340.47	14	338.69	15	338.29
16	336.85	17	335.07	18	335.32	19	333.21	20	337.04
21	336.30	22	334.98	23	334.93	24	334.80	25	336.92
26	336.23	27	332.61	28	333.59	29	331.78	30	334.47
31	340.20	32	337.85	33	351.18	34	351.01	35	341.79
36	341.79	37	341.77	40	322.66	41	302.68	42	298.47
43	297.99	44	297.93	45	297.90	46	297.09	47	295.65
48	294.53	49	294.08	50	326.32	51	327.29	52	324.84
53	322.49	54	310.11	55	300.26	56	298.04	57	297.76
58	297.70	59	297.67	60	296.88	61	295.52	62	294.49
63	294.08	70	306.04	71	306.30	72	307.60	73	304.25
74	301.24	75	298.51	76	297.76	77	297.65	78	297.54
79	297.49	80	296.42	81	295.17	82	294.39	83	294.08
90	301.39	91	301.26	92	300.97	93	300.09	94	299.16
95	298.18	96	297.76	100	301.23	101	301.10	102	300.79
103	299.95	104	299.03	105	298.08	106	297.64	110	301.12
111	301.00	112	300.67	113	299.86	114	298.94	115	298.01
116	297.55	120	298.49	121	298.46	122	298.92	123	297.77
124	297.14	125	296.55	126	296.13	127	295.12	128	294.58
129	294.25	130	294.12	131	298.53	132	298.32	140	295.15
141	295.15	142	295.22	143	294.97	144	294.81	145	294.66
146	294.55	147	294.32	148	294.21	149	294.18	150	294.18
151	295.16	152	295.10	160	294.22	161	294.22	162	294.22
163	294.19	164	294.16	165	294.14	166	294.11	167	294.09
168	294.10	169	294.16	170	294.21	171	294.21	172	294.21

PIG DRUM STEADY STATE (3 WATT DIST. HT. GEN. 115F AMB. TEMP. PEAK SUN, CASE 2D)

INTERNAL TEMPERATURES AT0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	365.69	2	365.64	3	364.72	4	353.37	5	353.65
6	342.84	7	342.70	8	342.48	9	342.47	10	342.36
11	342.31	12	342.66	13	342.63	14	341.20	15	340.86
16	339.69	17	338.29	18	338.52	19	337.02	20	339.88
21	339.27	22	338.21	23	338.17	24	338.09	25	339.79
26	339.22	27	336.50	28	337.20	29	335.91	30	337.85
31	342.30	32	340.46	33	353.36	34	353.18	35	343.95
36	343.95	37	343.93	40	329.52	41	315.50	42	312.58
43	312.26	44	312.23	45	312.19	46	310.76	47	308.19
48	306.17	49	305.35	50	331.99	51	332.66	52	330.86
53	329.23	54	320.43	55	313.59	56	312.07	57	311.88
58	311.85	59	311.80	60	310.39	61	307.93	62	306.08
63	305.34	70	317.11	71	317.31	72	318.28	73	315.95
74	313.88	75	312.07	76	311.64	77	311.58	78	311.45
79	311.38	80	309.48	81	307.26	82	305.87	83	305.33
90	313.68	91	313.60	92	313.41	93	312.88	94	312.30
95	311.72	96	311.53	100	313.54	101	313.46	102	313.25
103	312.76	104	312.19	105	311.62	106	311.40	110	313.41
111	313.34	112	313.11	113	312.65	114	312.08	115	311.51
116	311.25	120	310.40	121	310.41	122	311.06	123	310.00
124	309.58	125	309.20	126	308.81	127	307.14	128	306.18
129	305.58	130	305.34	131	310.55	132	310.44	140	306.54
141	306.53	142	306.64	143	306.45	144	306.35	145	306.25
146	306.13	147	305.75	148	305.53	149	305.41	150	305.37
151	306.54	152	306.54	160	305.47	161	305.44	162	305.44
163	305.46	164	305.45	165	305.43	166	305.40	167	305.36
168	305.34	169	305.36	170	305.39	171	305.40	172	305.46

PIG DRUM STEADY STATE (3 WATT - CONC. HT GEN. 70F AMB. TEMP. HANFORD SUN, CASE 3A)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	281.16	2	317.42	3	318.89	4	281.10	5	279.34
6	274.50	7	274.34	8	274.13	9	274.10	10	273.96
11	273.89	12	274.28	13	274.25	14	271.49	15	270.96
16	268.94	17	266.39	18	266.62	19	263.86	20	268.96
21	267.98	22	266.27	23	266.20	24	266.01	25	268.79
26	267.88	27	263.15	28	264.40	29	262.09	30	265.57
31	273.85	32	270.38	33	281.51	34	281.77	35	277.74
36	277.95	37	278.07	40	250.94	41	226.91	42	221.81
43	221.15	44	221.05	45	220.96	46	218.72	47	214.64
48	211.42	49	210.12	50	255.42	51	256.54	52	253.40
53	250.65	54	235.62	55	223.82	56	221.14	57	220.76
58	220.66	59	220.56	60	218.26	61	214.30	62	211.30
63	210.10	70	230.20	71	230.52	72	232.14	73	228.17
74	224.61	75	221.43	76	220.59	77	220.45	78	220.17
79	220.01	80	216.89	81	213.24	82	210.97	83	210.09
90	224.37	91	224.23	92	223.90	93	222.97	94	221.95
95	220.88	96	220.45	100	224.06	101	223.92	102	223.54
103	222.70	104	221.71	105	220.66	106	220.16	110	223.77
111	223.64	112	223.20	113	222.44	114	221.46	115	220.43
116	219.84	120	218.68	121	218.70	122	219.76	123	217.99
124	217.26	125	216.57	126	215.83	127	213.07	128	211.50
129	210.50	130	210.11	131	218.91	132	218.71	140	212.18
141	212.14	142	212.34	143	212.02	144	211.84	145	211.66
146	211.43	147	210.79	148	210.42	149	210.24	150	210.18
151	212.15	152	212.18	160	210.37	161	210.31	162	210.32
163	210.35	164	210.33	165	210.29	166	210.23	167	210.14
168	210.11	169	210.16	170	210.22	171	210.23	172	210.35

PIG DRUM STEADY STATE (3 WATT - CONC. HT. GEN. 90F AMB. TEMP. HANFORD SUN, CASE 3B)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	298.10	2	334.38	3	335.84	4	298.05	5	296.42
6	291.67	7	291.52	8	291.30	9	291.27	10	291.12
11	291.05	12	291.46	13	291.42	14	288.78	15	288.23
16	286.19	17	283.68	18	283.94	19	281.18	20	286.33
21	285.32	22	283.56	23	283.49	24	283.30	25	286.16
26	285.22	27	280.40	28	281.68	29	279.34	30	282.86
31	291.01	32	287.62	33	298.47	34	298.73	35	294.81
36	295.01	37	295.14	40	268.06	41	243.66	42	238.51
43	237.86	44	237.77	45	237.68	46	235.32	47	231.03
48	227.64	49	226.26	50	272.44	51	273.60	52	270.42
53	267.65	54	252.36	55	240.46	56	237.78	57	237.41
58	237.33	59	237.23	60	234.82	61	230.65	62	227.51
63	226.25	70	246.42	71	246.79	72	248.52	73	244.54
74	241.01	75	237.92	76	237.14	77	237.03	78	236.76
79	236.60	80	233.34	81	229.53	82	227.15	83	226.23
90	240.42	91	240.31	92	240.04	93	239.20	94	238.27
95	237.32	96	236.97	100	240.11	101	240.00	102	239.69
103	238.93	104	238.03	105	237.11	106	236.69	110	239.84
111	239.74	112	239.37	113	238.69	114	237.79	115	236.88
116	236.38	120	234.78	121	234.81	122	235.92	123	234.19
124	233.52	125	232.90	126	232.20	127	229.34	128	227.70
129	226.67	130	226.26	131	235.05	132	234.88	140	228.31
141	228.28	142	228.48	143	228.17	144	228.01	145	227.84
146	227.63	147	226.96	148	226.58	149	226.39	150	226.33
151	228.30	152	228.32	160	226.51	161	226.45	162	226.46
163	226.49	164	226.47	165	226.43	166	226.37	167	226.29
168	226.25	169	226.31	170	226.37	171	226.38	172	226.49

PIG DRUM STEADY STATE (3 WATT - CONC. HT. GEN. 100F AMB. TEMP. HANFORD SUN CASE 3C)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	303.39	2	339.65	3	341.10	4	303.33	5	301.72
6	296.98	7	296.83	8	296.65	9	296.62	10	296.48
11	296.42	12	296.77	13	296.74	14	294.31	15	293.84
16	292.01	17	289.74	18	289.95	19	287.30	20	292.07
21	291.20	22	289.64	23	289.57	24	289.38	25	291.91
26	291.11	27	286.62	28	287.85	29	285.60	30	288.96
31	296.38	32	293.31	33	303.74	34	303.99	35	300.10
36	300.30	37	300.42	40	274.60	41	250.84	42	245.83
43	245.20	44	245.11	45	245.02	46	242.79	47	238.73
48	235.53	49	234.23	50	278.89	51	280.06	52	277.05
53	274.31	54	259.46	55	247.78	56	245.14	57	244.78
58	244.69	59	244.60	60	242.32	61	238.38	62	235.41
63	234.22	70	254.07	71	254.41	72	256.02	73	252.09
74	248.57	75	245.41	76	244.59	77	244.46	78	244.20
79	244.05	80	240.95	81	237.33	82	235.08	83	234.20
90	248.33	91	248.19	92	247.87	93	246.95	94	245.94
95	244.87	96	244.45	100	248.05	101	247.91	102	247.54
103	246.70	104	245.72	105	244.68	106	244.18	110	247.78
111	247.66	112	247.24	113	246.47	114	245.49	115	244.46
116	243.89	120	242.74	121	242.75	122	243.82	123	242.05
124	241.32	125	240.63	126	239.91	127	237.16	128	235.60
129	234.62	130	234.23	131	242.97	132	242.77	140	236.28
141	236.24	142	236.44	143	236.12	144	235.94	145	235.76
146	235.54	147	234.90	148	234.53	149	234.35	150	234.30
151	236.25	152	236.27	160	234.48	161	234.42	162	234.43
163	234.46	164	234.44	165	234.40	166	234.34	167	234.26
168	234.22	169	234.27	170	234.34	171	234.34	172	234.46

PIG DRUM STEADY STATE (3 WATT - CONC. HT. GEN. 115F AMB. TEMP. HANFORD SUN CASE 3D)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	313.73	2	350.00	3	351.46	4	313.67	5	312.15
6	307.47	7	307.32	8	307.11	9	307.08	10	306.95
11	306.88	12	307.26	13	307.22	14	304.88	15	304.41
16	302.61	17	300.40	18	300.63	19	298.05	20	302.72
21	301.86	22	300.30	23	300.23	24	300.06	25	302.56
26	301.77	27	297.36	28	298.56	29	296.37	30	299.64
31	306.85	32	303.87	33	314.10	34	314.36	35	310.52
36	310.73	37	310.85	40	285.56	41	262.15	42	257.21
43	256.60	44	256.52	45	256.44	46	254.33	47	250.51
48	247.48	49	246.26	50	289.78	51	290.93	52	287.98
53	285.28	54	270.66	55	259.17	56	256.57	57	256.21
58	256.13	59	256.05	60	253.90	61	250.18	62	247.37
63	246.25	70	265.38	71	265.71	72	267.29	73	263.43
74	259.96	75	256.86	76	256.05	77	255.92	78	255.69
79	255.55	80	252.61	81	249.19	82	247.05	83	246.23
90	259.74	91	259.60	92	259.29	93	258.38	94	257.39
95	256.34	96	255.92	100	259.48	101	259.34	102	258.98
103	258.15	104	257.18	105	256.16	106	255.68	110	259.23
111	259.11	112	258.70	113	257.94	114	256.97	115	255.96
116	255.41	120	254.40	121	254.41	122	255.42	123	253.72
124	253.00	125	252.33	126	251.63	127	249.03	128	247.55
129	246.62	130	246.25	131	254.61	132	254.42	140	248.21
141	248.18	142	248.36	143	248.06	144	247.88	145	247.70
146	247.49	147	246.89	148	246.54	149	246.37	150	246.32
151	248.19	152	248.21	160	246.49	161	246.44	162	246.45
163	246.48	164	246.45	165	246.41	166	246.36	167	246.28
168	246.25	169	246.29	170	246.35	171	246.36	172	246.47

PIG DRUM STEADY STATE (3 WATT - CONC. HT. GEN. 115F AMB. TEMP HANFORD SUN, CASE 3D2, EMISSIVITY = 0.9)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	269.19	2	305.48	3	306.98	4	269.15	5	267.41
6	262.51	7	262.36	8	262.16	9	262.13	10	261.99
11	261.92	12	262.30	13	262.26	14	259.35	15	258.82
16	256.73	17	254.08	18	254.28	19	251.43	20	256.67
21	255.69	22	253.96	23	253.88	24	253.68	25	256.50
26	255.58	27	250.72	28	252.01	29	249.63	30	253.22
31	261.88	32	258.23	33	269.58	34	269.86	35	265.77
36	265.99	37	266.12	40	238.23	41	213.77	42	208.58
43	207.89	44	207.79	45	207.69	46	205.40	47	201.23
48	197.93	49	196.60	50	242.79	51	243.93	52	240.71
53	237.91	54	222.58	55	210.59	56	207.87	57	207.48
58	207.37	59	207.27	60	204.92	61	200.86	62	197.81
63	196.59	70	216.99	71	217.32	72	218.97	73	214.92
74	211.30	75	208.10	76	207.27	77	207.14	78	206.84
79	206.67	80	203.49	81	199.77	82	197.46	83	196.57
90	211.02	91	210.88	92	210.54	93	209.61	94	208.58
95	207.53	96	207.12	100	210.69	101	210.55	102	210.16
103	209.31	104	208.32	105	207.29	106	206.81	110	210.38
111	210.25	112	209.80	113	209.03	114	208.05	115	207.04
116	206.46	120	205.21	121	205.23	122	206.31	123	204.51
124	203.78	125	203.10	126	202.37	127	199.58	128	197.99
129	196.97	130	196.57	131	205.44	132	205.24	140	198.61
141	198.59	142	198.78	143	198.45	144	198.27	145	198.10
146	197.89	147	197.26	148	196.89	149	196.69	150	196.63
151	198.61	152	198.61	160	196.77	161	196.73	162	196.74
163	196.75	164	196.73	165	196.71	166	196.67	167	196.60
168	196.57	169	196.61	170	196.66	171	196.67	172	196.75

PIG DRUM STEADY STATE (3 WATT DIST. HT. GEN. 70F AMB. TEMP. HANFORD SUN, CASE 4A)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	286.46	2	286.41	3	285.50	4	274.14	5	274.42
6	263.60	7	263.46	8	263.26	9	263.23	10	263.11
11	263.05	12	263.41	13	263.38	14	260.97	15	260.52
16	258.79	17	256.61	18	256.80	19	254.50	20	258.75
21	257.93	22	256.51	23	256.45	24	256.29	25	258.61
26	257.85	27	253.92	28	254.95	29	253.04	30	255.92
31	263.02	32	260.03	33	274.13	34	273.94	35	264.71
36	264.71	37	264.69	40	243.85	41	224.06	42	219.86
43	219.31	44	219.22	45	219.14	46	217.28	47	213.87
48	211.18	49	210.08	50	247.57	51	248.47	52	245.87
53	243.61	54	231.26	55	221.54	56	219.33	57	219.01
58	218.93	59	218.84	60	216.92	61	213.59	62	211.08
63	210.07	70	226.79	71	227.06	72	228.38	73	225.13
74	222.21	75	219.59	76	218.90	77	218.78	78	218.55
79	218.41	80	215.78	81	212.71	82	210.80	83	210.06
90	221.99	91	221.87	92	221.60	93	220.85	94	220.02
95	219.14	96	218.78	100	221.73	101	221.61	102	221.30
103	220.62	104	219.82	105	218.96	106	218.54	110	221.48
111	221.38	112	221.02	113	220.41	114	219.61	115	218.76
116	218.27	120	217.24	121	217.25	122	218.14	123	216.68
124	216.08	125	215.51	126	214.89	127	212.57	128	211.24
129	210.40	130	210.07	131	217.43	132	217.27	140	211.80
141	211.77	142	211.93	143	211.68	144	211.53	145	211.38
146	211.19	147	210.65	148	210.34	149	210.18	150	210.13
151	211.78	152	211.80	160	210.29	161	210.24	162	210.25
163	210.28	164	210.26	165	210.23	166	210.18	167	210.10
168	210.08	169	210.11	170	210.16	171	210.17	172	210.27

PIG DRUM STEADY STATE (3 WATT DIST. HT. GEN. 90F AMB. TEMP. HANFORD SUN, CASE 4B)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	301.22	2	301.17	3	300.25	4	288.90	5	289.19
6	278.36	7	278.22	8	278.03	9	278.01	10	277.88
11	277.82	12	278.17	13	278.14	14	275.83	15	275.39
16	273.70	17	271.57	18	271.78	19	269.53	20	273.72
21	272.90	22	271.47	23	271.41	24	271.26	25	273.58
26	272.82	27	268.95	28	269.96	29	268.08	30	270.90
31	277.79	32	274.90	33	288.88	34	288.70	35	279.47
36	279.47	37	279.45	40	258.94	41	239.13	42	234.93
43	234.39	44	234.31	45	234.24	46	232.58	47	229.56
48	227.17	49	226.20	50	262.72	51	263.60	52	261.04
53	258.74	54	246.43	55	236.66	56	234.44	57	234.12
58	234.04	59	233.97	60	232.26	61	229.31	62	227.09
63	226.19	70	242.23	71	242.47	72	243.75	73	240.46
74	237.50	75	234.80	76	234.06	77	233.94	78	233.73
79	233.61	80	231.27	81	228.54	82	226.84	83	226.18
90	237.49	91	237.36	92	237.06	93	236.25	94	235.36
95	234.40	96	233.99	100	237.26	101	237.13	102	236.79
103	236.04	104	235.17	105	234.24	106	233.77	110	237.04
111	236.92	112	236.54	113	235.85	114	234.99	115	234.06
116	233.54	120	233.00	121	233.00	122	233.82	123	232.37
124	231.73	125	231.12	126	230.52	127	228.42	128	227.24
129	226.50	130	226.20	131	233.15	132	232.98	140	227.84
141	227.81	142	227.96	143	227.70	144	227.54	145	227.38
146	227.20	147	226.71	148	226.43	149	226.30	150	226.26
151	227.82	152	227.83	160	226.41	161	226.36	162	226.37
163	226.39	164	226.37	165	226.34	166	226.29	167	226.22
168	226.20	169	226.24	170	226.29	171	226.29	172	226.39

PIG DRUM STEADY STATE (3 WATT DIST. HT. GEN. 100F AMB. TEMP. HANFORD SUN, CASE 4C)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	322.80	2	322.76	3	321.84	4	310.48	5	310.78
6	299.94	7	299.80	8	299.62	9	299.60	10	299.45
11	299.38	12	299.73	13	299.70	14	297.16	15	296.66
16	294.75	17	292.35	18	292.58	19	289.80	20	294.82
21	293.90	22	292.25	23	292.17	24	291.98	25	294.65
26	293.80	27	289.07	28	290.36	29	288.00	30	291.53
31	299.34	32	296.11	33	310.47	34	310.29	35	301.05
36	301.05	37	301.03	40	276.42	41	251.41	42	246.13
43	245.47	44	245.37	45	245.28	46	243.00	47	238.85
48	235.57	49	234.24	50	280.93	51	282.17	52	279.00
53	276.12	54	260.49	55	248.21	56	245.43	57	245.05
58	244.95	59	244.86	60	242.53	61	238.49	62	235.45
63	234.22	70	254.79	71	255.15	72	256.85	73	252.72
74	249.02	75	245.72	76	244.86	77	244.72	78	244.46
79	244.30	80	241.13	81	237.42	82	235.10	83	234.21
90	248.75	91	248.61	92	248.27	93	247.32	94	246.26
95	245.16	96	244.72	100	248.46	101	248.32	102	247.93
103	247.06	104	246.03	105	244.95	106	244.44	110	248.19
111	248.05	112	247.62	113	246.82	114	245.80	115	244.73
116	244.14	120	242.99	121	243.00	122	244.10	123	242.27
124	241.51	125	240.80	126	240.06	127	237.24	128	235.64
129	234.63	130	234.23	131	243.22	132	243.02	140	236.34
141	236.30	142	236.50	143	236.18	144	235.99	145	235.80
146	235.57	147	234.92	148	234.55	149	234.36	150	234.30
151	236.32	152	236.34	160	234.49	161	234.43	162	234.44
163	234.47	164	234.45	165	234.41	166	234.35	167	234.26
168	234.23	169	234.28	170	234.34	171	234.35	172	234.47

PIG DRUM STEADY STATE (3 WATT DIST. HT. GEN. 115F AMB. TEMP. HANFORD SUN, CASE 4D)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	331.79	2	331.74	3	330.82	4	319.46	5	319.75
6	308.92	7	308.78	8	308.59	9	308.57	10	308.43
11	308.36	12	308.72	13	308.69	14	306.39	15	305.93
16	304.15	17	301.97	18	302.19	19	299.58	20	304.27
21	303.42	22	301.88	23	301.81	24	301.62	25	304.11
26	303.32	27	298.89	28	300.11	29	297.89	30	301.21
31	308.33	32	305.40	33	319.45	34	319.27	35	310.03
36	310.03	37	310.02	40	286.94	41	263.29	42	258.30
43	257.69	44	257.60	45	257.52	46	255.20	47	250.97
48	247.63	49	246.28	50	291.16	51	292.35	52	289.37
53	286.64	54	271.84	55	260.23	56	257.62	57	257.26
58	257.18	59	257.09	60	254.71	61	250.61	62	247.51
63	246.26	70	266.39	71	266.73	72	268.35	73	264.44
74	260.94	75	257.83	76	257.03	77	256.91	78	256.66
79	256.51	80	253.28	81	249.51	82	247.16	83	246.24
90	260.66	91	260.52	92	260.20	93	259.30	94	258.31
95	257.28	96	256.88	100	260.39	101	260.25	102	259.88
103	259.06	104	258.09	105	257.09	106	256.62	110	260.13
111	260.00	112	259.59	113	258.83	114	257.87	115	256.87
116	256.33	120	254.97	121	254.99	122	256.09	123	254.29
124	253.57	125	252.90	126	252.18	127	249.33	128	247.70
129	246.67	130	246.27	131	255.21	132	255.02	140	248.36
141	248.33	142	248.53	143	248.21	144	248.03	145	247.85
146	247.63	147	246.97	148	246.59	149	246.40	150	246.34
151	248.34	152	248.36	160	246.52	161	246.47	162	246.48
163	246.51	164	246.49	165	246.45	166	246.39	167	246.30
168	246.27	169	246.31	170	246.38	171	246.38	172	246.50

PIG DRUM STEADY STATE (3 WATT - CONC. HT. GEN. 70F AMB. TEMP. NO SUN CASE 5A)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	134.71	2	170.97	3	172.56	4	134.66	5	131.81
6	126.06	7	125.92	8	125.69	9	125.67	10	125.56
11	125.51	12	125.87	13	125.84	14	122.28	15	121.82
16	119.74	17	116.91	18	116.90	19	114.43	20	119.02
21	118.17	22	116.75	23	116.69	24	116.51	25	118.86
26	118.08	27	113.94	28	115.03	29	113.04	30	116.11
31	125.49	32	121.33	33	135.07	34	135.35	35	130.29
36	130.49	37	130.63	40	103.69	41	84.02	42	79.64
43	79.03	44	78.90	45	78.78	46	77.13	47	74.12
48	71.74	49	70.78	50	107.48	51	108.36	52	105.63
53	103.54	54	91.23	55	81.42	56	79.11	57	78.77
58	78.64	59	78.51	60	76.81	61	73.88	62	71.67
63	70.78	70	86.49	71	86.76	72	88.08	73	84.88
74	81.97	75	79.39	76	78.70	77	78.58	78	78.23
79	78.02	80	75.77	81	73.13	82	71.46	83	70.81
90	81.45	91	81.34	92	81.10	93	80.43	94	79.70
95	78.92	96	78.60	100	81.06	101	80.95	102	80.65
103	80.08	104	79.38	105	78.63	106	78.22	110	80.68
111	80.58	112	80.22	113	79.75	114	79.06	115	78.33
116	77.82	120	77.08	121	77.07	122	77.80	123	76.59
124	76.09	125	75.59	126	75.00	127	73.03	128	71.90
129	71.18	130	70.89	131	77.20	132	77.07	140	72.50
141	72.44	142	72.57	143	72.40	144	72.28	145	72.12
146	71.90	147	71.41	148	71.14	149	71.03	150	71.00
151	72.42	152	72.48	160	71.23	161	71.14	162	71.15
163	71.23	164	71.22	165	71.15	166	71.05	167	70.95
168	70.92	169	70.98	170	71.04	171	71.04	172	71.20

PIG DRUM STEADY STATE (3 WATT - CONC. HT. GEN. 90F AMB. TEMP. NO SUN CASE 5B)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	152.14	2	188.40	3	189.97	4	152.08	5	149.40
6	143.77	7	143.63	8	143.40	9	143.38	10	143.27
11	143.22	12	143.58	13	143.55	14	140.22	15	139.78
16	137.77	17	135.09	18	135.11	19	132.72	20	137.17
21	136.34	22	134.95	23	134.89	24	134.72	25	137.02
26	136.25	27	132.24	28	133.28	29	131.37	30	134.32
31	143.20	32	139.28	33	152.50	34	152.77	35	147.86
36	148.06	37	148.20	40	122.45	41	103.64	42	99.47
43	98.89	44	98.77	45	98.66	46	97.02	47	94.03
48	91.66	49	90.70	50	126.14	51	126.94	52	124.33
53	122.30	54	110.53	55	101.15	56	98.96	57	98.62
58	98.50	59	98.38	60	96.69	61	93.79	62	91.59
63	90.70	70	106.09	71	106.34	72	107.59	73	104.51
74	101.70	75	99.21	76	98.54	77	98.43	78	98.11
79	97.92	80	95.67	81	93.04	82	91.38	83	90.73
90	101.30	91	101.19	92	100.95	93	100.28	94	99.54
95	98.77	96	98.45	100	100.94	101	100.83	102	100.53
103	99.96	104	99.25	105	98.50	106	98.10	110	100.59
111	100.49	112	100.14	113	99.65	114	98.96	115	98.23
116	97.73	120	97.00	121	96.98	122	97.71	123	96.50
124	96.00	125	95.49	126	94.91	127	92.94	128	91.81
129	91.10	130	90.81	131	97.11	132	96.99	140	92.41
141	92.35	142	92.48	143	92.31	144	92.19	145	92.02
146	91.81	147	91.32	148	91.05	149	90.94	150	90.91
151	92.33	152	92.39	160	91.14	161	91.05	162	91.06
163	91.13	164	91.13	165	91.06	166	90.96	167	90.86
168	90.83	169	90.89	170	90.95	171	90.96	172	91.11

PIG DRUM STEADY STATE (3 WATT - CONC. HT. GEN. 100F AMB. TEMP. NO SUN CASE 5C)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	161.17	2	197.44	3	199.00	4	161.12	5	158.51
6	152.95	7	152.80	8	152.58	9	152.55	10	152.45
11	152.40	12	152.76	13	152.73	14	149.49	15	149.05
16	147.08	17	144.46	18	144.49	19	142.13	20	146.54
21	145.71	22	144.32	23	144.26	24	144.09	25	146.38
26	145.62	27	141.66	28	142.68	29	140.79	30	143.70
31	152.37	32	148.56	33	161.53	34	161.81	35	156.97
36	157.17	37	157.31	40	132.04	41	113.54	42	109.45
43	108.87	44	108.76	45	108.65	46	107.00	47	104.00
48	101.63	49	100.67	50	135.69	51	136.47	52	133.89
53	131.88	54	120.31	55	111.09	56	108.93	57	108.60
58	108.49	59	108.37	60	106.68	61	103.76	62	101.56
63	100.67	70	115.99	71	116.23	72	117.45	73	114.41
74	111.64	75	109.18	76	108.52	77	108.41	78	108.09
79	107.91	80	105.66	81	103.01	82	101.35	83	100.70
90	111.29	91	111.18	92	110.94	93	110.26	94	109.52
95	108.74	96	108.42	100	110.94	101	110.83	102	110.53
103	109.95	104	109.24	105	108.49	106	108.09	110	110.61
111	110.51	112	110.16	113	109.66	114	108.96	115	108.23
116	107.73	120	106.99	121	106.98	122	107.72	123	106.49
124	105.98	125	105.47	126	104.89	127	102.91	128	101.78
129	101.06	130	100.77	131	107.11	132	106.99	140	102.38
141	102.32	142	102.45	143	102.27	144	102.15	145	101.99
146	101.78	147	101.28	148	101.02	149	100.90	150	100.87
151	102.30	152	102.36	160	101.10	161	101.02	162	101.02
163	101.10	164	101.09	165	101.02	166	100.92	167	100.82
168	100.79	169	100.85	170	100.91	171	100.92	172	101.07

PIG DRUM STEADY STATE (3 WATT - CONC. HT. GEN. 115F AMB. TEMP. NO SUN CASE 5D)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	174.40	2	210.67	3	212.22	4	174.35	5	171.85
6	166.38	7	166.24	8	166.01	9	165.99	10	165.88
11	165.83	12	166.19	13	166.16	14	163.09	15	162.66
16	160.75	17	158.23	18	158.27	19	155.97	20	160.28
21	159.47	22	158.10	23	158.04	24	157.87	25	160.13
26	159.38	27	155.51	28	156.49	29	154.65	30	157.49
31	165.81	32	162.17	33	174.77	34	175.04	35	170.30
36	170.51	37	170.64	40	146.21	41	128.28	42	124.33
43	123.77	44	123.66	45	123.56	46	121.92	47	118.94
48	116.58	49	115.62	50	149.78	51	150.51	52	148.01
53	146.04	54	134.83	55	125.90	56	123.82	57	123.50
58	123.39	59	123.28	60	121.60	61	118.70	62	116.50
63	115.62	70	130.72	71	130.95	72	132.12	73	129.16
74	126.46	75	124.06	76	123.41	77	123.30	78	123.01
79	122.84	80	120.59	81	117.95	82	116.29	83	115.64
90	126.18	91	126.07	92	125.83	93	125.16	94	124.42
95	123.64	96	123.31	100	125.85	101	125.75	102	125.45
103	124.86	104	124.15	105	123.40	106	123.00	110	125.54
111	125.44	112	125.10	113	124.59	114	123.89	115	123.15
116	122.67	120	121.93	121	121.92	122	122.66	123	121.43
124	120.91	125	120.41	126	119.83	127	117.85	128	116.72
129	116.00	130	115.72	131	122.05	132	121.92	140	117.32
141	117.26	142	117.39	143	117.21	144	117.09	145	116.93
146	116.71	147	116.23	148	115.96	149	115.84	150	115.81
151	117.24	152	117.30	160	116.04	161	115.96	162	115.96
163	116.03	164	116.02	165	115.96	166	115.86	167	115.76
168	115.73	169	115.79	170	115.85	171	115.86	172	116.01

PIG DRUM STEADY STATE (3 WATT DIST. HT. GEN. 70F AMB. TEMP. NO SUN, CASE 6A)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	148.99	2	148.95	3	148.03	4	136.68	5	136.98
6	126.14	7	126.01	8	125.82	9	125.80	10	125.69
11	125.64	12	125.96	13	125.94	14	122.37	15	121.92
16	119.84	17	117.00	18	116.99	19	114.52	20	119.11
21	118.27	22	116.84	23	116.78	24	116.61	25	118.95
26	118.17	27	114.03	28	115.12	29	113.13	30	116.20
31	125.61	32	121.44	33	136.66	34	136.48	35	127.25
36	127.25	37	127.24	40	103.76	41	84.06	42	79.66
43	79.05	44	78.93	45	78.80	46	77.15	47	74.13
48	71.75	49	70.78	50	107.56	51	108.43	52	105.71
53	103.61	54	91.28	55	81.45	56	79.14	57	78.79
58	78.66	59	78.53	60	76.82	61	73.89	62	71.68
63	70.78	70	86.53	71	86.80	72	88.12	73	84.92
74	81.99	75	79.41	76	78.72	77	78.60	78	78.25
79	78.04	80	75.79	81	73.14	82	71.47	83	70.82
90	81.48	91	81.37	92	81.13	93	80.46	94	79.72
95	78.94	96	78.62	100	81.08	101	80.97	102	80.67
103	80.10	104	79.40	105	78.65	106	78.24	110	80.70
111	80.61	112	80.24	113	79.77	114	79.08	115	78.35
116	77.84	120	77.10	121	77.09	122	77.82	123	76.61
124	76.11	125	75.60	126	75.01	127	73.04	128	71.90
129	71.18	130	70.90	131	77.21	132	77.09	140	72.51
141	72.44	142	72.57	143	72.40	144	72.29	145	72.12
146	71.90	147	71.41	148	71.14	149	71.03	150	71.00
151	72.42	152	72.49	160	71.23	161	71.15	162	71.15
163	71.23	164	71.22	165	71.15	166	71.05	167	70.95
168	70.92	169	70.98	170	71.04	171	71.05	172	71.20

PIG DRUM STEADY STATE (3 WATT DIST. HT. GEN. 90F AMB. TEMP. NO SUN, CASE 6B)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	166.55	2	166.50	3	165.58	4	154.23	5	154.53
6	143.70	7	143.56	8	143.37	9	143.35	10	143.24
11	143.20	12	143.51	13	143.49	14	140.17	15	139.72
16	137.74	17	135.05	18	135.07	19	132.68	20	137.13
21	136.30	22	134.91	23	134.85	24	134.68	25	136.97
26	136.21	27	132.21	28	133.24	29	131.33	30	134.28
31	143.17	32	139.25	33	154.22	34	154.04	35	144.81
36	144.81	37	144.79	40	122.43	41	103.63	42	99.46
43	98.88	44	98.76	45	98.65	46	97.01	47	94.02
48	91.66	49	90.70	50	126.10	51	126.91	52	124.30
53	122.27	54	110.51	55	101.14	56	98.95	57	98.61
58	98.49	59	98.38	60	96.69	61	93.78	62	91.59
63	90.70	70	106.07	71	106.33	72	107.57	73	104.49
74	101.69	75	99.20	76	98.54	77	98.42	78	98.10
79	97.91	80	95.67	81	93.04	82	91.38	83	90.73
90	101.29	91	101.18	92	100.94	93	100.27	94	99.53
95	98.76	96	98.44	100	100.93	101	100.82	102	100.52
103	99.95	104	99.24	105	98.49	106	98.09	110	100.58
111	100.48	112	100.13	113	99.64	114	98.95	115	98.22
116	97.73	120	96.99	121	96.98	122	97.71	123	96.49
124	95.99	125	95.48	126	94.90	127	92.94	128	91.81
129	91.09	130	90.81	131	97.11	132	96.98	140	92.41
141	92.35	142	92.48	143	92.30	144	92.19	145	92.02
146	91.81	147	91.32	148	91.05	149	90.94	150	90.91
151	92.33	152	92.39	160	91.14	161	91.05	162	91.06
163	91.13	164	91.13	165	91.06	166	90.96	167	90.86
168	90.83	169	90.89	170	90.95	171	90.95	172	91.11

PIG DRUM STEADY STATE (3 WATT DIST. HT. GEN. 100F AMB. TEMP. NO SUN, CASE 6C)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	175.73	2	175.69	3	174.77	4	163.42	5	163.72
6	152.88	7	152.75	8	152.56	9	152.54	10	152.43
11	152.38	12	152.70	13	152.68	14	149.45	15	149.01
16	147.06	17	144.43	18	144.46	19	142.10	20	146.50
21	145.68	22	144.29	23	144.23	24	144.06	25	146.34
26	145.59	27	141.63	28	142.65	29	140.76	30	143.67
31	152.35	32	148.54	33	163.40	34	163.22	35	153.99
36	153.99	37	153.98	40	132.02	41	113.52	42	109.43
43	108.86	44	108.74	45	108.63	46	106.99	47	104.00
48	101.63	49	100.67	50	135.66	51	136.44	52	133.86
53	131.85	54	120.29	55	111.07	56	108.92	57	108.59
58	108.47	59	108.36	60	106.67	61	103.76	62	101.56
63	100.67	70	115.97	71	116.22	72	117.43	73	114.40
74	111.63	75	109.17	76	108.51	77	108.39	78	108.08
79	107.90	80	105.65	81	103.01	82	101.35	83	100.70
90	111.28	91	111.17	92	110.92	93	110.25	94	109.51
95	108.73	96	108.41	100	110.93	101	110.82	102	110.52
103	109.94	104	109.23	105	108.48	106	108.07	110	110.60
111	110.50	112	110.15	113	109.65	114	108.95	115	108.22
116	107.72	120	106.98	121	106.97	122	107.71	123	106.48
124	105.98	125	105.47	126	104.89	127	102.91	128	101.78
129	101.06	130	100.77	131	107.10	132	106.98	140	102.38
141	102.32	142	102.45	143	102.27	144	102.15	145	101.99
146	101.77	147	101.28	148	101.01	149	100.90	150	100.87
151	102.30	152	102.36	160	101.10	161	101.02	162	101.02
163	101.09	164	101.09	165	101.02	166	100.92	167	100.82
168	100.79	169	100.85	170	100.91	171	100.92	172	101.07

PIG DRUM STEADY STATE (3 WATT DIST. HT. GEN. 115F AMB. TEMP. NO SUN, CASE 6D)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	189.20	2	189.15	3	188.23	4	176.88	5	177.18
6	166.35	7	166.21	8	166.02	9	166.00	10	165.89
11	165.84	12	166.16	13	166.14	14	163.07	15	162.64
16	160.75	17	158.22	18	158.27	19	155.97	20	160.27
21	159.46	22	158.09	23	158.04	24	157.87	25	160.11
26	159.37	27	155.51	28	156.49	29	154.65	30	157.48
31	165.82	32	162.17	33	176.87	34	176.68	35	167.46
36	167.46	37	167.44	40	146.21	41	128.28	42	124.33
43	123.77	44	123.66	45	123.56	46	121.92	47	118.94
48	116.58	49	115.62	50	149.77	51	150.50	52	148.00
53	146.04	54	134.83	55	125.90	56	123.82	57	123.49
58	123.39	59	123.28	60	121.60	61	118.70	62	116.50
63	115.62	70	130.71	71	130.94	72	132.11	73	129.15
74	126.46	75	124.05	76	123.41	77	123.30	78	123.00
79	122.83	80	120.59	81	117.95	82	116.29	83	115.64
90	126.18	91	126.07	92	125.83	93	125.15	94	124.41
95	123.63	96	123.31	100	125.85	101	125.74	102	125.45
103	124.86	104	124.15	105	123.39	106	123.00	110	125.54
111	125.44	112	125.09	113	124.59	114	123.89	115	123.15
116	122.67	120	121.93	121	121.92	122	122.65	123	121.42
124	120.91	125	120.40	126	119.83	127	117.85	128	116.72
129	116.00	130	115.72	131	122.05	132	121.92	140	117.32
141	117.26	142	117.39	143	117.21	144	117.09	145	116.93
146	116.71	147	116.22	148	115.96	149	115.84	150	115.81
151	117.24	152	117.30	160	116.04	161	115.96	162	115.96
163	116.03	164	116.02	165	115.96	166	115.86	167	115.76
168	115.73	169	115.79	170	115.85	171	115.86	172	116.01

8.8.7 TAP-A Sample Pig Transient Temperatures

PIG PACKAGE TRANSIENT (3 WATT DIST. HT. GEN. 100F AMB. TEMP. FIRE CASE, CASE 11)

INTERNAL TEMPERATURES AT 0.0000 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	175.73	2	175.69	3	174.77	4	163.42	5	163.72
6	152.88	7	152.75	8	152.56	9	152.54	10	152.43
11	152.38	12	152.70	13	152.68	14	149.45	15	149.01
16	147.06	17	144.43	18	144.46	19	142.10	20	146.50
21	145.68	22	144.29	23	144.23	24	144.06	25	146.34
26	145.59	27	141.63	28	142.65	29	140.76	30	143.67
31	152.35	32	148.54	33	163.40	34	163.22	35	153.99
36	153.99	37	153.98	40	132.02	41	113.52	42	109.43
43	108.86	44	108.74	45	108.63	46	106.99	47	104.00
48	101.63	49	100.67	50	135.66	51	136.44	52	133.86
53	131.85	54	120.29	55	111.07	56	108.92	57	108.59
58	108.47	59	108.36	60	106.67	61	103.76	62	101.56
63	100.67	70	115.97	71	116.22	72	117.43	73	114.40
74	111.63	75	109.17	76	108.51	77	108.39	78	108.08
79	107.90	80	105.65	81	103.01	82	101.35	83	100.70
90	111.28	91	111.17	92	110.92	93	110.25	94	109.51
95	108.73	96	108.41	100	110.93	101	110.82	102	110.52
103	109.94	104	109.23	105	108.48	106	108.07	110	110.60
111	110.50	112	110.15	113	109.65	114	108.95	115	108.22
116	107.72	120	106.98	121	106.97	122	107.71	123	106.48
124	105.98	125	105.47	126	104.89	127	102.91	128	101.78
129	101.06	130	100.77	131	107.10	132	106.98	140	102.38
141	102.32	143	102.27	144	102.15	145	101.99	146	101.77
147	101.28	148	101.01	149	100.90	150	100.87	151	102.30
152	102.36	160	101.10	161	101.02	162	101.02	163	101.09
164	101.09	165	101.02	166	100.92	167	100.82	168	100.79
169	100.85	170	100.91	171	100.92	172	101.07		

INTERNAL TEMPERATURES AT 120.0 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	175.73	2	175.69	3	174.77	4	163.42	5	163.72
6	152.88	7	152.75	8	152.56	9	152.54	10	152.43
11	152.38	12	152.70	13	152.68	14	149.45	15	149.01
16	147.06	17	144.43	18	144.46	19	142.10	20	146.50
21	145.68	22	144.29	23	144.23	24	144.06	25	146.35
26	145.59	27	141.63	28	142.64	29	140.76	30	143.67
31	152.35	32	148.54	33	163.40	34	163.22	35	153.99
36	153.99	37	153.98	40	132.02	41	113.52	42	109.68
43	109.23	44	110.96	45	112.92	46	125.62	47	198.03
48	486.33	49	1137.62	50	135.66	51	136.44	52	133.86
53	131.85	54	120.29	55	111.07	56	109.15	57	108.96
58	110.68	59	112.64	60	125.34	61	197.82	62	486.25
63	1137.61	70	115.97	71	116.22	72	117.45	73	114.40
74	111.63	75	109.17	76	108.65	77	108.70	78	110.51
79	112.16	80	124.66	81	197.29	82	486.13	83	1137.72
90	111.30	91	111.26	92	111.38	93	110.33	94	109.53
95	108.75	96	108.48	100	111.02	101	111.08	102	113.53
103	110.16	104	109.31	105	108.56	106	108.34	110	110.75
111	110.67	112	116.34	113	109.82	114	109.10	115	108.37
116	107.89	120	117.77	121	117.92	122	161.32	123	117.42
124	116.77	125	116.26	126	115.92	127	132.77	128	202.93
129	490.89	130	1141.70	131	123.54	132	123.71	140	403.38
141	402.26	143	403.21	144	403.20	145	403.03	146	401.17
147	355.41	148	406.03	149	631.11	150	1184.88	151	394.90
152	402.45	160	1272.57	161	1270.05	162	1234.49	163	1272.39
164	1272.67	165	1272.61	166	1269.75	167	1192.87	168	1195.90
169	1216.12	170	1236.39	171	1241.66	172	1268.28		

INTERNAL TEMPERATURES AT 300.0 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	175.73	2	175.69	3	174.77	4	163.42	5	163.72
6	152.88	7	152.75	8	152.56	9	152.54	10	152.43
11	152.38	12	152.70	13	152.68	14	149.45	15	149.01
16	147.06	17	144.43	18	144.46	19	142.10	20	146.50
21	145.68	22	144.29	23	144.23	24	144.06	25	146.34
26	145.59	27	141.63	28	142.64	29	140.76	30	143.67
31	152.35	32	148.54	33	163.40	34	163.22	35	153.99
36	153.99	37	153.98	40	132.02	41	113.63	42	113.22
43	114.11	44	128.39	45	143.96	46	199.21	47	392.64
48	820.97	49	1276.08	50	135.66	51	136.44	52	133.87
53	131.85	54	120.29	55	111.17	56	112.45	57	113.72
58	128.09	59	143.70	60	198.97	61	392.47	62	820.90
63	1276.07	70	116.00	71	116.28	72	117.66	73	114.46
74	111.65	75	109.26	76	110.75	77	112.68	78	129.99
79	144.47	80	199.44	81	392.69	82	821.07	83	1276.21
90	111.73	91	112.23	92	114.57	93	111.21	94	109.89
95	109.14	96	109.68	100	112.29	101	113.11	102	126.03
103	112.10	104	110.54	105	109.81	106	111.08	110	112.91
111	112.84	112	139.57	113	112.10	114	111.25	115	110.49
116	109.88	120	212.17	121	207.18	122	243.33	123	211.82
124	210.86	125	209.24	126	195.25	127	255.61	128	423.51
129	835.69	130	1280.69	131	212.71	132	223.12	140	1302.94
141	1288.98	143	1301.94	144	1303.02	145	1299.35	146	1242.03
147	747.85	148	801.26	149	1037.27	150	1317.71	151	1265.12
152	1296.42	160	1356.34	161	1353.41	162	1324.83	163	1356.11
164	1356.45	165	1355.78	166	1346.96	167	1310.73	168	1315.39
169	1330.84	170	1338.21	171	1340.16	172	1352.82		

INTERNAL TEMPERATURES AT 600.0 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	175.73	2	175.69	3	174.77	4	163.42	5	163.72
6	152.88	7	152.75	8	152.56	9	152.54	10	152.43
11	152.38	12	152.70	13	152.67	14	149.45	15	149.01
16	147.06	17	144.43	18	144.46	19	142.10	20	146.50
21	145.68	22	144.29	23	144.23	24	144.06	25	146.34
26	145.59	27	141.64	28	142.66	29	140.76	30	143.67
31	152.35	32	148.54	33	163.40	34	163.22	35	153.99
36	153.99	37	153.98	40	132.03	41	114.90	42	139.57
43	147.79	44	194.03	45	243.60	46	351.54	47	618.47
48	1023.99	49	1317.23	50	135.66	51	136.45	52	133.94
53	131.86	54	120.31	55	112.38	56	136.86	57	146.22
58	193.15	59	243.26	60	351.35	61	618.36	62	1023.95
63	1317.22	70	116.33	71	116.93	72	119.27	73	115.05
74	111.95	75	110.43	76	126.85	77	139.08	78	200.40
79	251.26	80	357.40	81	621.96	82	1025.43	83	1317.62
90	115.26	91	118.43	92	128.96	93	117.01	94	113.01
95	113.01	96	120.41	100	118.82	101	122.45	102	160.21
103	121.00	104	116.79	105	116.57	106	125.93	110	122.34
111	123.05	112	195.96	113	122.30	114	120.61	115	119.91
116	121.11	120	365.21	121	362.69	122	356.15	123	365.92
124	364.23	125	362.58	126	357.11	127	527.35	128	715.22
129	1061.36	130	1324.73	131	370.24	132	375.21	140	1349.83
141	1348.43	143	1349.48	144	1349.89	145	1349.15	146	1332.49
147	1104.28	148	1130.72	149	1249.50	150	1353.91	151	1343.40
152	1347.00	160	1370.25	161	1369.53	162	1334.52	163	1370.04
164	1370.27	165	1370.08	166	1366.44	167	1349.76	168	1351.98
169	1359.17	170	1361.84	171	1362.60	172	1366.54		

INTERNAL TEMPERATURES AT 900.0 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	175.73	2	175.69	3	174.77	4	163.42	5	163.72
6	152.88	7	152.75	8	152.56	9	152.54	10	152.43
11	152.38	12	152.70	13	152.67	14	149.45	15	149.01
16	147.06	17	144.43	18	144.46	19	142.12	20	146.50
21	145.68	22	144.29	23	144.23	24	144.06	25	146.34
26	145.59	27	141.67	28	142.70	29	140.80	30	143.67
31	152.35	32	148.54	33	163.40	34	163.22	35	153.99
36	153.99	37	153.97	40	132.10	41	119.52	42	199.23
43	219.86	44	282.95	45	350.56	46	479.52	47	747.37
48	1101.83	49	1331.06	50	135.70	51	136.50	52	134.25
53	131.91	54	120.40	55	116.75	56	193.25	57	215.60
58	280.57	59	349.72	60	479.24	61	747.31	62	1101.83
63	1331.07	70	118.51	71	119.89	72	124.15	73	117.90
74	114.02	75	115.76	76	174.19	77	200.00	78	297.36
79	369.55	80	494.68	81	756.89	82	1105.69	83	1331.89
90	141.91	91	148.33	92	165.00	93	146.54	94	139.14
95	142.02	96	164.08	100	193.43	101	198.06	102	228.37
103	196.76	104	191.26	105	193.04	106	215.48	110	248.62
111	248.90	112	296.84	113	248.66	114	247.07	115	247.14
116	259.18	120	655.27	121	647.12	122	466.20	123	648.86
124	655.01	125	656.18	126	672.34	127	745.80	128	904.02
129	1162.13	130	1341.45	131	615.19	132	614.11	140	1228.67
141	1227.58	143	1227.24	144	1228.65	145	1228.87	146	1229.70
147	1211.22	148	1242.22	149	1308.98	150	1359.93	151	1226.47
152	1222.37	160	1349.68	161	1349.71	162	1336.97	163	1349.38
164	1349.68	165	1349.71	166	1349.90	167	1357.80	168	1359.93
169	1360.83	170	1354.51	171	1353.20	172	1347.53		

INTERNAL TEMPERATURES AT 1200. SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	175.73	2	175.69	3	174.77	4	163.42	5	163.72
6	152.88	7	152.75	8	152.56	9	152.54	10	152.43
11	152.38	12	152.70	13	152.67	14	149.45	15	149.01
16	147.06	17	144.43	18	144.46	19	142.15	20	146.50
21	145.68	22	144.29	23	144.24	24	144.06	25	146.35
26	145.59	27	141.80	28	142.85	29	140.92	30	143.68
31	152.35	32	148.54	33	163.40	34	163.22	35	153.99
36	153.99	37	153.97	40	132.31	41	129.51	42	285.92
43	317.30	44	378.02	45	443.13	46	576.58	47	829.82
48	1143.82	49	1338.19	50	135.91	51	136.77	52	135.23
53	132.16	54	120.80	55	126.61	56	283.39	57	313.76
58	375.94	59	441.89	60	576.12	61	829.75	62	1143.86
63	1338.22	70	131.65	71	133.57	72	138.33	73	131.50
74	127.16	75	137.29	76	284.94	77	310.90	78	410.16
79	475.21	80	602.39	81	846.48	82	1150.66	83	1339.53
90	248.56	91	250.76	92	254.97	93	249.92	94	247.33
95	255.58	96	288.66	100	333.85	101	332.34	102	330.71
103	332.21	104	333.15	105	339.41	106	373.52	110	422.11
111	416.60	112	408.27	113	417.28	114	421.67	115	424.79
116	456.75	120	795.45	121	777.20	122	580.12	123	780.00
124	797.05	125	802.18	126	828.05	127	904.03	128	1028.10
129	1220.96	130	1350.80	131	729.17	132	727.04	140	1246.66
141	1243.75	143	1243.49	144	1247.01	145	1248.12	146	1252.80
147	1256.13	148	1283.68	149	1330.16	150	1363.42	151	1240.79
152	1236.14	160	1351.90	161	1351.69	162	1341.57	163	1351.30
164	1351.95	165	1352.15	166	1353.15	167	1361.98	168	1363.65
169	1363.32	170	1356.80	171	1355.49	172	1349.41		

INTERNAL TEMPERATURES AT 1500. SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	175.73	2	175.69	3	174.77	4	163.42	5	163.72
6	152.88	7	152.75	8	152.56	9	152.54	10	152.43
11	152.38	12	152.70	13	152.67	14	149.45	15	149.02
16	147.07	17	144.44	18	144.47	19	142.25	20	146.51
21	145.69	22	144.31	23	144.25	24	144.08	25	146.37
26	145.61	27	142.19	28	143.24	29	141.28	30	143.72
31	152.35	32	148.54	33	163.40	34	163.22	35	153.99
36	153.99	37	153.97	40	132.77	41	146.05	42	383.32
43	421.48	44	470.98	45	524.12	46	652.82	47	888.62
48	1171.39	49	1342.77	50	136.68	51	137.63	52	137.75
53	132.99	54	122.01	55	143.94	56	390.29	57	423.62
58	472.54	59	524.20	60	652.90	61	888.76	62	1171.51
63	1342.81	70	163.57	71	164.86	72	167.25	73	162.95
74	159.78	75	184.93	76	426.31	77	446.31	78	523.24
79	570.18	80	689.87	81	912.70	82	1181.31	83	1344.61
90	390.73	91	385.43	92	375.50	93	386.30	94	393.59
95	408.29	96	446.93	100	462.65	101	455.11	102	438.27
103	456.28	104	465.10	105	477.03	106	518.57	110	537.37
111	527.69	112	501.29	113	529.11	114	538.83	115	546.51
116	593.60	120	867.82	121	848.06	122	674.52	123	851.12
124	870.94	125	879.70	126	916.64	127	1009.76	128	1110.83
129	1259.11	130	1356.79	131	802.62	132	800.68	140	1260.02
141	1256.61	143	1256.46	144	1260.70	145	1262.65	146	1270.26
147	1284.01	148	1306.81	149	1341.59	150	1365.71	151	1253.50
152	1248.99	160	1354.26	161	1353.95	162	1345.60	163	1353.59
164	1354.38	165	1354.73	166	1356.23	167	1364.77	168	1366.06
169	1365.24	170	1359.01	171	1357.75	172	1351.82		

INTERNAL TEMPERATURES AT 1800. SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	175.73	2	175.69	3	174.77	4	163.42	5	163.72
6	152.88	7	152.75	8	152.56	9	152.54	10	152.43
11	152.38	12	152.70	13	152.67	14	149.47	15	149.03
16	147.08	17	144.47	18	144.49	19	142.42	20	146.54
21	145.71	22	144.34	23	144.28	24	144.11	25	146.42
26	145.65	27	142.99	28	144.00	29	142.04	30	143.81
31	152.35	32	148.56	33	163.40	34	163.22	35	153.99
36	153.99	37	153.97	40	133.63	41	168.98	42	476.36
43	517.96	44	556.48	45	597.83	46	717.46	47	935.04
48	1192.01	49	1346.14	50	138.40	51	139.48	52	142.59
53	134.77	54	124.59	55	169.16	56	492.74	57	526.74
58	563.14	59	601.32	60	719.42	61	936.06	62	1192.40
63	1346.22	70	211.38	71	211.10	72	209.21	73	209.71
74	209.40	75	252.48	76	556.50	77	570.78	78	626.46
79	658.27	80	766.21	81	966.53	82	1204.93	83	1348.45
90	520.84	91	511.09	92	494.40	93	513.44	94	527.79
95	547.65	96	587.73	100	573.36	101	562.56	102	541.15
103	564.88	104	579.33	105	596.49	106	640.19	110	628.66
111	616.72	112	587.51	113	618.87	114	632.85	115	645.84
116	699.07	120	921.82	121	902.86	122	752.88	123	906.07
124	926.60	125	938.80	126	981.89	127	1080.95	128	1166.08
129	1284.41	130	1360.74	131	862.77	132	861.15	140	1270.56
141	1267.17	143	1267.11	144	1271.61	145	1274.35	146	1283.76
147	1302.09	148	1321.41	149	1348.72	150	1367.24	151	1264.36
152	1260.14	160	1356.11	161	1355.79	162	1348.91	163	1355.46
164	1356.29	165	1356.79	166	1358.60	167	1366.62	168	1367.64
169	1366.58	170	1360.72	171	1359.51	172	1353.89		

INTERNAL TEMPERATURES AT 120.0 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	175.73	2	175.69	3	174.77	4	163.42	5	163.72
6	152.88	7	152.75	8	152.56	9	152.54	10	152.43
11	152.38	12	152.70	13	152.67	14	149.48	15	149.04
16	147.09	17	144.49	18	144.50	19	142.52	20	146.56
21	145.73	22	144.36	23	144.30	24	144.13	25	146.46
26	145.68	27	143.46	28	144.43	29	142.47	30	143.86
31	152.35	32	148.57	33	163.40	34	163.22	35	153.99
36	153.99	37	153.97	40	134.11	41	179.56	42	510.54
43	552.73	44	586.89	45	623.49	46	732.29	47	905.22
48	1003.28	49	787.65	50	139.41	51	140.55	52	145.25
53	135.81	54	126.09	55	181.05	56	529.64	57	563.81
58	595.54	59	628.66	60	735.34	61	906.81	62	1003.92
63	787.93	70	233.09	71	232.13	72	228.43	73	230.99
74	232.01	75	282.48	76	598.76	77	613.26	78	661.01
79	689.04	80	785.34	81	939.71	82	1018.28	83	793.03
90	559.98	91	549.81	92	533.95	93	552.53	94	568.25
95	589.71	96	630.36	100	599.72	101	589.07	102	571.51
103	591.59	104	606.92	105	625.92	106	670.85	110	641.04
111	629.51	112	608.32	113	631.70	114	646.35	115	661.43
116	716.46	120	802.15	121	789.13	122	747.05	123	790.56
124	807.23	125	821.34	126	880.47	127	1077.83	128	1131.80
129	1098.28	130	814.78	131	771.15	132	768.27	140	806.90
141	805.69	143	803.04	144	808.21	145	812.83	146	843.36
147	1153.76	148	1171.31	149	1088.64	150	799.01	151	812.02
152	796.38	160	742.27	161	743.33	162	719.82	163	740.58
164	742.66	165	744.35	166	754.56	167	789.37	168	789.12
169	777.50	170	763.86	171	760.42	172	735.89		

INTERNAL TEMPERATURES AT 240.0 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	175.73	2	175.69	3	174.77	4	163.42	5	163.72
6	152.88	7	152.75	8	152.56	9	152.54	10	152.43
11	152.38	12	152.70	13	152.68	14	149.49	15	149.05
16	147.11	17	144.52	18	144.52	19	142.63	20	146.58
21	145.75	22	144.38	23	144.33	24	144.16	25	146.50
26	145.71	27	144.00	28	144.93	29	142.98	30	143.93
31	152.35	32	148.58	33	163.40	34	163.22	35	153.99
36	153.99	37	153.97	40	134.68	41	190.74	42	540.33
43	582.79	44	611.49	45	642.14	46	730.45	47	840.51
48	828.79	49	611.07	50	140.61	51	141.83	52	148.31
53	137.05	54	127.88	55	193.70	56	560.69	57	595.65
58	621.83	59	648.99	60	734.69	61	842.78	62	829.79
63	611.68	70	254.76	71	253.22	72	247.98	73	252.34
74	254.66	75	312.22	76	628.49	77	646.73	78	685.83
79	711.05	80	786.90	81	877.88	82	846.41	83	619.48
90	581.61	91	572.62	92	561.53	93	575.38	94	590.88
95	613.82	96	656.27	100	605.82	101	597.04	102	588.19
103	599.34	104	614.00	105	634.84	106	682.70	110	630.55
111	621.13	112	614.31	113	622.83	114	636.84	115	654.19
116	711.94	120	678.63	121	675.39	122	720.54	123	673.33
124	683.57	125	700.57	126	778.99	127	1038.72	128	1052.64
129	922.88	130	642.06	131	682.47	132	677.02	140	571.74
141	577.56	143	568.37	144	572.73	145	580.02	146	627.23
147	976.54	148	978.90	149	848.81	150	593.53	151	599.29
152	566.95	160	502.30	161	509.97	162	498.98	163	499.84
164	502.31	165	506.07	166	528.62	167	585.92	168	584.30
169	566.95	170	551.82	171	547.64	172	497.98		

INTERNAL TEMPERATURES AT 480.0 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	175.73	2	175.69	3	174.77	4	163.42	5	163.72
6	152.88	7	152.75	8	152.56	9	152.54	10	152.43
11	152.38	12	152.70	13	152.68	14	149.53	15	149.08
16	147.15	17	144.59	18	144.57	19	142.93	20	146.65
21	145.81	22	144.46	23	144.40	24	144.24	25	146.61
26	145.80	27	145.31	28	146.10	29	144.20	30	144.11
31	152.36	32	148.62	33	163.40	34	163.22	35	154.00
36	153.99	37	153.98	40	136.08	41	214.03	42	580.73
43	622.37	44	639.07	45	656.62	46	697.95	47	712.71
48	622.74	49	470.32	50	143.52	51	144.92	52	155.43
53	140.06	54	132.26	55	220.21	56	600.28	57	636.89
58	651.46	59	666.18	60	704.50	61	716.56	62	624.71
63	471.69	70	294.24	71	292.14	72	284.97	73	291.70
74	296.15	75	366.02	76	654.48	77	681.61	78	705.11
79	724.66	80	756.75	81	753.89	82	644.55	83	482.32
90	586.28	91	582.72	92	584.20	93	584.91	94	596.67
95	622.54	96	670.87	100	590.67	101	588.12	102	595.55
103	589.43	104	600.00	105	624.45	106	678.50	110	594.50
111	591.75	112	607.32	113	591.87	114	602.11	115	623.91
116	685.56	120	539.05	121	551.73	122	656.90	123	544.22
124	542.86	125	564.56	126	657.81	127	910.39	128	874.90
129	700.45	130	495.16	131	583.71	132	576.25	140	383.42
141	402.11	143	383.83	144	382.21	145	393.90	146	452.60
147	700.77	148	683.14	149	568.14	150	421.86	151	435.01
152	395.99	160	320.99	161	340.64	162	355.47	163	320.24
164	318.57	165	326.34	166	362.29	167	413.97	168	412.40
169	398.99	170	389.44	171	386.35	172	331.34		

INTERNAL TEMPERATURES AT 600.0 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE.	TEMP-F	NODE	TEMP-F
1	175.73	2	175.69	3	174.77	4	163.42	5	163.72
6	152.89	7	152.75	8	152.56	9	152.54	10	152.43
11	152.39	12	152.71	13	152.68	14	149.56	15	149.11
16	147.17	17	144.64	18	144.60	19	143.11	20	146.70
21	145.86	22	144.50	23	144.45	24	144.30	25	146.68
26	145.86	27	146.05	28	146.74	29	144.90	30	144.21
31	152.36	32	148.64	33	163.40	34	163.22	35	154.00
36	154.00	37	153.98	40	136.92	41	225.68	42	591.08
43	631.74	44	643.28	45	655.23	46	677.23	47	663.07
48	561.59	49	430.12	50	145.19	51	146.71	52	159.34
53	141.80	54	134.82	55	233.51	56	609.48	57	646.29
58	656.05	59	665.65	60	684.72	61	667.68	62	564.06
63	431.85	70	311.23	71	309.15	72	301.48	73	308.92
74	314.14	75	388.94	76	656.02	77	685.46	78	702.89
79	719.59	80	734.74	81	704.62	82	584.44	83	442.86
90	580.37	91	579.27	92	585.11	93	581.72	94	591.22
95	618.43	96	667.67	100	581.78	101	581.21	102	592.48
103	583.30	104	591.75	105	617.67	106	670.19	110	582.67
111	581.35	112	600.48	113	582.93	114	591.11	115	614.81
116	671.08	120	545.58	121	550.00	122	628.47	123	554.11
124	552.38	125	575.30	126	621.42	127	841.57	128	795.76
129	626.84	130	449.45	131	562.60	132	570.21	140	386.70
141	399.79	143	388.59	144	386.03	145	399.33	146	410.15
147	604.28	148	584.22	149	487.26	150	374.24	151	400.04
152	382.10	160	254.51	161	283.83	162	320.92	163	255.96
164	249.21	165	258.06	166	322.67	167	365.58	168	364.08
169	353.10	170	345.58	171	342.94	172	284.49		

INTERNAL TEMPERATURES AT 3600. SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	175.74	2	175.69	3	174.77	4	163.47	5	163.76
6	153.29	7	153.16	8	152.98	9	152.96	10	152.87
11	152.83	12	153.13	13	153.10	14	151.80	15	151.16
16	149.76	17	148.38	18	148.15	19	152.93	20	150.61
21	149.38	22	148.05	23	148.01	24	148.39	25	151.25
26	149.84	27	165.40	28	160.35	29	164.15	30	149.94
31	152.81	32	150.70	33	163.46	34	163.28	35	154.34
36	154.34	37	154.32	40	173.19	41	359.88	42	416.08
43	419.77	44	410.70	45	400.72	46	375.04	47	325.24
48	262.79	49	222.24	50	194.20	51	196.00	52	227.65
53	195.07	54	221.74	55	387.98	56	426.65	57	426.51
58	416.75	59	406.24	60	379.33	61	327.81	62	263.53
63	221.95	70	419.16	71	415.34	72	396.92	73	422.16
74	438.80	75	483.53	76	448.85	77	437.10	78	417.73
79	399.62	80	369.82	81	316.82	82	252.18	83	210.84
90	452.16	91	447.65	92	439.49	93	456.21	94	469.36
95	474.81	96	457.30	100	449.14	101	444.19	102	431.86
103	452.70	104	466.20	105	471.69	106	454.11	110	446.27
111	441.15	112	422.42	113	449.48	114	463.22	115	469.41
116	454.98	120	415.87	121	411.00	122	373.09	123	418.81
124	431.24	125	436.01	126	387.51	127	269.82	128	244.46
129	205.82	130	179.01	131	391.12	132	393.96	140	261.79
141	262.43	143	265.57	144	268.06	145	268.98	146	216.47
147	178.08	148	172.99	149	164.50	150	157.29	151	238.76
152	244.85	160	134.39	161	141.85	162	175.41	163	140.78
164	133.26	165	132.11	166	133.26	167	146.71	168	149.12
169	151.48	170	153.63	171	153.63	172	153.85		

INTERNAL TEMPERATURES AT 7200. SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	175.82	2	175.77	3	174.86	4	164.01	5	164.19
6	155.14	7	155.04	8	154.89	9	154.88	10	154.81
11	154.81	12	155.03	13	155.01	14	156.28	15	155.44
16	155.38	17	155.36	18	156.02	19	165.61	20	157.45
21	155.83	22	154.62	23	154.63	24	155.77	25	158.36
26	156.39	27	174.03	28	166.02	29	175.16	30	158.02
31	154.79	32	155.04	33	164.00	34	163.81	35	156.04
36	156.04	37	156.02	40	206.49	41	324.48	42	290.36
43	280.36	44	268.96	45	256.67	46	241.11	47	214.86
48	183.57	49	163.90	50	219.65	51	212.98	52	227.91
53	224.07	54	277.64	55	349.59	56	303.42	57	290.29
58	276.98	59	262.85	60	245.36	61	216.97	62	183.81
63	163.27	70	366.79	71	357.72	72	335.62	73	364.18
74	383.16	75	380.81	76	329.38	77	310.74	78	283.44
79	257.24	80	236.15	81	206.02	82	172.88	83	153.13
90	376.52	91	366.67	92	347.38	93	370.77	94	383.20
95	373.63	96	340.90	100	376.97	101	366.51	102	334.83
103	370.86	104	383.82	105	374.71	106	339.64	110	378.12
111	368.19	112	318.92	113	372.62	114	385.29	115	376.98
116	343.91	120	296.36	121	288.16	122	269.25	123	292.95
124	303.22	125	297.45	126	256.68	127	154.92	128	147.86
129	137.94	130	131.00	131	272.74	132	273.70	140	154.29
141	155.99	143	157.82	144	155.33	145	152.96	146	144.58
147	127.68	148	126.89	149	125.55	150	124.16	151	157.60
152	160.46	160	112.90	161	117.18	162	141.56	163	118.08
164	112.23	165	110.90	166	112.37	167	118.61	168	120.20
169	122.09	170	123.68	171	123.82	172	127.42		

INTERNAL TEMPERATURES AT0.1080E+05 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	176.17	2	176.12	3	175.22	4	165.35	5	165.33
6	158.02	7	157.93	8	157.83	9	157.82	10	157.78
11	157.80	12	157.94	13	157.92	14	160.39	15	159.67
16	160.58	17	161.37	18	162.57	19	172.63	20	162.65
21	161.24	22	160.52	23	160.57	24	161.93	25	163.47
26	161.71	27	176.26	28	169.06	29	178.87	30	164.03
31	157.79	32	159.42	33	165.34	34	165.15	35	158.75
36	158.75	37	158.73	40	215.73	41	271.01	42	230.21
43	219.57	44	208.78	45	197.23	46	186.67	47	170.08
48	150.98	49	139.27	50	219.74	51	209.29	52	215.14
53	226.17	54	282.77	55	291.90	56	241.13	57	228.46
58	215.97	59	202.80	60	190.75	61	172.43	62	151.73
63	139.25	70	311.77	71	302.46	72	284.03	73	307.42
74	323.52	75	304.70	76	260.36	77	245.62	78	221.16
79	198.62	80	184.43	81	165.17	82	144.62	83	132.67
90	310.66	91	302.20	92	286.22	93	302.79	94	310.32
95	296.99	96	268.65	100	311.13	101	301.90	102	273.93
103	302.84	104	311.10	105	298.02	106	266.83	110	312.22
111	303.24	112	258.90	113	304.41	114	312.68	115	299.91
116	269.35	120	246.51	121	238.29	122	221.01	123	240.44
124	247.76	125	238.55	126	204.62	127	132.61	128	128.43
129	122.86	130	119.07	131	224.02	132	224.40	140	139.84
141	140.17	143	141.54	144	139.78	145	136.75	146	129.38
147	117.24	148	116.90	149	116.37	150	115.76	151	140.36
152	142.94	160	109.13	161	111.79	162	129.32	163	112.85
164	108.67	165	107.49	166	108.15	167	112.17	168	113.29
169	114.68	170	115.86	171	115.99	172	119.41		

INTERNAL TEMPERATURES AT0.1440E+05 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	176.92	2	176.87	3	176.01	4	167.35	5	167.12
6	161.18	7	161.11	8	161.04	9	161.03	10	161.01
11	161.03	12	161.13	13	161.11	14	163.73	15	163.25
16	164.55	17	165.69	18	166.91	19	175.39	20	166.12
21	165.18	22	164.96	23	165.02	24	166.24	25	166.75
26	165.53	27	176.32	28	170.85	29	179.18	30	167.90
31	161.02	32	163.14	33	167.34	34	167.15	35	161.80
36	161.80	37	161.78	40	211.78	41	230.09	42	194.28
43	185.20	44	176.06	45	166.33	46	158.80	47	147.37
48	134.44	49	126.62	50	210.45	51	200.70	52	202.44
53	217.36	54	264.98	55	246.07	56	202.51	57	192.06
58	181.54	59	170.49	60	161.90	61	149.21	62	135.10
63	126.70	70	265.06	71	257.49	72	243.80	73	260.18
74	271.48	75	249.80	76	215.93	77	204.96	78	184.94
79	166.95	80	157.09	81	143.96	82	130.11	83	122.14
90	259.88	91	253.26	92	240.84	93	251.57	94	255.49
95	243.27	96	221.70	100	260.31	101	252.94	102	230.00
103	251.55	104	256.17	105	244.05	106	219.87	110	261.23
111	254.00	112	217.05	113	252.81	114	257.46	115	245.43
116	221.38	120	210.90	121	203.81	122	188.90	123	204.23
124	209.03	125	200.24	126	174.18	127	122.20	128	119.36
129	115.64	130	113.14	131	191.59	132	191.59	140	130.02
141	129.91	143	130.74	144	129.32	145	126.56	146	120.82
147	112.06	148	111.86	149	111.58	150	111.21	151	129.63
152	131.60	160	106.77	161	108.60	162	121.49	163	109.47
164	106.38	165	105.42	166	105.82	167	108.68	168	109.50
169	110.53	170	111.41	171	111.52	172	114.27		

INTERNAL TEMPERATURES AT0.1800E+05 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	178.11	2	178.06	3	177.24	4	169.68	5	169.34
6	164.10	7	164.04	8	163.97	9	163.97	10	163.94
11	163.97	12	164.05	13	164.04	14	166.29	15	166.03
16	167.31	17	168.48	18	169.47	19	175.76	20	168.35
21	167.84	22	167.94	23	167.99	24	168.93	25	168.79
26	168.08	27	175.43	28	171.66	29	177.91	30	170.12
31	163.96	32	166.01	33	169.67	34	169.48	35	164.67
36	164.67	37	164.65	40	202.74	41	200.47	42	170.33
43	162.88	44	155.43	45	147.53	46	142.00	47	133.77
48	124.54	49	119.00	50	199.41	51	191.80	52	191.49
53	205.47	54	240.65	55	211.83	56	176.29	57	167.95
58	159.41	59	150.47	60	144.18	61	135.05	62	124.99
63	119.03	70	228.55	71	222.79	72	213.07	73	223.82
74	231.14	75	211.14	76	185.63	77	177.47	78	161.51
79	147.42	80	140.36	81	131.06	82	121.30	83	115.71
90	221.63	91	216.54	92	207.01	93	214.00	94	215.94
95	205.81	96	189.68	100	221.98	101	216.21	102	197.77
103	213.90	104	216.46	105	206.36	106	188.01	110	222.72
111	217.01	112	186.92	113	214.84	114	217.41	115	207.33
116	188.92	120	184.17	121	178.33	122	165.92	123	177.84
124	181.00	125	173.65	126	153.99	127	115.84	128	113.82
129	111.20	130	109.44	131	168.21	132	168.01	140	122.73
141	122.47	143	122.91	144	121.77	145	119.51	146	115.16
147	108.76	148	108.63	149	108.46	150	108.21	151	122.04
152	123.47	160	105.09	161	106.40	162	115.94	163	107.05
164	104.74	165	103.99	166	104.27	167	106.37	168	106.98
169	107.76	170	108.41	171	108.50	172	110.60		

INTERNAL TEMPERATURES AT0.2160E+05 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	179.64	2	179.60	3	178.83	4	172.04	5	171.70
6	166.56	7	166.49	8	166.41	9	166.41	10	166.39
11	166.41	12	166.50	13	166.49	14	168.18	15	168.07
16	169.10	17	170.09	18	170.78	19	174.93	20	169.71
21	169.49	22	169.73	23	169.77	24	170.42	25	169.99
26	169.63	27	174.11	28	171.77	29	175.99	30	171.17
31	166.41	32	168.08	33	172.03	34	171.85	35	167.13
36	167.13	37	167.11	40	192.70	41	178.75	42	153.43
43	147.34	44	141.36	45	135.03	46	130.89	47	124.80
48	118.01	49	113.96	50	189.37	51	183.98	52	182.48
53	193.89	54	217.09	55	186.27	56	157.67	57	151.05
58	144.22	59	137.08	60	132.40	61	125.67	62	118.29
63	113.95	70	200.75	71	196.51	72	189.87	73	196.46
74	200.76	75	183.52	76	164.22	77	158.08	78	145.49
79	134.51	80	129.34	81	122.57	82	115.49	83	111.45
90	193.08	91	189.17	92	181.86	93	186.50	94	187.37
95	179.21	96	167.09	100	193.31	101	188.81	102	174.12
103	186.32	104	187.71	105	179.58	106	165.65	110	193.85
111	189.38	112	165.15	113	186.99	114	188.39	115	180.24
116	166.18	120	164.16	121	159.44	122	149.31	123	158.59
124	160.75	125	154.84	126	140.00	127	111.60	128	110.12
129	108.22	130	106.95	131	151.21	132	150.94	140	117.30
141	117.00	143	117.22	144	116.31	145	114.52	146	111.23
147	106.49	148	106.41	149	106.30	150	106.13	151	116.56
152	117.59	160	103.86	161	104.82	162	111.94	163	105.29
164	103.55	165	102.98	166	103.18	167	104.76	168	105.23
169	105.82	170	106.32	171	106.38	172	107.95		

INTERNAL TEMPERATURES ATO.2520E+05 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	181.41	2	181.37	3	180.64	4	174.26	5	174.00
6	168.60	7	168.54	8	168.45	9	168.45	10	168.42
11	168.44	12	168.54	13	168.53	14	169.55	15	169.51
16	170.19	17	170.84	18	171.27	19	173.58	20	170.46
21	170.40	22	170.62	23	170.65	24	171.04	25	170.62
26	170.47	27	172.63	28	171.39	29	173.88	30	171.46
31	168.43	32	169.52	33	174.25	34	174.08	35	169.20
36	169.20	37	169.19	40	183.42	41	162.54	42	141.13
43	136.13	44	131.35	45	126.30	46	123.16	47	118.57
48	113.48	49	110.45	50	181.03	51	177.49	52	175.25
53	183.82	54	196.86	55	167.08	56	144.09	57	138.83
58	133.40	59	127.73	60	124.19	61	119.15	62	113.64
63	110.41	70	179.84	71	176.78	72	172.45	73	175.99
74	178.04	75	163.49	76	148.74	77	144.07	78	134.16
79	125.60	80	121.75	81	116.72	82	111.49	83	108.51
90	171.84	91	168.83	92	163.19	93	166.30	94	166.55
95	160.01	96	150.81	100	171.96	101	168.44	102	156.76
103	166.06	104	166.76	105	160.23	106	149.58	110	172.32
111	168.81	112	149.38	113	166.50	114	167.22	115	160.68
116	149.88	120	149.25	121	145.47	122	137.29	123	144.53
124	146.02	125	141.32	126	130.03	127	108.64	128	107.54
129	106.13	130	105.19	131	138.84	132	138.55	140	113.25
141	112.97	143	113.06	144	112.35	145	110.93	146	108.44
147	104.87	148	104.82	149	104.74	150	104.62	151	112.55
152	113.31	160	102.94	161	103.66	162	109.04	163	104.01
164	102.69	165	102.25	166	102.40	167	103.59	168	103.94
169	104.39	170	104.77	171	104.82	172	106.02		

INTERNAL TEMPERATURES ATO.2880E+05 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	183.27	2	183.23	3	182.55	4	176.26	5	176.13
6	170.25	7	170.18	8	170.08	9	170.07	10	170.04
11	170.04	12	170.17	13	170.16	14	170.51	15	170.49
16	170.77	17	171.01	18	171.24	19	172.05	20	170.81
21	170.79	22	170.90	23	170.92	24	171.10	25	170.86
26	170.81	27	171.14	28	170.71	29	171.83	30	171.24
31	170.04	32	170.46	33	176.25	34	176.09	35	170.89
36	170.89	37	170.88	40	175.46	41	150.32	42	132.04
43	127.89	44	124.07	45	120.04	46	117.62	47	114.11
48	110.23	49	107.94	50	174.36	51	172.24	52	169.48
53	175.50	54	180.42	55	152.64	56	134.08	57	129.86
58	125.54	59	121.04	60	118.33	61	114.50	62	110.32
63	107.88	70	164.19	71	162.02	72	159.39	73	160.71
74	161.06	75	148.79	76	137.39	77	133.81	78	125.98
79	119.29	80	116.37	81	112.59	82	108.65	83	106.41
90	156.08	91	153.74	92	149.33	93	151.40	94	151.27
95	145.98	96	138.91	100	156.10	101	153.33	102	143.99
103	151.12	104	151.37	105	146.10	106	137.87	110	156.31
111	153.53	112	137.93	113	151.39	114	151.66	115	146.39
116	138.01	120	138.17	121	135.14	122	128.55	123	134.20
124	135.23	125	131.48	126	122.81	127	106.52	128	105.69
129	104.64	130	103.93	131	129.80	132	129.53	140	110.25
141	110.00	143	110.02	144	109.44	145	108.33	146	106.41
147	103.71	148	103.67	149	103.62	150	103.53	151	109.63
152	110.19	160	102.27	161	102.81	162	106.92	163	103.07
164	102.06	165	101.71	166	101.83	167	102.74	168	103.02
169	103.36	170	103.66	171	103.69	172	104.62		

INTERNAL TEMPERATURES AT0.3240E+05 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	185.14	2	185.10	3	184.45	4	178.00	5	178.01
6	171.51	7	171.43	8	171.32	9	171.32	10	171.27
11	171.27	12	171.42	13	171.41	14	171.13	15	171.10
16	170.99	17	170.81	18	170.89	19	170.52	20	170.86
21	170.82	22	170.77	23	170.77	24	170.80	25	170.84
26	170.79	27	169.69	28	169.87	29	169.91	30	170.73
31	171.26	32	171.02	33	177.99	34	177.84	35	172.21
36	172.21	37	172.19	40	168.92	41	141.13	42	125.20
43	121.74	44	118.68	45	115.46	46	113.57	47	110.86
48	107.87	49	106.10	50	169.12	51	168.04	52	164.91
53	168.80	54	167.47	55	141.81	56	126.57	57	123.19
58	119.74	59	116.16	60	114.06	61	111.11	62	107.91
63	106.04	70	152.52	71	151.00	72	149.60	73	149.29
74	148.40	75	137.97	76	128.98	77	126.19	78	120.00
79	114.73	80	112.50	81	109.61	82	106.60	83	104.90
90	144.38	91	142.53	92	139.03	93	140.37	94	139.99
95	135.64	96	130.13	100	144.31	101	142.10	102	134.58
103	140.06	104	140.01	105	135.69	106	129.25	110	144.40
111	142.18	112	129.56	113	140.20	114	140.17	115	135.86
116	129.29	120	129.94	121	127.50	122	122.18	123	126.59
124	127.28	125	124.25	126	117.52	127	104.99	128	104.36
129	103.55	130	103.02	131	123.18	132	122.93	140	108.02
141	107.80	143	107.78	144	107.31	145	106.41	146	104.92
147	102.85	148	102.82	149	102.79	150	102.72	151	107.48
152	107.90	160	101.77	161	102.18	162	105.37	163	102.38
164	101.59	165	101.32	166	101.41	167	102.12	168	102.33
169	102.60	170	102.83	171	102.86	172	103.58		

INTERNAL TEMPERATURES AT0.3600E+05 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	186.92	2	186.89	3	186.26	4	179.47	5	179.62
6	172.49	7	172.40	8	172.28	9	172.27	10	172.22
11	172.20	12	172.38	13	172.37	14	171.51	15	171.45
16	170.97	17	170.37	18	170.36	19	169.09	20	170.72
21	170.62	22	170.37	23	170.36	24	170.27	25	170.64
26	170.56	27	168.35	28	168.97	29	168.19	30	170.05
31	172.19	32	171.31	33	179.46	34	179.32	35	173.24
36	173.24	37	173.22	40	163.69	41	134.20	42	120.08
43	117.15	44	114.67	45	112.07	46	110.58	47	108.46
48	106.12	49	104.75	50	165.02	51	164.71	52	161.32
53	163.50	54	157.48	55	133.69	56	120.96	57	118.20
58	115.44	59	112.56	60	110.92	61	108.62	62	106.13
63	104.68	70	143.84	71	142.81	72	142.31	73	140.81
74	139.01	75	129.92	76	122.72	77	120.52	78	115.58
79	111.40	80	109.66	81	107.42	82	105.10	83	103.79
90	135.66	91	134.17	92	131.34	93	132.15	94	131.60
95	127.97	96	123.59	100	135.52	101	133.74	102	127.60
103	131.83	104	131.56	105	127.97	106	122.85	110	135.51
111	133.72	112	123.41	113	131.88	114	131.63	115	128.05
116	122.82	120	123.81	121	121.82	122	117.49	123	120.96
124	121.39	125	118.90	126	113.61	127	103.86	128	103.37
129	102.75	130	102.34	131	118.31	132	118.07	140	106.37
141	106.17	143	106.12	144	105.72	145	104.99	146	103.82
147	102.22	148	102.20	149	102.17	150	102.13	151	105.89
152	106.22	160	101.40	161	101.71	162	104.23	163	101.87
164	101.25	165	101.03	166	101.10	167	101.65	168	101.82
169	102.03	170	102.21	171	102.24	172	102.82		

INTERNAL TEMPERATURES AT0.3960E+05 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	188.57	2	188.54	3	187.93	4	180.69	5	180.97
6	173.19	7	173.09	8	172.96	9	172.95	10	172.88
11	172.86	12	173.07	13	173.05	14	171.70	15	171.59
16	170.79	17	169.81	18	169.73	19	167.79	20	170.46
21	170.26	22	169.82	23	169.80	24	169.64	25	170.33
26	170.18	27	167.12	28	168.06	29	166.67	30	169.30
31	172.85	32	171.40	33	180.68	34	180.56	35	173.99
36	173.99	37	173.98	40	159.53	41	128.93	42	116.25
43	113.72	44	111.69	45	109.56	46	108.37	47	106.68
48	104.83	49	103.74	50	161.83	51	162.06	52	158.48
53	159.33	54	149.82	55	127.54	56	116.78	57	114.49
58	112.24	59	109.90	60	108.60	61	106.78	62	104.82
63	103.68	70	137.38	71	136.69	72	136.83	73	134.47
74	131.97	75	123.89	76	118.07	77	116.30	78	112.31
79	108.95	80	107.58	81	105.82	82	104.00	83	102.97
90	129.15	91	127.93	92	125.59	93	126.03	94	125.36
95	122.27	96	118.73	100	128.96	101	127.49	102	122.41
103	125.70	104	125.27	105	122.22	106	118.09	110	128.88
111	127.41	112	118.87	113	125.67	114	125.27	115	122.24
116	118.01	120	119.24	121	117.60	122	114.04	123	116.77
124	117.00	125	114.92	126	110.70	127	103.03	128	102.65
129	102.16	130	101.85	131	114.70	132	114.48	140	105.13
141	104.96	143	104.89	144	104.54	145	103.94	146	103.01
147	101.75	148	101.74	149	101.73	150	101.69	151	104.72
152	104.98	160	101.12	161	101.37	162	103.39	163	101.50
164	100.99	165	100.81	166	100.87	167	101.31	168	101.45
169	101.62	170	101.77	171	101.79	172	102.26		

INTERNAL TEMPERATURES AT0.4320E+05 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	190.06	2	190.02	3	189.42	4	181.68	5	182.05
6	173.68	7	173.58	8	173.44	9	173.43	10	173.35
11	173.32	12	173.55	13	173.53	14	171.75	15	171.59
16	170.50	17	169.17	18	169.06	19	166.62	20	170.11
21	169.82	22	169.20	23	169.16	24	168.94	25	169.95
26	169.73	27	166.01	28	167.17	29	165.33	30	168.52
31	173.31	32	171.34	33	181.67	34	181.55	35	174.54
36	174.54	37	174.53	40	156.24	41	124.90	42	113.36
43	111.13	44	109.45	45	107.68	46	106.72	47	105.35
48	103.86	49	102.99	50	159.33	51	159.93	52	156.22
53	156.07	54	143.97	55	122.87	56	113.62	57	111.69
58	109.84	59	107.92	60	106.87	61	105.41	62	103.84
63	102.93	70	132.52	71	132.09	72	132.70	73	129.68
74	126.64	75	119.37	76	114.57	77	113.13	78	109.87
79	107.14	80	106.03	81	104.63	82	103.18	83	102.37
90	124.28	91	123.26	92	121.28	93	121.45	94	120.69
95	118.00	96	115.09	100	124.05	101	122.82	102	118.53
103	121.11	104	120.57	105	117.92	106	114.53	110	123.91
111	122.68	112	115.50	113	121.03	114	120.52	115	117.89
116	114.42	120	115.82	121	114.45	122	111.47	123	113.64
124	113.73	125	111.95	126	108.54	127	102.41	128	102.11
129	101.73	130	101.47	131	112.03	132	111.82	140	104.21
141	104.06	143	103.97	144	103.67	145	103.15	146	102.40
147	101.40	148	101.40	149	101.39	150	101.36	151	103.84
152	104.05	160	100.91	161	101.11	162	102.76	163	101.22
164	100.80	165	100.65	166	100.70	167	101.06	168	101.17
169	101.31	170	101.42	171	101.44	172	101.84		

PIG DRUM TRANSIENT (3 WATT - DIST. HEAT GEN. 90F AMBIENT TEMP. FIRE CASE 11C2)

INTERNAL TEMPERATURES AT 120.0 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	190.11	2	190.07	3	189.47	4	181.71	5	182.08
6	173.70	7	173.60	8	173.46	9	173.45	10	173.37
11	173.34	12	173.56	13	173.55	14	171.75	15	171.59
16	170.49	17	169.15	18	169.04	19	166.58	20	170.10
21	169.81	22	169.18	23	169.14	24	168.92	25	169.94
26	169.71	27	165.98	28	167.14	29	165.29	30	168.50
31	173.32	32	171.34	33	181.70	34	181.58	35	174.56
36	174.56	37	174.55	40	156.14	41	124.78	42	113.27
43	111.05	44	109.38	45	107.62	46	106.65	47	105.20
48	103.36	49	101.59	50	159.26	51	159.87	52	156.15
53	155.97	54	143.80	55	122.73	56	113.53	57	111.61
58	109.77	59	107.86	60	106.80	61	105.26	62	103.34
63	101.52	70	132.38	71	131.96	72	132.58	73	129.54
74	126.49	75	119.24	76	114.47	77	113.04	78	109.80
79	107.08	80	105.97	81	104.48	82	102.67	83	100.93
90	124.14	91	123.12	92	121.16	93	121.32	94	120.56
95	117.88	96	114.99	100	123.91	101	122.68	102	118.42
103	120.98	104	120.43	105	117.80	106	114.42	110	123.77
111	122.54	112	115.39	113	120.90	114	120.38	115	117.77
116	114.32	120	115.70	121	114.34	122	111.32	123	113.53
124	113.62	125	111.85	126	108.46	127	102.35	128	101.96
129	101.19	130	99.94	131	111.93	132	111.72	140	103.66
141	103.53	143	103.43	144	103.12	145	102.60	146	101.87
147	101.00	148	100.93	149	100.58	150	99.56	151	103.37
152	103.53	160	98.59	161	98.88	162	100.77	163	98.93
164	98.46	165	98.30	166	98.41	167	99.14	168	99.27
169	99.38	170	99.45	171	99.46	172	99.65		

INTERNAL TEMPERATURES AT 240.0 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	190.15	2	190.11	3	189.51	4	181.74	5	182.11
6	173.71	7	173.61	8	173.48	9	173.46	10	173.38
11	173.35	12	173.58	13	173.56	14	171.75	15	171.58
16	170.48	17	169.13	18	169.01	19	166.55	20	170.08
21	169.79	22	169.15	23	169.12	24	168.89	25	169.93
26	169.69	27	165.94	28	167.11	29	165.25	30	168.47
31	173.34	32	171.33	33	181.73	34	181.61	35	174.57
36	174.57	37	174.56	40	156.05	41	124.67	42	113.19
43	110.98	44	109.30	45	107.55	46	106.53	47	104.94
48	102.79	49	100.86	50	159.18	51	159.80	52	156.09
53	155.88	54	143.63	55	122.60	56	113.44	57	111.53
58	109.69	59	107.78	60	106.68	61	105.00	62	102.77
63	100.79	70	132.24	71	131.83	72	132.46	73	129.41
74	126.34	75	119.11	76	114.37	77	112.94	78	109.71
79	107.00	80	105.85	81	104.22	82	102.09	83	100.16
90	124.00	91	122.99	92	121.03	93	121.19	94	120.43
95	117.76	96	114.88	100	123.77	101	122.55	102	118.29
103	120.84	104	120.30	105	117.67	106	114.32	110	123.63
111	122.41	112	115.27	113	120.76	114	120.25	115	117.64
116	114.22	120	115.56	121	114.20	122	111.10	123	113.39
124	113.47	125	111.71	126	108.35	127	102.21	128	101.67
129	100.54	130	99.06	131	111.78	132	111.57	140	102.81
141	102.73	143	102.59	144	102.25	145	101.74	146	101.06
147	100.35	148	100.18	149	99.57	150	98.41	151	102.66
152	102.74	160	96.97	161	97.40	162	99.50	163	97.34
164	96.80	165	96.64	166	96.86	167	97.87	168	98.03
169	98.13	170	98.21	171	98.20	172	98.19		

INTERNAL TEMPERATURES AT 480.0 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	190.24	2	190.20	3	189.60	4	181.80	5	182.18
6	173.75	7	173.64	8	173.51	9	173.49	10	173.41
11	173.38	12	173.61	13	173.59	14	171.75	15	171.58
16	170.46	17	169.09	18	168.97	19	166.47	20	170.06
21	169.76	22	169.11	23	169.08	24	168.85	25	169.90
26	169.66	27	165.87	28	167.05	29	165.17	30	168.42
31	173.37	32	171.33	33	181.79	34	181.67	35	174.61
36	174.61	37	174.60	40	155.86	41	124.44	42	113.00
43	110.81	44	109.10	45	107.32	46	106.20	47	104.35
48	101.87	49	99.95	50	159.04	51	159.68	52	155.95
53	155.69	54	143.30	55	122.34	56	113.24	57	111.34
58	109.48	59	107.54	60	106.34	61	104.40	62	101.84
63	99.87	70	131.97	71	131.57	72	132.23	73	129.14
74	126.04	75	118.86	76	114.16	77	112.74	78	109.49
79	106.76	80	105.51	81	103.60	82	101.12	83	99.18
90	123.73	91	122.72	92	120.77	93	120.92	94	120.16
95	117.51	96	114.67	100	123.49	101	122.28	102	118.01
103	120.58	104	120.03	105	117.43	106	114.11	110	123.34
111	122.14	112	114.96	113	120.50	114	119.97	115	117.39
116	114.01	120	115.16	121	113.83	122	110.60	123	113.01
124	113.08	125	111.33	126	108.01	127	101.68	128	100.89
129	99.38	130	97.86	131	111.38	132	111.15	140	101.05
141	101.12	143	100.87	144	100.45	145	99.94	146	99.38
147	98.89	148	98.62	149	97.89	150	96.90	151	101.21
152	101.13	160	94.98	161	95.62	162	98.00	163	95.40
164	94.72	165	94.56	166	94.96	167	96.22	168	96.41
169	96.54	170	96.63	171	96.63	172	96.45		

INTERNAL TEMPERATURES AT 600.0 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	190.29	2	190.25	3	189.65	4	181.82	5	182.21
6	173.76	7	173.66	8	173.52	9	173.51	10	173.43
11	173.40	12	173.62	13	173.61	14	171.75	15	171.58
16	170.45	17	169.07	18	168.95	19	166.44	20	170.05
21	169.74	22	169.09	23	169.05	24	168.83	25	169.89
26	169.65	27	165.84	28	167.02	29	165.13	30	168.40
31	173.38	32	171.33	33	181.81	34	181.70	35	174.63
36	174.62	37	174.61	40	155.76	41	124.33	42	112.90
43	110.71	44	108.98	45	107.16	46	106.00	47	104.05
48	101.51	49	99.61	50	158.97	51	159.62	52	155.89
53	155.60	54	143.14	55	122.20	56	113.13	57	111.24
58	109.35	59	107.39	60	106.14	61	104.10	62	101.47
63	99.53	70	131.84	71	131.44	72	132.11	73	129.00
74	125.89	75	118.73	76	114.05	77	112.63	78	109.35
79	106.60	80	105.30	81	103.29	82	100.72	83	98.81
90	123.59	91	122.59	92	120.64	93	120.79	94	120.03
95	117.39	96	114.56	100	123.35	101	122.14	102	117.86
103	120.44	104	119.90	105	117.30	106	114.00	110	123.20
111	122.00	112	114.79	113	120.36	114	119.83	115	117.26
116	113.90	120	114.92	121	113.61	122	110.33	123	112.78
124	112.84	125	111.10	126	107.80	127	101.33	128	100.47
129	98.89	130	97.40	131	111.14	132	110.91	140	100.30
141	100.43	143	100.14	144	99.67	145	99.16	146	98.67
147	98.22	148	97.94	149	97.24	150	96.36	151	100.58
152	100.45	160	94.37	161	95.05	162	97.52	163	94.80
164	94.06	165	93.91	166	94.36	167	95.64	168	95.84
169	95.99	170	96.09	171	96.09	172	95.91		

INTERNAL TEMPERATURES AT 3600. SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	191.36	2	191.33	3	190.72	4	182.48	5	182.92
6	174.06	7	173.95	8	173.80	9	173.79	10	173.70
11	173.67	12	173.91	13	173.90	14	171.72	15	171.51
16	170.17	17	168.52	18	168.39	19	165.57	20	169.72
21	169.34	22	168.54	23	168.50	24	168.24	25	169.55
26	169.23	27	164.99	28	166.31	29	164.14	30	167.76
31	173.65	32	171.21	33	182.47	34	182.35	35	174.96
36	174.96	37	174.95	40	153.60	41	121.29	42	109.15
43	106.84	44	104.89	45	102.86	46	101.63	47	99.74
48	97.57	49	96.24	50	157.33	51	158.17	52	154.29
53	153.46	54	139.44	55	118.79	56	109.34	57	107.35
58	105.21	59	102.99	60	101.67	61	99.68	62	97.42
63	96.05	70	128.52	71	128.18	72	128.99	73	125.65
74	122.28	75	115.32	76	110.34	77	108.80	78	104.99
79	101.80	80	100.39	81	98.43	82	96.28	83	94.99
90	119.79	91	118.75	92	116.70	93	117.02	94	116.36
95	113.81	96	110.90	100	119.50	101	118.25	102	113.57
103	116.62	104	116.18	105	113.70	106	110.32	110	119.29
111	118.09	112	110.13	113	116.51	114	116.06	115	113.64
116	110.31	120	109.89	121	108.61	122	105.44	123	107.81
124	107.84	125	106.20	126	102.79	127	95.11	128	94.59
129	93.85	130	93.33	131	106.04	132	105.82	140	95.81
141	95.86	143	95.72	144	95.17	145	94.64	146	94.04
147	92.99	148	92.96	149	92.89	150	92.79	151	95.81
152	95.99	160	91.75	161	92.17	162	94.44	163	92.22
164	91.52	165	91.31	166	91.53	167	92.22	168	92.40
169	92.60	170	92.76	171	92.78	172	93.15		

INTERNAL TEMPERATURES AT 7200. SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	192.49	2	192.45	3	191.83	4	183.10	5	183.58
6	174.24	7	174.13	8	173.97	9	173.95	10	173.86
11	173.82	12	174.09	13	174.07	14	171.58	15	171.32
16	169.77	17	167.86	18	167.71	19	164.59	20	169.29
21	168.82	22	167.87	23	167.82	24	167.53	25	169.10
26	168.71	27	164.00	28	165.45	29	163.02	30	167.00
31	173.80	32	170.97	33	183.09	34	182.97	35	175.19
36	175.19	37	175.18	40	151.32	41	117.52	42	105.43
43	103.17	44	101.45	45	99.64	46	98.64	47	97.16
48	95.52	49	94.54	50	155.55	51	156.55	52	152.44
53	151.18	54	135.59	55	114.64	56	105.49	57	103.60
58	101.70	59	99.73	60	98.64	61	97.09	62	95.38
63	94.36	70	124.61	71	124.35	72	125.38	73	121.67
74	117.97	75	111.01	76	106.31	77	104.90	78	101.50
79	98.65	80	97.50	81	95.99	82	94.41	83	93.50
90	115.49	91	114.52	92	112.61	93	112.78	94	112.05
95	109.54	96	106.80	100	115.18	101	114.00	102	109.70
103	112.37	104	111.87	105	109.44	106	106.23	110	114.96
111	113.79	112	106.49	113	112.24	114	111.76	115	109.38
116	106.16	120	106.60	121	105.32	122	102.39	123	104.58
124	104.64	125	103.05	126	99.81	127	93.37	128	93.03
129	92.58	130	92.28	131	102.93	132	102.73	140	94.73
141	94.67	143	94.59	144	94.18	145	93.68	146	93.02
147	92.06	148	92.06	149	92.05	150	92.01	151	94.52
152	94.74	160	91.36	161	91.64	162	93.47	163	91.75
164	91.20	165	91.01	166	91.12	167	91.61	168	91.74
169	91.91	170	92.04	171	92.06	172	92.47		

INTERNAL TEMPERATURES ATO.1080E+05 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	193.44	2	193.40	3	192.76	4	183.54	5	184.06
6	174.28	7	174.16	8	173.99	9	173.97	10	173.87
11	173.83	12	174.11	13	174.09	14	171.33	15	171.04
16	169.32	17	167.18	18	167.03	19	163.65	20	168.81
21	168.27	22	167.19	23	167.13	24	166.82	25	168.60
26	168.14	27	163.05	28	164.61	29	161.97	30	166.25
31	173.81	32	170.66	33	183.53	34	183.41	35	175.27
36	175.27	37	175.25	40	149.27	41	114.35	42	102.82
43	100.72	44	99.23	45	97.66	46	96.83	47	95.63
48	94.32	49	93.55	50	153.92	51	155.05	52	150.79
53	149.13	54	132.21	55	111.15	56	102.76	57	101.05
58	99.42	59	97.73	60	96.83	61	95.57	62	94.21
63	93.41	70	121.32	71	121.17	72	122.44	73	118.33
74	114.29	75	107.50	76	103.38	77	102.16	78	99.26
79	96.85	80	95.91	81	94.70	82	93.44	83	92.73
90	112.08	91	111.20	92	109.49	93	109.44	94	108.60
95	106.21	96	103.78	100	111.75	101	110.69	102	106.86
103	109.03	104	108.41	105	106.09	106	103.24	110	111.51
111	110.45	112	103.99	113	108.87	114	108.27	115	106.00
116	103.11	120	104.19	121	103.03	122	100.43	123	102.26
124	102.23	125	100.72	126	97.89	127	92.63	128	92.36
129	92.03	130	91.80	131	100.90	132	100.70	140	94.02
141	93.93	143	93.84	144	93.48	145	93.01	146	92.43
147	91.65	148	91.65	149	91.65	150	91.63	151	93.77
152	93.96	160	91.13	161	91.35	162	92.90	163	91.46
164	90.99	165	90.82	166	90.91	167	91.30	168	91.41
169	91.56	170	91.67	171	91.68	172	92.06		

INTERNAL TEMPERATURES ATO.1440E+05 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	194.21	2	194.17	3	193.51	4	183.83	5	184.36
6	174.19	7	174.07	8	173.89	9	173.87	10	173.77
11	173.72	12	174.02	13	174.00	14	171.02	15	170.69
16	168.83	17	166.49	18	166.34	19	162.76	20	168.29
21	167.68	22	166.50	23	166.44	24	166.11	25	168.06
26	167.55	27	162.15	28	163.80	29	160.99	30	165.50
31	173.70	32	170.27	33	183.82	34	183.70	35	175.22
36	175.22	37	175.21	40	147.48	41	111.88	42	100.95
43	99.00	44	97.69	45	96.33	46	95.61	47	94.62
48	93.53	49	92.90	50	152.48	51	153.73	52	149.37
53	147.34	54	129.31	55	108.40	56	100.77	57	99.24
58	97.83	59	96.36	60	95.60	61	94.56	62	93.44
63	92.78	70	118.71	71	118.66	72	120.12	73	115.67
74	111.36	75	104.82	76	101.23	77	100.18	78	97.69
79	95.64	80	94.85	81	93.85	82	92.82	83	92.24
90	109.44	91	108.65	92	107.10	93	106.87	94	105.95
95	103.71	96	101.56	100	109.09	101	108.14	102	104.71
103	106.47	104	105.74	105	103.56	106	101.06	110	108.83
111	107.88	112	102.13	113	106.28	114	105.58	115	103.45
116	100.90	120	102.34	121	101.29	122	98.99	123	100.50
124	100.37	125	98.95	126	96.52	127	92.16	128	91.94
129	91.67	130	91.49	131	99.40	132	99.21	140	93.48
141	93.38	143	93.29	144	92.95	145	92.52	146	92.01
147	91.37	148	91.38	149	91.38	150	91.37	151	93.23
152	93.40	160	90.97	161	91.15	162	92.48	163	91.24
164	90.84	165	90.69	166	90.76	167	91.09	168	91.19
169	91.31	170	91.41	171	91.43	172	91.76		

INTERNAL TEMPERATURES AT0.1800E+05 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	194.81	2	194.78	3	194.09	4	183.98	5	184.53
6	174.02	7	173.89	8	173.71	9	173.68	10	173.58
11	173.53	12	173.84	13	173.82	14	170.64	15	170.29
16	168.30	17	165.81	18	165.66	19	161.91	20	167.74
21	167.09	22	165.81	23	165.75	24	165.40	25	167.51
26	166.95	27	161.31	28	163.03	29	160.07	30	164.77
31	173.50	32	169.85	33	183.97	34	183.85	35	175.08
36	175.08	37	175.07	40	145.92	41	109.97	42	99.56
43	97.74	44	96.58	45	95.37	46	94.75	47	93.90
48	92.98	49	92.44	50	151.23	51	152.58	52	148.15
53	145.80	54	126.90	55	106.28	56	99.29	57	97.91
58	96.67	59	95.38	60	94.73	61	93.84	62	92.89
63	92.34	70	116.67	71	116.69	72	118.29	73	113.60
74	109.08	75	102.80	76	99.63	77	98.71	78	96.54
79	94.76	80	94.09	81	93.24	82	92.37	83	91.88
90	107.40	91	106.68	92	105.26	93	104.91	94	103.93
95	101.82	96	99.91	100	107.04	101	106.17	102	103.07
103	104.50	104	103.71	105	101.66	106	99.44	110	106.76
111	105.90	112	100.71	113	104.29	114	103.53	115	101.52
116	99.26	120	100.91	121	99.97	122	97.90	123	99.16
124	98.95	125	97.63	126	95.51	127	91.82	128	91.64
129	91.41	130	91.26	131	98.27	132	98.07	140	93.06
141	92.97	143	92.86	144	92.54	145	92.14	146	91.71
147	91.17	148	91.18	149	91.19	150	91.18	151	92.82
152	92.97	160	90.85	161	91.00	162	92.17	163	91.08
164	90.73	165	90.59	166	90.65	167	90.94	168	91.03
169	91.13	170	91.22	171	91.23	172	91.54		

INTERNAL TEMPERATURES AT0.2160E+05 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	195.26	2	195.23	3	194.51	4	184.02	5	184.56
6	173.77	7	173.64	8	173.44	9	173.42	10	173.31
11	173.26	12	173.58	13	173.56	14	170.23	15	169.85
16	167.76	17	165.14	18	164.99	19	161.12	20	167.19
21	166.48	22	165.13	23	165.06	24	164.71	25	166.94
26	166.34	27	160.52	28	162.30	29	159.23	30	164.06
31	173.23	32	169.39	33	184.01	34	183.88	35	174.86
36	174.86	37	174.84	40	144.59	41	108.49	42	98.51
43	96.80	44	95.75	45	94.67	46	94.12	47	93.37
48	92.57	49	92.11	50	150.15	51	151.57	52	147.10
53	144.49	54	124.92	55	104.65	56	98.18	57	96.91
58	95.81	59	94.66	60	94.09	61	93.31	62	92.49
63	92.01	70	115.06	71	115.15	72	116.85	73	111.98
74	107.31	75	101.26	76	98.43	77	97.60	78	95.68
79	94.11	80	93.52	81	92.79	82	92.04	83	91.62
90	105.83	91	105.16	92	103.84	93	103.40	94	102.40
95	100.39	96	98.66	100	105.46	101	104.66	102	101.81
103	103.00	104	102.16	105	100.22	106	98.22	110	105.16
111	104.37	112	99.63	113	102.77	114	101.97	115	100.07
116	98.03	120	99.81	121	98.95	122	97.07	123	98.13
124	97.87	125	96.63	126	94.76	127	91.57	128	91.42
129	91.22	130	91.10	131	97.40	132	97.20	140	92.74
141	92.65	143	92.54	144	92.23	145	91.86	146	91.48
147	91.02	148	91.03	149	91.04	150	91.04	151	92.51
152	92.64	160	90.76	161	90.89	162	91.93	163	90.96
164	90.64	165	90.52	166	90.57	167	90.83	168	90.90
169	91.00	170	91.08	171	91.09	172	91.37		

INTERNAL TEMPERATURES AT0.2520E+05 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	195.57	2	195.54	3	194.79	4	183.96	5	184.50
6	173.46	7	173.32	8	173.13	9	173.11	10	172.99
11	172.94	12	173.27	13	173.24	14	169.79	15	169.39
16	167.22	17	164.48	18	164.33	19	160.37	20	166.63
21	165.88	22	164.47	23	164.40	24	164.04	25	166.38
26	165.74	27	159.79	28	161.59	29	158.45	30	163.37
31	172.91	32	168.90	33	183.95	34	183.82	35	174.57
36	174.57	37	174.56	40	143.45	41	107.33	42	97.71
43	96.08	44	95.13	45	94.14	46	93.64	47	92.98
48	92.26	49	91.85	50	149.21	51	150.68	52	146.18
53	143.37	54	123.32	55	103.39	56	97.33	57	96.15
58	95.15	59	94.12	60	93.60	61	92.91	62	92.19
63	91.77	70	113.79	71	113.93	72	115.71	73	110.71
74	105.94	75	100.08	76	97.51	77	96.77	78	95.03
79	93.62	80	93.10	81	92.45	82	91.79	83	91.42
90	104.61	91	103.99	92	102.75	93	102.24	94	101.22
95	99.30	96	97.71	100	104.24	101	103.49	102	100.84
103	101.84	104	100.98	105	99.12	106	97.30	110	103.93
111	103.19	112	98.79	113	101.61	114	100.77	115	98.96
116	97.10	120	98.96	121	98.17	122	96.43	123	97.35
124	97.04	125	95.87	126	94.19	127	91.38	128	91.25
129	91.08	130	90.97	131	96.73	132	96.54	140	92.50
141	92.41	143	92.29	144	92.00	145	91.65	146	91.30
147	90.91	148	90.92	149	90.93	150	90.93	151	92.27
152	92.39	160	90.68	161	90.80	162	91.75	163	90.87
164	90.57	165	90.46	166	90.50	167	90.74	168	90.81
169	90.90	170	90.97	171	90.98	172	91.24		

INTERNAL TEMPERATURES AT0.2880E+05 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	195.76	2	195.73	3	194.95	4	183.82	5	184.34
6	173.10	7	172.97	8	172.77	9	172.74	10	172.63
11	172.57	12	172.91	13	172.89	14	169.33	15	168.91
16	166.67	17	163.84	18	163.69	19	159.67	20	166.07
21	165.29	22	163.82	23	163.75	24	163.38	25	165.82
26	165.14	27	159.09	28	160.92	29	157.72	30	162.71
31	172.54	32	168.40	33	183.81	34	183.67	35	174.24
36	174.24	37	174.23	40	142.47	41	106.43	42	97.10
43	95.54	44	94.65	45	93.73	46	93.28	47	92.68
48	92.03	49	91.66	50	148.38	51	149.89	52	145.38
53	142.41	54	122.02	55	102.40	56	96.68	57	95.58
58	94.66	59	93.70	60	93.23	61	92.61	62	91.96
63	91.58	70	112.78	71	112.96	72	114.79	73	109.71
74	104.87	75	99.18	76	96.81	77	96.12	78	94.54
79	93.25	80	92.78	81	92.19	82	91.60	83	91.28
90	103.66	91	103.07	92	101.90	93	101.35	94	100.31
95	98.47	96	96.99	100	103.28	101	102.58	102	100.08
103	100.95	104	100.06	105	98.28	106	96.59	110	102.97
111	102.28	112	98.15	113	100.71	114	99.85	115	98.12
116	96.39	120	98.30	121	97.56	122	95.94	123	96.74
124	96.41	125	95.29	126	93.76	127	91.24	128	91.12
129	90.97	130	90.87	131	96.22	132	96.02	140	92.31
141	92.22	143	92.10	144	91.82	145	91.49	146	91.17
147	90.82	148	90.83	149	90.85	150	90.85	151	92.09
152	92.20	160	90.63	161	90.73	162	91.61	163	90.79
164	90.52	165	90.41	166	90.46	167	90.67	168	90.74
169	90.82	170	90.89	171	90.90	172	91.14		

INTERNAL TEMPERATURES AT0.3240E+05 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	195.84	2	195.80	3	195.00	4	183.61	5	184.12
6	172.72	7	172.58	8	172.37	9	172.35	10	172.23
11	172.17	12	172.52	13	172.49	14	168.85	15	168.41
16	166.12	17	163.22	18	163.07	19	159.01	20	165.51
21	164.71	22	163.19	23	163.12	24	162.75	25	165.26
26	164.56	27	158.44	28	160.28	29	157.04	30	162.07
31	172.15	32	167.90	33	183.60	34	183.45	35	173.87
36	173.87	37	173.86	40	141.62	41	105.71	42	96.62
43	95.12	44	94.29	45	93.43	46	93.01	47	92.45
48	91.85	49	91.52	50	147.65	51	149.18	52	144.66
53	141.57	54	120.96	55	101.64	56	96.18	57	95.13
58	94.27	59	93.38	60	92.95	61	92.38	62	91.78
63	91.44	70	111.97	71	112.18	72	114.05	73	108.92
74	104.03	75	98.49	76	96.28	77	95.63	78	94.16
79	92.97	80	92.53	81	92.00	82	91.46	83	91.16
90	102.92	91	102.36	92	101.23	93	100.65	94	99.60
95	97.82	96	96.43	100	102.54	101	101.87	102	99.50
103	100.25	104	99.36	105	97.64	106	96.05	110	102.22
111	101.56	112	97.64	113	100.01	114	99.14	115	97.46
116	95.85	120	97.79	121	97.08	122	95.55	123	96.27
124	95.92	125	94.85	126	93.42	127	91.13	128	91.02
129	90.89	130	90.80	131	95.81	132	95.63	140	92.16
141	92.08	143	91.95	144	91.68	145	91.36	146	91.07
147	90.76	148	90.77	149	90.78	150	90.78	151	91.95
152	92.05	160	90.59	161	90.68	162	91.50	163	90.74
164	90.48	165	90.38	166	90.42	167	90.62	168	90.68
169	90.76	170	90.82	171	90.83	172	91.06		

INTERNAL TEMPERATURES AT0.3600E+05 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	195.83	2	195.79	3	194.96	4	183.35	5	183.84
6	172.30	7	172.16	8	171.95	9	171.93	10	171.81
11	171.75	12	172.11	13	172.08	14	168.36	15	167.92
16	165.58	17	162.61	18	162.47	19	158.38	20	164.96
21	164.13	22	162.58	23	162.50	24	162.14	25	164.71
26	163.98	27	157.82	28	159.67	29	156.40	30	161.45
31	171.72	32	167.39	33	183.33	34	183.18	35	173.47
36	173.47	37	173.46	40	140.88	41	105.14	42	96.25
43	94.79	44	94.00	45	93.19	46	92.79	47	92.27
48	91.72	49	91.40	50	146.99	51	148.53	52	144.02
53	140.84	54	120.10	55	101.03	56	95.79	57	94.79
58	93.98	59	93.14	60	92.73	61	92.20	62	91.65
63	91.33	70	111.32	71	111.54	72	113.44	73	108.28
74	103.37	75	97.94	76	95.86	77	95.25	78	93.87
79	92.75	80	92.34	81	91.85	82	91.35	83	91.07
90	102.33	91	101.79	92	100.71	93	100.10	94	99.05
95	97.32	96	96.00	100	101.95	101	101.31	102	99.03
103	99.71	104	98.81	105	97.13	106	95.63	110	101.63
111	101.00	112	97.25	113	99.46	114	98.58	115	96.96
116	95.43	120	97.39	121	96.71	122	95.25	123	95.91
124	95.54	125	94.50	126	93.17	127	91.05	128	90.95
129	90.82	130	90.74	131	95.50	132	95.31	140	92.04
141	91.96	143	91.83	144	91.57	145	91.26	146	90.99
147	90.71	148	90.72	149	90.73	150	90.73	151	91.84
152	91.93	160	90.55	161	90.64	162	91.42	163	90.70
164	90.45	165	90.35	166	90.39	167	90.58	168	90.64
169	90.71	170	90.77	171	90.78	172	91.00		

INTERNAL TEMPERATURES AT0.3960E+05 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	195.73	2	195.69	3	194.84	4	183.04	5	183.51
6	171.87	7	171.73	8	171.52	9	171.49	10	171.37
11	171.31	12	171.67	13	171.64	14	167.87	15	167.41
16	165.04	17	162.03	18	161.89	19	157.79	20	164.42
21	163.57	22	161.99	23	161.91	24	161.54	25	164.16
26	163.42	27	157.23	28	159.08	29	155.80	30	160.86
31	171.28	32	166.88	33	183.03	34	182.87	35	173.05
36	173.05	37	173.04	40	140.22	41	104.68	42	95.96
43	94.53	44	93.78	45	93.00	46	92.63	47	92.13
48	91.61	49	91.32	50	146.38	51	147.93	52	143.43
53	140.19	54	119.38	55	100.55	56	95.48	57	94.52
58	93.75	59	92.95	60	92.56	61	92.06	62	91.54
63	91.25	70	110.78	71	111.02	72	112.94	73	107.76
74	102.84	75	97.52	76	95.53	77	94.95	78	93.64
79	92.58	80	92.20	81	91.73	82	91.26	83	91.01
90	101.86	91	101.34	92	100.29	93	99.67	94	98.62
95	96.93	96	95.66	100	101.48	101	100.86	102	98.67
103	99.28	104	98.37	105	96.74	106	95.30	110	101.16
111	100.55	112	96.94	113	99.03	114	98.15	115	96.56
116	95.10	120	97.07	121	96.42	122	95.01	123	95.62
124	95.24	125	94.23	126	92.97	127	90.98	128	90.89
129	90.78	130	90.70	131	95.25	132	95.07	140	91.95
141	91.87	143	91.74	144	91.48	145	91.19	146	90.93
147	90.67	148	90.68	149	90.69	150	90.69	151	91.75
152	91.84	160	90.53	161	90.61	162	91.35	163	90.66
164	90.43	165	90.33	166	90.37	167	90.55	168	90.60
169	90.67	170	90.73	171	90.74	172	90.95		

INTERNAL TEMPERATURES AT0.4320E+05 SECONDS IN DEG FARENHEIT

NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F	NODE	TEMP-F
1	195.56	2	195.52	3	194.65	4	182.69	5	183.15
6	171.42	7	171.28	8	171.07	9	171.04	10	170.92
11	170.86	12	171.22	13	171.19	14	167.38	15	166.91
16	164.51	17	161.46	18	161.32	19	157.22	20	163.89
21	163.02	22	161.41	23	161.34	24	160.97	25	163.63
26	162.87	27	156.66	28	158.51	29	155.23	30	160.29
31	170.83	32	166.37	33	182.68	34	182.52	35	172.62
36	172.61	37	172.60	40	139.63	41	104.30	42	95.73
43	94.33	44	93.61	45	92.85	46	92.50	47	92.02
48	91.53	49	91.25	50	145.83	51	147.37	52	142.89
53	139.60	54	118.78	55	100.17	56	95.24	57	94.31
58	93.57	59	92.80	60	92.43	61	91.96	62	91.46
63	91.18	70	110.34	71	110.59	72	112.52	73	107.33
74	102.42	75	97.18	76	95.27	77	94.72	78	93.46
79	92.45	80	92.08	81	91.64	82	91.20	83	90.95
90	101.49	91	100.98	92	99.96	93	99.32	94	98.28
95	96.62	96	95.40	100	101.11	101	100.50	102	98.37
103	98.93	104	98.03	105	96.43	106	95.05	110	100.78
111	100.19	112	96.69	113	98.68	114	97.80	115	96.25
116	94.84	120	96.81	121	96.19	122	94.83	123	95.39
124	95.01	125	94.02	126	92.81	127	90.93	128	90.84
129	90.74	130	90.67	131	95.06	132	94.87	140	91.88
141	91.80	143	91.67	144	91.42	145	91.13	146	90.88
147	90.64	148	90.64	149	90.66	150	90.66	151	91.68
152	91.76	160	90.51	161	90.58	162	91.30	163	90.63
164	90.41	165	90.32	166	90.35	167	90.53	168	90.58
169	90.65	170	90.70	171	90.71	172	90.91		

9.0 PRESSURE AND GAS GENERATION EVALUATION

Tank waste generates hydrogen, oxygen, nitrous oxide, ammonia, and methane by radiolytic and chemical interactions. This gas generation evaluation determines how long Hanford waste tank samples can be sealed inside the Sample Pig Shipping Container before a flammable gas mixture is created inside the package. This evaluation will calculate the shipping window for a worst-case source term, which is half of the length of time to reach the lower flammability limit (LFL) of the gas mixture generated within the Sample Pig Shipping Container. The sample volumes investigated are as follows:

- 0.125 L in the Sample Pig or LDUA Sampler
- 0.5 L in the Steel Pig
- 0.5 L and 1.0 L volumes in the Safesend.

9.1 GAS GENERATION

9.1.1 Radiolytic Gas Generation

The Radcalc for Windows[4] computer code (HNF-SD-TP-CSWD-003, Volume I [McFadden et al. 1998]) was used to determine the hydrogen generation rate from radiolytic interactions. Radcalc utilizes the G value method to calculate the radiolytic hydrogen gas generation rate. $G(H_2)$ is equal to the number of molecules of H_2 generated per 100 eV of ionizing radiation absorbed. The SARP for the LR-56 (WHC-SD-TP-SARP-009 [Smith 1996]) utilizes $G(H_2)$ values for Hanford tank waste of 0.119 for beta and gamma radiation and conservatively increases that value by a factor of four for alpha radiation interactions. That $G(H_2)$ value was determined by adding the G value for dissolved organic compound solutions containing nitrates/nitrites to a variable dependent upon the concentration of organics within the tanks.

The worst-case source term, decayed 4 years, from Table B2-3 was used in the Radcalc model. Radcalc does not include the radionuclide ^{126m}Sb. This omission has no effect on the calculated shipping window; this isotope makes negligible contributions to the overall radiolytic gas generation since the concentration is several orders of magnitude less than the major contributors, ^{90}Sr, ^{137}Cs, and plutonium. A model of the Sample Pig is contained within Radcalc, so that was used to determine the gamma absorption fraction for the 0.125 L case. Because the larger samples (0.5 L and 1 L) do not use the Sample Pig, the 4x4 liner configuration was selected to approximate these packaging configurations. A source density of 1.49 g/cc and the applicable package void volumes were also input into the model. The void volumes were provided by Tank Waste Remediation System personnel. The Radcalc output is provided in Section 9.5.1.

---

[4]Windows is a trademark of Microsoft Corporation.

For each sample configuration, the radiolytic hydrogen gas generation rate was calculated at a temperature of 20 °C using Radcalc.

Part B, Section 8.0, evaluated the maximum temperature of the Sample Pig Shipping Container payload and determined it to be as high as 117 °C. The gas generation rates are adjusted to account for the higher temperature.

$$\text{Rate (20 °C)} \times (390\ \text{K} / 293\ \text{K}) = \text{Rate (117 °C)}$$

The pressure rise within the Sample Pig Shipping Container is caused by all gases generated, not just hydrogen. Radiolytic generation produces oxygen as well as hydrogen in a volume ratio of 1.5 O_2/1 H_2. Nitrous oxide is also produced by radiolysis when organic constituents are present, but at the cost of oxygen. Therefore, the total generation rate of other gases from radiolysis is assumed to be 1.5 times that of hydrogen (Smith 1996). The *total* gas generation rate from radiolysis is:

$$2.5 \times \text{Rate (117 °C)}.$$

Results are listed in Table B9-1 for each sample configuration. Note that the 0.5 L and 1 L source terms for the Safesend have a reduced concentration of strong beta and gamma emitters due to the lack of shielding.

Table B9-1. Gas Generation Rates (cc/h).

Generation type	Source	Sample configuration			
		Sample Pig and LDUA 0.125 L	Steel Pig 0.5 L	Safesend* 0.5 L	Safesend* 1 L
Radiolysis	Hydrogen at 20 °C	0.0706	0.286	0.144	0.168
	Hydrogen adjusted to maximum payload temperature (117 °C)	0.094	0.381	0.192	0.224
	Total, including other gases (117 °C)	0.235	0.95	0.48	0.56
Chemical reaction	Hydrogen only	0.0337	0.135	0.135	0.27
	Total, including other gases	0.0775	0.31	0.31	0.62
Total	Hydrogen	0.128	0.516	0.327	0.494
	All gases	0.313	1.26	0.79	1.18

*Safesend is a trademark of the 3 M Corporation.
LDUA = Light-Duty Utility Arm.

9.1.2 Chemical Gas Generation

The chemical generation rate of hydrogen gas is dependent on the organic species, temperature, total organic carbon (TOC), and activation energy. As discussed above, the temperature of the payload is assumed to be 117 °C. As described in WHC-SD-TP-SARP-009

(Smith 1996), which, in turn, is based on two tank waste analyses (Henrie et al. 1986 and Meisel et al. 1993), experiments with tank waste simulant have led to the following equation, which can be used to estimate the chemical hydrogen generation rate:

$$V_{H2,C} = V_{H2,E} \times V_{liq} \times (TOC_W/TOC_E) \times \exp\{(-E_a/R) \times [(1/T_W) - (1/T_E)]\}$$

where:

$V_{H2,C}$	=	Hydrogen chemical generation rate (L/day)
$V_{H2,E}$	=	Hydrogen generation rate in experimental solution at 60 °C (3.3 x 10^{-4} L/day/L solution)
V_{liq}	=	Waste volume (0.125 L, 0.5 L, or 1.0 L, depending on configuration)
E_a	=	Activation energy (40,900 J/mol) (Meisel et al. 1993)
R	=	Universal gas constant (8.314 J/mol K)
T_W	=	Waste temperature (390 K)
T_E	=	Temperature of experimental solution (333 K)
TOC_w	=	TOC in the waste (see below)
TOC_E	=	TOC in the experimental solution (23 g/L)

As shown above, before the chemical gas generation rate of hydrogen can be determined, the TOC within the worst-case sludge must be determined. WHC-SD-TP-SARP-009 (Smith 1996) utilized a worst-case TOC value of 52 g/L, which is based on tank waste characterization results. That value is inserted into the above equation. Solving the above chemical hydrogen generation rate equation results in the following:

$$V_{H2,C} = 0.00033 \text{ mL gas/day/mL} \times 125 \text{ mL} \times (52 \text{ g/L}/23 \text{ g/L}) \times \exp\{(-40{,}900 \text{ J/mol}/8.314 \text{ J/mol K}) \times [(1/390 \text{ K}) - (1/333 \text{ K})]\}$$

$$V_{H2,C} = 0.81 \text{ mL/day} / 24 \text{ h/day} = 0.0337 \text{ mL/h.}$$

For a 0.125 L sample, the chemical gas generation rate is 0.0337 mL/h of hydrogen. Characterization studies have determined that hydrogen consists of 43.5 percent of the total gases produced by chemical reactions (Smith 1996). Therefore, the total chemical gas production rate for a 0.125 L sample will be:

$$0.0337 \text{ cc/h} / 0.435 = 0.0775 \text{ cc/h.}$$

The chemical gas production rates for the 0.5 L and the 1 L samples are scaled by volume without regard to radioisotopic content. The extrapolation is bounding for the Safesend configurations.

9.1.3 Total Gas Generation

The total gas generation rate from the worst-case sludge samples will be the sum of the radiolytic and chemical gas generation rates, which are shown in Table B9-1.

9.1.4 Shipping Window

The time required for the gas mixture within the Sample Pig Shipping Container to reach the LFL is calculated based on the hydrogen gas generation rate. Hydrogen gas in combination with other gases generated from tank waste reaches the mixture LFL when hydrogen totals 2.5 percent by volume (Smith 1996). Accordingly, the time to reach the LFL of the mixture can be derived by the following:

$$t = 0.025 \times (V_V / \text{Generation Rate}_{H2,tot})$$

where t is the time to 2.5-percent hydrogen and V_V is the void volume. The shipping window is conservatively set to half this time.

Table B9-2. Shipping Windows.

Sample Configuration	0.125 L Sample Pig	0.125L LDUA	0.5 L Steel Pig	0.5 L Safesend*	1 L Safesend*
Void volume (cc)	4972	7409	3709	1903	1400
Total hydrogen generation rate (cc/h)	0.128	0.128	0.516	0.327	0.494
Shipping window (hours[days])	485 (20.2)	723 (30.1)	89 (3.7)	72 (3)	35 (1.46)

*Safesend is a trademark of the 3 M Corporation.
LDUA = Light-Duty Utility Arm.

9.2 PACKAGE PRESSURE

Part B, Section 7.0, demonstrates the Sample Pig Shipping Container is capable of withstanding an internal pressure 78.4 psi greater than the external pressure. The Sample Pig Shipping Container is loaded at ambient temperature and pressure. If the minimum ambient air temperature is 0 °C when the container is loaded, the container will pressurize from heating up to the worst-case temperature of 117 °C. The calculations that follow use the subscript i to represent initial conditions and the subscript f for final conditions. The final pressure due to container warming will be:

$$P_f = P_i \times (T_f / T_i) = 14.7 \text{ psia} \times (390 \text{ K} / 273 \text{ K}) = 21 \text{ psia} = 6.3 \text{ psig}.$$

Therefore, gas generation can contribute 72.1 psig (78.4 psig - 6.3 psig) to the pressurization of the container within the shipping window determined above without resulting in exceeding the pressure limits. In fact, the pressure increase due to all gas generation will not exceed 3 percent during the shipping window, which yields a maximum possible pressure well below the 72.1 psig limit.

To calculate the potential pressure, the relative quantities of gas present at the time of closing the container at ambient pressure and the end of the shipping window were determined:

% increase in container pressure ={([(gas generation rate x shipping window) + void volume]/void volume)-1}*100%.

Table B9-3 shows the results.

Table B9-3. Percent of Package Pressure Increase.

Sample configuration	Void volume (cc)	Rate (cc/h)	Shipping window (hours)	% increase in pressure
0.125 L LDUA	7409	0.3125	673	2.839
0.125 L Sample Pig	4972	0.3125	485	3.0483
0.5 L Steel Pig	3709	1.261	89	3.025
0.5 L Safesend*	1903	0.79	72	2.989
1.0 L Safesend*	1400	1.18	35	2.95

*Safesend is a trademark of the 3 M Corporation.
LDUA = Light-Duty Utility Arm.

9.3 CONCLUSIONS

The shipping window is the maximum time that the Sample Pig Shipping Container can remain sealed and ensure that flammable concentrations of hydrogen do not accumulate. The shipping windows are 20 days, 30 days , 89 hours, 72 hours, and 35 hours for the 0.125 L Sample Pig, 0.125 L LDUA Sampler, 0.5 L Steel Pig, 0.5 L Safesend, and 1.0 L Safesend configurations, respectively. These shipping windows assume that if the samples are bagged, the bags are closed using a twist-and-tape (horsetail) method.

The potential pressurization of the Sample Pig Shipping Container due to gas generation is trivial (on the order of 3 percent) and does not approach design limits of the container.

9.5 APPENDICES: RADCALC OUTPUT FILES

9.5.1 0.125 L Case in Sample Pig

Radcalc for Windows 2.01 Date: 07-22-98 09:10

Performed By: ___________

Checked By: ___________

File: PIG125A.RAD
========== Input Information ==================================

Source from input:

Radionuclide:	Curies:	
H-3	4.46E-003	
C-14	2.98E-006	
Co-60	9.69E-004	
Ni-59	1.47E-005	
Ni-63	1.44E-003	
Se-79	1.39E-005	
Sr-90	8.82E+000	
Y-90	8.82E+000	(Daughter)
Zr-93	6.43E-005	
Nb-93m	5.06E-005	
Tc-99	4.05E-002	
Ru-106	1.90E-003	
Rh-106	1.90E-003	(Daughter)
Cd-113m	3.80E-004	
Sn-126	2.18E-005	
Sb-125	1.28E-002	
Sb-126	3.05E-006	
Te-125m	3.12E-003	
I-129	2.16E-005	
Cs-134	4.09E-003	
Cs-137	3.11E-001	
Ba-137m	2.94E-001	(Daughter)
Pm-147	4.24E-005	
Sm-151	5.04E-002	
Eu-152	4.39E-005	
Eu-154	2.72E-002	
Eu-155	1.41E-002	
Th-231	3.35E-008	(Daughter)
Th-234	5.83E-007	
Pa-231	1.13E-008	
Pa-233	3.35E-003	
Pa-234m	5.83E-007	(Daughter)
U-233	6.16E-008	
U-234	8.57E-007	
U-235	3.35E-008	
U-236	7.00E-008	
U-237	2.54E-007	(Daughter)
U-238	5.83E-007	
Np-237	3.35E-003	
Np-239	1.68E-006	(Daughter)

Pu-238	6.12E-004
Pu-239	5.30E-003
Pu-240	1.40E-003
Pu-241	1.06E-002
Pu-242	1.29E-008
Am-241	3.71E-002
Am-243	1.68E-006
Cm-242	8.50E-009
Cm-243	6.11E-007
Cm-244	1.77E-004

Total Activity: 1.85E+001
Total Activity Minus Daughters: 9.35E+000

Waste Form: Normal
Physical Form: Liquid
Container Type: Sample Pig

Package Void Volume: 4.97E+003 cc
Waste Volume: 125. cc
Waste Mass: 186. g
Waste Void Volume: 0.000 cc

Days to decay source before seal time: 0.00 days
Calculate number of days sealed until 2.50% hydrogen is reached.

Entered G Values:

G Alpha	G Beta	G Gamma
0.476	0.119	0.119

Comments:
125 ml sample
Source term from Table B2-3

========== Calculated Results ==================================

HYDROGEN:
The sealed package will contain 2.50 % hydrogen in 75.25 days.
H2 Volume: 127. cc
H2 Generation Rate: 0.0706 cc/hour

DECAY HEAT AND PRESSURE:
Heat Generated at seal time: 0.0626 Watts
Partial Pressure (H2): 2.60 kPa
Total Pressure (H2 and Air): 104. kPa

TRANSPORTATION:
Note: Transportation classifications assume three significant figures.
Calculations are made at user-specified decay time.

Radioactive: Yes (0.00E+000 nCi/g)
Effective A2 for Mixture: 0.768 Ci
Type Determination: B (from unity fraction 12.180)
Limited Quantity: No

LSA-I Determination: No (from LSA-I unity fraction 65397.)

LSA-II Determination: No (from LSA-II unity fraction 6539.7)
LSA-III Determination: Not Applicable

HRC Quantity Determination: No

Fissile Quantity: 0.101 g
Fissile Excepted: Yes
15g fissile radionuclides or less per 49CFR173.453(a)

TRU Waste: Yes (Transuranic Waste per Hanford Site WAC)

Reportable Quantity: Yes (from RQ unity fraction 93.362)

Source at start of seal time:

Radionuclide:	Curies:	
H-3	4.46E-003	
C-14	2.98E-006	
Co-60	9.69E-004	
Ni-59	1.47E-005	
Ni-63	1.44E-003	
Se-79	1.39E-005	
Sr-90	8.82E+000	
Y-90	8.82E+000	(Daughter)
Zr-93	6.43E-005	
Nb-93m	5.06E-005	
Tc-99	4.05E-002	
Ru-106	1.90E-003	
Rh-106	1.90E-003	(Daughter)
Cd-113m	3.80E-004	
Sn-126	2.18E-005	
Sb-125	1.28E-002	
Sb-126	3.05E-006	
Te-125m	3.12E-003	
I-129	2.16E-005	
Cs-134	4.09E-003	
Cs-137	3.11E-001	
Ba-137m	2.94E-001	(Daughter)
Pm-147	4.24E-005	
Sm-151	5.04E-002	
Eu-152	4.39E-005	
Eu-154	2.72E-002	
Eu-155	1.41E-002	
Th-231	3.35E-008	(Daughter)
Th-234	5.83E-007	
Pa-231	1.13E-008	
Pa-233	3.35E-003	
Pa-234m	5.83E-007	(Daughter)
U-233	6.16E-008	
U-234	8.57E-007	
U-235	3.35E-008	
U-236	7.00E-008	
U-237	2.54E-007	(Daughter)
U-238	5.83E-007	
Np-237	3.35E-003	
Np-239	1.68E-006	(Daughter)
Pu-238	6.12E-004	

Pu-239	5.30E-003
Pu-240	1.40E-003
Pu-241	1.06E-002
Pu-242	1.29E-008
Am-241	3.71E-002
Am-243	1.68E-006
Cm-242	8.50E-009
Cm-243	6.11E-007
Cm-244	1.77E-004

Total Activity: 1.85E+001
Total Activity Minus Daughters: 9.35E+000

Shipping Papers and Labels:

ISOTOPE	Number of A2s	Fraction of Total A2s	Cumulative Total A2s
* Am-241	6.86E+000	5.63E-001	0.563015
* Sr-90	3.27E+000	2.68E-001	0.831209
* Pu-239	9.80E-001	8.04E-002	0.911639
* Np-237	6.19E-001	5.08E-002	0.962478
Pu-240	2.59E-001	2.12E-002	0.983723
Pu-238	1.13E-001	9.29E-003	0.993011
Pu-241	3.93E-002	3.22E-003	0.996234
Cs-137	2.30E-002	1.89E-003	0.998125
Cm-244	1.64E-002	1.35E-003	0.999471
Eu-154	2.01E-003	1.65E-004	0.999636
Tc-99	1.67E-003	1.37E-004	0.999773
Sb-125	5.27E-004	4.32E-005	0.999816
Sm-151	4.67E-004	3.83E-005	0.999855
Ru-106	3.51E-004	2.88E-005	0.999884
Am-243	3.11E-004	2.55E-005	0.999909
Cs-134	3.03E-004	2.49E-005	0.999934
Eu-155	2.61E-004	2.14E-005	0.999955
Cd-113m	1.56E-004	1.28E-005	0.999968
Pa-233	1.38E-004	1.13E-005	0.999979
Co-60	8.97E-005	7.37E-006	0.999987
Cm-243	7.53E-005	6.19E-006	0.999993
U-234	3.17E-005	2.61E-006	0.999996
Te-125m	1.28E-005	1.05E-006	0.999997
Zr-93	1.19E-005	9.76E-007	0.999998
Pa-231	6.98E-006	5.73E-007	0.999998
H-3	4.13E-006	3.39E-007	0.999999
Sn-126	2.69E-006	2.21E-007	0.999999
U-236	2.59E-006	2.13E-007	0.999999
Pu-242	2.38E-006	1.96E-007	0.999999
U-233	2.28E-006	1.87E-007	1.00000
Eu-152	1.81E-006	1.48E-007	1.00000
Ni-63	1.78E-006	1.46E-007	1.00000
Pm-147	1.74E-006	1.43E-007	1.00000
Nb-93m	3.12E-007	2.56E-008	1.00000
Sb-126	2.82E-007	2.32E-008	1.00000

Se-79	2.57E-007	2.11E-008	1.00000
Th-234	1.08E-007	8.85E-009	1.00000
C-14	5.51E-008	4.52E-009	1.00000
Cm-242	3.15E-008	2.58E-009	1.00000
Ni-59	1.36E-008	1.12E-009	1.00000
Th-231	0.00E+000	0.00E+000	1.00000
I-129	0.00E+000	0.00E+000	1.00000
Pa-234m	0.00E+000	0.00E+000	1.00000
U-238	0.00E+000	0.00E+000	1.00000
U-237	0.00E+000	0.00E+000	1.00000
Ba-137m	0.00E+000	0.00E+000	1.00000
U-235	0.00E+000	0.00E+000	1.00000
Np-239	0.00E+000	0.00E+000	1.00000
Y-90	0.00E+000	0.00E+000	1.00000
Rh-106	0.00E+000	0.00E+000	1.00000

* *Contains 95% of the total A2s and must be included per 49 CFR 173.433.*

9.5.2 0.5 L Case in Safesend

Radcalc for Windows 2.01 Date: 07-19-98 11:55

Performed By: ___________

Checked By: _____________

File: PIG500.RAD

========== Input Information ===================================

Source from input:

Radionuclide:	Curies:	
H-3	1.78E-002	
C-14	1.16E-005	
Co-60	1.74E-003	
Ni-59	5.88E-005	
Ni-63	5.76E-003	
Se-79	5.56E-005	
Sr-90	1.59E+001	
Y-90	1.59E+001	(Daughter)
Zr-93	2.57E-004	
Nb-93m	2.02E-004	
Tc-99	1.62E-001	
Ru-106	3.41E-003	
Rh-106	3.41E-003	(Daughter)
Cd-113m	1.52E-003	
Sn-126	8.72E-005	
Sb-125	2.30E-002	
Sb-126	1.22E-005	
Te-125m	1.25E-002	
I-129	8.64E-005	
Cs-134	7.31E-003	
Cs-137	5.56E-001	
Ba-137m	5.26E-001	(Daughter)
Pm-147	1.70E-004	
Sm-151	2.02E-001	

Eu-152	1.76E-004	
Eu-154	4.87E-002	
Eu-155	5.64E-002	
Th-231	1.34E-007	(Daughter)
Th-234	2.33E-006	
Pa-231	4.52E-008	
Pa-233	1.34E-002	
Pa-234m	2.33E-006	(Daughter)
U-233	2.46E-007	
U-234	3.43E-006	
U-235	1.34E-007	
U-236	2.80E-007	
U-237	1.02E-006	(Daughter)
U-238	2.33E-006	
Np-237	1.34E-002	
Np-239	6.72E-006	(Daughter)
Pu-238	2.45E-003	
Pu-239	2.12E-002	
Pu-240	5.60E-003	
Pu-241	4.24E-002	
Pu-242	5.16E-008	
Am-241	1.48E-001	
Am-243	6.72E-006	
Cm-242	3.40E-008	
Cm-243	2.44E-006	
Cm-244	7.08E-004	

Total Activity: 3.37E+001
Total Activity Minus Daughters: 1.72E+001

Waste Form: Normal
Physical Form: Liquid
Container Type: 4 x 4 Liner

Package Void Volume: 1.90E+003 cc
Waste Volume: 500. cc
Waste Mass: 745. g
Waste Void Volume: 0.000 cc

Days to decay source before seal time: 0.00 days
Calculate number of days sealed until 2.50% hydrogen is reached.

Entered G Values:

G Alpha	G Beta	G Gamma
0.476	0.119	0.119

Comments:
500 ml sample
Source term from Table B2-3

========== Calculated Results ================================

HYDROGEN:
The sealed package will contain 2.50 % hydrogen in 14.16 days.
H2 Volume: 48.8 cc
H2 Generation Rate: 0.144 cc/hour

DECAY HEAT AND PRESSURE:
Heat Generated at seal time: 0.116 Watts
Partial Pressure (H2): 2.60 kPa
Total Pressure (H2 and Air): 104. kPa

TRANSPORTATION:
Note: Transportation classifications assume three significant figures.
Calculations are made at user-specified decay time.

Radioactive: *Yes (0.00E+000 nCi/g)*
Effective A2 for Mixture: 0.416 Ci
Type Determination: B (from unity fraction 41.411)
Limited Quantity: No

LSA-I Determination: No (from LSA-I unity fraction 55586.)
LSA-II Determination: No (from LSA-II unity fraction 5558.6)
LSA-III Determination: Not Applicable

HRC Quantity Determination: No

Fissile Quantity: 0.403 g
Fissile Excepted: Yes
15g fissile radionuclides or less per 49CFR173.453(a)

TRU Waste: Yes (Transuranic Waste per Hanford Site WAC)

Reportable Quantity: Yes (from RQ unity fraction 178.90)

Source at start of seal time:

Radionuclide:	Curies:	
H-3	1.78E-002	
C-14	1.16E-005	
Co-60	1.74E-003	
Ni-59	5.88E-005	
Ni-63	5.76E-003	
Se-79	5.56E-005	
Sr-90	1.59E+001	
Y-90	1.59E+001	(Daughter)
Zr-93	2.57E-004	
Nb-93m	2.02E-004	
Tc-99	1.62E-001	
Ru-106	3.41E-003	
Rh-106	3.41E-003	(Daughter)
Cd-113m	1.52E-003	
Sn-126	8.72E-005	
Sb-125	2.30E-002	
Sb-126	1.22E-005	
Te-125m	1.25E-002	
I-129	8.64E-005	
Cs-134	7.31E-003	
Cs-137	5.56E-001	
Ba-137m	5.26E-001	(Daughter)
Pm-147	1.70E-004	
Sm-151	2.02E-001	
Eu-152	1.76E-004	

Eu-154	4.87E-002	
Eu-155	5.64E-002	
Th-231	1.34E-007	(Daughter)
Th-234	2.33E-006	
Pa-231	4.52E-008	
Pa-233	1.34E-002	
Pa-234m	2.33E-006	(Daughter)
U-233	2.46E-007	
U-234	3.43E-006	
U-235	1.34E-007	
U-236	2.80E-007	
U-237	1.02E-006	(Daughter)
U-238	2.33E-006	
Np-237	1.34E-002	
Np-239	6.72E-006	(Daughter)
Pu-238	2.45E-003	
Pu-239	2.12E-002	
Pu-240	5.60E-003	
Pu-241	4.24E-002	
Pu-242	5.16E-008	
Am-241	1.48E-001	
Am-243	6.72E-006	
Cm-242	3.40E-008	
Cm-243	2.44E-006	
Cm-244	7.08E-004	
Total Activity:	3.37E+001	
Total Activity Minus Daughters:		1.72E+001

Shipping Papers and Labels:

ISOTOPE	Number of A2s	Fraction of Total A2s	Cumulative Total A2s
* Am-241	2.74E+001	6.61E-001	0.660608
* Sr-90	5.89E+000	1.42E-001	0.802812
* Pu-239	3.92E+000	9.46E-002	0.897440
* Np-237	2.48E+000	5.98E-002	0.957251
Pu-240	1.04E+000	2.50E-002	0.982247
Pu-238	4.53E-001	1.09E-002	0.993183
Pu-241	1.57E-001	3.79E-003	0.996975
Cm-244	6.56E-002	1.58E-003	0.998558
Cs-137	4.12E-002	9.95E-004	0.999553
Tc-99	6.67E-003	1.61E-004	0.999714
Eu-154	3.61E-003	8.71E-005	0.999801
Sm-151	1.87E-003	4.52E-005	0.999846
Am-243	1.24E-003	3.00E-005	0.999876
Eu-155	1.04E-003	2.52E-005	0.999901
Sb-125	9.47E-004	2.29E-005	0.999924
Ru-106	6.30E-004	1.52E-005	0.999939
Cd-113m	6.26E-004	1.51E-005	0.999954
Pa-233	5.51E-004	1.33E-005	0.999968
Cs-134	5.41E-004	1.31E-005	0.999981

Cm-243	3.01E-004	7.27E-006	0.999988
Co-60	1.61E-004	3.89E-006	0.999992
U-234	1.27E-004	3.07E-006	0.999995
Te-125m	5.14E-005	1.24E-006	0.999996
Zr-93	4.75E-005	1.15E-006	0.999997
Pa-231	2.79E-005	6.74E-007	0.999998
H-3	1.65E-005	3.98E-007	0.999998
Sn-126	1.08E-005	2.60E-007	0.999999
U-236	1.04E-005	2.50E-007	0.999999
Pu-242	9.54E-006	2.30E-007	0.999999
U-233	9.11E-006	2.20E-007	0.999999
Eu-152	7.24E-006	1.75E-007	0.999999
Ni-63	7.10E-006	1.72E-007	1.00000
Pm-147	7.00E-006	1.69E-007	1.00000
Nb-93m	1.25E-006	3.01E-008	1.00000
Sb-126	1.13E-006	2.73E-008	1.00000
Se-79	1.03E-006	2.48E-008	1.00000
Th-234	4.31E-007	1.04E-008	1.00000
C-14	2.14E-007	5.18E-009	1.00000
Cm-242	1.26E-007	3.04E-009	1.00000
Ni-59	5.44E-008	1.31E-009	1.00000
Th-231	0.00E+000	0.00E+000	1.00000
U-235	0.00E+000	0.00E+000	1.00000
Pa-234m	0.00E+000	0.00E+000	1.00000
U-238	0.00E+000	0.00E+000	1.00000
U-237	0.00E+000	0.00E+000	1.00000
Ba-137m	0.00E+000	0.00E+000	1.00000
Rh-106	0.00E+000	0.00E+000	1.00000
Np-239	0.00E+000	0.00E+000	1.00000
I-129	0.00E+000	0.00E+000	1.00000
Y-90	0.00E+000	0.00E+000	1.00000

* Contains 95% of the total A2s and must be included per 49 CFR 173.433.

9.5.3 1.0 L Case in Safesend

Radcalc for Windows 2.01 — Date: 07-19-98 11:54

Performed By: ____________

Checked By: ______________

File: PIG1000.RAD

========== Input Information ===================================

Source from input:

Radionuclide:	Curies:	
H-3	3.57E-002	
C-14	2.31E-005	
Co-60	1.71E-003	
Ni-59	1.18E-004	
Ni-63	1.15E-002	
Se-79	1.11E-004	
Sr-90	1.56E+001	
Y-90	1.56E+001	(Daughter)

Zr-93	5.14E-004	
Nb-93m	4.05E-004	
Tc-99	3.24E-001	
Ru-106	3.38E-003	
Rh-106	3.38E-003	(Daughter)
Cd-113m	3.04E-003	
Sn-126	1.74E-004	
Sb-125	2.27E-002	
Sb-126	2.44E-005	
Te-125m	2.50E-002	
I-129	1.73E-004	
Cs-134	7.28E-003	
Cs-137	5.53E-001	
Ba-137m	5.23E-001	(Daughter)
Pm-147	3.39E-004	
Sm-151	4.03E-001	
Eu-152	3.51E-004	
Eu-154	4.84E-002	
Eu-155	1.13E-001	
Th-231	2.68E-007	(Daughter)
Th-234	4.66E-006	
Pa-231	9.04E-008	
Pa-233	2.68E-002	
Pa-234m	4.66E-006	(Daughter)
U-233	4.93E-007	
U-234	6.86E-006	
U-235	2.68E-007	
U-236	5.60E-007	
U-237	2.03E-006	(Daughter)
U-238	4.66E-006	
Np-237	2.68E-002	
Np-239	1.34E-005	(Daughter)
Pu-238	4.90E-003	
Pu-239	4.24E-002	
Pu-240	1.12E-002	
Pu-241	8.48E-002	
Pu-242	1.03E-007	
Am-241	2.97E-001	
Am-243	1.34E-005	
Cm-242	6.80E-008	
Cm-243	4.89E-006	
Cm-244	1.42E-003	

Total Activity: 3.38E+001
Total Activity Minus Daughters: 1.76E+001

Waste Form: Normal
Physical Form: Liquid
Container Type: 4 x 4 Liner

Package Void Volume: 1.40E+003 cc
Waste Volume: 1.00E+003 cc
Waste Mass: 1.49E+003 g
Waste Void Volume: 0.000 cc

Days to decay source before seal time: 0.00 days

Calculate number of days sealed until 2.50% hydrogen is reached.

Entered G Values:

G Alpha	G Beta	G Gamma
0.476	0.119	0.119

Comments:
1000 ml sample
Source term from Table B2-3

========== Calculated Results ==================================

HYDROGEN:
The sealed package will contain 2.50 % hydrogen in 8.88 days.
H2 Volume: 35.9 cc
H2 Generation Rate: 0.168 cc/hour

DECAY HEAT AND PRESSURE:
Heat Generated at seal time: 0.121 Watts
Partial Pressure (H2): 2.60 kPa
Total Pressure (H2 and Air): 104. kPa

TRANSPORTATION:
Note: Transportation classifications assume three significant figures.
Calculations are made at user-specified decay time.

Radioactive: Yes (0.00E+000 nCi/g)
Effective A2 for Mixture: 0.229 Ci
Type Determination: B (from unity fraction 76.961)
Limited Quantity: No

LSA-I Determination: No (from LSA-I unity fraction 51652.)
LSA-II Determination: No (from LSA-II unity fraction 5165.2)
LSA-III Determination: Not Applicable

HRC Quantity Determination: No

Fissile Quantity: 0.807 g
Fissile Excepted: Yes
15g fissile radionuclides or less per 49CFR173.453(a)

TRU Waste: Yes (Transuranic Waste per Hanford Site WAC)

Reportable Quantity: Yes (from RQ unity fraction 195.32)

Source at start of seal time:

Radionuclide:	Curies:	
H-3	3.57E-002	
C-14	2.31E-005	
Co-60	1.71E-003	
Ni-59	1.18E-004	
Ni-63	1.15E-002	
Se-79	1.11E-004	
Sr-90	1.56E+001	
Y-90	1.56E+001	(Daughter)
Zr-93	5.14E-004	

Nb-93m	4.05E-004	
Tc-99	3.24E-001	
Ru-106	3.38E-003	
Rh-106	3.38E-003	(Daughter)
Cd-113m	3.04E-003	
Sn-126	1.74E-004	
Sb-125	2.27E-002	
Sb-126	2.44E-005	
Te-125m	2.50E-002	
I-129	1.73E-004	
Cs-134	7.28E-003	
Cs-137	5.53E-001	
Ba-137m	5.23E-001	(Daughter)
Pm-147	3.39E-004	
Sm-151	4.03E-001	
Eu-152	3.51E-004	
Eu-154	4.84E-002	
Eu-155	1.13E-001	
Th-231	2.68E-007	(Daughter)
Th-234	4.66E-006	
Pa-231	9.04E-008	
Pa-233	2.68E-002	
Pa-234m	4.66E-006	(Daughter)
U-233	4.93E-007	
U-234	6.86E-006	
U-235	2.68E-007	
U-236	5.60E-007	
U-237	2.03E-006	(Daughter)
U-238	4.66E-006	
Np-237	2.68E-002	
Np-239	1.34E-005	(Daughter)
Pu-238	4.90E-003	
Pu-239	4.24E-002	
Pu-240	1.12E-002	
Pu-241	8.48E-002	
Pu-242	1.03E-007	
Am-241	2.97E-001	
Am-243	1.34E-005	
Cm-242	6.80E-008	
Cm-243	4.89E-006	
Cm-244	1.42E-003	

Total Activity: 3.38E+001
Total Activity Minus Daughters: 1.76E+001

Shipping Papers and Labels:

ISOTOPE	Number of A2s	Fraction of Total A2s	Cumulative Total A2s
* Am-241	5.49E+001	7.13E-001	0.713328
* Pu-239	7.84E+000	1.02E-001	0.815164
* Sr-90	5.78E+000	7.51E-002	0.890238

* Np-237	4.95E+000	6.44E-002	0.954606
Pu-240	2.07E+000	2.69E-002	0.981505
Pu-238	9.06E-001	1.18E-002	0.993274
Pu-241	3.14E-001	4.08E-003	0.997355
Cm-244	1.31E-001	1.71E-003	0.999064
Cs-137	4.10E-002	5.32E-004	0.999596
Tc-99	1.33E-002	1.73E-004	0.999769
Sm-151	3.73E-003	4.85E-005	0.999818
Eu-154	3.59E-003	4.66E-005	0.999864
Am-243	2.48E-003	3.22E-005	0.999896
Eu-155	2.09E-003	2.71E-005	0.999923
Cd-113m	1.25E-003	1.63E-005	0.999940
Pa-233	1.10E-003	1.43E-005	0.999954
Sb-125	9.34E-004	1.21E-005	0.999966
Ru-106	6.25E-004	8.12E-006	0.999974
Cm-243	6.03E-004	7.83E-006	0.999982
Cs-134	5.39E-004	7.01E-006	0.999989
U-234	2.54E-004	3.30E-006	0.999992
Co-60	1.58E-004	2.06E-006	0.999995
Te-125m	1.03E-004	1.34E-006	0.999996
Zr-93	9.50E-005	1.23E-006	0.999997
Pa-231	5.58E-005	7.25E-007	0.999998
H-3	3.31E-005	4.30E-007	0.999998
Sn-126	2.15E-005	2.79E-007	0.999999
U-236	2.07E-005	2.69E-007	0.999999
Pu-242	1.90E-005	2.47E-007	0.999999
U-233	1.83E-005	2.37E-007	0.999999
Eu-152	1.44E-005	1.88E-007	0.999999
Ni-63	1.42E-005	1.84E-007	1.00000
Pm-147	1.40E-005	1.81E-007	1.00000
Nb-93m	2.50E-006	3.25E-008	1.00000
Sb-126	2.26E-006	2.94E-008	1.00000
Se-79	2.05E-006	2.67E-008	1.00000
Th-234	8.61E-007	1.12E-008	1.00000
C-14	4.27E-007	5.55E-009	1.00000
Cm-242	2.52E-007	3.27E-009	1.00000
Ni-59	1.09E-007	1.42E-009	1.00000
Th-231	0.00E+000	0.00E+000	1.00000
U-238	0.00E+000	0.00E+000	1.00000
Pa-234m	0.00E+000	0.00E+000	1.00000
Ba-137m	0.00E+000	0.00E+000	1.00000
U-237	0.00E+000	0.00E+000	1.00000
U-235	0.00E+000	0.00E+000	1.00000
Rh-106	0.00E+000	0.00E+000	1.00000
Np-239	0.00E+000	0.00E+000	1.00000
I-129	0.00E+000	0.00E+000	1.00000
Y-90	0.00E+000	0.00E+000	1.00000

* Contains 95% of the total A2s and must be included per 49 CFR 173.433.

9.5.4 0.5 L Case in Steel Pig

Radcalc for Windows 2.01

Date: 10-10-98 12:04

Performed By:

Checked By: J. E. Mercado

File: PIG500SP.RAD

========== Input Information ==================================

Source from input:

Radionuclide:	Curies:	
H-3	1.78E-002	
C-14	1.16E-005	
Co-60	3.88E-003	
Ni-59	5.88E-005	
Ni-63	5.76E-003	
Se-79	5.56E-005	
Sr-90	3.53E+001	
Y-90	3.53E+001	(Daughter)
Zr-93	2.57E-004	
Nb-93m	2.02E-004	
Tc-99	1.62E-001	
Ru-106	7.60E-003	
Rh-106	7.60E-003	(Daughter)
Cd-113m	1.52E-003	
Sb-125	5.12E-002	
Te-125m	1.25E-002	
Sn-126	8.72E-005	
Sb-126	1.22E-005	
I-129	8.64E-005	
Cs-134	1.64E-002	
Cs-137	1.24E+000	
Ba-137m	1.18E+000	(Daughter)
Pm-147	1.70E-004	
Sm-151	2.02E-001	
Eu-152	1.76E-004	
Eu-154	1.09E-001	
Eu-155	5.64E-002	
Pa-231	4.52E-008	
Th-231	1.34E-007	(Daughter)
Pa-233	1.34E-002	
Pa-234m	2.33E-006	(Daughter)
Th-234	2.33E-006	
U-233	2.46E-007	
U-234	3.43E-006	
U-235	1.34E-007	
U-236	2.80E-007	
U-237	1.02E-006	(Daughter)
U-238	2.33E-006	
Np-237	1.34E-002	
Np-239	6.72E-006	(Daughter)
Pu-238	2.45E-003	
Pu-239	2.12E-002	
Pu-240	5.60E-003	

Pu-241	4.24E-002
Pu-242	5.16E-008
Am-241	1.48E-001
Am-243	6.72E-006
Cm-242	3.40E-008
Cm-243	2.44E-006
Cm-244	7.08E-004

Total Activity:7.39E+001
Total Activity Minus Daughters: 3.74E+001

Waste Form: Normal
Physical Form: Liquid
Container Type: 4 x 4 Liner

Package Void Volume: 3.71E+003 cc
Waste Volume: 500. cc
Waste Mass: 745. g
Waste Void Volume: 0.000 cc

Date to begin source decay: 11:00 Oct. 10, 1998
Date container sealed: 11:00 Oct. 10, 1998
Days to decay source before seal time: 0.00 days
Calculate number of days sealed until 2.50% hydrogen is reached.

Entered G Values:

G Alpha	G Beta	G Gamma
0.476	0.119	0.119

Comments:
500 mL tank sample in PAS-1 Pig packed in Sample Pig Carrier

========== Calculated Results ================================

HYDROGEN:
The sealed package will contain 2.50 % hydrogen in 13.85 days.
This corresponds to date: 7:00 Oct. 24, 1998
H2 Volume: 95.1 cc
H2 Generation Rate: 0.286 cc/hour

DECAY HEAT AND PRESSURE:
Heat Generated at seal time: 0.250 Watts
Partial Pressure (H2): 2.60 kPa
Total Pressure (H2 and Air): 104. kPa

TRANSPORTATION:
Note: Transportation classifications assume three significant figures.
Calculations are made at user-specified decay time.

Radioactive: Yes (0.00E+000 nCi/g)
Effective A2 for Mixture: 0.769 Ci
Type Determination: B (from unity fraction 48.655)
Limited Quantity: No

LSA-I Determination: No (from LSA-I unity fraction 65308.)
LSA-II Determination: No (from LSA-II unity fraction 6530.8)

LSA-III Determination: Not Applicable

HRC Quantity Determination: No

Fissile Quantity: 0.403 g
Fissile Excepted: Yes
15g fissile radionuclides or less per 49CFR173.453(a)

TRU Waste: Yes (Transuranic Waste per Hanford Site WAC)

Reportable Quantity: Yes (from RQ unity fraction 373.61)

Source at start of seal time:

Radionuclide:	Curies:	
H-3	1.78E-002	
C-14	1.16E-005	
Co-60	3.88E-003	
Ni-59	5.88E-005	
Ni-63	5.76E-003	
Se-79	5.56E-005	
Sr-90	3.53E+001	
Y-90	3.53E+001	(Daughter)
Zr-93	2.57E-004	
Nb-93m	2.02E-004	
Tc-99	1.62E-001	
Ru-106	7.60E-003	
Rh-106	7.60E-003	(Daughter)
Cd-113m	1.52E-003	
Sb-125	5.12E-002	
Te-125m	1.25E-002	
Sn-126	8.72E-005	
Sb-126	1.22E-005	
I-129	8.64E-005	
Cs-134	1.64E-002	
Cs-137	1.24E+000	
Ba-137m	1.18E+000	(Daughter)
Pm-147	1.70E-004	
Sm-151	2.02E-001	
Eu-152	1.76E-004	
Eu-154	1.09E-001	
Eu-155	5.64E-002	
Pa-231	4.52E-008	
Th-231	1.34E-007	(Daughter)
Pa-233	1.34E-002	
Pa-234m	2.33E-006	(Daughter)
Th-234	2.33E-006	
U-233	2.46E-007	
U-234	3.43E-006	
U-235	1.34E-007	
U-236	2.80E-007	
U-237	1.02E-006	(Daughter)
U-238	2.33E-006	
Np-237	1.34E-002	
Np-239	6.72E-006	(Daughter)
Pu-238	2.45E-003	
Pu-239	2.12E-002	

Pu-240	5.60E-003
Pu-241	4.24E-002
Pu-242	5.16E-008
Am-241	1.48E-001
Am-243	6.72E-006
Cm-242	3.40E-008
Cm-243	2.44E-006
Cm-244	7.08E-004

Total Activity:7.39E+001
Total Activity Minus Daughters: 3.74E+001

Shipping Papers and Labels:

ISOTOPE	Number of A2s	Fraction of Total A2s	Cumulative Total A2s
* Am-241	2.74E+001	5.62E-001	0.562264
* Sr-90	1.31E+001	2.69E-001	0.830976
* Pu-239	3.92E+000	8.05E-002	0.911517
* Np-237	2.48E+000	5.09E-002	0.962424
Pu-240	1.04E+000	2.13E-002	0.983699
Pu-238	4.53E-001	9.31E-003	0.993007
Pu-241	1.57E-001	3.23E-003	0.996235
Cs-137	9.19E-002	1.89E-003	0.998122
Cm-244	6.56E-002	1.35E-003	0.999470
Eu-154	8.07E-003	1.66E-004	0.999636
Tc-99	6.67E-003	1.37E-004	0.999773
Sb-125	2.11E-003	4.33E-005	0.999816
Sm-151	1.87E-003	3.84E-005	0.999855
Ru-106	1.40E-003	2.89E-005	0.999883
Am-243	1.24E-003	2.55E-005	0.999909
Cs-134	1.21E-003	2.50E-005	0.999934
Eu-155	1.04E-003	2.14E-005	0.999955
Cd-113m	6.26E-004	1.29E-005	0.999968
Pa-233	5.51E-004	1.13E-005	0.999979
Co-60	3.59E-004	7.38E-006	0.999987
Cm-243	3.01E-004	6.18E-006	0.999993
U-234	1.27E-004	2.61E-006	0.999996
Te-125m	5.14E-005	1.06E-006	0.999997
Zr-93	4.75E-005	9.76E-007	0.999998
Pa-231	2.79E-005	5.73E-007	0.999998
H-3	1.65E-005	3.39E-007	0.999999
Sn-126	1.08E-005	2.21E-007	0.999999
U-236	1.04E-005	2.13E-007	0.999999
Pu-242	9.54E-006	1.96E-007	0.999999
U-233	9.11E-006	1.87E-007	1.00000
Eu-152	7.24E-006	1.49E-007	1.00000
Ni-63	7.10E-006	1.46E-007	1.00000
Pm-147	7.00E-006	1.44E-007	1.00000
Nb-93m	1.25E-006	2.56E-008	1.00000
Sb-126	1.13E-006	2.32E-008	1.00000
Se-79	1.03E-006	2.11E-008	1.00000

Th-234 4.31E-007 8.85E-009 1.00000
C-14 2.14E-007 4.41E-009 1.00000
Cm-242 1.26E-007 2.59E-009 1.00000
Ni-59 5.44E-008 1.12E-009 1.00000
Pa-234m 0.00E+000 0.00E+000 1.00000
I-129 0.00E+000 0.00E+000 1.00000
U-237 0.00E+000 0.00E+000 1.00000
U-238 0.00E+000 0.00E+000 1.00000
Th-231 0.00E+000 0.00E+000 1.00000
Ba-137m 0.00E+000 0.00E+000 1.00000
U-235 0.00E+000 0.00E+000 1.00000
Np-239 0.00E+000 0.00E+000 1.00000
Y-90 0.00E+000 0.00E+000 1.00000
Rh-106 0.00E+000 0.00E+000 1.00000

* Contains 95% of the total A2s and must be included per 49 CFR 173.433.

9.5.5 0.125 L Case in LDUA Sampler

Radcalc for Windows 2.01 Date: 12-20-98 22:50

Performed By: ___________

Checked By: _____________

File: PIG125LD.RAD
========== Input Information ==================================

Source from input:

Radionuclide:	Curies:	
H-3	4.46E-003	
C-14	2.98E-006	
Co-60	9.69E-004	
Ni-59	1.47E-005	
Ni-63	1.44E-003	
Se-79	1.39E-005	
Sr-90	8.82E+000	
Y-90	8.82E+000	(Daughter)
Zr-93	6.43E-005	
Nb-93m	5.06E-005	
Tc-99	4.05E-002	
Ru-106	1.90E-003	
Rh-106	1.90E-003	(Daughter)
Cd-113m	3.80E-004	
Sn-126	2.18E-005	
Sb-125	1.28E-002	
Sb-126	3.05E-006	
Te-125m	3.12E-003	
I-129	2.16E-005	
Cs-134	4.09E-003	
Cs-137	3.11E-001	
Ba-137m	2.94E-001	(Daughter)
Pm-147	4.24E-005	
Sm-151	5.04E-002	
Eu-152	4.39E-005	

Eu-154	2.72E-002	
Eu-155	1.41E-002	
Th-231	3.35E-008	(Daughter)
Th-234	5.83E-007	
Pa-231	1.13E-008	
Pa-233	3.35E-003	
Pa-234m	5.83E-007	(Daughter)
U-233	6.16E-008	
U-234	8.57E-007	
U-235	3.35E-008	
U-236	7.00E-008	
U-237	2.54E-007	(Daughter)
U-238	5.83E-007	
Np-237	3.35E-003	
Np-239	1.68E-006	(Daughter)
Pu-238	6.12E-004	
Pu-239	5.30E-003	
Pu-240	1.40E-003	
Pu-241	1.06E-002	
Pu-242	1.29E-008	
Am-241	3.71E-002	
Am-243	1.68E-006	
Cm-242	8.50E-009	
Cm-243	6.11E-007	
Cm-244	1.77E-004	

Total Activity: 1.85E+001
Total Activity Minus Daughters: 9.35E+000

Waste Form: Normal
Physical Form: Liquid
Container Type: Sample Pig Carrier

Package Void Volume: 7.41E+003 cc
Waste Volume: 125. cc
Waste Mass: 186. g
Waste Void Volume: 0.000 cc

Days to decay source before seal time: 0.00 days
Calculate number of days sealed until 2.50% hydrogen is reached.

Entered G Values:

G Alpha	G Beta	G Gamma
0.476	0.119	0.119

Comments:
125 ml sample
Source term from Table B2-3

========== Calculated Results ==================================

HYDROGEN:
The sealed package will contain 2.50 % hydrogen in 112.26 days.
H2 Volume: 190. cc
H2 Generation Rate: 0.0705 cc/hour

DECAY HEAT AND PRESSURE:
Heat Generated at seal time: 0.0626 Watts
Partial Pressure (H2): 2.60 kPa
Total Pressure (H2 and Air): 104. kPa

TRANSPORTATION:
Note: Transportation classifications assume three significant figures.
Calculations are made at user-specified decay time.

Radioactive: Yes (0.00E+000 nCi/g)
Effective A2 for Mixture: 0.768 Ci
Type Determination: B (from unity fraction 12.180)
Limited Quantity: No

LSA-I Determination: No (from LSA-I unity fraction 65397.)
LSA-II Determination: No (from LSA-II unity fraction 6539.7)
LSA-III Determination: Not Applicable

HRC Quantity Determination: No

Fissile Quantity: 0.101 g
Fissile Excepted: Yes
15g fissile radionuclides or less per 49CFR173.453(a)

TRU Waste: Yes (Transuranic Waste per Hanford Site WAC)

Reportable Quantity: Yes (from RQ unity fraction 93.362)

Source at start of seal time:

Radionuclide:	Curies:	
H-3	4.46E-003	
C-14	2.98E-006	
Co-60	9.69E-004	
Ni-59	1.47E-005	
Ni-63	1.44E-003	
Se-79	1.39E-005	
Sr-90	8.82E+000	
Y-90	8.82E+000	(Daughter)
Zr-93	6.43E-005	
Nb-93m	5.06E-005	
Tc-99	4.05E-002	
Ru-106	1.90E-003	
Rh-106	1.90E-003	(Daughter)
Cd-113m	3.80E-004	
Sn-126	2.18E-005	
Sb-125	1.28E-002	
Sb-126	3.05E-006	
Te-125m	3.12E-003	
I-129	2.16E-005	
Cs-134	4.09E-003	
Cs-137	3.11E-001	
Ba-137m	2.94E-001	(Daughter)
Pm-147	4.24E-005	
Sm-151	5.04E-002	
Eu-152	4.39E-005	
Eu-154	2.72E-002	

Eu-155	1.41E-002	
Th-231	3.35E-008	(Daughter)
Th-234	5.83E-007	
Pa-231	1.13E-008	
Pa-233	3.35E-003	
Pa-234m	5.83E-007	(Daughter)
U-233	6.16E-008	
U-234	8.57E-007	
U-235	3.35E-008	
U-236	7.00E-008	
U-237	2.54E-007	(Daughter)
U-238	5.83E-007	
Np-237	3.35E-003	
Np-239	1.68E-006	(Daughter)
Pu-238	6.12E-004	
Pu-239	5.30E-003	
Pu-240	1.40E-003	
Pu-241	1.06E-002	
Pu-242	1.29E-008	
Am-241	3.71E-002	
Am-243	1.68E-006	
Cm-242	8.50E-009	
Cm-243	6.11E-007	
Cm-244	1.77E-004	

Total Activity: 1.85E+001
Total Activity Minus Daughters: 9.35E+000

Shipping Papers and Labels:

ISOTOPE	Number of A2s	Fraction of Total A2s	Cumulative Total A2s
* Am-241	6.86E+000	5.63E-001	0.563015
* Sr-90	3.27E+000	2.68E-001	0.831209
* Pu-239	9.80E-001	8.04E-002	0.911639
* Np-237	6.19E-001	5.08E-002	0.962478
Pu-240	2.59E-001	2.12E-002	0.983723
Pu-238	1.13E-001	9.29E-003	0.993011
Pu-241	3.93E-002	3.22E-003	0.996234
Cs-137	2.30E-002	1.89E-003	0.998125
Cm-244	1.64E-002	1.35E-003	0.999471
Eu-154	2.01E-003	1.65E-004	0.999636
Tc-99	1.67E-003	1.37E-004	0.999773
Sb-125	5.27E-004	4.32E-005	0.999816
Sm-151	4.67E-004	3.83E-005	0.999855
Ru-106	3.51E-004	2.88E-005	0.999884
Am-243	3.11E-004	2.55E-005	0.999909
Cs-134	3.03E-004	2.49E-005	0.999934
Eu-155	2.61E-004	2.14E-005	0.999955
Cd-113m	1.56E-004	1.28E-005	0.999968
Pa-233	1.38E-004	1.13E-005	0.999979
Co-60	8.97E-005	7.37E-006	0.999987

Cm-243	7.53E-005	6.19E-006	0.999993
U-234	3.17E-005	2.61E-006	0.999996
Te-125m	1.28E-005	1.05E-006	0.999997
Zr-93	1.19E-005	9.76E-007	0.999998
Pa-231	6.98E-006	5.73E-007	0.999998
H-3	4.13E-006	3.39E-007	0.999999
Sn-126	2.69E-006	2.21E-007	0.999999
U-236	2.59E-006	2.13E-007	0.999999
Pu-242	2.38E-006	1.96E-007	0.999999
U-233	2.28E-006	1.87E-007	1.00000
Eu-152	1.81E-006	1.48E-007	1.00000
Ni-63	1.78E-006	1.46E-007	1.00000
Pm-147	1.74E-006	1.43E-007	1.00000
Nb-93m	3.12E-007	2.56E-008	1.00000
Sb-126	2.82E-007	2.32E-008	1.00000
Se-79	2.57E-007	2.11E-008	1.00000
Th-234	1.08E-007	8.85E-009	1.00000
C-14	5.51E-008	4.52E-009	1.00000
Cm-242	3.15E-008	2.58E-009	1.00000
Ni-59	1.36E-008	1.12E-009	1.00000
Th-231	0.00E+000	0.00E+000	1.00000
I-129	0.00E+000	0.00E+000	1.00000
Pa-234m	0.00E+000	0.00E+000	1.00000
U-238	0.00E+000	0.00E+000	1.00000
U-237	0.00E+000	0.00E+000	1.00000
Ba-137m	0.00E+000	0.00E+000	1.00000
U-235	0.00E+000	0.00E+000	1.00000
Np-239	0.00E+000	0.00E+000	1.00000
Y-90	0.00E+000	0.00E+000	1.00000
Rh-106	0.00E+000	0.00E+000	1.00000

* Contains 95% of the total A2s and must be included per 49 CFR 173.433.

CHECKLIST FOR CHECKING OF ANALYSIS/CALCULATIONS

Document Number/Revision: HNF-SD-TP-SARP-001, Rev.2, Section B-9

Document Title: Pressure and Gas Generation Evaluation

Yes	No	N/A	
[x]	[ ]	[ ]	Problem completely defined.
[x]	[ ]	[ ]	Appropriate analytical method used.
[x]	[ ]	[ ]	Necessary assumptions are appropriate and explicitly stated.
[x]	[ ]	[ ]	Computer codes and data files documented.
[x]	[ ]	[ ]	Data used in calculations explicitly stated in document.
[x]	[ ]	[ ]	Sources of non-standard formula/data are referenced and the correctness of the reference verified.
[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.
[x]	[ ]	[ ]	Code run streams correct and consistent with analysis documentation.
[x]	[ ]	[ ]	Code output consistent with input and with results reported in analysis documentation.
[x]	[ ]	[ ]	Acceptability limits on analytical results applicable and supported. Limits checked against sources.
[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.

I have checked the analysis/calculation and it is complete and accurate to the best of my knowledge.

Engineer/Checker J.G. McFadden *J.G. McFadden* Date 1/21/99

NOTE: Any hand calculations, notes or summaries generated as part of this check should be signed, dated, and attached to this checklist. Material should be labeled and recorded so that it is intelligible to a technically qualified third party.

WMNW-PE-006

This page intentionally left blank.

10.0 PACKAGE TIEDOWN SYSTEM EVALUATION

10.1 SYSTEM DESIGN

The N-55 package containing the Sample Pig Transport System is attached to its transport vehicle by a lift/tiedown assembly as shown in Figures B10-1 and B10-2. The N-55 is held in place by a frame which fits over the top of the overpack and is held in place by four tiedown straps which connect the frame to a baseplate which in turn is bolted to the bed of the truck. The entire assembly with the exception of the J-bolts forms the tiedown assembly. The loads and resulting stresses are evaluated in Part B, Section 10.2.

Figure B10-1. Tiedown Assembly Dimensions.

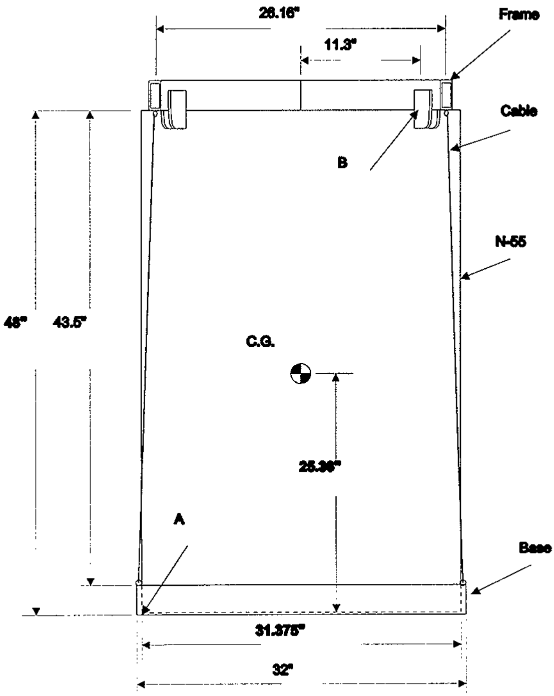
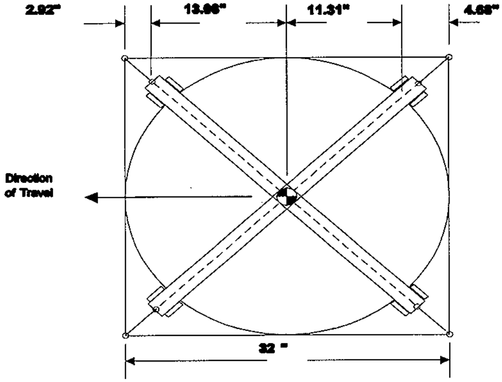


Figure B10-2. Tiedown Plan View.



10.1.1 Tiedown Devices

The tiedown assembly is loaded by transportation loads as defined by 49 CFR 393.102 and 49 CFR 393.104. The required tiedown loads due to an acceleration of 0.5*g* acting on the package center of gravity are calculated below. This analysis considers vertical and lateral directions and also considers an acceleration applied at a 45° angle to the direction of travel. The effect of gravity is conservatively ignored in the analyses below. This is because the specified loadings are not meant to reflect actual loads experienced by the tiedowns but rather are to demonstrate a safe margins above expected transportation loads. The loaded gross weight of the N-55 in the Sample Pig configuration is assumed to be 363 kg (800 lb) (390 kg [860 lb] including the tiedown frame). Figures B10-1 and B10-2 above illustrate the assembled package and tiedown assembly with appropriate dimensions.

The transportation load induced stresses are calculated below and are to be compared with manufacturer's working load limits for tiedown hardware. These are normally 1/5 of breaking loads. For the tiedown frame the working load limit is considered to be the lesser of 1/3 of material yield stress or 1/5 of material ultimate stress. A Safety Margin, SM, will be calculated to evaluate all stress calculations against the above allowables.

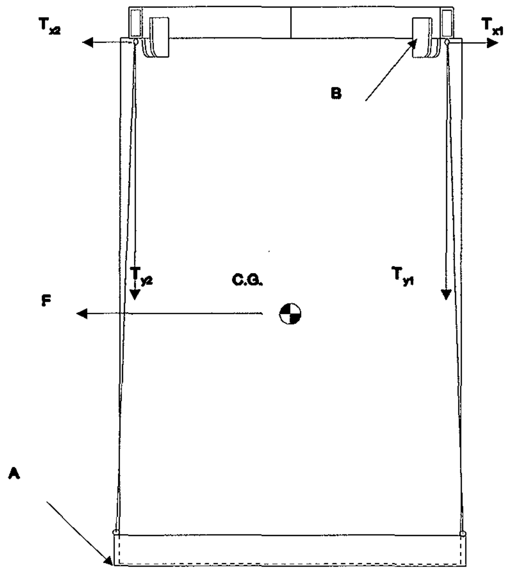
$$SM = lesser\ of: \frac{0.2\,F_U}{f} \quad or \quad \frac{0.33\,F_Y}{f} \quad 1$$

10.1.1.1 Vertical Direction Acceleration. Assume that only two of the tiedown straps are effective in resisting an upward acceleration of 0.5*g*.

$$T = \frac{0.5\,F}{\sin 84.6°} = \frac{(0.5)(0.5)(800)}{0.996} = 893\,N\,(200.8\,lb)\,2$$

10.1.1.2 Longitudinal and Lateral Direction Accelerations. Assume the package pivots at its lower corner (point A in Figure B10-3) and that the upper opposite corner of the N-55 forms a pivot point for the tiedown frame. This occurs because the frame is not tied to the overpack, but is only restrained from moving horizontally with respect to the N-55 by the tabs welded to the tiedown frame. All cables are thus in tension in order to provide equilibrium of the tiedown frame. The force components are shown in Figure B10-3.

Figure B10-3. Transport Load Components.



Writing an expression summing moments of the overall system about point A using the dimensions given in Figures B10-1 and B10-2:

$$(25.36)\,F = (2.92)\,T_{y2} - (48)\,T_{x2} + (29.08)\,T_{y1} + (48)\,T_{x1}$$

Using the assumption that the tiedown frame is free to pivot about point B results in the following expression for T_{y2} in terms of T_{y1}:

$$(24.39)\,T_{y2} = (1.77)\,T_{y1}$$
$$T_{y2} = (0.073)\,T_{y1}$$

Since the tiedown cables can carry only tensile loads and given that all cables are oriented symmetrically with respect to the package (again using dimensions given in Figures B10-1 and B10-2), the horizontal component of the tension in any cable can be expressed in terms its vertical component:

$$T_x = \frac{2.92}{43.5} T_y = (0.067)\,T_y$$

Substituting into the above expression, F can be expressed in terms of T_{y1}:

$$(25.36)F = (2.92)(0.073)T_{y2} - (48)(0.067)(0.073)T_{y1} + (29.08)T_{y1} + (48)(0.067)T_{y1} = (32.27)T_{y1}$$

$$T_{y1} = (0.786)\,F$$

This cable value represents the sum of the vertical tension component in both aft cables. The horizontal component T_{x1} is the sum of both cables also but also is the component in the plane of the page. Since the vertical plane containing the cables is at a 45° angle to the page the horizontal component must be increased by a factor of 1.414. Applying these corrections:

$$T_Y = \frac{T_{y1}}{2} = (0.393)\,F$$
$$T_X = (1.414)(0.067)T_Y = (0.037)\,F$$

The total tensile load in either of the aft cables is then:

$$T_A = \sqrt{(0.393)^2 + (0.037)^2}\;\; F = (0.395)\,F$$

A similar procedure for the forward cables results in a value of

$$T_F = (0.029)\,F$$

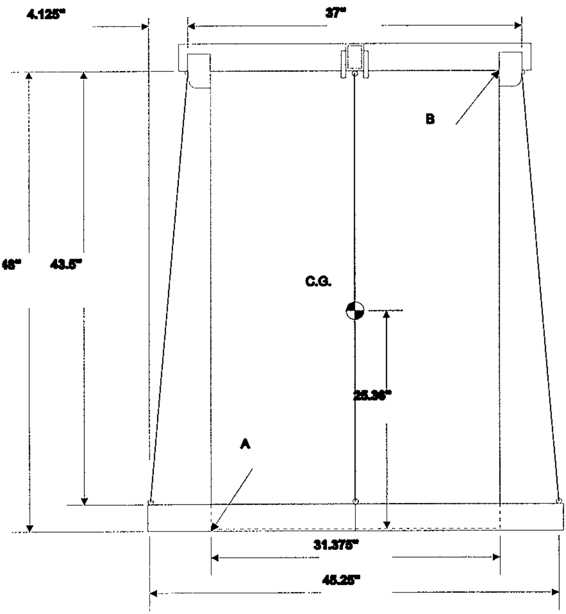
Applying a 0.5*g* load to the center of gravity of the 390 kg (860 lb) load results in the following cable tension values:

$$T_A = (0.395)(430) = 752\ N\ (169\ lb)$$
$$T_F = (0.029)(430) = 53\ N\ (12\ lb)$$

10.1.1.3 Oblique Direction Acceleration. Assume a load is directed at an angle of 45° from the direction of travel. Dimensions for this orientation are shown in Figure B10-4. Force components are similar to those shown in Figure B10-3. Conservatively assume only the tiedown cables at the front and back of the package are effective. Summing moments about A:

$$(25.36)\,F = -(2.81)\,T_{y2} - (48)\,T_{x2} + (34.19)\,T_{y1} + (48)\,T_{x1}$$

Figure B10-4. Oblique Direction Dimensions.



Again, assuming the tiedown frame pivots about point B shown above and that the two center cables are not loaded

$$T_{y2} = (0.0822)\,T_{y1}$$

The cable angle is slightly different for this orientation, resulting the following ratio of horizontal to vertical force in both forward and aft cables

$$T_X = \frac{4.125}{43.5} T_Y = (0.0948) T_Y$$

Substituting gives T_{y1} and T_{x1} in terms of F

$$T_{yl} = \frac{25.36}{38.13} F = (0.665) F$$
$$T_{xl} = (0.0948)(0.665) F = (0.063) F$$

The total tensile load in the aft cable is

$$T_A = \sqrt{0.665^2 + 0.063^2}\ F = 0.668\ F$$

Similarly, the forward cable load is:

$$T_F = \sqrt{0.054^2 + 0.005^2}\ F = 0.055\ F$$

Substituting a 0.5*g* load to the center of gravity of the 390 kg (860 lb) load results in the following cable tension values:

$$T_A = (0.688)(430) = 1.3\ kN\ (286\ lb)$$
$$T_F = (0.055)(430) = 102\ N\ (23\ lb)$$

The loads calculated above are summarized in the following list. They are considerably lower than the lifting loads calculated in Part B, Section 7.0. Therefore, only components not loaded in lifting will be addressed in the analyses given below.

1. Load due to 0.5*g* forward acceleration of the payload: 765 N (172 lb).

2. Load due to 0.5*g* oblique (45° sideward) acceleration of the payload: 1.3 kN (286 lb).

3. Load due to 0.5*g* upward acceleration of the payload: 894 N (201 lb).

10.1.1.4 Tiedown Frame Eyebolt. The eyebolt in each arm of the tiedown frame is the attachment point for the tiedown strap. Thus, the maximum load calculated for each eyebolt is 121 kg (266 lb). Listed working limit for a Crosby G-277 1/2 x 6 shoulder nut eyebolt is 1,000 kg (2,200 lb). Again, this component easily meets the working strength requirements.

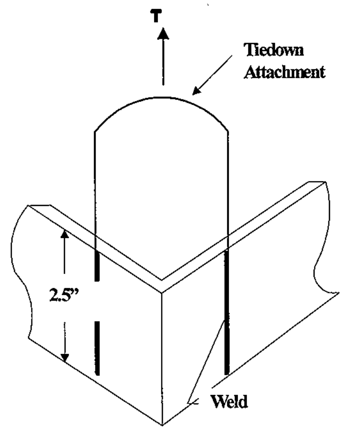
10.1.1.5 Stops Welded to Tiedown Frame. Eight stops are welded to the tiedown frame as a means of restraining the N-55 when it is placed in position on top of the N-55. The worst-case loading is considered to be the oblique transport loading analyzed above which is reacted by a single set of stops. The load determination above resulted in a horizontal stress of approximately 89 N (20 lb). This load produces negligible stress in the stops or the attaching welds.

10.1.1.6 Tiedown Cables. As shown above, the maximum load seen by a tiedown cable is 121 kg (266 lb). The working strength of a cable is required to be at least 0.5 times the maximum load calculated. The weakest portion of the cable assembly is the buckle with a working load limit of 907 kg (2,000 lb). Therefore, the tiedown straps easily meet requirements.

10.1.1.7 Tiedown Base. The tiedown base consists of a rectangular frame constructed of 2.5 x 2.5 x 0.375 angle iron. The frame forms a receptacle for the base of the N-55 and reacts all loads transmitted through the base of the N-55. In addition, lengths of 3/8 rod are welded to the four corners of the frame to form attachment points for the tiedown cables. The tiedown base is bolted to the transport vehicle bed and frame.

10.1.1.8 Frame Tiedown Attachments. The rod is formed into a u shape with the ends welded to the outside of the frame angles as shown in Figure B10-5. The welds are 0.32 cm (0.125 in.) by 6.35 cm (2.5 in.) and are placed on both sides of the rod. The radius of curvature of the centerline of the rod is approximately 33 cm (1.3 in.).

Figure B10-5. Tiedown Attachment.



The tiedown attachment can be considered as 1/2 of a chain link with a central stud joining the two sides of the link as was done with the lifting bail above. The maximum bending moment occurs at the point of loading.

$$M_0 = \frac{WRC_1}{2}$$

Where C_1 is a function of the ratio L/R

$$C_1 = \frac{(k+2)[k^3+6k^2+12k(4-\pi)+48(\pi-3)]}{k^4+4\pi k^3+48k^2+24\pi k+24(\pi^2-8)}$$

and k = L/R.

The value of L is approximately 6.35 cm (2.5 in.) with R = 3.3 cm (1.3 in.) given above. Substituting k = 2.5/1.3 = 1.923 gives C_1 = 0.466 and thus the maximum moment becomes:

$$M_0 = \frac{266(1.3)(0.466)}{2} = 81\ in\text{-}lb$$

Similarly, a tensile load, H, is produced at the point of loading

$$H = \frac{WC_2}{2}$$

where C_2 is given by

$$C_2 = \frac{12(k+2)[(\pi-2)k+2(4-\pi)]}{k^4+4\pi k^3+48k^2+24\pi k+24(\pi^2-8)}$$

Substituting gives C_2 = 0.392 and the tensile load becomes

$$H = \frac{266(0.392)}{2} = 231\ N\ (52\ lb)$$

At the point of loading, on the outer surface the maximum tensile stress is due to both the tensile loading, H, and the moment, M_0. The stress due to H is:

$$S_t = \frac{H}{A} = \frac{52}{0.11} = 3.2\ MPa\ (471\ psi)$$

The bending stress can be calculated for a curved beam using *Formulas for Stress and Strain* (Roark and Young 1975) Table 16, Case 2 with R/c = 6.93. The correction factor for the inner surface is by interpolation, k_i = 1.12. The section modulus of the tiedown attachment is:

$$S_x = \frac{\pi\ d^3}{32} = 0.085\ cm^3\ (0.0052\ in^3)\ 3$$

The bending stress on the inner surface of tiedown attachment (compressive):

$$f_b = k_i \frac{M_b}{S} = 1.12 \frac{81}{0.0052} = 120\ MPa\ (17{,}446\ \ psi)$$

The sum of the tensile stress and the compressive bending stress is:

$$S_T = S_t + S_b = 471 + -17{,}446 = -117\ MPa\ (-16{,}975\ psi)$$

From above the maximum stress in the tiedown attachment occurs at the point of loading. The Safety Margin is:

$$SM = \frac{\left(\frac{58{,}000}{5}\right)}{16{,}975} = 0.683$$

Assume the tensile load is equal to the maximum cable load calculated above and that the entire load is reacted by one leg of the attachment.

$$f = \frac{T}{A} = \frac{286}{(0.25\,\pi\,0.375^2)} = 12\ kN\ (2{,}589\ lb)$$

$$SM = \frac{11{,}600}{2{,}589} = 4.48$$

The shear stress in the attachment weld is conservatively assumed to result from the entire load being carried by one leg of the attachment.

$$A_W = 2\,(2.5) = 12.7\ cm\ (5.0\ in.)$$

$$f_w = \frac{T}{A_w} = \frac{286}{5.0} = 10\ kN/m\ (57.2\ lb/in)$$

The allowable weld load for a 1/8 in. weld is:

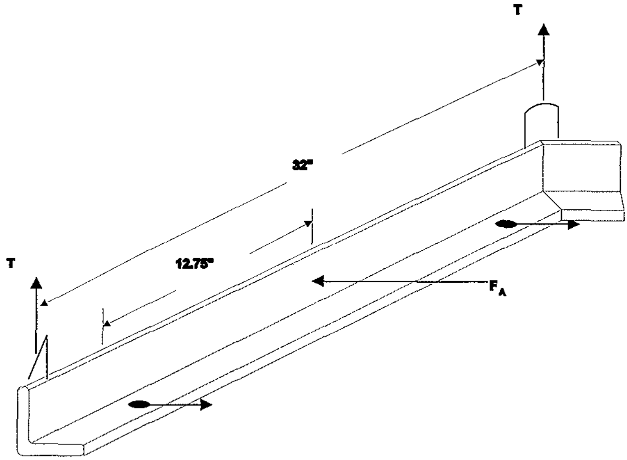
$$\tau_w = (0.6)(0.125)(.707)\left(\frac{58{,}000}{5}\right) = 107\ kN/m\ (615\ \ lb/in)$$

$$SM = \frac{615}{57.2} = 10.75$$

10.1.1.8 Tiedown Base Frame. The frame carries the loads from the N-55 to the bed and frame of the transport vehicle (Figure B10-6). The bearing load from the base of the package is carried from the center of the beam to the frame bolts. The frame can be considered blocking as defined in 49 CFR 393.104. Therefore it must resist a deceleration of 20 ft/sec^2 (0.62 g). Using a payload weight (including the tiedown frame) of 390 kg (860 lb) the horizontal load, F, becomes

$$F_A = (0.62)(860) = 2.4kN\ (533\ lb)$$

Figure B10-6. Tiedown Base Frame.



Consider the frame carrying the load to be a simple beam 64.77 cm (25.5 in.) in length. The section modulus, S_y of a 2.5 x 2.5 x 0.375 angle is 9.28 cm^3 (0.566 in^3).

$$M = \frac{F_A l}{4} = \frac{533\,(25.5)}{4} = 384\ N\text{-}m\ (3{,}399\ \ in\text{-}lb)$$

$$f_b = \frac{M}{S_y} = \frac{3{,}399}{0.566} = 41.4\ MPa\ (6{,}005\ \ psi)$$

$$SM = \frac{11{,}600}{6{,}005} = 1.93$$

10.1.1.9 Bolts. The frame carrying the N-55 is attached to the truck bed with 4 ½-13UNC bolts of A-307 material (F_u = 414 MPa [60,000 psi]). Assume two of the bolts react the moment of payload experiencing a 0.62g deceleration. The moment arm from the pivot point of the N-55 to the bolts is assumed to be 81.3 cm (32 in.). From the loads analysis above, the moment due to a 0.5g acceleration is:

$$M_A = (860)(25.36) = 2.5\ kN - m\ (21,810\ \ in - lb)$$

The force per bolt is then,

$$T_b = \frac{M_A}{2\ l} = \frac{21,810}{2\,(32)} = 1.5\ kN\ (341\ \ lb)$$

Tensile area of the bolt is 0.142 in^2. Bolt stress is then,

$$f_b = T_b\ /\ A = 341\ /\ 0.142 = 17\ MPa\ (2,400\ \ psi)$$

$$SM = \frac{60,000/5}{2,400} = 5.0$$

Due to the large margin for the bolts, the additional analyses involving the bolts are not considered necessary.

10.2 ATTACHMENTS AND RATINGS

The following attachments and ratings were used to evaluate the tiedown system:

Attachment	Rating
Frame eyebolt	1,000 kg (2,200 lb)
Tiedown cables	907 kg (2,000 lb)
Tiedown base	1/3 S_y
Tiedown bolts	1/5 S_u

10.3 REFERENCES

Blake, Alexander, 1960, *Practical Stress Analysis in Engineering Design*, Second Edition, Marcel Dekker, Inc., New York, New York.

Roark, R. J., and W. C. Young, 1975, *Formulas for Stress and Strain*, Fifth Edition, McGraw Hill Book Company, New York, New York.