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Safety Evaluation Report for Packaging (Onsite) Concrete-Lined Waste Packaging

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

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Abstract: The Pacific Northwest National Laboratory developed a package to ship Type A, non-transuranic, fissile excepted quantities of liquid or solid radioactive material and radioactive mixed waste to the Central Waste Complex for storage on the Hanford Site.

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ACI	American Concrete Institute
ALARA	as low as reasonably achievable
ASTM	American Society for Testing and Materials
CLWP	Concrete-Lined Waste Packaging
CWC	Central Waste Complex
DOT	U.S. Department of Transportation
HDPE	high-density polyethylene
IC	ion chromatography
ICP	inductively coupled plasma
ID	inside diameter
OD	outside diameter
Pacific Northwest	Pacific Northwest National Laboratory
QA	quality assurance
QC	quality control
SEP	Safety Evaluation for Packaging
TCLP	toxicity characteristic leaching procedure
TRU	transuranic
UN	United Nations

SAFETY EVALUATION FOR PACKAGING (ONSITE) CONCRETE-LINED WASTE PACKAGING

PART A: DESCRIPTION AND OPERATIONS

1.0 INTRODUCTION

1.1 GENERAL INFORMATION

Pacific Northwest National Laboratory (Pacific Northwest) has developed a package to ship Type A, non-transuranic (TRU), fissile excepted quantities of liquid or solid radioactive material and radioactive mixed waste to the Central Waste Complex (CWC) for storage on the Hanford Site.

In order to safely transport the radioactive liquid to CWC, a Safety Evaluation for Packaging (SEP) is needed to provide the onsite safety authorization. This SEP will demonstrate safety for transport of the Pacific Northwest Type A Liquid Packaging, hereafter referred to as the Concrete-Lined Waste Packaging (CLWP), in accordance with the requirements of WHC-CM-2-14, *Hazardous Material Packaging and Shipping*.

1.2 SYSTEM DESCRIPTION

The CLWP system consists of a galvanized 55-gallon, U.S. Department of Transportation (DOT) United Nations (UN) 1A2, DOT Specification 7A, Type A drum, lined with a 90 to 110 mil high-density polyethylene (HDPE) liner with a slip lid closure. A ½ in. thick square steel plate is tack welded to the bottom of a 12 in. schedule 40 steel pipe and placed in the liner. Concrete or foam filler, commensurate with shielding requirements, is placed between the pipe and the liner. A layer of grout or foam is placed on the bottom, inside of the pipe if additional shielding is necessary. Up to three, 5 qt cans containing bottles of liquid are placed inside the pipe (depending on space and dose). Polypropylene absorbent pads are placed around and on top of the cans to provide absorbent and keep the load from shifting. The closure is provided by a ½ in. thick square steel plate placed on top of the pipe. The plate has tabs welded to the bottom to prevent shifting. The liner lid is placed over the pipe cover and an anti-corrosive rad pad is placed on top of the liner. The final closure mechanism is a standard drum lid with a bolt and jam nut. The inner containers may be vented to prevent flammable gas from collecting in the package void spaces. The drum lid will be equipped with a NucFil[1] filter when a gas generating payload is transported.

[1]NucFil is a trademark of NFT Incorporated.

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2.0 PACKAGING SYSTEM

2.1 CONFIGURATION AND DIMENSIONS

The packaging system is fabricated in accordance with drawing H-3-307599 and consists of a galvanized steel 55-gallon, DOT UN1A2, DOT Specification 7A Type A drum, lined with a 90 to 110 mil HDPE liner with a slip lid closure. A ½ in. thick square steel plate is tack welded to the bottom of a 12 in. schedule 40 steel pipe and placed in the liner. Concrete or foam filler, commensurate with shielding requirements, are placed on the outside of the pipe. A layer of grout or foam is placed on the bottom, inside of the pipe if that shielding is necessary. A maximum of three, 5 qt (Imperial gallon) paint cans are placed inside the pipe (depending on space and dose). Polypropylene absorbent pads are placed around and on top of the cans to provide absorbent and keep the load from shifting. A ½ in. thick square steel plate is then placed on top of the pipe. Tabs welded to the plate limit shifting of the plate. The liner lid is put in place. An anti-corrosive rad pad is placed on top of the liner. Then the drum is closed using a bolted ring closure system.

The liquid is contained in poly (polypropylene or polyethylene), Teflon[2], or glass containers compatible with the waste matrix. Sizes of the container may vary up to a maximum of 2 L and must fit comfortably into a lined 5 qt paint can. Smaller glass or poly vials may be carefully placed upright in a 2 L poly bottle to minimize handling and comply with as low as reasonably achievable (ALARA). Where feasible the lids of the containers should be tape sealed. When containers are handled inside a hot-cell taping the lids may not be feasible. Only one inner waste container is allowed per 5 qt paint can.

The 5 qt can should be lined with ½ in. rubber matting for shielding. If containers smaller than 2 L are used, additional polypropylene absorbent should be used to keep the containers from shifting. If rubber is not needed for shielding, the can should be lined (top and bottom) with enough polypropylene absorbent to assure the container does not shift. The can will be sealed after the waste container is appropriately placed inside.

The HDPE liner is fabricated in accordance to Rocky Flats Plant drawing 38886-001-M (Part A, Section 10.0). It is a Type IV, 55-gallon, 90 to 110 mil straight wall liner with approximate dimensions of 31.25 in. high with outside diameter (OD) of 22.12 in. and an inside diameter (ID) of 21.85 in. minimum. The paint can has a diameter of 16.8 cm (6.6 in.) and is 24.1 cm (9.5 in.) high.

If a gas generating payload is transported, the inner containers will be vented and the drum lid will be fitted with a NucFil filter as described in Part A, Section 6.0.

2.2 MATERIALS OF CONSTRUCTION

The paint can is fabricated from 85 and 90 lb electrolytic tin-plate with a welded side seam. The Schedule 40 pipe is fabricated from American Society for Testing and Materials (ASTM) A53 Type S, Grade B carbon steel. The steel plates are fabricated from ASTM A36 carbon steel. The drum is fabricated from ASTM A653 or A653M mil galvanized steel. The grout density is between 105 and 118 lb/ft^3 and the foam density is 2 lb/ft^3. The liner is fabricated from 90 to 110 mil high density polyethylene.

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

2.3 DESIGN AND FABRICATION METHODS

The design and fabrication of the packaging shall be performed in accordance with drawing H-3-307599 (see Part A, Section 10.0). Materials of construction shall be as identified in the drawing.

2.4 WEIGHTS AND CENTER OF GRAVITY

The maximum gross weight of the package shall not exceed 453 kg (1,000 lb). Since the package is symmetrical, the center of gravity is located at the approximate geometric center of the package.

2.5 CONTAINMENT BOUNDARY

The containment boundary is defined as the drum, drum lid and gasket, bolted locking ring, and the NucFil filter.

2.6 CAVITY SIZE

The inner cavity has a diameter of 29.9 cm (11.75 in.) and is 75.0 cm (29.5 in.) long.

2.7 HEAT DISSIPATION

Decay heat within the package has been determined to be less than 0.03 W. Heat is dissipated passively.

2.8 SHIELDING

Shielding will be provided by grouting between the pipe and the liner.

2.9 LIFTING DEVICES

There are no lifting devices on the packaging.

2.10 TIEDOWN DEVICES

There are no tiedown devices which are a structural part of the package. The packages shall be secured to the transport vehicle as described in Part A, Section 4.2.

2.11 VENTING

In any case where gas generating contents are transported, venting is required to prevent over pressurization of the packaging and a buildup of flammable gasses. Venting will be provided in accordance with the procedures in Part A, Section 6.0.

3.0 PACKAGE CONTENTS

3.1 GENERAL DESCRIPTION

Contents to be transported in the CLWP will consist of liquid or solid materials in quantities not to exceed Type A, fissile excepted, and non-transuranic quantity limits. The contents may include mixed waste and gas generating materials if the package is vented. The chemical constituents allowed in this packaging include acids, bases, toxicity characteristic leaching procedure (TCLP) metals, flammable organics, other cations and anions identified by ion chromatography (IC) or inductively coupled plasma (ICP) analysis, and other inorganic and organic constituents. All wastes will under go a chemical compatibility review prior to packaging to ensure compliance with DOT and CWC requirements. If necessary some of the wastes may be treated to make them more amenable to acceptance and transportation.

Acids may include, but are not limited to nitric acid, hydrochloric acid, sulfuric acid, hydrofluoric acid, and phosphoric acid. Bases may include, but are not limited to sodium hydroxide, potassium hydroxide, aluminum hydroxide, and chromium hydroxide. Flammable organics may include, but are not limited to, methanol, ethanol, acetone, and ethyl acetate. Cations may include aluminum, calcium, potassium, sodium, iron, and nickel. Anions may include chloride, sulfate, carbonate, fluoride, bromide, nitrite, nitrate, and phosphate. Tank waste will often be present in the waste in concentrations of $<1\%$ to 20%. Included with tank waste are minor concentrations of F-listed organic solvents and TCLP metals.

3.2 CONTENT RESTRICTIONS

The maximum amount of liquid allowed in this package is 6 L. Polypropylene or and equivalent absorbent shall be capable of absorbing twice the amount of liquid in the package. The absorbing material must be compatible with the packaging contents. It is the shippers responsibility to ensure that all packaging materials and contents are physically and chemically compatible. This includes ensuring that gas generating properties of the payload are evaluated prior to shipment. If excessive gas may be generated, the packaging shall be vented as described in Part A, Section 6.0.

3.2.1 Content Matrix

The contents matrix consists of the radioactive liquid solution or solids; the poly, glass, or Teflon bottles; the polypropylene absorbent; rubber matting; and the paint can.

3.2.2 Radioactive Materials

The contents of the package will contain up to Type A quantities of radioactive solid or liquid materials. In addition the contents will also be limited as follows:

1. Fissile excepted, no more than 15 g of fissile materials in a package.

2. Non-transuranic quantity, no more than 3700 Bq/g (100 nCi/g) of TRU isotopes (DOE Order 5820.2A).

3. Dose rate, transportation safety requires that the dose rate at the surface of the packaging be 2 mSv/h (200 mrem/h) or less and 0.01 mSv/h (10 mrem/h) at a distance of 2 m (6.6 ft) from the package surface. In addition, the package must meet the dose rate requirements of the CWC of 2 mSv/h (200 mrem/h) or less at the surface of the package and 1 mSv/h (100 mrem/h) or less at 30 cm (11.8 in.) from the package surface.

3.2.3 Non-Radioactive Materials

Polypropylene absorbent or equivalent is used to provide cushioning and to absorb any liquid should leakage occur.

4.0 TRANSPORT SYSTEM

4.1 TRANSPORTER

The drums shall be transported exclusive use using a closed van or flatbed trailer with sides and front structure of welded steel, with a capacity greater than 8,165 kg (18,000 lb).

4.2 TIEDOWN SYSTEM

Figure A4-1. Tiedown - Closed Van.

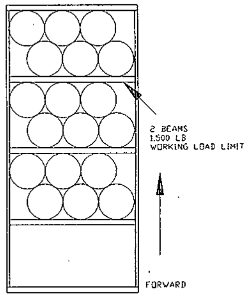
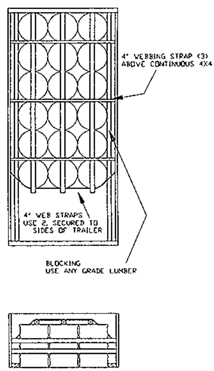


Figure A4-2. Tiedown - Open Trailer.



Up to 18 drums are to be transported. The load tiedown must have a working strength of 4,082 kg (9,000 lb) in any direction.

By using a closed van with strong sides, the drums can be longitudinally restrained using beams that span from between the sides of the van. The van walls, top and front must be capable of providing sideways and forward restraint, and the capacity of the van must be greater than 8,165 kg (18,000 lb). The drums must be shipped in rows of three, using empty drums to fill out partial. The total working load limit for the beams must be 227 kg (500 lb) for each drum in the shipment (4,082 kg [9,000 lb] if 18 drums are restrained by beams), and the beams must be arranged so that they provide rear restraint for no more drums than they can support. For beams that have a working load limit of 680 kg (1,500 lb), this can be provided by placing beams between each row of three drums or by using two beams between two rows, as shown in Figure A4-1. If beams with a working load limit of 2,041 kg (4,500 lb) are available, and the van walls have beam anchor points designed for 1,021 kg (2,250 lb) for each beam end, two beams at the rear of the load are adequate. Two straps can secure the last row of drums, providing that the straps have a working load limit of 499 kg (1,100 lb) and lead into the side anchor points at an angle of 45° or more away from perpendicular with the sides of the trucks.

Up to 18 drums can also be transported in an open trailer with side and front rails of welded structural steel, as shown in Figure A4-2. The rails must have sufficient strength to anchor web straps, and a capacity greater than 8,170 kg (18,000 lb). Synthetic webbing straps with a strength of at least 1,800 kg (4,000 lb) are used as follows: three straps over the tops of the drums and two around the back. The top straps require 4 x 4 wood beams to be laid lengthwise on top of the drums. These beams must be continuous over the row of drums (about 4.5 m [14 ft]) or additional straps must be used. If there is a space of more than 10 cm (4 in.) between the bottom of the drums and the side frames, additional timbers are laid on the trailer floor to block. The webs are secured to the sides making an angle of no more than 45° with the length of the trailer or 45° vertically.

If transported in an open trailer, use synthetic webbing with a working load limit of 1,800 kg (4,000 lb) or more. The wood beams on top of the drums must be Douglas Fir-Larch graded "standard" or better.

4.3 SPECIAL TRANSFER REQUIREMENTS

4.3.1 Routing and Access Control

The packaging described in this SEP is authorized for onsite transport only. Transfers shall be made in accordance with WHC-CM-2-14 over a predetermined route. The route between the 300 Area and the Wye Barricade shall be barricaded to prevent public access during the transfer.

4.3.2 Radiological Limitations

Transportation safety requires that the dose rate at the surface of the packaging be 2 mSv/h (200 mrem/h) or less and 0.01 mSv/h (10 mrem/h) at a distance of 2 m (6.6 ft). Transport of a package which exceeds these limits is not authorized. In addition, the package must meet the dose rate requirements of the CWC of 2 mSv/h (200 mrem/h) or less at the surface of the drum and 1 mSv/h (100 mrem/h) or less at 30 cm (11.8 in.) from the drum surface. The shielding analysis in Part B, Section 4.0, shows the projected dose rates meet these limits for the authorized source term. However, the dose rates will vary significantly based on the source material distribution, source geometry, and shielding. Since the package has no shielding near the top of the inner pipe or the top, the highest dose rates will be seen in this area. Prior to shipment, the dose rates must be surveyed to verify that the dose rates do not exceed the limits stated above.

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

Table A4-1. External Container Contamination Limits.

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

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

4.3.3 Time Restrictions

There are no time restrictions placed on the package described in this SEP.

4.3.4 Speed Limitations

There are no speed limitations other than the posted speed limit.

4.3.5 Environmental Conditions

In order to reduce the possibility of an accident, there shall be no transfers during periods of dense fog or adverse road conditions (such as snow or ice). In order to prevent freezing the contents, there shall be no transfers during freezing weather (i.e., below 0 °C [32 °F]).

4.3.6 Frequency of Use and Mileage Limitations

There are no frequency of use or mileage limitations for this packaging when packaged and shipped according to the requirements of this SEP.

4.3.7 Emergency Response

In the event of an accident, notify the emergency response individual at the number given on the shipping paper.

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5.0 ACCEPTANCE OF PACKAGING FOR USE

5.1 NEW PACKAGING

The new packaging shall be fabricated per drawing H-3-307599 (Part A, Section 10.0).

5.1.1 Acceptance Requirements

Prior to using the packaging, the following requirements shall be verified and/or inspections performed in accordance with Part A, Section 7.0.

5.1.2 Inspection and Testing

- Verify that the packaging was fabricated as specified in drawing H-3-307599.
- Visually inspect the drum body, lid, lid gasket, closure ring, closure ring bolt and nut, and the NucFil filter for excessive corrosion or damage.
- Verify that there are no gouges, dents, or scratched on the drum body sealing surface that would prevent sealing.
- Verify that the bolts do not have headmarks matching those on the "Suspect Fastener Headmark List" located in QI 15.6 of WHC-CM-4-2, *Quality Assurance Manual*.
- Prior to installing the NucFil filter in the drum lid, inspect the filter gasket and threads if not previously installed by the manufacturer.

5.1.3 Documentation

Inspections shall be documented per the plant operating procedures with appropriate quality control (QC) inspection points. All check sheets and documentation shall be maintained for the life of the package or five years, whichever is longer.

5.2 PACKAGING FOR REUSE

The packaging shall not be reused.

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6.0 OPERATING REQUIREMENTS

6.1 GENERAL REQUIREMENTS

The following are requirements for the use of the CLWP. Prior to loading and shipment of the packaging, specific approved operating procedures with appropriate quality assurance (QA)/QC hold points shall be in place. The procedures shall implement the requirements of this section and the additional requirements found in this SEP.

For loading and unloading operations, the following general requirements shall be performed and verified in user operating procedures:

1. Visually inspect the packaging for cracks, damage, or deterioration.

2. Verify that the contents to be transported in the CLWP do not to exceed Type A, fissile excepted (< 15 g of fissile materials), and non-TRU (< 100 nCi/g of TRU isotopes [DOE Order 5820.2A]) quantity limits. The contents may include mixed waste.

3. Verify that external radiological contamination limits are within the allowable limits shown in Table A4-1 of this SEP.

4. Verify radiological dose rates are acceptable prior to shipment of the cask in accordance with Part A, Section 4.3.2, of this SEP.

5. Polypropylene or equivalent absorbent material shall be used for loading the packaging. Note that different combinations of absorbing material may be required based on the payload.

6. Verify that the contents and packaging are physically and chemically compatible under normal conditions of transport.

7. A maximum of three paint cans are authorized to be loaded into the packaging. A maximum of 2 L of liquid per paint can is authorize up to a maximum of 6 L.

8. Perform a gas generation assessment of the contents to be shipped (Part B, Section 7.0). Due to the variability of the payload, the potential for the contents to produce flammable gas and for those gasses to collect in the package voids in quantities exceeding the lower flammability limit must be assessed prior to shipment. This assessment will address the gas generating characteristics of the waste venting and diffusion rates, packaging configuration (waste volume, void volume, etc.), and the chemical properties of the waste materials that may effect hydrogen gas generation. The gas generation evaluation must show that the no more than 2.5 % by volume of hydrogen gas may collect in any package void space during transportation of the package.

   If the results indicate that gas generating contents are part of the payload, and there is a possibility for gasses to collect in excess of the lower flammability limit for the gas, venting will be provided as described below:

   a. The poly or glass bottle screw caps and the paint can lid shall be provided with a vent hole (#60 drill). Absorbent material will be placed over the vent hole and taped in place. This absorbent material will be provided in addition to the absorbent material already in the packaging.

b. The drum lid shall be provided with a NucFil-013 filter.

If the gas diffusion rate is not sufficient to prevent the lower flammability limit from being reached, even with venting, material must be removed from the package.

6.2 LOADING CONTENTS INTO PACKAGE

6.2.1 Paint Can Loading

1. The maximum size bottle which can be placed in the Imperial Gallon (5 qt) paint can is 2 L. Smaller glass or poly vials may be placed upright in a 2 L poly bottle to minimize handling.

2. If the package is to be vented, verify the bottle cap and paint can lid have a vent hole.

3. Line the paint can with rubber matting as required for shielding. The thickness of the matting depends on the amount of shielding required.

4. Place an absorbent pad in the bottom of the paint can and position the bottle in the center of the paint can. As necessary, surround the bottle with absorbent material to prevent it from shifting.

5. Fill the remaining void space in the paint can with absorbent material such that the paint can is completely full and the bottle is completely surrounded by absorbent material (including the top).

6. If more that one bottle or vile is to be placed in a 2 L bottle in the paint can, they should be completely surrounded by absorbent material to prevent movement and contact with each other or the paint can. The paint can shall be completely filled with absorbent material.

7. Place rubber matting or absorbent on top and install the paint can lid.

6.2.2 Drum Loading

1. Place absorbent material on the bottom of the inner cavity of the drum. Install a loaded paint can and completely surround with absorbent material.

2. If more that one paint can is to be loaded, completely surround each can with absorbent material to prevent movement of the cans and prevent contact with the each other and the inner cavity.

3. Fill any void space with absorbent material and install the steel plate on top of the inner cavity. The tabs of the steel plate should be facing down.

4. Fill any void space in the liner with absorbent material and install the liner lid. Be sure to completely fill the liner with absorbent to prevent the steel plate from shifting.

5. Install an anti-corrosive pad on top of the liner lid and completely fill remaining void space with absorbent material.

6. Verify that the drum lid is equipped with a NucFil-013 filter.

7. Install drum lid and locking ring. Torque locking ring bolt to 54.2 N-m (40 ft-lb). Use rubber mallet to tap the locking ring while tightening the bolt.

8. To prevent unintentional loosening, the NucFil filter shall be:

   a. Installed and torqued to 13.6 N-m (10 ft-lb) and tack-welded; or

   b. Secured by use of Loctite[3] No. 262 (red) and torqued to 13.6 N-m (10 ft-lb); or

   c. Torqued to 20.3 N-m (15 ft-lb).

9. Verify that the contamination levels on the exterior of the package and the dose rate is in accordance with the requirements of Part B, Section 4.3.2.

10. Install a tamper indication device to the drum closure system.

6.3 UNLOADING PACKAGE

Should it be desirable to remove the drum contents, unloading shall be as described below. Provisions must be made to prevent exposure from high dose contents as they are removed.

1. Verify that the contamination levels on the exterior of the package and the dose rate is in accordance with the requirements of Part A, Section 4.3.2.

2. Remove the drum lid and locking ring.

3. Remove the anti-corrosive pad and absorbent material.

4. Remove the liner lid and absorbent material to expose the steel cover plate.

5. Remove the steel plate taking precautions to avoid high dose levels.

6. Remove the absorbent material to expose paint cans and remove paint can.

6.4 EMPTY PACKAGING

To be transported as an empty radioactive container, the packaging must be prepared for transport in accordance with 49 CFR 173.428.

[3] Loctite is a trademark of the Loctite Corporation.

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7.0 QA REQUIREMENTS

7.1 INTRODUCTION

This section describes the QA requirements for a 55-gallon DOT UN1A2, DOT Specification 7A, Type A drum transporting Type A quantities of solid or liquid radioactive material on the Hanford Site. Design, construction, testing, and verification activities for the containers shall be in accordance with WHC-CM-4-2 and WHC-CM-2-14.

7.2 GENERAL REQUIREMENTS

These requirements apply to activities that could affect the quality of the DOT 7A, Type A drum and associated hardware. The overall requirements are classified per WHC-CM-2-14, Part II.

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, Loading Facility Operations, and Storage Facility managers are responsible for the quality of the work performed by their respective organizations and for performing the following activities.

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

The Director, Quality Assurance is responsible for establishing and administering the Pacific Northwest QA program, as stated in PNL-MA-70, *Quality Assurance Manual*.

7.4 QA ACTIVITIES

Each cognizant engineer involved with design, procurement, fabrication, use, or maintenance of the DOT 7A, Type A drum 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.

Design, procurement, and fabrication of DOT 7A, Type A containers are based on the performance-based criteria established in 49 CFR 178.350. and WHC-S-0466 (WHC 1996).

Requirements are imposed by direct reference in plans and procedures. Table A7-1, "Functional Responsibility Matrix," assigns responsibility for review and approval to the appropriate organization either designing or using the Type A container.

Table A7-1. Functional Responsibility Matrix.

Document	PE	Facility Engineering	Quality Assurance	Safety	Facility Operations
SEP	P,R,A	R,A	R,A	R,A	R,A
Drawings	R	P,R,A	R,A	R,A	R,A
Specifications	R,A	P,R,A	R,A	R,A	R,A
Container purchase order	NA	P,R,A	R,A	R,A	R,A
Operating procedures	R,A	P,R,A	R,A	R,A	R
Maintenance procedures	R	P,R,A	R,A	R,A	R
Leak test procedures	R,A	P,R,A	R,A	R,A	NA
Container fabrication	R	P,R,A	R,A	R	NA

A = Approval.
P = Primary responsibility (organization responsible for developing the document).
PE = Packaging Engineering.
R = Review.
SEP = Safety evaluation for packaging.

7.5 QUALITY REQUIREMENTS

Quality requirements for the procurement of DOT 7A, Type A drums shall follow WHC-S-0466 (WHC 1996).

7.5.1 Design Inputs

Design criteria for the DOT 7A, Type A drum are specified in specification WHC-S-0466 (WHC 1996). Any changes to the specification shall be identified, documented, approved, and controlled in the same manner as the original document.

7.5.2 Procurement and Fabrication Control

After the issue date of this SEP, specification WHC-S-0466 (WHC 1996) shall be used to procure DOT 7A, Type A drums intended for onsite transport in compliance with this SEP.

7.5.2.1 Control of Purchased Items and Services. The procurement of DOT 7A, Type A drums shall be documented and controlled to ensure conformance to specified requirements of WHC-CM-4-2.

7.5.3 QA Records and Document Control

Records that furnish documentary evidence of quality shall be specified, prepared, and maintained per WHC-CM-4-2. All documents used to perform and/or verify quality-related activities are controlled. Controlled documents include (but are not limited to) the following: drawings, specifications, purchase orders, plans and procedures to inspect and test, reports, quality verification reports, nonconformance reports, corrective action reports, the SEP, and operational and maintenance procedures.

The cognizant engineer is responsible for ensuring accessibility to the latest issue of all such documents. Use or maintenance of the container does not start until all required documents are readily accessible at the work location.

All records associated with hazardous material packaging and transportation shall be retained for the life of the package. All lifetime storage QA records required for the container shall be stored with Packaging Engineering, the facility, or the responsible storage organization, depending upon the purpose of the document.

7.6 SEP CONTROL SYSTEM

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

Any review comment records produced during the initial release or subsequent changes will be on file with Packaging Engineering.

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8.0 MAINTENANCE

8.1 GENERAL REQUIREMENTS

Maintenance of the Type A drums shall be per the manufacturer's recommendations or instructions. Wherever possible, empty and new drums shall be stored indoors or under protective cover to eliminate or minimize the adverse effects of sun, wind, snow, rain, or other environmental conditions that could cause packaging degradation.

8.2 INSPECTION AND VERIFICATION SCHEDULES

These inspections are only required as maintenance of the Type A drums prior to the shipment after being in storage longer than the manufacturer's recommendations or instructions. If operations require, the inspections may be performed during storage.

8.2.1 Visual Container Inspections

Surveillance of Type A drums include a visual inspection of any package degradation. The following are examples of additional periodic maintenance visual inspections.

- Determine container external contamination levels and document.
- Determine container external dose rates and document.
- Visually inspect package markings for deterioration.
- Visually inspect surface for paint chipping, discoloration, or other surface defects. If found, correct defect by repair, if necessary, and repaint the affected area.

8.2.2 Subsystem Maintenance

8.2.2.1 Fasteners. All threaded parts, will be inspected prior to use for deformed or stripped threads. Any damaged parts shall be replaced. Bolts that are found to exhibit headmarks matching those on the U.S. Department of Energy-Headquarters (DOE-HQ) "Suspect Fastener Headmark List" shall be segregated and dispositioned in accordance with governing Pacific Northwest procedures.

8.2.2.2 Paint. The painted surfaces of the drum shall be periodically inspected and touch-up paint applied to any locations where the coating has deteriorated.

8.3 RECORDS AND DOCUMENTATION

Visual inspection shall be documented, including QC verification and maintained for the life of storage or five years, whichever is longer.

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9.0 REFERENCES

49 CFR 173, 1996, "Shippers--General Requirements for Shipments and Packagings," *Code of Federal Regulations*, as amended.

49 CFR 178, 1996, "Shipping Container Specifications," *Code of Federal Regulations*, as amended.

DOE, 1989, *General Design Criteria*, DOE 6430.1A, U.S. Department of Energy, Washington, D.C.

PNL-MA-70, *Quality Assurance Manual*, Pacific Northwest National Laboratory, Richland, Washington.

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

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

WHC, 1996, *Drums; UN1A2; Type A; Solid Material, Painted*, WHC-S-0466, Westinghouse Hanford Company, Richland, Washington.

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10.0 DRAWINGS

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QTY	PN	DESCRIPTION	MATL/REF
X	1	ASSEMBLY	
1	2	WELDMENT A	
1	3	WELDMENT B	
1	4	LINER, 55 GALLON, TYPE IV, 110 MIL THK, HDPE STRAIGHT WALL WITH REMOVABLE LID, FABRICATED IN ACCORDANCE WITH ROCKY FLATS PLANT DWG #38886-001-M, #0397-0400-0400	STORES
1	5	DRUM, 55 GALLON, DOT 7A TYPE A, WITH REMOVABLE LID AND BOLTED LOCKING RING	GALVANIZED STEEL

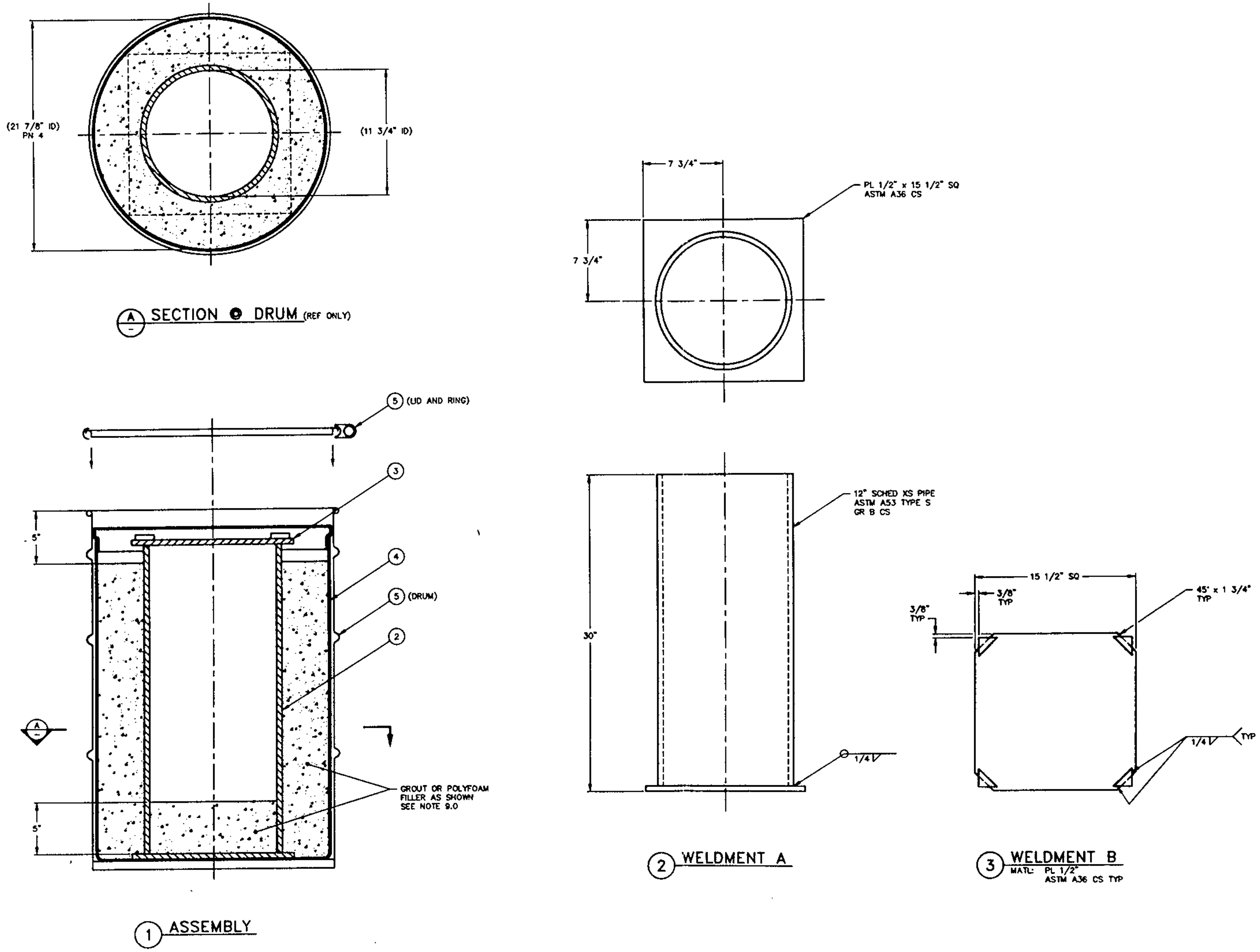
GENERAL NOTES

(UNLESS OTHERWISE SPECIFIED)

1. ALL MATERIALS SHALL BE AS SPECIFIED OR AN APPROVED EQUAL QUALITY BY A PNNL ENGINEER.
2. FIELD VERIFY ALL DIMENSIONS PRIOR TO FABRICATION.
3. ABBREVIATIONS ARE IN ACCORDANCE WITH ANSI Y1.1-1989.
4. DIMENSIONING AND TOLERANCING ARE PER ANSI Y14.5M-1982.
5. ALL DIMENSIONS ARE IN INCHES.

   TOLERANCES: FRACTIONS +/- 1/16

   ANGLES +/- 0°-30'
6. BREAK ALL SHARP EDGES AND REMOVE ALL BURRS.
7. WELDING QUALIFICATIONS AND PROCEDURES FOR CS STRUCTURES SHALL BE PER ASME SECTION IX-1995 OR AWS B2.1-1984. FABRICATION STANDARDS SHALL BE PER AWS D1.1-1994, SECTION 3.
8. PERFORM 100% VISUAL EXAMINATION OF ALL FINAL CS WELDS PER AWS D1.1-1994, SECTION 6, WITH ACCEPTANCE CRITERIA PER SECTION 8.15.1.
9. GROUT DENSITY SHALL BE BETWEEN 105 AND 118 LBS PER CUBIC FOOT. CARE SHALL BE TAKEN TO PREVENT AIR VOIDS (E.G., USING VIBRATORS). GROUT CAN BE REPLACED WITH A POLYFOAM FILLER HAVING A DENSITY OF 2 LBS PER CUBIC FOOT DEPENDING UPON THE ACTUAL DENSITY NEEDED FOR SHIELDING PER CUSTOMER REQUIREMENTS. NO VERIFICATION OR TESTING REQUIRED.



RELEASE 08-06-97 DATE

D01850-EDP01R1

REFERENCE DRAWINGS	DRAWING NO	DRAWING TITLE	NEXT USED ON

REVISIONS — RR | MF | QA BY DATE | ENGR BY DATE | CHK BY DATE | REV BY DATE | DESCRIPTION

CADCODE 30:IBM:ACD2:13.0:SS — CADFILE W307599A

DRAWN KS KOSCHIK 7/8/97
CHECKED [signature]
ENGR [signature]
DSGN KP BROOKS 8/4/97
APVD
OTHER BO BARNES
APPROVED FOR IMPLEMENTATION BY [signature] FOR PNNL DATE 8/6/97

U. S. DEPARTMENT OF ENERGY
RICHLAND OPERATIONS OFFICE

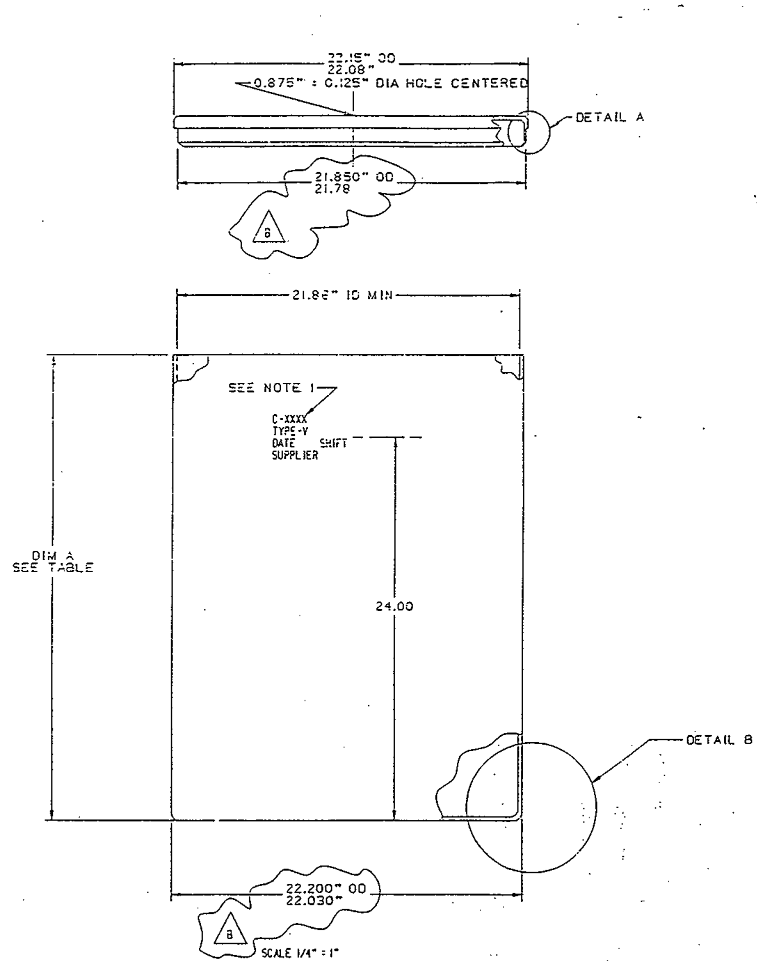
PACIFIC NORTHWEST NATIONAL LABORATORY
OPERATED BY BATTELLE MEMORIAL INSTITUTE

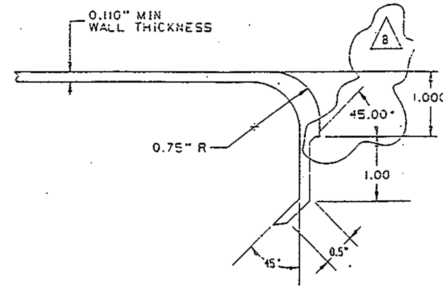
CONCRETE-LINED WASTE PACKAGE ASSEMBLY

C-107 WASTE DISPOSAL

SIZE F | INDEX NO 5010 | BLDG NO 324 | DWG NO H-3-307599 | REV NO 0

SCALE 1/4 | SHEET 1 OF 1

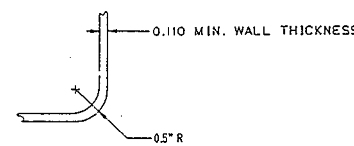




DETAIL - "A"
SCALE - FULL

CONTAINER	DIMENSION-A-	COLOR
TYPE IV	31.13" - 31.38"	BLACK
TYPE V	29.13" - 29.38"	BROWN

NOTE:
1. IDENTIFICATION REQUIREMENTS LOCATED APPROXIMATELY 90° FROM THE MOLD PARTING LINE. LETTER SIZE SHALL BE 0.25 INCH HIGH.



DETAIL - "B"
SCALE - FULL

MATERIAL - POLYETHYLENE - HIGH DENSITY

A10-5/6

MASTER DRAWING
MAINTAIN AS-BUILT PER DES-8
FE GROUP RESPONSIBLE WPOE

RFP STANDARD
F.E. MGR. AUTHORIZATION REQUIRED TO MODIFY DRAWING
STD. NO. SX-239

REV.	DESCRIPTION	DATE				DOC	CLASS	JOB NO.
B	REV. DIMENSIONS/ADDED ANGLE	8/28/91				6D	90045	
A	ORIGINAL ISSUE	6-29-89	DLK	DJS	LAB	TCB	DLG	90045

	BY	DATE
DESIGNED	MITCHELL	12-7-88
DRAWN	SWIFT	3-20-89
CHECKED	BEARLY	6/29/89
APPROVED	BROWN	6/29/89

KEYWORDS

TOLERANCES FRACT. ± ANGLE ± DEC. ± UNLESS NOTED OTHERWISE

REMOVE BURRS AND SHARP EDGES

SCALE: NOTED

U.S. DEPARTMENT OF ENERGY
ROCKY FLATS OFFICE GOLDEN, COLORADO
Rocky Flats Plant
GOLDEN, COLORADO

55 GALLON 110 MIL STRAIGHT WALL LINER

SIZE D DRAWING NUMBER 38886-001-M ISSUE B

COMPUTER GENERATED
NO MANUAL CHANGES ALLOWED
R.MSTI20.STD.38886.001.B.M.R.LINER

RETAIN

ROCKY FLATS STANDARD NO. SX-239 ATTACHMENT

PART B: PACKAGE EVALUATION

1.0 INTRODUCTION

1.1 SAFETY EVALUATION METHODOLOGY

The Concrete-Lined Waste Packaging (CLWP) is evaluated in this part for normal transport conditions for onsite transportation. There are no requirements to evaluate this packaging for any hypothetical accident conditions as the contents are limited to Type A quantities. Documentation is required to demonstrate that the container will maintain containment of the contents during all normal handling and transportation conditions. The container is evaluated at increased and reduced external pressurization, thermal loading, penetration, normal transport vibration, water spray, inertial loading, compression, and brittle fracture. The tiedown system is evaluated to meet 49 CFR 393.102-104.

1.2 EVALUATION SUMMARY AND CONCLUSION

As shown by the following evaluations, the CLWP will maintain confinement of its contents through all normal transport conditions. The normal transport conditions evaluated are reduced external pressure, increased external pressure, vibration, water spray, inertial loading, compression, penetration, and brittle fracture.

1.3 REFERENCE

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

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2.0 CONTENTS EVALUATION

2.1 CHARACTERIZATION

Contents to be transported in the CLWP will consist of liquid or solid materials in quantities not to exceed a Type A, fissile excepted (< 15 g of fissile materials), and non-TRU (< 100 nCi/g of TRU isotopes [U.S. Department of Energy (DOE) Order 5820.2A]) quantity limits. The contents may include mixed waste. Transportation safety requires that the dose rate at the surface of the packaging be 2 mSv/h (200 mrem/h) or less and 0.01 mSv/h (10 mrem/h) at a distance of 2 m (6.6 ft). Transport of a package which exceeds these limits is not authorized. In addition, the package must meet the dose rate requirements of the Central Waste Complex (CWC) of 2 mSv/h (200 mrem/h) or less at the surface of the drum and 1 mSv/h (100 mrem/h) or less at 30 cm (11.8 in.) from the drum surface. The maximum allowable source term for some selected isotopes with respect to Type A, fissile excepted, or shielding limits are shown in Table B2-1. Table B2-1 also identifies whether the activity limit for the isotopes shown is established by Type A, fissile excepted, or shielding limits. Because the quantity and type of material will vary from shipment to shipment, Part B Section 2.2 lists the material and quantity restrictions. Note that the data shown in Table B2-1 only applies to the isotopes shown and the geometry evaluated in Part B, Section 4.0. Although the package has concrete shielding or polyfoam filler in the sides and bottom, the filler material does not extend completely up the side of the package and the package has no appreciable amount of shielding on the top, therefore, the quantities of gamma-emitting isotopes is limited by the dose rate on the top of the container.

Table B2-1. Maximum Allowable Activity for Some Selected Isotopes.

Isotope	Activity Limit		Comment
	TBq	Ci	
^{60}Co	7.59 E-04	2.05 E-02	Activity limited by shielding
^{90}Sr	1.0 E-02	2.70 E+00	Activity limited by A_2 value
^{137}Cs	3.47 E-03	9.38 E-02	Activity limited by shielding
^{238}Pu	2.00 E-04	5.41 E-03	Activity limited by A_2 value
^{239}Pu	2.00 E-04	5.41 E-03	Activity limited by A_2 value
^{233}U	9.99 E-04	2.70 E-02	Activity limited by A_2 value
^{235}U	1.22 E-06	3.30 E-05	Assumed to be 15 g, limited by fissile excepted criteria, see Part B, Section 2.2.2
^{241}Am	2.00 E-04	5.41 E-03	Activity limited by A_2 value
^{243}Am	2.00 E-04	5.41 E-03	Activity limited by A_2 value
^{242}Cm	9.99 E-03	2.70 E-01	Activity limited by A_2 value

The thermal characteristics of the isotopes listed in Table B2-1 are shown in Table B2-2. Note that the thermal characteristics must be determined prior to shipment, as discussed in Part B, Section 2.2.

Table B2-2. Decay Heat Calculation for Selected Isotopes in the CLWP.

Nuclide	Activity		Heat Production Factor (W/Ci)	Heat Generation Rate (W)
	TBq	Ci		
^{90}Sr	1.0 E-02	2.70 E+00	1.16 E-03	3.13 E-03
^{90}Y	1.0 E-02	2.70 E+00	5.54 E-03	1.50 E-02
^{60}Co	7.59 E-04	2.05 E-02	1.54 E-02	3.16 E-04
^{137}Cs	3.47 E-03	9.38 E-02	1.01 E-03	9.47 E-05
^{137m}Ba	3.28 E-03	8.87 E-02	3.92 E-03	3.48 E-04
^{238}Pu	2.00 E-04	5.41 E-03	3.26 E-02	1.76 E-04
^{239}Pu	2.00 E-04	5.41 E-03	3.06 E-02	1.66 E-04
^{233}U	9.99 E-04	2.70 E-02	2.86 E-02	7.72 E-04
^{235}U	1.22 E-06	3.30 E-05	2.71 E-02	8.94 E-07
^{241}Am	2.00 E-04	5.41 E-03	3.28 E-02	1.77 E-04
^{243}Am	2.00 E-04	5.41 E-03	3.17 E-02	1.71 E-04
^{242}Cm	9.99 E-03	2.70 E-01	3.62 E-02	9.77 E-03

2.2 RESTRICTIONS

2.2.1 General

The contents of the package will vary from shipment to shipment and the shipper must ensure that each shipment is in compliance with the onsite transportation requirements.

The contents of this packaging are restricted as follows:

1. The quantity of material that may be shipped in a single package shall not exceed the excepted fissile material quantity limitations as shown in Part B, Section 2.2.2, shielding limitations as shown in Part B, Section 2.2.3, or Type A normal form material limits as shown in Part B, Section 2.2.4, whichever is more restrictive.

2. Liquids or wetted materials will be placed in polypropylene, polyethylene, glass, or Teflon[1] bottles which are placed in 4.7 L (5 qt) cans with absorbent materials. The maximum bottle size is 2 L, but smaller bottles may be used. The amount of absorbent materials shall be sufficient for twice the amount of liquid present. Note that different absorbent materials have different absorption rates as a function of the liquid to be absorbed.

[1]Teflon is a trademark of E. I. du Pont de Nemours and Company.

3. Up to 3, 4.7 L (5 qt) cans will fit into the packaging cavity, without the grout or polyfoam filler, or 2 cans with the filler material, see drawing H-3-307599.

4. Solid materials may be placed in the 4.7 L (5 qt) cans directly with padding, wrapping, or other packaging as required to meet the criteria of this section.

5. All contents and packaging materials shall be physically and chemically compatible under normal conditions of transport.

6. The package, including all internal spaces, shall be vented as required herein to prevent the buildup of flammable gasses. Due to the variability of the payload, the potential for the contents to produce flammable gas and for those gasses to collect in the package voids in quantities exceeding the lower flammability limits must be evaluated prior to shipment.

2.2.2 Fissile Material Content

The fissile isotopes considered for transportation are ^{238}Pu, ^{239}Pu, ^{241}Pu, ^{233}U, and ^{235}U (49 CFR 173.403). The Type A normal form limits bound the fissile excepted limits as shown in Table B2-3, except for ^{235}U, which has an unlimited A_2 value. As shown in Part B, Section 4.0, the fissile material limits are not restricted by shielding considerations in Type A normal form or fissile excepted quantities. In the case of ^{235}U, the limit shall be 15 g or less per package. Mixtures of fissile materials must meet Type A material limits (total of all fissile isotopes must be equal to or less than 15 g).

Table B2-3. Fissile Material Limits.

Isotope	Type A Quantity Limit (normal form, A_2)		Specific Activity (TBq/g)	Mass of Material (g)
	TBq	Ci		
^{238}Pu	2 E-04	5.41 E-03	6.3 E-01	3.17 E-04
^{239}Pu	2 E-04	5.41 E-03	2.3 E-03	8.7 E-02
^{241}Pu	1 E-02	0.27	3.8	2.63 E-03
^{233}U	1 E-03	2.7 E-02	3.6 E-04	2.8
^{235}U	unlimited	unlimited	8.0 E-08	15 g*

*Limited by fissile excepted limits.

2.2.3 Radiological Dose Limitations

The dose rate of the materials to be shipped in the package shall be limited as shown below:

1. The dose rate is limited to 2 mSv/h (200 mrem/h) on the external surface of the package, 1 mSv/h (100 mrem/h) at 30 cm (11.8 in) from the package (CWC requirement), 0.1 mSv/h (10 mrem/h) at 2 m (6.6 ft), and:

2. The dose rate in any normally occupied space; i.e., the driver position, shall not exceed 0.02 mSv/h (2 mrem/h) unless the driver is a radiological worker, in which case the dose rate shall not exceed 0.05 mSv/h (5 mrem/h).

If any package exceeds the dose rate limits of (1) above, material shall be removed prior to shipment.

The dose rate to the driver cannot exceed the limits stated in (2) above at any time. If the measured dose rate in the driver's position exceeds the limits, packages or materials shall be removed, rearranged, or supplemental shielding shall be added to ensure compliance with the requirements.

2.3 SIZE AND WEIGHT

The packaging is constructed as shown in drawing H-3-307599. It is constructed using a standard United Nations (UN) 1A2 208 L (55-gallon) drum manufactured and supplied to the standards of U.S. Department of Transportation (DOT) Specification 7A, Type A. The drum exterior dimensions are 87.7 cm (34.51 in.) in height and 61.2 cm (24.1 in.) in diameter. The drum is equipped with a 110 mil liner which contains a steel pipe assembly. The steel pipe assembly is 1.27 cm (0.5 in.) thick with an internal height of 74.9 cm (29.5 in.) and an internal diameter of 29.9 cm (11.75 in.). The bottom and top of the pipe assembly is covered by a 1.27 cm (0.5 in.) steel plate. The bottom of the pipe may be filled with grout or polyfoam filler commensurate with shielding requirements. The void space between the pipe and liner shall be filled with either grout or polyfoam filler. The grout or polyfoam filler thickness at the bottom of the pipe is 12.7 cm (5 in.) and the thickness along the sides is on the order of 11.6 cm (4.6 in.).

The packaging weight is 453 kg (1,000 lb) if the void spaces are filled with grout.

2.4 CONCLUSIONS

The CLWP contents are limited to solid or liquid materials in fissile excepted, Type A, non-TRU, quantities which meet the radiological dose rate limits, and fissile excepted material limits discussed in Part B, Section 2.2. Note that in order to meet the dose rate limits and fissile material limits, many isotopes may only be shipped in less than Type A quantities. Because the material quantities and configuration may vary greatly from shipment to shipment, the shipper must verify compliance in all cases.

2.5 REFERENCE

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

3.0 CONTAINMENT EVALUATION

3.1 INTRODUCTION

As demonstrated in this part, the CLWP will provide containment of its contents through all normal transport conditions.

Should an accident occur, the maximum predicted dose consequences are below onsite transportation safety acceptance criteria as required for a shipment of Type A quantity materials.

3.2 CONTAINMENT SOURCE SPECIFICATION

The worse case source term analyzed for the liquids intended for this packaging does not exceed Type A, fissile excepted (< 15 g of fissile materials), and non-transuranic (< 100 nCi/g of transuranic isotopes [DOE Order 5820.2A]) quantity limits.

3.3 NORMAL TRANSPORT CONDITIONS

The container shall prevent any loss or dispersal of the radioactive contents and will prevent any significant increase in the radiation levels at the external surfaces when exposed to the normal transfer conditions. The normal transport condition tests evaluated are increased and decreased external pressurization, penetration, compression, water spray, and forces due to normal transport vibration on the container and closure bolt.

3.4 CONTAINMENT EVALUATION

The results of the evaluations indicate that no loss or dispersal of the radioactive contents will occur during normal transport conditions. The stresses that are induced on the packaging do not exceed the ability of the drum to maintain containment of its contents.

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4.0 SHIELDING EVALUATION

4.1 INTRODUCTION

This shielding evaluation supports the shipment of the CLWP on the Hanford Site. The packaging may have concrete or polyfoam filler in the sides and bottom. For the purposes of this evaluation, only the concrete filler will be evaluated. Because no version of the packaging has shielding on the top, except for a 1.27 cm (0.5 in.) steel plate, the maximum surface dose rate will occur on the top without regard to the shielding in the package sides. Using ISO-PC (Rittmann 1995), the quantities of one strong beta emitting isotope and several gamma emitting isotopes and daughters were iterated until the dose rate limits for transportation and acceptance at the CWC were met. Transportation safety requires that the dose rate at the surface of the packaging be 2 mSv/h (200 mrem/h) or less and 0.01 mSv/h (10 mrem/h) at a distance of 2 m (6.6 ft). In addition, the package must meet the dose rate requirements of the CWC of 2 mSv/h (200 mrem/h) or less at the surface of the drum and 1 mSv/h (100 mrem/h) or less at 30 cm (11.8 in.) from the drum surface. A number of neutron emitting isotopes were also evaluated in Type A or fissile excepted quantities for their neutron dose rate contribution at the surface of the package. After the CWC limits were established, the calculated dose rates were evaluated against the dose rate limits around the vehicle and the driver. Note that the source terms and geometry evaluated are only representative and will vary in practice.

The results indicate that for strong beta or gamma emitting isotopes, the quantities must be limited far below the Type A quantity limits due to the shielding characteristics of the package. The neutron emitting isotopes evaluated contribute only a small neutron dose in Type A or fissile excepted quantities. However, neutron emitting isotopes which have a significant spontaneous fission rate, such as californium and einsteinium, would have a significant neutron dose rate even in Type A quantities, and must be evaluated prior to shipment.

4.2 DIRECT RADIATION SOURCE SPECIFICATION

The materials and the geometry of the inner containers transported by the package will be highly variable, but the contents will not exceed a Type A quantity of material as defined by 49 CFR 173 or the restrictions discussed in Part B, Section 2.2. A strong beta emitting isotope, ^{90}Sr, a number of strong gamma emitting isotopes, and a number of neutron emitting isotopes were individually considered for shielding as shown in Table B4-1. Note that for all the gamma emitters evaluated and ^{90}Sr, the material limits were far below a Type A quantity for normal form material due to the source geometry and the lack of shielding in the top of the container. The activity limits for each isotope were arrived at by iterating the material quantities until the dose rate limit was met at the top of the package, which is the most restrictive area for the geometry considered.

Table B4-1. Maximum Allowable Activity for Some Selected Isotopes.

Isotope	Activity Limit		Comment
	TBq	Ci	
^{60}Co	7.59 E-04	2.05 E-02	Activity limited by shielding
^{90}Sr	1.0 E-02	2.70 E+00	Activity limited by A_2 value
^{137}Cs	3.47 E-03	9.38 E-02	Activity limited by shielding
^{238}Pu	2.00 E-04	5.41 E-03	Activity limited by A_2 value
^{239}Pu	2.00 E-04	5.41 E-03	Activity limited by A_2 value
^{233}U	9.99 E-04	2.70 E-02	Activity limited by A_2 value
^{235}U	1.22 E-06	3.30 E-05	Assumed to be 15 g, limited by fissile excepted criteria, see Part B, Section 2.2.2
^{241}Am	2.00 E-04	5.41 E-03	Activity limited by A_2 value
^{243}Am	2.00 E-04	5.41 E-03	Activity limited by A_2 value
^{242}Cm	9.99 E-03	2.70 E-01	Activity limited by A_2 value

4.2.1 Gamma Source

The gamma source term evaluated is an inventory of either, ^{60}Co, ^{137}Cs, or ^{90}Sr with an equilibrium amount of the ^{137}Cs daughter, ^{137m}Ba, and the ^{90}Sr daughter ^{90}Y.

4.2.2 Beta Source

Beta particles originating in the source do not contribute directly to the dose rate outside the casks because of the shielding provided. However, the bremsstrahlung radiation produced by the deceleration of the beta particles in the source is a potential contribution to the source. Because this packaging has minimal shielding, bremsstrahlung was considered for the isotopes considered, particularly ^{90}Sr.

4.2.3 Neutron Source

The neutron emitting materials to be shipped are limited to Type A quantities and fissile excepted quantities. Because the material which may be shipped in the package can vary greatly, only a limited number of isotopes were evaluated for their neutron source contribution as shown in Table B4-2.

Table B4-2. Selected Neutron Emitting Isotopes to be Evaluated in the CLWP.

Isotope	Activity		Comments
	TBq	Ci	
^{238}Pu	2.00 E-04	5.41 E-03	Activity limited by A_2 value
^{239}Pu	2.00 E-04	5.41 E-03	Activity limited by A_2 value
^{233}U	9.99 E-04	2.70 E-02	Activity limited by A_2 value
^{235}U	1.22 E-06	3.30 E-05	Assumed to be 15 g, limited by fissile excepted criteria, see Part B, Section 2.2.2
^{241}Am	2.00 E-04	5.41 E-03	Activity limited by A_2 value
^{243}Am	2.00 E-04	5.41 E-03	Activity limited by A_2 value
^{242}Cm	9.99 E-03	2.70 E-01	Activity limited by A_2 value

4.3 SUMMARY OF SHIELDING PROPERTIES OF MATERIALS

The shielding in the CLWP is primarily provided by the steel in the pipe assembly and concrete in the side and bottom of the package. Some shielding is also provided by the source itself, depending on the source material, and the distance from the source to the container surface. The default material densities and shielding properties provided in the ISO-PC (Rittman 1995) computer code were used for the shielding calculations.

4.4 NORMAL TRANSPORT CONDITIONS

4.4.1 Conditions To Be Evaluated

Gamma dose rates were evaluated at the surface of the package (with an offset of 1 cm) and at 30 cm (11.8 in.), and 2 m (6.6 ft) from the package surface. These results were then evaluated for the dose rate to the vehicle driver from a single package. Neutron dose rates were estimated at the surface of the package only. Although multiple packages may be shipped together, the vehicle to be used and the shipping configuration is not known, therefore, no evaluation for the dose rate to the driver was done for this condition.

4.4.2 Acceptance Criteria

1. The dose rate on the external surface of the package is limited to 2 mSv/h (200 mrem/h),

2. The dose rate at any point 30 cm (11.8 in.) from the packaging surface is limited to 1 mSv/h (100 mrem/h) (CWC criteria); and

3. The dose rate in any normally occupied space; i.e., the driver position shall not exceed 0.02 mSv/h (2 mrem/h) unless the driver is a radiological worker, in which case the dose rate shall not exceed 0.05 mSv/h (5 mrem/h).

The dose rates at the surface of the package and at the driver location cannot be exceeded under any circumstances. The dose rate limit at 30 cm (11.8 in.) Is not a transportation requirements, but is a requirement for the package at the CWC.

4.4.3 Assumptions

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

1. The source was uniformly distributed in a 6 L of liquid (water) column in the package approximating 3 stacked 2 L bottles.
2. The liner or packing materials were not considered for shielding purposes.
3. Bremsstrahlung was only considered for isotopes evaluated.
4. Since the shipping configuration is not known, the dose rates will be determined with respect to the packaging, not the vehicle.
5. The driver is assumed to be no closer to the package than 2 m (6.6 ft).
6. Although the shielding in the side of the package does not extend all the way to the top of the inner steel pipe, it was assumed to extend all the way to the top for this evaluation.

4.4.4 Shielding Model

The source parameters are shown in Tables B4-3 and the package parameters are shown in Table B4-4. The data for the packaging and source parameters were taken from drawing H-3-307599.

Table B4-3. Source Parameters.

Source Material	Density (g/cm^3)	Diameter		Length		Volume (cm^3)
		cm	in.	cm	in.	
6 L of water with a uniformly distributed source.	1.0	11.08	4.36	62.23	24.5	6000

Table B4-4. Package Shielding Parameters.

Detector location	Airspace between source and inner pipe wall		Pipe wall thickness		Concrete Shield Thickness		Airspace between pipe/or shield and drum wall		Drum wall thickness (16 ga)	
	cm	in.	cm	in.	cm	in.	cm	in.	cm	in.
Side	9.380	3.690	1.270	0.500	11.590	4.560	0.795	0.313	0.15	0.0598
Top	NA	NA	1.270	0.500	NA	NA	6.980	2.750	0.15	0.0598
Bottom	NA	NA	1.270	0.500	12.700	5.000	NA	NA	0.15	0.0598

4.4.5 Shielding Calculations

The ISO-PC program (Rittmann 1995) was used for the gamma-ray dose rate calculations. ISO-PC uses the point-kernel integration method to compute the dose rate at a detector location. Bremsstrahlung photons are accounted for in the dose rate calculations. Fluence-to-dose conversion factors were based on an anterior-to-posterior irradiation pattern (ANS 1991). Table B4-5 shows the gamma dose rate estimates calculated by ISO-PC for the isotopes listed.

Table B4-5. Maximum Gamma Dose Rates Around the CLWP.

Detector orientation	Detector location					
	Surface (1cm offset)		30 cm		2 m	
	mSv/h	mrem/h	mSv/h	mrem/h	mSv/h	mrem/h
^{60}Co, 7.59 x 10^{-4} TBq (0.0205 Ci)						
Side	0.59	58.96	0.204	20.42	0.015	1.53
Top	1.985	198.50	0.288	28.75	0.016	1.56
Bottom	0.366	36.58	0.076	7.58	0.005	0.47
^{90}Sr, 1.0 x 10^{-2} Tbq (2.7 Ci)						
Side	0.07	7.48	0.028	2.75	0.002	0.21
Top	0.349	34.94	0.046	4.59	0.002	0.24
Bottom	0.03	3.02	0.006	0.60	0.000	0.04
^{137}Cs, 3.47 x 10^{-3} Tbq (0.0938 Ci)						
Side	0.491	49.07	0.177	17.71	0.014	1.35
Top	1.989	198.90	0.270	27.01	0.014	1.37
Bottom	0.226	22.56	0.045	4.47	0.003	0.26

The neutron dose rate was determined using a method discussed in *Estimation of Neutron Dose Rates from Nuclear Waste Packages* (Nelson 1996). This is a very conservative method that does not take shielding or moderation into account. The neutron dose rate calculations utilized data for α,n and spontaneous fission neutron production rates generated by ORIGEN. The estimated neutron dose rates for the isotopes shown in Table B4-2 are presented in Table B4-6.

Table B4-6. Unshielded Neutron Dose Rates on the Side of the CLWP.

Isotope	Dose (side only)	
	mSv/h	mrem/h
^{238}Pu	3.67 E-06	3.67 E-04
^{239}Pu	2.42 E-06	2.42 E-04
^{233}U	9.86 E-06	9.56 E-04
^{235}U	1.46 E-08	1.46 E-06
^{241}Am	3.18 E-06	3.18 E-04
^{243}Am	2.88 E-06	2.88 E-04
^{242}Cm	1.30 E-03	1.30 E-01

The ISO-PC input file, the ORIGEN input files, and the neutron dose calculations are attached in Part B, Section 4.7.

4.5 CONCLUSIONS

The dose rates listed in Tables B4-5 and B4-6 are within the acceptance criteria for a single package only. This assumes that the driver is 2 m (6.6 ft) from the package. Note that the neutron dose rates for the isotopes evaluated are not significant compared to the gamma dose rates. However, if even small amounts (less than Type A quantities) of neutron emitting isotopes such as ^{252}Cf, ^{254}Es, or ^{254m}Es are known to be present, the neutron dose rates could be significant. In that case, a more detailed shielding evaluation is required to estimate the neutron dose rate versus the use of the simplistic and very conservative method discussed in Nelson (1996).

The dose rates will vary significantly based on the source material distribution, source geometry, and shielding. Since the package has no shielding near the top of the inner pipe or the top, the highest dose rates will be seen in this area. Prior to shipment, the dose rates must be evaluated in accordance with Part B, Section 2.2.

4.6 REFERENCES

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

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

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

Schmittroth, F. A., 1994, *Conversion of ORIGEN2 to Sun Workstations*, WHC-SD-NR-SWD-006, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

4.7 APPENDICES

4.7.1 ISO-PC Input Files

```
0       2  TYPE A LIQ, 60 Co
 Case Side
&Input Next= 1, IPrnt=0, IGeom= 7, SFACT= 0.0019,
 DUNIT=1,  NTheta= 30, NPsi= 30, NShld= 6, JBuf= 4, OPTION=0,
 Slth= 62.23,
 T(1)= 5.54, 9.38, 1.27, 11.59, 0.795, 0.15,
 X= 29.72, 58.72, 228.72, 298.72,
 Y= 31.1,
 WEIGHT(472) =  10.8, &
 H2O    1     1.0
 Air    3          0.00129
 Steel  9                       7.86
 Conc   16                                  2.35
 Air    3                                        0.00129
1Steel  9                                                      7.86 &
 Case Top
&Input Next= 1, IPrnt=0, IGeom= 9, SFACT= 0.0019,
 DUNIT= 1, NTheta= 30, NPsi= 30, NShld= 4, JBuf= 2, OPTION=0,
 Slth= 5.54,
 T(1)= 62.23, 1.27, 6.98, 0.15,
 X= 71.63, 100.63, 270.63,
 WEIGHT(472) =  10.8, &
 H2O    1     1.0
 Steel  9           7.86
 Air    3                 0.00129
1Steel  9                               7.86 &
 Case Bottom
&Input Next= 1, IPrnt=0, IGeom= 9, SFACT= 0.0019,
 DUNIT= 1, NTheta= 30, NPsi= 30, NShld= 3, JBuf= 3, OPTION=0,
 Slth= 5.54,
 T(1)= 62.23, 12.7, 1.42,
 X= 77.35, 106.35, 276.35,
 WEIGHT(472) =  10.8, &
 H2O    1     1.0
 Conc   16          2.35
1Steel  9                   7.86 &
End of Input
&Input Next= 6 &

0       2  TYPE A LIQ, 90 Sr
 Case Side
&Input Next= 1, IPrnt=0, IGeom= 7, SFACT= 1,
 DUNIT=1,  NTheta= 30, NPsi= 30, NShld= 6, JBuf= 4, OPTION=0,
 Slth= 62.23,
 T(1)= 5.54, 9.38, 1.27, 11.59, 0.795, 0.15,
 X= 29.72, 58.72, 228.72, 298.72,
 Y= 31.1,
 WEIGHT(82) =  2.7,
 WEIGHT(84) =  2.7, &
 H2O    1     1.0
 Air    3          0.00129
 Steel  9                       7.86
 Conc   16                                  2.35
 Air    3                                        0.00129
1Steel  9                                                      7.86 &
 Case Top
&Input Next= 1, IPrnt=0, IGeom= 9, SFACT= 1,
 DUNIT= 1, NTheta= 30, NPsi= 30, NShld= 4, JBuf= 2, OPTION=0,
 Slth= 5.54,
 T(1)= 62.23, 1.27, 6.98, 0.15,
 X= 71.63, 100.63, 270.63,
 WEIGHT(82) =  2.7,
 WEIGHT(84) =  2.7, &
```

```
 H2O   1     1.0
 Steel  9          7.86
 Air    3                0.00129
1Steel  9                              7.86 &
 Case Bottom
&Input Next= 1, IPrnt=0, IGeom= 9, SFACT= 1,
 DUNIT= 1, NTheta= 30, NPsi= 30, NShld= 3, JBuf= 3, OPTION=0,
 Slth= 5.54,
 T(1)= 62.23, 12.7, 1.42,
 X= 77.35, 106.35, 276.35,
 WEIGHT(82) =  2.7,
 WEIGHT(84) =  2.7, &
 H2O    1     1.0
 Conc   16          2.35
1Steel  9                 7.86 &
End of Input
&Input Next= 6 &

0      2  TYPE A LIQ, 137 Cs
 Case Side
&Input Next= 1, IPrnt=0, IGeom= 7, SFACT= 0.00695,
 DUNIT=1,  NTheta= 30, NPsi= 30, NShld= 6, JBuf= 4, OPTION=0,
 Slth= 62.23,
 T(1)= 5.54, 9.38, 1.27, 11.59, 0.795, 0.15,
 X= 29.72, 58.72, 228.72, 298.72,
 Y= 31.1,
 WEIGHT(335) =  13.5,
 WEIGHT(336) =  12.771, &
 H2O    1     1.0
 Air    3        0.00129
 Steel  9                 7.86
 Conc   16                          2.35
 Air    3                              0.00129
1Steel  9                                           7.86 &
 Case Top
&Input Next= 1, IPrnt=0, IGeom= 9, SFACT= 0.00695,
 DUNIT= 1, NTheta= 30, NPsi= 30, NShld= 4, JBuf= 2, OPTION=0,
 Slth= 5.54,
 T(1)= 62.23, 1.27, 6.98, 0.15,
 X= 71.63, 100.63, 270.63,
 WEIGHT(335) =  13.5,
 WEIGHT(336) =  12.771, &
 H2O    1     1.0
 Steel  9          7.86
 Air    3                0.00129
1Steel  9                              7.86 &
 Case Bottom
&Input Next= 1, IPrnt=0, IGeom= 9, SFACT= 0.00695,
 DUNIT= 1, NTheta= 30, NPsi= 30, NShld= 3, JBuf= 3, OPTION=0,
 Slth= 5.54,
 T(1)= 62.23, 12.7, 1.42,
 X= 77.35, 106.35, 276.35,
 WEIGHT(335) =  13.5,
 WEIGHT(336) =  12.771, &
 H2O    1     1.0
 Conc   16          2.35
1Steel  9                 7.86 &
End of Input
&Input Next= 6 &
```

4.7.2 ORIGEN Input and Output Files

```
-1
-1
-1
TIT    ORIGEN-II - A2s
BAS    Neutron Emitters
LIP    0 0 0
LIB    0 1 2 3 381 382 383 9 0 0 1 1
PHO    101 102 103 10
INP    -1 1 -1 -1 1 1
RDA    DECAY FUEL
MOV    -1 1 0 1.00
RDA
DEC    1.0      1 2 4 1
DEC    5.0      2 3 4 0
DEC    10.0     3 4 4 0
DEC    50.0     4 5 4 0
DEC    100.0    5 6 4 0
DEC    200.0    6 7 4 0
DEC    1.0      7 8 5 0
DEC    2.0      8 9 5 0
DEC    5.0      9 10 5 0
DEC    10.0     10 11 5 0
RDA
CUT    5 1.E-10 7 1.E-10 9 1.E-10 25 1.E-20 26 1.E-20 -1
OPTL   24*8
OPTF   24*8 4*7 7 13*8 7 7 8 7 7
OPTA   4*8 7 7 7 8 7 8 14*8
OUT    11 1 -1 0
STP    4
1  802030 1.760E-03 812040 2.928E-02 832100 1.088E-04 832101 1.430E+03
1  842100 1.205E-04      0 0.000E+00      0 0.000E+00      0 0.000E+00
2  822100 3.183E-03 832120 5.537E-07 822120 5.838E-06 862220 7.023E-07
2  882230 1.584E-05 882240 1.017E-05 892250 4.653E-06 882250 1.380E-05
2  882260 5.473E-01 892270 7.481E-06 902270 8.786E-06 892280 4.818E-06
2  882280 4.616E-03 902280 1.318E-05 902290 3.813E-03 902300 2.681E-01
2  922300 9.894E-06 912310 3.430E-02 902310 4.572E-05 922320 3.790E-04
2  912330 1.171E-03 922330 2.790E+00 902340 2.337E-04 922340 4.322E+00
2  932350 7.700E-01 932360 2.050E+00 942360 3.558E-05 922360 4.174E+02
2  932370 7.676E+00 942370 4.478E-02 942380 3.161E-04 932390 5.821E-05
2  942390 8.705E-02 942400 2.375E-02 952410 1.577E-03 962410 1.615E-03
2  942410 2.621E-03 952421 5.568E-04 962420 8.168E-05 942420 1.417E+00
2  952430 2.714E-02 962430 1.571E-04 962440 1.335E-04 942440 3.051E+02
2  962450 3.151E-02 962460 1.762E-02 962470 5.832E+01 962480 3.176E-01
2  972490 1.318E-03 982490 1.321E-03 982500 1.235E-04 982510 3.412E-03
2  982520 5.022E-05 982530 5.592E-05 992530 2.142E-05 982540 1.907E-06
2  992540 4.350E-05 992541 3.441E-05 922350 1.500E+01      0 0.000E+00
0
END
```

OUTPUT UNIT = 6 PAGE 18

* ORIGEN-II - A2s
ACTINIDES+DAUGHTERS
POWER= 1.00000E+00 MW, BURNUP= 1.00000E+00 MWD, FLUX= 1.00E+00 N/CM**2-SEC

7 SUMMARY TABLE: RADIOACTIVITY, CURIES
Neutron Emitters

	0.0S	1.0D	5.0D	10.0D	50.0D	100.0D	200.0D	1.0YR	2.0YR	5.0YR	10.0YR
TL207	0.000E+00	7.772E-01	6.617E-01	5.419E-01	1.147E-01	1.784E-02	9.745E-04	5.741E-04	6.077E-04	6.999E-04	8.354E-04
TL208	0.000E+00	1.084E+00	2.615E-01	9.427E-02	2.381E-02	4.122E-02	7.282E-02	1.166E-01	1.830E-01	2.388E-01	1.818E-01
TL209	0.000E+00	6.211E-03	7.160E-03	7.465E-03	2.537E-03	3.211E-04	2.129E-05	1.761E-05	1.763E-05	1.779E-05	1.806E-05
PB209	0.000E+00	2.686E-01	3.315E-01	3.456E-01	1.174E-01	1.487E-02	9.858E-04	8.151E-04	8.164E-04	8.238E-04	8.362E-04
PB210	2.431E-01	2.431E-01	2.432E-01	2.434E-01	2.447E-01	2.461E-01	2.486E-01	2.527E-01	2.615E-01	2.863E-01	3.227E-01
PB211	0.000E+00	7.794E-01	6.635E-01	5.434E-01	1.150E-01	1.789E-02	9.772E-04	5.757E-04	6.094E-04	7.018E-04	8.377E-04
PB212	8.115E+00	2.839E+00	7.272E-01	2.623E-01	6.626E-02	1.147E-01	2.027E-01	3.245E-01	5.094E-01	6.647E-01	5.061E-01
PB214	0.000E+00	1.799E-01	3.663E-01	4.706E-01	5.415E-01	5.412E-01	5.411E-01	5.410E-01	5.408E-01	5.401E-01	5.389E-01
BI210	0.000E+00	3.140E-02	1.214E-01	1.822E-01	2.443E-01	2.465E-01	2.488E-01	2.528E-01	2.617E-01	2.865E-01	3.229E-01
BI211	0.000E+00	7.794E-01	6.635E-01	5.434E-01	1.150E-01	1.789E-02	9.772E-04	5.757E-04	6.094E-04	7.018E-04	8.377E-04
BI212	8.114E+00	3.017E+00	7.278E-01	2.624E-01	6.627E-02	1.147E-01	2.027E-01	3.245E-01	5.094E-01	6.647E-01	5.061E-01
BI213	0.000E+00	2.875E-01	3.315E-01	3.456E-01	1.174E-01	1.487E-02	9.856E-04	8.151E-04	8.164E-04	8.238E-04	8.362E-04
BI214	0.000E+00	1.799E-01	3.663E-01	4.706E-01	5.415E-01	5.412E-01	5.411E-01	5.410E-01	5.408E-01	5.401E-01	5.389E-01
PO210	0.000E+00	8.030E-05	1.678E-03	5.480E-03	4.691E-02	9.020E-02	1.508E-01	2.052E-01	2.472E-01	2.802E-01	3.229E-01
PO211	0.000E+00	2.182E-03	1.858E-03	1.522E-03	3.220E-04	5.010E-05	2.736E-06	1.612E-06	1.706E-06	1.965E-06	2.346E-06
PO212	0.000E+00	1.933E+00	4.663E-01	1.681E-01	4.246E-02	7.350E-02	1.299E-01	2.079E-01	3.264E-01	4.259E-01	3.243E-01
PO213	0.000E+00	2.813E-01	3.243E-01	3.381E-01	1.149E-01	1.455E-02	9.643E-04	7.974E-04	7.988E-04	8.060E-04	8.181E-04
PO214	0.000E+00	4.415E-01	5.951E-01	6.643E-01	5.925E-01	5.508E-01	5.413E-01	5.409E-01	5.407E-01	5.400E-01	5.388E-01
PO215	0.000E+00	7.794E-01	6.635E-01	5.434E-01	1.150E-01	1.789E-02	9.772E-04	5.757E-04	6.094E-04	7.018E-04	8.377E-04
PO216	0.000E+00	1.344E+00	6.394E-01	2.620E-01	6.625E-02	1.147E-01	2.027E-01	3.245E-01	5.094E-01	6.647E-01	5.061E-01
PO218	0.000E+00	1.799E-01	3.663E-01	4.707E-01	5.416E-01	5.413E-01	5.412E-01	5.411E-01	5.409E-01	5.402E-01	5.390E-01
AT217	0.000E+00	2.875E-01	3.315E-01	3.456E-01	1.174E-01	1.487E-02	9.855E-04	8.151E-04	8.164E-04	8.238E-04	8.362E-04
RN218	0.000E+00	2.616E-01	2.289E-01	1.938E-01	5.110E-02	9.656E-03	3.448E-04	1.400E-06	7.247E-12	1.004E-27	0.000E+00
RN219	0.000E+00	7.794E-01	6.635E-01	5.434E-01	1.150E-01	1.789E-02	9.772E-04	5.757E-04	6.094E-04	7.018E-04	8.377E-04
RN220	0.000E+00	1.344E+00	6.394E-01	2.620E-01	6.625E-02	1.147E-01	2.027E-01	3.245E-01	5.094E-01	6.647E-01	5.061E-01
RN222	1.081E-01	1.799E-01	3.663E-01	4.706E-01	5.416E-01	5.413E-01	5.412E-01	5.411E-01	5.409E-01	5.402E-01	5.390E-01
FR221	0.000E+00	2.875E-01	3.315E-01	3.456E-01	1.174E-01	1.487E-02	9.855E-04	8.151E-04	8.164E-04	8.238E-04	8.362E-04
FR223	0.000E+00	7.472E-06	7.477E-06	7.484E-06	7.535E-06	7.600E-06	7.729E-06	7.938E-06	8.391E-06	9.668E-06	1.154E-05
RA222	0.000E+00	2.616E-01	2.289E-01	1.938E-01	5.110E-02	9.656E-03	3.448E-04	1.400E-06	7.247E-12	1.004E-27	0.000E+00
RA223	8.115E-01	7.794E-01	6.635E-01	5.434E-01	1.150E-01	1.789E-02	9.772E-04	5.757E-04	6.094E-04	7.018E-04	8.377E-04
RA224	1.621E+00	1.343E+00	6.393E-01	2.620E-01	6.625E-02	1.147E-01	2.027E-01	3.245E-01	5.094E-01	6.647E-01	5.061E-01
RA225	5.412E-01	5.165E-01	4.284E-01	3.392E-01	5.281E-02	5.815E-03	8.589E-04	8.143E-04	8.164E-04	8.238E-04	8.362E-04
RA226	5.413E-01	5.413E-01	5.413E-01	5.413E-01	5.413E-01	5.413E-01	5.412E-01	5.411E-01	5.409E-01	5.402E-01	5.390E-01
RA228	1.081E+00	1.080E+00	1.079E+00	1.078E+00	1.066E+00	1.051E+00	1.021E+00	9.745E-01	8.787E-01	6.443E-01	3.841E-01
AC225	2.701E-01	2.875E-01	3.314E-01	3.455E-01	1.174E-01	1.487E-02	9.855E-04	8.151E-04	8.164E-04	8.238E-04	8.362E-04
AC227	5.413E-04	5.414E-04	5.418E-04	5.423E-04	5.460E-04	5.507E-04	5.600E-04	5.752E-04	6.081E-04	7.005E-04	8.363E-04
AC228	1.081E+01	1.725E+00	1.079E+00	1.078E+00	1.066E+00	1.051E+00	1.021E+00	9.746E-01	8.788E-01	6.443E-01	3.841E-01
TH226	0.000E+00	2.616E-01	2.289E-01	1.938E-01	5.110E-02	9.656E-03	3.448E-04	1.400E-06	7.247E-12	1.004E-27	0.000E+00
TH227	2.702E-01	2.604E-01	2.246E-01	1.867E-01	4.285E-02	7.182E-03	7.134E-04	5.652E-04	6.010E-04	6.922E-04	8.262E-04
TH228	1.081E-02	1.519E-02	1.968E-02	2.495E-02	6.598E-02	1.144E-01	2.021E-01	3.235E-01	5.082E-01	6.638E-01	5.055E-01
TH229	8.114E-04	8.114E-04	8.115E-04	8.115E-04	8.118E-04	8.121E-04	8.128E-04	8.139E-04	8.164E-04	8.238E-04	8.362E-04
TH230	5.414E-03	5.414E-03	5.414E-03	5.414E-03	5.414E-03	5.414E-03	5.414E-03	5.414E-03	5.414E-03	5.415E-03	5.416E-03
TH231	2.432E+01	1.267E+01	9.340E-01	3.591E-02	3.258E-05	3.270E-05	3.293E-05	3.322E-05	3.364E-05	3.403E-05	3.410E-05
TH234	5.414E+00	5.261E+00	4.689E+00	4.061E+00	1.285E+00	3.050E-01	1.718E-02	1.482E-04	4.056E-09	4.198E-12	8.397E-12
PA231	1.621E-03	1.622E-03	1.623E-03	1.623E-03	1.623E-03	1.623E-03	1.623E-03	1.623E-03	1.623E-03	1.623E-03	1.623E-03
PA233	2.431E+01	2.370E+01	2.139E+01	1.881E+01	6.740E+00	1.871E+00	1.487E-01	7.504E-03	5.445E-03	5.445E-03	5.445E-03
PA234M	0.000E+00	5.261E+00	4.689E+00	4.061E+00	1.285E+00	3.050E-01	1.718E-02	1.482E-04	4.056E-09	4.198E-12	8.397E-12
PA234	0.000E+00	6.317E-03	6.096E-03	5.279E-03	1.671E-03	3.965E-04	2.234E-05	1.926E-07	5.335E-12	5.458E-15	1.092E-14
U230	2.702E-01	2.613E-01	2.287E-01	1.936E-01	5.105E-02	9.646E-03	3.444E-04	1.399E-06	7.239E-12	1.003E-27	0.000E+00
U232	8.115E-03	8.116E-03	8.117E-03	8.118E-03	8.129E-03	8.142E-03	8.167E-03	8.201E-03	8.256E-03	8.294E-03	8.151E-03
U233	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.703E-02	2.703E-02	2.703E-02	2.703E-02	2.703E-02	2.703E-02	2.703E-02
U234	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.702E-02

OUTPUT UNIT = 6 PAGE 19

* ORIGEN-II - A2s
ACTINIDES+DAUGHTERS
POWER= 1.00000E+00 MW, BURNUP= 1.00000E+00 MWD, FLUX= 1.00E+00 N/CM**2-SEC

7 SUMMARY TABLE: RADIOACTIVITY, CURIES
Neutron Emitters

	0.0S	1.0D	5.0D	10.0D	50.0D	100.0D	200.0D	1.0YR	2.0YR	5.0YR	10.0YR
U235	3.244E-05	3.244E-05	3.245E-05	3.247E-05	3.258E-05	3.270E-05	3.293E-05	3.322E-05	3.364E-05	3.403E-05	3.410E-05
U236	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.702E-02
U237	0.000E+00	6.458E-07	2.657E-06	4.245E-06	6.545E-06	6.541E-06	6.458E-06	6.321E-06	6.031E-06	5.238E-06	4.146E-06
U240	0.000E+00	3.745E-03	5.392E-03	5.406E-03	5.406E-03	5.406E-03	5.406E-03	5.406E-03	5.406E-03	5.406E-03	5.406E-03
NP235	1.081E+03	1.079E+03	1.071E+03	1.062E+03	9.901E+02	9.072E+02	7.615E+02	5.703E+02	3.009E+02	4.422E+01	1.810E+00
NP236	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.702E-02	2.701E-02	2.701E-02
NP237	5.413E-03	5.414E-03	5.415E-03	5.418E-03	5.430E-03	5.438E-03	5.443E-03	5.445E-03	5.445E-03	5.445E-03	5.445E-03
NP238	0.000E+00	7.558E-06	2.180E-05	2.604E-05	2.705E-05	2.703E-05	2.700E-05	2.695E-05	2.682E-05	2.646E-05	2.586E-05
NP239	1.351E+01	1.007E+01	3.106E+00	7.172E-01	5.418E-03	5.412E-03	5.412E-03	5.412E-03	5.412E-03	5.412E-03	5.412E-03
NP240M	0.000E+00	3.745E-03	5.392E-03	5.406E-03	5.406E-03	5.406E-03	5.406E-03	5.406E-03	5.406E-03	5.406E-03	5.406E-03
PU236	1.891E-02	1.890E-02	1.886E-02	1.880E-02	1.837E-02	1.785E-02	1.686E-02	1.536E-02	1.257E-02	7.318E-03	3.880E-03
PU237	5.413E+02	5.331E+02	5.017E+02	4.650E+02	2.532E+02	1.184E+02	2.591E+01	2.103E+00	8.156E-03	4.763E-10	4.186E-22
PU238	5.414E-03	5.419E-03	5.442E-03	5.470E-03	5.671E-03	5.879E-03	6.182E-03	6.467E-03	6.676E-03	6.683E-03	6.592E-03
PU239	5.413E-03	5.414E-03	5.416E-03	5.417E-03	5.417E-03	5.417E-03	5.417E-03	5.417E-03	5.417E-03	5.418E-03	5.419E-03
PU240	5.414E-03	5.414E-03	5.414E-03	5.414E-03	5.414E-03	5.414E-03	5.415E-03	5.415E-03	5.416E-03	5.419E-03	5.423E-03
PU241	2.701E-01	2.701E-01	2.700E-01	2.698E-01	2.684E-01	2.667E-01	2.632E-01	2.577E-01	2.458E-01	2.135E-01	1.690E-01
PU242	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03
PU243	0.000E+00	5.225E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03
PU244	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03
AM241	5.415E-03	5.520E-03	5.924E-03	6.388E-03	8.865E-03	1.022E-02	1.101E-02	1.131E-02	1.170E-02	1.274E-02	1.416E-02
AM242M	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.410E-03	5.407E-03	5.400E-03	5.389E-03	5.364E-03	5.291E-03	5.172E-03
AM242	0.000E+00	3.480E-03	5.356E-03	5.386E-03	5.383E-03	5.380E-03	5.373E-03	5.362E-03	5.338E-03	5.265E-03	5.146E-03
AM243	5.412E-03	5.412E-03	5.412E-03	5.412E-03	5.412E-03	5.412E-03	5.412E-03	5.412E-03	5.412E-03	5.412E-03	5.412E-03
AM245	0.000E+00	3.129E-05	3.110E-05	3.088E-05	2.918E-05	2.667E-05	2.162E-05	1.512E-05	6.855E-06	6.387E-07	1.223E-08
CM241	2.432E+01	2.385E+01	2.208E+01	2.006E+01	9.285E+00	3.546E+00	5.170E-01	2.146E-02	1.895E-05	1.303E-14	6.982E-30
CM242	2.702E-01	2.690E-01	2.646E-01	2.591E-01	2.193E-01	1.782E-01	1.181E-01	6.076E-02	1.636E-02	4.477E-03	4.258E-03
CM243	8.113E-03	8.112E-03	8.110E-03	8.108E-03	8.086E-03	8.059E-03	8.006E-03	7.918E-03	7.728E-03	7.184E-03	6.361E-03
CM244	1.081E-02	1.080E-02	1.080E-02	1.079E-02	1.075E-02	1.069E-02	1.058E-02	1.040E-02	1.001E-02	8.923E-03	7.369E-03
CM245	5.412E-03	5.412E-03	5.412E-03	5.412E-03	5.412E-03	5.412E-03	5.412E-03	5.412E-03	5.413E-03	5.414E-03	5.416E-03
CM246	5.415E-03	5.415E-03	5.415E-03	5.415E-03	5.415E-03	5.415E-03	5.416E-03	5.417E-03	5.419E-03	5.424E-03	5.431E-03
CM247	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03	5.413E-03
CM248	1.351E-03	1.351E-03	1.351E-03	1.351E-03	1.351E-03	1.351E-03	1.351E-03	1.351E-03	1.351E-03	1.351E-03	1.351E-03
CM249	0.000E+00	4.845E-03	4.147E-03	3.414E-03	7.198E-04	1.029E-04	2.100E-06	3.386E-09	2.275E-15	0.000E+00	0.000E+00
BK249	2.161E+00	2.157E+00	2.144E+00	2.129E+00	2.012E+00	1.839E+00	1.491E+00	1.043E+00	4.726E-01	4.403E-02	8.432E-04
BK250	0.000E+00	8.052E-02	8.017E-02	7.917E-02	7.159E-02	6.314E-02	4.910E-02	3.241E-02	1.294E-02	8.231E-04	8.345E-06
CF249	5.414E-03	5.426E-03	5.472E-03	5.530E-03	5.977E-03	6.497E-03	7.393E-03	8.507E-03	9.913E-03	1.092E-02	1.092E-02
CF250	1.351E-02	1.477E-02	1.675E-02	1.718E-02	1.757E-02	1.793E-02	1.848E-02	1.899E-02	1.910E-02	1.692E-02	1.302E-02
CF251	5.414E-03	5.414E-03	5.414E-03	5.414E-03	5.413E-03	5.413E-03	5.411E-03	5.410E-03	5.405E-03	5.393E-03	5.372E-03
CF252	2.702E-02	2.700E-02	2.692E-02	2.682E-02	2.606E-02	2.514E-02	2.340E-02	2.077E-02	1.597E-02	7.263E-03	1.952E-03
CF253	1.621E+00	1.559E+00	1.334E+00	1.098E+00	2.316E-01	3.310E-02	6.758E-04	1.089E-06	7.320E-13	2.282E-31	0.000E+00
CF254	1.621E-02	1.610E-02	1.550E-02	1.466E-02	9.274E-03	5.230E-03	1.663E-03	2.504E-04	3.813E-06	1.346E-11	1.102E-20
ES253	5.403E-01	6.751E-01	6.842E-01	7.654E-01	5.441E-01	1.636E-01	8.505E-03	4.109E-05	2.008E-10	1.582E-26	0.000E+00
ES254M	1.081E+01	7.078E+00	1.302E+00	1.568E-01	6.950E-09	4.469E-18	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ES254	8.115E-02	8.094E-02	8.013E-02	7.913E-02	7.156E-02	6.311E-02	4.908E-02	3.239E-02	1.293E-02	8.227E-04	8.341E-06

ORIGEN-II - A2s
(ALPHA,N) NEUTRON SOURCE, NEUTRONS/SEC

BASIS= Neutron Emitters

	0.0S	1.0D	5.0D	10.0D	50.0D	100.0D	200.0D	1.0YR	2.0YR	5.0YR	10.0YR
BI211	0.000E+00	1.313E+03	1.118E+03	9.155E+02	1.938E+02	3.015E+01	1.646E+00	9.699E-01	1.027E+00	1.182E+00	1.411E+00
BI212	7.139E+03	2.654E+03	6.403E+02	2.308E+02	5.830E+01	1.009E+02	1.783E+02	2.855E+02	4.482E+02	5.848E+02	4.453E+02
PO210	0.000E+00	6.781E-02	1.417E+00	4.628E+00	3.961E+01	7.617E+01	1.273E+02	1.733E+02	2.088E+02	2.366E+02	2.727E+02
PO211	0.000E+00	4.849E+00	4.128E+00	3.381E+00	7.155E-01	1.113E-01	6.080E-03	3.582E-03	3.791E-03	4.367E-03	5.212E-03
PO212	0.000E+00	5.629E+03	1.358E+03	4.895E+02	1.236E+02	2.140E+02	3.782E+02	6.054E+02	9.504E+02	1.240E+03	9.443E+02
PO213	0.000E+00	7.689E+02	8.865E+02	9.241E+02	3.140E+02	3.976E+01	2.636E+00	2.180E+00	2.183E+00	2.203E+00	2.236E+00
PO214	0.000E+00	1.043E+03	1.406E+03	1.570E+03	1.400E+03	1.302E+03	1.279E+03	1.278E+03	1.278E+03	1.276E+03	1.273E+03
PO215	0.000E+00	1.703E+03	1.450E+03	1.188E+03	2.513E+02	3.910E+01	2.136E+00	1.258E+00	1.332E+00	1.534E+00	1.831E+00
PO216	0.000E+00	2.408E+03	1.146E+03	4.697E+02	1.187E+02	2.056E+02	3.633E+02	5.815E+02	9.130E+02	1.191E+03	9.071E+02
PO218	0.000E+00	2.297E+02	4.676E+02	6.009E+02	6.914E+02	6.911E+02	6.909E+02	6.908E+02	6.905E+02	6.896E+02	6.881E+02
AT217	0.000E+00	5.693E+02	6.564E+02	6.842E+02	2.325E+02	2.944E+01	1.951E+00	1.614E+00	1.616E+00	1.631E+00	1.656E+00
RN218	0.000E+00	5.280E+02	4.621E+02	3.912E+02	1.031E+02	1.949E+01	6.959E-01	2.826E-03	1.463E-08	2.027E-24	0.000E+00
RN219	0.000E+00	1.444E+03	1.230E+03	1.007E+03	2.131E+02	3.316E+01	1.811E+00	1.067E+00	1.129E+00	1.300E+00	1.552E+00
RN220	0.000E+00	1.969E+03	9.370E+02	3.840E+02	9.707E+01	1.681E+02	2.970E+02	4.754E+02	7.464E+02	9.741E+02	7.416E+02
RN222	1.028E+02	1.710E+02	3.483E+02	4.475E+02	5.150E+02	5.147E+02	5.146E+02	5.145E+02	5.143E+02	5.136E+02	5.125E+02
FR221	0.000E+00	4.413E+02	5.087E+02	5.304E+02	1.802E+02	2.282E+01	1.512E+00	1.251E+00	1.253E+00	1.264E+00	1.283E+00
RA222	0.000E+00	4.303E+02	3.766E+02	3.188E+02	8.407E+01	1.589E+01	5.673E-01	2.304E-03	1.192E-08	1.652E-24	0.000E+00
RA223	9.805E+02	9.417E+02	8.017E+02	6.566E+02	1.390E+02	2.162E+01	1.181E+00	6.956E-01	7.363E-01	8.480E-01	1.012E+00
RA224	1.738E+03	1.440E+03	6.855E+02	2.809E+02	7.103E+01	1.230E+02	2.173E+02	3.479E+02	5.462E+02	7.127E+02	5.427E+02
RA226	3.038E+02	3.038E+02	3.038E+02	3.038E+02	3.038E+02	3.037E+02	3.037E+02	3.036E+02	3.035E+02	3.031E+02	3.025E+02
AC225	3.070E+02	3.266E+02	3.766E+02	3.926E+02	1.334E+02	1.689E+01	1.120E+00	9.262E-01	9.277E-01	9.361E-01	9.502E-01
TH226	0.000E+00	3.910E+02	3.422E+02	2.897E+02	7.639E+01	1.443E+01	5.154E-01	2.093E-03	1.083E-08	1.501E-24	0.000E+00
TH227	3.524E+02	3.396E+02	2.929E+02	2.435E+02	5.590E+01	9.368E+00	9.306E-01	7.372E-01	7.839E-01	9.028E-01	1.078E+00
TH228	9.809E+00	1.379E+01	1.786E+01	2.265E+01	5.989E+01	1.038E+02	1.835E+02	2.937E+02	4.613E+02	6.025E+02	4.589E+02
TH229	5.745E-01	5.745E-01	5.745E-01	5.746E-01	5.748E-01	5.750E-01	5.755E-01	5.763E-01	5.780E-01	5.833E-01	5.920E-01
TH230	2.792E+00	2.792E+00	2.792E+00	2.792E+00	2.792E+00	2.792E+00	2.792E+00	2.792E+00	2.792E+00	2.792E+00	2.793E+00
TH232	0.000E+00	9.138E-13	4.569E-12	9.138E-12	4.569E-11	9.138E-11	1.828E-10	3.338E-10	6.676E-10	1.669E-09	3.338E-09
PA231	1.081E+00	1.082E+00	1.082E+00	1.083E+00	1.083E+00	1.083E+00	1.083E+00	1.083E+00	1.083E+00	1.083E+00	1.083E+00
U230	3.237E+02	3.131E+02	2.740E+02	2.320E+02	6.116E+01	1.156E+01	4.127E-01	1.676E-03	8.673E-09	1.202E-24	0.000E+00
U232	6.891E+00	6.891E+00	6.892E+00	6.893E+00	6.903E+00	6.914E+00	6.934E+00	6.963E+00	7.010E+00	7.043E+00	6.921E+00
U233	1.559E+01	1.559E+01	1.559E+01	1.559E+01	1.560E+01	1.560E+01	1.560E+01	1.560E+01	1.560E+01	1.560E+01	1.560E+01
U234	1.501E+01	1.501E+01	1.501E+01	1.501E+01	1.501E+01	1.501E+01	1.501E+01	1.501E+01	1.501E+01	1.501E+01	1.501E+01
U235	1.186E-02	1.186E-02	1.186E-02	1.187E-02	1.191E-02	1.195E-02	1.204E-02	1.214E-02	1.230E-02	1.244E-02	1.246E-02
U236	1.152E+01	1.152E+01	1.152E+01	1.152E+01	1.152E+01	1.152E+01	1.152E+01	1.152E+01	1.152E+01	1.152E+01	1.152E+01
U238	0.000E+00	7.230E-13	3.615E-12	7.230E-12	3.615E-11	7.230E-11	1.446E-10	2.641E-10	5.282E-10	1.320E-09	2.641E-09
NP237	3.818E+00	3.819E+00	3.820E+00	3.821E+00	3.830E+00	3.836E+00	3.839E+00	3.840E+00	3.841E+00	3.841E+00	3.841E+00
PU236	2.123E+01	2.122E+01	2.117E+01	2.111E+01	2.062E+01	2.004E+01	1.892E+01	1.724E+01	1.411E+01	8.215E+00	4.356E+00
PU238	5.151E+00	5.156E+00	5.177E+00	5.204E+00	5.396E+00	5.594E+00	5.882E+00	6.153E+00	6.352E+00	6.358E+00	6.272E+00
PU239	3.943E+00	3.944E+00	3.945E+00	3.945E+00	3.946E+00	3.946E+00	3.946E+00	3.946E+00	3.946E+00	3.946E+00	3.947E+00
PU240	4.102E+00	4.102E+00	4.102E+00	4.102E+00	4.102E+00	4.103E+00	4.103E+00	4.103E+00	4.104E+00	4.106E+00	4.110E+00
PU242	3.328E+00	3.328E+00	3.328E+00	3.328E+00	3.328E+00	3.328E+00	3.328E+00	3.328E+00	3.328E+00	3.328E+00	3.328E+00
PU244	2.507E+00	2.507E+00	2.507E+00	2.507E+00	2.507E+00	2.507E+00	2.507E+00	2.507E+00	2.507E+00	2.507E+00	2.507E+00
AM241	5.193E+00	5.295E+00	5.682E+00	6.127E+00	8.503E+00	9.800E+00	1.056E+01	1.084E+01	1.122E+01	1.222E+01	1.358E+01
AM243	4.617E+00	4.617E+00	4.617E+00	4.617E+00	4.617E+00	4.617E+00	4.617E+00	4.617E+00	4.617E+00	4.617E+00	4.617E+00
CM242	3.627E+02	3.612E+02	3.552E+02	3.478E+02	2.944E+02	2.392E+02	1.585E+02	8.156E+01	2.196E+01	6.010E+00	5.716E+00
CM243	1.080E+01	1.080E+01	1.080E+01	1.079E+01	1.077E+01	1.073E+01	1.066E+01	1.054E+01	1.029E+01	9.565E+00	8.469E+00
CM244	1.233E+01	1.233E+01	1.232E+01	1.232E+01	1.227E+01	1.220E+01	1.207E+01	1.187E+01	1.142E+01	1.018E+01	8.409E+00
CM245	5.172E+00	5.172E+00	5.172E+00	5.172E+00	5.172E+00	5.172E+00	5.172E+00	5.172E+00	5.172E+00	5.174E+00	5.176E+00
CM246	4.772E+00	4.772E+00	4.772E+00	4.772E+00	4.773E+00	4.773E+00	4.773E+00	4.774E+00	4.776E+00	4.781E+00	4.787E+00
CM247	4.516E+00	4.516E+00	4.516E+00	4.516E+00	4.516E+00	4.516E+00	4.516E+00	4.516E+00	4.516E+00	4.516E+00	4.516E+00
CM248	6.146E-01	6.146E-01	6.146E-01	6.146E-01	6.146E-01	6.146E-01	6.146E-01	6.146E-01	6.146E-01	6.147E-01	6.147E-01
CM250	0.000E+00	9.957E-10	4.894E-09	9.540E-09	3.853E-08	6.028E-08	7.946E-08	8.706E-08	8.838E-08	8.839E-08	8.837E-08
CF249	1.271E+01	1.274E+01	1.285E+01	1.298E+01	1.403E+01	1.525E+01	1.736E+01	1.997E+01	2.327E+01	2.564E+01	2.564E+01
CF250	1.726E+01	1.888E+01	2.141E+01	2.196E+01	2.246E+01	2.292E+01	2.362E+01	2.427E+01	2.441E+01	2.162E+01	1.664E+01
CF251	6.610E+00	6.610E+00	6.610E+00	6.610E+00	6.610E+00	6.609E+00	6.607E+00	6.605E+00	6.600E+00	6.585E+00	6.559E+00
CF252	3.196E+01	3.193E+01	3.184E+01	3.173E+01	3.083E+01	2.974E+01	2.767E+01	2.457E+01	1.889E+01	8.590E+00	2.309E+00
ES254M	2.671E+04	1.749E+04	3.218E+03	3.876E+02	1.718E-05	1.105E-14	4.697E-33	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ES254	1.305E+02	1.301E+02	1.288E+02	1.272E+02	1.151E+02	1.015E+02	7.891E+01	5.209E+01	2.079E+01	1.323E+00	1.341E-02

TOTALS

TABLE	3.868E+04	4.358E+04	2.001E+04	1.366E+04	6.149E+03	4.671E+03	5.012E+03	5.917E+03	7.331E+03	8 .544E+03	7.291E+03
ACTUAL	3.868E+04	4.358E+04	2.001E+04	1.366E+04	6.149E+03	4.671E+03	5.012E+03	5.917E+03	7.331E+03	8.544E+03	7.291E+03

ORIGEN-II - A2s
SPONTANEOUS FISSION NEUTRON SOURCE, NEUTRONS/SEC
BASIS= Neutron Emitters

	0.0S	1.0D	5.0D	10.0D	50.0D	100.0D	200.0D	1.0YR	2.0YR	5.0YR	10.0YR
TH230	1.126E-04	1.126E-04	1.126E-04	1.126E-04	1.126E-04	1.126E-04	1.126E-04	1.126E-04	1.126E-04	1.127E-04	1.127E-04
PA231	2.243E-04	2.245E-04	2.246E-04	2.246E-04	2.246E-04	2.246E-04	2.247E-04	2.247E-04	2.247E-04	2.247E-04	2.247E-04
U232	4.112E-04	4.112E-04	4.113E-04	4.113E-04	4.119E-04	4.126E-04	4.138E-04	4.155E-04	4.183E-04	4.203E-04	4.130E-04
U233	1.939E-03	1.939E-03	1.939E-03	1.939E-03	1.939E-03	1.940E-03	1.940E-03	1.940E-03	1.940E-03	1.940E-03	1.940E-03
U234	1.614E-02	1.614E-02	1.614E-02	1.614E-02	1.614E-02	1.614E-02	1.614E-02	1.614E-02	1.614E-02	1.614E-02	1.614E-02
U235	5.287E-03	5.287E-03	5.289E-03	5.292E-03	5.310E-03	5.330E-03	5.367E-03	5.415E-03	5.483E-03	5.547E-03	5.558E-03
U236	1.978E+00	1.978E+00	1.978E+00	1.978E+00	1.978E+00	1.978E+00	1.978E+00	1.978E+00	1.978E+00	1.978E+00	1.978E+00
U238	0.000E+00	8.672E-11	4.336E-10	8.672E-10	4.336E-09	8.672E-09	1.734E-08	3.168E-08	6.335E-08	1.584E-07	3.168E-07
PU236	1.242E+00	1.242E+00	1.239E+00	1.235E+00	1.207E+00	1.173E+00	1.107E+00	1.009E+00	8.254E-01	4.807E-01	2.549E-01
PU238	8.400E-01	8.408E-01	8.443E-01	8.487E-01	8.799E-01	9.122E-01	9.592E-01	1.003E+00	1.036E+00	1.037E+00	1.023E+00
PU239	1.973E-03	1.974E-03	1.974E-03	1.974E-03	1.975E-03	1.975E-03	1.975E-03	1.975E-03	1.975E-03	1.975E-03	1.975E-03
PU240	2.162E+01	2.162E+01	2.163E+01	2.163E+01	2.163E+01	2.163E+01	2.163E+01	2.163E+01	2.163E+01	2.165E+01	2.166E+01
PU242	2.389E+03	2.389E+03	2.389E+03	2.389E+03	2.389E+03	2.389E+03	2.389E+03	2.389E+03	2.389E+03	2.389E+03	2.389E+03
PU244	5.526E+05	5.526E+05	5.526E+05	5.526E+05	5.526E+05	5.526E+05	5.526E+05	5.526E+05	5.526E+05	5.526E+05	5.526E+05
AM241	1.957E-03	1.995E-03	2.141E-03	2.308E-03	3.203E-03	3.692E-03	3.980E-03	4.085E-03	4.226E-03	4.604E-03	5.116E-03
AM242M	8.297E-02	8.297E-02	8.296E-02	8.296E-02	8.292E-02	8.286E-02	8.276E-02	8.259E-02	8.222E-02	8.110E-02	7.927E-02
AM243	9.080E-02	9.080E-02	9.080E-02	9.080E-02	9.080E-02	9.080E-02	9.080E-02	9.080E-02	9.080E-02	9.080E-02	9.080E-02
CM242	1.760E+03	1.752E+03	1.723E+03	1.688E+03	1.429E+03	1.161E+03	7.691E+02	3.957E+02	1.065E+02	2.916E+01	2.773E+01
CM244	1.485E+03	1.484E+03	1.484E+03	1.483E+03	1.477E+03	1.469E+03	1.454E+03	1.429E+03	1.375E+03	1.226E+03	1.012E+03
CM246	1.568E+05	1.568E+05	1.568E+05	1.568E+05	1.568E+05	1.568E+05	1.568E+05	1.569E+05	1.569E+05	1.571E+05	1.573E+05
CM248	1.382E+07	1.382E+07	1.382E+07	1.382E+07	1.382E+07	1.382E+07	1.382E+07	1.382E+07	1.382E+07	1.382E+07	1.382E+07
CM250	0.000E+00	4.388E-01	2.157E+00	4.205E+00	1.698E+01	2.657E+01	3.502E+01	3.837E+01	3.895E+01	3.896E+01	3.895E+01
BK249	1.367E+02	1.365E+02	1.357E+02	1.347E+02	1.273E+02	1.164E+02	9.433E+01	6.598E+01	2.991E+01	2.787E+00	5.336E-02
CF249	3.444E+00	3.451E+00	3.481E+00	3.518E+00	3.802E+00	4.133E+00	4.703E+00	5.412E+00	6.306E+00	6.948E+00	6.947E+00
CF250	1.369E+06	1.497E+06	1.698E+06	1.742E+06	1.782E+06	1.818E+06	1.873E+06	1.925E+06	1.936E+06	1.715E+06	1.320E+06
CF252	1.154E+08	1.153E+08	1.150E+08	1.146E+08	1.113E+08	1.074E+08	9.993E+07	8.873E+07	6.822E+07	3.102E+07	8.338E+06
CF254	2.331E+09	2.316E+09	2.229E+09	2.108E+09	1.334E+09	7.520E+08	2.391E+08	3.601E+07	5.483E+05	1.936E+00	1.585E-09
ES253	6.815E+03	7.253E+03	8.630E+03	9.654E+03	6.863E+03	2.064E+03	1.073E+02	5.183E-01	2.533E-06	1.995E-22	0.000E+00
ES254M	1.674E+09	1.096E+09	2.016E+08	2.428E+07	1.076E+00	6.920E-10	2.943E-28	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ES254	3.637E+02	3.628E+02	3.592E+02	3.547E+02	3.208E+02	2.829E+02	2.200E+02	1.452E+02	5.797E+01	3.688E+00	3.739E-02
TOTALS											
TABLE	4.136E+09	3.543E+09	2.562E+09	2.263E+09	1.461E+09	8.757E+08	3.555E+08	1.412E+08	8.524E+07	4.726E+07	2.419E+07
ACTUAL	4.136E+09	3.543E+09	2.562E+09	2.263E+09	1.461E+09	8.757E+08	3.555E+08	1.412E+08	8.524E+07	4.726E+07	2.419E+07
OVERALL TOTALS											
TABLE	4.136E+09	3.543E+09	2.562E+09	2.263E+09	1.461E+09	8.757E+08	3.555E+08	1.412E+08	8.525E+07	4.727E+07	2.420E+07
ACTUAL	4.136E+09	3.543E+09	2.562E+09	2.263E+09	1.461E+09	8.757E+08	3.555E+08	1.412E+08	8.525E+07	4.727E+07	2.420E+07

4.7.3 Neutron Dose Calculations

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

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

S(SF) and S(a,n) are determined from Nelson (1996) or ORIGEN, see Part B, Section 4.7.2. After S(ST) is determined, it is used to determine the dose rate in the equation;

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

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

For example, the neutron dose on the side of the CLWP is estimated for ^{239}Pu as follows. Using S(SF) and S(α,n) from ORIGEN and conservatively assuming a k_{eff} of 0.8, S(ST) is determined to be,

$$S(ST) = \frac{1.973 \times 10^{-3} + 3.943}{(1 - 0.8)} = 19.72\ n/s.$$

Assuming r to be 28.57 cm (the approximate surface of cask as measured radially), the total neutron dose rate is estimated to be,

$$D(r) = \frac{0.01 \cdot 19.72}{28.57^2} = 2.42 \times 10^{-4}\ mrem/h$$

CHECKLIST FOR TECHNICAL PEER REVIEW

Document: "PNNL Type A Liquid Packaging SEP," September 10, 1997, by John Mccoy.

Scope: Shielding (Part B, Section 4) and contents (Part B, Section 2) sections.

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

Anthony Savino *[signature]* 9/10/97

Reviewer (Printed Name and Signature) Date

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5.0 STRUCTURAL EVALUATION

5.1 INTRODUCTION

This section evaluates a concrete- or foam-filled steel drum with an inner cavity formed by a 12-in. pipe. Low density concrete is used to fill the drum only in those packages that need it for shielding. The liquid contents are sealed in glass or poly bottles packed into sealed cans. The contents are protected from impact with 1.3-cm (0.5-in.) rubber pads inside the pipe and poly absorbent pads filling the can. The packaging is described in Pacific Northwest drawing H-3-307599.

5.2 STRUCTURAL EVALUATION OF PACKAGE

5.2.1 Structural Design and Features

The outermost package layer is a 208-L (55-gallon), DOT UN1A2 drum, closed with a gasketed lid and bolted locking ring. The drum is lined with a 90-to-110-mil high-density polyethylene liner with a slip lid closure. Inside the drum is an assembly of steel pipe and plate forming an inner cavity. A square steel plate 1.3 cm (0.5-in.) thick is tack welded to the bottom of a 12-in. diameter, 76.2 cm (30.0 in.) long, schedule 80 steel pipe, and placed in the liner. Concrete or foam filler is placed between the drum and the pipe according to the shielding requirements. If concrete is used as shielding, it is compacted during placement to prevent voids, and a 13-cm (5.00-in.) layer of grout is placed in the bottom of the pipe. This makes the cavity of a concrete-shielded drum smaller than that of the foam-filled drum.

Two or three 4.7-L (5-qt) cans, depending on the cavity size and the resulting dose rate, are placed inside the pipe and surrounded by polypropylene absorbent. Enough absorbent padding is added around the cans to keep them from shifting within the cavity.

The 4.7-L (5-qt) cans contain one capped poly or glass bottle, which is the innermost container. The poly (polypropylene or polyethylene) or glass containers are selected for chemical compatibility with the waste matrix and the requirements for long-term storage as determined by the accepting contractor. If required for shielding, rubber matting 1.3-cm (0.5 -in.) thick lines the inside of the can, and sufficient polypropylene absorbent pads are added to prevent the bottle from moving inside the can. If the mat is not used, only the polypropylene absorbent pads are added. There is sufficient absorbent pads to absorb twice the amount of liquid being shipped.

A square steel plate 1.3-cm (0.5-in.) thick is placed on top of the pipe and is prevented from moving laterally by tabs welded to the underside. The lid of the drum liner is placed on top of the plate, an anticorrosive rad pad is placed on top of the liner, and the drum lid is locked on.

In cases when the contents have the potential for generating gas, the bottles, cans, and the drum are vented. The bottles and cans are vented simply by poking a small hole in them, while the drum will have a filtered, liquid-retaining vent installed.

5.2.2 Chemical and Galvanic Reactions

The bottle is selected for chemical compatibility with the contents, and will not corrode. The liner insulates the carbon steel pipe from the drum, and concrete, if used, provides further protection from galvanic reactions between the drum and the steel plate and pipe that form the inner cavity.

5.2.3 Size of Package and Cavity

The cavity is 76 cm (30 in) long and 30 cm (11.75 in) in diameter. As shown in the attached calculations, the cavity size is 53 L (14 gal).

The maximum amount of liquid allowed in this package is 6 L (1.5 gal), and the gross weight of the package shall not exceed 453 kg (1000 lb).

5.2.4 Weights and Center of Gravity

The package is required to weigh 453 kg (1000 lb) or less. As shown in part A of the attached calculations, the concreted drums will weigh less than 390 kg (860 lb) assuming that the padding and contents weigh less than 23 kg (50 lb.) and that lightweight concrete with a density of 1891 kg/m^3 (118 pcf) is used. If normal-density concrete, 2400 kg/m^3 (150 pcf), is used the total weight would be 453 kg (1000 lb) and the higher weight was used in all calculations where weights were required. If the package is filled with 160 kg/m^3 (10 pcf) foam instead of concrete, the package weight will be 160 kg (360 lb). In all cases, the center of gravity will be at or slightly below the midheight.

5.2.5 Tamper-Indicating Feature

The drum will be protected with a tamper indicator.

5.2.6 Positive Closure

The drum is positively closed by installing the gasketed lid and locking ring, torquing the locking bolt to 40 lb-ft, and installing a jam nut.

5.2.7 Lifting and Tiedown Devices

There are no lifting or tiedown devices attached to the drum. Because the gross weight is 453 kg (1000 lb), normal drum handling equipment that grip the drum can be used. Due to the vented bottles and cans, the drums must not tipped more than 45°, and the drums must be shipped upright.

5.3 NORMAL TRANSFER CONDITIONS

5.3.1 Conditions To Be Evaluated

5.3.1.1 Reduced External Pressure. Evaluate the package with the exterior pressure reduced to 95.22 kPa, absolute (13.81 psia), assuming the package was loaded at normal pressure 101.35 kPa, absolute (14.7 psia). Include the effects of a temperature rise, assuming the package was loaded at 21.1 °C (70 °F).

5.3.1.2 Increased External Pressure. Evaluate the package with the exterior pressure increased to 102.4 kPa, absolute (14.85 psia), assuming the package was loaded at normal pressure 101.35 kPa, absolute (14.7 psia). Include the effects of a temperature decrease, assuming the package was loaded at 21.1 °C (70 °F).

5.3.1.3 Vibration. Evaluate package fatigue performance for vibration normally incident to transport using response parameters given in American National Standards Institute (ANSI) N14.23 (ANSI 1992). For a 453-kg (1000-lb) package, the vertical force applied to the package is 374 N (84.0 lbf), multiplied by 2.3, at a frequency of 2 Hz.

5.3.1.4 Water Spray. Evaluate the package performance for resistance to water in-leakage due to water spay simulating a rainfall of 5.0 cm/h (2.0 in/h) for 1 hour.

5.3.1.5 Inertial Loading. Loads resulting from rough transport of the package. Assume the shock loading parameters from ANSI N14.23 (ANSI 1992): 3.5*g* vertical, 2.3*g* longitudinal, and 1.6*g* lateral. No drop loadings are considered.

5.3.1.6 Compression. Evaluate this package (less than 5,000 kg [11,000 lb]) under a compression load of five times the weight of the package, applied uniformly on the top and bottom of the package.

5.3.1.7 Penetration. Evaluate the package under the impact of a hemispherically-ended steel cylinder dropped from 1.0 m (3.0 ft). The missile has a mass of 6.0 kg (12.0 lb) and a diameter of 3.2 cm. It is dropped vertically onto the surface of the package in the region most vulnerable to puncture.

5.3.1.8 Brittle Fracture. Evaluate all metallic materials susceptible to brittle fracture per *Boiler and Pressure Vessel Code,* Section VIII, Division 1 (ASME 1995), criteria.

5.3.2 Acceptance Criteria

The drum must remain upright during transportation in order for the liquid to be contained in the vented bottles, and the concrete shielding must not be damaged. In order to assess damage to the concrete, stresses due to transportation must be less than 1/4 of the tensile strength or 1/2 of the compressive strength. Since there are no specified concrete properties, and lightweight concrete is used, (ρ = 118 lb/ft^3), the following assumptions are made: the concrete compressive strength is 2500 psi, and the modulus of rupture is as specified by ACI 1989:

$$f_r = (.75)7.5\sqrt{(f_c')} = 5.6\sqrt{(2500)} = 280\ psi$$

The 0.75 reduction is for lightweight concrete (ACI section 9.5.2.3). Concrete stress is acceptable if it is between +70 psi and -1250 psi.

5.3.3 Structural Model

The concrete is loaded by the tiedown forces using classical methods.

5.4 STRUCTURAL EVALUATION AND CONCLUSIONS

5.4.1 Reduced External Pressure

Reduced external pressure will affect a non-vented drum by effectively increasing the internal pressure. Part E of the calculations in Part B, Section 5.6.1 show that the equivalent pressure due to decrease of external pressure combined with interior temperature rise is 14.7 kPa

(1.3 psi). Using the test report attached as Part B, Section 5.6.2, a UN1A2 steel drum with 0.9 mm walls (0.035 in. 20 gage) and 1.2 mm heads (0.047 in., 18 gage) can be hydrostatically tested to 100 kPa (14.5 psi) and leak tested to 20 kPa (2.9 psi) without leaking. Using the 20 kPa test pressure as an acceptance criteria, there is a of 0.36 against loss of contents due to a combination of external pressure and increased internal temperature due to normal conditions of transportation.

5.4.2 Increased External Pressure

Increased external pressure, combined with a temperature drop in the package, causes a total external pressure of 19.6 kPa (2.84 psi). In Part F of the calculations in Part B, Section 5.6.1, the compression caused by this pressure acting on the drum heads is found to be 512 kg. The test report in Part B, Section 5.6.2 shows that a drum with 0.9 mm walls and 1.2 mm heads can withstand a compressive load of 2,235 kg uniformly distributed over the head without deformation. This shows that the unvented drum can resist the effects of the increased external pressure of normal conditions of transportation with a large margin.

5.4.3 Vibration

Using ANSI N14.23 (ANSI 1992), the package is subjected to a vertical acceleration of 0.2*g*, which will have no discernable affect on the drum or contents. Since this is a one-time, short distance shipment, there are no fatigue concerns. Because the seal bolt is torqued to 40 ft-lb and a jam nut installed, no vibration analysis is needed for this (Cruse 1992; Section 5.6, Appendix, page C-7).

5.4.4 Water Spray

The drum is typically sealed with a gasket; consequently, in-leakage of water due to spray is not a concern.

5.4.5 Inertial Loading

Part D of the calculations in Part B, Section 5.6 show that a concrete-filled drum, loaded by simultaneously applied accelerations of 2.3 and 1.6*g* and supported on a rigid surface, will have a maximum concrete tension of 58 psi and a compressive stress of 35 psi. These stresses are within the limits of +70 psi and -1250 psi. The vertical inertial loads are bounded by the compression case below.

5.4.6 Compression

The drums are certified for compression for a maximum drum weight. Assuming that the drum is procured for 453-kg (1000-lb) maximum loading, the drum alone is adequate for the compression test. If the drum is procured to a lower limit, Part C of the calculations in Part B, Section 5.6 shows that the drum will support 5 times its gross weight without buckling, with a large margin.

5.4.7 Penetration

Part B of the calculations in Part B, Section 5.6 shows that a drum with a 16-gage wall will resist penetration by the specified missile with a margin of over 80, and a 20-gage wall will have a margin of over 40.

5.4.8 Brittle Fracture

The drum steel is sufficiently thin that it is not susceptible to brittle fracture. The liquid-filled bottles are the limiting components for temperature considerations because they cannot be shipped under freezing conditions; if the contents freeze and expand, the bottles will fail.

5.5 REFERENCES

ANSI, 1992, *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, DRAFT, American National Standards Institute, New York, New York.

ASME, 1995, *Boiler and Pressure Vessel Code*, Section VIII, Division 1, American Society of Mechanical Engineers, New York, New York.

Bechtel, 1974, *Topical Report: Design of Structures for Missile Impact*, BC-TOP-9A, Rev. 2, Bechtel Power Corporation, San Francisco, California.

Cruse, J. M., 1992, *Test and Evaluation Document for DOT Specification 7A Type A Packaging*, WHC-EP-0558, Westinghouse Hanford Company, Richland, Washington, June 1992

Roark, R. J., and W. C. Young, 1982, *Formulas for Stress and Strain*, McGraw-Hill Book Company, New York, New York.

5.6 APPENDICES

5.6.1 Concrete-Lined Waste Package Analysis

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Section Chief: S. S. Shiraga	Date 18 Sept 1997

1.0 OBJECTIVE

Evaluate glass and poly bottles in a DOT 7A drum as shipping containers for radioactive liquids.

2.0 REFERENCES

Roark, 1982: Formulas for Stress and Strain, Raymond J. Roark and Warred C. Young, McGraw-Hill, 1982

Bechtel, 1974: Topical Report: Design of Structures for Missile Impact, BC-TOP-9A, revision 2, Bechtel Power Corporation, San Francisco, CA.

3.0 ASSUMPTIONS, RESULTS, AND CONCLUSIONS

This structural evaluation justifies shipping type A quantities of radioactive liquid in this package under the following assumptions:

1. Bottles are glass, polypropylene, or high density polyethelene chosen for chemical compatibility with the liquid contents..

2. Sufficient padding is available to completely fill the pipe cavity and the paint can to prevent the bottle from moving in the cavity under moderate force. There is sufficient absorbant surrounding the bottles to absorb twice the liquid contents.

3. No shipments are permitted during freezing conditions to prevent damage to the filled bottles.

4. The drum remains upright during loading and transportation.

The conclusions of this analysis are:

A. The package will have a maximum weight of 389kg (858 lb) and a cavity volume of 53 l (14 gal).

B. The drum wall will resist penetration due to the test specified in section 5.3.1.7, with adequate margin, even if the resistance of the concrete and padding is neglected.

C. The drums will resist buckling due to being stacked 5-high.

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D. The drums will resist the effects of lateral inertial loading as specified in section 5.3.1.5. The concrete will not crack or crush.

E. A UN1A2 drum with 20 gage cylinder wall and 18 gage heads will resist the effects of increased external pressure and internal temperatue increse, without loss of contents, with a margin of .36. Most drums used for this shipment will have heavier walls, so the actual margin will be higher.

F. Since the drums are filled with foam or concrete, the effects of increased external pressure and internal temperature drop are bounded by the compression loading considered in part C. Thus, there will be no loss of contents due to increased external pressure and drop of interior temperature.

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4.0 EVALUATION

A. Package weight and cavity volume calculation:

Calculate the maximum weight of a loaded drum. Break the total weight into components:

- w_{steel} = weight of internal pipe and plate
- w_{dr} = weight of drum
- w_{co} = total concrete weight = $w_i + w_o$
  - w_i = weight of concrete inside of pipe
  - w_o = weight concrete outside of pipe
- w_L = weight of liquid
- w_{misc} = allowance for liner, cushioning, and absorbant pads

steel components $\rho_s := 490\frac{lbf}{ft^3}$ 12" extra-strong pipe od = 12.75", id = 11.75"

pipe $vol := \pi \cdot \frac{(12.75in)^2 - (11.75in)^2}{4} \cdot 30 \cdot in$ $w_p := \rho_s \cdot vol$ $w_p = 164 \cdot lbf$

2 plates $vol := (15 \cdot in)^2 \cdot .5 \cdot in$ $w_{pl} := \rho_s \cdot vol$ $w_{pl} = 32 \cdot lbf$

$w_{steel} := w_p + w_{pl}$ $w_{steel} = 196 \cdot lbf$

16 ga drum assume 16 ga (.0598"), 37.5" outside height, 22.5 OD

$t := .0598 in$ $h_{out} := 37.5 in$ $d := 22.5 in$

$$vol := \left[t \cdot d \cdot \pi \cdot h_{out} + 2 \cdot \pi \cdot \left(\frac{d}{2}\right)^2 \cdot t \right] \quad w_{dr} := \rho_s \cdot vol \quad w_{dr} = 58 \cdot lbf$$

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concrete $\rho_c := 118 \frac{lbf}{ft^3}$

inside of pipe $h := 5 \cdot in$ $d := 11.75 in$ $vol := \frac{\pi \cdot d^2}{4} \cdot h$

$w_{ci} := \rho_c \cdot vol$ $w_{ci} = 37 \cdot lbf$

outside of pipe $h := 33.25 in - 5 \cdot in$ $d_1 := 12.75 in$ $d_2 := 22.25 in$

$vol := \frac{\pi \cdot \left(d_2^{\,2} - d_1^{\,2}\right)}{4} \cdot h$ $w_{co} := \rho_c \cdot vol$ $w_{co} = 504 \cdot lbf$

$w_c := w_{co} + w_{ci}$ $w_c = 541 \cdot lbf$

6 liters of liquid, sp.g = 1.0: $w_L := 6 \cdot kgf$ $w_L = 13 \cdot lbf$

Liner and padding estimate: $w_{misc} := 50 \cdot lbf$

$Wt := w_{steel} + w_{dr} + w_c + w_{misc} + w_L$ $Wt = 858 \cdot lbf$ $Wt = 389 \cdot kgf$

Cavity Volume: $Vol := 30 \cdot in \cdot \pi \cdot \left(\frac{11.75 in}{2}\right)^2$

$Vol = 53.3 \cdot liter$ $Vol = 14.1 \cdot gal$

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. Penetration:

The package is protected against penetration by various thicknesses of steel sheet, steel plate, and concrete in various parts of the package. First, check the resistance of the steel drum material alone to determine its resistance. If a 16 gage sheet of mild steel will resist penetration, then there is no need to further consider the concrete or 1/2 in thick steel plate: these will simply increase the margin. Using Bechtel, 1974 as a guide:

For use in equation 2-7, use the following parameters for the dimensionless formulation

$$T(M, V_s, D) := \frac{\left(\frac{M \cdot V_s^2}{2}\right)^{\frac{2}{3}}}{672 D}$$

M = mass, lbf*sec²/ft

D = missile diameter, inches

V = velocity, ft/sec

$\text{mass} := 6 \cdot \text{kg}$ $\quad M := \frac{\text{mass}}{g}$ $\quad M = 0.411 \cdot \text{lb} \cdot \text{ft}^{-1} \cdot \text{sec}^2$

$h := 1 \cdot \text{m}$ drop height $\quad V := \sqrt{2 \cdot g \cdot h}$ $\quad V = 14.53 \, \text{ft} \cdot \text{sec}^{-1}$

$D := 3.2 \, \text{cm}$ $\quad D = 1.26 \cdot \text{in}$

$T(.411, 14.53, 1.26) = 0.0146$

The report states that 1.25 T is the recommended thickness to prevent penetration. For 16 gage drums, the margin against penetration is:

$\text{margin} := \frac{.0598}{1.25 .0146} - 1$ $\quad \text{margin} = 2.277$

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C. Compression:

Drums purchased to meet UN1A2 requirements are usually certified for stacking 5 high for a gross weight of less than 1000 lb. In this case, the central 12" heavy-walled pipe will support a large weight in the event that uncertified drums are used or if the drum is overweight. Since the pipe is a short column, prevented from buckling by its short length and continuous support from the fill material, compare the column yield load to the force applied by 5 times the package weight.

Assuming 20 gage drum thickness, calculate the buckling strength of the drum and compare it to the calculated compression stress:

$A_{drum} := \pi \cdot 22.5 \cdot in \cdot .0359 in$ $\quad \sigma := \frac{5 \cdot 1000 \cdot lbf}{A_{drum}}$ $\quad \sigma = 1970 \cdot psi$

Use Roark and Young for buckling strength:

$r := \frac{22.5 \cdot in}{2}$ $\quad t := .0359 in$ $\quad E := 30 \cdot 10^6 \cdot psi$

$1.72 \cdot \sqrt{r \cdot t} = 1.093 \cdot in$ Length is 37" > 1.093" so table 35, case 15 is appropriate:

$\sigma_{cr} := .3 \cdot E \cdot \frac{t}{r}$ $\quad \sigma_{cr} = 28720 \cdot psi$

Margin against buckling of the drum: $\frac{\sigma_{cr}}{\sigma} - 1 = 14$

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D: Inertial loading.

The drum reaction to a 3.5g vertical acceleration is bounded by the compression load (case C, above).

For resistance to lateral loading, the load cases are either 2.3g longitudinal acceleration or 1.6g laterally. Combine these for a total acceleration and determine whether the concrete lining can resist the forces without cracking. If the concrete loads are acceptable, neither the shielding nore the drum walls will be affected.

$a := \sqrt{1.6^2 + 2.3^2} \qquad a = 2.802$

Use Roark table 17,case 13: ring supported at bottom, loaded by its own weight

$r_o := \frac{23.5\cdot in}{2} \qquad r_i := \frac{12.75\cdot in}{2} \qquad h := 30\cdot in$ height of concrete

$d := (r_o - r_i) \qquad c := \frac{d}{2} \qquad R := r_i + c \qquad d = 5.375\cdot in \qquad R = 9.063\cdot in$

$w := \frac{a\cdot 1000\,lbf}{2\cdot\pi\cdot R} \qquad w = 49.205\cdot\frac{lbf}{in}$ loading on 30" high concrete

Geometric properties of the ring

$A := d\cdot h \qquad I := \frac{d^3\cdot h}{12} \qquad A = 161.25\cdot in^2 \qquad I = 388.218\cdot in^4$

Concrete properties

$w_c := 118 \qquad f_c := 2000 \qquad E := w_c^{1.5}\cdot 33\cdot\sqrt{2000} \qquad v := .17$

$G := \frac{E}{2\cdot(1+v)} \qquad F := \frac{6}{5}$ Shear correction for rectangular beam

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Constants for forces in a ring

$$\alpha := \frac{I}{A \cdot R^2} \qquad \beta := \frac{F \cdot E \cdot I}{G A \cdot R^2} \qquad k_1 := 1 + \alpha + \beta \qquad k_2 := 1 - \alpha + \beta \qquad k_4 := \frac{k_2}{k_1}$$

$$\alpha = 0.029 \qquad \beta = 0.082 \qquad k_1 = 1.112 \qquad k_2 = 1.053 \qquad k_4 = 0.947$$

Maximum + moment, at bottom of ring.

$$M_C := w \cdot R^2 \cdot \left(2 - \frac{k_4}{2}\right) \qquad M_C = 6168 \cdot \mathrm{lbf \cdot in}$$

$$\sigma := M_C \cdot \frac{c}{I} \qquad \sigma = 43 \cdot \mathrm{psi}$$

This is the basic straight-beam stress, and must be corrected for curatuve. + stress in on the inside.

$$R_c := \frac{R}{c} \qquad \mathrm{const} := \frac{R_c + 1}{R_c - 1} \qquad h_c := R_c - \frac{2}{\ln(\mathrm{const})}$$

$$h := c \cdot h_c \qquad h = 0.272 \cdot \mathrm{in}$$

h = Distance from centroid to neutral axis, toward center of curvature.

$$k_i := \frac{1}{3 \cdot h_c} \cdot \frac{1 - h_c}{R_c - 1} \qquad k_i = 1.247$$

stress multiplier for inside of ring

$$k_o := \frac{1}{3 \cdot h_c} \cdot \frac{1 + h_c}{R_c + 1} \qquad k_o = 0.829$$

stress multiplier for outside of ring

$$\sigma_i := k_i \cdot \sigma \qquad \sigma_i = 53 \cdot \mathrm{psi} \qquad \sigma_o := -k_o \cdot \sigma \qquad \sigma_o = -35 \cdot \mathrm{psi}$$

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Find the stress at point of maximum -M. Moment at any section, measure by angle from top:

$T_A := \frac{w \cdot R}{2} \cdot k_4$ $\quad M_A := \frac{w \cdot R^2}{2} \cdot k_4$ force and moment at top of ring

$T_A = 211.2 \cdot lbf$ $\quad M_A = 1914 \cdot in \cdot lbf$

$z(x) := \sin(x)$ $\quad u(x) := \cos(x)$ define some auxillary functions

$LT_M(x) := -w \cdot R^2 \cdot (x \cdot z(x) + u(x) - 1)$

$M(x) := M_A - T_A \cdot R \cdot (1 - u(x)) + LT_M(x)$

check it out: $M(0) = 1914 \cdot in \cdot lbf$ compare with M_A

$M(180 \cdot deg) = 6168 \cdot in \cdot lbf$ compare with M_C

find the local minimum

$\max(x) := \frac{x}{\tan(x)} + \frac{k_4}{2}$ max = 0 for point of minimum

guess: $x := 90 \cdot deg$

$\phi := root(\max(x), x)$ $\quad \phi = 105 \cdot deg$ $\quad M(\phi) = -2562 \cdot in \cdot lbf$

$\sigma := M(\phi) \cdot \frac{c}{I}$ $\quad \sigma = -18 \cdot psi$ straight beam stress at point of max - moment

$\sigma_i := k_i \cdot \sigma$ $\quad \sigma_i = -22 \cdot psi$

$\sigma_o := -k_o \cdot \sigma$ $\quad \sigma_o = 15 \cdot psi$

Section 7.4.5 shows that the acceptable range of stress in the concrete grout is -1250 psi to +70, so there is a margin of 3.7 against cracking and a much larger margin against crushing due to the inertial forces.

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E: Reduced external pressure.

In the event that the drum and contents are not vented, the drum must resist the combined effects of reduced external pressure and internal temperature rise.

$kPa := 1000 Pa$ $p_a := 101.35 kPa$ normal atmospheric pressure

$p_0 := 95.22 kPa$ reduced external pressure:

For increased internal pressure due to temperature rise, assume the contents are loaded at T_0 and rise to T_1.

$T_0 := (70 \cdot R + 460 \cdot R)$ $T_1 := (115 \cdot R + 460 \cdot R)$

$p_1 := p_a \cdot \frac{T_1}{T_0}$ $\Delta p := (p_a - p_0) + (p_1 - p_a)$ $\Delta p = 2.137 \cdot psi$

$\Delta p = 14.735 \cdot kPa$

Margin to 20 kPa leak test pressure: $\frac{20 \cdot kPa}{\Delta p} - 1 = 0.36$

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F. Increased external pressure.

In the event that the drum and contents are not vented, the drum must resist the combined effects of increased external pressure and internal temperature drop.

$p_a := 101.35\text{kPa}$ normal atmospheric pressure, absolute pressure inside of drum $p_a = 14.7\cdot\text{psi}$

absolute external pressure drops to: $p_0 := 14.85\text{psi}$ $p_0 - p_a = 0.15\cdot\text{psi}$

increased internal pressure due to temperature rise: assume the contents are loaded at T_0 and drop to T_1.

$$T_0 := (70\cdot R + 460R) \qquad T_1 := (-27\cdot R + 460R)$$

$$p_1 := p_a\cdot\frac{T_1}{T_0} \qquad \Delta p := (p_0 - p_a) + (p_a - p_1) \qquad \Delta p = 2.84\cdot\text{psi}$$

$$\Delta p = 19.584\cdot\text{kPa}$$

total compression force resisted by cylinder walls: $P := \pi\cdot\Delta p\cdot r^2$ $P = 512\cdot\text{kgf}$

UN1A2 drums with 20 ga side walls and 18 ga heads can be loaded with 2235 Kg during stacking tests without deformation, indicating that there will be no loss of contents caused by the increased external pressure and temperature drop in normal conditions of transportation.

5.6.2 UN1A2 Test Summary

08/18/97 07:54 ☎ 002

Myers Container Corporation
UN Testing Laboratory
Myers Container Corporation
900 Brookside Drive
San Pablo, CA 94806

UN Test Summary

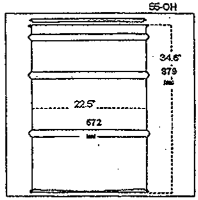
Non-Bulk Steel Packagings

As required by 49 CFR 178

Test Date	Test Type	UNUM#	Design Number
12/13/96	Design Qualification	00435	5558

Style	1A2
Condition	NEW
Capacity	208 liters 55 gal
Overflow	226 liters 59.6 gal
Tare	18.6 kg 41 lbs
Height	879 mm 34.6" in
Diameter	572 mm 22.5" in
Steel-Head	1.2 mm
Steel-Body	0.900 mm
Steel-Bottom	1.2 mm
Special Construction	Cargile Curl, DOT 7-A compliant with 4 mil bag, UNUM 390

End Seam	TRIPLE
Side Seam	WELDED
Swedges	3
Head Fittings	2" X 3/4"
Body Fittings	
Fitting Gasket	Poly
Covers	2 Re-enforce Ring
Gasket	EPDM
Gasket Diameter	7/16"
Ring Gage	12 GA
Closure Ring	V-BACK
Bolt Size	5/8"



*Dimension tolerance + - .375"

Drop Test-Liquid (§178.603)

Six samples are filled to >= 98% capacity with water. Each sample is dropped from the indicated height onto a solid surface using various attitudes. Drums are vented after each drop. Weakest Part: Tight-heads, second drop is flat on side seam. Open-heads second drop diagonal on head.

1.5 Meters

Sample	Attitude	Result
1	Chime Diagonal	No Leak
2	Chime Diagonal	No Leak
3	Chime Diagonal	No Leak
4	Weakest Part *	No Leak
5	Weakest Part *	No Leak
6	Weakest Part *	No Leak

eakproofness-Liquid (§178.604)

Three samples, with all closures in place, are subjected to the following internal pressure and restrained under water for a minimum of five minutes.

20 kPa

Sample	Result
1	No Leak
2	No Leak
3	No Leak

Hydrostatic Pressure Test - Liquid (§178.605)

Three samples are filled to >= 98% capacity with water and subjected to the following internal hydraulic pressure for five minutes.

100 kPa

Sample	Result
1	No Leak
2	No Leak
3	No Leak

Stacking Test - Liquid (§178.606)

Three samples are filled to >= 98% capacity with water and subjected to a force applied to the top surface of the drum for 24 hours equal to the total weight of identical packages which might be stacked on it during transport. Minimum stack height is 3 m.

2235 Kilograms

Sample	Result
1	No Deformation
2	No Deformation
3	No Deformation

Drop Test - Solid (§178.603)

Six samples are filled to 95% capacity with a small grain lading. Each sample is dropped from the indicated height onto a solid surface using various attitudes.

Packing Group I 1.8 Meters			Packing Group II 1.2 Meters			Packing Group III .8 Meters		
240 Net Mass - Kilograms			415 Net Mass - Kilograms			415 Net Mass - Kilograms		
Sample	Attitude	Result	Sample	Attitude	Result	Sample	Attitude	Result
1	Chime Diagonal	No Leak	1	Chime Diagonal	No Leak	1	Chime Diagonal	No Leak
2	Chime Diagonal	No Leak	2	Chime Diagonal	No Leak	2	Chime Diagonal	No Leak
3	Chime Diagonal	No Leak	3	Chime Diagonal	No Leak	3	Chime Diagonal	No Leak
4	Closure Diagonal	No Leak	4	Closure Diagonal	No Leak	4	Closure Diagonal	No Leak
5	Closure Diagonal	No Leak	5	Closure Diagonal	No Leak	5	Closure Diagonal	No Leak
6	Closure Diagonal	No Leak	6	Closure Diagonal	No Leak	6	Closure Diagonal	No Leak

Stacking Test - Solid (§178.606)

Three samples are filled to 95% capacity with a small grain lading and subjected to a force applied to the top surface of the drum for 24 hours equal to the total weight of identical packages which might be stacked on it during transport. Minimum stack height is 3 m.

2235 Kilograms

Sample	Result
1	No Deformation
2	No Deformation
3	No Deformation

Liquid Rating	Solid Rating
-	UN 1A2/X240/S
UN 1A2/Y1.5/100	UN 1A2/Y415/S
UN 1A2/Z2.2/100	UN 1A2/Z415/S

Assembly Instructions

Recommended Fitting Torque (ft-lbs)

Plug Size	Tri-Sure Steel Plug Rubber Gasket	Tri-Sure Steel Plug Poly Gasket	Tri-Sure Poly Plug	Rieke Steel Plug Rubber Gasket	Rieke Steel Plug Poly Gasket	Rieke Poly Plug
2"	20	30	12	30	40	20
3/4"	12	20	6	15	20	9

Recommended Open Head Assembly:
* Gaskets must be seated in drum cover for proper performance.
* Bolt ring must be tightened to 60 ft. lb. and lock nut tightened. The two ends of the ring should not touch, 1/4" gap is ideal.

Cap Seals: Cap seals must be installed by filler when non-threaded fittings are used.

Test Type	Date	UN Testing Lab Coordinator
DESIGN QUALIFICATION	12/13/96	Craig Spittler
PERIODIC RETEST		
PERIODIC RETEST		
PERIODIC RETEST		

Document # UFO/U/003	Issue Date: 6/25/94	Revision # 6	Authority: Craig Spittler	Page 1 of 1

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6.0 THERMAL EVALUATION

6.1 INTRODUCTION

The CLWP is a Pacific Northwest package for shipping Type A, non-TRU, fissile excepted quantities of liquids, and mixed waste to the CWC. The package may also transport gas generating materials. This section of the document defines and evaluates the normal transport condition thermal requirements for inter-area transport of this package. Thermal performance of the package is evaluated only for normal conditions of transport (NTC), accident conditions are evaluated in the risk and dose consequence section of this document.

6.2 THERMAL EVALUATION OF PACKAGE

6.2.1 Package Description

The CLWP consists of a galvanized 55-gallon drum lined with a 90 to 110 mil high-density polyethylene liner with a slip closure lid. A ½ in. thick square steel plate is tack welded to the bottom of a 12 in. schedule 40 steel pipe and placed in the liner. Concrete or foam filler, depending upon shielding needs, are poured between the pipe and liner. Also a layer of concrete or foam is placed on the bottom, inside the pipe for additional shielding when necessary. Up to three, 5 qt cans containing bottles of liquid are inside the pipe. Polypropylene absorbent pads are placed around and on top of the cans to provide absorbent and keep the load from shifting. A ½ in. thick steel plate is placed on the top of the pipe. The tabs are welded to the bottom of the plate to prevent sliding. An anti-corrosive rad pad is placed on top of the liner.

6.3 NORMAL TRANSPORT CONDITIONS THERMAL EVALUATION

6.3.1 Conditions to be Evaluated

Thermal performance of the package is assessed for Hanford Site normal transport conditions in this section. The package is evaluated for the worst case Hanford Site thermal loading condition of still air ambient temperature of 46 °C (115 °F) (Fadeff 1992) with decay heat sources with and without solar insolation.

6.3.2 Acceptance Criteria

The criterion for acceptable performance of the package is the accessible surface of the package in still air at 46 °C (115 °F) and in the shade is not to exceed 85 °C (185 °F). This is based on this package being transported as an exclusive use shipment.

6.3.3 Thermal Evaluation and Conclusions

Based on the low thermal output from the source of 0.03 W, the temperature at the exterior surface of the package will remain at ambient conditions and will not exceed the 85 °C (185 °F) requirement. Also based on this low heat load, the temperature inside the bottles will remain under the boiling point of water during transport.

6.4 REFERENCE

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

7.0 PRESSURE AND GAS GENERATION EVALUATION

7.1 INTRODUCTION

The wide range of materials authorized for transport in the CLWP will have different rates of gas generation depending on the chemical and radiological properties. The particular properties that will have an effect on the gas generation rate are the radioisotope concentration, the total quantity of material, and the chemical composition of the material. The concentration of hydrogen and other flammable gases inside the packaging during shipping depends on this gas generation rate, the rate at which the gas diffuses out of the system, the length of time which the package has been assembled, and available void space in the system. The criteria for a safe shipment are less than 2.5% by volume of hydrogen gas in the system and no excess build-up of pressure in the system. Because the first criterion is so restrictive, the over pressurization of the package is not a concern.

The user of the CLWP is required to perform a thorough hydrogen gas generation assessment prior to shipment. This assessment will address the gas generating characteristics of the waste venting and diffusion rates, packaging configuration (waste volume, void volume, etc.), and the chemical properties of the waste materials that may effect hydrogen gas generation. The gas generation evaluation must show that the safety criteria are met.

7.2 SUMMARY OF RESULTS

As described in Part A, Section 3.0, the authorized package contents encompass a vast array of chemical and radioactive constituents, so it is not feasible to develop a bounding case for the flammable gas concentration. Consequently, it is the responsibility of the shipper to ensure that the rate of gas generation does not exceed the rate of diffusion. In cases where gas generation is negligible, the use of a sealed system (i.e., one without vent holes) is authorized.

The attached Engineering Safety Evaluation gives the results for the five packages already assembled. Gas generation calculations were performed to verify that the hydrogen concentration is maintained below 2.5% by volume within the bottles containing the radioactive liquid payload. Of the ten bottles evaluated, the shortest time that it would take for the hydrogen gas concentration to reach 2.5% by volume is 593 days.

7.3 PACKAGE PRESSURE

The results of the gas generation calculations for the 5 packages already assembled show that the potential pressure increases are negligible.

7.4 APPENDIX: GAS GENERATION MODEL, CALCULATIONS, AND DATA

ENGINEERING SAFETY EVALUATION

Subject Hydrogen Gas Generation Concrete Lined Waste Packaging Page 1 of 9
Originator J. E. Mercado Date 8/26/97
Checker J. R. Green Date 9/15/97

I. Objectives:

Radioactively contaminated water will be shipped from the 300 Area in five Concrete Lined Waste Packagings for storage in the 200 Area. An evaluation of gas generation is necessary to ensure transportation safety. The purpose of this analysis is to quantify the amount of hydrogen in the bottles. A shipping window of half of the estimated time to reach 5% hydrogen by volume will be used to ensure safe transport of the material. Pressure increases due to hydrogen generation will also be calculated.

II. References:

Green, J. R., K. Hillesland, V. E. Roetman, and J. G. Field, 1995, *Radcalc for Windows*, Version 1.0, Westinghouse Hanford Company, Richland, Washington.

NRC, 1984, *Clarification of Conditions for Waste Shipments Subject to Hydrogen Gas Generation*, IN 84-72, Nuclear Regulatory Commission, Washington, D.C.

III. Results and Conclusions:

This section summarizes the results calculated using the methods described in Section IV of this report. Based on the time required for transport and the estimated contents of the boxes, neither pressure buildup nor flammable gases pose a concern for this operation. Radcalc for Windows was used to determine that it would take at least 593 days for any of the bottles to reach 2.5% hydrogen. The pressure increase due to hydrogen generation would be less than 1 psi over this time period.

ENGINEERING SAFETY EVALUATION

Subject Hydrogen Gas Generation Concrete Lined Waste Packaging Page 2 of 9
Originator J. E. Mercado J.E. Mercado Date 8/26/97
Checker J. R. Green J.R. Green Date 9/15/97

IV. **Engineering Evaluation:**

For performing the hydrogen gas generation calculations, the volume of each bottle was assumed to be 2 liters.

The model for the 30 gallon drum is included in RadCalc for Windows and is used in the determination of gamma absorption fractions for the bottles. For more information on these models see Volume II, *Technical Manual*, of the RadCalc for Windows computer code (Green et al. 1995).

Radcalc for Windows was used to determine the gas generation rates for each bottle. The input data used was as follows:

Interior volume:	2000 cc
Waste Volume:	varies by bottle (data provided below, assume density is 1 g/cc)
Void Volume:	varies by bottle
Activity:	Data provided below
Package Type:	2 liter bottle (modeled as a 30 gallon drum)
G values:	water with a pH of 13
Decay time:	30 days

The output determined is the time until 2.5% hydrogen concentration is reached.

9/5/97 8:42:10 AM

Item #		DESCRIPTION	Drum #	WASTE CODES EPA		WDOE
2543 97-R156	Kriston Brooks SPD-C106-102 5476	WATER 89.6%, SODIUM HYDROXIDE 7.27%, SODIUM OXALATE 1.84%, SODIUM ALUMINATE .51%, SODIUM SILICATE .09%, SODIUM SULFATE .09%, SODIUM BORATE .08%, SODIUM NITRATE .09%, SODIUM NITRITE .43%, Tank Waste 3% CS-137 0.0407 ci, SR-90 0.00026 ci, PU-239 9.51e-7 ci, AM-241 4.57e-6 ci, TC-99 5.24e-6 ci	PNL-324-97-039 Kgs of Waste 1.50 POLY 2 L Dose Rate	D002 F001 F002 F004 F005 D004 D005 D006 D007 D008	D009 D010 D018 D030 D033 D043	F003
2551 97-R156	Kriston Brooks SPD-C107-999 5476	WATER 74.6%, SODIUM NITRITE 3.72%, SODIUM HYDROXIDE 1.86%, ALUMINUM HYDROXIDE 5.35%, IRON OXIDE 3.73%, BISMUTH NITRATE 3.41%, SILICA 2.09%, SODIUM CARBONATE 1.98%, CALCIUM HYDROXIDE .51%, SODIUM PHOSPHATE 1.44%, POTASSIUM NITRATE .42%, NICKEL NITRATE .37%, LEAD NITRATE .29%, MANGANESE OXIDE .2% Tank Waste 20% CS-137 0.002000000ci, SR-90 0.130000000ci, TC-99 0.000045600ci,	PNL-324-97-039 Kgs of Waste 0.12 POLY 2 L Dose Rate	D002 F001 F002 F004 F005 D004 D005 D006 D007 D008	D009 D010 D011 D018 D019 D027 D028 D029 D030 D033	F003
2544 97-R156	Kriston Brooks SPD-C106-103 5476	WATER 89.6%, SODIUM HYDROXIDE 7.27%, SODIUM OXALATE 1.84%, SODIUM ALUMINATE .51%, SODIUM SILICATE .09%, SODIUM SULFATE .09%, SODIUM BORATE .08%, SODIUM NITRATE .09%, SODIUM NITRITE .43%, Tank Waste 3% CS-137 0.0407 ci, SR-90 0.00026 ci, PU-239 9.51e-7 ci, AM-241 4.57e-6 ci, TC-99 5.24e-6 ci	PNL-324-97-040 Kgs of Waste 1.50 POLY 2 L Dose Rate	D002 F001 F002 F004 F005 D004 D005 D006 D007 D008	D009 D010 D018 D030 D033 D043	F003
2545 97-R156	Kriston Brooks SPD-C106-104 5476	WATER 89.6%, SODIUM HYDROXIDE 7.27%, SODIUM OXALATE 1.84%, SODIUM ALUMINATE .51%, SODIUM SILICATE .09%, SODIUM SULFATE .09%, SODIUM BORATE .08%, SODIUM NITRATE .09%, SODIUM NITRITE .43%, Tank Waste 3% CS-137 0.0407 ci, SR-90 0.00026 ci, PU-239 9.51e-7 ci, AM-241 4.57e-6 ci, TC-99 5.24e-6 ci	PNL-324-97-040 Kgs of Waste 1.50 POLY 2 L Dose Rate	D002 F001 F002 F004 F005 D004 D005 D006 D007 D008	D009 D010 D018 D030 D033 D043	F003
2546 97-R156	Kriston Brooks SPD-C106-105 5476	WATER 89.6%, SODIUM HYDROXIDE 7.27%, SODIUM OXALATE 1.84%, SODIUM ALUMINATE .51%, SODIUM SILICATE .09%, SODIUM SULFATE .09%, SODIUM BORATE .08%, SODIUM NITRATE .09%, SODIUM NITRITE .43%, Tank Waste 3% CS-137 0.0407 ci, SR-90 0.000²6 ci, PU-239 9.51e-7 ci, AM-241 4.57e-6 ci, TC-99 5.24e-6 ci	PNL-324-97-041 Kgs of Waste 1.50 POLY 2 L Dose Rate	D002 F001 F002 F004 F005 D004 D005 D006 D007 D008	D009 D010 D018 D030 D033 D043	F003
2547 97-R156	Kriston Brooks SPD-C106-106 5476	WATER 89.6%, SODIUM HYDROXIDE 7.27%, SODIUM OXALATE 1.84%, SODIUM ALUMINATE .51%, SODIUM SILICATE .09%, SODIUM SULFATE .09%, SODIUM BORATE .08%, SODIUM NITRATE .09%, SODIUM NITRITE .43%, Tank Waste 3% CS-137 0.0407 ci, SR-90 0.00026 ci, PU-239 9.51e-7 ci, AM-241 4.57e-6 ci, TC-99 5.24e-6 ci	PNL-324-97-041 Kgs of Waste 1.50 POLY 2 L Dose Rate	D002 F001 F002 F004 F005 D004 D005 D006 D007 D008	D009 D010 D018 D030 D033 D043	F003
2550 97-R156	Kriston Brooks SPD-C107-998 5476	WATER 93.78%, SODIUM HYDROXIDE 3.34%, SODIUM ALUMINATE 1.83%, POTASSIUM NITRATE .19%, SODIUM NITRITE .18%, SODIUM PHOSPHATE .21%, SODIUM SILICATE .46%, LEAD NITRATE .01% Tank Waste 3% CS-137 0.002300000ci, SR-90 0.000500000ci, TC-99 1.900000000e-06ci,	PNL-324-97-042 Kgs of Waste 0.50 POLY 2 L Dose Rate	D002 F001 F002 F004 F005 D004 D005 D006 D007 D008	D009 D010 D030 D033 D043 D018	F003
2554 97-R156	Kriston Brooks SPD-C106-109 5476	WATER 89.6%, SODIUM HYDROXIDE 7.27%, SODIUM OXALATE 1.84%, SODIUM ALUMINATE .51%, SODIUM SILICATE .09%, SODIUM SULFATE .09%, SODIUM BORATE .08%, SODIUM NITRATE .09%, SODIUM NITRITE .43%, Tank Waste 3% CS-137 0.0407 ci, SR-90 0.00026 ci, PU-239 9.51e-7 ci, AM-241 4.57e-6 ci, TC-99 5.24e-6 ci	PNL-324-97-042 Kgs of Waste 1.50 POLY 2 L Dose Rate	D002 F001 F002 F004 F005 D004 D005 D006 D007 D008	D009 D010 D018 D030 D033 D043	F003
2548 97-R156	Kriston Brooks SPD-C106-107 5476	WATER 89.6%, SODIUM HYDROXIDE 7.27%, SODIUM OXALATE 1.84%, SODIUM ALUMINATE .51%, SODIUM SILICATE .09%, SODIUM SULFATE .09%, SODIUM BORATE .08%, SODIUM NITRATE .09%, SODIUM NITRITE .43%, Tank Waste 3% CS-137 0.0407 ci, SR-90 0.00026 ci, PU-239 9.51e-7 ci, AM-241 4.57e-6 ci, TC-99 5.24e-6 ci	PNL-324-97-043 Kgs of Waste 1.50 POLY 2 L Dose Rate	D002 F001 F002 F004 F005 D004 D005 D006 D007 D008	D009 D010 D018 D030 D033 D043	F003
2549 97-R156	Kriston Brooks SPD-C106-108 5476	WATER 89.6%, SODIUM HYDROXIDE 7.27%, SODIUM OXALATE 1.84%, SODIUM ALUMINATE .51%, SODIUM SILICATE .09%, SODIUM SULFATE .09%, SODIUM BORATE .08%, SODIUM NITRATE .09%, SODIUM NITRITE .43%, Tank Waste 3% CS-137 0.0407 ci, SR-90 0.00026 ci, PU-239 9.51e-7 ci, AM-241 4.57e-6 ci, TC-99 5.24e-6 ci	PNL-324-97-043 Kgs of Waste 1.50 POLY 2 L Dose Rate	D002 F001 F002 F004 F005 D004 D005 D006 D007 D008	D009 D010 D018 D030 D033 D043	F003

```
Radcalc for Windows 1.0                                  Date:  08-06-97 09:46
                                                         Performed By: [signature]
                                                         Checked By: [signature]
File:  PNL7.RAD
========== Input Information ==================================

Source from input:
        Radionuclide:   Curies:
        Sr-90           2.60e-004
        Tc-99           5.24e-006
        Cs-137          4.07e-002
        Pu-239          9.51e-007
        Am-241          4.57e-006

Waste Form:      Normal
Physical Form:   Liquid
Container Type: 30 Gallon Drum

Package Void Volume:      500. cc
Waste Volume:             1.50e+003 cc
Waste Mass:               1.50e+003 g
Waste Void Volume:        0.000 cc

Days to decay source before seal time:  30.00 days
Calculate number of days sealed until 2.50% hydrogen is reached.

G Value Material Selection:
   Contribution    Weight      G-Alpha       G-Beta      G-Gamma   Name
   100.00%         1             2.8*          0.43          0.7   Water (liquid) pH = 13
( * indicates the value was calculated from a given value)

G Values calculated from list averaging:
   G Alpha       G Beta          G Gamma
   2.8           0.43            0.7

Comments:
In already assembled drums:

2543
2544
2545
2546
2547
2548
2549
2554

========== Calculated Results ================================

The sealed container will generate 2.47 % hydrogen in 821.96 days
H2 Volume:                     12.6 cc
H2 Generation Rate:            0.000641 cc/hour

Heat Generated:                0.000198 Watts
Partial Pressure (H2):         2.56 kPa
Total Pressure (H2 and Air):   104. kPa

Radioactive:                   Yes
Type Determination:            A  (from unity fraction 0.0057579)
Limited Quantity:              No
LSA Determination:             Yes  (from LSA unity fraction 0.16169)
HRC Quantity Determination:    No
Fissile Quantity:              1.5328e-005 g
15g Fissile Radionuclides or Less:  Yes
(Fissile Excepted per 49CFR173.453(a))
Note:  Transportation classifications assume three significant figures.

Bulk Density:                  1.00 g/cc

Source decayed to start of seal time:
        Radionuclide:   Curies:
        Sr-90           2.59e-004
        Y-90            2.59e-004
        Tc-99           5.24e-006
        Cs-137          4.06e-002
        Ba-137m         3.84e-002
```

Pu-239	9.51e-007
U-235	7.69e-017
Am-241	4.57e-006
Np-237	1.22e-013
Pa-233	3.68e-014
U-233	4.67e-021

Source decayed to end of seal time:

Radionuclide:	Curies:
Sr-90	2.46e-004
Y-90	2.46e-004
Tc-99	5.24e-006
Cs-137	3.86e-002
Ba-137m	3.65e-002
Pu-239	9.51e-007
U-235	2.18e-015
Am-241	4.55e-006
Np-237	3.45e-012
Pa-233	3.29e-012
U-233	1.60e-017

Radcalc for Windows 1.0

Date: 08-06-97 09:48

Performed By: [signature]

Checked By: [signature]

File: PNL8.RAD

========== Input Information ==================================

Source from input:

Radionuclide:	Curies:
Sr-90	5.00e-004
Cs-137	2.30e-003
Pu-239	7.28e-007
Am-241	1.17e-006

Waste Form: Normal
Physical Form: Liquid
Container Type: 30 Gallon Drum

Package Void Volume: 1.50e+003 cc
Waste Volume: 500. cc
Waste Mass: 500. g
Waste Void Volume: 0.000 cc

Days to decay source before seal time: 30.00 days
Calculate number of days sealed until 2.50% hydrogen is reached.

G Value Material Selection:

Contribution	Weight	G-Alpha	G-Beta	G-Gamma	Name
100.00%	1	2.8*	0.43	0.7	Water (liquid) pH = 13

(* indicates the value was calculated from a given value)

G Values calculated from list averaging:

G Alpha	G Beta	G Gamma
2.8	0.43	0.7

Comments:
Drum already assembled. 2550

========== Calculated Results ==================================

The hydrogen concentration of 2.50 % was not calculated in 36500.00 days.
The hydrogen concentration of 1.19 % is calculated at 36500.00 days.
H2 Volume: 18.1 cc
H2 Generation Rate: 2.06e-005 cc/hour

Heat Generated: 1.45e-005 Watts
Partial Pressure (H2): 1.22 kPa
Total Pressure (H2 and Air): 103. kPa

Radioactive: Yes
Type Determination: A (from unity fraction 0.0019874)
Limited Quantity: No
LSA Determination: Yes (from LSA unity fraction 0.25287)
HRC Quantity Determination: No
Fissile Quantity: 1.1734e-005 g
15g Fissile Radionuclides or Less: Yes
(Fissile Excepted per 49CFR173.453(a))
Note: Transportation classifications assume three significant figures.

Bulk Density: 1.00 g/cc

Source decayed to start of seal time:

Radionuclide:	Curies:
Sr-90	4.99e-004
Y-90	4.99e-004
Cs-137	2.30e-003
Ba-137m	2.17e-003
Pu-239	7.28e-007
U-235	5.89e-017
Am-241	1.17e-006
Np-237	3.11e-014

Source decayed to end of seal time:

Radionuclide:	Curies:
Sr-90	4.63e-005
Y-90	4.63e-005
Cs-137	2.28e-004

Ba-137m	2.16e-004
Pu-239	7.26e-007
U-235	7.16e-014
Th-231	7.16e-014
Pa-231	7.57e-017
Ac-227	4.24e-017
Th-227	4.17e-017
Ra-223	4.17e-017
Po-215	4.17e-017
Pb-211	4.17e-017
Bi-211	4.17e-017
Tl-207	4.16e-017
Am-241	9.97e-007
Np-237	3.50e-011
Pa-233	3.50e-011
U-233	7.85e-015
Th-229	2.49e-017
Ra-225	2.48e-017
Ac-225	2.48e-017
Fr-221	2.48e-017
At-217	2.48e-017
Bi-213	2.48e-017
Po-213	2.43e-017
Pb-209	2.43e-017

Radcalc for Windows 1.0

Date: 08-06-97 09:51

Performed By: J.E. Hurd

Checked By: J.G. McFadden

File: PNL9.RAD

========== Input Information ==================================

Source from input:

Radionuclide:	Curies:
Sr-90	1.30e-001
Cs-137	2.00e-003
Pu-239	1.75e-005
Am-241	2.81e-005

Waste Form: Normal
Physical Form: Liquid
Container Type: 30 Gallon Drum

Package Void Volume: 1.88e+003 cc
Waste Volume: 120. cc
Waste Mass: 120. g
Waste Void Volume: 0.000 cc

Days to decay source before seal time: 30.00 days
Calculate number of days sealed until 2.50% hydrogen is reached.

G Value Material Selection:

Contribution	Weight	G-Alpha	G-Beta	G-Gamma	Name
100.00%	1	2.8*	0.43	0.7	Water (liquid) pH = 13

(* indicates the value was calculated from a given value)

G Values calculated from list averaging:

G Alpha	G Beta	G Gamma
2.8	0.43	0.7

Comments:
Drum already assembled. 2551

========== Calculated Results ==================================

The sealed container will generate 2.48 % hydrogen in 593.63 days
H2 Volume: 47.9 cc
H2 Generation Rate: 0.00336 cc/hour

Heat Generated: 0.000880 Watts
Partial Pressure (H2): 2.58 kPa
Total Pressure (H2 and Air): 104. kPa

Radioactive: Yes
Type Determination: A (from unity fraction 0.33683)
Limited Quantity: No
LSA Determination: No (from LSA unity fraction 220.10)
HRC Quantity Determination: No
Fissile Quantity: 0.00028207 g
15g Fissile Radionuclides or Less: Yes
(Fissile Excepted per 49CFR173.453(a))
Note: Transportation classifications assume three significant figures.

Bulk Density: 1.00 g/cc

Source decayed to start of seal time:

Radionuclide:	Curies:
Sr-90	1.30e-001
Y-90	1.30e-001
Cs-137	2.00e-003
Ba-137m	1.89e-003
Pu-239	1.75e-005
U-235	1.42e-015
Am-241	2.81e-005
Np-237	7.48e-013
Pa-233	2.26e-013
U-233	2.87e-020

Source decayed to end of seal time:

Radionuclide:	Curies:
Sr-90	1.25e-001
Y-90	1.25e-001

Cs-137	1.92e-003
Ba-137m	1.82e-003
Pu-239	1.75e-005
U-235	2.94e-014
Th-231	2.79e-014
Pa-231	4.79e-019
Am-241	2.80e-005
Np-237	1.55e-011
Pa-233	1.46e-011
U-233	5.11e-017

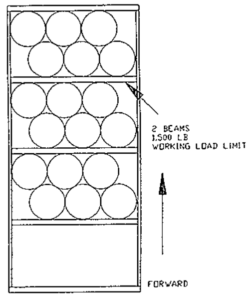
8.0 PACKAGE TIEDOWN SYSTEM EVALUATION

8.1 SYSTEM EVALUATION

Up to 18 drums are to be transported. The load tiedown must have a working strength of 4,082 kg (9,000 lb) in any direction.

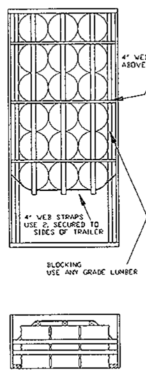
By using a closed van with strong sides, the drums can be longitudinally restrained using beams that span from between the sides of the van. The van walls, top and front must be capable of providing sideways and forward restraint, and the capacity of the van must be greater than 8,165 kg (18,000 lb). The drums must be shipped in rows of three, using empty drums to fill out partial. The total working load limit for the beams must be 227 kg (500 lb) for each drum in the shipment (4,082 kg [9,000 lb] if 18 drums are restrained by beams), and the beams must be arranged so that they provide rear restraint for no more drums than they can support. For beams that have a working load limit of 680 kg (1,500 lb), this can be provided by placing beams between each row of three drums or by using two beams between two rows, as shown in Figure A4-1. If beams with a working load limit of 2,041 kg (4,500 lb) are available, and the van walls have beam anchor points designed for 1,021 kg (2,250 lb) for each beam end, two beams at the rear of the load are adequate. Two straps can secure the last row of drums, providing that the straps have a working load limit of 499 kg (1,100 lb) and lead into the side anchor points at an angle of 45° or more away from perpendicular with the sides of the trucks.

Figure A4-1. Tiedown - Closed Van.



Up to 18 drums can also be transported in an open trailer with side and front rails of welded structural steel, as shown in Figure A4-2. The rails must have sufficient strength to anchor web straps, and a capacity greater than 8,170 kg (18,000 lb). Synthetic webbing straps with a strength of at least 1,800 kg (4,000 lb) are used as follows: three straps over the tops of the drums and two around the back. The top straps require 4 x 4 wood beams to be laid lengthwise on top of the drums. These beams must be continuous over the row of drums (about 4.5 m [14 ft]) or additional straps must be used. If there is a space of more than 10 cm (4 in.) between the bottom of the drums and the side frames, additional timbers are laid on the trailer floor to block. The webs are secured to the sides making an angle of no more than 45° with the length of the trailer or 45° vertically.

Figure A4-2. Tiedown - Open Trailer.



8.2 ATTACHMENTS AND RATINGS

If transported in an open trailer, use synthetic webbing with a working load limit of 4,000 lb or more. The wood beams on top of the drums must be Douglas Fir-Larch graded "standard" or better.

8.3 REFERENCE

49 CFR 393, 1996, "Parts and Accessories Necessary for Safe Operation," *Code of Federal Regulations*, as amended.

8.4 APPENDIX: TIEDOWN ANALYSIS

ENGINEERING SAFETY EVALUATION

Subject: TIEDOWN FOR CONCRETE LINED WASTE DRUM — Page 1 of 4
Preparer: W. W. Smyth W. W. Smyth — Date 4 SEPT 1997
Checker: S. S. SHIRIAGA — Date 4 SEPT 1997
Section Chief: S.S.SHIRAGA — Date 4 SEPT 1997

1.0 OBJECTIVE

Demonstrate the adequacy of 4 x 4 beams and 100 mm wide (4 in) synthetic webbing straps to restrain 18 drums against 0.5*g* vertical and horizontal acelleration

2.0 REFERENCES

UBC, 1988, *Uniform Building Code*, 1988 edition, International Conference of Building Officials, Whittier, California.

49 CFR 393, 1996, "Parts and Accessories Necessary for Safe Operation," *Code of Federal Regulations*, as amended.

3.0 ASSUMPTIONS, RESULTS, AND CONCLUSIONS

Two straps of 100 mm (4 in) wide synthetic webbing provides sufficient restraint for longitudinal tiedown, and 3 straps provides sufficient tiedown for vertical restraint, when configured as shown in the sketch below. The webbing must have a working load limit of 1800 kg (4,000 lb) or greater. A 4 x 4 beam of Douglas Fir-Larch lumber, Standard grade or better, is needed on top of the drums to complete the vertical tiedown, and the base of the drums must be blocked to prevent lateral movement.

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Section Chief: S.S.SHIBAGA	Date 4 SEPT 1997

4.0 EVALUATION

$Wt := 9 \cdot 1000\,lbf$ total weight of 9 drums. $Wt = 40033 \cdot newton$

$P_{all} := 4000\,lbf$ allowable working strength of 4" synthetic straps (49 CFR193)

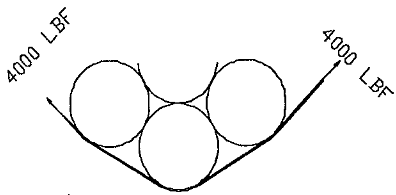
$P_{all} = 17792 \cdot newton$

$g := 0.5$ total aggregate strength of tiedowns must be 1/2 of weight.

Assume the front end structure takes all forward loading

$\theta := 45 \cdot deg$ Assumed angle for webbing straps where they are fastened to truck sides. Considering only the longitudinal forces in a free-body diagram, calculate the total force one strap will resist if it has at its 4000 lbf working load limit:

$WLL := 4000\,lbf$ $Resist := 2 \cdot WLL \cdot \cos(\theta)$ $Resist = 5657 \cdot lbf$



Total capacity for longitudinal loading, based on 2 straps:

$Cap_{long} := 2 \cdot Resist$ $Cap_{long} = 11314 \cdot lbf$

$Cap_{long} = 50325 \cdot newton$

$margin := \frac{Cap_{long}}{Wt \cdot .5} - 1$ $margin = 1.514$

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ENGINEERING SAFETY EVALUATION

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Section Chief: S.S.SHIRAGA Date 4 SEPT 1997

Use the same reasoning for the straps over the tops of the drums. First assume that the beams are adequate and check the strap capacity for vertical load with 3 straps

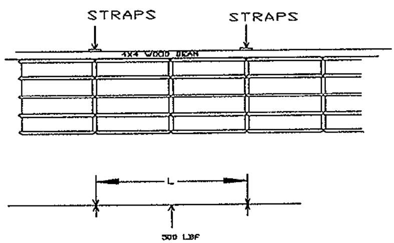
$Cap_{vert} := 3 \cdot Resist$ $\quad Cap_{vert} = 16971 \cdot lbf$ $\quad Cap_{vert} = 75487 \cdot newton$

$$margin := \frac{Cap_{vert}}{Wt \cdot g} - 1 \qquad margin = 2.771$$

The drums comply with DOT 7A compression requirements, so can withstand the crushing force of 6 drums at .5g

The drums are 38" high and 28" wide with a center of mass at mid-height, 19" above the floor. Since their width is greater than the height of the center of mass, they will not tip under .5g lateral loading with the bottoms blocked. No load resistance is needed in the webbing over the tops of the drums for this; the beams and webbing will provide additional margin.

Now check the beam capscity to ensure that the beams on top of the drums can distribute forces from the drums into the straps.



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A single 4x4 beam supported by straps is loaded by 2 drums. Due to the drum rim, consider the beam as simply supported with a concentrated load in the center. Each drum contributes 500 lbf of loading: 1/2 of this is taken directly by the straps, and 1/2 is distributed to the straps by the beam

$L := 30 \cdot in$ Simple beam span

$P := 500 \cdot lbf$ $P = 2224 \cdot newton$

$M := \frac{P \cdot L}{4}$ bending moment, neglecting continuity

$s := 3.5 \cdot in$ actual size of 4"lumber

$S := \frac{s^3}{6}$ $S = 7.146 \cdot in^3$ beam section modulus

$f_b := \frac{M}{S}$ $f_b = 525 \cdot psi$ beam bending stress

Using UBC, 1988 criteria, the bending strength of Douglas Fir- Larch, standard grade , single member, is:

$$F_b := 600 \cdot psi$$

apply the increase in strength for impact forces (100%) allowed by UBC section 2504 (c4)

$margin := \frac{2 \cdot F_b}{f_b} - 1$ $margin = 1.287$

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