# Appendix 2.10.9

## Alternative Secondary Lid Leak Test Port Performance

# Alternative Secondary Lid Leak Test Port Performance

## Introduction

The LiquiRad (LR) provides a leak-tight closure at the primary and secondary lids using double O-ring seals. Leak test ports are provided at each double O-ring seal to facilitate the required leakage tests.

The primary lid test port is a vertical port located on the primary lid, as shown in Detail L of drawing LR-SAR, sheet 3 (see Appendix 1.3.1). The secondary lid test port has three optional configurations: a vertical port located on the secondary lid, a horizontal port located on the secondary lid, and a horizontal port located on the secondary lid flange (also shown on LR-SAR, sheet 3).

The performance test prototype (described in Appendix 2.10.4) used the vertical test ports at both the primary lid and the secondary lid. The objective of this evaluation is to demonstrate that the O-ring seal performance is not compromised by the use of the optional test port configurations that were not present in the performance testing.

## Discussion

During the performance testing of the LR prototype, the package was subjected to a 30-foot drop onto the top end of the package. Post-test inspection of the outer lid and inner lid assembly showed that the outer lid had contacted the secondary lid, leaving an imprint on the outer lid as shown in photo 1. The secondary lid was found to be undamaged. Thus, the design performed as expected, with the outer lid absorbing the energy of the impact.

The vertical test port used for the performance tests (Test Port Option 1) is plugged when not in use and has a relatively low profile. Impact by the outer lid during the 30-foot drop scenario did not occur, since the port plug was shielded by the secondary lid bolts. Indeed, the test port plug was easily removed and the test port performed as required during post-test leakage testing.

Test Port Option 2 provides a horizontal test port on the secondary lid that is plugged during shipment. Again, the low profile of the plug assures that impact by the outer lid under hypothetical accident drop conditions does not occur. Thus, the secondary lid and flange are not subjected to additional stresses during impact that could disrupt the O-ring seal.

Test Port Option 3 provides a horizontal test port on the secondary lid flange with a capped elbow fitting to facilitate pre-shipment leakage testing. The capped elbow remains in place during shipment. With the secondary lid in place, the elbow is recessed approximately 1/32" from the upper surface of the secondary lid. However, the elbow projects approximately 1" beyond the radial edge of the secondary lid. These dimensions are shown in Figure 1. This placement allows the elbow to be impacted by the outer lid during hypothetical accident drop conditions, applying load to both the elbow and the secondary lid flange. In order to assure that the elbow does not disrupt the O-ring seal on impact during hypothetical accident conditions, a stress groove is placed just beyond the NPT threading. The stress groove assures that the elbow yields before plastic deflection of the flange occurs.

## Analysis

As stated in the discussion section, Option 1 and Option 2 do not impact the performance of the secondary lid seal during drop conditions; therefore, Options 1 and 2 are not analyzed. The Option 3 configuration has the potential to disrupt the secondary lid seal; thus, it was analyzed. The objective of the analysis was not to quantify the load applied to the elbow/flange connection during the drop impact, but rather to demonstrate that the elbow will yield and fail before the flange.

If the elbow is impacted during hypothetical accident conditions, there are three possibilities: the elbow yields and fractures before any plastic deformation of the flange, both the flange and elbow are deformed plastically, or the flange yields and fractures before any plastic deformation of the elbow.

Since the weakest part of the flange is the section below the test port, its dimensions are used in the analysis. The material properties of the flange and the elbow are provided in Table 2.10.9-1. The maximum wall thickness at the stress groove, as shown in Figure 2.10.9-1, is 1/16". The thickness of the flange below the test port is 0.122".

Considering only direct shear and assuming a thread engagement of 0.431", the force required to initiate yield in the flange below the test port is:

$$2(0.122")(0.431")(30{,}000 \text{ psi}) = 3{,}155 \text{ lb.}$$

The force required to initiate yield in the elbow at the stress groove, conservatively neglecting bending, is:

$$[\pi\,((0.180"+2(0.0625"))^2 - 0.180"^2)/4]\,(32{,}000\text{psi}) = 1{,}523 \text{ lb.}$$

Thus, the elbow yields before the flange, and the factor of safety is:

$$3{,}155 \text{ lb}/1{,}523 \text{ lb} = 2.07.$$

The force required to fracture the flange below the test port is:

$$2(0.122")(0.431")(75{,}000 \text{ psi}) = 7{,}887 \text{ lb.}$$

The force required to fracture the elbow at the stress groove, conservatively neglecting bending, is:

$$[\pi\,((0.180"+2(0.0625"))^2 - 0.180"^2)/4]\,(64{,}000\text{psi}) = 3{,}047 \text{ lb.}$$

Thus, the elbow fractures before the flange, and the factor of safety is:

$$7{,}887 \text{ lb} / 3{,}047 \text{ lb} = 2.588.$$

Thus, conservatively considering only direct shear, the elbow fractures at a load below that causing plastic deformation in the flange. The factor of safety against plastic yielding of the flange is:

$$3{,}155 \text{ lb} / 3{,}047 \text{ lb} = 1.04.$$

If the elbow is oriented in any direction other than vertical, a torsional stress will be induced in the elbow, causing fracture of the elbow at a much lower load. Therefore, the vertical orientation evaluated is conservative. Additionally, bending stresses in the stress groove are significant when the load is applied at the free end of the elbow. If bending stresses are considered, the elbow yields at a load of approximately 150 lb (loaded at the free end of the elbow).

In order for bending of the bolted lid/flange to occur (at a location other than the test port), the loading at the free end of the elbow would have to exceed 5,000 lb:

$$30{,}000 \text{ psi } (0.45159 \text{ in}^4) \,/\, (\tfrac{3}{4}\text{"})(3.456\text{"}) = 5{,}227 \text{ lb.}$$

Thus, the elbow yields and fractures well before any plastic bending of the bolted lid/flange occurs.

Thus, in all cases (direct shear, torsion, and bending), the elbow yields and fractures before any plastic deflection of the flange. Since the elbow yields and fractures before plastic deflection of the flange occurs, the O-ring seal is not disrupted by an impact to the elbow during hypothetical accident conditions.

Following an impact, the elbow fitting may be sheared completely from the flange (leaving the threaded portion of the elbow intact with the flange). Because the test port does not access the containment boundary, the un-sealed test port itself does not represent a loss of containment. Containment of the payload is first assured by the primary lid seals, and then by the innermost O-ring on the Secondary Lid. Since the Primary Lid seals and the Secondary Lid inner O-ring are not disturbed by an impact sustained by the elbow fitting, containment of the payload during hypothetical accident conditions is not compromised. Movement of the loose fitting within the annulus area is not a concern, since there are no vulnerable parts in that area and the brass fitting is softer than the steel material used throughout the remainder of the packaging.

## Conclusion

The optional test port configurations that were not tested as a part of the performance test program do not compromise the O-ring seal performance as a result of hypothetical accident conditions.

Table 2.10.9- 1 Material Properties

| | Secondary Lid Flange | Elbow fitting and cap |
|---|---|---|
| Material of construction | 304 or 316 Stainless Steel | Forged Brass |
| Yield Strength | 30 ksi | 32 ksi |
| Density | 0.286 $lb/in^3$ | 0.305 $lb/in^3$ |
| Modulus of Elastiticty | 28.3E3 ksi | 14.2E3 ksi |
| Poisson's Ratio | 0.3 | 0.33 |

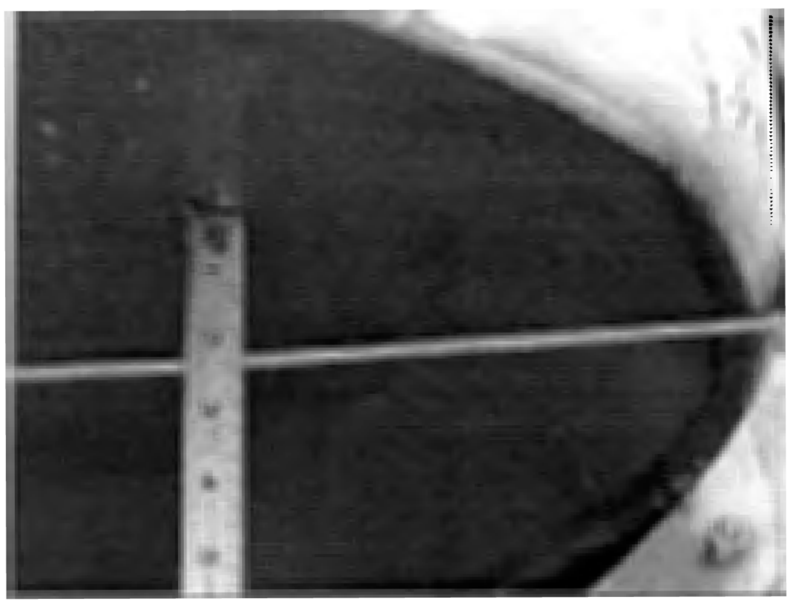

**Photo 1 Outer Lid Performance Test Damage**

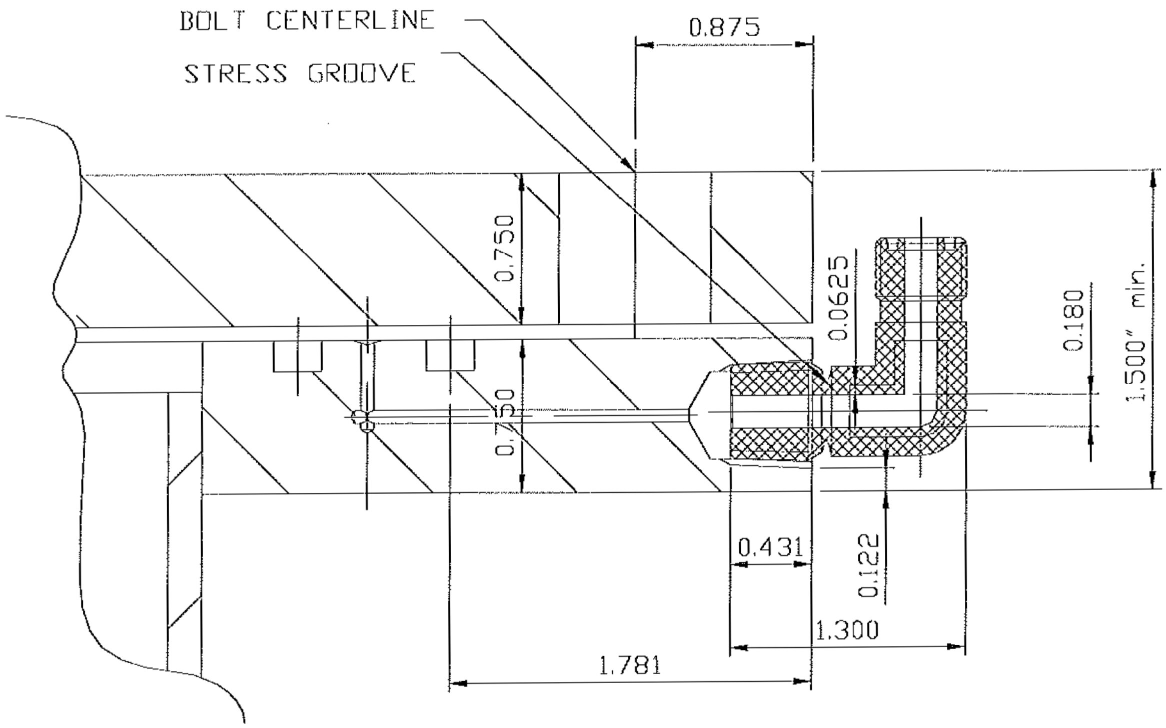


**Figure 1 Dimensions of the Elbow Fitting used for Test Port Option 3**

# SECTION 3
# THERMAL EVALUATION

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# 3 THERMAL EVALUATION

## 3.1 Discussion

The Eco-Pak LR is designed to maintain the temperature of the contents within specified limits during normal transportation and hypothetical accident conditions. The temperature of the contents must be maintained below 210°F. This limit is provided to prevent damage to the containment vessel. Analytical evaluations were performed to assure that, under the worst-case normal conditions, the content temperature and internal pressure of the vessel remain within the specified limits. In order to evaluate the worst case hypothetical accident condition, fire testing was performed. The results of these analyses and tests, provided in Table 3-1, demonstrate that the Eco-Pak LR meets the requirements of 10CFR71 for both the normal and hypothetical accident conditions.

## 3.2 Description of Thermal Design

### 3.2.1 Design Features

The Eco-Pak LR is provided with insulation around the entire surface of the containment vessel to assure that the contents are maintained below the liquid's boiling point. Several different types of insulation are used, including rigid foam, ceramic fiber board, and ceramic fiber blanket insulation. The thermal conductivity of these insulators are provided in Table 3-2. Table 3-3 lists the containment vessel dimensions used, and Table 3-4 lists the heat loads and initial conditions imposed. These insulators have been shown by the manufacturer to perform adequately over extended periods of time, with no shrinkage, settling, or loss of insulative properties. Additionally, these insulators do not burn, and their melting points are well above the temperature of the 1475°F fire specified by 10CFR71.73.

### 3.2.2 Contents Decay Heat

The worst-case contents of the package consists of uranyl nitrate solution as described Section 1. Table 3-5 provides the disintegration energy per isotope and the total energy available for thermal dissipation. The total energy available is less than 0.18 BTU/hr. Therefore, the heat input due to radiological decay is negligible when compared with the insolation and fire heat input.

### 3.2.3 Maximum Working Pressure and Temperature

The maximum allowable working pressure of the contents and packaging is 50 psig. The nominal package internal pressure is 0 psig and pressurization to 50 psig does not occur unless the contents begin to change from liquid to gaseous phase. Therefore, to avoid the phase change, the maximum working temperature is 210°F (99°C).

### *3.3 Thermal Evaluation for Normal Conditions of Transport*

#### 3.3.1 Maximum Package and Content Temperatures

No significant heat is generated from radioactive decay of the contents during transport; therefore, under the normal condition, the only heat source is that provided by incident solar radiation. Table 3-2 provides the material properties used in the analysis. Table 3-3 lists the containment vessel dimensions used, and Table 3-4 lists the heat loads and initial conditions imposed. The absorptivity of the outer shell is conservatively assumed to be 1.0. The convection heat transfer coefficient is conservatively assumed to be 1 Btu/hr-ft$^2$. Assuming steady state conditions:

$$q_{insolation} = \varepsilon\sigma A\left(T^4_{outershell} - T^4_{ambient}\right) + hA(T_{ambient} - T_{outershell})$$

where:

| | |
|---|---|
| $q_{insolation}$ | is the specified thermal energy incident upon the package averaged over a 24-hour period, |
| $\varepsilon$ | is the absorptivity of the surface (1.0), |
| $\sigma$ | is Boltzman's Constant, |
| $A$ | is the surface area affected by the insolation, |
| $T_{outer\ shell}$ | is the surface temperature of the outer shell of the package, |
| $T_{ambient}$ | is the ambient air temperature (100°F) , |
| $h$ | is the convection heat transfer coefficient. |

An insolation rate of 800 g-cal/cm$^2$ per 12-hour period is applied to the top surface of the packaging. An insolation rate of 400 g-cal/cm$^2$ per 12-hour period is applied to the curved vertical sides of the packaging. Insolation is not applied to the base of the packaging. With these insolation rates averaged over a 24-hour period and at steady state, the maximum average temperature reached at the surface of the package for the normal condition of transport is 179°F (82°C).

At the steady state, the temperature of the contents can not be hotter than the exterior of the packaging, since there is no appreciable decay heat associated with the contents. Therefore, the maximum average temperature of the contents is less than 179°F (82°C). This is well below the maximum allowable temperature of 210°F.

Due to the fact that the contents are largely water, the thermal response of the system is fairly rapid ($C_p$ is approximately 4.1 kJ/kg-K) and the contents reach the steady state temperature within one 24-hour period.

Without insolation and with an ambient temperature of 100°F, the maximum temperature of the accessible surfaces of the packaging is 100°F, and the maximum temperature of the contents does not exceed 100°F.

### 3.3.2 Minimum Package and Content Temperatures

Table 3-2 provides the material properties used in the analysis. Table 3-3 lists the containment vessel dimensions used, and Table 3-4 lists the heat loads and initial conditions imposed. Assuming steady state conditions, with no sources of thermal energy present, the minimum temperature reached by the package and contents is -40°F (-40 °C).

### 3.3.3 Maximum Normal Operating Pressure

The maximum normal temperature reached by the contents is clearly much less than the boiling point of the liquid; therefore, any pressure increase due to vaporization of the contents is well below the internal pressure limit for the package. Because the contents are largely made up of water, the internal vapor pressure is essentially that of the vapor pressure of water at the maximum normal temperature, 1.5 psig.

At low temperatures, the liquid contents freeze and expand. This expansion causes a reduced headspace in the packaging, and the air occupying the space is compressed. Using the density of water at 24°C (62.26 $lb/ft^3$) and the density of ice (57 $lb/ft^3$) and assuming the maximum fill volume of 230 gallons (870 liters), the headspace is reduced from 33 gallons to 12 gallons. Using the ideal gas law and assuming the original air pressure was atmospheric, the final pressure of the air in the package due to the expansion of the contents is 31 psia.

The additional gas generated due to radiolysis of the solution increases the maximum pressure by approximately 1 psi for the frozen condition described above (see Section 2.4.4.2). Therefore, the maximum normal operating pressure is 32 psia.

### 3.3.4 Maximum Thermal Stresses

Because the maximum operating temperature of the containment vessel is not significantly different from nominal, there are no significant thermal stresses induced.

## *3.4 Thermal Evaluation for Hypothetical Accident*

The LR was drop tested and fire tested consistent with the requirements of 10CFR71.73. The conditions and results of the fire testing are provided in Appendix 2.10.5. An additional analytical evaluation is provided in Appendix 3.5.1.

### 3.4.1 Initial Conditions

Prior to the fire test, the package was subjected to the Free Drop and Puncture tests required by 10CFR71.73. The damage accumulated due to these tests is documented in Section 2. Containment of the vessel was not breached; however, there was a significant reduction of the insulation thickness at the puncture test impact location. The minimum insulation thickness was compressed from the 4.5" nominal to approximately 0.5". There was also a small tear in the outer shell at the same location as a result of the puncture test.

The contents of the package were simulated using a saltwater solution and steel shot. Because the uranyl nitrate solution to be shipped is largely water, the saltwater solution used in the simulation is a good approximation for the relevant physical properties (physical form, density, specific heat, boiling point) of the contents.

Due to variations in wind speed during the fire test, the flame test was repeated on the same package, with no repairs or modifications to it (with the exception of a weld seam that split during the first fire test). The conditions reported in this Section are those of the second fire test performed. The measured ambient temperature during the fire test was 99°F. The average wind speed during the first half-hour of testing was 3.1 mph. The package rested upon a simple support system that was incapable of shielding the package from the fire or cooling the package in any significant way. Thermocouples and thermal insulation labels were placed both on the surface of the package and on the interior of the containment vessel. In order to obtain a fully engulfing fire, the fuel source extended beyond the package between 2 and 4m, exceeding the requirements of 10CFR71.73.

### 3.4.2 Package Temperatures

The duration of the fire was 31 minutes, and the average measured flame temperature was 1375°F. The fire was allowed to burn until all of the fuel was consumed, and following the test the package was protected from precipitation and wind effects to eliminate enhanced cooling of the package. Temperature monitoring of the package continued for 20 minutes after the fire burned out. The maximum bulk temperature of the package contents during the fire test was 148°F (64°C). The maximum temperature attained by the package during the fire test was approximately 1150°F (621°C). The maximum temperatures attained are well within the acceptable short-term temperature limits for the package.

### 3.4.3 Maximum Internal Pressure

The contents of the package remained below the boiling point throughout the fire test; therefore, a change of phase did not occur. Since the contents remain in liquid form, even during a fire, the maximum internal pressure for the hypothetical accident condition is bounded by the Normal Cold condition (32 psia).

### 3.4.4 Maximum Thermal Stresses

Because the design of the package is such that the containment vessel and outer shell are not restrained from thermal expansion, thermal stresses during a fire event are negligible. The outer shell is much hotter than the containment vessel, and as a result, a gap grows between the two shells. However, the outer shell and containment vessel are not attached and there is no stress applied to either component. The insulation provided between the outer shell and the containment vessel is not affected by the thermal expansion.

## *3.5 Appendix*

3.5.1 Report of Thermal Evaluation

**Table 3-1 Thermal Analysis and Test Results**

| Condition | Peak Content Temperature | | Peak Package Temperature | | Peak Package Internal Pressure |
|---|---|---|---|---|---|
| | °F | °C | °F | °C | psia |
| Normal Hot Transport | 179 | 82 | 179 | 82 | 16.7 |
| Normal Cold Transport | -40.0 | -40.0 | -40 | -40 | 32.0 |
| Fire Accident | 148 | 64 | 1150 | 621 | <17.7 |

**Table 3-2 Relevant Thermal Material Properties**

| Material | Thermal Conductivity[1] (BTU/hr*ft*R) | Density ($lb/ft^3$) | Specific Heat (BTU/lb°F) | Emmisivity/absorptivity | Melting Point (K) | Continuous Use Limit (K) |
|---|---|---|---|---|---|---|
| Carbon Steel | 21.8 | 488 | 0.104 | 1 | 1750 | 588 |
| Stainless Steel | 8.6 | 493 | 0.115 | N/A | 1670 | 588 |
| Foam Insulation | 0.046 | N/A | N/A | N/A | N/A Foam insulation is difficult to ignite and tends to not support combustion when the flame source is removed. | |
| O-ring | N/A | N/A | N/A | N/A | 543 | 477 |
| Ceramic Fiber Board | 0.013 | N/A | N/A | N/A | 2033 | 1533 |
| Ceramic Fiber Blanket | 0.205 | 8.0 | N/A | N/A | 2033 | 1533 |
| Uranyl Nitrate Solution | 0.350 | 63.7 | 0.999 | N/A | Boiling point 373.15 | N/A |

[1] The thermal conductivity listed is the maximum allowable for the material. This is conservative, since a lower thermal conductivity results in lower payload temperatures for Normal Hot and Fire Accident conditions. For Normal Cold transport, a lower thermal conductivity does not change the resulting payload temperature.

**Table 3-3 Package Dimensions**

| Component | Dimension (in) |
|---|---|
| Package OD | 56 |
| Minimum Insulation thickness | 4.5 |
| Containment Vessel ID | 46 |
| Overall Package height | 64.75 |
| Package top surface area | 2,463 $in^2$ |
| Package vertical curved surface area | 11,390 $in^2$ |

**Table 3-4 Applied Heat Loads and Initial Conditions**

| Parameter | Normal Transport Hot | Normal Transport Cold | Hypothetical Accident |
|---|---|---|---|
| Ambient Temperature, °F | 100 | -40 | 99.5 |
| Top surface insolation, BTU/hr*$ft^2$ | 123 | 0 | N/A |
| Vertical curved surface insolation, BTU/hr*$ft^2$ | 61.5 | 0 | N/A |
| Radiological Decay Heat, BTU/hr | 0 | 0 | 0 |
| Analysis performed | Steady State | Steady State | Tested |
| Initial Package/Content Temperature | N/A | N/A | 99.5 |
| Average Flame Temperature, °F | N/A | N/A | 1375 |

**Table 3-5 Thermal Decay Heat**

| Isotope | Maximum content | Total Activity, Ci[1] | Total Activity, DPS | Energy of disintegration, MeV | Energy available for deposit into the package, MeV/sec | Energy available for deposit into the package, BTU/hr |
|---|---|---|---|---|---|---|
| U232 | 2.00E-09 g/gU | 5.60E-03 | 2.07E+08 | 5.4 | 1.12E+09 | 6.11E-04 |
| U234 | 2.00E-03 g/gU | 1.55E+00 | 5.74E+10 | 4.9 | 2.81E+11 | 1.54E-01 |
| U235 | 5.00E-02 g/gU | 1.35E-02 | 4.96E+08 | 4.5 | 2.23E+09 | 1.22E-03 |
| U236 | 2.50E-02 g/gU | 2.02E-01 | 7.47E+09 | 4.6 | 3.44E+10 | 1.88E-02 |
| U238 | 9.23E-01 g/gU | 3.73E-02 | 1.38E+09 | 4.3 | 5.95E+09 | 3.25E-03 |
| NP237 | 1.66E-06 g/gU | 1.46E-04 | 5.40E+06 | 5 | 2.70E+07 | 1.48E-05 |
| PU238 | 6.20E-11 g/gU | 1.32E-04 | 4.88E+06 | 5.5 | 2.69E+07 | 1.47E-05 |
| PU239/240 | 3.04E-09 g/gU | 3.69E-05 | 1.37E+06 | 5.25 | 7.17E+06 | 3.92E-06 |
| Gamma Emitters | 1.91E+08 MeV-Bq | --- | --- | --- | 1.91E+08 | 1.05E-04 |
| Total | | | | | | 0.18 BTU/HR |

[1] Based on 263 gallons at 125 gU/liter

# Appendix 3.5.1

# Report of Thermal Evaluation

SOUTHWEST RESEARCH INSTITUTE™

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August 21, 2001


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Cleveland, Ohio 44125
Phone No. 216/271-6100
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E-mail: DCPARTNERS@AOL.COM


Subject: Pool Fire Exposure Conditions of 10 CFR Part 71.73

Ref: SwRI Final Report No. 01-02759, "Hypothetical Accident Testing of Uranyl Nitrate Shipping Containers per Title 10 CFR Part 71.73," Eco-Pak Liqui-Rad 250®

**ENGINEERING EVALUATION**
**(Consisting of 7 Pages)**

Dear Mr. Dougherty:

This letter and attachments are provided in accordauce with your request to address the Nuclear Regulatory Commission's (NRC's) request for additional information (RAI) concerning the pool fire exposure conditions during the above-reference test program.

As you know, 10 CFR Part 71.73, *Section (4) Thermal* states:

> "Exposure of the specimen, fully engulfed, except for a simple support system, in a hydrocarbon fuel/air fire of sufficient extent, and in sufficiently quiescent ambient conditions, to provide an average emissivity coefficient of at least 0.9, with an average flame temperature of at least 800°C (1475°F) for a period of 30 minutes, or any other thermal test that provides the equivalent total heat input to the package and which provides a time averaged environmental temperature of 800°C. The fuel source must extend horizontally at least 1 m (40 in.), but may not extend more than 3 m (10 ft), beyond any external surface of the specimen, and the specimen must be positioned 1 m (40 in.) above the surface of the fuel source. For purposes of calculation, the surface absorptivity coefficient must be either that value which the package may he expected to possess if exposed to the fire specified or 0.8, whichever is greater; and the convective coefficient must be that value which may be demonstrated to exist if the package were exposed to the fire specified. Artificial cooling may not be applied after cessation of external heat input, and any combustion of materials construction, must he allowed to proceed until it terminates naturally."

The pool fire exposure test conducted September 22, 1999, on the Eco-Pak Liqui-Rad 250® shipping container met the intent of the hypothetical fire exposure conditions specified in 10 CFR 71.73.

The Eco-Pak Liqui-Rad 250® shipping container was exposed to a diesel fuel pool fire which reached temperatures in excess of 2000°F with a maximum temperature over 2400°F (see Figure 1). Figure 2 presents the average flame temperature for the four flame thermocouples (TC's) located on the north, south, east and west side of the shipping container. The integrated area beneath the time temperature curve for the period of 2 to 32 min yields an average flame temperature of approximately 1400°F. Calculation of the weighted average flame temperature yields 1500°F. Omitting the East TC, which was affected by wind conditions, yields an average flame temperature of 1533°F for the 30-min period.

The wind direction and velocity plots are shown in Figures 3 and 4. These plots show the trend that increased wind velocity from the East caused flame displacement from the East TC and reduced temperature readings. Note that the size of the pool fire and the position of the test article are fixed by the test procedure. Increasing the size of the pool fire would reduce the effect of wind on the flame temperature. It is important to note that 10 CFR 71.73 does not specify where the flame temperatures should be measured. Relocating the flame TC's as little as 6 in. lower into the flame plume would minimize the effect of wind on the flame temperature measurements and yield much higher average flame temperature readings. Note that it would still be the same fire exposure but you would have higher temperature readings.

I hope this information is sufficient for your immediate needs. If I may be of further assistance, please contact me at (210) 522-3716 or by fax (210) 522-3377, or e-mail at JGriffith@swri.org.

Sincerely,

STATE OF TEXAS
JAMES R. GRIFFITH, JR.
77757
REGISTERED PROFESSIONAL ENGINEER

James R. Griffith

James R. Griffith, Jr., P.E., FPE
Manager
Fire Resistance Section

Approved by:

Alex B. Wenzel

Alex B. Wenzel
Director
Department of Fire Technology

ABW/jgm

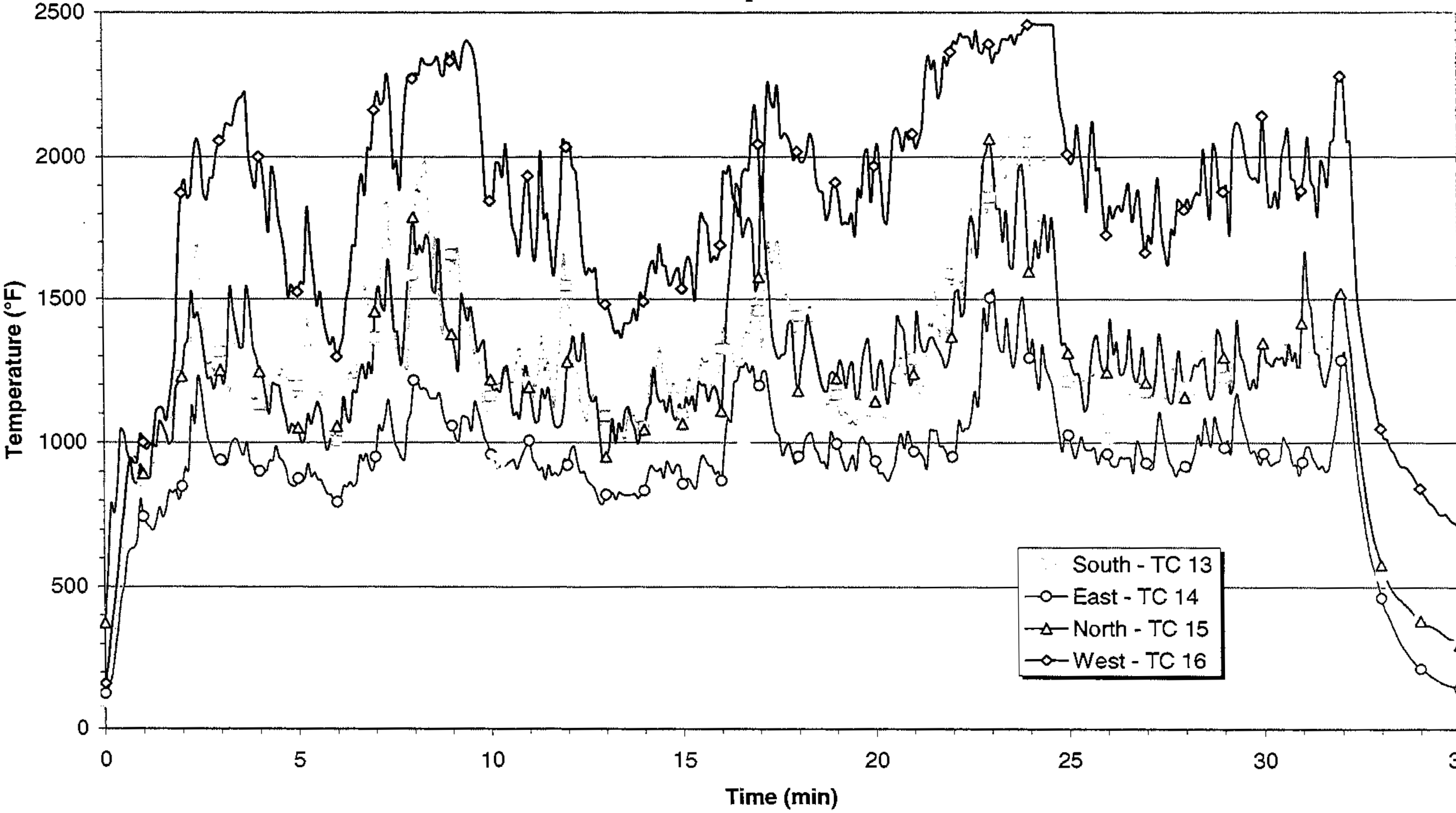
Attachment A: Figures 1 – 4

# ATTACHMENT A

## Consisting of 4 Pages

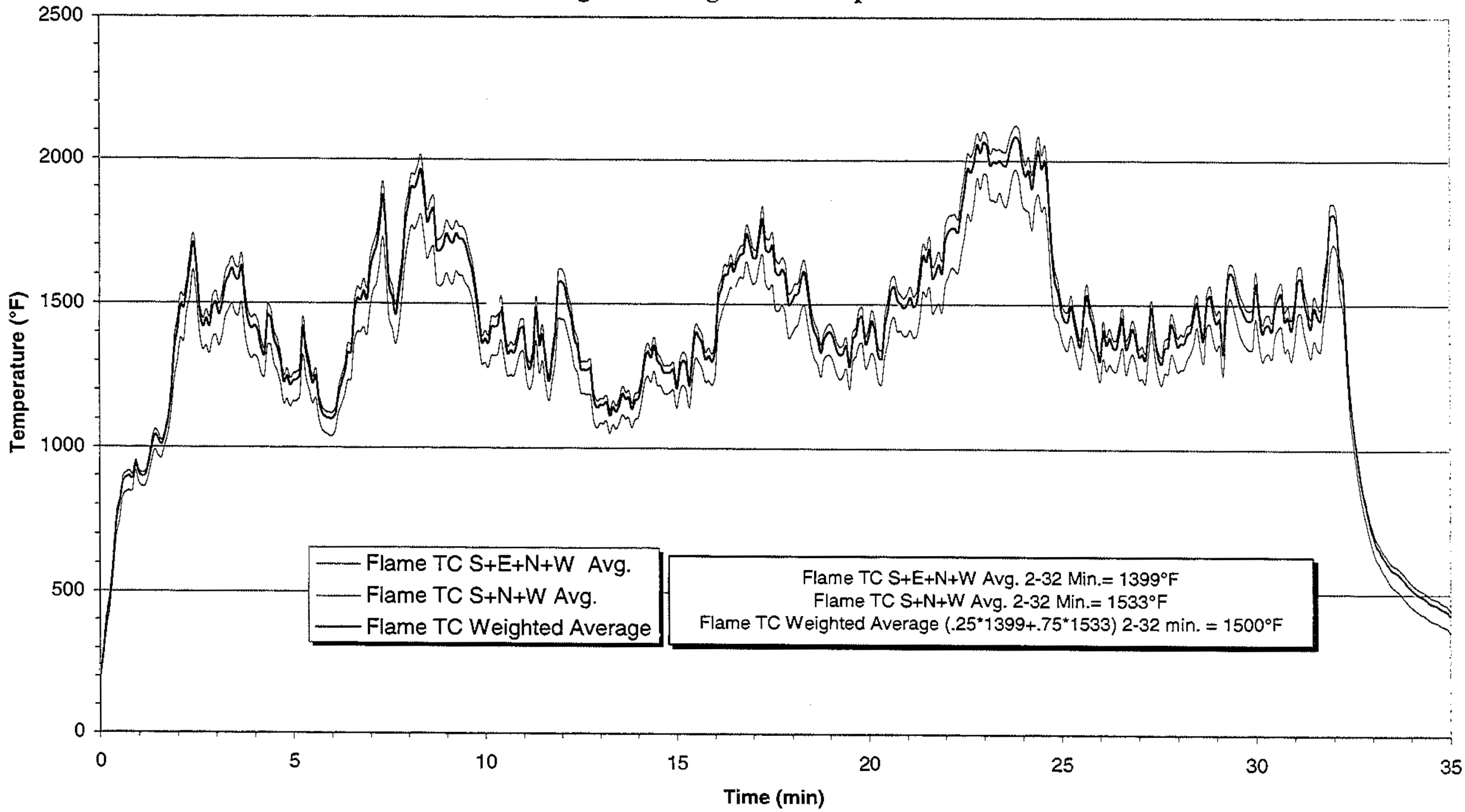
Client: ECO-PAK Specialty Packaging
Project No: 01.02759.001
Date: 22 September 1999
File: 265ECOP2.DAT

**Figure 1.**
**Flame Temperatures**



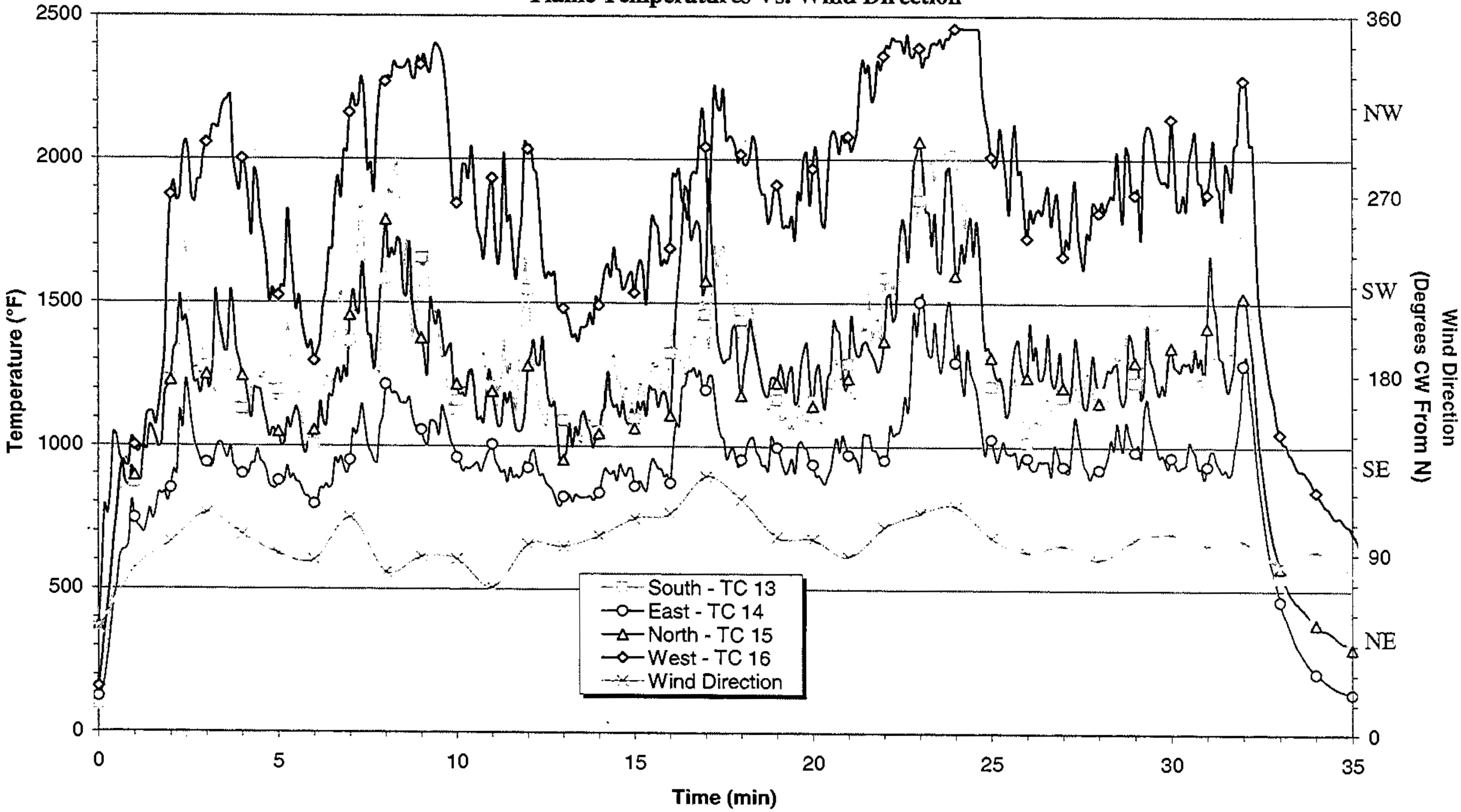
Client: ECO-PAK Specialty Packaging
Project No: 01.02759.001
Date: 22 September 1999
File: 265ECOP2.DAT

**Figure 2.**
**Weighted Average Flame Temperature**



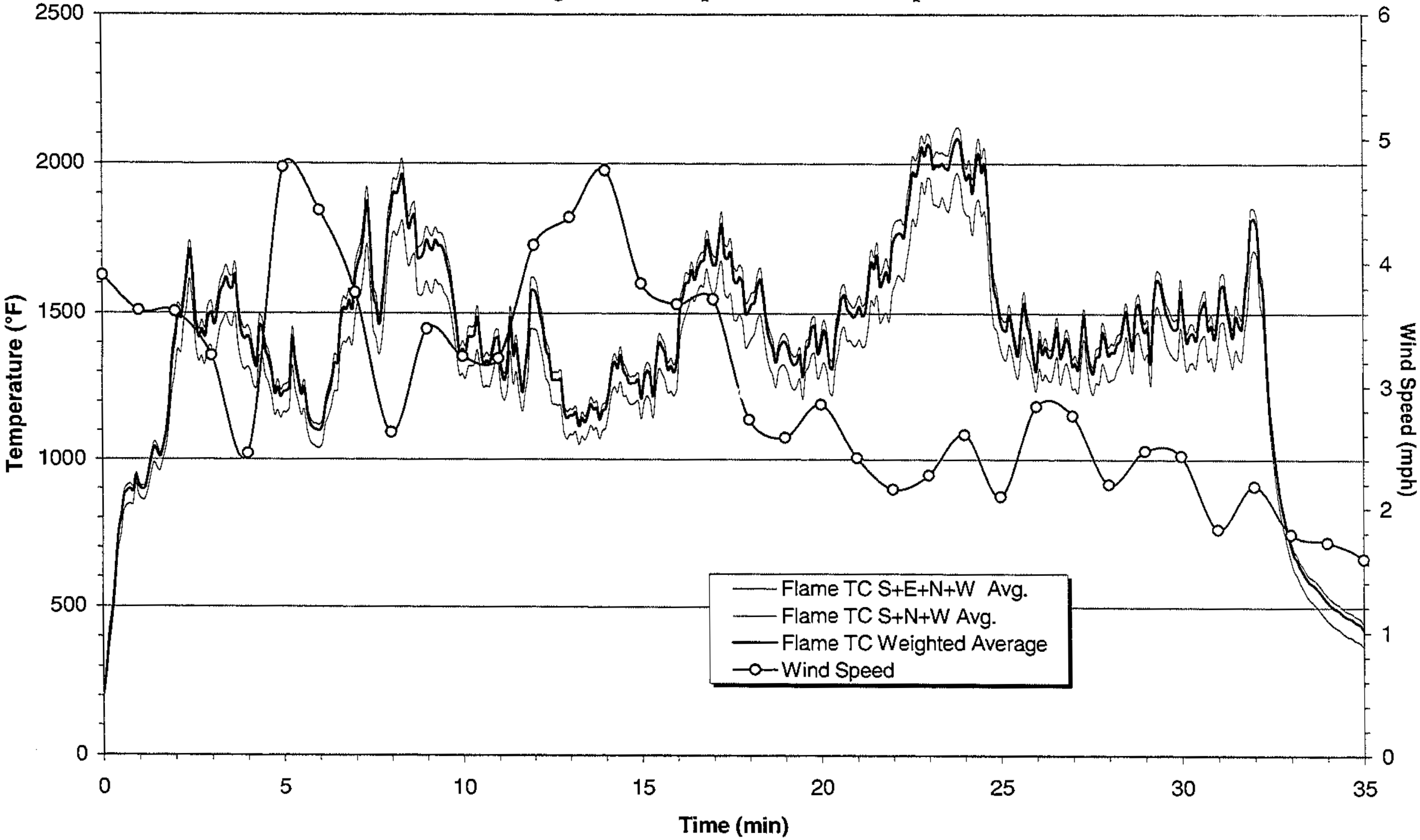
Client: ECO-PAK Specialty Packaging
Project No: 01.02759.001
Date: 22 September 1999
File: 265ECOP2.DAT

**Figure 3.**
**Flame Temperatures Vs. Wind Direction**



Client: ECO-PAK Specialty Packaging
Project No: 01.02759.001
Date: 22 September 1999
File: 265ECOP2.DAT

**Figure 4.**
**Average Flame Temperature vs. Wind Speed**



# CBC MEMORANDUM

**Date: 06/25/01**

**To: US NRC with respect to Request for Additional Information for the Model No. Eco-Pak Liqui-Rad Transport Unit Pcakage dated May 15, 2001**

**Cc: File**

**From: Tom Dougherty, Chairman**

**RE: Explanatory Representation as to the average flame temperature of the fire test performed at Southwest Research Institute**

THERMAL EVALUATION

The LR experienced two separate fire events, as set forth in 10 CFR 71.73, on two separate days, without any repairs or modifications. The first fire event generated an average flame temperature, as measured by all the thermocouples of 1315 degrees F. This condition was caused by intermittent winds as described in the Safety Analysis Report.

The second fire event generated an average flame temperature, as measured by all the thermocouples of 1375 degrees F. This condition was caused by intermittent winds as described in the Safety Analysis report.

In the first fire event TC South, TC West averaged above 1475 degree F. TC East and North averaged below 1475 degrees F, while experiencing periods that exceeded 1475 degrees F.

In the second fire event TC North averaged significant above 1475 degrees F. TC West averaged significantly above 1475 degrees F. TC South averaged below 1475 degrees F while generating significant periods in excess of 1475 degrees F.

It is the opinion of the applicant that all periods of low temperatures were cause by intermittent wind conditions. Further the LR package experienced more than 60 minutes of fire events (2 x the required). The LR package accumulated four thermocouples that accumulated an average temperature of 1532 degrees F over two fire events, therefore meeting the average flame temperature requirements stated in 10CFR 71.73 9c) (4). See Test 1-TC-1 plus Test Two TC-1, TC-3, TC-4.

Thomas F Dougherty

Thomas F. Dougherty, Chairman

LAW
LAWGIBB Group Member

November 16, 1999

Eco-Pak Specialty Packaging
Division of CBC
200 West Railroad Street
Columbiana, OH 44408

Attention: Mr. Mike Arnold/Mr. Jerry Rasel

Subject: **Report of Thermal Analysis**
**Eco-Pak Liqui-Rad-250 Shipping Container**
**Law Engineering and Environmental Services Project 10810-9-7003, Phase 13**

Dear Mr. Arnold:

Per your verbal request and as authorized by signing our annual Proposal Acceptance Sheet, Law Engineering and Environmental Services (LAW) is pleased to present this report of thermal analysis for the Eco-Pak Liqui-Rad-250 container. The purpose of this thermal analysis was to calculate the approximate temperature of the container water at the end of a 30 minute fire test. This report provides our understanding of the background information, services performed, and results.

**Background Information**

Mr. Mike Arnold and Ms. Heather Little of Eco-Pak Specialty Packaging requested LAW to perform a thermal analysis of the subject container during a 30 minute fire test considering the following conditions:

- Container is ½ full of water (approximately 125 gallons of water).
- Initial temperature of inside vessel and water is 100°F.
- Outside fire temperature is 1500°F (constant).

We were provided the following drawings:

- Preliminary Design Arrangement for the Eco-Pak Liqui-Rad-250 Drawing No. 111898/250 Sheet 1 of 2

Preliminary Design Arrangement for the Eco-Pak Liqui-Rad-250 Drawing No. 111898/250
Sheet 2 of 2

**Description of Vessel**

The subject container consists of a rectangular box supported on eight legs. There is an outer shell constructed of 0.135 inch thick carbon steel plate (A-569). Dimensions of the outer shell are 55 inch in diameter and 64 inch high. In addition, there is an inner shell constructed of 0.135 inch thick stainless steel plate. Housed inside the inner shell is a vessel measuring approximately 46 inch in diameter and 44 inch high. The vessel is constructed of 0.25 inch thick stainless steel plate (316 SS). There are three layers of Fiberfrax insulation between the outer and inner shells, totaling approximately 4.5 inch thick. The top section of the Liqui-Rad-250 container contains an air pocket approximately 7 inch high and 8 inch high Duraboard insulation. In addition, it has 18 inches of Thermo Cor II support insulation.

The bottom section of the container contains approximately 8 inch high of Thermo-Cor II support insulation.

Please refer to your drawing number 111898/250, Preliminary Design Arrangement for the ECO-PAK LIQUI-RAD-250, for a more detailed description of the vessel construction.

**Services Performed**

The heat transferred to the vessel due to the fire was calculated assuming three components to it as follows:

- Heat transferred through the shell
- Heat transferred through the top section
- Heart transferred through the bottom section

In our analysis we assumed conduction to be the mode of heat transfer and that the heat transfer rate per unit area is proportional to the normal temperature gradient.

**Heat Transferred through the Shell**

The heat transfer due to the outside fire through the side walls of the container was calculated. The calculations were performed neglecting the effect, if any, of the rectangular box. It was assumed that the heat transfer rate was affected by the outer shell, Fiberfrax insulation, inner shell and the vessel and its contents. Please refer to Figure 1, attached to this report showing a schematic of the heat transfer path. In addition, the following data was used.

- Initial temperature of vessel and water is 100°F
- Outside fire temperature is 1500°F constant
- Conductance of outer surface air is 2 BTU/hr/ft$^2$/°F
- Conductance of air inside vessel is 2 BTU/hr/ft$^2$/°F
- Conductivity of stainless steel material is 8 BTU/hr/ft/°F
- Conductivity of Fiberfrax insulation is 0.62 BTU in/hr/ft$^2$/°F at 600°F (copy attached)
- Conductivity of carbon steel material is 26 BTU/hr/ft/°F

**Heat Transferred through Top section**

The heat transfer due to the outside fire through the top section of the container was calculated. The calculations were performed neglecting the effect, if any, of the rectangular box. It was assumed that the heat transfer rate was affected by the top plate, top lid, Thermo Cor II support insulation, Duraboard, air pocket and the vessel and its contents. Please refer to Figure 1, attached to this report showing a schematic of the heat transfer path. In addition, the following data was used.

- Initial temperature of vessel and water is 100°F
- Outside fire temperature is 1500°F constant
- Conductance of outer surface air is 2 BTU/hr/ft$^2$/°F
- Conductance of air inside vessel is 2 BTU/hr/ft$^2$/°F
- Conductivity of stainless steel material is 8 BTU/hr/ft/°F
- Conductivity of II support insulation is 0.318 BTU in/hr/ft$^2$/°F

(Ms. Heather Little provided this information. Thermo-Cor II support insulation thermal properties are reportedly similar to ESP-PF-1 phenolic foam thermal properties. Copy of thermal properties for ESP-PF-1 is attached to this report.).

- Conductivity of carbon steel material is 26 BTU/hr/ft/°F
- Conductivity of air is 0.032 BTU/hr/ft/°F
- Conductivity of Duraboard (LD type) is 0.556 BTU in./hr/ft$^2$/°F at 400°F (copy attached)

**Heat Transferred through Bottom section**

The heat transfer due to the outside fire through the bottom section of the container was calculated. The calculations were performed neglecting the effect, if any, of the rectangular box. It was assumed that the heat transfer rate was affected by the bottom plate, Thermo-Cor II support insulation and the vessel and its contents. Please refer to Figure 1, attached to this report showing a schematic of the heat transfer path. In addition, the following data was used.

- Initial temperature of vessel and water is 100°F
- Outside fire temperature is 1500°F constant
- Conductance of outer surface air is 2 BTU/hr/ft$^2$/°F
- Conductance of air inside vessel is 2 BTU/hr/ft$^2$/°F
- Conductivity of stainless steel material is 8 BTU/hr/ft/°F
- Conductivity of Thermo-Cor II support insulation is 0.318 BTU in/hr/ft$^2$/°F
- Conductivity of carbon steel material is 26 BTU/hr/ft/°F

**Results Obtained**

Based on our thermal analysis, we calculated a total heat transfer rate of approximately 3.81 BTU/sec from outside to the vessel. That is equivalent to approximately 6858 BTU's transferred to the vessel over a 30 minute fire test. The distribution of heat transfer rate is shown in following table for three components.

| Component | Heat Transfer Rate BTU/sec | Heat Transfer over 30 Minutes In BTU |
|---|---|---|
| Side walls | 3.42 | 6156 |
| Top section | 0.13 | 234 |
| Bottom Section | 0.26 | 468 |
| Total | 3.81 | 6858 |

**As a result of 6858 BTU's heat transfer to the container and assuming specific heat of water to be 1 BTU/lbm/°F, the temperature of 125 gallons container water would rise from 100°F to approximately 106.6°F at the end of a 30 minute fire test.**

**Qualification**

This report summarizes our thermal analysis for Eco-Pak Liquid Rad-250 container. The results of our analysis are based on the information provided to us. If the data contained in this report are known to be incorrect or inappropriate for use in this analysis, please contact us so that we may reevaluate our calculations accordingly.

Law Engineering and Environmental Services appreciates the opportunity to assist you with this project. Please contact this office at 704-357-8600 if you have any questions. We look forward to continuing our working relationship with you on this and future projects.

Sincerely,

**LAW ENGINEERING AND ENVIRONMENTAL SERVICES**

M.N. Parikh

Mike N. Parikh, P.E.
Senior Engineer

Lakshman Santanam

Lakshman Santanam, P.E.
Director of Projects

Attachment: Figure: 1
Facsimile Copy from Ms. Heather dated July 30, 1997 (Fiberfrax Duraboard Product Specifications)
Facsimile Copy from Ms. Heather dated July 23, 1997

FILE COPY

November 16, 1999

Eco-Pak Specialty Packaging
Division of CBC
200 West Railroad Street
Columbiana, OH 44408

Attention: Mr. Mike Arnold/Mr. Jerry Rasel

Subject: **Report of Thermal Analysis**
**Eco-Pak Liqui-Rad-250 Shipping Container**
**Law Engineering and Environmental Services Project 10810-9-7003, Phase 13**

Dear Mr. Arnold:

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**Background Information**

Mr. Mike Arnold and Ms. Heather Little of Eco-Pak Specialty Packaging requested LAW to perform a thermal analysis of the subject container during a 30 minute fire test considering the following conditions:

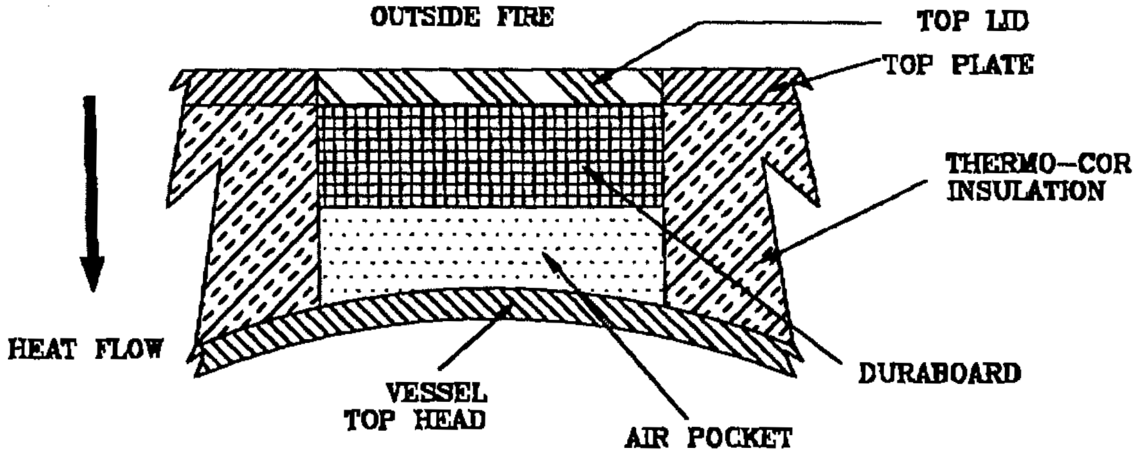
- Container is ½ full of water (approximately 125 gallons of water).
- Initial temperature of inside vessel and water is 100°F.
- Outside fire temperature is 1500°F (constant).

We were provided the following drawings:

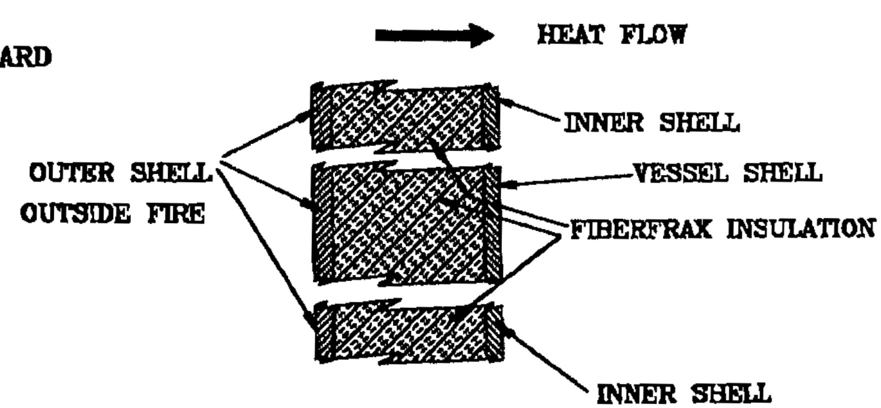
- Preliminary Design Arrangement for the Eco-Pak Liqui-Rad-250 Drawing No. 111898/250 Sheet 1 of 2

# SCHEMATIC OF HEAT TRANSFER BY CONDUCTION

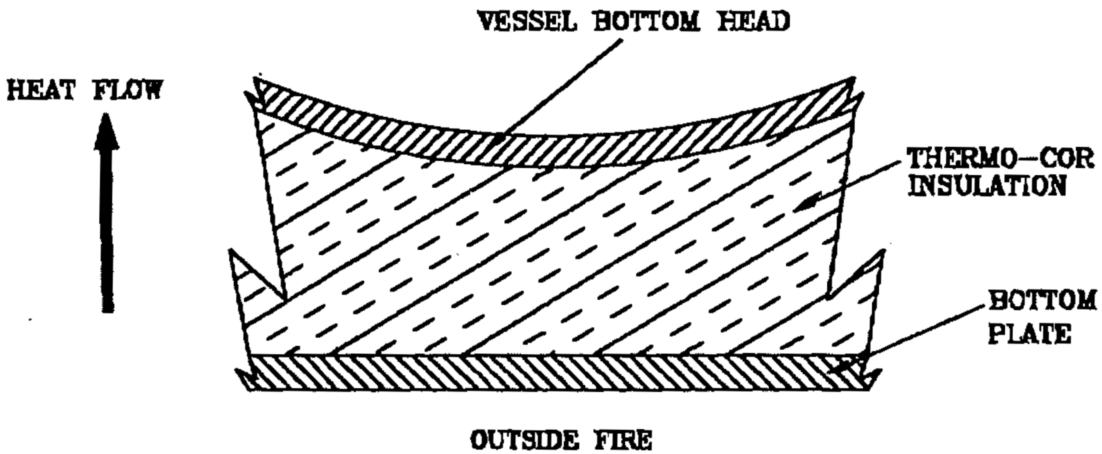
## HEAT TRANSFER THROUGH THE TOP SECTION




## HEAT TRANSFER THROUGH THE SHELL




## HEAT TRANSFER THROUGH THE BOTTOM SECTION




LAWGIBB GROUP

LAW ENGINEERING
INDUSTRIAL SERVICES
CHARLOTTE, NORTH CAROLINA

ECO-PAK, SPECIALTY PACKAGING
ECO-PAK LIQUI-RAD-250 SHIPPING CONTAINER
COLUMBIA, OH

| | |
|---|---|
| JOB#: 10810-9-7003 | FIGURE: 1 |
| DRAWN BY: MNP | SCALE: NTS |
| APPR'D BY: LS | DATE:11-15-99 |

Heather Little
Eco-Pak Specialty Packaging
107 Meadowview Farms Drive
Jonesborough, TN 37659
Phone/Fax: (423) 913-1205

# facsimile transmittal

| | | | |
|---|---|---|---|
| **To:** | Mike Parikh | **Fax:** | 704-357-8637 |
| **From:** | Heather Little | **Date:** | July 30, 1999 |
| **Re:** | Thermal Conductivities | **Pages:** | 5 |
| **CC:** | | | |

☐ Urgent ☐ For Review ☐ Please Comment ☐ Please Reply ☐ Please Recycle

Mike:

I have more data points for the Duraboard LD than those shown on the following pages. They are:

| | |
|---|---|
| 400°F | 0.556 Btu-in/hr-ft$^2$-°F |
| 600 | 0.631 |
| 800 | 0.727 |
| 1000 | 0.847 |
| 1200 | 0.988 |
| 1400 | 1.15 |
| 1600 | 1.33 |
| 1800 | 1.54 |
| 2000 | 1.78 |

Hope these help. The graph I used to get approximately 0.45 is on the last page.

Have a good vacation!!

Best regards,

Heather

Heather

CARBORUNDUM

The Carborundum Company
Fibers Division
P.O. Box 808
Niagara Falls, New York 14302-0808
Telephone: 716 278-6221 Telex: 68-54335
Telefax: 716 278-4962
Cable (Foreign): CRBCINUW

# Fiberfrax® Duraboard™ Products

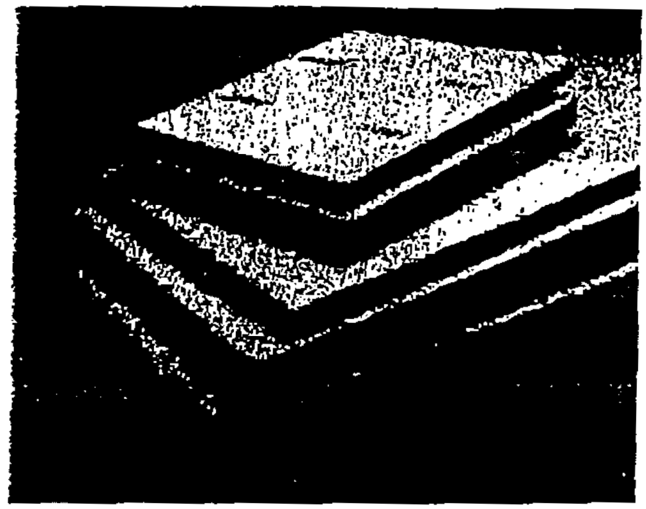
# Product Specifications

## Introduction

Fiberfrax® Duraboard™ products are a family of rigid, high temperature ceramic fiber boards manufactured in a wet forming process using Carborundum® Fiberfrax alumina-silica fibers and binders. All Duraboard products offer low thermal conductivity, high temperature stability, uniform density, and excellent resistance to thermal shock and chemical attack.

They are also well-suited for applications experiencing vibration, mechanical stress and strong erosive forces. The excellent rigidity and modulus of rupture possessed by these boards makes them strong and self-supporting, yet relatively lightweight and easy to cut or machine.

These product features allow for quick, efficient handling and high installation rates, thereby enabling fast turnaround times in a variety of industrial insulation applications. Once installed, they can help reduce energy costs and cycling times due to their high insulating capability, as well as serving to protect refractory surfaces from thermal shock.



## Product Range

| Temperature | Density | Board | Description |
|---|---|---|---|
| 2300°F | 15-18# | RG | — A rolled, rigidized surface finish and high MOR give a tough, economic refractory grade product. |
| | 15-18# | LD | — A higher quality surface finish and tighter dimensional tolerances make this board suitable for use in situations where aesthetic quality as well as performance is important. |
| | 24-28# | HD | — The addition of clay gives a higher density, MOR, and strength. |
| | 35# | GH | — A board manufactured with inorganic binding agents and post-soaked to give an inorganic, high density product. |
| 2600°F | 12-14# | 2600 | — Formed from a special blend of regular Fiberfrax alumina silica fibers and Fibermax® Mullite fibers. These boards give high stability at elevated temperatures. |
| 3000°F | 10-12# | 3000 | — Formed from a special blend of regular Fiberfrax alumina silica fibers and Fibermax Mullite fibers. These boards give high stability at elevated temperatures. |

Mike
7 4 [illegible]

## Availability

| Sheet Size | Thickness 1/8" 3 mm | 1/4" 6 mm | 1/2" 13 mm | 1" 25 mm | 1 1/2" 38 mm | 2" 51 mm |
|---|---|---|---|---|---|---|
| 12x36<br>305x914 mm | | GH* | | HD | HD | HD |
| 18x18<br>457x457 mm | | | | 2600<br>3000 | 2600<br>3000 | 2600<br>3000 |
| 24x24<br>610x610 mm | | | | 2600<br>3000 | 2600<br>3000 | 2600<br>3000 |
| 24x36<br>610x914 mm | | LD | LD | LD<br>HD | LD<br>HD | LD<br>HD |
| 24x48<br>610x1120 mm | | LD | LD | RG<br>LD<br>HD<br>2600<br>3000 | LD<br>HD<br>2600<br>3000 | RG<br>LD<br>HD<br>2600<br>3000 |
| 42x48 | LD | LD | LD | | | |

Duraboard™ HD & Duraboard LD are available 3" & 4" thick by special order. *Other sizes by special request.

## Product Properties

| Properties | | Board RG | | LD | | HD | | GH | | 2600 | | 3000 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nominal Density | lb/ft³ kg/m³ | 18 | 288 | 16 | 256 | 26 | 419 | 35 | 560 | 14 | 224 | 12 | 192 |
| Continuous Use Limit | °F/°C | 2300 | 1260 | 2300 | 1260 | 2300 | 1260 | 2300 | 1260 | 2600 | 1427 | 3000 | 1649 |
| Product Melting Point | °F/°C | 3200 | 1760 | 3200 | 1760 | 3200 | 1760 | 3200 | 1760 | 3300 | 1816 | 3400 | 1871 |
| MOR PSI | Green (typ.)<br>Fired (24 hrs @ cont. use) | 250<br>110 | | 200<br>60 | | 300<br>125 | | 300<br>125 | | 150<br>65 | | 150<br>55 | |
| LOI (% by Wt) | | 5-7% | | 6-7% | | 6-7% | | 0 | | 4-6% | | 4-6% | |
| Dielectric Strength | | — | | 27 volts/mil | | 27 volts/mil | | 27 volts/mil | | — | | — | |
| Color | | Cream to tan | | Cream/white | | Cream | | White | | Cream | | Cream | |
| Shrinkage | (%) | | | | | | | | | | | | |
| 24 Hrs @ Cont. Use Limit | | 5% | | 4.6% | | 4.5% | | 5% | | 1.5 (168 hrs 1.5) | | — | |
| 24 Hrs @ 1600°F/817°C | | — | | — | | — | | 0% | | — | | — | |
| 24 Hrs @ 1800°F/920°C | | — | | 1.8% | | 1.7% | | — | | — | | — | |
| 24 Hrs @ 2540°F/1343°C | | — | | — | | — | | — | | 1.4% | | 1.0% | |
| 24 Hrs @ 2600°F/1427°C | | — | | — | | — | | — | | — | | 1.0% | |
| 24 Hrs @ 2700°F/1482°C | | — | | — | | — | | — | | — | | 1.2% | |
| 168 Hrs @ 2450°F/1343°C | | — | | — | | — | | — | | 1.4% | | 1.2% | |
| Compressive Strength | lb/in² | Green | Fired | Green | Fired | Green | Fired | Green | Fired | Green | Fired | Green | Fired |
| Deformation @ | 5% | 46 | 25 | 42 | 23 | 59 | 35 | — | — | 22 | 19 | 42 | 14 |
| | 10% | 61 | 25 | 50 | 22 | 70 | 33 | — | — | 25 | 18 | 44 | 14 |
| | 15% | 71 | 25 | 57 | 23 | 81 | 32 | — | — | 27 | 18 | 47 | 14 |
| Fiber Content | | | | | | | | | | | | | |
| Fiberfrax®** | | 100% | | 100% | | 100% | | 100% | | 75% | | 50% | |
| Fibermax®*** | | | | | | | | | | 25% | | 50% | |
| Thermal Conductivity**** | Temperature | Btu-in/hr ft² °F | | | | | | | | | | | |
| | 600°F/316°C | 0.82 | | 0.82 | | 0.82 | | 0.74 | | 0.50 | | 0.47 | |
| | 1000°F/538°C | 0.85 | | 0.85 | | 0.85 | | 1.07 | | 0.71 | | 0.73 | |
| | 1400°F/760°C | 1.14 | | 1.14 | | 1.44 | | 1.44 | | 1.02 | | 1.16 | |
| | 1800°F/982°C | 1.53 | | 1.53 | | 1.56 | | 1.83 | | 1.36 | | 1.70 | |
| | 2200°F/1093°C | — | | — | | — | | — | | 1.85 | | 2.40 | |

**Fiberfrax is Carborundum's patented 2300°F/1260°C amorphous alumina-silica fiber.
***Fibermax is Carborundum's patented 3000°F/1649°C polycrystalline mullite fiber.
****As per ASTM C-177.

Form C-1434
New 3/96

Printed in U.S.A.


CARBORUNDUM

### Typical Physical Properties

| | Duraback™ | Durablanket® S | Durablanket HP-S | Durablanket 2600 |
|---|---|---|---|---|
| Color | White | White | White | White |
| Continuous Use Limit* | 982°C (1800°F) | 1260°C (2300°F) | 1260°C (2300°F) | 1430°C (2600°F) |
| Melting Point | 1648°C (3000°F) | 1760°C (3200°F) | 1760°C (3200°F) | 1760°C (3200°F) |
| Fiber Diameter | 2-4 microns (mean) | 2.5-3.5 microns (mean) | 2.5-3.5 microns (mean) | 3.6 microns (average) |
| Specific Heat @ 1093°C (2000°F) | 1130 J/kg °C (0.27 Btu/lb °F) | 1130 J/kg °C (0.27 Btu/lb °F) | 1130 J/kg °C (0.27 Btu/lb °F) | 1130 J/kg °C (0.27 Btu/lb °F) |
| Specific Gravity | 2.73 g/cm³ | 2.73 g/cm³ | 2.73 g/cm³ | 2.73 g/cm³ |
| Average Tensile Strength (ASTM 686-76) | — | 5.5 lb/in² @ 4 PCF<br>8.9 lb/in² @ 6 PCF<br>12.5 lb/in² @ 8 PCF | — | — |
| Available Density kg/m³ (lb/ft³) | 64 (4) | 64, 96, 128 (4, 6, 8) | 64, 96, 128 (4, 6, 8) | 96, 128 (6, 8) |

### Typical Chemical Analysis

| | PH Blanket | Moist-Pack™ D | Fibermat™ Blanket | Fibermax® Mat |
|---|---|---|---|---|
| $Al_2O_3$ | 44% | 34.6% | 31-35% | 72% |
| $SiO_2$ | 51% | 62.8% | 50-54% | 27% |
| $ZrO_2$ | 5% | — | 5% | — |
| $Fe_2O_3$ | — | 0.64-0.80% | 1.3% | 0.02% |
| $TiO_2$ | — | 0.54-1.37% | 1.7% | 0.001% |
| MgO | — | — | **0.5% | 0.05% |
| CaO | — | — | ≤7.5% | 0.05% |
| $Na_2O_3$ | — | — | — | 0.10% |
| Alkali | — | 0.23% | — | — |
| Leachable Chlorides | <10 ppm | — | <10 ppm | 11 ppm |
| Other Inorganics | — | — | — | — |

### Typical Physical Properties PH Blanket

| | |
|---|---|
| Color: | Tan |
| Continuous Use Limit*: | 1260°C (2300°F) |
| Melting Point: | 1790°C (3260°F) |
| Fiber Diameter: | |
| PH Fine: | 5 microns (mean) |
| PH Coarse: | 13 microns (mean) |
| Fiber Length: | Up to approximately 254 mm (10") |
| Density: | 96 kg/m³ (6 lb/ft³) |
| Binder Content: | 3-5% |

### Typical Physical Properties Moist-Pack D

| | |
|---|---|
| Color: | White |
| Basic Composition: | Alumina-silica |
| Recommended Use Limit*: | 1093°C (2000°F) |
| Melting Point: | 1790°C (3260°F) |
| Typical Dry Density: | 190-290 kg/m³ (12-18 lb/ft³) |
| Specific Heat Capacity at 1093°C (2000°F): | 1130 J/kg °C (0.27 Btu/lb °F) |
| Tensile Strength - 6.4 mm (¼"): | Wet = 1.2 x 10⁵ N/m² (17 psi)<br>Dry = 3.5 x 10⁵ N/m² (50 psi) |
| Hot Gas Erosion Resistance: | Test procedure based on British Gas Council Research Comm. GC173 = over 30.5 m/sec (100 ft/sec) |

Normal shelf life one year in unopened containers.

*The continuous use limit of Fiberfrax® insulation is determined by irreversible linear change criteria, not product melting point.
**MgO and other trace inorganics

Form C-1421
New 8/90

Printed in U.S.A.


CARBORUNDUM

### Typical Physical Properties
### Fibermat™ Blanket

| | |
|---|---|
| Color: | White |
| Continuous Use Limit*: | 760°C (1400°F) |
| Fiber Diameter: | 2.5-3.5 microns (mean) |
| Specific Gravity: | 2.73 g/cm³ |
| Nominal Weight: | ½" thickness = 3.7 oz/ft² |
| | 1" thickness = 7.3 oz/ft² |
| | 2" thickness = 14.7 oz/ft² |
| Tensile Strength (ASTM 686-76): | 7-10 psi (typical) |

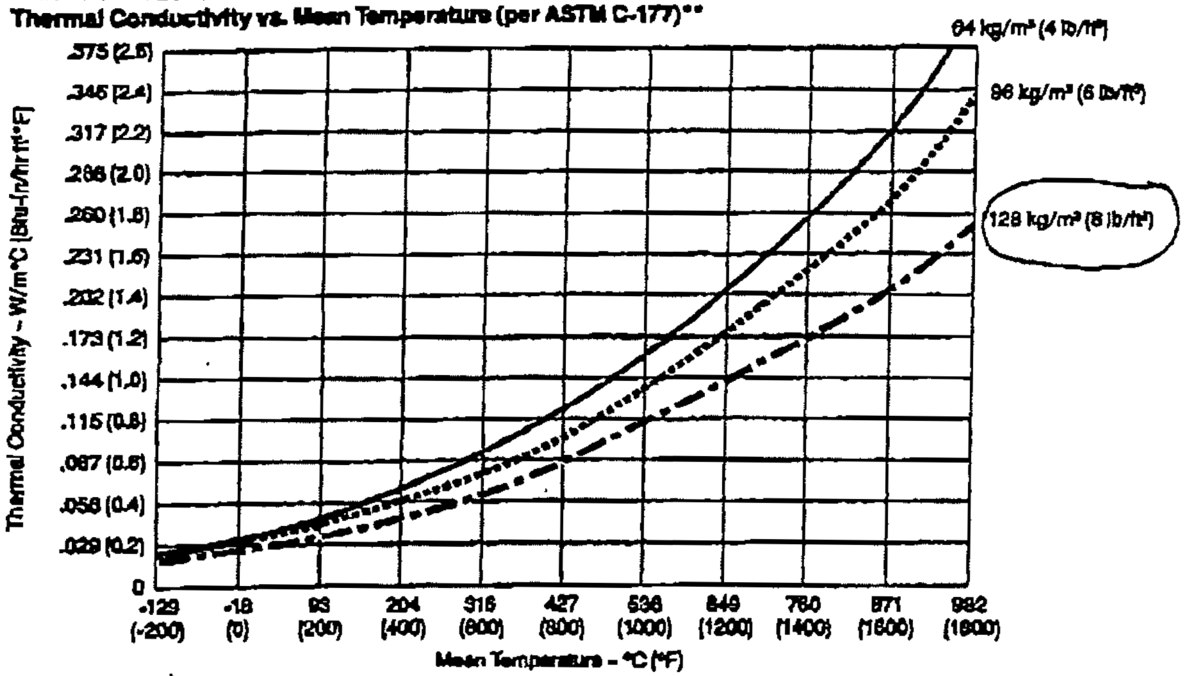
### Typical Mechanical Properties
### Compression Recovery

| Percent Compression | Percent Recovery |
|---|---|
| 10 | 93 |
| 30 | 82 |
| 50 | 71 |

### Typical Physical Properties
### Fibermax® Mat

| | |
|---|---|
| Color: | White |
| Continuous Use Limit*: | 1650°C (3000°F) |
| Melting Point: | 1870°C (3400°F) |
| Fiber Diameter: | 2-3.5 microns (mean) |
| Specific Gravity: | 3 g/cm³ |
| Specific Heat Capacity at 1093°C (2000°F): | 1246 J/kg °C (0.297 Btu/lb °F) |
| Fiber Surface Area: | 7.65 m²/g |

**Duraback™**
**Durablanket® S**
**Durablanket HP-S**
**Durablanket 2600**
**Thermal Conductivity vs. Mean Temperature (per ASTM C-177)****




*The continuous use limit of Fiberfrax® insulation is determined by irreversible linear change criteria, not product melting point.

**All heat flow calculations are based on a surface emissivity factor of 0.90, an ambient temperature of 27°C (80°F), and zero wind velocity, unless otherwise stated. All thermal conductivity values for Fiberfrax materials have been measured in accordance with ASTM Test Procedure C-177. When comparing similar data, it is advisable to check the validity of all thermal conductivity values and ensure the resulting heat flow calculations are based on the same condition factors. Variations in any of these factors will result in significant differences in the calculated data.





CARBORUNDUM

Heather Little
Eco-Pak Specialty Packaging
107 Meadowview Farms Drive
Jonesborough, TN 37659
Phone/Fax: (423) 913-1205

# facsimile transmittal

| | | | |
|---|---|---|---|
| **To:** | Mike Parikh | **Fax:** | 704-357-8637 |
| **From:** | Heather Little | **Date:** | July 23, 1999 |
| **Re:** | Thermal Conductivities | **Pages:** | 1 |
| **CC:** | | | |

☐ Urgent ☐ For Review ☐ Please Comment ☐ Please Reply ☐ Please Recycle

**Mike:**

I can't get the specifications of the following materials sent today, but I believe the following thermal conductivity numbers (Btu-in/hr-ft$^2$-°F) can be used:

| | |
|---|---|
| ESP-PF-1 Phenolic Foam | 0.318 |
| Fiberfrax 1/2-inch and 2-inch 8 pcf Insulation | 0.200 |
| 1/2-inch Duraboard LD | ? |

I wish I had more, but I will try to get more detail and confirmation of these numbers to you, Monday morning.

Have a good weekend!

Heather

Heather

# SECTION FOUR
# CONTAINMENT

## TABLE OF CONTENTS



## LIST OF TABLES

# 4 CONTAINMENT

## 4.1 Containment Boundary

The containment boundary is defined as the containment vessel, primary lid (excluding the portion inside the secondary wall) and seal, and secondary lid and seal.

### 4.1.1 Containment vessel

Although it is not stamped as such, the containment vessel is built in accordance with the ASME pressure vessel Code (Section VIII Division 1). The containment vessel's primary closures are at the primary and secondary lids. The primary lid is sealed using a double O-ring and is secured by sixteen 5/8" stainless steel studs and nuts. The primary lid includes a fill port consisting of a vent and pressurization valve and a stainless steel threaded (plugged) quick-disconnect fitting. The secondary lid assembly provides a sealed enclosure around the valving and fittings on the primary lid. The secondary lid is sealed using a double O-ring and is secured by twelve 5/8" stainless steel bolts and nuts.

### 4.1.2 Containment Penetrations

The LR containment vessel has no penetrations.

### 4.1.3 Seals and Welds

The containment vessel uses four circumferential welds: the joint between the lower head and the vessel body, the joint between the upper head and the vessel body, the joint between the upper head and the studding outlet, and the joint on the primary lid assembly. All welds are completed, inspected, tested, and maintained in accordance with Drawing Number LR-SAR, Sheets 1, 2, 3, & 4 for the Liqui-Rad Transport Unit (Appendix 1.3.1). Minimum requirements are specified in Sections 7 and 8 of this Safety Analysis Report.

Both the primary and secondary lids are sealed using a double O-ring rated for continuous use up to 400°F.

### 4.1.4 Closure

The containment vessel has two closures, one at the primary lid and one at the secondary lid. The primary lid is sealed using a double O-Ring and is secured by sixteen 5/8" stainless steel studs and nuts. The secondary lid is sealed using a double O-ring and is secured by twelve 5/8" stainless steel bolts and nuts. The closure torque required for each bolt or stud is 75 ft.-lbs. [+10-0].

## 4.2 Requirements for Normal Conditions of Transport

### 4.2.1 Containment of Radioactive Material

The package contents, as defined in Section 1.2.3, are assumed to be completely releasable in the form of uranyl nitrate liquid at the maximum Normal Hot content temperature (179°F) and the maximum Normal Hot pressure for the package (16.7 psia) (see Section 3). It is noted that the Normal Cold pressure is higher (32.0 psia); however, the contents are solid under the Normal Cold condition and therefore are not completely releasable. Thus, the Normal Hot condition is bounding.

The maximum total radioactivity contained in the package is 2.32 Ci (calculated in Table 4-1). The maximum volume of liquid contained in the cylinder is 9.96E05 $cm^3$. The radioactivity concentration (releasable activity per unit volume) of the package for both Normal and Hypothetical Accident conditions is therefore:

$$2.32 \text{ Ci} / 9.96\text{E}05 \text{ cm}^3 = 2.33\text{E-}06 \text{ Ci/cm}^3.$$

The $A_2$ value for the mixture in the package is 0.192 Ci (calculated in Table 4-2). 6s

The maximum allowable release rate for normal conditions, per ANSI N14.5-1997, is:

$$10^{-6} A_2 \text{ per hour} = 10^{-6} (0.192 \text{ Ci}) \text{ per hour} = 5.3\text{E-}11 \text{ Ci/sec.}$$ 6s

The maximum allowable leakage rate for normal conditions is:

$$5.3\text{E-}11 \text{ Ci/sec} / 2.33\text{E-}06 \text{ Ci/cm}^3 = 2.3\text{E-}05 \text{ cm}^3\text{/sec uranyl nitrate solution.}$$

For the normal condition, the uranyl nitrate is conservatively assumed to be liquid with the properties of water. The leakage of liquid from the package is assumed to be laminar, and Poiseuille's Law is applied consistent with the methods described in ANSI N14.5-1997. The uranyl nitrate maximum allowable leakage rate is correlated to the reference air leakage rate using the methods described in ANSI N14.5-1997 Annex B and the conditions listed in Table 4-3. The calculated allowable leak rate for the package for the normal condition is 1.72E-3 ref-$cm^3$/sec.

### 4.2.2 Pressurization of Containment Vessel

Although the LR is designed as an ASME pressure vessel, the contents are not meant to be shipped in a pressurized environment. Pressurization of the vessel will occur if the contents are permitted to exceed the boiling point of the solution; however, all tests for heat, cold, and fire demonstrate that the solution is maintained well below the boiling point under normal and hypothetical accident conditions.

During cold weather shipments it is possible that the contents will freeze. The volumetric expansion of the contents due to the phase change causes a reduction in the air headspace, resulting in a pressure increase to 31 psia (see Section 3.3.3). In addition, the UN solution produces hydrogen gas due to radiolysis. The hydrogen production rate, calculated in Section 2.4.4.2, is 1.7 liters/year. After a year of transport time, under the Normal Cold (frozen) condition, the maximum internal pressure is 31.4 psia.

The internal pressure of the containment vessel is maintained below the design pressure of 50 psig under normal and hypothetical accident conditions.

### 4.2.3 Containment Criterion

Leak tests will be performed pre-shipment per the requirements of ANSI N14.5-1997, as described in Section 7. Leak tests will be performed post-fabrication and periodically per the requirements of ANSI N14.5-1997, as described in Section 8. Post-fabrication, the package containment boundary is tested to leaktight conditions. The maximum allowable leakage rate of 1.72E-03 ref-cc/sec (as bounded by the normal condition) is conservatively reduced to 1.00E-03 ref-cc/sec for periodic and pre-shipment tests. 6s

Leak test ports are provided at each double O-ring seal to facilitate the required leak tests. Although several optional leak test port configurations are provided, all perform in the same manner. Further information concerning the optional test port designs is provided in Appendix 2.10.9.

The primary lid is usually only operated during periodic testing and maintenance activities; therefore, it has been fitted with loops to secure tamper-indicating devices. The devices are intended to indicate to the User whether or not the lid has been operated in the time since the last periodic test. If the primary lid has not been opened from the time of the last periodic test (as indicated by the presence of the tamper indicating devices located at the primary lid seal), the pre-shipment leakage test may be waived for the primary lid only.

## *4.3 Containment Requirements for Hypothetical Accident Conditions*

### 4.3.1 Fission Gas Products

Fission gas products are not present in the contents to be transported in the LR.

### 4.3.2 Containment of Radioactive Material

The package contents, as defined in Section 1.2.3, are assumed to be completely releasable in the form of uranyl nitrate liquid at the maximum allowable working temperature (210°F) and a conservative bounding pressure for the package (100 psig). The maximum total radioactivity contained in the package is 2.32 Ci (calculated in Table 4-1). The maximum volume of liquid contained in the cylinder is 9.96E05 $cm^3$. The radioactivity concentration (releasable activity per unit volume) of the package for both Normal and Hypothetical Accident conditions is therefore:

$$2.32 \text{ Ci} / 9.96\text{E}05 \text{ cm}^3 = 2.33\text{E-}06 \text{ Ci/cm}^3.$$

The $A_2$ value for the mixture in the package is 0.192 Ci (calculated in Table 4-2).

The maximum allowable release rate for HAC, per ANSI N14.5-1997, is:

$$A_2 \text{ per week} = (0.192 \text{ Ci}) \text{ per week} = 3.2\text{E-}7 \text{ Ci/sec.}$$

The maximum allowable leakage rate for HAC is:

$$3.2\text{E-}7 \text{ Ci/sec} / 2.33\text{E-}06 \text{Ci/cm}^3 = 1.4\text{E-}01 \text{ cm}^3\text{/sec uranyl nitrate solution.}$$

The uranyl nitrate maximum allowable leakage rate is correlated to the reference air leakage rate using the methods described in ANSI N14.5-1997 Annex B and the conditions listed in Table 4-4. The calculated maximum allowable leak rate calculated for the package for HAC is 1.60E-01 ref-$cm^3$/sec.

### 4.3.3 Containment Criterion

Leak tests will be performed pre-shipment per the requirements of ANSI N14.5-1997, as described in Section 7. Leak tests will be performed post-fabrication, periodically, and pre-shipment per the requirements of ANSI N14.5-1997, as described in Section 8. Post-fabrication, the package containment boundary is tested to leaktight conditions. The maximum allowable leakage rate of 1.72E-03 ref-cc/sec (as bounded by the normal condition) is conservatively reduced to 1.00E-03 ref-cc/sec for periodic and pre-shipment tests. 6s

Leak test ports are provided at each double O-ring seal to facilitate the required leak tests. Although several optional leak test port configurations are provided, all perform in the same manner. Further information concerning the optional test port designs is provided in Appendix 2.10.9.

The primary lid is usually only operated during periodic testing and maintenance activities; therefore, it has been fitted with loops to secure tamper-indicating devices. The devices are intended to indicate to the User whether or not the lid has been operated in the time since the last periodic test. If the primary lid has not been opened from the time of the last periodic test (as indicated by the presence of the tamper indicating devices located at the primary lid seal), the pre-shipment leakage test may be waived for the primary lid only.

**Table 4-1 Package Total Maximum Radioactivity**[1]

| Isotope | Maximum content | Maximum mass, g | Specific Activity[2], TBq/g | Total Activity, TBq | Total Activity, Ci |
|---|---|---|---|---|---|
| U232 | 2.00E-09 g/gU | 2.49E-04 | 0.83 | 2.07E-04 | 5.60E-03 |
| U234 | 2.00E-03 g/gU | 2.49E+02 | 2.30E-04 | 5.74E-02 | 1.55E+00 |
| U235 | 5.00E-02 g/gU | 6.24E+03 | 8.00E-08 | 4.99E-04 | 1.35E-02 |
| U236 | 2.50E-02 g/gU | 3.12E+03 | 2.40E-06 | 7.48E-03 | 2.02E-01 |
| U238 | 9.23E-01 g/gU | 1.15E+05 | 1.20E-08 | 1.38E-03 | 3.73E-02 |
| NP237 | 1.66E-06 g/gU | 2.07E-01 | 2.61E-05 | 5.40E-06 | 1.46E-04 |
| PU238 | 6.20E-11 g/gU | 7.73E-06 | 6.33E-01 | 4.90E-06 | 1.32E-04 |
| PU239/240 | 3.04E-09 g/gU | 3.79E-04 | 3.60E-03 | 1.37E-06 | 3.69E-05 |
| Gamma Emitters | 1.91E+08 MeV-Bq | N/A | N/A | 1.90E-02 | 5.15E-01 |
| Total | | | | **0.09** | **2.32** |

[1] Based on 263 gallons at 125 gU/l.

[2] 10CFR71, App. A

**Table 4-2 Mixture $A_2$ Calculation**

| Isotope | Maximum Radioactive content (Ci) | 10CFR71 $A_2$ per isotope (Ci) | Activity Fraction | $A_2$ Fraction |
|---|---|---|---|---|
| **U232** | 5.60E-03 | 0.027 | 2.41E-03 | 8.93E-02 |
| **U234** | 1.55E+00 | 0.16 | 6.67E-01 | 4.17E+00 |
| **U235** | 1.35E-02 | Unlimited | N/A | N/A |
| **U236** | 2.02E-01 | 0.16 | 8.69E-02 | 5.43E-01 |
| **U238** | 3.73E-02 | Unlimited | N/A | N/A |
| **NP237** | 1.46E-04 | 0.054 | 6.28E-05 | 1.16E-03 |
| **PU238** | 1.32E-04 | 0.027 | 5.68E-05 | 2.10E-03 |
| **PU239/240** | 3.69E-05 | 0.027 | 1.59E-05 | 5.88E-04 |
| **Gamma Emitters** | 5.15E-01 | 0.54 | 2.22E-01 | 4.10E-01 |
| Total | **2.32** | | | **5.22** |
| Mixture $A_2$ | | | | **0.192 Ci** |

**Table 4-3 Normal Condition Fluid Properties**

| Property | Uranyl Nitrate Solution Normal Condition | Equivalent Reference Air |
|---|---|---|
| Upstream Pressure, atm | 1.136[3] | 1.00 |
| Downstream Pressure, atm | 1.00 | 0.01 |
| Temperature, K | 355 | 298 |
| Molecular Weight, g/gmol | N/A | 29 |
| Viscosity, cP | 0.3460[4] | 0.0185 |
| Assumed hole length, cm | 1.0 | 1.0 |
| Hole diameter[5], cm | 1.435E-03 | 1.435E-03 |

**Table 4-4 HAC Fluid Properties**

| Property | Uranyl Nitrate Solution HAC Condition | Equivalent Reference Air |
|---|---|---|
| Upstream Pressure, atm | 7.80[6] | 1.00 |
| Downstream Pressure, atm | 1.00 | 0.01 |
| Temperature, K | 372 | 298 |
| Molecular Weight, g/gmol | N/A | 29 |
| Viscosity, cP | 0.2848[7] | 0.0185 |
| Assumed hole length, cm | 1.0 | 1.0 |
| Hole diameter[8], cm | 4.5E-03 | 4.5E-03 |

---

[3] Normal Hot pressure for the vessel.

[4] Physical properties of water, CRC Handbook, 60th Edition, CRC Press, Boca Raton, FL, 1980.

[5] Calculated for Uranyl Nitrate per ANSI N14.5-1997 Annex B, Section B.3, Equations B.3 and B.9.

[6] Conservative bounding pressure for the package.

[7] Viscosity of water, CRC, 60th Edition, CRC Press, Boca Raton, FL, 1980.

[8] Calculated for Uranyl Nitrate per ANSI N14.5-1997 Annex B, Section B.3, Equations B.3 and B.9.

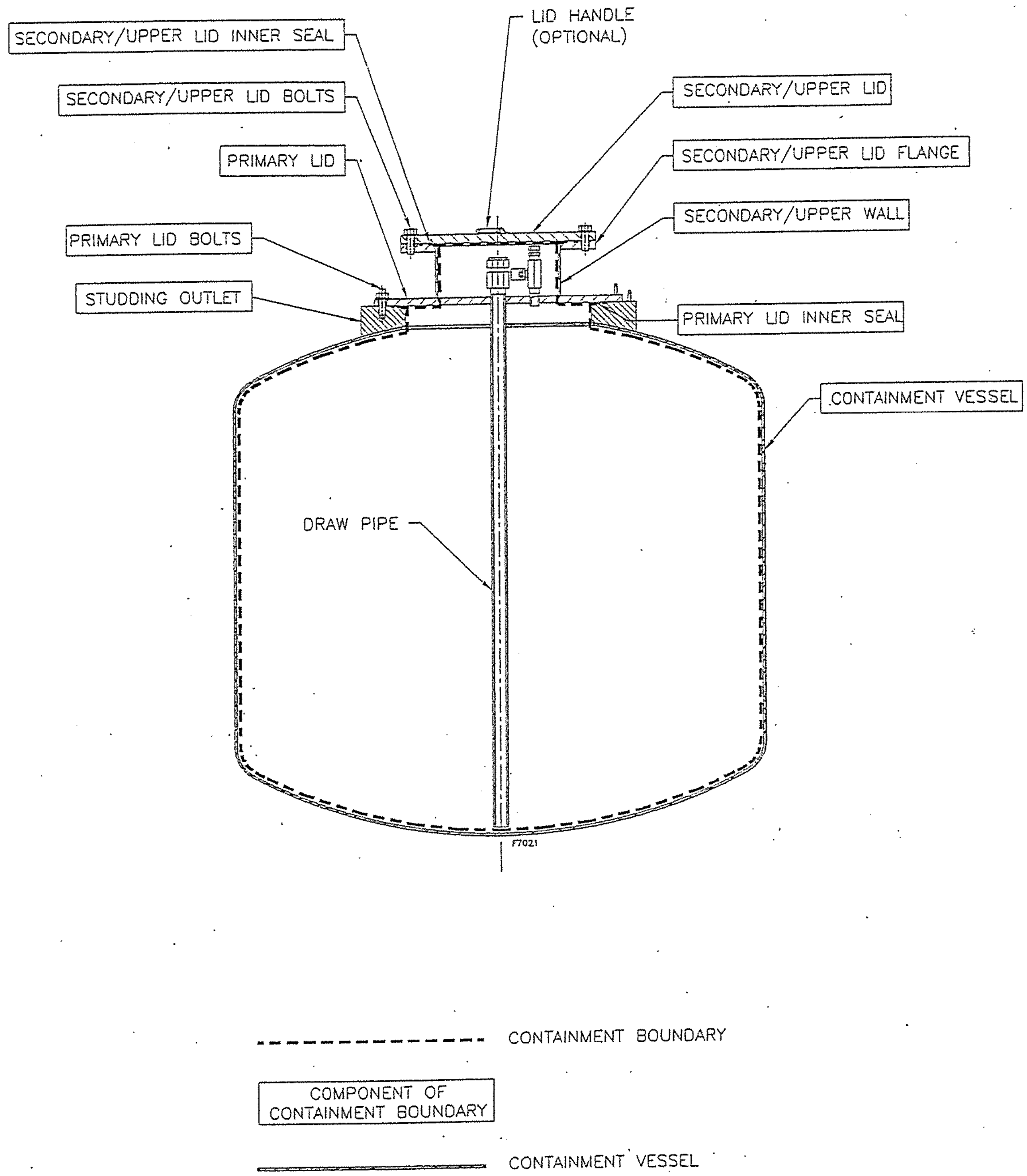



FIGURE 4-1 CONTAINMENT BOUNDARY

# SECTION 5
# SHIELDING EVALUTATION

# 5 SHIELDING EVALUATION

Gamma and neutron shielding is not required for the vessel because the 3/16-inch thick storage vessel walls provide more than adequate shielding for the material being transported. The estimated dose rate on the surface of the package is less than 5 mrem/h, based on the worst case contents and 263 gallons (996 liters). This dose rate is well below the limits specified in 10CFR71.47. However, it is the responsibility of the shipper to assure compliance with 10CFR71.47 regarding radiation standards for each shipment.

# SECTION 6
# CRITICALITY EVALUATION

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# 6 Criticality Evaluation

The Liqui-Rad is a Type B packaging designed for shipment of uranyl nitrate solution with concentrations up to 125 grams of Uranium per liter and enriched to 5wt% U-235. Non-fissile chemical impurities do not adversely impact the critical behavior of the material and packaging; therefore, they may be present in any quantity in the uranyl nitrate solution. Fissile impurities are limited to the quantities specified in Table 6-1. Although U-233 is included in the criticality evaluation for conservatism, actual U-233 content in the solution remains below measurable quantities. Any number of packages may be stored together in any arrangement in either a vertical or horizontal orientation.

The Liqui-Rad consists of a stainless steel cylindrical containment vessel with a total capacity of 263 gallons (996 liters) including ullage encased in a carbon steel cylindrical outer liner. A rectangular frame constructed of carbon steel angle provides stability for the package. The overall package dimensions are 56" x 56" x 73". The overall height of the containment vessel is 41.1875" with an outer diameter of 46.25". The volume between the containment vessel and the outer packaging surface is filled with a fire-retardant foam and fibrous insulation. The containment vessel is centered radially within the outer shell. An insulation-filled gap of approximately 6.5" and 12" exists between the bottom and the top, respectively, of the containment vessel and the outer shell.

## *6.1 Discussion and Results*

Criticality control of the Liqui-Rad relies on control of the uranyl nitrate concentration and enrichment, and non-U235 fissile impurity levels. An unlimited number of packages containing uranyl nitrate solution at the maximum enrichment and concentration, with the maximum quantities of the isotopes specified in Table 6-1, are subcritical with optimum interspersed hydrogenous moderation under Normal conditions. Additionally, an infinite array of packages is subcritical in any arrangement under Hypothetical Accident conditions with optimum interspersed hydrogenous moderation.

Table 6-2 provides a summary of the results of the criticality evaluation of the Liqui-Rad. A detailed description of the analytical models and methodology is provided in Section 6-4.

For Uranyl Nitrate concentrations less than or equal to 125 gU/L and enrichment ≤5w% U-235, an unlimited number of packages may be shipped together in any arrangement and no nuclear criticality safety controls are required during transport. Therefore, the Criticality Safety Index (CSI) is 0.

## *6.2 Package Fuel Loading*

Table 6-3 summarizes the maximum fuel loading and conditions for the Normal and Hypothetical Accident conditions. The nominal fuel loading for the Liqui-Rad is 230 gallons (870 liters) of uranyl nitrate solution at a concentration of 125 gU/L or less and enriched to 5wt% U-235 or less. It is possible to over-fill the package, resulting in a maximum fuel loading of 263 gallons (996 liters). The fuel is assumed to be in solution form, with no free acid, under Normal conditions. Under Hypothetical Accident conditions, the entire mass of the fuel is assumed to be concentrated and/or crystallized in the cylinder. Both the Normal and Hypothetical Accident fuel loadings are conservative with respect to anticipated working loads.

## *6.3 Model Specification*

### 6.3.1 Description of Calculational Model

The Liqui-Rad is a large package, and as such, there is very little neutron leakage from the package. Each package is an isolated system. Therefore, modeling a single package yields the same result as modeling an infinite array of the packages. However, the number of packages stipulated by regulatory requirements has been analyzed for expediency.

#### 6.3.1.1 Normal Conditions of Transport

The Normal Transport condition postulates an unlimited number of Liqui-Rad packages, close-packed in a rectangular-pitched infinite array, with optimum interspersed moderation. Table 6-4 provides the materials and key dimensions for the Liqui-Rad [Reference 6.1]. The maximum volume of liquid contained in the package is 263 gallons [230 gallons + 33 gallon ullage] (996 liters). An additional 10% is added for conservatism, for a total of 289 gallons modeled. This additional 10% exceeds any variances in the package capacity due to tolerancing of the parts. Additionally, the steel walls of the outer shell and the insulation used in the package were conservatively neglected and were modeled as fuel and moderator, respectively. The U-234 and U-236 contained in the package was also conservatively neglected. The Liqui-Rad was modeled in an infinite array as an equivalent-volume sphere with a homogeneous concentration of Uranyl Nitrate solution and maximum fissile impurities using the SCALE package [Reference 6-2]. The assumption that there is no free acid in the solution is conservative, since nitrogen is an absorber. Figure 6-1 provides a graphical representation of the model. A single package with full reflection and optimum interspersed moderation was also modeled.

#### 6.3.1.2 Hypothetical Accident Conditions (HAC)

Hypothetical accident conditions postulate an infinite array of damaged packages with optimum interspersed moderation. However, the results of the testing reported in Section Two showed minimal structural damage to the package under Hypothetical Accident conditions. The structural damage sustained did not cause the containment vessel to shift, nor would the damage at the outer wall of the package lead to an overall decrease in the package-to-package spacing. Therefore, the package-to-package and vessel-to-vessel pitch was maintained at the nominal dimensions reported for the Normal condition.

##### 6.3.1.2.1 HAC 1: Precipitation

Precipitation of the uranyl nitrate solution could be initiated by the addition of a strong base to the package. Data from industry [Reference 6-3] shows that the maximum concentration achieved due to the introduction of non-fissile impurities from a precipitating agent is 300 gU/L. Higher concentrations are not attainable unless the water is decanted and the solid dried. The precipitate and impurities, due to their weight, settle to the bottom of the package. Although it would be very difficult to precipitate the entire mass of uranium due to the limited volume available for addition of a precipitant (33 gallon ullage), all of the uranium (136 kg for 289 gallons at 125 gU/l), along with the maximum allowable fissile impurity content, is assumed to precipitate. The precipitate was modeled in a slab on the bottom of the upright cylinder at a concentration of 300 gU/L. The remainder of the cylinder was filled with water. The free acid, U-234 and U-236 contained in the package were conservatively neglected.

The package was also modeled in a horizontal orientation; however, the horizontal orientation creates a thinner slab of material with a higher surface area, resulting in lower multiplication factors.

Table 6-4 provides a listing of the materials and dimensions used to model the Hypothetical Accident condition. Figure 6-2 provides a graphical representation of the model. A single package with full reflection and optimum interspersed moderation was also modeled.

#### 6.3.1.2.2 HAC 2: Freezing

Severe cold weather conditions could cause freezing of the package contents. At a concentration of 125 gU/L and a nitric acid normality between 0 and 1, the solution is approximately 17 wt% UNH, 82 wt% water, and 1 wt% $HNO_3$. The Gmelin Handbook of Inorganic Chemistry [Reference 6-4] lists the crystallization temperatures of $UO_2(NO_3)_2$ in various nitric acid concentrations. Interpolation of the data shows that crystallization of the 125 gU/L solution begins at –4°C. The differential between the crystallization point of the uranyl nitrate solution and the crystallization point of water, and the high water content of the liquid, suggests that the solution develops a concentration gradient as it freezes. However, because the differential crystallization temperature is small (4°C), the concentration gradient is also expected to be small. Preliminary testing performed at Nuclear Fuel Services, Inc. in Erwin, Tennessee indicates that the solution freezes in layers, with a layer of concentrated solution (approximately twice the nominal) falling to the bottom of the container. As shown previously (see Precipitation), a layer of the entire mass of uranium concentrated to more than twice the original 125 gU/l is subcritical in both the horizontal and vertical orientations for a single package and an infinite array of packages. Therefore, layered freezing is subcritical for the maximum fuel loading of the Liqui-rad.

It is also possible that a concentration gradient may develop radially in the frozen solid, with a higher concentration of UN at the core. In this scenario, the solution freezes in annular sections, moving from the exterior cylinder surface to the interior, with the more exposed surfaces freezing sooner. This pattern of freezing would be the same, regardless of whether the cylinder is vertical or horizontal. The preliminary test data provided by Nuclear Fuel Services does not support this scenario; however, to assure that the package has been evaluated for the worst case conditions the annular freeze scenario was analyzed.

In order to analyze the effects of radial freezing on the criticality of the system, the package was conservatively modeled as an infinite array of spheres in water. Each sphere contains concentric layers of solution concentration, 550 gU/L at the core and dissipating radially in a linear concentration gradient, for a total uranium mass of approximately 136 kg (300 lb). The concentrations modeled are highly conservative, with the core area modeled at more than 4 times the nominal solution concentration of 125 gU/L (approximately half the density of pure UNH crystals). The overall average concentration of the sphere is 125 gU/L. Once again, the free acid, U-234, and U-236 were conservatively neglected. Table 6-4 provides a listing of the materials and dimensions used to model the Hypothetical Accident condition. Figure 6-3 provides a graphical representation of the model. A single package with full reflection and optimum interspersed moderation was also modeled.

### 6.3.2 Package Regional Densities

The material density for each region of the models is provided in Table 6-4. The default atomic number densities from the SCALE library were used for all materials and mixtures.

## *6.4 Criticality Calculation*

### 6.4.1 Calculational Method

The SCALE43 code with the 44 Group Standard Cross Section Library was used to evaluate $K_{eff}$ of the Liqui-Rad Transport Unit under all conditions of transport. Input decks for all bounding cases are provided in Section 6.6.

### 6.4.2 Loading Optimization

#### 6.4.2.1 Moderation Optimization

The full range of interspersed moderation densities for the package was evaluated. There is very little neutron leakage from the package and thus, there is almost no interaction between packages. Figure 6-4 plots the multiplication factor as a function of interspersed moderation. For the accident scenarios (HAC 1 and HAC 2), the individual packages are isolated from one another, and the multiplication factor is maintained almost constant. For the Normal condition, a slight peak exists at an interspersed moderation density of 0.0001 $gH_20$/cc, primarily due to the conservative modeling of the package spacing (packaging walls neglected).

### 6.4.3 Criticality Results

All results demonstrate a package subcritical margin of more than 5%. Table 6-2 presents the results of the analysis. As a final check, a 250 gallon sphere of the Uranyl Nitrate solution was modeled in an infinite array. Also, an infinite mass of the solution was also evaluated. As shown in Figure 6-4, both the infinite mass and infinite array of spheres produced results very close to the results of the cylinder model due to the absence of neutron leakage and interaction in this system.

## 6.5 Critical Benchmark Experiments

Reference 6-5 documents 303 critical experiments (ranging in enrichments from 0.74 to 10.0 wt% U-235) modeled using the SCALE43 code with the 44 Group Standard Cross Section Library. Of the 303 experiments, 15 were uranyl nitrite solutions in cylinders with enrichments from 5 to 10wt% U-235 and solution concentrations from 225 to 420 gU/L. The KENO results of the experimental uranyl nitrate solutions were evaluated as a group in Reference 6-5. The bias and uncertainty associated with the uranyl nitrate critical experiments reported in Reference 6-5 was +0.0009 and 0.0054, respectively. Reference 6-5 additionally reports an upper subcritical limit of 0.9928 based on $K_{eff} + 2\sigma$ for the uranyl nitrate group; however, for conservatism, an administrative upper subcritical limit of 0.95, adjusted for the bias and uncertainty reported in Reference 6-5, is used in this study. The adjusted upper subcritical limit for the SCALE43 code with the 44 Group Standard Cross Section Library is therefore 0.9500 – 0.0054 = 0.9446 (neglecting the positive bias as recommended by NUREG 5661).

## 6.6 Appendix - SCALE43 Input Decks - Bounding Cases

**LIQUI-RAD Normal Case**

```
289 gallon equivalent sphere (63.873 radius sphere volume equals 289
gallons) at 5 wt% U235 and with max impurities, infinite array in optimum
moderation
44GR      INFHOM
H2O            2 0.0001 294 END
SOLNUO2(NO3)2  3 125 0 0.99998 294 92232 0.000002  92233 0.005
                 92235 5.0 92238 94.994998 END
SOLNPU(NO3)4   3 125 0 0.00002 294 94239 100 END
H2O            4 1.0 294 END
END COMP
5 wt% U235 and with max impurities, infinite array in optimum moderation
READ PARM NUB=YES GEN=305 NPG=600 NSK=5 FLX=YES FDN=YES
END PARM
READ GEOM
GLOBAL
UNIT 1
SPHERE     3 1 63.873
CUBOID     2 1 6P63.873
END GEOM
READ BOUNDS
ALL=REFL
END BOUNDS
END DATA
END
```

**LIQUI-RAD HAC 1 - precipitation**

```
Explicit cylinder modeled with precipitate settling in a slab at the
bottom, 300gU/liter, 5% enrichment, water above.  42.281 cm is the depth
required for all of uranium at 300 gU/liter.
44GR      INFHOM
H2O            2 0.1 294 END
```

```
SOLNUO2(NO3)2 3 300 0 0.99998 294 92232 0.000002  92233 0.005
                92235 5.0 92238 94.994998 END
SOLNPU(NO3)4  3 300 0 0.00002 294 94239 100 END
H2O           4 1.0 294 END
END COMP
Explicit cylinder modeled with precipitate settling in a slab
READ PARM NUB=YES GEN=305 NPG=600 NSK=5 FLX=YES FDN=YES
END PARM
READ GEOM
GLOBAL
UNIT 1
CYLINDER  3 1 58.42 42.281 0.0
CYLINDER  4 1 58.42 101.6 0.0
CUBOID    2 1 4P58.42 101.6 0.0
END GEOM
READ BOUNDS
ALL=REFL
END BOUNDS
END DATA
END
```

**LIQUI-RAD HAC 2 - freezing**

```
Equivalent volume sphere with frozen UN layered concentrations from 550
gU/liter at the core to pure water at the outer shell.
44GR     INFHOM
H2O           2 0.4 233 END
SOLNUO2(NO3)2 3 550 0 0.99998 233 92232 0.000002  92233 0.005
                92235 5.0 92238 94.994998 END
SOLNPU(NO3)4  3 550 0 0.00002 233 94239 100 END
SOLNUO2(NO3)2 4 440 0 0.99998 233 92232 0.000002  92233 0.005
                92235 5.0 92238 94.994998 END
SOLNPU(NO3)4  4 440 0 0.00002 233 94239 100 END
SOLNUO2(NO3)2 5 330 0 0.99998 233 92232 0.000002  92233 0.005
                92235 5.0 92238 94.994998 END
SOLNPU(NO3)4  5 330 0 0.00002 233 94239 100 END
SOLNUO2(NO3)2 6 230 0 0.99998 233 92232 0.000002  92233 0.005
                92235 5.0 92238 94.994998 END
SOLNPU(NO3)4  6 230 0 0.00002 233 94239 100 END
SOLNUO2(NO3)2 7 115 0 0.99998 233 92232 0.000002  92233 0.005
                92235 5.0 92238 94.994998 END
SOLNPU(NO3)4  7 115 0 0.00002 233 94239 100 END
SOLNUO2(NO3)2 8 33 0 0.99998 233 92232 0.000002  92233 0.005
                92235 5.0 92238 94.994998 END
SOLNPU(NO3)4  8 33 0 0.00002 233 94239 100 END
H2O           9 1.0 233 END
END COMP
frozen UN layered
READ PARM NUB=YES GEN=305 NPG=600 NSK=5
END PARM
READ GEOM
GLOBAL
UNIT 1
SPHERE 3 1 12
SPHERE 4 1 22
SPHERE 5 1 32
```

```
SPHERE 6 1 42
SPHERE 7 1 52
SPHERE 8 1 62
SPHERE 9 1 63.873
CUBOID 2 1 6P63.873
END GEOM
READ BOUNDS
ALL=REFL
END BOUNDS
END DATA
END
```

**LIQUI-RAD Normal Case Single Package**

289 gallon equivalent sphere (63.873 radius sphere volume equals 289 gallons) at 5 wt% U235 and with max impurities, full reflection, optimum moderation

```
44GR      INFHOM
H2O            2 0.0001 294 END
SOLNUO2(NO3)2  3 125 0 0.99998 294 92232 0.000002  92233 0.005
                 92235 5.0 92238 94.994998 END
SOLNPU(NO3)4   3 125 0 0.00002 294 94239 100 END
H2O            4 1.0 294 END
END COMP
5 wt% U235 and with max impurities, Single Package
READ PARM NUB=YES GEN=305 NPG=600 NSK=5 FLX=YES FDN=YES
END PARM
READ GEOM
GLOBAL
UNIT 1
SPHERE     3 1 63.873
CUBOID     4 1 6P94.353
END GEOM
END DATA
END
```

**LIQUI-RAD HAC 1 - precipitation Single Package**

Explicit cylinder modeled with precipitate settling in a slab at the bottom, 300gU/liter, 5% enrichment, water above.  42.281 cm is the depth required for all of uranium at 300 gU/liter.

```
44GR      INFHOM
H2O            2 0.0001 294 END
SOLNUO2(NO3)2  3 300 0 0.99998 294 92232 0.000002  92233 0.005
                 92235 5.0 92238 94.994998 END
SOLNPU(NO3)4   3 300 0 0.00002 294 94239 100 END
H2O            4 1.0 294 END
END COMP
Explicit cylinder modeled with precipitate settling in a slab
READ PARM NUB=YES GEN=305 NPG=600 NSK=5 FLX=YES FDN=YES
END PARM
READ GEOM
GLOBAL
UNIT 1
CYLINDER  3 1 58.42 42.281 0.0
CYLINDER  4 1 58.42 101.6 0.0
CUBOID    4 1 4P88.90 132.08 -30.48
```

```
END GEOM
END DATA
END
```

**LIQUI-RAD HAC 2 - freezing Single Package**

```
Equivalent volume sphere with frozen UN layered concentrations from 550
gU/liter at the core to pure water at the outer shell.
44GR      INFHOM
H2O             2 0.0001 233 END
SOLNUO2(NO3)2 3 550 0 0.99998 233 92232 0.000002  92233 0.005
                92235 5.0 92238 94.994998 END
SOLNPU(NO3)4  3 550 0 0.00002 233 94239 100 END
SOLNUO2(NO3)2 4 440 0 0.99998 233 92232 0.000002  92233 0.005
                92235 5.0 92238 94.994998 END
SOLNPU(NO3)4  4 440 0 0.00002 233 94239 100 END
SOLNUO2(NO3)2 5 330 0 0.99998 233 92232 0.000002  92233 0.005
                92235 5.0 92238 94.994998 END
SOLNPU(NO3)4  5 330 0 0.00002 233 94239 100 END
SOLNUO2(NO3)2 6 230 0 0.99998 233 92232 0.000002  92233 0.005
                92235 5.0 92238 94.994998 END
SOLNPU(NO3)4  6 230 0 0.00002 233 94239 100 END
SOLNUO2(NO3)2 7 115 0 0.99998 233 92232 0.000002  92233 0.005
                92235 5.0 92238 94.994998 END
SOLNPU(NO3)4  7 115 0 0.00002 233 94239 100 END
SOLNUO2(NO3)2 8 33 0 0.99998 233 92232 0.000002  92233 0.005
                92235 5.0 92238 94.994998 END
SOLNPU(NO3)4  8 33 0 0.00002 233 94239 100 END
H2O             9 1.0 233 END
END COMP
frozen UN layered
READ PARM NUB=YES GEN=600 NPG=800 NSK=5
END PARM
READ GEOM
GLOBAL
UNIT 1
SPHERE 3 1 12
SPHERE 4 1 22
SPHERE 5 1 32
SPHERE 6 1 42
SPHERE 7 1 52
SPHERE 8 1 62
SPHERE 9 1 63.873
CUBOID 9 1 6P63.873
CUBOID 9 1 6P94.353
END GEOM
END DATA
END
```

## 6.7 References:

[6-1] Drawing Number LR-SAR, Sheets 1, 2, 3, & 4, Revision 0 for the Liqui-Rad Transport Unit

[6-2] SCALE 43: Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation, NUREG/CR-200, Rev. 4, CCC-545, Radiation Shielding Information Center, Oak Ridge National Laboratory.

[6-3] Sanders, C.F. and R.D. Montgomery. *Criticality Evaluation of UN storage Tanks*, Westinghouse NFD, 1994.

[6-4] Becker, Richard, et. al. *Gmelin Handbook of Inorganic Chemistry, 8th Edition, Uranium Suppliment Volume C7, Compounds with Nitrogen*, Springer-Verlag, Berlin, 1981.

[6-5] Montgomery, Rosemary A. *Validation of SCALE-PC for Uranium Systems with Enrichments between 0.72 and 10.0 wt% U-235*, MTS985, Rev. 1, 10/99.

**Table 6-1 Quantity of Fissile Isotopes Evaluated**

| Fissile Isotope | Maximum Allowable Concentration (Uranium Basis) |
|---|---|
| U-232 | 20 ppb |
| U-233 | 50 ppm[1] |
| U-235 | 5.0 wt% |
| Pu-239/240/241 | 20 ppm |

[1] The U-233 isotope is included for conservatism only. Actual U-233 content in the solution is below the measurement capabilities of current instrumentation, and is therefore negligible.

**Table 6-2 Summary of Results**

| Transport Case | Number of packages in Array | Array Size | U-235 Enrichment | Close Water Reflection | Interspersed Moderation (g/cc $H_20$) | $K_{eff}$ | $\sigma$ | $K_{eff} + 2\sigma$ | Applicable Upper Subcritical Limit |
|---|---|---|---|---|---|---|---|---|---|
| Normal | Unlimited | Infinite | 5 wt% | N/A | 0.0001 | 0.6280 | 0.0004 | 0.6288 | 0.9446 |
| Hypothetical Accident - Precipitation | Unlimited | Infinite | 5 wt% | N/A | 0.1000 | 0.9337 | 0.0009 | 0.9355 | 0.9446 |
| Hypothetical Accident – Freezing | Unlimited | Infinite | 5 wt% | N/A | 0.4000 | 0.9405 | 0.0011 | 0.9427 | 0.9446 |
| Normal | 1 | 1x1x1 | 5 wt% | Yes | N/A | 0.5910 | 0.0006 | 0.5922 | 0.9446 |
| Hypothetical Accident - Precipitation | 1 | 1x1x1 | 5 wt% | Yes | N/A | 0.8554 | 0.0010 | 0.8574 | 0.9446 |
| Hypothetical Accident – Freezing | 1 | 1x1x1 | 5 wt% | Yes | N/A | 0.9363 | 0.0006 | 0.9375 | 0.9446 |

**Table 6-3 Package Fuel Loading**

| Transport Case | Fuel | Maximum Enrichment | Maximum Concentration | U-232 Concentration | U-233 Concentration | Plutonium Concentration |
|---|---|---|---|---|---|---|
| Normal | Uranyl Nitrate | 5wt% | 125 gU/L | 20 ppb | 50 ppm | 20 ppm |
| Hypothetical Accident - Freezing | Uranyl Nitrate/UNH | 5wt% | 550 gU/L at the core | 20 ppb | 50 ppm | 20 ppm |
| Hypothetical Accident – Precipitation | Uranyl Nitrate/UNH | 5wt% | Layer of 300 gU/L concentrate on the bottom | 20 ppb | 50 ppm | 20 ppm |

**Table 6-4 Liqui-Rad Materials of Construction and Relevant Dimensions**

| Component | Actual Dimension inches | Actual Dimension cm | Actual Volume $cm^3$ | Modeled Volume $cm^3$ | Actual Material | Modeled Material | Modeled Normal Condition Density (g/cc) | Modeled HAC 1 Density (g/cc) | Modeled HAC 2 Density (g/cc) |
|---|---|---|---|---|---|---|---|---|---|
| Containment vessel | 45.5 ID | 115.57 ID | 9.464E5 | 1.090E6 | Uranyl Nitrate with free acid | Uranyl Nitrate without free acid | 1.1688 | 1.4025 | 1.7806 to 1.0689 |
| Containment vessel wall | 0.25 thickness | 0.635 thickness | >2.412E4 | 0 | Stainless Steel | Uranyl Nitrate without free acid | 1.1688 | 1.4025 | 1.7806 to 1.0689 |
| Vessel Insulation | 4.62525 thickness | 11.74725 thickness | 2.305E5 | 0 | Foam Insulation | Water | 0.0001 | 0.1000 | 0.4000 |
| Outer Liner wall | 0.138225 thickness | 0.35125 thickness | 0 | 0 | Carbon Steel | Water | 0.0001 | 0.1000 | 0.4000 |

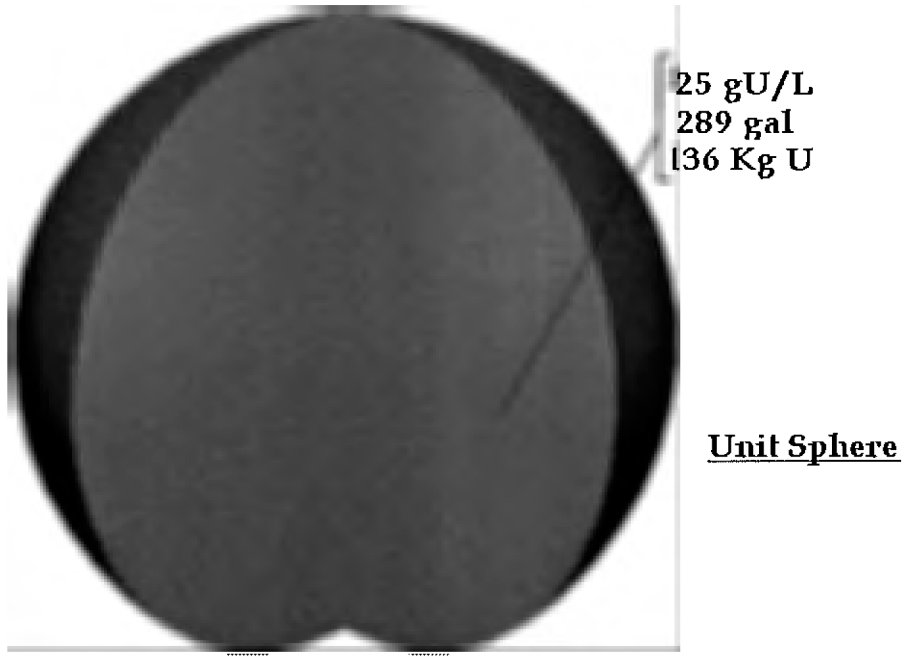



**Figure 6-1 Liqui-Rad Unit Model for Normal Conditions**

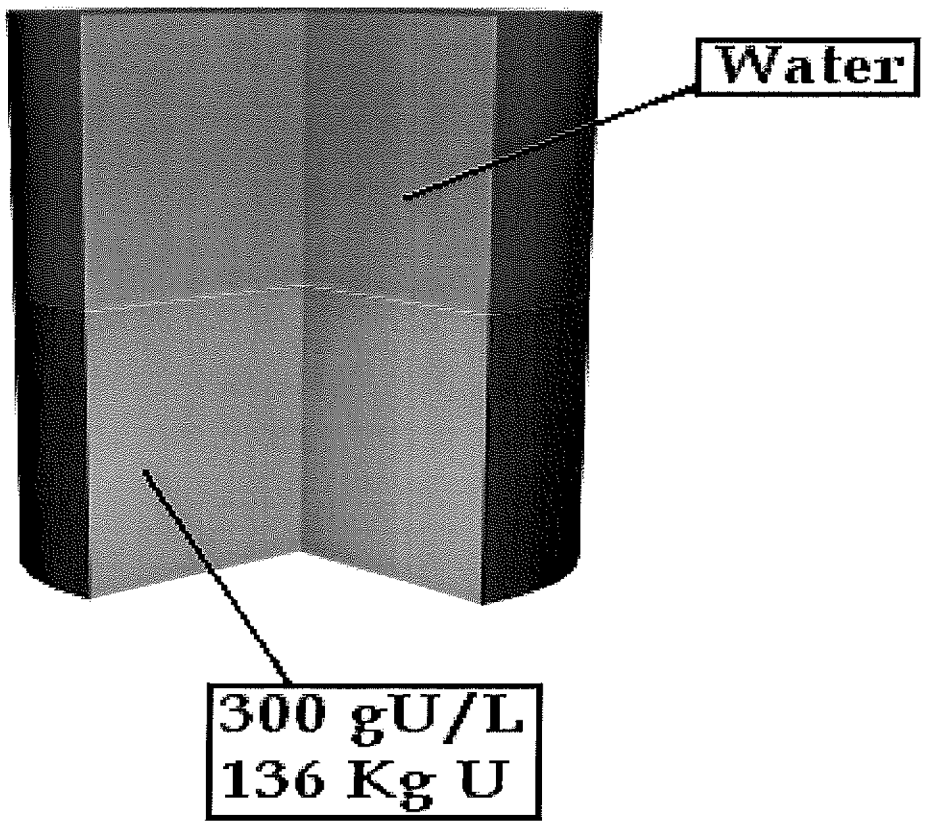
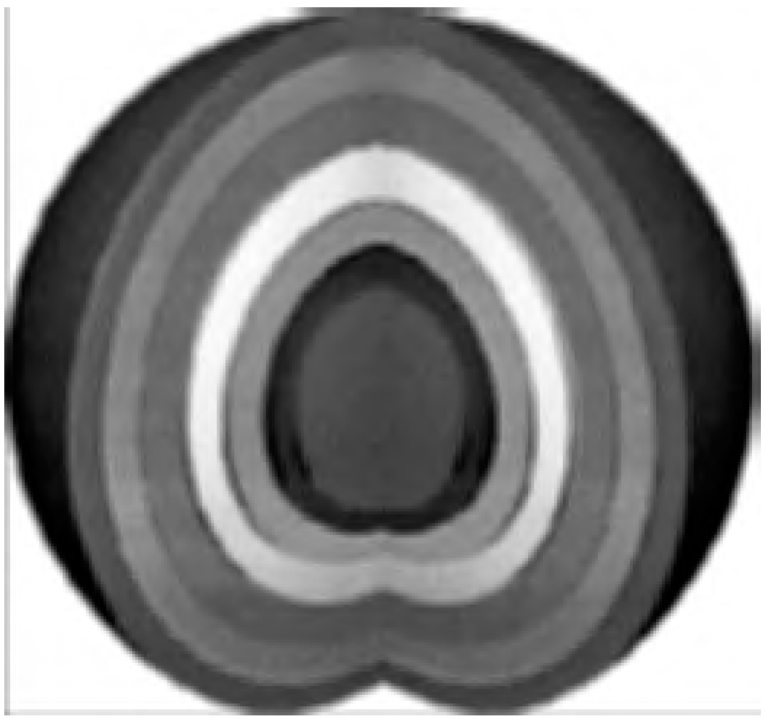



**Figure 6-2 HAC 1 Unit Model – Precipitation and Layered Freezing**



| Layer Concentration (gU/L) | Volume in Layer (liters) | Total U in Layer (kg) | Layer Thickness (cm) |
|---|---|---|---|
| 0 | 93.2 | 0 | 1.873 |
| 33 | 409.3 | 13.5 | 10 |
| 115 | 278.6 | 32.0 | 10 |
| 230 | 173.1 | 39.8 | 10 |
| 330 | 92.7 | 30.6 | 10 |
| 440 | 37.4 | 16.4 | 10 |
| 550 | 7.2 | 4.0 | 12 |
| | 1091.5 | 136.3 | TOTAL |

**Figure 6-3 HAC 2 Unit Model – Radial Freezing**

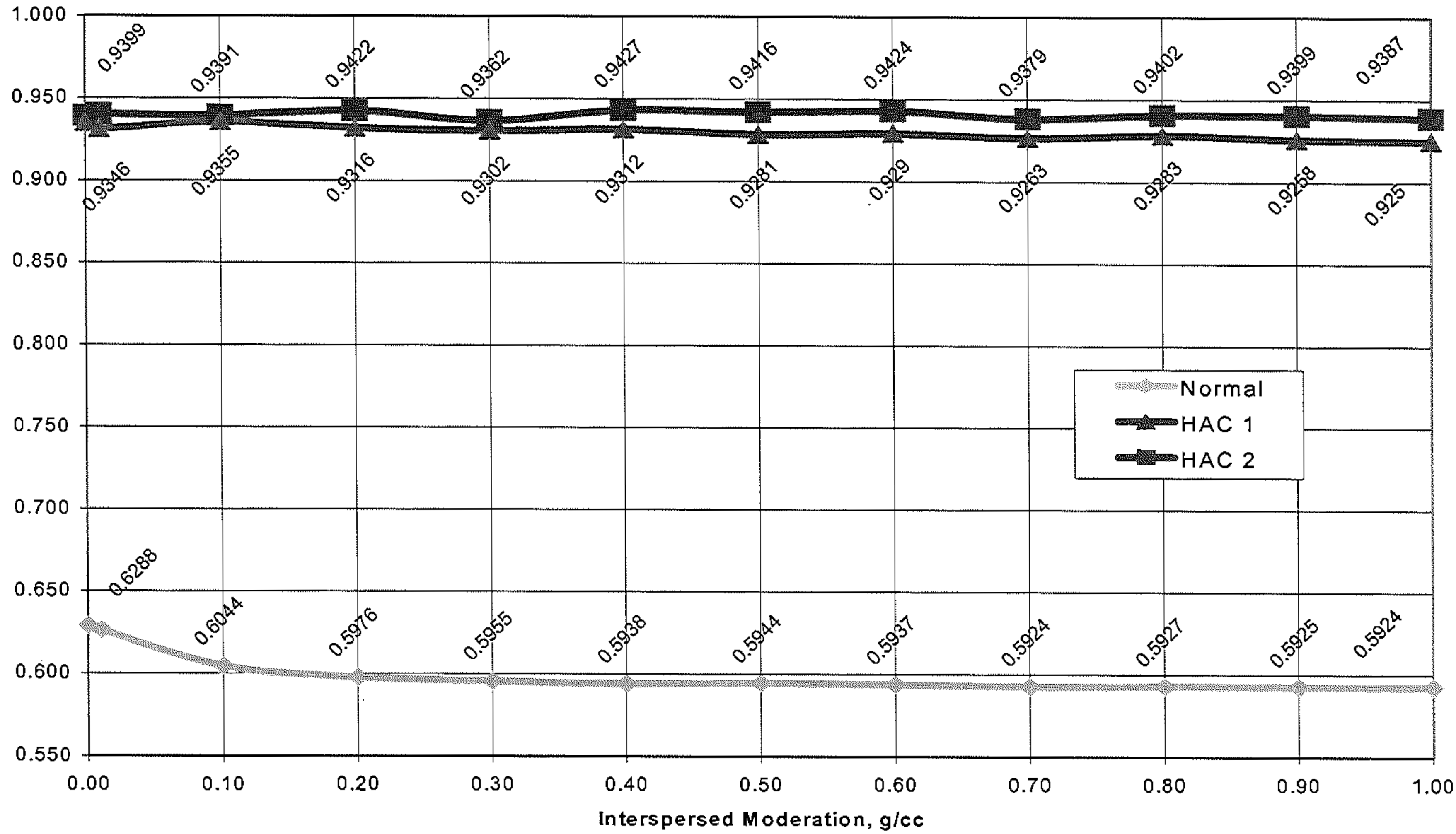



**Figure 6-4 Multiplication Factor as a function of Interspersed Moderation**

# SECTION SEVEN
# OPERATING PROCEDURES

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# 7 OPERATING PROCEDURES

The LR is loaded, unloaded, inspected and handled in accordance with standard, in-plant, operating procedures as stipulated in this section. The only approved commodity is uranyl nitrate solution that falls within the specifications delineated in Section 1.2.3.

## *7.1 Procedure for Loading the LR*

The isotopic distribution of the material to be shipped must be determined prior to loading and the contents must meet the specifications of Section 1.2.3. If the contents are verified and documented as containing less than an A2 quantity, the leak test requirement of 7.1.2(d) can be waived.

### 7.1.1 Pre-loading inspection

a. Inspect the LR exterior for visible flaws. Visually inspect all accessible welds for cracks or corrosion. The exterior welds should be free of cracks, and the exterior surface should not be torn or substantially crushed (more than 2 inches of crush depth). If the exterior surface is torn or substantially crushed, or if cracks or corrosion are discovered, the unit should not be used.

b. If the MVE feature is present, remove the MVE lid and verify that the test valve is closed. If the optional MVE feature is used, verify that the valve is operational. If the valve is found to be non-operational it should be replaced prior to loading the LR. After verification, replace the MVE lid and torque the bolts to 30 ft-lbs [+10-0].

c. Remove the outer lid and check the annulus space for radioactive contamination or debris. If radioactive contamination is present, decontaminate. Remove any solid debris. If standing water is present, it must be removed. Visually inspect the outer lid tor corrosion or damage to the stud holes. Visually inspect the studs for stripping, cracking and corrosion. If any are found to be defective, replace them with an equivalent stud.

d. Remove the secondary lid and inspect for corrosion or damage to the bolt holes. Visually inspect the bolts for stripping, cracking and corrosion. If any are found to be defective replace them with an equivalent bolt. Visually inspect the optional elbow fitting (if present) and the secondary lid flange at the elbow connection for deformation or misalignment. While deformation or misalignments at this location do not impact the performance of the containment boundary, they could be a source of over-estimation of the pre-shipment, maintenance or fabrication leakage rate, and should be corrected if possible.

e. Check for scratches or nicks on sealing surfaces. If scratches or nicks me observed, leak check the package prior to loading per 7.1.2 (d).

f. Visually inspect the LR secondary lid O-rings and the outer lid gasket. They should be in place, intact, and in serviceable condition. If any are found to be defective, they must be replaced. Regular replacement of the O-rings is recommended and does not require testing per 8.2(g) except during the maintenance activities described in Section 8.

### 7.1.2 Loading the Contents and Securing the Package for Shipment

a. Filling of the containment vesselshall be performed in accordance with the Shipper's operating procedures. Remove old labels prior to filling, and re-label the packaging for the contents to be transported. The label shall include the actual gallons of the content loaded. UN solution content must not exceed 230 gallons (870 liters).
b. Install the secondary lid. Nut and bolt threads should be lubricated with anti-seize to avoid galling. Hand tighten until the nuts or bolts are snug against the flange.
c. All secondary lid closure bolts shall be torqued to 75 [+10 -0] ft-lbs, alternating bolts on opposing sides of the lid. After reaching 100% of final torque, the torque should be checked one final time using clockwise or counter clockwise sequence around the flange.
d. Confirm that the containment system is properly assembled for shipment. Perform a leak test of the primary and secondary lid seals to show no detected leakage when tested to a sensitivity of $1 \times 10^{-3}$ ref-cm$^3$/sec per ANSI N14.5. If the primary lid has not been opened from the time of the last periodic test required by Section 8.1(c) or 8.2(h) (as indicated by the presence of the tamper indicating devices located at the primary lid seal), this test may be waived for the primary lid only. If tamper indicating devices are not present, perform the maintenance required by Section 8.2(h). After testing, install the port plug at each leak test port and tighten to 60 [ +10 -0] in-lbs.
e. Install outer lid. Nut and stud threads should be lubricated with anti-seize to avoid galling. The stud nuts should be hand tightened snug against the flange.
f. All outer lid stud nuts shall be tightened to 30 [+10 -0] ft-lbs, alternating stud nuts on opposing sides of the lid. After reaching 100% of final torque, torque should be checked one final time using a clockwise or counter sequence around the flange.
g. Install security seals and record their numbers.
h. Complete contamination survey in accordance with 10 CFR Part 71.87 (i) and (j).
i. Load the LR on the conveyance and secure per the Shipper's Operating Procedures. Shackles shall be removed or secured to top angle with nylon tie to prevent shackle from being used as tie down. Visually inspect all tie-down devices to confirm they are in place.

## *7.2 Procedures for Unloading the LR*

Unload the LR as follows:

a. Complete a receiving report per the Receiver's operating procedures and specifications.
b. Remove and record the package seal.
c. If the MVE feature is present and it is desired to check the annulus pressure or vent the annulus area as directed in Section 7.4, complete these functions before continuing.
d. Remove the outer lid from the LR.
e. Survey for radioactive contamination in the annulus area of the package. If contamination is present, decontaminate as required.

f. Remove the secondary lid by loosening and removing the secondary lid bolts. Care should be taken to avoid impacting the elbow fitting on the secondary lid flange (if present).

g. If the package has been stored filled for more than six months venting of the containment vessel is recommended prior to unloading. Venting can be accomplished using the quick disconnect fittings available on the fill port. Any venting should be performed using a filtered system. Packages must be unloaded within one year of filling.

h. Unload the containment vessel in accordance with the Receiver's operating procedures. A temporary draw pipe, of smaller diameter than the permanent draw pipe, may be inserted through the fill port identified in Detail D of drawing LR-SAR to unload the containment vessel. If the permanent draw pipe is suspected of being damaged, such as by experiencing reduced or no flow when unloading through the permanent draw pipe, then the package shall be emptied using the temporary draw pipe mentioned above, and the package maintained per SAR section 8.2(g).

i. Following unloading, the package should be decontaminated as is practical, and the lids secured in place for storage. Ali shipment labeling should be removed and replaced with markings that meet DOT requirements.

## *7.3 Preparation of Empty LR for Transport*

a. After initial usage, all-applicable steps set forth in Section 7.1.2 are required for transportation of the empty packaging, with the exception that the leak test required by 7.1.2 (d) can be waived if the heel contains less than an A2 quantity. A newly fabricated package that has never carried UN solution is exempted from the requirements of Section 7.

## *7.4 Use of the MVE Feature*

The outer lid of the LR may include an optional Manual Valve Enclosure (MVE) that allows the User to check the pressure of the package annulus space and to vent the annulus space if necessary.

a. Unless the package is being venting or the annulus pressure is being measured, the MVE valve should be closed.

b. If the MVE feature is present and it is desired to check the pressure within the annulus space, loosen and remove all bolts on the MVE lid. Connect any required equipment to the MVE valve and measure the package annulus pressure. Following the pressure measurement, disconnect all equipment and close the MVE valve. If the package annulus will be vented, continue to 7.4(c); otherwise, replace the MVE lid. Bolt threads should be lubricated with anti-seize to avoid galling. The bolts should be hand tightened snug against the MVE lid. All MVE lid bolts shall be tightened to 30 [+10 -0] ft.-lbs.

c. If the MVE feature is present and it is desired to vent the annulus space, loosen and remove all bolts on the MVE lid. The User should use a filtered system to vent the package annulus. Connect any required equipment to the MVE. If the venting system provides pressure regulation, the venting system pressure must be within the design pressure of the package (-11 to 30 psig external to the containment vessel). Open the MVE valve and vent the package annulus. Following venting, disconnect all equipment and allow the package annulus to return to atmospheric pressure by opening the MVE valve to atmosphere. Close the MVE valve. Replace the MVE lid. Bolt threads should be lubricated with anti-seize to avoid galling. The bolts should be hand tightened snug against the MVE lid. All MVE lid bolts shall be tightened to 30 [+10 -0] ft.-lbs.

# SECTION EIGHT
# ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

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# 8 ACCEPTANCE AND MAINTENANCE PROGRAMS

This section describes the activities to be performed in compliance with Subpart G of 10CFR71 to assure that the LR conforms to the requirements of this Safety Analysis Report for Packaging and remains in conformance following loading.

## *8.1 Acceptance Tests*

Each newly fabricated LR shall be inspected to document compliance with the following requirements:

a. The as-built dimensions of the following components shall be within the tolerances prescribed by the fabrication drawings:
   - Containment vessel dimensions
   - Outer package dimensions
   - Closure bolt locations
   - Lifting shackles
   - Assembled package weight

b. Installation of the following components shall be verified and documented:
   - Gaskets and O-rings
   - Security seal tabs
   - Fastening Components
   - Permanent markings and nameplates

c. Prior to acceptance for use, each packaging shall be subjected to the following tests:
   - Prior to first use, leak rate testing of the primary lid and secondary lid seals shall be performed per ANSI N14.5-1997 to a rate less than $1.0 \times 10^{-7}$ std. cc/sec. and per the requirements of Sections 4 of this SARP. After testing the primary lid, tamper indicating devices shall be installed at the primary lid seal.
   - Hydrostatic testing of the containment vessel per the requirements of ASME Section 8, Division 1

## *8.2 Maintenance Programs*

The user shall establish written procedures for the annual maintenance and inspection of each LR requiring the following as a minimum.

a. Inspect the LR exterior for visible flaws. Visually inspect all accessible welds for cracks or corrosion. The exterior welds should be free of cracks, and the exterior surface should not be torn or substantially crushed (more than 2 inches of crush depth). If the exterior surface is torn or substantially crushed or cracks are discovered, the unit should be repaired by the owner and re-certified for use. The user may remove light surface corrosion by polishing as required. If the corrosion is not easily removed or if pitting or scaling is observed, the unit should be repaired by the owner and re-certified for use.

b. Remove the MVE lid and verify that the test valve is operational and closed. If the valve is found to be non-operational is must be replaced. After verification, replace the MVE lid and torque the bolts to 30 ft-lbs [+10 -0].

c. Remove the outer lid and check the annulus space for radioactive contamination and debris. If radioactive contamination is present, decontaminate. Remove any solid debris. If standing water is present, it must be removed. Visually inspect the outer lid for corrosion or damage to the stud holes. Visually inspect the studs for stripping, cracking and corrosion. If any are found to be defective, replace them with an equivalent stud.

d. Check that the lifting shackles and all closure bolts and supports are sound and free from weld cracks, damage and deterioration.

e. Check that the outer lid and secondary lid closure surfaces are sound and undamaged.

f. Check that outer lid gasket, secondary lid 0-ring, and primary lid 0-ring is in place, intact, and is not damaged or deteriorated. The owner recommends replacement of 0-rings and gaskets every 12 months. After replacement of 0-rings, each package shall be leak tested as per paragraph (h) below.

g. Check that the weld of the draw pipe to the primary lid and the draw pipe itself are in good condition, with no cracks; repair if necessary.

h. Periodic leak tests, as described by ANSI Nl4.5-1997, shall be performed to verify that the containment boundaries of the package remain capable of limiting leakage of the payload to less than the maximum allowable leakage rate criterion of $1.0 \times 10^{-3}$ ref-cc/sec (see Section 4). The seal at the primary lid and the seal at the secondary lid shall be leak tested to a rate less than $1.0 \times 10^{-3}$ ref-cc/sec using a test having a sensitivity of at least $0.5 \times 10^{-3}$ ref-cc/sec. Install tamper indicating seals on primary lid. If the leak test results are unacceptable, remove the lid and inspect the sealing surface and 0-rings. Clean the sealing surface and replace the 0-ring as required. Also inspect the optional elbow fitting on the secondary lid flange (if present) and assure that it is properly installed. Install the lid, liberally using an anti-seize lubricant on the stud threads. Tighten all studs/bolts, alternating opposing sides of the lid, to the proper torque of 75 ft-lbs [+10 -0]. Re-test as per above. If the leak results continue to be unacceptable, the unit should be repaired by the owner and re-certified for use.

i. As a minimum, the optional elbow fitting (if present) located at the secondary lid flange should be inspected yearly by successful leak test examination at the exterior stress groove. If any defects are found, the elbow should be replaced with an identical item per drawing provided in Appendix 1.3.1

j. Sandblasting is permitted provided material thickness remains greater than minimum wall thickness. Coating of sandblasted surfaces shall use Sherwin Williams Macropoxy 646 Fast Cure B58 Series primer or equivalent.