KE BASIN SLUDGE TRANSPORTATION SYSTEM 100% DESIGN REPORT – Project A.16

Fluor Hanford, Inc.

Date Published
DECEMBER 2002

Prepared for the U.S. Department of Energy
Fluor Hanford
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200
P.O. Box 1000
Richland, Washington

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Printed in the United States of America

Total Pages: 339
SNF-13268, Rev. 0

KE BASIN SLUDGE TRANSPORTATION SYSTEM
100% DESIGN REPORT

December 6, 2002
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1.0 DESIGN ANALYSIS REPORT SUMMARY

1.1 Introduction

The Hanford K Basins have an accumulation of sludge on the basin floors, in canisters, and in the basin pits from operation of the Basins over the past 30 years. The sludge is composed of irradiated nuclear fuel particles, fuel corrosion products, cladding, storage canister corrosion products, structural degradation and corrosion products from features in the basin pools (e.g., racks, pipes, sloughed off concrete, etc.), beads lost from ion exchange modules (IXM), environmental debris (e.g., sand, insects, pieces of vegetation, etc.), and various other materials (e.g., sand, filter media, hardware, plastic, etc.). The KE Basin Sludge Transportation System (STS) will be used for the onsite shipment of KE Basins sludge and water to T Plant for subsequent storage. The STS basically consists of a large diameter sludge container, a shielded shipping cask, and transport trailer.

A Fluor Hanford project team performed a conceptual design study (Ref. 1) during 2001 for the STS. The project team developed a Functional Design Criteria document, SNF-8166 (Ref. 2) and a Performance Specification, SNF-8163 (Ref. 3), which documented the results of this conceptual design study. A Statement of Work (Ref. 4) was then developed that documented those portions of the Performance Specification that were to be accomplished through a design-fabricate contract that Fluor Hanford subsequently awarded to Packaging Technology, Inc. (PacTec) of Tacoma, Washington.

During the execution of this STS design-fabrication contract, certain portions of the Performance Specification were performed by Fluor Hanford. These portions included criticality safety analyses and the safety basis thermal and gas generation analyses.

1.2 Scope

The scope of this 100% Design Report includes all design documentation and supporting information generated by both Fluor Hanford and PacTec. The documentation supplied by PacTec consists of that specified in the Statement of Work. This report addresses design documentation for the STS only. A separate 100% Design Report has been prepared for the K-Basin Sludge Retrieval System (SRS). Together the STS and SRS 100% design reports constitute the KE Basin Sludge Water System 100% design.

1.3 Summary of STS Design

The STS package consists of three major elements: the Cask, the Large Diameter Container (LDC) that is transported inside the cask and which provides storage for the sludge, and the Transport Trailer that transports the cask containing the LDC to T Plant. Each of these elements is described briefly below. More detailed description of the design of the STS is provided in the PacTec Design Analysis Report (PacTec DAR) (Ref. 5) and shown in Figures 1.1 through 1.4.
1.3.1 STS Cask

The STS cask is cylindrical in shape with a diameter of 72.3 inches and a maximum height of 132 inches. It provides containment and biological shielding for the transportation conditions prescribed with in SNF-8163 (Ref. 3). The cask is made of Type 304 austenitic stainless steel. The cask wall consists of inner and outer shells of stainless steel with a 3 1/8-inch thick layer of lead cast between the two shells. The closure lid containment seal is a metallic O-ring. Metallic O-rings are also provided for the vent and drain port containment penetrations. No lifting components are integral to the packaging. The STS Cask components are described more fully below. The maximum permissible gross shipping weight of the STS Cask is 85,000 pounds including maximum payload and cask body.

The cask is designed to provide shielding for both neutron and gamma sources. The inner and outer structural steel shells of the cask and the lead shell in between provide shielding between the payload and the exterior surface of the package for the attenuation of gamma radiation. The neutron source term is not of great enough significance to require design specific attenuation.

The cask design includes a seal test port, a vent port and a drain port. The seal test port accesses the cavity between the inner (containment) and outer O-ring bore seals on the closure lid, thereby allowing leak tight verification prior to shipping the loaded package. The vent port permits venting and purging of the cask cavity during loading and unloading of the package. Each port is an integral part of the lid, and each port plug is well recessed into the lid for protection. The drain port permits draining of the case, should that be required. There are no receptacles or valves utilized on this package.

The cask serves as the containment boundary for the payload of K East sludge during transportation. The cask components that form the containment boundary are the inner cylindrical shell, the bottom forging, the drain port plug and metallic O-ring, the upper forging, the closure lid, the vent port plugs and metallic O-ring, and the closure lid containment metallic O-ring. The cylindrical cavity formed by these components is 61 inches in diameter and 121 inches in length.

The 1-inch thick cask inner shell is made from ASME SA-240, Type 304 austenitic stainless steel. The inner shell thickness transition to the bottom and upper forging is a 3:1 minimum taper. The 1%-inch outer shell is also made from ASME SA-240, Type 304 austenitic stainless steel. Gamma shielding is provided by cast lead. The gamma shield is sealed inside an annular cavity formed between the inner and outer shells and end forgings.

The bottom end closure is made from SA-182, Type F304 austenitic stainless steel. It provides a bottom thickness of 6-inches. A drain port is provided thru the bottom end forging and the penetration to containment is sealed using the drain port plug and metallic O-ring. The upper forging, made from SA-182, Type F304 austenitic stainless steel, provides a transition for the inner and outer shells to the sealing region and lid closure.

The closure lid is made from SA-182, Type F304 austenitic stainless steel, provides a thickness of 5-inches and locations for the metallic containment O-ring seal and adjacent elastomeric O-
rings used for leak testing, as well as providing a location for the vent, fill, and test ports. The lid is attached to the cask using 24, 1½-10 UNC ASTM A564, 630 (H1100) bolts.

The closure lid is sealed using a single 0.268-inch diameter face-type O-ring Helicoflex seal. An O-ring seal made from butyl is located outboard the containment O-ring to facilitate leak testing. The outer O-ring is used to create a cavity, which is evacuated and tested for the presence of helium during leak testing.

1.3.2 Large Diameter Container

The LDC is a 59-inch diameter cylindrical pressure vessel fitted with 2:1 elliptical heads fabricated of Type 316/316L stainless steel. The lower head and cylindrical portions are of nominal %-inch thickness. The upper head has a nominal thickness of ¾ -inches. The overall height of the LDC is 120-inches, including the lower support skirt, top mounted processing flanges and centrally mounted lifting lug. The upper elliptical head together with an integral lifting lug transfers lifting lug loads to the cylindrical side walls of the LDC. The LDC is designed as an ASME Section VIII, Division I pressure vessel, with a design pressure rating of 150 psig. The LDC serves as a processing vessel to receive and store sludge wastes and as such is fitted with internal filter components and a variety of penetration ports. The internal volume of the LDC accommodates a maximum payload of 3.0 m³ (105.9 ft³) of as-settled sludge covered with a minimum of 25.4 cm (10 in.) of water. The minimum void space above the payload is 1.6 m³, including void space within the cask cavity.

1.3.3 Transport Trailer

The Trailer is a 4-axle single drop flatbed with an overall length of 35-feet and width of 10-feet. The height of the drop deck is 42-inches and the overall height, including superstructure work platform railings is 181-inches. The trailer is fabricated of welded carbon steel shapes, plates and tubular sections. The materials and fabrication are in accordance with industry accepted standards (ASTM, AISC, ANSI, AWS) and all surfaces are primed and painted with coatings appropriate for use. The superstructure is a welded framework surrounding the cask allowing access to the containers during loading and handling operations. The integral cask tie-down system consists of deck mounted lugs which engage 4 slots at the base of the STS Cask plus a tubular framework which envelopes the top of the cask. A work stand for storage and inspection of the cask lid is located at the Trailer stem. This stand includes features allowing the lid to be rotated 180° for inspections, seal installation and replacement.

1.3.4 Other Components

The STS includes several other significant elements. These include the Process Shield Plate (PSP), the Lid Lift Device and the Cask Lift Device.

The PSP is 84.5 inch in diameter and is fabricated of all carbon steel. It weighs some 14,000 lbs. It provides primary gamma shielding to workers during loading operations. The stepped PSP envelopes the open end of the cask and fits tightly around the several nozzles and fittings located at the top of the Large Container. Appropriate guides and lead-ins are provided to assure that the
PSP properly interfaces with both cask and LDC without endangering the rather fragile nozzles of the LDC.

The Lid Lift Device serves dual functions. The primary function is as simple device that bolts directly to the cask lid using 3 ¾-10UNC A320, Grade LM7 bolts. The secondary function is as an element of the trailer Lid Turning Fixture. In this lid turning application, the fixture serves as the axle of the turning device.

The Cask Lift Device is also a simple strongback that bolts directly to the cask using four 1-1/2 inch UNC-2A bolts threaded into four lid bolt tapped holes locations. The cask is never lifted during operations and is never lifted loaded. The only occasions when this lift will occur is during initial installation of the cask on the Trailer and for periodic servicing, as required.

1.3.5 Operational Features

The STS Cask normally remains attached to the trailer throughout transport as well as during operations at the KE Basin and T-Plant facilities. At the KE Basin, the cask lid is removed, set-aside, and the PSP is positioned above an empty LDC. Process lines and instrumentation cabling are connected to the LDC and the loading process commences. In this loading process, Basin sludge and water is pumped into the Large Container. The sludge remains in the LDC whereas filtered water is returned to the processing system. Upon completion of loading, excess water is removed from the LDC, the lid is installed and the cask is prepared for shipment. Upon arrival at the T-Plant, the lid is removed and the LDC is lifted and placed into its designated interim storage location. Next, an empty LDC is positioned in the cask, the lid is re-installed and the system is returned to K-Basin for another shipping sortie.

1.4 Summary of Incorporated Documents

This 100% Design Report incorporates the documents listed and briefly described below. The first twelve documents were developed as direct products of the design effort. That is, the first three documents (see Sections 1.4.1 – 1.4.3) established requirements, specifications and the scope of work for the design-build contract that was let to PacTec. The next six documents (see Sections 1.4.4 – 1.4.7) were produced to document the products of the design efforts that led up to the ultimate fabrication of the hardware for the STS. Section 1.4.4 contains three reports for the design effort (30%, 60%, 90% reviews). The three documents described in Sections 1.4.8 – 1.4.10 document analyses that were performed to confirm that the hardware being designed would be acceptable from the nuclear and criticality safety perspectives. Each of these twelve documents is discussed in the main body of this report.

The last six documents listed below (see Sections 1.4.11-1.4.16) are not discussed in the main body of this report. A brief discussion of the purpose and scope of each of these documents is provided in Section 11.0
1.4.1 Functional Design Criteria

The Functional Design Criteria (Ref. 2) identifies the minimum criteria and requirements that form the authorized baseline for the SWS project. This document is included as Attachment 1.

1.4.2 Performance Specification

The Performance Specification document, SNF-8163 (Ref. 3) specifies the necessary requirements and criteria for procurement of the STS. This document is included as Attachment 2.

1.4.3 Statement of Work

The Statement of Work (Ref. 4) documents those portions of the Performance Specification that were to be accomplished through a design-fabricate contract that Fluor Hanford subsequently awarded to Packaging Technology, Inc. (PacTec) of Tacoma, Washington. This document is included as Attachment 3.

1.4.4 Design Review Report Summaries

Design reviews were conducted on the STS design being developed by PacTec at the points in time when their design efforts were approximately 30%, 60% and 90% complete. The design review meetings involved SWS project personnel and members of the PacTec design team. The SWS project prepared a Design Review Report following each of these meetings to document the state of the design at that point, comments made by reviewers on the design, and the resolution of these comments are incorporated herein as Refs. 6, 7 and 8. These documents are included as Attachments 4, 5 and 6.

1.4.5 PacTec Design Analysis Report

The PacTec DAR incorporated the comments received at the 90% design review meeting and thus documented the final design that governs fabrication. The PacTec report, ED-073 (Ref. 5), is included as Attachment 7. It is referred to hereafter as the PacTec DAR.

1.4.6 PacTec Design Analysis Report Addendum

Following issuance of the Design Analysis Report, PacTec performed some additional design work in closing out the design effort. The additional design documentation prepared by PacTec is presented in a Design Analysis Report addendum, (Ref. 9). The Design Analysis Report addendum is included as Attachment 8.

1.4.7 Fluor Hanford Supplemental Design Information

Fluor Hanford performed or supplemented PacTec analyses for the STS. This information has been compiled in a number of position papers, supplemental analysis and updated drawings. Issues addressed consisted of:
• Calculation SWS-A-16-(3-010, Rev. 2 – Sludge container maximum sludge loading
• Position paper – Rising slug plug disruptor
• Position paper – Deflector plate analysis to promote uniform distribution
• Position paper – Radiation hardening of level sensor
• Position paper – Hydrogen flammability
• Analysis – Thermal/gas evaluation for normal and accident conditions for transportation using TI-015, Rev. 9
• Analysis – Shielding analysis for process shield plate well area
• Updated PacTec 100% design drawings (changes after 90% PacTec DAR approval)

This documentation is included as Attachment 9.

1.4.8 SWS Criticality Safety Report

Fluor Hanford performed the criticality safety analyses for the SWS project. The results of these analyses, which demonstrate that an accidental criticality is an incredible event for all normal and credible off-normal conditions, are documented in HNF-8513 (Ref. 10). This report is included as Attachment 10.

1.4.9 Safety Basis Thermal and Gas Generation Analysis

Fluor Hanford performed the safety basis thermal and gas generation analyses for the STS. The results of these analyses are documented in the report SNF-9955 (Ref. 11). This report is included as Attachment 11.

1.4.10 Design Basis Thermal and Gas Generation Analysis

Fluor Hanford also performed the thermal and gas generation analyses for the STS for design basis conditions. The results of these analyses are documented in the report SNF-10415 (Ref. 12). This report is included as Attachment 12.

1.4.11 Design Verification and Validation Plan

Fluor Hanford prepared a plan for performing verification and validation of the SWS design completed by PacTec. This plan is documented in SNF-6470 (Ref. 13). This document is included as Attachment 13.

1.4.12 Design Verification and Validation Report

Fluor Hanford will perform a verification and validation of the PacTec design for the SWS. The results of this effort along with the STS FDC compliance matrix will be documented following completion of the Acceptance Test Program.
1.4.13  SWS Human Factors Report

During the course of the design effort for the SWS, analyses were performed and design reviews were conducted that focused on various Human Factors aspects of the design and operation of the system. The results of these efforts are documented in SNF-13144 (Ref. 14). This document is included as Attachment 15.

1.4.14  SWS ALARA Report

During the conceptual design phase of the SWS, ALARA reviews were held frequently to discuss the radiation protection aspects of the evolving design. The results of these efforts are documented in SNF-8509 (Ref. 15). This document is included as Attachment 16.

1.4.15  SWS Hazards Analysis

Fluor Hanford performed a hazards analysis of the entire SWS as an initial step in developing the safety basis for the SWS project. This hazard analysis was updated throughout the SWS design. The hazards analysis is documented in SNF-I0020 (Ref. 16). This document is included as Attachment 17.

1.4.16  K Basins Hazards Analysis

Given the results of the hazards analysis, Fluor Hanford performed a hazards analysis of the entire K Basins operation as the next step in developing the safety basis for the SWS project. This hazards analysis is documented in HNF-3960 (Ref. 17). This document is included as Attachment 18.

1.5  References

References 2, 3, and 4 have subsequently been updated during the execution of the design contract to incorporate all design modifications. All modifications and changes to the referenced documents were incorporated in the presented design and analyses. The references were not updated in the individual chapter write-ups because those revisions (with appropriate contract modifications) were in effect at the time of supporting document generation and the cross link to the supporting analyses refers to the old revision.

3 SNF-8163, Rev. 5, Performance Specificationfor the K East Basin Sludge Transportation System – Project A.16, Fluor Hanford, Inc., March 2002
4 Statement of Work, Revision 4, For The Sludge Transportation System Project A-16, Contract 12329, Attachment 8, Fluor Hanford, Inc., March 13, 2002
5 ED-073, Sludge Transportation System Design Analysis Report, PacTec, Tacoma, WA, September 2002


7 SNF-10914, Rev. 0, K Basins Sludge Transportation System STS 60% Design Review, Fluor Hanford, Inc., May 2002

8 SNF-12345, Rev. 0, K Basin Sludge Transportation System 90% Design Report, Fluor Hanford, Inc., October 2002

9 PacTec Submittal 12329/STS 22, PacTec Final Design Analysis Report, PacTec, Inc., 11/1/02.


11 SNF-9955, Rev. 1, Safety-Basis Thermal Analysis for KE Basis Sludge Transport and Storage, Fluor Hanford, Inc., October 2002

12 SNF-10415, Rev. 0, Design-Basis Thermal and Gas Generation Analysis for KE Basis Sludge in Large Diameter Containers, Fluor Hanford, Inc., August 2002


17 HNF-3960, Rev. 5, K Basin Hazard Analysis, Fluor Hanford, Inc., October 2002
Figure 1-1 - STS Cask Basic Dimensions

Figure 1-2 - STS Cask Primary Structural Components
Figure 1-3  STS Container with initial sludge loading of 2.0 m$^3$
2.0  STRUCTURAL EVALUATION

2.1  Introduction

This chapter presents the structural design criteria, weights, mechanical properties of materials, and structural evaluations that demonstrate that the STS Cask and Large Diameter Container (LDC) design meets all applicable structural criteria. The package that is designed to transport a single LDC is a cask including the containment (inner) shell, outer shell, lead shielding, bottom forging, and closure lid. Evaluations of Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) were performed using analytical techniques to address the performance requirements in the SNF-8163 (Ref. 1). All events were evaluated analytically.

2.2  Structural Design Criteria

This section defines the allowable stresses and load combinations used to design the STS Cask for the analytical evaluations of the transportation load conditions. These design criteria meet the following safety requirements of 10 CFR §71.51 [Reference 3]:

- For normal conditions of transport, there shall be no loss or dispersal of radioactive contents, as demonstrated to a sensitivity of $10^{-6} A_2$ per hour, no significant increase in external radiation levels, and no substantial reduction in the effectiveness of the package.

- For hypothetical accident conditions, there shall be no escape of radioactive material exceeding a total amount $A$, in one week, and no external radiation dose rate exceeding one rem-per-hour at one meter from the external surface of the package.

The acceptance criterion for STS Cask analytical assessments is in accordance with Regulatory Guide 7.6 and Section III, the ASME Boiler and Pressure Vessel Code, and the Hanford Sitewide Transportation and Safety Document.

The acceptance criterion for LDC analytical assessments is in accordance with Section VIII, Division I of the ASME Boiler and Pressure Vessel Code.

2.3  PacTec Structural Evaluations

The scope of the activity was to cover structural and stress analysis for the entire STS package (Cask, container, trailer, lifting devices and tiedown system). Areas analyzed and presented in the reference documentation are:

- Chemical and Galvanic Reactions - The materials from which the STS cask and Large Container is fabricated (i.e., primarily stainless steel, lead) will not cause significant chemical, galvanic, or other reactions in air, helium, or water environments. The lead
gamma shield material is enclosed inside sealed (welded closed) cavity. Thus, the requirement of 10 CFR §71.43(d) is satisfied.

- **Size of the Package and Cavity** - The cask is a right circular cylinder with flat end with a cavity diameter of 61 inches and length of 121 inches. The STS cask has an outer diameter of 72 1/4 inches and total length of 132 inches. The STS cask is designed to transport one Large Container. The Large Container is a right circular cylinder with standard ellipsoidal heads, 59 inches in diameter, and 120 inches in height.

- **Weights and Center of Gravity** - The calculated weights of the major components of the STS cask, Large Container, payload and Trailer are tabulated in Table 2-1.

- **Tamper-Indicating Features** - A lock wire is used on the vent, test and drain ports caps and a minimum of 2 lid closure bolts after installation. Failure of the lock wire indicates deliberate tampering. Once installed, the contents of the package may not be accessed without deliberately removing the lockwire(s). This satisfies the tamper indicating requirement of 10 CFR §71.43(b).

- **Positive Closure** - Inadvertent opening of the cask closure cannot occur for the STS transportation cask. Upon completion of loading the cask payload, the top closure plate's 24, ½-6UNC-2A socket head cap screws are tightened to a relatively high torque value thereby eliminating access to the containment cavity. Following containment seal leak testing, the vent, test and drain port caps are installed. Once installed, lock wire. Thus, inadvertent opening of the cask cannot occur, and the requirement of 10 CFR §71.43(c) is satisfied.

- **Lifting and Tiedown Features** - The Sludge Transportation System (STS) Cask is typically not lifted during any of the loading, unloading, or transportation operations. Installation of the cask onto the trailer is performed by utilizing a sub-set of lifting devices that attach to the cask by means of the cask lid closure bolt-holes. The sub-set of cask lifting devices are evaluated within Calculation 12099-23. The cask lid is lifted separately via the Lid Lifting Device that interfaces with threads in the top of the cask lid. These Lid Lifting Device threads are analyzed in Calculation 12099-24.

Two types of tie-down devices secure the cask for transportation. The cask bottom forging has four machined grooves that interface with trailer tie-down bars to prevent motion in the vertical direction. The main device used to prevent motion in the horizontal plane is a trailer tie-down clamp that encompasses the circumference of the cask at approximately 7' 2" (up from the bottom of the cask). In this calculation the grooves of the cask bottom forging are analyzed for a vertical load, and the cask is analyzed for loading in the horizontal plane caused by bearing forces applied by the trailer tie-down clamps. The tie-down components of the STS cask and trailer are evaluated in Chapter 8 of this report.
<table>
<thead>
<tr>
<th>Component Configuration</th>
<th>Nominal Weight (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Containment Boundary</strong></td>
<td></td>
</tr>
<tr>
<td>- inner shell</td>
<td>6,720</td>
</tr>
<tr>
<td>- lead</td>
<td>31,650</td>
</tr>
<tr>
<td>- outer shell</td>
<td>11,503</td>
</tr>
<tr>
<td>- lid</td>
<td>4,952</td>
</tr>
<tr>
<td>- bottom</td>
<td></td>
</tr>
<tr>
<td><strong>Component SubTotal</strong></td>
<td>63,691</td>
</tr>
<tr>
<td><strong>Large Container</strong></td>
<td></td>
</tr>
<tr>
<td>- large container</td>
<td>4,800</td>
</tr>
<tr>
<td><strong>Component SubTotal</strong></td>
<td>4,800</td>
</tr>
<tr>
<td><strong>Payload</strong></td>
<td></td>
</tr>
<tr>
<td>- sludge (3 m³)</td>
<td>10,912</td>
</tr>
<tr>
<td><strong>Component SubTotal</strong></td>
<td>10,912</td>
</tr>
<tr>
<td><strong>Trailer</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>35,000</td>
</tr>
<tr>
<td><strong>Component SubTotal</strong></td>
<td>35,000</td>
</tr>
</tbody>
</table>

|                                |                      |
|                                | **Loaded Cask Total**| **Loaded Trailer Total** |
|                                | 79,403               | 114,403                  |

- **Brittle Fracture** - With the exception of the cask lid closure bolts lead biological shielding, all structural components of the STS Cask are fabricated of austenitic stainless steels. These materials do not undergo a ductile-to-brittle transition in the temperature range of interest (i.e., down to -27°F), and thus do not need to be evaluated for brittle fracture. Further, Regulatory Guide 7.11 [Reference 8] states, “Since austenitic stainless steels are not susceptible to brittle failure at temperatures encountered in transport, their use in containment vessels is acceptable to the staff and no tests are needed to demonstrate resistance to brittle fracture.”

The closure lid bolts are fabricated from ASME SA564, Type 630 (H1100), alloy steel bolting material. Per Section 5 of NUREG/CR-1815 [Reference 9], bolts are not considered as fracture-critical components because multiple load paths exist and bolting systems are generally redundant, as is the case with the STS Cask. Therefore brittle fracture is not a failure mode of concern.
2.3 Summary and Conclusions

Four area of analysis were performed for the structural analysis (normal conditions for transfer; hypothetical accident conditions; trailer, lifting devices and tiedown system; and earthquake and stability analysis). A summary of each of the structural evaluations is provided below.

2.3.1 Normal Conditions of Transfer (NCT)

Ten normal conditions are defined for K-East Basin, transportation and T Plant structural analyses:

- The maximum heat generation rate based on the limiting payload as described in Section 3.0 of SNF-8163, (Ref. 1), plus maximum normal initial environment conditions, plus maximum solar heat load (see Table 5-2 of SNF-8163, (Ref. 1)) plus maximum air temperature of 46°C (115°F).
- The maximum heat generation rate based on the limiting payload as described in Section 3.0 of SNF-8163, (Ref. 1), plus minimum normal initial environment conditions.
- A minimum air temperature of -33°C (-27°F) and zero heat generation rate.
- Reduced External Pressure: An external pressure of 25 kPa (3.5 psi) absolute.
- Increased External Pressure: An external pressure of 140 kPa (20 psi) absolute.
- Maximum Internal Pressure: An internal operating pressure of 551.58 kPag (80 psig) is the maximum achievable pressure during transportation.
- Vibration: Vibration normally incident to transport. The cask shall be evaluated per Draft American National Standard Design Basis for Resistance to Shock and Vibration of Radioactive Material Packages Greater Than One Ton in Truck Transport (Reference 1) to demonstrate containment when exposed to normal vibration due to the onsite transfers defined herein by the selected transport vehicle. Tiedowns and hold down bolts shall also be evaluated for this scenario.
- Water Spray: The cask shall be evaluated to demonstrate containment through a water spray that simulates exposure to rainfall of approximately 5 cm (2 in.) per hour for at least one hour.
- Penetration: The cask shall be evaluated to demonstrate the impact of the hemispherical end of a vertical steel cylinder of 3.2 cm (1.25 in.) diameter and 6 kg (13 lb.) mass, dropped from a height of 1 m (40 in.) onto the exposed surface of the package that is expected to be most vulnerable to puncture. The long axis of the cylinder must be perpendicular to the cask surface.
- Free Drop: The cask shall be evaluated to demonstrate containment subsequent to a 0.3 m (1 ft) free drop onto a 20.3 cm (8 in.) thick concrete surface with a concrete strength of
20,685 kPa (3,000 psi), Grade 60, No. 7 reinforcing bar spaced 30.5 cm (12. in.) apart with 5.1 cm (2 in.) cover, each way, each face, and soil properties in accordance with DOE/RL-2001-0036, Hanford Sitewide Transportation Safety Document [Reference 6]. The cask shall impact in an orientation expected to cause maximum damage. If the worst case orientation does not bound the corner drop accident, additional analysis will be performed.

A summary of the above ten K Basin and NCT analyzed conditions is provided below:

<table>
<thead>
<tr>
<th>NCT Analyzed Conditions</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot Environment</td>
<td>115°F ambient temperature, maximum insolation, and maximum decay heat per Section 5.1.1 of SNF-8163, (Ref. 1).</td>
</tr>
<tr>
<td>Cold Environment</td>
<td>-27°F steady state ambient temperature is utilized per Section 5.1.1 of SNF-8163, (Ref. 1), with both zero insulation and zero decay heat and zero insulation and maximum decay heat.</td>
</tr>
<tr>
<td>Reduced External Pressure</td>
<td>3.5 psia, per Section 5.1.2.4 of SNF-8163, (Ref. 1)</td>
</tr>
<tr>
<td>Increased Internal Pressure</td>
<td>20 psia, per Section 5.1.2.4 of SNF-8163, (Ref. 1)</td>
</tr>
<tr>
<td>Water Spray</td>
<td>NA • Reg. Guide 7.8 (Ref. 3) exemption for large packages</td>
</tr>
<tr>
<td>Vibration</td>
<td>NA • Bounded by NCT Free Drop</td>
</tr>
<tr>
<td>Penetrations</td>
<td>NA • Free Drop per Regulatory Guide 7.8 (Ref. 3), the penetration condition of Section 5.1.2.9 of SNF-8163, (Ref. 1) is not considered a general requirement for large packages.</td>
</tr>
<tr>
<td>Free Drop</td>
<td>1 foot worst case orientation drop</td>
</tr>
</tbody>
</table>

For these analyzed conditions, several acceptance criteria were defined:

- Containment: The cask shall be designed, constructed, and prepared for shipment so that when subjected to normal conditions, the containment boundary shall remain leak-tight in accordance with the Radioactive Materials Leakage Tests on Packages for Shipment (Ref. 5) definition of "leak-tight" (leakage less than $10^{-7}$ std cc/sec air). If the cask design incorporates a venting feature, the leakage rate evaluation shall be made with the vent(s) sealed. For conditions normally incident to transfer, the packaging shall be evaluated by analysis to meet the containment criteria listed above.

- The STS Cask is designed to provide containment for all normal conditions of transport (NCT). The NCT conditions affecting containment capability are fully evaluated in Sections 2.7.1 and 3.6.1.1 and shown to meet the acceptance criteria described in Sections 2.4.2 and 3.4.2. Chapter 4 also provides a discussion of the STS Cask containment.
• **Thermal**: Maximum accessible outside surface temperature of the cask shall be less than 85 °C (185 °F) in 37.8 °C (100 °F) air temperature and in the shade. The STS design shall ensure the maximum temperature of the payload does not exceed 100°C (212°F) at any time during loading, transportation and storage.

• The STS Cask thermal analysis address all NCT thermal conditions are fully evaluated in Section 3.6.1.1 and shown to meet the acceptance criteria.

• **Shielding**: Shielding shall meet the DOT requirements for shipments of radioactive materials as defined in *Shippers General Requirements for Shipments and Packaging* [Reference 8].

• The Cask is shielding analysis is contain in Chapter 5, and conservatively demonstrates that the shielding criteria are met.

When subjected to the Normal Conditions of Transfer (NCT) as specified above, the STS cask meets the performance requirements and the applicable design criteria.

### 2.3.2 Hypothetical Accident Conditions (HAC)

Three accident conditions are defined for transportation:

• **Impact**: The worst case failure threshold evaluation for the cask system shall be a free drop of 9.1 m (30 ft) onto an 20.3 cm (8 in.) thick concrete surface with a concrete strength of 20,685 kPa (3,000 psi), Grade 60, No. 7 rebar spaced 30.5 cm (12 in.) apart with 5.1 cm (2 in.) cover, each way, each face, and soil properties in accordance with [Reference 9]. The cask shall impact in an orientation expected to cause maximum damage.

• **Puncture**: The worst case credible puncture incident is equivalent to a free drop of the cask through a distance of 1 m (40 in.) in a position expected to cause the maximum damage, onto the upper end of a solid, vertical, cylindrical, mild-steel bar. The bar must be 15 cm (6 in.) in diameter, with the top horizontal and its edge rounded to a radius of not more than 6 mm (0.25 in.) and of a length to cause maximum damage to the cask, but not less than 20 cm (8 in.) long. The puncture bar is mounted on a 20.3 cm (8 in.) thick concrete horizontal surface with a concrete strength of 20,685 kPa 3,000 psi, Grade 60, No. 7 rebar spaced 30.5 cm (12 in.) apart with a 5.1 cm (2 in.) cover, each way, each face, and soil properties in accordance with [Reference 9].

• **Fire**: The worst-case fire that the cask system can be exposed to during transport is a 30-minute, 800 °C (1,475 °F) engulfing fire that has an emissivity coefficient of 0.9. The surface absorptivity of the cask shall be the greater of the anticipated absorptivity or 0.8. Insolation may be assumed to be 'inactive' following the fire. Active cooling of the cask following the 30-minute fire can be assumed. If assumed, the active cooling shall consist of quenching the outer cask surfaces using water spray from a fire hose rated at 473 L/m (125 gal/min.) Flow at this maximum rate shall be assumed to occur for a maximum of 45 minutes. If needed, additional quenching water flow can be assumed for an additional period of 100 minutes at a maximum flow rate of 189 L/m (50 gal/min.). Assume a water
temperature of 29 °C (85 °F) for this procedure. Any active cooling system for the packaging shall be assumed to be inoperative during the fire.

A summary of three HAC analyzed conditions is provided below:

<table>
<thead>
<tr>
<th>HAC Condition</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free Drop Crush</td>
<td>30 foot worst case orientation drop.</td>
</tr>
<tr>
<td>Crush</td>
<td>NA – The crush test specified in 10 CFR §71.73(c)(2) (Ref. 4) is required only when the specimen has a mass not greater than 1,100 lbs. Because the STS cask weighs much more than 1,100 lbs, no crush test is required.</td>
</tr>
<tr>
<td>Puncture</td>
<td>40 inch puncture drop condition preceded by a worst case orientation 30 foot drop.</td>
</tr>
<tr>
<td>Thermal &amp; Fire</td>
<td>30 minute fire of 1,475°F (802°C) per Section 5.2.2.3 of SNF-8163 (Ref. 1).</td>
</tr>
</tbody>
</table>

For these conditions, several acceptance criteria are defined below:

- **Containment**: Subsequent to the conditions described in above, the packaging system shall maintain a single containment barrier for the payload. The system must structurally retain the container and its contents. Gas or radiological material (except Kr 85) leakage past the seals following accident conditions shall limit releases to 1 A2 per week.

The STS Cask is designed to provide containment for all Hypothetical Accident Conditions (HAC). The HAC conditions affecting containment capability are fully evaluated in Sections 2.7.2 and 3.6.1.2 and shown to meet the acceptance criteria. Chapter 4 also provides a discussion of the STS Cask containment.

- **Thermal**: The STS design shall ensure the maximum temperature of the payload does not reach 100°C (212°F) at any time during loading, transportation, storage and subjected to accident conditions.

The STS Cask thermal analysis address all NCT thermal conditions are fully evaluated in Section 3.5 and shown to meet the acceptance criteria described in Section 3.4.2.

- **Shielding**: Subsequent to the conditions described in above, the dose 1 m (3.3 ft) from the surface of the packaging system shall not exceed 1 rem/h. With respect to the thermal condition, there shall be no net loss of lead shielding if lead is used. Lead may melt but cannot be lost.

The Cask shielding analysis is contained in Chapter 5, and conservatively demonstrates that the shielding criteria are met. Additionally, it should be noted, that although possible lead melt is predicted during the fire, the cask will not lose any gamma shielding. This conclusion is based on a review of the structural analysis:
The accident conditions structural acceptance criteria do not allow for rupture of the cask structural components (inner & outer shells, and the forgings, including the welded joints).

The accident conditions analyses show positive margin, demonstrating there will be no rupture of the cask structural components.

Without rupture, there can be no lead leakage path.

Therefore, no lead is lost for any normal or accident conditions and shielding is retained.

When subjected to Hypothetical Accident Conditions (HAC) as specified above, the STS cask meets the performance requirements and the applicable design criteria.

2.3.3 Lifting Attachments, Trailer and Tiedown system

As specified in Section 7.5 of SNF-8163, (Ref. 1), the following functional requirements are:

- Lifting attachments are designed per ANSI N14.6 (Ref. 5). Lifting attachments are provided for removing the cask from the trailer, and for removing the lid from the cask.
- The tie-down system is designed to secure the cask system to the trailer. The tie-down system meets the requirements of 10 CFR 71.45(b) (Ref. 6).

Lifting Attachments

The maximum weight of the cask is 85,000 lbs. The weight of the lid, for the purpose of this calculation, is bounded by 6,250 lbs. The cask and cask lid are both evaluated for a static vertical lift. The cask lifting analysis is evaluated to the criteria specified for a non-critical lift in ANSI N14.6. ANSI N14.6 specifies that the lifting devices be capable of lifting three times the load without generating a combined shear stress or maximum tensile stress in excess of the minimum yield tensile strength of the material of construction. The lifting devices shall also be capable of lifting five times the weight without exceeding the ultimate tensile strength of the material. The cask and cask lid are each hoisted vertically, so only a tension load is applied to the threads. The threaded holes used for hoisting the cask and cask lid are evenly spaced circumferentially.

Two lifts were analyzed: 1) the cask lift and, 2) the lid lift. The cask normal operations did not include a lift and thus there are no lifting devices that are a structural part of the cask. For all normal cask lift operations, the cask is lifted empty. Conservatively, the cask lifting analysis was performed using the maximum loaded weight of the cask of 85,000 lbs.

The lifting attachments, lid lifting device and bolt threads met the acceptance and design criteria.
Trailer and Tiedown System

The following paragraphs summarize the Trailer’s structural features and behavior. Details are found PacTec DAR (Ref. 7).

The trailer and tiedown structure were modeled with MSC Nastran. A mid-surface model was generated from the Nelson supplied 2-dimensional drawing files. Plate elements were constructed on the midsurfaces representing the trailer structure. A global mesh size of 2" was used. Beam elements are used to represent the axles, suspension and tires. Rigid elements were used to connect the suspension to the underside of the main beams of the trailer. Beam elements were also used to represent the cask and the structural tubes in the tiedown structure to allow for quick tube sizing. The densities of the cask and trailer were modified so that a cask weight of 85,000 lb and empty trailer weight of 35,000 lb. was obtained for analysis.

An additional model was created of the tiedown structure only, consisting of all tiedown components located above the trailer deck. Plate elements are used to model all the rectangular tubes, top cask clamp lower tiedown devices, and the cask. Compression only gap elements were added between the cask, tiedown devices and top clamp to simulate contact due to the acceleration loads. A static-nonlinear analysis is used for this model in order to utilize the gap elements.

Four operational and one tiedown load case were analyzed. The operational loadings were evaluated versus, structural safety factors of 2:1. Tiedown loads enveloped past and current DOT criteria and were evaluated versus structural safety factors of 1:1, again consistent with DOT criteria.

The results of the analysis indicated that loads are acceptable:

- The minimum operational factor of safety was found to be $+2.05$, representing a 1g aft and 1g down loading.
- The minimum tiedown factor of safety was found to be $+4.12$.

2.3.4 Earthquake Analyses of STS

The seismic analysis model utilized the trailer structural model described above in PacTec DAR (Ref. 7), converting it into a single super-element accurately representing the elastic and inertial properties of the trailer, tiedown structure and cask. To this super element were added discrete models of each element of the suspension system. All modeling properties were derived from manufacturers supplied data. Tire and landing gear model restraints were accurately modeled as gaps to ground surface with lateral friction forces acting when the gap was compressively loaded.

The loading was applied via time history ground motion excitations whose spectral transformations matched the Performance Specification, SNF 8163 (Ref. 1), requirements for a K-basin PC-3 earthquake.
The evaluation demonstrates that the STS Trailer will not overturn during the specified earthquake. Specifically,

- Maximum uplift on either landing leg is 2.43 inches.
- Maximum tire lift is 1.06 inches
- Lateral sway of the cask top is 6.12 inches.

Details are provided in the PacTec DAR (Ref. 7).

2.4 References

1 SNF-8163, Rev. 4, Performance Specification for the K East Basin Sludge Transportation System – Project A.16, Fluor Hanford, Inc., March 2002
7 ED-073, Sludge Transportation System Design Analysis Report, PacTec, Tacoma, WA, September 2002
3.0 THERMAL EVALUATION

3.1 Introduction

Both PacTec and Fluor Hanford performed extensive evaluations of the thermal performance of a loaded LDC sitting in one of the shipping casks. Additionally, Fluor Hanford performed analyses of six LDC sitting in a cell at T-Plant during the storage mission. These evaluations were performed to demonstrate that the STS as designed met the performance criteria established in the Functional Design Criteria document, SNF-8166 (Ref. 1), and the Performance Specification, SNF-8163 (Ref. 2). The thermal evaluations were performed for both normal operating conditions and under postulated accident conditions. This section summarizes the thermal evaluations that were performed and the results that were obtained.

3.2 PacTec Thermal Evaluations

The thermal evaluations performed by PacTec are documented in Chapter 3.0 of the PacTec DAR (Ref. 3). This document is included as Attachment 6.

The specific objectives of the PacTec thermal calculations were as follows:

- Evaluate the thermal performance of the STS under normal and accident conditions of transportation and ensure the compliance of the system design with all thermal criteria.
- Evaluate the gas generation of the payload and the venting performance of the system to ensure that internal pressures and hydrogen gas concentrations remain within design criteria.

PacTec performed thermal evaluations for a range of payload volumes and compositions. Specifically, PacTec evaluated payloads consisting of both the design basis sludge mixture of 80% floor sludge and 20% canister sludge (80/20 sludge) and the safety basis mixture of 60% floor sludge and 40% canister sludge (60/40 sludge). The sludge quantities considered in the PacTec evaluations ranged from a minimum of 2.0 m³ of as-settled sludge without gas retention (which expanded to 3.08 m³ with 35% gas retention) to a maximum of 3.38 m³ of as-settled sludge without gas retention. The 2.0 m³ sludge payload was assumed to consist of four “layers” of sludge, each having an initial volume of 0.5 m³. Each layer was further assumed to consist of an “active” sub-layer occupying the lower 2/3 of the layer and an “inactive” layer forming the upper 1/3 of the layer. The uranium fuel particles were assumed to be spread uniformly throughout the active sub-layer.

The 3.38 m³ sludge payload was assumed to consist of six “layers” of sludge, each having a volume of 0.55 m³. These six layers were assumed to be identical in composition to those in the four-layer model. In addition to performing analyses on these layered models, PacTec analyzed a homogeneous payload with no layering within the sludge and no retained gas. The thermal model developed by PacTec included heat sources from radioactive decay, radiolytic decomposition of water, and chemical reaction between the uranium metal fuel particles and...
water. The model also treated the heating and cooling effect of the external environment during each diurnal cycle.

PacTec’s analyses focused on the period of time during which the STS is being moved from the K-Basins to T-Plant. This shipping window was modeled as being 60 hours in duration, which is twice the expected maximum transportation time (defined as the time period from the completion of inerting of the cask/LDC at K-East Basin to start of re-inerting of the cask/LDC at T-Plant). PacTec analyzed a total of 11 cases that included both normal transportation scenarios and accident conditions. In addition, they performed sensitivity analyses around the conditions developed as the starting point for the postulated accident case (a fire).

The transportation cask and LDC were modeled in axi-symmetric cylindrical geometry in the thermal analysis computer codes used by PacTec for the non-accident cases. A 180° three-dimensional model was used for the accident calculations. In addition to computing transient temperatures within the model, the computer codes calculated the generation and subsequent diffusion of hydrogen from within the sludge to the gas-filled region at the top of the LDC and on into the cask. The gas generation results are discussed in Section 7.0.

For the safety basis case calculated for non-accident conditions (the safety basis sludge loading under worst-case insolation conditions), the computer model used by PacTec predicted peak temperatures and internal gas pressures that are well within acceptance criteria for the STS. The several parametric cases that were run to examine the effect of additional conservatisms in the modeling also resulted in peak temperatures and pressures that were well within acceptance criteria. The results of these PacTec evaluations are documented in Section 7.1 of PacTec Calculation 12099-05, which is included in Attachment 3.1 of the PacTec DAR. Tables 7-1 through 7-7 from this PacTec calculation summarize key results.

PacTec evaluated three configurations for the hypothetical accident conditions. In all of these cases, the cask and LDC were assumed to be on their sides with a fire burning around them for 30 minutes. The results of these analyses were provided to the Fluor Hanford team that developed the transportation safety documentation for the STS that serves as the safety basis for the STS during transportation from K-Basins to T-Plant.

These hypothetical accident evaluations are presented in Section 7.2 of the PacTec calculation. The results are summarized in Tables 7-8 through 7-10 in the calculation.

### 3.3 Fluor Hanford Thermal Evaluations

Fluor Hanford personnel performed two sets of thermal evaluations. The first set of evaluations is reported in SNF-9955 (Ref. 4). This document is included as Attachment 11. This set of evaluations considered a safety basis payload consisting of a mixture of 60/40 sludge. The sludge quantity considered in Fluor Hanford safety basis evaluations was 2.0 m$^3$ of as-settled sludge that had expanded to 3.08 m$^3$ with 35% gas retention. The 2.0 m$^3$ sludge payload was assumed to consist of four “layers” of sludge, each having an initial volume of 0.5 m$^3$. Each layer was further assumed to consist of an “active” sub-layer occupying the lower 2/3 of the layer and an “inactive” layer forming the upper 1/3 of the layer. The uranium fuel particles were
assumed to be spread uniformly throughout the active sub-layer. This is the same starting point as was used for the baseline safety basis evaluation performed by PacTec.

The Fluor Hanford safety basis thermal evaluations used as their starting point the time when the STS is ready to leave K-East Basis for its trip to T-Plant. The evaluations followed the STS through 30- and 60-hour transportation windows during maximum insolation conditions for the Hanford site. As with the PacTec analyses, the Fluor Hanford safety basis evaluation predict that peak pressures in the cask and LDC would not exceed the 80 psig acceptance criterion during the 30- and 60-hour transportation windows and that peak temperatures in the sludge would be well below the boiling point of water, indicating that the sludge is thermally stable.

The Fluor Hanford safety basis thermal evaluations also examined the thermal and gas generation response of a safety basis LDC to storage conditions in a T-Plant cell. The thermal model included one LDC with a safety basis loading of sludge and five LDCs with loadings of 75% floor sludge and 25% canister sludge (75/25 sludge) sitting in a single cell in T-Plant. These evaluations predict that even under a loss of forced ventilation condition lasting for 30 days at T-Plant, temperatures in the sludge would remain well below 100°C.

The results of the Fluor Hanford safety basis thermal evaluation were used to establish sludge loading process requirements for the LDC at K-East Basis and to establish the safety basis for the sludge-filled LDCs at T-Plant.

The second set of Fluor Hanford thermal evaluations are reported in SNF-10415 (Ref. 5). This report is included as Attachment 12. These evaluations considered a design basis loading of 80/20 sludge, as did the design basis thermal evaluations performed by PacTec. The results from the Fluor Hanford design basis calculations were confirmatory of the PacTec results that the thermal analysis results meet acceptance criteria for K-East Basin and T-Plant and are also acceptable during the 60 hour transport window.

3.4 References

5 SNF-10415, Rev. 0, *Design-Basis Thermal and Gas Generation Analysis for KE Basis Sludge in Large Diameter Containers*, Fluor Hanford, Inc., August 2002
4.0 CONTAINMENT/CONFINEMENT EVALUATION

4.1 Introduction

This section describes the evaluations that were performed to verify that the containment/confinement requirements spelled out in the Functional Design Criteria documents, SNF-8166 (Ref. 1), and the Performance Specification, SNF-8163 (Ref. 2), are met by the STS design.

4.2 Containment/Confinement Description

The STS cask provides a single level of containment for the STS payload. In general, all containment components are fabricated from Type 304 austenitic stainless steel, with exceptions noted in the following description. The containment boundary for the STS cask is identified as the 1.0 inch thick inner shell, the 6.0 inch thick cask bottom, the 5.0 inch thick closure lid, and the cask body upper forging. The non-stainless steel components included in the containment boundary are the metallic inner O-ring for the closure lid, the closure bolts, the vent and drain port plugs, and their associated metal O-ring sealing elements.

The drain port, vent ports, and closure lid comprise the only penetrations into the containment boundary. Each penetration is designed to demonstrate “leaktight” sealing integrity, i.e., a leak rate not to exceed $1 \times 10^{-7}$ standard cubic centimeters per second (scm/sec), air, per ANSI N14.5 (Ref. 3). The seals of the containment boundary are comprised of a nominally 0.286 inch diameter, HN200 Helicoflex O-ring face seal in a groove in the closure lid, and Garlock metallic O-ring sealing elements for the vent and drain port plugs.

Additional details regarding the design of the cask containment system are provided in the PacTec DAR (Ref. 4), which is included as Attachment 7.

4.3 Containment/Confinement Performance Evaluations

4.3.1 Normal Conditions

PacTec performed structural and thermal and gas generation evaluations of the containment/confinement system represented by the STS cask with an LDC containing sludge payloads under normal conditions. The structural evaluations for normal conditions are discussed in Section 2.0 of this report and in more detail in Section 2.4 of the PacTec DAR. The thermal and gas generation calculations are discussed in Section 3.2 of this report and presented in more detail in Section 3.4 of the PacTec DAR.

Fluor Hanford performed extensive thermal and gas generation evaluations of the STS cask and LDC for normal conditions. These are discussed in Section 3.3 of this report and presented in detail in the report SNF-10415 (Ref. 5). This report is included as Attachment 12.
The PacTec structural evaluations and the PacTec and Fluor Hanford thermal and gas generation evaluations demonstrate that the STS cask maintains a leak-tight containment boundary during normal conditions of transport and storage at T-Plant.

4.3.2 Accident Conditions

PacTec performed structural and thermal evaluations of the containment/confine ment system represented by the STS cask with an LDC containing sludge payloads hypothetical accident conditions. For structural evaluation purposes, each hypothetical accident condition was applied sequentially to determine the maximum cumulative damage in the following order: a 30-foot drop, followed by a 40-inch drop onto a mild steel puncture bar, followed by exposure to a 30 minute, 1,475°F thermal environment. The structural evaluations for hypothetical accident conditions are discussed in Section 2.0 of this report and in more detail in Sections 2.5-2.7 of the PacTec DAR. The thermal and gas generation calculations are discussed in Section 3.2 of this report and presented in more detail in Sections 6.3 and 7.2-7.3 of Attachment 3.1 of the PacTec DAR.

The PacTec structural evaluations for hypothetical accident conditions demonstrate that the STS cask has adequate design margin to withstand the hypothetical accident conditions without experiencing failure (see Section 2.7.2 of the PacTec DAR).

The PacTec thermal evaluations for hypothetical accident conditions demonstrate that the STS cask with payload also meets the thermal requirements for these conditions. The safety basis case considers the cask and LDC to be on their sides with a minimal amount of water leaked into the annulus between the cask and the LDC. The thermal analyses cover the time period that includes the 30-minute fire, followed by water quenching and a 11.5 hour cool-down period. These same analyses also demonstrate that gas pressures within the cask meet the performance specifications. The results of the thermal and gas generation analyses for hypothetical accident conditions are summarized in Table 7-8 of Attachment 3.1 to the PacTec DAR.

4.4 References

5. SNF-10415, Rev. 0, Design-Basis Thermal and Gas Generation Analysis for KE Basis Sludge in Large Diameter Containers, Fluor Hanford, Inc., August 2002
5.0 SHIELDING EVALUATION

5.1 Introduction

This section describes the evaluations that were performed to verify that the radiation shielding requirements spelled out in the Functional Design Criteria documents, SNF-8166 (Ref. 1), and the Performance Specification, SNF-8163 (Ref. 2), are met by the STS design. PacTec performed the shielding evaluations for the complete STS. Avantech performed the shielding evaluations for the LDC with its payload. The latter analyses were performed to assure that requirements for handling and storage of the LDC at T-Plant were met.

5.2 Radiation Source Specification for STS Evaluations

Section 5 of the PacTec DAR (Ref. 3) documents the shielding evaluations performed by PacTec for the cask with a loaded LDC in it. For radiation shielding purposes, PacTec evaluated LDC payloads consisting of the safety basis mixture of 60% by volume floor sludge and 40% by volume canister sludge (60/40 sludge) and the design basis mixture of 80% by volume floor sludge and 20% by volume canister sludge (80/20 sludge). The safety basis payload resulted in higher dose rates because it contained significantly more fuel particles. The radionuclide compositions of both mixtures was obtained from the SNF Project Technical Databook (Ref. 4). The gamma and neutron sources were determined using the ORIGEN-S module of the SCALE code package (Ref. 5).

5.3 STS Shielding Evaluation for Normal Transportation Conditions

For normal conditions, PacTec chose to evaluate a payload consisting of 3.6 m$^3$ of 80/20 sludge. This quantity was chosen because it represents the maximum amount of sludge that could be loaded into the LDC. Two cases were run, one with the source evenly distributed throughout the entire sludge volume and one with the source evenly distributed throughout the bottom 50% of the sludge volume. Dose rates were calculated using the MCNP shielding code (Ref. 6). The acceptance criteria for normal conditions were taken from 49 CFR 173. Dose limits of 200 mrem/hr on the cask surfaces and 10 mrem/hr at 2 meters radially were imposed to meet 49 CFR 173 requirements.

The results of the shielding calculations for all four cases considered under normal conditions are summarized in Section 5.4.4 of the PacTec DAR. All calculated dose rates were within their respective limits.

5.4 STS Shielding Evaluation for Transportation Accident Conditions

For evaluating STS shielding performance under hypothetical accident conditions, PacTec assumed that the LDC no longer provided either containment or shielding so that it was ignored in the MCNP calculations. Because the cask lid is thinner than the cask bottom, the sludge was assumed to have migrated to the top of the cask with the source compressed into the half of the sludge closest to the top lid. As with the normal conditions analysis, two loadings were
analyzed: 3.6 m³ of 80/20 sludge and 2.0 m³ of 60/40 sludge. The acceptance criterion used was that the dose rate 1 meter from the surface of the cask not exceed 1000 mrem/hr.

The results of the shielding evaluation for accident conditions are presented in Section 5.5.4 of the PacTec DAR. In both cases analyzed, dose rates were less than the acceptance criterion.

### 5.5 LDC Shielding Evaluations for Storage

Avantech performed the shielding evaluations for the LDC with its sludge payload. These evaluations are documented in Attachment 1 to Section 5 of the PacTec DAR. For these evaluations, a loading of 3.35 m³ of 60/40 sludge was assumed. The MicroShield computer code (Ref. 7) was used to calculate gamma dose rates based on a point kernel model. The neutron dose rate was calculated using a one-dimensional model in the SCALE SAS 1 computer code (Ref. 8). The acceptance criterion was that the dose rate be less than 500 rad/hr at 1 meter from the surface of the LDC. The results of the evaluations were that the highest contact dose rate was less than 350 rad/hr and the maximum dose rate at 1 meter was 121 rad/hr. Therefore, the unshielded LDC was shown to meet applicable performance requirements.

### 5.6 References

6.0 CRITICALITY EVALUATION

6.1 Introduction

This section describes the criticality safety evaluations that were performed to demonstrate that a criticality event is incredible for the STS as characterized the Functional Design Criteria document, SNF-8166 (Ref. 1), and the Performance Specification, SNF-8163 (Ref. 2). Fluor Hanford performed the criticality safety evaluations for the STS. These evaluations are documented in HNF-8513 (Ref. 3).

6.2 Criticality Safety Evaluation Model

Fluor Hanford performed the criticality safety evaluations using the MCNP computer code (Ref. 4). Criticality calculations were performed both for a single LDC and cask and for six loaded LDCs stored in a single T-Plant cell. The cask and LDC were modeled based on their nominal dimensions. The fissionable material was modeled as spherical pieces of unirradiated uranium metal in a cubic lattice filled with homogeneous UO₂ sludge in water. The uranium was modeled as enriched to 0.95 wt% U²³⁵. The sludge pumped into the LDC was assumed to be canister sludge with an as-settled density of 2.0 g/cm³. Each LDC was modeled as containing at least 3 m³ of material consisting of homogeneous sludge and 2,000 kg of 0.95 wt% U²³⁵ metal (unirradiated). Taken collectively, these modeling assumptions result in a very conservative representation of the LDC loaded with sludge. Table 4-2 of HNF-8513 (Ref. 3) provides a concise summary of these modeling assumptions and conservatisms.

6.3 Criticality Safety Evaluation Results

A number of cases involving a single cask and LDC were run on MCNP. These cases examined various degrees of sludge compaction while holding the mass of uranium metal constant at approximately 2,000 kg. The largest keff calculated for this range of cases was 0.942. The results of all of the cases run on MCNP are shown in Table 4-4 of HNF-8513. These calculations demonstrate that criticality is incredible for a single cask and loaded LDC and therefore that neither a criticality alarm or criticality detection system is required.

6.4 References

7.0 GAS GENERATION EVALUATION

7.1 Introduction

As discussed in Section 3.1, both PacTec and Fluor Hanford performed extensive evaluations of the thermal performance of a loaded LDC sitting in one of the shipping casks. Additionally, Fluor Hanford performed analyses of six LDCs sitting in a cell at T-Plant during the storage mission. These evaluations were performed to demonstrate that the STS as designed met the thermal and gas generation-related performance criteria established in the Functional Design Criteria document, SNF-8166 (Ref. 1), and the Performance Specification, SNF-8163 (Ref. 2). The results of the thermal evaluations were discussed in Sections 3.2 and 3.3. This Section presents the results of the gas generation evaluations that were performed in conjunction with the thermal evaluations.

7.2 PacTec Gas Generation Evaluations

The PacTec gas generation evaluations are presented in Attachment 3.1 to the PacTec DAR (Ref. 3). The gas generation evaluations were performed in conjunction with the thermal evaluations for both the normal conditions of transport and for hypothetical accident conditions.

7.2.1 Gas Generation for Normal Transportation Conditions

PacTec performed gas generation evaluations for a range of payload volumes and compositions. Specifically, PacTec evaluated payloads consisting of both the design basis sludge mixture of 80% floor sludge and 20% canister sludge (80/20 sludge) and the safety basis mixture of 60% floor sludge and 40% canister sludge (60/40 sludge). The sludge quantities considered in the PacTec evaluations ranged from a minimum of 2.0 m³ of as-settled sludge without gas retention (which expanded to 3.08 m³ with 35% gas retention) to a maximum of 3.38 m³ of as-settled sludge without gas retention. The 2.0 m³ sludge payload was assumed to consist of four “layers” of sludge, each having an initial volume of 0.5 m³. Each layer was further assumed to consist of an “active” sub-layer occupying the lower 2/3 of the layer and an “inactive” layer forming the upper 1/3 of the layer. The uranium fuel particles were assumed to be spread uniformly throughout the active sub-layer.

The 3.38 m³ sludge payload was assumed to consist of six “layers” of sludge, each having a volume of 0.55 m³. These six layers were assumed to be identical in composition to those in the four-layer model. In addition to performing analyses on these layered models, PacTec analyzed a homogeneous payload with no layering within the sludge and no retained gas.

The thermal model developed by PacTec included heat sources from radioactive decay, radiolytic decomposition of water, and chemical reaction between the uranium metal fuel particles and water. The model also treated the heating and cooling effect of the external environment during each diurnal cycle. The gas generation model that was integrated with the thermal model considered hydrogen and oxygen generation from the radiolytic decomposition of water and hydrogen generation from the chemical reaction between the uranium metal fuel particles and
water. The model also treated the diffusion of hydrogen gas from the void space above the water in the LDC through the HEPA filter at the top of the LDC into the void space in the cask.

The results of the gas generation evaluations are presented in Section 7.3 of Attachment 3.1 to the PacTec DAR for both normal transport conditions and hypothetical accident conditions. For the safety basis normal transportation case, the cask pressure at the end of the 60-hour transportation window was predicted to be approximately 29 psia, compared to an acceptance criterion of 95 psia. The predicted gas pressures in the cask at the end of the 60-hour window were also significantly less than the acceptance criterion of the ten other cases considered by PacTec for the transportation window.

Hydrogen gas concentrations are predicted to exceed the lower flammability limit of 4% during the 60-hour window. However, the void space in the cask and LDC will have been inerted prior to the time when the STS leaves the K-Ease Basin, and only a small quantity of oxygen is generated by radiolysis of water during the 60-hour window. The absence of oxygen makes it impossible for the hydrogen to burn.

7.2.2 Gas Generation for Hypothetical Accident Conditions

PacTec evaluated three configurations for the hypothetical accident conditions. In all of these cases, the cask and LDC were assumed to be on their sides with a fire burning around them for 30 minutes, followed by a 11.5-hour post-fire cool down period. The results of these analyses were provided to the Fluor Hanford team that developed the transportation safety documentation for the STS that serves as the safety basis for the STS during transportation from K-Basins to T-Plant.

In each case, the hypothetical accident was assumed to occur at the end of the 60-hour transportation window. Thus, gas pressures in the void space were elevated but were within the acceptance limits. The fire that is assumed to bum for 30 minutes when the accident occurs heats the water that is assumed to have leaked into the annulus between the cask and LDC to the point that the water is predicted to boil after about 20 minutes. The steam produced causes the pressure to increase to about 123 psia. Once the quenching begins after the 30-minute fire, boiling is predicted to cease in about 5 more minutes. PacTec performed structural evaluations of the cask with LDC inside using the temperature distributions and pressures predicted for the accident conditions that demonstrated that the cask would maintain its integrity under these hypothetical accident conditions.

7.3 Fluor Hanford Gas Generation Evaluations

Fluor Hanford performed two sets of thermal evaluations. The first set of evaluations is reported in SNF-9955 (Ref. 4). This document is included as Attachment 11. This set of evaluations considered a safety basis payload consisting of a mixture of 60/40 sludge. The sludge quantity considered in Fluor Hanford safety basis evaluations was 2.0 m³ of as-settled sludge that had expanded to 3.08 m³ with 35% gas retention. The 2.0 m³ sludge payload was assumed to consist of four “layers” of sludge, each having an initial volume of 0.5 m³. Each layer was further assumed to consist of an “active” sub-layer occupying the lower 2/3 of the layer and an
“inactive” layer forming the upper 1/3 of the layer. The uranium fuel particles were assumed to be spread uniformly throughout the active sub-layer. This is the same starting point as was used for the baseline safety basis evaluation performed by PacTec.

The Fluor Hanford safety basis gas generation evaluations used as their starting point the time when the STS is ready to leave K-East Basin for its trip to T-Plant. The evaluations followed the STS through 30- and 60-hour transportation windows during maximum insolation conditions for the Hanford site. As with the PacTec analyses, the Fluor Hanford safety basis evaluation predict that peak pressures in the cask and LDC would not exceed the 80 psig (94.7 psia) acceptance criterion during the 30- and 60-hour transportation windows. At the end of the 30- and 60-hour transportation windows, the analyses predict internal cask pressures of 22.55 psia and 31.36 psia, respectively. Starting with a hydrogen-free environment in the cask following inerting at K-East Basin, the hydrogen concentrations in the cask are predicted to increase to 21.0% at the end of 30 hours and to 41.4% after 60 hours. These hydrogen concentrations necessitate putting the cask through a re-inerting process once it has arrived at T-Plant.

The Fluor Hanford safety basis gas evaluations also examined the gas generation response of a safety basis LDC to storage conditions in a T-Plant cell. The thermal model included one LDC with a safety basis loading of sludge and five LDCs with loadings of 75% floor sludge and 25% canister sludge (75/25 sludge) sitting in a single cell in T-Plant. These evaluations predict that even under a loss of forced ventilation condition lasting for 30 days at T-Plant, the maximum hydrogen concentration in the T-Plant cell would be 2.11%.

The results of the Fluor Hanford safety basis gas generation evaluation were used to establish sludge loading process requirements for the LDC at K-East Basis and to establish the safety basis for the sludge-filled LDCs at T-Plant.

The second set of Fluor Hanford thermal evaluations are reported in SNF-10415 (Ref. 5). This report is included as Attachment 12. These evaluations considered a design basis loading of sludge, as did the design basis gas generation evaluations performed by PacTec. The results from the Fluor Hanford design basis calculations were confirmatory of the PacTec results that the gas generation results meet acceptance criteria for K-East Basin and T-Plant and are also acceptable during the 60 hour transport window.

### References

5 SNF-10415, Rev. 0, Design-Basis Thermal and Gas Generation Analysis for KE Basis Sludge in Large Diameter Containers, Fluor Hanford, Inc., August 2002
8.0 TIEDOWN DEVICES AND SPECIAL TOOLS EVALUATION

8.1 Introduction

Because the STS will be moved across the quasi-public roads while being moved from K-East Basin to T-Plant, its design and fabrication have been subjected to the requirements of 10 CFR 71 (Ref. 1). Specific requirements are imposed upon the cask tiedown system that secures the cask to the trailer 10 CFR 71.45(b). For this reason, the PacTec DAR (Ref. 2) addressed the cask tiedown system as a separate topic. The cask tiedown system is discussed in Section 8.0 of the PacTec DAR.

8.2 Cask Tiedown System

The cask tiedown system is simple in concept. Horizontal loading from the cask is resisted by bearing against tiedown clamps mounted on the trailer. Vertical loading is resisted by trailer tiedown bars that engage grooves in the cask bottom forging. For design purposes, the loading conditions that serve as the design basis are taken from 10 CFR 71.45(b). The cask tiedown system must be capable of withstanding a load 10 times the weight of the cask in the horizontal direction or travel, a load five times the cask weight in the transverse horizontal direction, and a load two times the cask weight in the vertical direction. The horizontal loads are combined by taking their vector sum. The stress on the cask that would be generated from loading against the trailer tiedown clamps is calculated by using the bearing area over one-half of the circumference.

Stress calculations presented in Section 8.0 of the PacTec DAR demonstrate that the tiedown system as designed has substantial design margins for all of the required loading cases.

8.3 References

1. 10 CFR 71, Packaging and Transportation of Radioactive Material, Code of Federal Regulations, as amended
9.0 OPERATING PROCEDURES

9.1 Introduction

PacTec provided a limited set of outlines for operating procedures for the STS in Section 10.0 of the PacTec DAR (Ref. 1). These procedures are described in more detail in PacTec document OM-07 (Ref. 2). In addition, AVANTech provided an Operations and Maintenance (O&M) Manual for the LDC in AVANTech Calculation ER-3C-0126-01 (Ref. 3). The procedure information provided by PacTec and AVANTech is being incorporated into the operations and maintenance procedures under development by the SNF Project.

9.2 Summary of Operating Procedures

The STS cask is to be loaded on the transport trailer before the cask and trailer arrive on the Hanford site. The PacTec DAR provides outlines for procedures for the following activities:

- Load empty LDC into empty cask
- Prepare the cask for start of loading of the LDC
- Remove the loaded LDC from the cask at T-Plant

The AVANTech calculation serves as a vehicle for transmitting the Instruction Manual from Milltronics (Ref. 4) for the level detector that is installed on the LDC. The level detector is the only device on the LDC that requires maintenance and calibration.

9.3 References

1 PacTec Report, ED-073, Sludge Transportation System Design Analysis Report, PacTec, Tacoma, WA, September 2002
2 PacTec Report, OM-07, Rev. 1, Sludge Transportation System Installation, Repair and Maintenance (IORM), PacTec, Tacoma, WA, September 2002
3 Calculation ID No. ER-3C-0126-01, Rev. 0, K-East Sludge Transport System – A-170 (Large Container): O&M Manual (90% Final Design), AVANTech, Inc.
10.0 ACCEPTANCE TEST AND MAINTENANCE PROGRAM

10.1 Introduction

PacTec developed inspection, testing and maintenance requirements for the cask and its various components. These are documented in Section 11.0 of the PacTec DAR (Ref. 1). These requirements will be incorporated into SNF Project procedures as appropriate.

10.2 Initial Testing Requirements

Several types of tests are required as a part of the acceptance process for the STS cask. These are listed below:

- Lifting Device Load Testing – There are four threaded holes in the cask lid into which bolts are inserted to attach both the cask and the cask lid lifting devices. These lifting points are to be subjected to an initial load test per ANSI N14.6 (Ref. 2). Additional visual inspections, examination with a thread go/no-go gauge, and liquid penetrant testing are also to be conducted.
- Pressure Testing – The cask containment boundary is to be pressure tested to 150% of the maximum normal operating pressure per 10 CFR 71.85(b) (Ref. 3), which results in testing to 120 pslg. Following the pressure test, accessible welds are to be visually inspected and subjected to dye penetrant testing.
- Leak Testing – Five leak tests are to be conducted on the cask at the completion of fabrication. These include 1) a test to determine the response time for the helium mass spectrometer leak detector; 2) a test to determine the actual leak rate of the metallic containment boundary; 3) three leak tests to verify containment integrity for the vent port bolt, the drain port bolt, and the closure lid.
- Shielding Integrity Testing – Gamma scans are to be conducted to verify the integrity of the lead that is cast into the walls of the cask.

All of these tests will be performed by PacTec before the STS is delivered to the Hanford site.

10.3 Duty Cycle-Related Inspection, Testing and Maintenance Requirements

Several tests and inspections are required each duty cycle experienced by the STS. These are noted below.

- Leak Testing – Three leak tests are to be performed each time the cask lid is placed on the cask following loading of the LDC contained in it. Leak testing is to be performed on the vent port bolt, the drain port bolt and the closure lid.
- Containment 0-Ring Seal Replacement – All containment O-ring seals are to be replaced after each use (or when damaged).
- Routine Inspections – Inspections are to be performed during each loading and unloading operation for the following items: 1) condition of bolts and seals, 2) indications of
corrosion, and 3) evidence of dents, cracks or other deformations. In addition, surfaces are to be inspected for any sign of containment failure, and the ease of use of removable components is to be observed for signs of wear.

10.4 References


11.0 ANCILLARY DOCUMENTS

The last six documents listed in Section 1.4 were not prepared as part of the design effort required to support the fabrication of the various components of the STS. Rather, their preparation was driven by other requirements and purposes. Each of the documents is described briefly below.

11.1 Design Verification and Validation Plan

Fluor Hanford prepared a plan for performing verification and validation of the SWS design completed by PacTec. Preparation and implementation of the verification and validation activity is required by HNF-RD-1819 (Ref 1). This plan is documented in SNF-6470 (Ref. 2). This document is included as Attachment 13.

11.2 Design Verification and Validation Report

Fluor Hanford will perform a verification and validation of the PacTec design for the SWS. The results of this effort along with the STS FDC compliance matrix will be documented following completion of the Acceptance Test Program. The verification and validation effort is intended to demonstrate that the design produced by the several vendors who supported the SWS Project complies with the requirements and specifications imposed on it.

11.3 SWS Human Factors Report

During the course of the design effort for the SWS, analyses were performed and design reviews were conducted for that focuses on various Human Factors aspects of the design and operation of the system. The results of these efforts are documented in SNF-13143 (Ref. 3). This document is included as Attachment 15.

11.4 SWS ALARA Report

During the conceptual design phase of the SWS, ALARA reviews were held frequently to discuss the radiation protection aspects of the evolving design. The results of these efforts are documented in SNF-8509 (Ref. 4). The ALARA Report identifies a number of design features that should be given attention during the design effort for SWS to assure that ALARA goals are achieved. It also identifies aspects of the full cycle of operations activities required to fill and ship an LDC to which attention will need to be given to assure fulfillment of ALARA goals. This document is included as Attachment 16.

11.5 SWS Hazards Analysis

Fluor Hanford performed a hazards analysis of the entire SWS as an initial step in developing the safety basis for the SWS project. This hazards analysis is documented in SNF-I0020 (Ref. 5). This document is included as Attachment 17.
11.6 K Basins Hazards Analysis

Given the results of the hazards analysis, Fluor Hanford performed a hazards analysis of the entire K Basins operation as the next step in developing the safety basis for the SWS project. This Hazards analysis is documented in HNF-3960 (Ref. 6). This document is included as Attachment 17.

11.7 References

1  HNF-RD-1819, Rev. 0, *PHMC Engineering Requirements*, Fluor Hanford, Inc., August 2002
6  HNF-3960, Rev. 5, *K Basins Hazards Analysis*, Fluor Hanford, Inc., October 2002
12.0 SUPPORTING REFERENCE DOCUMENTS

During the course of developing the functional design criteria and performance specifications for the STS, Fluor Hanford consulted a large number of requirements documents, including the Code of Federal Regulations, DOE Orders, the State of Washington’s Administrative Code and various consensus national codes and standards. A partial listing of these documents is provided below.

12.1 Code of Federal Regulations

1. 10 CFR 71, *Packaging and Transportation of Radioactive Material.*
2. 10 CFR 820, *General Statement of Enforcement Policy*
3. 10 CFR 830, *Nuclear Safety Management*
4. 10 CFR 830.120, *Quality Assurance*
5. 10 CFR 835, *Occupational Radiation Protection*
6. 29 CFR 1910, *Occupational Safety and Health Standards*
7. 29 CFR 1926, *Safety and Health Regulations for Construction*
8. 40 CFR *Part 60, Appendix A, Methods 1, 1A, 2, 2A, 2C, 2D, 4, 5, and 17.*
11. 49 CFR 173, *Shippers--General Requirements for Shipments and Packaging*

12.2 Department of Energy

1. DOE 1994, *Spent Nuclear Fuel Program Requirements Document, SNF-RD-PM-001, Rev. 1*
2. DOE Order 460.1A, *Packaging and Transportation Safety*
3. DOE Order 474.1, *Control and Accountability of Nuclear Materials*
4. DOE Order 5400.5, *Radiation Protection of the Public and the Environment*
5. DOE Order 5480.24, *Nuclear Criticality Safety*
6. DOE Order 5480.28, *Natural Phenomena Hazards Mitigation*
7. DOE Order 5480.7A, *Fire Protection*
8. DOE Order 5820.2A, *Radioactive Waste Management*
9. DOE Order 6430.1A, *General Design Criteria*

12.3 Washington Administrative Code


### 12.4 National Consensus Codes and Standards

#### 12.4.1 American National Standards Institute, New York, New York

1. ANSI A13.1, *Scheme for the Identification of Piping Systems*

2. ANSI C50.2, *Alternating-Current Induction Motors, Induction Machines in General, and Universal Motors*

3. ANSI/ANS 57.7, *Design Criteria for an Independent Spent Fuel Storage Installation (Water Pool Type)*


#### 12.4.2 American Society of Civil Engineers, New York, New York


#### 12.4.3 American Society of Mechanical Engineers, New York, New York

1. ASME B31.1, *Power Piping*

2. ASME Section VIII, *Rules for Construction of Pressure Vessels, Boiler and Pressure Vessel Code*

3. ASME Section IX, *Qualification Standards for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators, ASME Boiler and Pressure Vessel Code*

4. ASME N509, *Nuclear Power Plant Air-Cleaning Units and Components*

5. ASME N510, *Testing of Nuclear Air-Treatment Systems*

6. ASME NQA-1, *Quality Assurance Requirements for Nuclear Facility Applications*

7. ASME Y14.5, *Dimensioning and Tolerancing*

8. ASME Y14.5.1, *Mathematical Definition of Dimensioning and Tolerancing Principles*


#### 12.4.4 American Welding Society, Miami, Florida

1. AWS D1.1, *Structural Welding Code-Steel*

2. AWS D1.2, *Structural Welding Code-Aluminum*
4. AWS D14.1, Specification for Welding of Industrial and Mill Cranes and Other Material Handling Equipment
5. AWS D9.1, Structural Welding Code – Sheet Metal
6. AWS QC-1, Guide to AWS Welding Inspector Qualifications and Certification

12.4.5 Institute of Electrical and Electronics Engineers, New York, New York

2. IEEE 1008, IEEE Standard for Software Unit Testing
3. IEEE 1012, IEEE Standard for Software Verification and Validation Plans
5. IEEE 336, Standard Installation, Inspection, and Testing Requirements for Power, Instrumentation, and Control Equipment at Nuclear Facilities

12.4.6 Illuminating Engineering Society of North America, New York, New York

1. IES, Lighting Handbook Reference and Application, Eighth Edition

12.4.7 International Conference of Building Officials, Whittier, California

1. UBC-97, 1997 Uniform Building Code

12.4.8 International Society for Measurement and Control, Research Triangle Park, North Carolina

1. ISA S5.1, Instrument Symbols and Identification
2. ISA S5.1, Binary Logic Diagrams for Process Operations
3. ISA S5.4, Instrument Loop Diagrams
4. ISA S18.1, Annunciator Sequences and Specifications
5. ISA S50.1, Compatibility of Analog Signals for Electronic Industrial Process Instruments
6. ISA S82.01, Safety Standard for Electrical and Electronic Test, Measuring, Controlling and Related Equipment – General Requirements
7. ISA S82.02, Safety Standard for Electrical and Electronic Test, Measuring, Controlling and Related Equipment – Electrical and Electronic Test and Measuring Equipment
8. ISA S82.03, Safety Standard for Electrical and Electronic Test, Measuring, Controlling and Related Equipment – Electrical and Electronic Process Measurement and Control Equipment

12.4.9 National Electrical Manufacturers Association, Washington, D. C.

1. NEMA AB1, Molded Case Circuit Breakers and Molded Case Switches
2. NEMA C84.1, Electric Power Systems and Equipment – Voltage Ratings (60 Hertz)
3. NEMA ICS 6, Industrial Control and Systems: Enclosures
4. NEMA SG 3, Low Voltage Power Circuit Breakers
5. NEMA SG 5, Power Switch Gear Assemblies
6. NEMA SG 6, Power Switching Equipment
7. NEMA TR 1, Transformers, Regulators, and Reactors
8. NEMA MG-1, Motors and Generators
9. NEMA WC 5/ICEA S 61 402, Thermoplastic-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy
10. NEMA WC 7/ICEA S 66 524, Cross Linked Thermosetting Polyethylene Insulated Wire and Cable for Transmission and Distribution of Electrical Energy
11. NEMA WC 3/ICEA S 19, Rubber Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy

12.4.10 National Fire Protection Association, Quincy, Massachusetts

1. NFPA 701, Standard Methods of Fire Test for Flame-Resistant Textiles and Films
2. NFPA 69, Standard on Explosion Prevention
3. NFPA 70, National Electric Code

12.4.11 Electrical Council of Underwriters Laboratories, Northbrook, Illinois

1. UL 508, Standard for Safety Industrial Control Equipment

12.4.12 U.S. Naval Publication and Forms Center, Philadelphia, Penn

1. Mil-C-17, Coaxial Cable, Military Specifications

12.5 Hanford Specific Documents


ATTACHMENT 1

SNF-8166, Rev. 2
*Functional Design Criteria for the KE Basins Sludge and Water System, Rev. 2 – Project A-16*

Consisting of 1 Pages
Including this cover page.
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ATTACHMENT 2

SNF-8163, Rev. 5
Performance Specification for the K East Basin Sludge Transportation System – Project A.16

Consisting of 1 Pages
Including this cover page.
Retrievable from RMIS
ATTACHMENT 3

Statement of Work, Revision 4, For The Sludge Transportation System Project A-16, Contract 12329, Attachment 8

Consisting of 1 Pages
Including this cover page.

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ATTACHMENT 4


Consisting of 3 Pages
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January 10, 2002

Mr. S. J. Veitenheimer, Director
Office of Spent Nuclear Fuels
U.S. Department of Energy
Richland Operations Office
Post Office Box 550
Richland, Washington 99352

Dear Mr. Veitenheimer:

CONTRACT NUMBER DE-AC06-96RL13200 - TRANSMITTAL OF THE SLUDGE TRANSPORTATION SYSTEM THIRTY PERCENT DESIGN REVIEW PACKAGE

Attached for your information is the Sludge Transportation System 30% Design Review Package. The attachment includes Review Meeting Minutes, comments for internal and vendor resolution and the submittals from the vendor. Additionally. a submittal log is included that shows what submittals were provided within the 30% design review package.

If you have any questions, please contact Mr. J. E. Crocker on 372-0021.

Very truly yours,

R. P. Heck, Vice President and Project Director
Spent Nuclear Fuel Project

Attachment

cc:  RI. -  P. A. Corbin  A4-79
     S.L. Helmann  A4-79
     S. A. Sieracki  A7-80 w/o attachment
     S. J. Veitenheimer  IV-79
ATTACHMENT 5

SNF-10914, Rev. 0
*K Basins Sludge Transportation System STS 60% Design Review*

Consisting of 1 Pages
Including this cover page.

Retrievable from RMIS
ATTACHMENT 6

SNF-12345, Rev. 0
K Basin Sludge Transportation System 90% Design Report

Consisting of 1 Pages
Including this cover page.

Retrievable from RMIS
ATTACHMENT 7

ED-073
Sludge Transportation System Design Analysis Report

Consisting of 1 Pages
Including this cover page.

Retrievable from Project A-16 Project Files
ATTACHMENT 8

PacTec Submittal 12329/STS 22

*Final Design Report*

Consisting of 88 Pages
Including this cover page.
**SUPPLIER DOCUMENT SUBMITTAL FORM**

| QTY | DOCUMENT NUMBER | REV | PRO | H&S | MED | TRG | CON | ENG | QAC | OPER | TITLE/DESCRIPTION | DESI/ DRTF | AFC | INF | REC | VI | ASSOCIATED SPECIFICATION | A | B | C |
|-----|-----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|----------------------|-----------|-----|-----|-----|---|--------------------------|---|---|---|
| *   | System Design Analysis Report | 0   | X   |     |     |     |     |     |     |     | Final Design Review Report | X         |     |     |     |   |                          |   |   |   |

**SUBCONTRACTOR / COMMENTS** (PLEASE USE SPACE BELOW FOR COMMENTS OR INDICATE IF ATTACHMENTS)

*Submitted Electronically Only*

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**REVIEW DISTRIBUTION**

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**FLUOR HANFORD / COMMENTS**

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**SUBMITTAL TYPE:** (BY SUPPLIER)

AFC - CERTIFIED FOR CONSTRUCTION
DES/DRTF - (30%, 60%, 90%, OR DRAFT)
INF/REC - INFORMATION/RECORD
VEND - VENDOR INFORMATION

**SUBMITTAL ACTION CODE:** (BY FH)

A - Conforms to the Contract Requirements
B - Minor Comments - Approved with exceptions - Incorporate and Resubmit
C - Revise and Resubmit (SEE COMMENTS)

**REVIEWER:**

---

**Revised By:**

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**Date:**
**Sludge** Transportation System Design Analysis Report  
Insert-Remove Instructions for Revision 1

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<td>Section 2.9.8.3 Cover Sheet (Structural Analysis of (A-170) Large Container. EN-3C-0126-04, Revision 3, Aventech Incorporated. 37 pages)</td>
</tr>
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Page 8-3
Table 2.2-2 - ASME SA564, Type 630 (H1100) Bolt Material Properties

<table>
<thead>
<tr>
<th>Material Specification</th>
<th>Temp, °F</th>
<th>Yield Strength ( (S_y) ) ksi</th>
<th>Ultimate Strength ( (S_u) ) ksi</th>
<th>Design Stress Intensity ( (S_m) ) ksi</th>
<th>Elastic Modulus ( (E) \times 10^6 ) psi</th>
<th>Coefficient of Thermal Expansion ( (\alpha) \times 10^{-6} ) in/in/°F</th>
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<tbody>
<tr>
<td>SA564, Type 630 (H1100)</td>
<td>-40</td>
<td>115.0</td>
<td>140.0</td>
<td>38.3</td>
<td>29.1</td>
<td>5.9</td>
</tr>
<tr>
<td></td>
<td>-20</td>
<td>115.0</td>
<td>140.0</td>
<td>38.3</td>
<td>29.0</td>
<td>5.9</td>
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<tr>
<td></td>
<td>70</td>
<td>115.0</td>
<td>140.0</td>
<td>38.3</td>
<td>28.5</td>
<td>5.9</td>
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<tr>
<td></td>
<td>100</td>
<td>115.0</td>
<td>140.0</td>
<td>38.3</td>
<td>28.3</td>
<td>5.9</td>
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<td></td>
<td>200</td>
<td>106.3</td>
<td>140.0</td>
<td>35.4</td>
<td>27.8</td>
<td>5.9</td>
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<td></td>
<td>300</td>
<td>101.8</td>
<td>140.0</td>
<td>33.9</td>
<td>27.2</td>
<td>5.9</td>
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<td></td>
<td>400</td>
<td>98.3</td>
<td>136.1</td>
<td>32.7</td>
<td>26.6</td>
<td>5.9</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>95.2</td>
<td>133.4</td>
<td>31.7</td>
<td>26.1</td>
<td>5.9</td>
</tr>
<tr>
<td></td>
<td>600</td>
<td>92.7</td>
<td>131.4</td>
<td>30.9</td>
<td>25.5</td>
<td>5.9</td>
</tr>
<tr>
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<td>700</td>
<td>90.3</td>
<td>128.4</td>
<td>30.1</td>
<td>24.9</td>
<td>5.9</td>
</tr>
<tr>
<td></td>
<td>800</td>
<td>86.9</td>
<td>122.5</td>
<td>29.0</td>
<td>24.2</td>
<td>6.0</td>
</tr>
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</table>

Notes:

1. ASME B&PV Code, Section II, Part D, Table Y-1.
2. ASME B&PV Code, Section II, Part D, Table U.
3. ASME B&PV Code, Section II, Part D, Table 4, except for values at 700°F and 800°F, which were calculated by taking one-third of yield at temperature.
4. ASME B&PV Code, Section II, Part D, Table TM-1, S17400.
5. ASME B&PV Code, Section II, Part D, Table TE-1. Coefficients for Precipitation Hardened 17Cr-4Ni-4Cu Stainless Steels, Coefficient B (mean from 70°F).
6. When necessary, values are linearly interpolated or extrapolated and **given** in bold text.
occur. For this reason, the variable Dlo, closure lid diameter at the outer edge, is identical with Dlb, the closure lid diameter at the bolt circle.

In cases where a moment in the lid is considered (Mt), the formulae developed in Section 2.9.2 are used to determine the bolt bending moment.

### 2.9.1.3.1 Preload

The closure bolts are prrloaded to 600 ± 100 to a maximum of 800 ft-lb torque, resulting in a minimum. The evaluation includes an evaluation of a minimum and maximum preload torque of 500 ft-lb and 700 ft-lb, respectively.

From Subsection 4.2 of NUREG/CR-6007, the maximum non-prying tensile force per bolt, $F_{a_{max}}$, is found from

$$ F_{a_{max}} = \frac{Q_{max}}{(K)( Db)} $$

where $Q_{max}$ is the maximum applied closure bolt torque, K is the nut factor (0.186), and Db is the closure bolt nominal diameter. The minimum preload force is computed in the same way except for the use of $Q_{min}$ in the place of $Q_{max}$.

The maximum residual torsional bolt moment is conservatively assumed to be 50% of the maximum applied torque (Reference 12, Page 662):

$$ M_{tr} = 0.5(Q_{max}) $$

Preload forces on the bolts under each loading condition are given in Table 2.9-6.

### 2.9.1.3.2 Gasket Loads

From Subsection 4.3 of NUREG/CR-6007, some gasket types can produce loads in the closure bolts. The STS cask seals are relatively small and soft and do not apply a load to the closure bolts.

### 2.9.1.3.3 Pressure Loads

From Subsection 4.4 of NUREG/CR-6007, utilizing appropriate temperature dependent material properties from Section 2.2.2, the maximum non-prying tensile force per bolt, $F_{a}$, shear force, $F_{s}$, and moment, $M_{f}$, due to pressure loads are based on the following formulae:

$$ F_{a} = \frac{\pi(Dl)^{2}(P_{li} - P_{lo})}{4Nb} $$

$$ F_{s} = \frac{\pi(E)(t)(P_{ci} - P_{co})(Dl)^{2}}{2(Nb)(Ec)(tc)(1 - Nul)} $$

$$ M_{f} = \frac{(P_{li} - P_{lo})Dl^{2}}{32} $$

where Dl is the closure lid diameter at the location of gasket load reaction (i.e., the O-ring seal diameter). $P_{li}$ is the pressure inside the closure lid, $P_{lo}$ is the pressure outside the closure lid, $P_{ci}$ is the pressure inside the cask wall. $P_{co}$ is the pressure outside the cask wall, Ec is the elastic modulus.
Table 2.9-5 - Geometric Parameters Used in Bolt Evaluations

<table>
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<tr>
<th>Property</th>
<th>Description</th>
<th>Dimension</th>
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</thead>
<tbody>
<tr>
<td>Db</td>
<td>Closure bolt nominal diameter. inches</td>
<td>1.50</td>
</tr>
<tr>
<td>Dbp</td>
<td>Closure bolt diameter for tensile stress calculation. inches</td>
<td>1.34</td>
</tr>
<tr>
<td>Dbs</td>
<td>Closure bolt diameter for shear stress calculation. inches</td>
<td>1.34</td>
</tr>
<tr>
<td>Dbb</td>
<td>Closure bolt diameter for bending stress calculation. inches</td>
<td>1.34</td>
</tr>
<tr>
<td>Dbt</td>
<td>Closure bolt diameter for torsional stress calculation. inches</td>
<td>1.34</td>
</tr>
<tr>
<td>Lb</td>
<td>Bolt length between the top and bottom surfaces of the closure lid at the bolt circle. inches</td>
<td>0.94</td>
</tr>
<tr>
<td>Nb</td>
<td>Number of closure bolts</td>
<td>24</td>
</tr>
<tr>
<td>K</td>
<td>Nut factor</td>
<td>0.186'</td>
</tr>
<tr>
<td>Q&lt;sub&gt;max&lt;/sub&gt;</td>
<td>Maximum applied preload torque, ti-lb</td>
<td>800</td>
</tr>
<tr>
<td>Q&lt;sub&gt;min&lt;/sub&gt;</td>
<td>Minimum applied preload torque, ti-lb</td>
<td>500</td>
</tr>
<tr>
<td>Dl1b</td>
<td>Closure lid diameter at the bolt circle, inches</td>
<td>67.00</td>
</tr>
<tr>
<td>Dl1i</td>
<td>Closure lid diameter at the inner edge, inches</td>
<td>62.38</td>
</tr>
<tr>
<td>Dl1o</td>
<td>Closure lid diameter at the outer edge, inches</td>
<td>67.00</td>
</tr>
<tr>
<td>Dl1g</td>
<td>Seal diameter, inches</td>
<td>63.10</td>
</tr>
<tr>
<td>tc</td>
<td>Cask wall thickness, inches</td>
<td>5.63</td>
</tr>
<tr>
<td>tl</td>
<td>Cask Lid thickness, inches</td>
<td>5.00</td>
</tr>
<tr>
<td>tlf</td>
<td>Lid flange thickness, inches</td>
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<tr>
<td>Wl</td>
<td>Weight of closure lid, lb</td>
<td>5.000</td>
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<tr>
<td>Wc</td>
<td>Weight of cask-contents, lb</td>
<td>18.500</td>
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Notes:

① For cadmium plated bolts [Reference 7, Table 4.1]
## Table 2.9-6  Closure Bolt Forces

<table>
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<tr>
<th>Load Combination</th>
<th>Pre-Load</th>
<th>Pressure</th>
<th>Temperature</th>
<th>Impact</th>
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<tr>
<td></td>
<td>(lbs.)</td>
<td>(lbs.)</td>
<td>(lb-in)</td>
<td>(lb-in)</td>
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<td>(lb-in)</td>
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<tr>
<td></td>
<td>(lbs.)</td>
<td>(lbs.)</td>
<td>(lb-in)</td>
<td>(lb-in)</td>
</tr>
</tbody>
</table>

### Notes:
- Results of calculations are based on loads, geometric properties, and mechanical properties per NUREG:CR-6007.
- \( L \) = Pre-load
- \( T \) = Thermal load
- \( P \) = Pressure load
- \( I \) = Impact Load
<table>
<thead>
<tr>
<th>Load Combination</th>
<th>Identification per Table 4.9 of NUREG/CR-6007</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Fa\textsubscript{pt} (lbs.)</td>
</tr>
<tr>
<td>1. NCT Cold Operating (-40) {L}, {T}</td>
<td>8.872</td>
</tr>
<tr>
<td>2. NCT Cold Operating (-27) {L}, {P}, {T}</td>
<td>10.178</td>
</tr>
<tr>
<td>3. NCT Cold Impact (End) {L}, {P}, {T}, {I}</td>
<td>23.081</td>
</tr>
<tr>
<td>4. HAC Hot Impact (End) {L}, {P}, {T}, {I}</td>
<td>45.718</td>
</tr>
<tr>
<td>5. HAC Cold Impact (Oblique) {L}, {P}, {T}, {I}</td>
<td>34.409</td>
</tr>
<tr>
<td>6. HAC Hot Impact (Oblique) {L}, {P}, {T}, {I}</td>
<td>34.409</td>
</tr>
<tr>
<td>7. HAC Cold Impact (Side) {L}, {P}, {T}, {I}</td>
<td>34.409</td>
</tr>
<tr>
<td>8. HAC Hot Impact (Side) {L}, {P}, {T}, {I}</td>
<td>34.409</td>
</tr>
</tbody>
</table>

**Notes:**

1. Fa\textsubscript{pt} is the summation of Fa\{L\} + Fa\{T\} for NCT and Fa\{L\} for HAC. from Table 1.9-6.
2. Fa\textsubscript{al} is the summation of Fa\{P\} + Fa\{I\} or Fa\{P\}, from Table 2.9-6, whichever is the application load combination.
3. Fa\textsubscript{c} is the greater of Fa\textsubscript{pt} or Fa\textsubscript{al}.
4. Fs\textsubscript{c} is the summation of Fs\{P\} + Fs\{I\}, from Table 2.9-6.
5. Mbb is the summation of Mbb\{P\} + Mbb\{I\}, from Table 2.9-6.
6. Mtr is the closure bolt residual torsional moment (is not used for HAC evaluations).
### Table 2.9-8 - Closure Bolt Stress Analysis Results

<table>
<thead>
<tr>
<th>Load Combination</th>
<th>Tensile Stress $S_{ba}$ (psi)</th>
<th>Shear Stress $S_{bs}$ (psi)</th>
<th>Bending Stress $S_{bb}$ (psi)</th>
<th>Torsion Stress $S_{bt}$ (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. NCT Cold Operating (-40) {L}, {P}, {T}, {V}</td>
<td>6.313</td>
<td>0</td>
<td>0</td>
<td>6.384</td>
</tr>
<tr>
<td>1.0 NCT Cold Impact (End) {L}, {P}, {T}, {I}</td>
<td>19,555</td>
<td>20.940</td>
<td>45.128</td>
<td>10.215</td>
</tr>
<tr>
<td>2.0 NCT Hot Impact (End) {L}, {P}, {T}, {I}</td>
<td>32,533</td>
<td>20.940</td>
<td>45.046</td>
<td>10.215</td>
</tr>
<tr>
<td>3.0 NCT Hot Operating {L}, {P}, {T}, {V}</td>
<td>32,533</td>
<td>23.871</td>
<td>20.948</td>
<td>10.215</td>
</tr>
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<td>3. HAC Hot (Fire) Pressure {L}, {P}, {T}</td>
<td>24,485</td>
<td>28.871</td>
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<tr>
<td>4. HAC Cold Impact (End) {L}, {P}, {T}, {I}</td>
<td>78.937</td>
<td>20.940</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. HAC Hot Impact (End) {L}, {P}, {T}, {I}</td>
<td>78.931</td>
<td>20.940</td>
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<td></td>
</tr>
<tr>
<td>6. HAC Cold Impact (Olique) {L}, {P}, {T}, {I}</td>
<td>30.133</td>
<td>23.465</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. HAC Hot Impact (Olique) {L}, {P}, {T}, {I}</td>
<td>30.133</td>
<td>23.465</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. HAC Cold Impact (Side) {L}, {P}, {T}, {I}</td>
<td>24,483</td>
<td>31.673</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. HAC Hot Impact (Side) {L}, {P}, {T}, {I}</td>
<td>24,485</td>
<td>31.673</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**

- Bending and torsion stresses are not limited for HAC and therefore not calculated.
<table>
<thead>
<tr>
<th>Load Combination</th>
<th>Applied Tensile Stress (psi)</th>
<th>Allowable Tensile Stress (psi)</th>
<th>Tensile Stress Ratio</th>
<th>Applied Shear Stress (psi)</th>
<th>Allowable Shear Stress (psi)</th>
<th>Shear Stress Ratio</th>
<th>Combined Stress Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. NCT Cold Operating (-40) {L}, {T}, {V}</td>
<td>6,313</td>
<td>76,667</td>
<td>0.08</td>
<td>0</td>
<td>46,000</td>
<td>0.00</td>
<td>0.08</td>
</tr>
<tr>
<td>2. NCT Cold Operating (-27) {L}, {P}, {T}, {V}</td>
<td>8,456</td>
<td>76,667</td>
<td>0.11</td>
<td>23,871</td>
<td>46,000</td>
<td>0.52</td>
<td>0.53</td>
</tr>
<tr>
<td>10. NCT Cold Impact (End) {L}, {P}, {T}, {I}</td>
<td>32,533</td>
<td>73,767</td>
<td>0.44</td>
<td>20,940</td>
<td>44,260</td>
<td>0.47</td>
<td>0.65</td>
</tr>
<tr>
<td>11. NCT Hot Impact (End) {L}, {P}, {T}, {I}</td>
<td>32,533</td>
<td>73,767</td>
<td>0.44</td>
<td>23,871</td>
<td>44,260</td>
<td>0.54</td>
<td>0.70</td>
</tr>
<tr>
<td>12. NCT Hot Operating {L}, {P}, {T}, {V}</td>
<td>24,485</td>
<td>85,750</td>
<td>0.29</td>
<td>28,871</td>
<td>51,450</td>
<td>0.56</td>
<td>0.63</td>
</tr>
<tr>
<td>13. HAC Hot (Fire) Pressure {L}, {P}, {T}</td>
<td>78,937</td>
<td>98,000</td>
<td>0.81</td>
<td>20,940</td>
<td>58,800</td>
<td>0.36</td>
<td>0.88</td>
</tr>
<tr>
<td>3. HAC Cold Impact (End) {L}, {P}, {T}, {I}</td>
<td>78,937</td>
<td>98,000</td>
<td>0.81</td>
<td>20,940</td>
<td>58,800</td>
<td>0.36</td>
<td>0.88</td>
</tr>
<tr>
<td>4. HAC Hot Impact (End) {L}, {P}, {T}, {I}</td>
<td>30,133</td>
<td>98,000</td>
<td>0.31</td>
<td>23,465</td>
<td>58,800</td>
<td>0.40</td>
<td>0.50</td>
</tr>
<tr>
<td>5. HAC Cold Impact (Oblique) {L}, {P}, {T}, {I}</td>
<td>30,133</td>
<td>98,000</td>
<td>0.31</td>
<td>23,465</td>
<td>58,800</td>
<td>0.40</td>
<td>0.50</td>
</tr>
<tr>
<td>6. HAC Hot Impact (Oblique) {L}, {P}, {T}, {I}</td>
<td>24,485</td>
<td>98,000</td>
<td>0.25</td>
<td>31,673</td>
<td>58,800</td>
<td>0.54</td>
<td>0.59</td>
</tr>
<tr>
<td>7. HAC Cold Impact (Side) {L}, {P}, {T}, {I}</td>
<td>24,485</td>
<td>98,000</td>
<td>0.25</td>
<td>31,673</td>
<td>58,800</td>
<td>0.54</td>
<td>0.59</td>
</tr>
<tr>
<td>8. HAC Hot Impact (Side) {L}, {P}, {T}, {I}</td>
<td>32,533</td>
<td>73,767</td>
<td>0.44</td>
<td>20,940</td>
<td>44,260</td>
<td>0.47</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Notes:

1. The combined tensile and shear stress ratio must be less than 1.0 and is calculated as 
   \[(\text{Tensile Stress Ratio}) + (\text{Shear Stress Ratio})\]?
<table>
<thead>
<tr>
<th>Load Combination</th>
<th>Applied Stress Intensity (psi)</th>
<th>Allowable Stress Intensity (psi)</th>
<th>Stress Intensity Ratio&lt;1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. NCT Cold Operating (-40) {L}, {T}</td>
<td>14,244</td>
<td>103,500</td>
<td>0.14</td>
</tr>
<tr>
<td>6. NCT Cold Operating (-27) {L}, {P}, {T}</td>
<td>67,293</td>
<td>103,500</td>
<td>0.65</td>
</tr>
<tr>
<td>9. NCT Cold Impact (End) {L}, {P}, {T}, {I}</td>
<td>89,811</td>
<td>103,500</td>
<td>0.87</td>
</tr>
<tr>
<td>7. NCT Hot Impact (End) {L}, {P}, {T}, {I}</td>
<td>99,503</td>
<td>99,585</td>
<td>0.9992</td>
</tr>
<tr>
<td>8. NCT Hot Operating {L}, {P}, {T}</td>
<td>86,646</td>
<td>99,585</td>
<td>0.87</td>
</tr>
</tbody>
</table>
2.9.3 Main Seal Evaluation

Using the Garlock Helicoflex catalog (See Attachment #1) methods, the Helicoflex seal is evaluated. For a pressure of 123 psia (108.3 psig) and at a temperature of 800°F, the applied load is greater than the 'load to be applied'. Therefore the seal design is acceptable. This evaluation only evaluates the Fire case, which bounds all other cases. The Helicoflex seal catalog that contains the seal data and methods used for this evaluation is can be found in Chapter 4.

Table 2.9-11 Helicoflex Seal Evaluation - Input

<table>
<thead>
<tr>
<th>Definition of Characteristic Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groove Inner Diameter</td>
</tr>
<tr>
<td>Seal Cross Sectional Diameter</td>
</tr>
<tr>
<td>Mean Seal Diameter (D1+D2)</td>
</tr>
<tr>
<td>Linear Load Corresponding to e2 compression</td>
</tr>
<tr>
<td>Load on the seal to maintain sealing in service at low pressure (=Y_m1)</td>
</tr>
<tr>
<td>Intrinsic power of the seal under pressure at 68°F when the reaction force of the seal is maintained at Y_2, regardless of the operating conditions</td>
</tr>
<tr>
<td>Value of P_1 at temperature θ</td>
</tr>
<tr>
<td>Operating or proof pressure</td>
</tr>
<tr>
<td>Linear Tightening load on the seal at room temperature to maintain sealing under pressure</td>
</tr>
<tr>
<td>Value of Y_m2 at temperature θ</td>
</tr>
<tr>
<td>Young's modulus of bolt material at 68°F</td>
</tr>
<tr>
<td>Young's modulus of bolt material at operating pressure (Fire Case, 800°F)</td>
</tr>
</tbody>
</table>
Table 2.9-12 - Helicoflex Seal Evaluation - Output

<table>
<thead>
<tr>
<th>Load Calculations</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Tightening load to compress the seal to the operating point (Y_2, e_2)</td>
<td>496,112</td>
<td>(F_i), lbs</td>
</tr>
<tr>
<td>Total hydrostatic end force</td>
<td>339,390</td>
<td>(F_r), lbs</td>
</tr>
<tr>
<td>Minimum total load to be maintained on the seal in service to preserve sealing</td>
<td>2,316</td>
<td>(F), lbs</td>
</tr>
<tr>
<td>Total load to be applied on the bolts to maintain sealing service</td>
<td>341,706</td>
<td>(F_s), lbs</td>
</tr>
<tr>
<td>Increased value of (F), to compensate for Young's modulus at temperature</td>
<td>402,422</td>
<td>(F_s^*), lbs</td>
</tr>
<tr>
<td>Load to be applied</td>
<td>402,422</td>
<td>(F_b), lbs</td>
</tr>
<tr>
<td>Applied Load (24 x Individual Bolt Preload)</td>
<td>722,581</td>
<td>lbs</td>
</tr>
</tbody>
</table>

### 2.9.4 Port Seal Evaluation

The vent/test port O-ring is a U221200875SEB. Per the Garlock Helicoflex catalog, the \(Y_2\) compression load is 799 lb/in. The OD of the O-ring is 0.875 inches, therefore the total required load to compress the seal is:

\[
F_{min} = Y_2 \cdot ID \cdot \pi = 2,196 \text{ lbs}
\]

Assuming a nut factor \(K\) of 0.25 for an un-lubricated bolt, the required torque on the \(\frac{3}{4}-10\) UNC bolt is:

\[
T = F_{min} \cdot K \cdot d = 2.196 \cdot 0.25 \cdot 0.75 = 411 \text{ in-lb} = 34 \text{ ft-lb}
\]

The groove design for this seal prevents excessive compression and therefore excessive torque will not harm the O-ring. **Assuming** a maximum torque of 50 ft-lb (600 in-lb), the tensile force is:

\[
F_{max} = \frac{T}{Kd} = \frac{600}{0.25 \cdot 0.75} = 3,200 \text{ lbs}
\]

The tensile area of the bolt is 0.334 in\(^2\). Therefore the tensile stress in the bolt is:

\[
\sigma = \frac{F_{max}}{A} = \frac{3,200}{0.334} = 9,580 \text{ psi}
\]

The yield stress of the ASTM A320, Grade L43 bolting material is 105 ksi. Therefore excessive preload is not of concern.

The vent/test tool shaft must be capable of driving a 50 ft-lb torque. The shaft is constructed of ASTM A193, Grade B7 alloy steel and the smallest cross sectional diameter is 0.50 inches. The yield strength of the shaft material is 105 ksi and therefore the maximum shear stress allowed is
0.6(105) = 63 ksi. The minimum cross section resisting the torsional stress is the 0.50 hex at the top of the shaft. The torsion stress in the shaft, where \( b \) is the width of one flat on the hex, is:

\[
\tau = \frac{1.09 \cdot T}{b^2} = \frac{1.09 \cdot 600}{0.29} = 26.815 \text{ psi}
\]

The torsion stress of 26,815 psi is much less than the allowable shear stress of 63,000 psi.

### 2.9.5 Drain Seal Evaluation

The vent/test port O-ring is a U231801437SEB. Per the Garlock Helicoflex catalog, the Y2 compression load is 1.313 lb/in. The OD of the O-ring is 1.437 inches, therefore the total required load to compress the seal is:

\[
F_{\text{max}} = 1.3 \cdot 1D \cdot \pi = 5,927 \text{ lbs}
\]

Assuming a nut factor \((K)\) of 0.25 for an un-lubricated bolt, the required torque on the 1-1/4-7UNC bolt is:

\[
T = F_{\text{min}} \cdot K \cdot d = 5,927 \cdot 0.25 \cdot 1.25 = 1,852 \text{ in-lb} = 154 \text{ ft-lb}
\]

The groove design for this seal prevents excessive compression and therefore excessive torque will not harm the O-ring. Assuming a maximum torque of 250 ft-lb (3,000 in-lb), the tensile force is:

\[
F_{\text{max}} = \frac{T}{Kd} = \frac{3,000}{0.25 \cdot 1.25} = 9,600 \text{ lbs}
\]

The tensile area of the bolt is 0.969 in². Therefore the tensile stress in the bolt is:

\[
\sigma = \frac{F_{\text{max}}}{A} = \frac{9,600}{0.969} = 9,907 \text{ psi}
\]

The yield stress of the ASTM A320, Grade L43 bolting material is 125 ksi. Therefore excessive preload is not of concern.

The vent/test tool shaft must be capable of driving a 250 ft-lb torque. The shaft is constructed of ASTM A193, Grade B7 alloy steel and the smallest cross sectional diameter is 0.75 inches. The yield strength of the shaft material is 105 ksi and therefore the maximum shear stress allowed is 0.6(105) = 63 ksi. The minimum cross section resisting the torsional stress is the 0.50 hes at the top of the shaft. The torsion stress in the shaft, where \( b \) is the width of one flat on the hex, is:

\[
\tau = \frac{1.09 \cdot T}{b^2} = \frac{1.09 \cdot 3000}{0.43^2} = 41,128 \text{ psi}
\]

The torsion stress of 41,128 psi is much less than the allowable shear stress of 63,000 psi.

---

2.9.6 STS Cask Drop Analysis -
Calculation Package 12099-08, Revision 2, 199 pages, includes PE Stamp
2.9.7 Summary Evaluations of Ancillary Equipment

None of the STS ancillary components are considered as part of the formal packaging used for transport of the radioactive K-Basin sludge. None are required to survive or function following application of the Hypothetical Accident Conditions, Section 2.5. The design loadings for each component have been developed based upon operational or storage conditions applicable to the equipment.

2.9.7.1 Process Shield Plate

The following paragraphs highlight the Large Container's structural features and behavior. Details are found in Appendix 2.9.8.2

2.9.7.1.1 Geometry

The Process Shield Plate (PSP) is a circular ring structure with a two lifting lug located 180° degrees apart. The PSP is lifted with a double hook lifting device for installation onto the STS Cask during routine sludge loading operations. The PSP is shown in PacTec Drawing 12099-400.

2.9.7.1.2 Loading Conditions Analysis

- The PSP is analyzed for being lifted for installation with a bounding weight of 18138 lbs from its double lifting lugs. The PSP lifting components are designed in accordance with ANSI N14.6. Load Bearing members are capable of lifting three and five times the total weight without generating a combined shear stress or maximum tensile stress in excessive of the minimum tensile yield and ultimate stress, respectfully.

2.9.7.1.3 Conclusions

The PSP is fully capable of being lifted for installation onto the STS Cask in accordance with the design criteria. Design Margins include:

- Double Lifting Lug Pin +0.60
- Double Lifting Lug +0.18

2.9.7.2 Lifting Devices

2.9.7.2.1 Cask Lift Device

The following paragraphs highlight the Cask Lift Device's structural features and behavior. Details are found in Appendix 2.9.8.1

2.9.7.2.1.1 Geometry

The Cask Lift Device is an I-beam structure that is a separate component from the cask. The cask is lifted for initial placement onto the transport trailer, and does not require lifting during routine operation. The Cask Lift Device attaches to the cask using four bolts (1 ¼-6UNC-2B) that thread into existing cask lid bolt holes. The Cask Lift Device is shown in PacTec Drawing 12099-510.
2.9.7.2.1.2 Loading Conditions & Analysis

The Cask Lift Device is analyzed for two load cases, being lifting with a single crane hook from the center lifting lug and being lifted with a double hook device from the double lifting lugs. The Cask Lift Device is analyzed to lift the gross cask weight of 85,000 lbs. which is extremely conservative because the cask is not loaded when lifted for initial placement onto the transport trailer.

The Cask Lift Device is designed in accordance with ANSI N14.6. Load Bearing members are capable of lifting three and five times the total weight without generating a combined shear stress or maximum tensile stress in excessive of the minimum tensile yield and ultimate stress, respectively.

2.9.7.2.1.3 Conclusions

The Cask Lift Device is fully capable of lifting the STS Cask with a gross weight of 85,000 lbs in accordance with the design criteria. Design Margins include:

- Center Lifting Lug +1.11
- Double Lifting Lug +0.99
- Main Beam minimum required section modulus = 229.32 in³. Supplied = 232 in³
- Attachment Bolts +0.66

2.9.7.2.2 Cask Lid Device

The following paragraphs highlight the Cask Lid Device's structural features and behavior. Details are found in Appendix 2.9.8.2

2.9.7.2.2.1 Geometry

The Lid Lift Device is a circular plate structure that is a separate component from the cask. The cask lid is lifted during routine operation. The Lid Lift Device attaches to the cask lid using three bolts (3/4-10UNC-2B) spaced 120° apart, which thread into cask lid lifting bolt holes. The Lid Lift Device is shown in PacTec Drawing 12099-500.

2.9.7.2.2.2 Loading Conditions & Analysis

The Lid Lift Device is analyzed for lifting 6250 lbs by a single crane hook from the center lifting lug. The Lid Lift Device is designed in accordance with ANSI N14.6. Load Bearing members are capable of lifting three and five times the total weight without generating a combined shear stress or maximum tensile stress in excessive of the minimum tensile yield and ultimate stress, respectfully.

2.9.7.2.2.3 Conclusions

- The Lid Lift Device is fully capable of lifting the STS Cask Lid with a bounding weight of 5,280 lbs in accordance with the design criteria.

2.9.7.2.3 Double Hook Adapter Lift Device

The following paragraphs highlight the Large Container's structural features and behavior. Details are found in Appendix 2.9.8.1 & 2.9.8.3.
2.9.7.2.3.1 Geometry

The Container Lifting Adapter is an I-beam structure with a lifting lug on each end and a center lug bolt for attaching a standard lifting hook. The container is lifted during routine operation. The Container Lifting Adapter attaches to the container using a single Crosby lifting hook. The Container Lifting Adapter is shown in PacTec Drawing 12099-520.

2.9.7.2.3.2 Loading Conditions & Analysis

The Container Lifting Adapter is analyzed for lifting a bounding load of 19,500 lbs with a double hook device from the double lifting lugs. The Container Lifting Adapter is designed in accordance with ANSI N14.6. Load Bearing members are capable of lifting three and five times the total weight without generating a combined shear stress or maximum tensile stress in excess of the minimum tensile yield and ultimate stress, respectively.

2.9.7.2.3.3 Conclusions

The Container Lifting Adapter is fully capable of lifting the STS Container with a gross weight of 19,500 lbs in accordance with the design criteria. Design Margins include:

- Center Lifting Lug Bolt +0.2
- Double Lifting Lug +0.91
- Main Beam minimum required section modulus = 44.5 in', Supplied = 52.0 in'

2.9.7.3 Large Container

The following paragraphs highlight the Large Container’s structural features and behavior. Details are found in Appendix 2.9.8.3

2.9.7.3.1 Geometry

The Large Container (LC) vessel structure is a 5' diameter, 10' tall, ASME (Section VIII Division 1) pressure vessel having a working design pressure of 150 psig. The vessel is of welded 316 stainless steel construction fabricated from 3/16 inch thick upper head, 1\% inch thick lift lug, and 5/8 inch thick shell, lower head, and lower skirt. Commercially available 2:1 formed ellipsoidal heads are used in the assembly. The shell is rolled from plate material for fabrication. Nozzles are installed in accordance with the Code requirements as applicable.

The LC is vented during transport and storage activities. During filling and storage, it is operated as a pressure vessel. The design operating temperature range is -33 to 60°C. The LC design life is 30 years, and all non-serviceable components are designed to perform during that time. Corrosion allowance is provided to maintain its' pressure rating during its' lifetime. The Performance Specification, SNF 8163, limits maximum weight with maximum payload to less than or equal to 8,390 kg (18,500 lbs). In fact, the maximum loaded weight of the Large Container is 7,773 kg (17,100 lbs), assuming a 3 m³ 60/40 sludge load and 10 inches of cover water.
2.9.7.3.2 Loading Conditions Analysis

The Large Container is designed and fabricated in complete conformance with ASME Section VIII. Division 1 rules. The upper head was initially sized for the pressure (@200°F) load case with 150-psig pressure to determine the head thickness. A finite element model (with upper head penetrations) considers these pressure and lift conditions to confirm the ¾ inch upper head thickness. The Pressure (hot) case is considered more critical than the cold case (-27°F) since the hot condition allowable stress value is less than the cold case value.

The upper head requires 8 total penetrations, which vary from 1 to 4 inches diameter (nominal) for LC loading and storage operations. The head penetrations are spaced to meet code guidelines conservatively neglecting connecting pipe reinforcements. Verification of the upper head hole penetrations has been confirmed by finite element analysis for Lift and Pressure case conditions.

Three sets of analyses have been performed:

- Section VIII code calculations for thickness requirements, nozzle reinforcement requirements, and lifting requirements.
- An FEM analysis of the upper half of the Large Container to verify structural integrity of the composite structure considering the close proximity of lifting lugs and process nozzles. Allowable stresses are governed by ANSI N14.6 requirements.
- An FEM analysis of the lower half of the Large Container to verify structural integrity at the lower head to shell and skirt junctures.

The 1st FEM model is representative of a ½ symmetric (fixed perimeter) arrangement of the upper head and cylindrical shell. The model utilizes 4 node quadrilateral shell elements located at mean geometry (wall thickness mid-plane) to recover peak stress intensity in the structural assembly. The 1-1/4 inch thick lift lug incorporates a 5” wide x 8-1/2” tall oval slot for single lift operations. The lug cross section is 12” in height at vessel center gradually decreasing to ½ inch tall at 49.5” diameter (lug width). For each load condition displacement boundary conditions are applied at the model cylindrical shell mid-span.

The 2nd finite element model is an axisymmetric representation of the lower and upper heads, skirt and shell only. This model uses 3 node quadrilateral 2 dimensional solid elements. The Pressure case steady state temperatures are applied to the model to determine thermal stresses. Mechanical pressure loading are applied to the vessel interior in a separate load case. Results from the two load cases are superimposed to recover the combined stress state.

The Performance Specification, SNF 8163, Section 6.5.2.4, requires that the Large Container be evaluated to demonstrate consequences of an object impact. The demonstration is provided in Appendix 2.9.8.4. In summary, the demonstration analysis concludes that penetration and rupture of the Large Container is bounded (by and order of magnitude) by existing T-Plant Preliminary Accident Analyses.

2.9.7.3.3 Conclusions

- Code calculations for required shell thicknesses to resist pressure show generous margins. The minimum corrosion allowance for any of the shell components exceeds the Performance Specification, SNF 8163, requirements by 63%.
FEM analyses show the minimum Factor of Safety in the upper head for lift conditions is +2.13. In the 1-1/4 inch thick lift lug itself the minimum Factor of Safety is +1.034 based on a peak stress intensity of 8.05 ksi. This peak stress is highly localized and on the inner surface of the lug cutout at the two upper radiused corners. Notably both hand analyses and FEM analyses predict average (primary membrane) stresses of about 3 ksi in the main body of the lift lug.

FEM analyses show the minimum Factor of Safety for pressure and temperature effects is +1.33.

The FEM results all assume nominal material thicknesses with no corrosion allowance applied. Should a corrosion allowance of 1/8 inch be applied per the requirements of the Performance Specification, SNF 8163, adjusted minimum Factor of Safety would be as follows:

- Lift Load, Upper Head: +1.78
- Lift Load, Lug (unchanged): +1.034
- Pressure & Temperature, Upper Head: +1.11
- Pressure & Temperature, Shell: +1.25

### 2.9.7.4 STS Transport Trailer Including Tiedown Structure

The following paragraphs highlight the Trailer's structural features and behavior. Details are found in Appendix 2.9.8.5

#### 2.9.7.4.1 Description and Geometry

The Trailer is a 4-axle single drop flatbed with an overall length of 35-feet and width of 10-feet. The height of the drop deck is 42-inches and the overall height, including superstructure work platform railings is 181-inches (15'-1"). The trailer is fabricated of welded carbon steel shapes, plates and tubular sections. The materials and fabrication are in accordance with industry accepted standards (ASTM, AISC, ANSI, AWS) and all surfaces are primed and painted with coatings appropriate for use. The superstructure is a welded framework surrounding the cask allowing access to the containers during loading and handling operations. The integral cask tie-down system consists of deck mounted lugs which engage 4 slots at the base of the STS Cask plus a tubular framework which envelopes the top of the cask. A work stand for storage of the cask lid is located at the Trailer stem.

#### 2.9.7.4.2 Loading Conditions & Analysis

The trailer and tiedown structure were modeled with MSC Nastran. A mid-surface model was generated from the Nelson supplied 2-dimensional drawing tiles. Plate elements were constructed on the midsurfaces representing the trailer structure. A global mesh size of 2" was used. Beam elements are used to represent the axles, suspension and tires. Rigid elements were used to connect the suspension to the underside of the main beams of the trailer. Beam elements were also used to represent the cask and the structural tubes in the tiedown structure to allow for quick tube sizing. The densities of the cask and trailer were modified so that a cask weight of 85,000 lb and empty trailer weight of 35,000 lb. was obtained for analysis.
An additional model was created of the tiedown structure only, consisting of all tiedown components located above the trailer deck. Plate elements are used to model all the rectangular tubes, top cask clamp lower tiedown devices, and the cask. Compression only gap elements were added between the cask, tiedown devices and top clamp to simulate contact due to the acceleration loads. A static-nonlinear analysis is used for this model in order to utilize the gap elements.

Four operational and one tiedown load case were analyzed. The operational loadings were evaluated versus structural safety factors of 2:1. Tiedown loads enveloped past and current DOT criteria and were evaluated versus structural,safety factors of 1:1, again consistent with DOT criteria.

2.9.7.4.3 Conclusions
- The minimum operational factor of safety was found to be +2.05, representing a 1g aft and 1g down loading.
- The minimum tiedown factor of safety was found to be +4.12.

2.9.7.5 Earthquake Analyses of STS
The Performance Specification, SNF 8163, Section 4.3.2.3, requires evaluation of the STS system (cask and trailer) to a performance category 3 (PC3) earthquakes. The detailed evaluation is provided as Attachment 2.9.8.6

2.9.7.5.1 Description & Geometry
The seismic analysis model utilized the trailer structural model described above in Appendix 2.9.7.4, converting it into a single super-element accurately representing the elastic and inertial properties of the trailer, tiedown structure and cask. To this super element were added discrete models of each element of the suspension system. All modeling properties were derived from manufacturers supplied data. Tire and landing gear model restraints were accurately modeled as gaps to ground surface with lateral friction forces acting when the gap was compressively loaded.

2.9.7.5.2 Loading Conditions & Analysis
The loading was applied via time history ground motion excitations whose spectral transformations matched the Performance Specification, SNF 8163, requirements for a K-basin PC-3 earthquake.

2.9.7.5.3 Conclusions
- The evaluation demonstrates that the STS Trailer will not overturn during the specified earthquake.
- Maximum uplift on either landing leg is 2.43 inches.
- Maximum tire lift is 1.06 inches
- Lateral sway of the cask top is 6.12 inches.

2.9.8 Supporting Ancillary Equipment Calculation Packages
The following structural calculations are attached:
- Sludge Transfer Cask Lifting Devices Analysis. PacTec Calculation Number 12099-23, Revision 0, 32 Pages + PE Stamp cover sheets for calculation packages 12099-23, Revision 0, 2 pages
- Installation/Removal & Maintenance Devices. PacTec Calculation Number 12099-24, Revision 2.40 Pages + PE Stamp cover sheets for calculation packages 12099-24, Revision 2, 2 pages
- Structural Analysis of (A-170) Large Container. EN-3C-0126-04. Revision 1, Avantech Incorporated, 33 Pages.
- Accident Analysis of (A-170) Large Container. EN-3C-0126-06, Revision 1, Avantech Incorporated, 8 Pages.
- Finite Element Analysis (of STS Trailer & Tiedown Frame), J152-01, Revision 0, Sun Engineering, 20 Pages.
- Seismic Analysis of the STS Trailer, PacTec Calculation Number 12099-30. Revision 0, 66 Pages + PE Stamp cover sheets for calculation packages 12099-30, Revision 0, 1 pages
- Stress Analysis of STS Trailer Lid Inspection Fixture, PacTec Calculation Number 12099-25, Revision 1, 35 Pages.
2.9.8.3 Structural Analysis of (A-170) Large Container, EN-3C-0126-04. Revision 3, Avantech Incorporated, 37 Pages.
PROBLEM STATEMENT OR OBJECTIVE OF THE CALCULATION:

Provide structural analyses for evaluation of the K-East Basin Sludge Transport System Large Container (LC) considering the following conditions:

- 150 psig Internal LC Pressure combined with maximum 200°F temperature
- Lift (no internal pressure) combined with LC maximum 200°F temperature at 17,100 lbs weight
- Internal pressure and payload weight combined with maximum steady state thermal loads

Note: The LC thermal response is developed in a separate calculation. see EN-3C-0126-02 Rev.C.

**Revision Notes**

Revision 3: Revise reinforcement calculation Table 7-2.

Revision 2: Incorporates analysis for skin redesign with additional holes and sludge growth affect on filter cage (stability analysis of sleeves).

Revision 1: Incorporates code calculation and further engineering analysis to consider 1/8" inch loss of material due to corrosion for pressurization and lift conditions. Penetration reinforcement analysis has been revised to consider corrosion and area exceeding required vessel thickness and takes FEA results into consideration. Owner comments to Rev.0 have been incorporated.

Revision 0: Incorporates an axisymmetric finite element model to supplement evaluation and for corroboration of the LC design / analysis. The model provides evaluation of skirt to lower head juncture under Pressure case temperatures with pressure. Minor notes are added for clarification. ASME penetration reinforcement calculation/notes are provided.
APPENDIX B - CALCULATION REVIEW CHECKLIST

<table>
<thead>
<tr>
<th>Item</th>
<th>Yes</th>
<th>N/A*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Design Inputs such as design bases, regulatory requirements, codes, and standards are identified and documented.</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>2. Effect of design package on compliance with the Safety Analysis Report or Certificate of Compliance identified and documented.</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>3. Revision numbers correct on the list of drawings?</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>4. Assumptions reasonable?</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>5. Appropriate analysis method used?</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>6. Correct values used from drawings?</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>7. Answers and units correct?</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>8. Summary of results matches calculations?</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>9. Material properties properly taken from credible references?</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>10. Figures match design drawings?</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>11. Computer input complete and properly identified?</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>12. Documentation of all hand calculations attached?</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>13. Meeting minutes of the Design Review?</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

*N/A, SAR or CoC evaluation not included in work scope

Comments

REVIEWED: 10-21-02
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1 Introduction

The K Basin Sludge Transportation System includes a Large Container (LC) and a Transport Cask [Reference 9.1]. The scope of work requires the design and evaluation of the Large Container and Transport Cask, and the construction of a working prototype of the Large Container. The Large Container pressure boundary and level sensor are classified as Quality Level 2 and the internals are classified as Quality Level 3. Evaluations are to be submitted in four phases: 30% completion, 60% completion, 90% completion, and the final submittal. The information provided in this document represents the Final Design completion submittal for the Large Container Structural (and Lifting Attachment) Evaluation including analysis of design modifications, as noted.

2 Design Input

2.1 Geometry

The K-Basin Large Container (LC) vessel structure is a 59" diameter, 10' tall, ASME (Section VIII Division 1) pressure vessel having a working design pressure of 150 psig. Note that this analysis considers a 60 diameter vessel with all other parameters consistent with the design being verified – the larger diameter offers conservatism to the results. The vessel is of welded 316 stainless steel construction fabricated from 7/32 inch thick upper head, 11/16 inch thick lift lug, and 1/2 inch thick shell, lower head, and lower skirt. Commercially available 2:1 formed ellipsoidal heads are used in the assembly. The shell is rolled from plate material for fabrication. Nozzles are installed in accordance with the Code requirements and intent, as applicable.

2.2 Design

The LC is vented during transport and storage activities. During filling and storage, it is operated as a pressure vessel. The design operating temperature range is -33 to 60°C. The LC storage design life is 30 years, and all non-serviceable components are designed to perform during that time. Corrosion allowance is defined as 1/8" maximum (by the Owner) and excess material provided to maintain pressure rating during the defined lifetime. The LC maximum weight with maximum payload is less than 8,390 kg (18,500 lbs). Support for the analytical weight is provided in section 4.

The upper head was initially sized for the pressure (@200°F) load case with 150-psig internal pressure to determine the head thickness. A finite element model (with upper head penetrations) considers pressure and lift conditions to confirm the 7/32 inch upper head thickness. The Pressure (hot) case is considered more critical than the cold case (-27°F) since the hot condition allowable stress value is less than the cold case value.

The upper head requires 8 total penetrations, which vary from 1 to 5-1/2 inches diameter (nominal) for LC loading and storage operations. Verification of the upper head hole penetrations is confirmed by finite element analysis stress recovery for Lift and Pressure case conditions. The model for these analyses also conservatively ignores any pipe reinforcements. The finite element model without consideration of nozzle, weld or reinforcing pads does not show any stress intensity above those allowed. Accordingly, the construction meets with Code intent of controlling stress at these zones.

The upper head incorporates gentle 3:1 minimum angular transition between shell and head flange required by the Code. Both head to shell welds require wall beveling (30° to
45' from the horizon) for full weld penetration. The upper weld will be single side welded with backing strip to prevent damage to the filters. The final weld group design configuration is presented to meet applicable code welding requirements for (SA-240 Type 316 is P No. 8) materials in the given thickness. Consideration for various weld configurations and examinations are observed for the joint efficiency factor of 0.9 assuming full radiography in the standard pressure case code calculations for the head and shell. Two different Finite element models are used to corroborate stress levels at the weld seams and are shown within allowable stress intensities. After fabrication the vessel requires no special Postweld Heat Treatment for code compliance (Ref 9.2, Table UHA-32, Page 216 - P No 8 Gr1).

2.3 Analysis Considerations

The lower ellipsoidal head analysis conservatively considers the pressure case (150-psig @200°F temperature) combined with the maximum 17,100 pound (Reference Section 4) gross weight distributed, as a uniform interior pressure using required code internal pressure formulas.

The maximum possible increase in vessel length is determined considering a conservative classical evaluation of the elevated temperature change of the entire assembly from 50°F to 200°F at fabrication and in operations respectively. Since the thermal growth is observed by adequate design clearance there are no resulting compression forces occurring between the cask and the LC. Accordingly, the lower skirt is considered in axial compression by transfer of 17,100 pound gross payload weight to the bottom of the cask at 1 g gravity load conditions. An axisymmetric finite element model has also been considered to recover stress intensities due to thermal and pressure loading from the pressure case steady state condition for the vessel. The evaluation determines the stress intensities at the juncture of the skirt to lower head and in the local areas of head bending under these conditions. Since the temperature difference across each section of the vessel wall is nearly constant the thermal stress due to the wall temperature differences were found negligible (634-psi maximum).

Two finite element models (FEM) results were provided to 1) confirm classical analysis and results from code calculations and 2) to ensure code compliance through stress recovery / comparison to allowable stresses. The 1st FEM model is representative of a 1/2 symmetric (fixed perimeter) arrangement of the upper head and cylindrical shell. The model utilizes 4 node quadrilateral shell elements located at mean geometry (wall thickness mid-plane) to recover peak stress intensity in the structural assembly. For analysis the 1-1/4 inch thick lift lug incorporates a 5" wide x 8-1/2" tall oval slot for single lift operations. The lug cross section is 12" in height at vessel center gradually decreasing to ½ inch tall at 49.5" diameter (lug width). The lug is groove and fillet welded from both sides to the 3/4" head forming an integral arrangement. The lifting loads are uniformly applied on the oval upper slot surface corresponding with the hook engagement. Subsequent to analysis revision 1 the lift lug slot was modified to remove the lug material under the slot. This modification was assessed for impact to design and determined to have no adverse affect. The model also recovers stress results for the pressure case by applying 150 psig pressure over the interior shell surfaces. For each load condition displacement boundary conditions are applied at the model cylindrical shell mid-span using a cylindrical coordinate system at the center of the section (X=R is radial, Y=Theta coordinate, Z is oriented toward lift lug).
The 2nd finite element model representation considers the lower and upper heads, skirt and shell only. This model uses 4 node quadrilateral 2 dimensional solid elements modeled in the positive quadrant of the X-Y plane. The centerline of the model resides along X=0 representing a symmetric solid body of revolution about the Y-axis. The Pressure case steady state temperatures performed by separate heat transfer calculations (Reference 9.7) are applied to the model to determine the thermal stress. Mechanical pressure loading is applied to the vessel interior in a separate load case. Results from the two load cases are superimposed to recover the combined stress state.

The LC geometry is shown (Reference 9.4) in Drawing 3C40-0126-D. Analysis plots and information concerning the model, loads, structural response, boundary conditions (free body diagrams, etc) are included in the Appendix.

3 Material Properties

The LC vessel and lift lug structural materials of fabrication are composed from SA-240 316 stainless steel. Temperature dependent material properties are obtained from Section II, Part D, of the ASME Code Reference 9.5. Table 3-1 provides summary of the LC temperature dependant mechanical properties.

Table 3-1 - Type 316 Stainless Steel Material Properties

<table>
<thead>
<tr>
<th>Material Specification</th>
<th>Temperature, °F</th>
<th>Yield Strength (S_y) psi</th>
<th>Ultimate Strength (S_u) psi</th>
<th>Design Stress Intensity (S_m) psi</th>
<th>Elastic Modulus (E) x10⁶ psi</th>
<th>Coefficient of Thermal Expansion (α) x10⁻⁶ in/in°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA-240 Type 316 UNS Designation 531600 P No 8 Gr 1 16Cr-12Ni-2Mo</td>
<td>-20</td>
<td>30,000</td>
<td>75,000</td>
<td>20,000</td>
<td>28.7</td>
<td>8.2</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>30,000</td>
<td>75,000</td>
<td>20,000</td>
<td>26.1</td>
<td>8.6</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>25,900</td>
<td>75,000</td>
<td>17,300</td>
<td>27.6</td>
<td>8.9</td>
</tr>
</tbody>
</table>

Table 3-2 outlines the stainless steel, sludge, and water densities used in Section 4 vessel gross weight calculations.

Table 3-2 - Regional Material Density

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (g/cc)</th>
<th>Density (lb/inch³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4 Conditions Analyzed

The Large Container is analyzed using ASME Code pressure vessel design and manufacturers requirements and for T-Plant lift lug design parameters. Based on the Large Container (LC) 60% Thermal Analysis (Reference 9.7) and to conservatively envelop the LC thermal conditions, the Large Container materials are assumed to be at a constant temperature of 200°F throughout the Container combined 30-year process and storage lives for Code calculations. However, the LC axisymmetric finite element model analysis has also considered thermal stress affects using the Steady State Temperatures developed in Reference 9.7. Stress intensities from this analysis are generally compared to the material allowable stress intensities at 200°F.

The Large Container lift members and load paths are analyzed assuming a maximum 17,100 pound gross weight including payload. The weight breakdown is outlined below.

<table>
<thead>
<tr>
<th>Component</th>
<th>Design Weight (Pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>½ inch thick Shell</td>
<td>2,025</td>
</tr>
<tr>
<td>¾ inch thick Upper Elliptical Head</td>
<td>980</td>
</tr>
<tr>
<td>% inch thick Lower Elliptical Head</td>
<td>603</td>
</tr>
<tr>
<td>¼ vessel skirt</td>
<td>385</td>
</tr>
<tr>
<td>Miscellaneous Vessel Components</td>
<td>673 (4.666 lbs. empty wt.)</td>
</tr>
</tbody>
</table>

Payload:
- Sludge (3 m³ max fill) 10,248
- Water (10-inch column height) 988
- Conservatism Factor (7.5%) 1,198

Totals 17,100

5 Acceptance Criteria

5.1 ASME Code Vessel Conditions (Pressure case)

The ASME Boiler and Pressure Vessel Code (References 9.2 and 9.5) provides the acceptance criteria, material properties, and allowable stresses for the 150-psig (200°F Pressure Case) design pressure input parameter specified by Specification SNF-8163 Rev.4, Reference 9.1. Section 3 Table 3-1 - Type 316 Stainless Steel Material Properties outlines the allowable stress intensity depending on temperature. Consistent with classical strength of materials (Reference 9.6 page 169, maximum shear stress theory for linear elastic response of isotropic materials) the allowable shear stress is conservatively taken at 50% of the allowable stress intensities.¹

¹ The allowable shear strength may be taken as 57.7% (0.577 Sy) of the allowable stress intensity limit using Mises–Hencky (distortion energy) theory when compared with Von-Mises stress (Ref: 9.6 P 170).
5.2 Lift Conditions

ANSI 14.6 Lift requirements, reference 9.3, outline safety factors for the Lift conditions. The allowable stress intensity consistent with this standard is the lower of $1/3$rd yield or $1/5$th ultimate strengths. Material Properties Section 3 Table 3-1 - Type 316 Stainless Steel Material Properties provides $S_y$ and $S_{ult}$ strengths dependency on temperature for evaluation of the allowable stress. This results in the following lowest possible allowable stress values for the Lift using 200°F maximum service temperature.

\[
\frac{1}{3} S_y = \frac{1}{3}(25,000) = 8,333 \text{ psi} \quad \text{or} \quad \frac{1}{5} S_{ult} = \frac{1}{5}(75,000) = 15,000 \text{ psi}
\]

The allowable stress intensity is the lower 8,333-psi limit. The allowable shear strength is 50% of this value (4,166-psi).

6 Assumptions

The material is a linear elastic isotropic medium. Stresses recovered are in the linear elastic region and qualify the design by comparison to the allowable stresses outlined in Section 5. All construction details, fabrication processes, and operational loads will be in accordance with assumptions and Code requirements.

Following revision 0, the specification defining the LC maximum outside diameter was reduced from 60-inches to 59-inches. The structural analysis continues to use the 60-inch maximum OD generally providing a level of conservatism to the analysis.

Section 7 provides particular assumptions concerning each calculation.

7 Calculations

The classical calculations were performed using MathCad 2000 with results spot checked by hand. The FEM analyses were performed using Cosmos/m ver.1.71a and were benchmarked using theoretical classical results for similar analytical configurations and conditions. The Benchmark report is maintained on file.

7.1 Upper Ellipsoidal Head - Notes & Assumption

Reference 9.2, UG-32, Mandatory Appendix1

- Basis: 2:1 Ellipsoidal head assuming full penetration welding from outer side with multi-pass welds and use of an interior un-reinforced backing strip. The backing strip is required for protection of filters located near this region.
- Category B (Location) Type 2 (c) assumed for connection of Upper Ellipsoidal Head to Main Body Shell
- Variables:
  - $D = 59$ inch inside head Diameter
AVANTech Calculation Sheet

**Title**: A-170 Structural Analysis  
**Calculation Number**: EN-3C-0126-04  
**Rev**: 3 (CON-11)

- $S = S_m = 17.3$ Ksi for SA240 Type 316 material at 200°F
- $P=150$ psig internal design pressure
- $h = 14.75$ inch inside head depth to start of straight formed skirt
- $k = \text{factor for ellipsoidal heads formulation depends on head proportion } D/2h$ generally taken as 1.0 for 2:1 heads
- $t_{\text{actual}} = \frac{3}{4}$ (inch) for the desired upper head construction

- Thermal stress is considered negligible
- Full radiography joint efficiency factor, $E = 0.9$
- Calculate maximum corrosion rates the design can sustain in service ($\text{IPY} - \text{inches/year}$) conservatively based on 150 psig internal pressure during full 30 Year Life.

**Variable Declaration:**

\[
\begin{align*}
D &: = 59.0 \\
S &: = 17300 \\
P &: = 150 \\
h &: = 14.75 \\
E &: = 0.9 \\
t_{\text{actual}} &: = 0.75
\end{align*}
\]

\[
k = \frac{1}{6} \left[ 2 + \left( \frac{D}{(2 \cdot h)} \right)^2 \right] \quad k = 1.00000
\]

K factor used in thickness calculation Appendix 1, ASME Code Section VIII - Div 1

\[
t = \frac{(P \cdot D \cdot k)}{(2 \cdot S \cdot E - 0.2 \cdot P)} \quad t = 0.284
\]

Required Code thickness - inch

\[
F_I \geq 0.385 \cdot S \cdot E \quad F_I = 5994.430
\]

$P \geq (\text{pressure, psi})$ therefore valid by code

\[
t_{\text{allowance}} = t - t_{\text{allowance}} = 0.466
\]

corrosion allowance (inch) exceeding the required head thickness to retain pressure

\[
\text{IPY}_{\text{corrosion}} = \frac{t_{\text{allowance}}}{30'}
\]

allowable corrosion rate inches per year

\[
\text{IPY}_{\text{corrosion}} = 0.01552
\]

allowable corrosion rate inches per year

Considering the geometry with $D$ equal to 59.25 inch (i.e., loss of $\frac{1}{8}$ inch wall thickness) the upper head thickness is required to be a minimum of 0.286 inches in the above formula. Accordingly, the wall thickness of 0.625 inch (0.75-0.125) in the fully corroded condition is adequate.

### 7.2 Evaluation of Cylindrical Shell Section under Pressure

**Ref**: Part UG-Section 27 Requirements Circumferential requirements for Longitudinal weld joints

Assumptions and Notes:
Longitudinal seam(s) in the right circular cylinder must be full penetration butt weld complying with requirements of Table UW-12, Figure UW-13.1, and Section uw-35.

Category A - Single Side Welding, Type 2(c) with full radiographs

200°F service temperature conditions

SA-240 Type 316 shell material

Variable Declaration:

Joint Efficiency and allowable stress (psi) at 200°F

\[ E_j = 0.90 \]
\[ S = 17300 \]
\[ t_{shell} = 0.50 \text{ inch} \]
\[ R_{shell} = 29.50 \text{ inch} \]

\[ R_{shell} = \frac{D}{2} \]

\[ F_I = 0.385 \cdot E_j \cdot S \]
\[ F_I = 5994.450 \]

\[ t_{shell\text{required}} = \frac{P \{ R_{shell} \}}{S \cdot E_j - 0.60P} \]
\[ t_{shell\text{required}} = 0.286 \text{ inch} \]

\[ t_{allowance} = t_{shell} - t_{shell\text{required}} \]
\[ t_{allowance} = 0.214 \text{ inch} \]

\[ IPY_{corrosion} = \frac{t_{allowance}}{30} \]
\[ IPY_{corrosion} = 0.00714 \]

Considering geometry with \( D \) equal to 59.25 inch (i.e., loss of \( 1/8 \) inch wall thickness) the cylindrical shell thickness is required to be a minimum of 0.287 inch by the above formula. Accordingly, the wall thickness of 0.375 inch (0.5-0.125) in the fully corroded condition is adequate.

7.3 Evaluation of Lower Ellipsoidal Head - Notes & Assumption

Ref: 9.2, UG-32, Mandatory Appendix 1

- Basis: 2:1 Ellipsoidal head assuming full penetration welding from either side with multi-pass welds
- Full radiograph inspection
- Category B (Location) Type 1 (c) assumed for connection of Ellipsoidal Head to Main Body Shell
- Variables:
  - \( t_{actual} = 1/2 \) (inch) for the desired lower head construction
  - Use other Section 7.1 geometry data
- Combine 6.25 psi uniform pressure with the 150 psi Pressure case internal design pressure to account for 17,100 pounds gross weight supported by lower head
LC Gross weight (pounds) 

\[ P_g = \frac{4 \cdot W_g}{\pi \cdot D^2} \]

Pressure due to LC 17,100 pound Gross weight

Variable Declaration:

- \( D := 59.0 \)
- \( S := 17300 \)
- \( P = 156.25 \)
- \( h := 14.75 \)
- \( E := 0.90 \)
- \( t_{\text{actual}} := 0.5 \)

\[ k := \frac{1}{6} \left( 2 + \frac{D}{2 \cdot h} \right) \]

K factor used in thickness calculation Appendix 1, ASME Code Section VIII - Div 1

\[ t := \frac{(P \cdot D \cdot k)}{(2 \cdot S \cdot E - 0.2 \cdot P)} \]

\[ F_1 := 0.385 \cdot S \cdot E \]

\[ F_1 = 5994.450 \]

\( \text{ allowable} := t_{\text{actual}} - t \)

\[ \text{allowance} = 0.204 \]

allowable corrosion rate (inch) exceeding the required head thickness to retain pressure

\[ \text{IPY}_{\text{corrosion}} := \frac{t_{\text{allowance}}}{30} \]

allowable corrosion rate inches per year

\[ \text{IPY}_{\text{corrosion}} = 0.00679 \]

Considering geometry with \( D \) equal to 59.25 inch (i.e., loss of \( 1/8 \) inch wall thickness) the lower head thickness is required to be a minimum of 0.298 inch by the above formula. Accordingly, the lower head wall thickness of 0.375 inch (0.5-0.125) in the fully corroded condition is adequate.

### 7.4 Alternate Evaluation of Cylindrical Shell Section under Pressure

**Ref:** Pari UG-Section 27 Requirements Longitudinal Stress requirements for Circumferential weld Joints

UG-27 Longitudinal stress requirements imposed on shell circumferential welds are bounded by weld joint requirements previously developed for the upper heads. This is demonstrated by assuming a joint efficiency (\( E = 0.90 \)) for weld achieved by welding from one side with full radiographs and 200°F service temperatures.
7.5 Thermal Growth

\[ a := 8.9 \times 10^{-6} \]
\[ L_{LC} := 108 \]
\[ T_1 := 200 \quad T_2 := 50 \]
\[ AT := T_1 - T_2 \quad AT = 150.00 \]
\[ AL := L_{LC} \cdot \alpha \cdot AT \quad AL = 0.144 \]

Adequate clearance of \%inch minimum is observed in the design to accommodate axial growth in LC length under maximum elevated temperatures. Since the diameter is less than the LC length the radial expansion will be less critical due to the spacing of \%inch minimum observed between the Cask and LC radii.

7.6 Lower Skirt Compression

\[ A_{skirt} := \pi \left[ (R_{shell})^2 - (R_{shell} - l_{shell})^2 \right] \]
\[ A_{skirt} = 91.89 \quad \text{skirt area - square inch} \]
\[ w_g = 1.71 \times 10^4 \quad \text{Maximum LC weight and payload-pounds} \]
\[ \sigma_{skirt} := \frac{w_g}{A_{skirt}} \quad \sigma_{skirt} = 186.09 \quad \text{Nominal Skirt Stress - psi} \]
\[ \sigma_{skirtpeak} := 3.5 \cdot \sigma_{skirt} \quad \text{Skirt Stress near lower holes} \]
\[ \sigma_{skirtpeak} = 651.31 \quad \text{Peak Skirt Compressive Stress - psi} \]

Initial skirt design (i.e., revision 0 and 1 designs) included holes located at the lower zone of the skirt. Even with Consideration of a stress concentration factor near 3.5 at the holes this location does not pose a concern for compressive stress intensity. Accordingly, the lower skirt depicts a large factor of safety on compressive stresses.

Additional holes were added to the skirt to promote purge gas circulation and heat transfer. This modified skirt design was analyzed via FEA. Refer to Section 7.9.
7.7 Container Lift Analysis & Pressure (Hot) Case Confirmation

7.7.1 Classical and \( \frac{1}{2} \) Symmetric Finite Element Model

Input: Max gross weight 17,100 lbs. maximum
Lift lug dimensions 1-1/4" thick, 12" H with Lift slot
LC Upper head 3/4" thick w/ nozzle penetrations
Cylindrical Shell \( \frac{1}{2} \) inch thick

Classical Analysis
Lift Lug transfer Lift loads from the lug to large container

\[
S_{y_{lift}} = 8313
\]

Allowable Stress Intensity - psi

\[
\tau_{weld_{allowable}} = S_{y_{lift}} \times 0.50
\]

Allowable Weld Shear Stress - psi

\[
\tau_{weld_{allowable}} = 4166.50
\]

Lift Weight - Pounds

\[
V_{lug} = W_{lift}
\]

Lug Tensile Loading - Pounds

\[
V_{lug} = 17100
\]

Lug Length - inch

\[
B_{lug} = 49.5
\]

Groove Weld Size Lug to Head - inch

\[
\kappa_{lug_{weld}} = 0.375
\]

Outer Weld Size Lug to Head - inch

\[
\kappa_{lug_{weld}} = 0.375
\]

Total weld area in shear - sq inch

\[
A_{lug_{weld}} = 2 \left( S_{lug_{weld}} + S_{lug_{weld}} \right) \times 0.707 \times B_{lug}
\]

Lug Fillet Weld Shear Stress - psi

\[
\tau_{weld} = \frac{V_{lug}}{A_{lug_{weld}}}
\]

Factor of Safety - Lug to Head attachment

\[
\tau_{weld} = 325.75
\]

Lug Shear

Loads are applied at the upper slot. The crane hook must shear through two Lug cross-sections in order to fail the Lug

\[
\tau_{allowable} = S_{y_{lug}} \times 0.50
\]

lug allowable shear stress - psi

\[
\tau_{allowable} = 4166.50
\]

Lug thickness - inch

\[
b_{lug} = 1.25
\]

Minimum lug height in shear - inch

\[
b_{lug} = 1.5
\]

Lug shear Area - sq. inch

\[
A_{lug} = 3.13
\]

Lug Shear Stress - psi

\[
\frac{V_{lug}}{2A_{lug}}
\]

\[
b_{lug_{y}} = 2716.00
\]

Factor of Safety - Lug

\[
FS_{lug} = 1.52
\]
Finite Element Analysis

A finite element model was developed based on the LC design found in Reference 9.4 to address the lift condition and confirm code calculations. The lift lug is used to distribute vertical loads into the 3/4 inch thick head and shell. The lug incorporates a central 5" x 8-1/2" oval hole to ensure the crane hook can be engaged for remote lift. The 360-degree shell model considers 8 penetrations to evaluate peak stress intensities.

The stiffened head is expected to be compliant for ASME Section VIII internal pressure requirements since the previous calculations determined the 314' thick 2:1 elliptical head is sufficient for the design pressure. The finite element model simulates a 1/4 symmetric arrangement by application of shell elements at the center of vessel wall thickness (mid plane). The 17,100-pound lift load was applied to the upper oval cutout and the structural response was recovered.

The lug cross section is 12" in height at vessel center gradually decreasing to 3/4 inch tall at 49.5" diameter (lug width). It is groove and fillet welded from both sides to the 3/4" upper head forming an integral arrangement. The lift loads are uniformly applied on the oval upper slot surface corresponding with the hook engagement.

The model recovers stress results for the pressure case by application of 150-psi pressure over the interior shell surfaces. For each load case the displacement boundary conditions are applied at the model cylindrical shell mid-span using a cylindrical coordinate system at the center of the section (X=R is radial, Y=Theta coordinate, Z is oriented toward lift lug).

Results from the finite element analysis for the lift condition are as follows (ref: Section 10 FEM plots):

<table>
<thead>
<tr>
<th>Component</th>
<th>Peak Stress Intensity (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>%inch thick Elliptical Head</td>
<td>3.91 (outer surface under lift lug)</td>
</tr>
<tr>
<td>%inch thick Elliptical Head</td>
<td>1.20 (near outer shell weld)</td>
</tr>
<tr>
<td>%inch thick Elliptical head</td>
<td>2.70 (Near Penetrations)</td>
</tr>
<tr>
<td>1-1/4&quot; thick Lift Lug</td>
<td>8.05 (near upper slot)</td>
</tr>
<tr>
<td>Shell</td>
<td>0.60 (away from weld joint)</td>
</tr>
</tbody>
</table>

The allowable stress intensity at the outer surface is 8.33 ksi. Accordingly, the Factors of Safety at these zones are:

\[
\begin{align*}
FS_{\text{Head}} &= \frac{8.33}{3.91} = 2.13 & \text{Head Factor of Safety} \\
FS_{\text{Lug}} &= \frac{8.33}{8.05} = 1.034 & \text{Lift Lug Factor of Safety} \\
FS_{\text{Shell}} &= \frac{8.33}{1.20} = 6.94 & \text{Shell Factor of Safety at weld joint}
\end{align*}
\]

Note the stresses under the analysis slot oval are extremely low and the attachment points in this region are also low. Removal of the lug material below
the slot has no adverse affect on the lug and head attachment design, as analyzed.

**Corroded Geometry Considerations**

The lift Lug is not subject to corrosion from the contents or the process or storage environments. The factor of safety for the head in the head is extremely large. The increment in stress intensity for the head is proportional to the inverse of \( t \) where \( t \) is the head wall thickness. The increment in head stress intensity increases 44% from 3.91 to 5.63 ksi due to ratio of thickness squared \((0.75^2 / 0.625^2)\) from the new to fully corroded condition. The minimum factor of safety for this condition is at the Lift Lug which remains greater than 1.

Results from the finite element analysis for the Pressure Case (200°F and 150-psig) condition are as follows (reference Appendix Section 10.1 FEM plots):  

<table>
<thead>
<tr>
<th>Component</th>
<th>Peak Stress Intensity (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4 inch thick Elliptical Head</td>
<td>12.30 (outer surface under lift lug)</td>
</tr>
<tr>
<td>3/4 inch thick Elliptical Head</td>
<td>6.14 (near outer shell weld)</td>
</tr>
<tr>
<td>3/4 inch thick Elliptical head</td>
<td>13.00 (Near Penetrations)</td>
</tr>
<tr>
<td>Shell</td>
<td>10.40 (away from weld joint)</td>
</tr>
</tbody>
</table>

The allowable stress intensity at the outer surface is 17.3 ksi (Table 3-1). Accordingly, the Factors of Safety at these zones are:

\[
FS_{\text{Head}} = 17.3 / 13.00 = 1.33 \quad \text{Head Factor of Safety}
\]
\[
FS_{\text{Shell}} = 17.3 / 10.40 = 1.66 \quad \text{Shell Factor of Safety}
\]

Please refer to the Appendix (Section 10.1) figures (eight total) for more information.

**Corroded Geometry Considerations**

The Stress Intensity will increase for internal pressure imposed on the corroded geometry. The critical design region is the upper head due to thickness reduction from 3/4-inch (corroded) to 5/8-inch (new). The design stress intensity increment is controlled by membrane stresses occurring in the region. Accordingly, the stress intensity at unreinforced penetrations for this condition increases 20% from 13 to 15.6 ksi \((0.75/0.625 = 0.20)\). The cylindrical shell stress intensity will also increase 20% from 10.4 to 12.48 ksi due to 20% increase in hoop and longitudinal stress components. The limiting factor of safety for the fully corroded head condition remains acceptable as shown by:

\[
FS_{\text{Head}} = 17.3 / 15.6 = 1.11 \quad \text{Corroded Head Factor of Safety}
\]

**7.7.2 Axisymmetric Finite Element Model**

A separate model was developed to recover stress intensity in the upper and lower head, skirt and cylindrical shell considering steady state thermal and mechanical loading. The model considers 3/4" thick lower head, 5/8" thick shell and 3/4" thick upper
### Table: Loadings of Stress Intensity

<table>
<thead>
<tr>
<th>Zone of Stress Recovery</th>
<th>Thermal Loading Stress Intensity (Psi)</th>
<th>Pressure Loading Stress Intensity (Psi)</th>
<th>Combined Loading Stress Intensity (Psi)</th>
<th>Allowable Stress Intensity (Psi)</th>
<th>Factor of Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Head</td>
<td>&lt;634</td>
<td>9,980</td>
<td>9,980</td>
<td>17,300</td>
<td>1.73</td>
</tr>
<tr>
<td>Lower Head</td>
<td>&lt;634</td>
<td>13,200</td>
<td>13,300</td>
<td>17,300</td>
<td>1.30</td>
</tr>
<tr>
<td>Shell</td>
<td>&lt;634</td>
<td>&lt;9,980</td>
<td>9,980</td>
<td>17,300</td>
<td>1.73</td>
</tr>
<tr>
<td>Skirt Weld at Lower Head Juncture</td>
<td>&lt;634</td>
<td>12,291</td>
<td>&lt;12,000</td>
<td>17,300</td>
<td>&gt;1.44</td>
</tr>
</tbody>
</table>

### 7.8 Reinforcements for Nozzle Penetrations

In consideration of reinforcement pads for nozzle penetrations, this evaluation uses vessel head area removed (A) by the penetration, pad reinforcement thickness (tₚ), if required, excessive vessel area (Aₑₚ) above the required 0.286 inch head thickness (corroded condition), and associated weld areas. Weld areas consider fillet type equal to the pad or nozzle. Weld areas are considered only when the penetration is reinforced.
Excessive vessel areas are shown to exceed the head area removed (A). The calculation does not consider excessive reinforcing shell area beyond \( D_n \), although it can be as large as twice the nozzle inner diameter. Accordingly, the calculation considers adjacent reinforcements not overlapping or exceeding ligament spacing between any two penetrations.

The head stresses are within stress intensity requirements without reinforcements as shown by the shell model. The level sensor nozzle has increased with respect to the model (i.e., 5.563 versus 4.5) yet is expected to result in reduced stress concentration (and therefore reduced stress intensity) at its' edge since design ligament spacing between holes are not changed from original assumptions of the model.

Table 7-2  - Penetration Re-Pad Assessment - Fully Corroded Head Condition

<table>
<thead>
<tr>
<th>Pipe Nozzle</th>
<th>d</th>
<th>tr</th>
<th>A</th>
<th>Dp</th>
<th>tn</th>
<th>te</th>
<th>Apad</th>
<th>Awelds</th>
<th>t</th>
<th>Ashell</th>
<th>Areinf't</th>
</tr>
</thead>
<tbody>
<tr>
<td>5'' Sch 10</td>
<td>5.295</td>
<td>0.286</td>
<td>1.514</td>
<td>7.5</td>
<td>0.258</td>
<td>0</td>
<td>0</td>
<td>0.625</td>
<td>1.795</td>
<td>1.795</td>
<td></td>
</tr>
<tr>
<td>Level Sensor</td>
<td>3.06</td>
<td>0.286</td>
<td>0.875</td>
<td>NA</td>
<td>0.216</td>
<td>0</td>
<td>0</td>
<td>0.625</td>
<td>1.037</td>
<td>1.037</td>
<td></td>
</tr>
<tr>
<td>3'' Schedule 40 Outlet</td>
<td>3.5</td>
<td>0.286</td>
<td>1.001</td>
<td>NA</td>
<td>0.357</td>
<td>0</td>
<td>0</td>
<td>0.625</td>
<td>1.187</td>
<td>1.187</td>
<td></td>
</tr>
<tr>
<td>3''-3000# Coupling Clean-Out</td>
<td>2.067</td>
<td>0.286</td>
<td>0.591</td>
<td>NA</td>
<td>0.154</td>
<td>0</td>
<td>0</td>
<td>0.625</td>
<td>0.701</td>
<td>0.701</td>
<td></td>
</tr>
<tr>
<td>2'' Schedule 40 Vents</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

With consideration of excess head area and the FEM analysis, no reinforcement pads are needed.

7.9 Skirt Design with Additional Holes

Evaluation is provided to determine stress intensities for skirt redesign with additional holes. The modification includes holes near the upper portion of the skirt attachment to the vessel, 1/2 shaped slots in the lower skirt support surface, and mid skirt section holes. The mid section holes are aligned with the upper holes. Stress intensities are low in magnitude near the lower support skirt support surface. Accordingly, an alignment slot feature (comparable slot size) to engage the cask orientation key can be safely provided.
with negligible effect on the evaluation. The construction and full penetration continuous skirt weld to shell is comparable to that for jacketed vessels as shown in Reference 9.2.

A single one-fourth symmetric shell model is provided to evaluate the structural response of the lower skirt area, lower head, and attaching cylindrical shell for internal pressure (150 psig) when combined with hot case temperatures (see axisymmetric model thermal load description and appendix figures) and 1G design weight (17,100 lbs) static analysis conditions. The model considers fully corroded uniform upper head (5/8 inch thick), uniform shell (3/8 inch thick), uniform lower head (3/8 inch thick), and the skirt (1/2 inch thick) assembly configuration.

Displacement boundary conditions (restraints) are applied along the model at symmetric free edges and the lower skirt surface. Nodes along X=O have restraints Ux = Roty = Rotz = 0 for translations and rotations. Similarly, nodes located along Z=O have Uz = Rotx = Roty = 0 restraints. Vertical supports (Uy=0) are applied at nodes along the lower skirt surface.

The results from this evaluation are as follows:

<table>
<thead>
<tr>
<th>Zone of Stress Recovery</th>
<th>Combined Loading Stress Intensity (Psi)</th>
<th>Allowable Stress Intensity (Psi)</th>
<th>Factor of Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Head</td>
<td>16,500</td>
<td>17,300</td>
<td>1.08</td>
</tr>
<tr>
<td>Shell</td>
<td>14,400</td>
<td>17,300</td>
<td>1.20</td>
</tr>
<tr>
<td>Skirt (Hole)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
area within the grating boundary is 22.2% for a total of 404 square inches of metal area for the sludge to apply loads upwards.

Between the upper and lower grating, fourteen ½" sch.40 pipes are installed (not fastened) as sleeves surrounding each of the all-thread tie rods. Mechanical stops are included to retain the sleeves between the upper and lower support grids (grating).

The total upward grating load is a maximum of 606 pounds (1.5 psi x 404).

The average compressive force on each pipe is 43.3 pounds

Pipe column stability evaluation

½ inch schedule 40 pipe properties
Inside Diameter = 0.622 inch
Outside Diameter = 0.840 inch
Cross Sectional Area = 0.250 square inches
Moment of Inertia = 0.026 inch²

The average pipe column stress is low (43.3 / 0.250 = 173.1 psi).

The allowable most conservative pipe load for stability assuming pinned ends is:

\[ P_{\text{critical}} = 3.14 \times E \times I / L^2 \]  
[Reference 9.61]

For \( L = 32 \) inch, \( E = 28 \) million psi, \( I = 0.026 \) inch²

\[ P_{\text{critical}} = 2,233 \text{ pounds} \]

\[ FS = 2233 / 606 = 3.68 \]

Since the critical load exceeds the applied load the pipes remain stable. Note this analysis does not consider the additional restraint (opposing the upward load) provided by the flex connection between the outlet header and the outlet nozzle.

The assembly is subject to 1G static loads downward.

Total Filter Assembly weight acting onto the lower grate are as follows:

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>top grating with support bars</td>
<td>130 lbs</td>
</tr>
<tr>
<td>bottom grating</td>
<td>94 lbs</td>
</tr>
<tr>
<td>all-thread and fasteners</td>
<td>20 lbs</td>
</tr>
<tr>
<td>filters</td>
<td>70 lbs</td>
</tr>
<tr>
<td>piping</td>
<td>125 lbs</td>
</tr>
<tr>
<td>sleeves and stops</td>
<td>35 lbs</td>
</tr>
<tr>
<td><strong>The total Filter Assembly total weight:</strong></td>
<td><strong>474 lbs</strong></td>
</tr>
</tbody>
</table>

This exceeds the net force (difference of sludge growth force and weight) acting on the lower grate. Accordingly, 1G static tests will be used to qualify the assembly.
AVANTech Calculation Sheet

Title: A-170 Structural Analysis Calculation Number EN-3C-0126-04 Rev 3 (CON-17)
Project Name: Sludge Transportation System Job Number 0126

Lower Grid Overall Geometry

Individual Grating Cell

Lower Grid Free Body Diagram
Summary

8.1 ASME Code Vessel
The ellipsoidal head, shell and skirt thickness are shown to provide adequate safety factor beyond the allowable stress intensities for design. The design exhibits the desired corrosion allowance under all code vessel requirements imposed at longitudinal and circumferential weld seams.

The Specification (Reference 9.1) Section 7.3 requires the LC corrosion allowance of no greater than 3-5 millyr or 1/8" over a 30 year service life. The design exhibits excess material thickness far exceeding the specified corrosion allowance.

8.2 Lifting - Lug & Vessel
The analysis demonstrates that the lift lug and vessel design provides adequate margin beyond the allowable stress intensities based on ANSI 14.6 (ref. 9.3) criteria. The classical analysis develops proper weld and preparation to attach the lug to the upper head.

References


9.2 ASME Boiler and Pressure Vessel Code, Section VIII Division 1, 1998 Editionw/ Addenda.

9.3 ANSI N14.6, Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4,500 kg) or More

9.4 Large Container drawing 3C40-0126-D Rev.1, K-East Basin STS Large Container Assembly.

9.5 ASME Boiler and Pressure Vessel Code, Section II, Part D, 1998 Editionw/ Addenda


9.7 EN-3C-0126-03 Rev. C (full text not submitted to Fluor Hanford), K-East Basin Sludge Transport System, Large Container Thermal Analysis (60% Preliminary Design), February 2002.

9.8 Large Container drawing 3C42-0126-D Rev.1, K-East Basin STS Large Container Filter Assembly.

9.9 Email from Gary Sly to Mike Brubaker, "Change Order #3 GS to SS for LDC", dated August 8, 2002.
10 Appendix (Figures)
10.1 Half Symmetric FEM

Figure 10.1-1 Free Body Diagram (Container Lift)

Figure 10.1-2 Large Container Finite Element Model
Figure 10.1-3 Large Container Finite Element Model
( Local View of Head with Applied Lift Loads )

Figure 10.14 Large Container under Lifting Loads
(Deformed View- Pressure - "Lift Case")
Figure 10.1-5 Large Container under Internal Pressure
(Deformed View - Pressure - "Pressure Case")

Figure 10.1-6 Large Container Finite Element Model
(Lift Case - Stress Intensity - psi)
Figure 10.1-7 Large Container Finite Element Model

(Pressure Case, Stress Intensity, psi)

Figure 10.1-8 Large Container Finite Element Model Head Local View

(Pressure Case - Stress Intensity - psi)
10.2 Axisymmetric FEM

Figure 10.2-1 Axisymmetric Finite Element Model
(Views: Overall Model (Upper Right), Skirt to Lower Head, Upper Head to Shell)

Figure 10.2-2 Axisymmetric Finite Element Model
(Isotherms: Pressure Case Steady State Temperature Field Loading)
Figure 10.2-3 Axisymmetric Finite Element Model
(Isotherms: Temperature Field Loading at Lower Head and Skirt)

Figure 10.24 Axisymmetric Finite Element Model
(Isotherms: Temperature Field Loading at Upper Head to Shell)
Figure 10.2-5 Axisymmetric Finite Element Model
(Thermal Loading: Deformed Shape)

Figure 10.2-6 Axisymmetric Finite Element Model
(Thermal Stress: Stress Intensity - Psi)
Figure 10.2-7 Axi-symmetric Finite Element Model
(Mechanical Pressure Load Vectors at Interior Surfaces, Vertical Restraint at Skirt)

Figure 10.2-8 Axi-symmetric Finite Element Model
(Mechanical Pressure Loading: Deformed Shape)
Figure 10.2-9 Axisymmetric Finite Element Model
(Mechanical Pressure Loading: Stress Intensity - Psi)

Figure 10.2-10 Axisymmetric Finite Element Model
(Combined Loading Stress Intensity & Deformed Shape - Psi)
Figure 10.2-11 Axisymmetric Finite Element Model
(Combined Loading: Stress Intensity Deformed Shape @ Skirt / Head Juncture- Psi)

Figure 10.2-12 Axisymmetric Finite Element Model
(Combine Loading Stress Intensity Deformed Shape Upper Head / Shell- Psi)
Figure 10.2-13 Axisymmetric Finite Element Model
(Combined Loading: Stress Intensity @ Mid Shell Section - Psi)

Figure 10.2-14 Axisymmetric Finite Element Model
(Combined Loading. Stress Intensity @ Skirt Juncture - Psi)
Figure 10.2-15 Axisymmetric Finite Element Model
(Combined Loading: Shear Stress @Skirt Juncture- Psi)
10.3 Skirt Quarter Symmetric FEM

Figure 10.3-1 – ¼ Symmetric Skirt Shell Model
Figure 10.3-2 – Skirt Shell Model – Deformed Shape
Figure 10.3-3 – Skirt Shell Model – Isotherms – Hot Case
Figure 10.3-4 – Skirt Shell Model – Skirt Stress Intensity – psi
Figure 10.3-5 - Skirt Shell Model – Lower Head Stress Intensity – psi
Figure 10.3-6 – Skirt Shell Model – Circumferential Shell Stress Intensity – psi
**SUPPLIER DOCUMENT SUBMITTAL FORM**

**PROJECT NO.:** A16  
**CONTRACT NO. (TASK NO./PHASE NO.)** 12329/PSP  
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**DATE:** 10/31/02

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Fax: 253.383.8002

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- VEN - VENDOR INFORMATION

**SUBMITTAL ACTION CODE** (BY PH)

- A - Conforms to the Contract Requirements
- B - Minor Comments - Appr. with exceptions - Incorporate and Resubmit
- C - Revise and Resubmit (SEE COMMENTS)
Title:   STS Process Shield Plate Analysis

Customer:  Fluor Hanford  Project No.: 12099

Prepared by:  Jim Livingston  Date: November 1, 2002  
Checked by:  Rick Migliore  Date: 11/1/02
Approved by:  Fred Yapuncich  Date: 11/1/02

Summary Description:
This analysis evaluates the dose rates at the top of the Process Shield Plate (PSP) for 1) an off normal condition of the container completely filled with 60% KE floor sludge+40% KE canister sludge and 2) a 2.0 m³ of revised activity waste composed of 60% KE floor sludge+40% KE canister sludge.
The 2.0 m³ payload is modeled with 10" of water covering the sludge mix.
The specification dose limits are 20 mrem/hr at 30 cm above the shield for normal operations and 80 mrem/hr for the off-normal condition.
The average dose 30 cm above the shield plate for the current source term and shield design is calculated to be 20% above the limit at 24.3±0.5 mrem/hr. This dose rate is sensitive to the cover water thickness and source distribution. Calculated doses adjacent to the shield plate (in areas were operators are likely to be standing) meet the 20 mrem/hr dose limit for the normal operations and the 80 mrem/hr limit under off-normal condition. The off-normal dose limit is calculated to be exceeded directly over the penetrations when the tank is overfilled.

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<th>Document Revision</th>
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<th>Revision Description</th>
<th>Approved by: Name/Date</th>
<th>Names of Preparers &amp; Verifiers</th>
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<tr>
<td>0</td>
<td>All</td>
<td>Initial issue</td>
<td>Fred Yapuncich/ 5/13/02</td>
<td>JV Livingston, RJ Migliore</td>
</tr>
<tr>
<td>1</td>
<td>All</td>
<td>Revised Source Term</td>
<td>Joe Nichols/ September 2002</td>
<td>JV Livingston, RJ Migliore</td>
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<td>2</td>
<td>All</td>
<td>Revised and Additional penetrations</td>
<td>Joe Nichols/ September 2002</td>
<td>JV Livingston, RJ Migliore</td>
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<td>3</td>
<td>9-23</td>
<td>Revised penetrations and puck locations</td>
<td>Fred Yapuncich/ November 2002</td>
<td>JV Livingston, RJ Migliore</td>
</tr>
</tbody>
</table>
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1.0 Introduction

The K Basins, built in the early 1950's, have been used to store irradiated N Reactor SNF underwater starting in 1975 for K East (KE) Basin, 1981 for K West (KW) Basin, and much earlier for Single Pass Reactor SNF. In 1992, the decision to deactivate the Plutonium Uranium Reduction Extraction (PUREX) Facility precluded processing the approximately 2,100 metric tons (2,315 tons) of heavy metal from the SNF left in the K Basins, where it has remained. The SNF in the KE Basin is stored in open-top canisters; some have closed bottoms while others have screened bottoms. The SNF in the KW Basin is stored in canisters that have closed tops and bottoms; therefore, most of the corrosion products are retained within the canisters. A significant fraction of the SNF in the K Basins has become degraded due to cladding breaches during reactor discharge. Corrosion has continued during underwater storage.

Associated with this SNF is an accumulation of particulate-layered material that is generally called sludge. Sludge is found on the basin floors, in canisters, and in the basin pits. As defined by the SNF Project and used herein, the term “sludge” refers to particulate matter that shall pass through a screen with 0.64 cm (0.25 in.) openings. The sludge is composed of irradiated nuclear fuel, fuel corrosion products, cladding, storage canister corrosion products, structural degradation, and corrosion products from features in the basin pools (e.g., racks, pipes, sloughed off concrete, etc.), beads lost from Ion Exchange Modules (IXM beads), environmental debris (e.g., wind blown sand, insects, pieces of vegetation, etc.), and various materials accumulated through the operation (e.g., sand filter media, hardware, plastic, etc.) of the basins over the past 30 years [Reference 6]. The estimated total sludge volume in the KE Basin is nominally 43.8 m$^3$ (11,572 gal) [Ref. 9]. The total sludge volume in the KW Basin is estimated to be nominally 6.66 m$^3$ (1,759 gal) [Ref. 9].

The SNF Project mission includes safe removal and transportation of all sludge from these storage basins to a more secure storage state in the 200 West Area (currently identified as T Plant). This calculation estimates the dose rates in the vicinity of the process shield plate for the prescribed source term. Sludge transferred from KW in the “small” container is beyond the scope of this calculation.

2.0 Design Input

2.1 Discussion

The “as-settled sludge” is a radioactive mixture of solids and interstitial water (approximately 30 vol% solids). The solids consist of windblown sand, vegetation, and insects; spalled concrete from the basin walls, iron and aluminum corrosion products, ion exchange resin beads, uranium oxides, uranium fuel particles and other debris that may have fallen into the basin. The basin process water is radioactive and provides the covering to the sludge. The process water comes from loading and flushing operations. Table 2-1 lists some of the basic design properties used for the sludge.
Table 2-1 Design Basis As-Settled Sludge Properties

<table>
<thead>
<tr>
<th></th>
<th>Large Container Sludge Sources</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>KE Floor</td>
<td>KE Canister</td>
</tr>
<tr>
<td>Density</td>
<td>1.4 g/cm³</td>
<td>1.9 g/cm³</td>
</tr>
<tr>
<td>Percent Water (Vol%)</td>
<td>65%</td>
<td>70%</td>
</tr>
<tr>
<td>(\text{Total } \text{U} \ (I))</td>
<td>0.060 gU/cm³</td>
<td>0.77 gU/cm³</td>
</tr>
</tbody>
</table>

References 1 and 8 provide a description of “floor” and “canister” sludge characteristics that are required to be used. The canister sludge has a larger radionuclide inventory. A homogeneous mixture, i.e., payload, of floor and canister sludge is modeled. The payload configurations considered for the large container:

1) the off normal condition of a container completely filled (maximum payload of \(4.15 \text{ m}^3\)) with 60% floor and 40% canister sludge and;

2) \(71 \text{ ft}^3 \ (2.0 \text{ m}^3)\) of KE 60% floor and KE 40% canister sludge with a nominal cover of 10 inch \((25.4 \text{ cm})\) of basin process water.

2.2 Geometry

As discussed above, the large container will consist of \(2.0 \text{ to } 4.15 \text{ m}^3\) of settled sludge, with a nominal cover of 10 inches \((25.4 \text{ cm})\) of basin process water when possible. The large container wall thickness is \(\frac{1}{2} \text{ inch} \ (1.27 \text{ cm})\) thick, has an outer diameter of 59 inches \((149.86 \text{ cm})\) and is elliptical on each end. The processes shield plate is 5.5 inches thick with several strait access penetrations. See Figure 2-1 for a visual summary of the geometry and Section 6.0 for a discussion of the shielding assumptions.

Each source of sludge is a unique, non-homogeneous mixture, possibly containing irradiated fuel, fuel corrosion products, and/or fission products in addition to non-radioactive debris. The KE floor, KW floor, and KW Canister inventories given in reference 8 \((\text{HNF-SD-SNF-TI-015, Rev. 9, Spent Nuclear Fuel Project Technical Databook, Volume 2, Sludge, Fluor Hanford, Richland, Washington, 2002})\) are design basis values and do not necessarily represent an individual shipment payload.
Figure 2-1 Source Term Geometry
2.3 Functional Requirements

Section 10 of [Ref. 1], specify the following functional requirements for the Process Shield Plate:

- Shielding thickness shall be designed based on the highest specific-activity sludge, with the sludge settled to the bottom of the large container. Individual large containers (in the cask with the process shield plate on) shall be < 20 mrem/hr at 30 cm. The design shall mitigate radiation streaming from the penetrations. If lead is used, it shall be isolated from contact with radioactive material.

- Process shield plates shall be designed per 10 CFR 835, subpart K and shall be documented per 10 CFR 835, Section 704(b).

- The off-normal and/or accident conditions shielding evaluation shall be with the sludge filling the canister volume. The off-normal conditions dose above the Process shield Plate shall be limited to <80 mrem/hr at 30 cm.

2.4 Source Term

The design payload for the large container is as 80-vol% KE floor and 20-vol% KE canister sludge (80/20) and the worst case ratio is 60/40 (reference 1) is used. HNF-SD-SNF-TI-015 (reference 8) provides the shielding design basis source term and Table 2-2 lists the revised source term based on Revision 9 of TI-015. The source inventories for the large container are based on a mixture of the floor sludge and the KE canister sludge. The curie inventory for the large container is assumed decayed to May 2000 (time at which the last samples collected from the KE Basin were analyzed). HNF-SD-SNF-TI-015 lists the mass and activity of the basin process water. This activity is considered for the interstitial, cover water and filter loading. Details of the source term development are presented in reference 10. The revised source term for this calculation was processed using ORIGEN-S to generate a new and lower photon spectrum following the same process as presented in reference 10.

The radioisotopes given in the tables include only those reported in the project specification [Ref. 8]. Other unlisted isotopes of importance include $^{208}$TI and $^{212}$Bi, which are decay products of $^{238}$Pu and contribute to the high-energy gamma-ray source; and $^{144}$Pr, $^{106}$Rh, and $^{121}$Sb, which also make major contributions to the gamma ray source term. As part of the design analysis, further evaluations (e.g., ORIGEN decay calculations) will be conducted by the buyer (Fluor Hanford) to ensure the design is bounded and shall meet the performance requirements prescribed herein.
### 3.0 Material Properties

The important material properties of the cask are given in Table 3-1. A lower steel density of 7.82 g/cm³ was conservatively used in the calculations, rather than a more nominal value of 8.02 g/cm³. A single sludge composition is used, with a density of 1.41 g/cm³ for the 601-40 sludge.

---

#### Table 2-2 - Large Container Shielding Design Basis Revised Source Terms

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Rev 9 of TI-015 Sludge Reference Data</th>
<th>Bounding Sludge (60% floor, 40% canister)</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Floor Ci/m³</td>
<td>Canister Ci/m³</td>
<td>Floor Ci/m³</td>
</tr>
<tr>
<td>²⁴¹Am</td>
<td>1.22E+01</td>
<td>1.12E+02</td>
<td>52.12</td>
</tr>
<tr>
<td>²³⁷Np</td>
<td>3.67E-03</td>
<td>1.54E-02</td>
<td>0.008362</td>
</tr>
<tr>
<td>²³³Pu</td>
<td>2.05E+00</td>
<td>2.31E+01</td>
<td>10.47</td>
</tr>
<tr>
<td>²³⁹Pu</td>
<td>8.26E+00</td>
<td>8.91E+01</td>
<td>40.596</td>
</tr>
<tr>
<td>²⁴⁰Pu</td>
<td>4.54E+00</td>
<td>4.89E+01</td>
<td>22.284</td>
</tr>
<tr>
<td>²⁴¹Pu</td>
<td>2.44E+02</td>
<td>2.63E+03</td>
<td>1198.4</td>
</tr>
<tr>
<td>²⁴²Pu</td>
<td>2.19E-03</td>
<td>2.36E-02</td>
<td>0.010754</td>
</tr>
<tr>
<td>⁶⁰Co</td>
<td>9.98E-01</td>
<td>9.44E-01</td>
<td>0.9764</td>
</tr>
<tr>
<td>¹³⁷Cs</td>
<td>2.52E+02</td>
<td>1.02E+03</td>
<td>559.2</td>
</tr>
<tr>
<td>¹³⁴Cs</td>
<td>6.03E-02</td>
<td>2.84E-01</td>
<td>0.14978</td>
</tr>
<tr>
<td>¹⁵²Eu</td>
<td>1.09E-01</td>
<td>(i)</td>
<td>0.0654</td>
</tr>
<tr>
<td>¹⁵⁴Eu</td>
<td>1.92E+00</td>
<td>1.40E+01</td>
<td>6.752</td>
</tr>
<tr>
<td>¹⁵⁵Eu</td>
<td>9.44E-01</td>
<td>7.91E+00</td>
<td>3.7304</td>
</tr>
<tr>
<td>⁹⁰Sr</td>
<td>1.88E+02</td>
<td>1.82E+03</td>
<td>840.8</td>
</tr>
<tr>
<td>⁹⁹Tc</td>
<td>(i)</td>
<td>1.54E+01</td>
<td>6.16</td>
</tr>
</tbody>
</table>

Notes:

(i) No data reported.
### Table 3-1: Material Densities and Material Compositions Used in Calculation Models.

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (g/cm³)</th>
<th>Dens. (a/b-cm)</th>
<th>Isotope</th>
<th>Mass fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sludge (30 vol% SiO₂, 70 vol% Water)</td>
<td>1.41</td>
<td>0.09452</td>
<td>H</td>
<td>0.05890</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O</td>
<td>0.71969</td>
</tr>
<tr>
<td>Lead</td>
<td>11.35</td>
<td>0.03298</td>
<td>Pb</td>
<td>1.000000</td>
</tr>
<tr>
<td>SS-304</td>
<td>1.81</td>
<td>0.08634</td>
<td>C</td>
<td>0.00080</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N</td>
<td>0.00100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Si</td>
<td>0.00750</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>P</td>
<td>0.00045</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>S</td>
<td>0.00030</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cr</td>
<td>0.19000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mn</td>
<td>0.02000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fe</td>
<td>0.68745</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ni</td>
<td>0.09250</td>
</tr>
<tr>
<td>Water/liter</td>
<td>1.00</td>
<td>0.10032</td>
<td>H</td>
<td>0.1193</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O</td>
<td>0.88807</td>
</tr>
<tr>
<td>Air</td>
<td>0.00123</td>
<td>0.0000513</td>
<td>N</td>
<td>0.75633</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O</td>
<td>0.24367</td>
</tr>
</tbody>
</table>

### 4.0 Conditions Analyzed

The source terms identified in Section 2.4 are analyzed with the shield plate in place and all transfer connections (e.g., fill and vent pipes) removed. Each source term is evaluated with the shield plate and penetrations. Average dose rates are calculated above the shield plate and in adjacent areas that may be accessible.

### 5.0 Acceptance Criteria

Shielding thickness shall be designed based on the highest specific-activity sludge, with the sludge settled to the bottom of the large container. Average doses from individual large containers (in the cask with the process shield plate on) shall be < 20 mrem/hr at 30 cm in the areas that are typically accessible to the operators. The design shall mitigate radiation streaming to the extent possible given that the penetrations will be straight through the shield. Lead will be isolated from contact with the radioactive material.

Shielding shall meet the requirements set forth in 10 CFR 835, subpart K, for loading and cask lid operations and shall be documented per 10 CFR 835, Section 704(b).
6.0 Assumptions

The density assumed for the sludge is 1.41 g/cm³ with composition mix of 30 vol% solid (assumed to be SiO₂) and 70 vol% water for the 60/40 sludge source. Because the payload region is large, this material provides significant internal attenuation. Isotopes not listed in the reference source term are ignored. The source term is assumed to be homogenous within the sludge volume.

The filters are analyzed assuming a 275 gram loading of sludge material. Due to the vertical orientation of the filters and radiation streaming concerns, attenuation by the filters is ignored. The filter source is uniformly distributed over 28 vertical inches from the hemispherical head joint down to just above the 10" water layer.

7.0 Calculations

The source term and geometry model is based on the “STS Cask Shielding Analysis” (Reference 10) and changed for this STS Process Shield Plate Analysis. The main differences are: the sludge volumes; sludge radionuclide inventory; the lid of the cask is replaced with a steel process shield plate; and dose rates are tallied at 30 cm intervals above the top of the process shield plate.

7.1 Source Terms

The “STS Cask Shielding Analysis” (Reference 10) concluded that the dose from the neutron sources was inconsequential and the doses are dominated by the photons from the waste. Consequently, this STS Process Shield Plate Analysis considers only photons from the waste.

“STS Cask Shielding Analysis” (Reference 10) used ORIGEN-S to obtain the neutron and photon source terms in the sludge. The inventory was revised from the reference to that listed in Table 2-2. Using this radioisotope inventory an energy dependent photon source spectra calculated with ORIGEN-S is obtained as given in Table 7-2 for the sludge mixtures and the water. ORIGEN-S determines the photon intensity at discrete photon energies to exactly conserve energy so these discrete energies are used to specify the photon source in MCNP.

The photon source intensity for each energy group is orders of magnitude less in the water than in the sludge so the activated water is negligible within the sludge.

The filter loading was assumed to be 275 grams of sludge mix (60/40 mix) over a 28 inch vertical volume (above the 10 inches of cover water). The filter loading source term was found by multiplying the sludge source by the ratio of the densities. For the 60/40 sludge at a density of 1.41 g/cm³ the density the filter source is 1.258x10⁸ p/s.

The source strengths and spectra are listed in Table 7-1 and Table 7-2. These source calculations are performed in the ‘Source Term’ sheet of the Excel file “Working3”.

11/01/02
### Table 7-1: Photon Source Strength for Shielding Calculations

<table>
<thead>
<tr>
<th>Source Region</th>
<th>Source Volume ( (m^3) )</th>
<th>Source Strength ( \text{Photons/s} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sludge, nominal</td>
<td>2.0</td>
<td>1.2885e14</td>
</tr>
<tr>
<td>10&quot; Water</td>
<td>0.4330</td>
<td>1.0226e9</td>
</tr>
<tr>
<td>Filter</td>
<td>1.21</td>
<td>1.258e10</td>
</tr>
<tr>
<td>Total-nominal</td>
<td>3.64</td>
<td>1.2886e14</td>
</tr>
<tr>
<td>Sludge, Accident</td>
<td>4.15</td>
<td>2.673e14</td>
</tr>
</tbody>
</table>

### Mean Photon Energy (MeV) and Source Strength

<table>
<thead>
<tr>
<th>Mean Photon Energy (MeV)</th>
<th>Rev 9 of TI-015 Sludge Water (Photons/m³/s)</th>
<th>Rev 9 of TI-015 Water (Photons/m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>2.30E+13</td>
<td>5.35E+08</td>
</tr>
<tr>
<td>0.03</td>
<td>8.63E+12</td>
<td>2.53E+08</td>
</tr>
<tr>
<td>0.055</td>
<td>5.52E+12</td>
<td>1.83E+08</td>
</tr>
<tr>
<td>0.085</td>
<td>2.66E+12</td>
<td>5.91E+07</td>
</tr>
<tr>
<td>0.12</td>
<td>1.91E+12</td>
<td>4.93E+07</td>
</tr>
<tr>
<td>0.17</td>
<td>1.76E+12</td>
<td>3.41E+07</td>
</tr>
<tr>
<td>0.3</td>
<td>1.86E+12</td>
<td>3.58E+07</td>
</tr>
<tr>
<td>1.13</td>
<td>3.44E+11</td>
<td>7.16E+07</td>
</tr>
<tr>
<td>1.58</td>
<td>1.90E+10</td>
<td>8.49E+05</td>
</tr>
<tr>
<td>2</td>
<td>7.45E+08</td>
<td>1.39E+04</td>
</tr>
<tr>
<td>2.4</td>
<td>4.62E+05</td>
<td>8.72E+00</td>
</tr>
<tr>
<td>3.25</td>
<td>9.79E+03</td>
<td>2.37E-02</td>
</tr>
<tr>
<td>3.75</td>
<td>5.63E+03</td>
<td>1.19E-02</td>
</tr>
<tr>
<td>4.25</td>
<td>3.24E+03</td>
<td>5.97E-03</td>
</tr>
<tr>
<td>4.75</td>
<td>1.87E+03</td>
<td>3.00E-03</td>
</tr>
<tr>
<td>5.5</td>
<td>1.68E+03</td>
<td>2.23E-03</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6.442E+13</strong></td>
<td><strong>2.36E+09</strong></td>
</tr>
</tbody>
</table>
7.2 MCNP Model Specification

The dimensions utilized in the MCNP calculation models for NCT are summarized in Table 7-6. An axial view of the MCNP model is shown in Figure 7-1 with expanded views of the process shield plate vicinity shown in Figure 7-2 and Figure 7-3. The cask steel and lead are divided into additional regions for optimization. Five MCNP geometry models were utilized, as listed in Table 7-3, where they differ by the treatment of the source strength and dimension. The photon source strength (p/m²/s) in HNF-SD-SNF-TI-015 is multiplied by the volume of the source. The photon sludge source is uniformly distributed over the 2.0 cubic meters of sludge. The water source is uniformly distributed over 10 inches of water. and the filter source is distributed over 28 inches of air. The analysis assumes there is 275 g of sludge in the filter volume. The total source strengths of these MCNP models are listed in Table 7-3:

<table>
<thead>
<tr>
<th>Case</th>
<th>Shield Penetrations</th>
<th>Source</th>
<th>Source Volume</th>
<th>Total Source Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psp5zi</td>
<td>na</td>
<td>Rev 9 of TI-015</td>
<td>2.0m³ sludge and 10” water and 275 g filter</td>
<td>1.2886x10⁴ (p/s)</td>
</tr>
<tr>
<td>Psp70zi</td>
<td>Open</td>
<td>Psp5zi tape</td>
<td>Uses Psp5zi</td>
<td>1.2886x10⁴ (p/s)</td>
</tr>
<tr>
<td>Psp71zi</td>
<td>Plugged</td>
<td>Psp5zi tape</td>
<td>Uses Psp5zi</td>
<td>1.2886x10⁴ (p/s)</td>
</tr>
<tr>
<td>Psp72zi</td>
<td>Open</td>
<td>Rev 9 of TI-015</td>
<td>4.15 m³</td>
<td>2.673x10⁴ (p/s)</td>
</tr>
<tr>
<td>Psp73zi</td>
<td>Plugged</td>
<td>Rev 9 of TI-015</td>
<td>4.15 m³</td>
<td>2.673x10⁴ (p/s)</td>
</tr>
</tbody>
</table>

The [$\text{ANSI/ANS-6.1.1-1977}$] flyx-to-dose conversion factors are used for the photons and the neutrons as given in Appendix H of the MCNP manual.

The material densities and material compositions used in the MCNP models are given in Table 3-1. Sludge was assumed to be 70 vol% water and the remainder SiO₂ with a total mix density of 1.41 g/cm³. SiO₂ was used for the solid portion since it is more conservative to use silicon with its low neutron absorption cross-section and small atomic number (for photons) than a more representative mix that might be non-conservative.

The dimensions for the shield plate and penetrations were obtained from the drawings listed in Table 7-4. Shield collars are modeled around penetrations. Dimensions from the drawing were used to define the shield plate penetrations and collars (aka pucks). The collars were assumed tight to the penetration piping and have a top surface elevation at 110.13” above the bottom of the tank (i.e., 0.13 inches into the bottom of the shield plate). The penetration (piping) plugs are a solid steel section extending from the bottom of the collars to the top of the lower shield plate.

The penetration and counter bore dimensions provided are listed in Table 7-5. The model uses a uniform 0.75 inch counter bore (the increase in radii and depth of the hole for the collars) for all penetrations except for the
Title: STS Process Shield Plate Analysis  
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Outlet pipe (uses a 0.80 inch counter bore). The bottom of the PSP was set at 19.0” above the head body joint. The lifting lug penetration is a square shape 31.50 inches long and 1.60 inches wide.

<table>
<thead>
<tr>
<th>Penetration</th>
<th>Penetration Diameter (in)</th>
<th>Counter bore depth (in)</th>
<th>Counter bore Diameter (in)</th>
<th>Collar/Puck Diameter (in)</th>
<th>Collar/Puck thickness (in)</th>
<th>Plug Diameter (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rupture/ Air Vent</td>
<td>5.35</td>
<td>0.75</td>
<td>6.5</td>
<td>5.92</td>
<td>2.0</td>
<td>1.652</td>
</tr>
<tr>
<td>HEPA inlet</td>
<td>5.35</td>
<td>0.75</td>
<td>6.5</td>
<td>5.92</td>
<td>2.0</td>
<td>1.652</td>
</tr>
<tr>
<td>outlet</td>
<td>4.96</td>
<td>0.75</td>
<td>6.12</td>
<td>5.50</td>
<td>2.0</td>
<td>1.25</td>
</tr>
<tr>
<td>Sensor wash</td>
<td>4.42</td>
<td>0.75</td>
<td>7.5</td>
<td>5.90</td>
<td>2.0</td>
<td>0.625 Not modeled</td>
</tr>
<tr>
<td>Water addition</td>
<td>5.29</td>
<td>Not modeled</td>
<td>Not modeled</td>
<td>5.29</td>
<td>2.75” cap 1.75” used</td>
<td>5.25, 5.29 used</td>
</tr>
<tr>
<td>level sensor ²</td>
<td>3.13</td>
<td>1.63</td>
<td>11.5</td>
<td>10.</td>
<td>0.5” for plate and sensor</td>
<td>none</td>
</tr>
</tbody>
</table>

¹ The water addition penetration and cap were simplified to include just the inserted portion of the cap with no counter bore or gap.
² Details of the level sensor penetration were not included; instead a 0.5 inch thick disk was modeled.
### Table 7-6– Dimensions Used in Calculation Models

#### Radial Dimensions

<table>
<thead>
<tr>
<th>Region</th>
<th>Material</th>
<th>Inner Radius (cm)</th>
<th>Outer Radius (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>Sludge</td>
<td>10.00</td>
<td>73.66, or to inner ellipse of lower IC</td>
</tr>
<tr>
<td>Water/Filter Zone</td>
<td>Water</td>
<td>0.00</td>
<td>73.66</td>
</tr>
<tr>
<td>Inner Container – side</td>
<td>SS-304</td>
<td>73.66</td>
<td>74.93</td>
</tr>
<tr>
<td>Inner Container – bottom</td>
<td>SS-304 bounded by ellipses Thickness=1.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inner Container – top</td>
<td>SS-304 bounded by ellipses Thickness=1.905</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inner Cask Steel – side</td>
<td>SS-304</td>
<td>77.47</td>
<td>80.01</td>
</tr>
<tr>
<td>Middle Cask – side</td>
<td>Lead</td>
<td>80.01</td>
<td>87.9475</td>
</tr>
<tr>
<td>Outer Cask Steel – side</td>
<td>SS-304</td>
<td>87.9475</td>
<td>91.7575</td>
</tr>
<tr>
<td>Bottom Cask Steel</td>
<td>SS-304</td>
<td>0.00</td>
<td>91.7575</td>
</tr>
<tr>
<td>Process Shield Plate</td>
<td>SS-304</td>
<td>0.00</td>
<td>91.7575</td>
</tr>
<tr>
<td>Inside Air</td>
<td>Air</td>
<td>Above water/filter and below top of IC Also beyond IC and inside cask</td>
<td></td>
</tr>
<tr>
<td>Outside Air</td>
<td>Air</td>
<td>Beyond cask</td>
<td></td>
</tr>
</tbody>
</table>

#### Region Information

<table>
<thead>
<tr>
<th>Region</th>
<th>Material</th>
<th>Bottom of region, z(cm)</th>
<th>Thickness of Region (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>Sludge</td>
<td>1.27</td>
<td>130.8787</td>
</tr>
<tr>
<td>Water Zone(10&quot;)</td>
<td>Water</td>
<td>130.8787</td>
<td>25.4</td>
</tr>
<tr>
<td>Inner Container – side</td>
<td>SS-304</td>
<td>38.735</td>
<td>196.85</td>
</tr>
<tr>
<td>Inner Container – bottom</td>
<td>SS-304 0.00, outside ellipse</td>
<td>0.00</td>
<td>Outer ellipse-z half-height=36.83, thickness=1.27</td>
</tr>
<tr>
<td>Inner Container – top</td>
<td>SS-304 235.585, outside ellipse</td>
<td>235.585</td>
<td>Outer ellipse-z half-height=36.83, thickness=1.905</td>
</tr>
<tr>
<td>Cask – side</td>
<td>SS-304 with lead in center</td>
<td>0.00</td>
<td>1307.34</td>
</tr>
<tr>
<td>Cask – bottom</td>
<td>SS-304</td>
<td>-15.24</td>
<td>15.24</td>
</tr>
<tr>
<td>Process SP (recessed)</td>
<td>SS-304</td>
<td>1279.4</td>
<td>13.97</td>
</tr>
</tbody>
</table>
Source Geometries

Figure 7-1: Axial 0 Degree View of the MCNP 2.0, 4.15 m$^3$ and source tape sludge Models.
Un-plugged level, inlet and outlet penetrations

Plugged level, inlet and outlet penetrations

Un-plugged HEPA Vent and Rupture penetrations

Plugged HEPA Vent and Rupture penetrations

Lifting Lug (both cases)

Figure 7-2 - Expanded Axial Views of MCNP Model Process Shield Plate Penetrations and Lifting Lug.
Figure 7-3 Horizontal Views of the MCNP Model in the Vicinity of the Process Shield Plate
7.3 Results
The calculated dose rates at 30 cm intervals above the top of the process shield plate are summarized in Figure 7-4 through Figure 7-7. The dose rates include the contribution from the photon source uniformly in the sludge volume and from the photon source in the water/filter volume. The dose rates represent volume and surface averages over a 360 degree annulus. Local dose rates above the penetrations were also calculated. The one standard deviation statistical uncertainties in the Monte Carlo calculations are expressed as a percent of the dose rate. Dose rate for both plugged and open shield penetrations are listed.

The average dose rate 30 cm above the shield plate lip and centered over the penetrations was calculated to be 24.3 ± 0.5 mRem/hr. Although the dose rates over some of the plugged penetrations are larger, they have large statistical uncertainties and thus are not considered sufficiently converged for use. Due to the complexity of the shield and high dependency on the source distribution, determining the maximum dose is problematic. The presence of local hot particles in the waste at inopportune locations could significantly increase the actual dose above the shield. Conversely, the use of a thicker cover water layer will significantly reduce the dose rates.

Dose rates above the open penetrations are expected to be near the local maxima with the larger openings having the higher dose rates. The dose rates directly above the open penetrations are comparable to the average dose rates with a moderate peaking above open penetrations. For plugged penetrations there is no discernable peaking calculated directly above the penetrations. When the penetrations are plugged, the location of the maximum dose rate can not be readily identified, thus average values are reported.

The dose rates above the shield are sensitive to the cover water depth, sludge volume and sludge composition. Since these properties will vary during filling, the dose rates above the shield plate can be expected to significantly vary as well. The maximum dose rate can readily change location and magnitude based on waste concentrations and distribution. The dose rate calculated here use the “worse case” source term and anticipated maximum sludge volume.

The accident condition, with the canister filled with waste, represents the bounding limit for waste geometry. The calculated dose rates are likewise bounding for the worst case source term.
<table>
<thead>
<tr>
<th>Penetration</th>
<th>HEPA</th>
<th>rupture disk</th>
<th>inlet</th>
<th>outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 cm Dose rate Centered (mrem/hr)</td>
<td>17±14%</td>
<td>21±17%</td>
<td>44±21%</td>
<td>21±8%</td>
</tr>
</tbody>
</table>

30 cm Dose rate Annulus
### Penetration

<table>
<thead>
<tr>
<th>Penetration</th>
<th>HEPA</th>
<th>rupture disk</th>
<th>inlet</th>
<th>outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 cm Dose rate Centered (mrem/hr)</td>
<td>38±16%</td>
<td>51±17%</td>
<td>63±20%</td>
<td>64±12%</td>
</tr>
<tr>
<td>30 cm Dose rate <strong>Annulus</strong> (mrem/hr)</td>
<td>47±8%</td>
<td>56±10%</td>
<td>43±7%</td>
<td>53±6%</td>
</tr>
</tbody>
</table>

11/01/02
### Penetration HEPA rupture disk inlet outlet

<table>
<thead>
<tr>
<th>Penetration</th>
<th>HEPA</th>
<th>rupture disk</th>
<th>inlet</th>
<th>outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 cm Dose rate Centered (mrem/hr)</td>
<td>311±5%</td>
<td>291±5%</td>
<td>331±7%</td>
<td>318±4%</td>
</tr>
<tr>
<td>30 cm Dose rate Penetration Annulus (mrem/hr)</td>
<td>297±2%</td>
<td>295±3%</td>
<td>342±2%</td>
<td>306±2%</td>
</tr>
</tbody>
</table>

11/01/02
### Table: Penetration and Dose Rate Analysis

<table>
<thead>
<tr>
<th>Penetration</th>
<th>HEPA</th>
<th>rupture disk</th>
<th>inlet</th>
<th>outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 cm Dose rate Centered (rremi/hr)</td>
<td>535±7%</td>
<td>457±7%</td>
<td>445±16%</td>
<td>625±5%</td>
</tr>
<tr>
<td>30 cm Dose rate Penetration Annulus (rremi/hr)</td>
<td>493±4%</td>
<td>452±5%</td>
<td>451±3%</td>
<td>632±4%</td>
</tr>
</tbody>
</table>

---

11/01/02
8.0 Summary

Calculations show that the average annular dose rates around the case perimeter will meet the 20 mrem/hr dose specification for normal operations and the 80 mrem/hr for the off-normal conditions. Average doses over plugged penetrations are 20% above the specification using the revised source term in revision 9 of HNF-SD-SNF-TI-015. The 20 mrem/hr dose rate will be exceeded above open penetrations and in the PSP well. The dose rates for the off-normal condition also exceed the specification above the PSP, but are within the specification at the perimeter of the PSP.

The use of collars and penetration plugs in the design reduces the radiation streaming through and around the penetrations and reduces the dose in the normally occupied areas, thus along with adequate operational controls the ALARA objective can be met.

9.0 References

10.0 Appendices

<table>
<thead>
<tr>
<th><strong>A</strong></th>
<th><strong>PACTEC</strong></th>
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<tbody>
<tr>
<td>Computer Run Number</td>
<td>Revision 3</td>
</tr>
<tr>
<td>Analysis Software</td>
<td>MCNP, SCALE4.4, MCNP4c2L</td>
</tr>
<tr>
<td>Hardware Description</td>
<td>Dell Pentium 4, Windows XP- Serial Number 6GSN911, <em>AMD</em> DURON processor running Windows 98 (no serial number)</td>
</tr>
<tr>
<td>Disk Storage Description</td>
<td>CD labeled &quot;Process Shield Plate&quot;</td>
</tr>
<tr>
<td><strong>File Description</strong></td>
<td><strong>File Name</strong></td>
</tr>
<tr>
<td>Input files</td>
<td>Psp5zi, Psp70zi, Psp71zi, Psp72zi, Psp73zi or6040.in, or8020.in</td>
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<tr>
<td>Cross sections</td>
<td>XSDIR, cross-section files</td>
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<tr>
<td>Output files</td>
<td>Psp5zio, psp5ziw Psp70zio, Psp71zio, Psp72zio, Psp73zio, Psp70zim, Psp71zim, Psp72zim, Psp73zim OR6040.in.out, OR8020.in.out</td>
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<td>Excel Spreadsheet</td>
<td>Working3</td>
</tr>
<tr>
<td>Printed Attachments</td>
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</table>

11/01/02
ATTACHMENT 9

FH Supplemental Design Information

Consisting of 182 Pages
Including this cover page.
Position Paper

Expected Behavior of Sludge Due to Hydrogen Generation
And Adequacy of Filter Array Assembly Design for
SWS Large Diameter Container (LDC)

Issue/Concern

The sludge currently accumulated at the bottom of the K-East Basin contains an unknown but significant quantity of irradiated metallic uranium fuel particles. In their current undisturbed state, the irradiated metallic fuel particles are expected to be largely coated with a protective layer of oxide material that formed when the metallic fuel reacted with water. This reaction would have created a relatively stable coating of metal oxide on the surface and generated heat and hydrogen gas in the process. Once the oxide layer formed, further oxidation of the fuel occurs at a significantly slower rate, generally when a crack forms in the oxide layer and water is able to come in contact with freshly exposed metal underneath the oxide layer. Support for this hypothesis that the fuel particles are currently experiencing only very limited further oxidation comes from the fact that bubbles (presumably hydrogen gas) can be currently observed to be emerging from the surface of the sludge at a relatively low rate.

As the sludge/water slurry is being pumped into the Large Diameter Container (LDC) during the loading phase in the K-East Basin, it is expected that the protective oxide layer coating on the metallic fuel particles will be disturbed and possibly knocked off many of the particles, leaving a large surface area of fresh metallic fuel exposed to the surrounding water. This is expected to lead to a significant increase in the rate of hydrogen generation from the renewed oxidation of exposed metallic fuel particles once they settle out of the sludge/water slurry in the LDC. Eventually, it is expected that the rate of hydrogen generation will once again diminish significantly as a relatively stable oxide coating again forms on the fuel particles. However, there are substantial uncertainties associated with 1) how rapidly hydrogen gas will be generated in the freshly settled sludge in the LDC, 2) how long it will be before rate of hydrogen generation slows either because of the oxide layer formation phenomenon or because the fuel particles have been consumed and 3) how the sludge will respond to the expected increased rate of hydrogen gas generation.

Two possible modes of gross sludge behavior (with variations) have been proposed, based on laboratory scale observations, gross behavior of similar materials experiencing internal hydrogen gas generation, and various analyses. One predicted mode of behavior is predicated on the expectation that the fuel particles will settle out of the sludge/water slurry mixture so that they are distributed more or less homogeneously in the axial dimension at any particular radius in the LDC. This mode, which is the anticipated mode, would lead to hydrogen gas bubbles forming sufficiently close together that the bubbles will ultimately join in the axial direction to provide flow paths for the hydrogen to escape up through the sludge. In this scenario, the overall height of the sludge in the LDC would change very little as the fuel particles continue to oxidize until (and if) the rate of hydrogen generation slows as discussed above.

A proposed variation on this first mode of behavior would result from some portion of the growing quantity of hydrogen gas being generated remaining trapped in small bubbles
throughout the sludge. These trapped bubbles would slowly grow in volume, causing the sludge mass to grow in volume as its internal structure becomes “Swiss cheese-like” in appearance. This mode of behavior was postulated based on observations of the behavior of the caustic waste that is being stored in the Hanford Tank Farms. The caustic waste consists of the radioactive fission products recovered from the reprocessing of spent fuel from the plutonium production reactors at the Hanford site. The radiation field leads to the production of hydrogen gas from the radiolytic decomposition of water and any other hydrogenous material present in the waste. In at least some of the large tanks, sufficient hydrogen has remained trapped in the interstitial volume of the waste material to cause it to become somewhat porous and thus increase significantly in volume.

The second postulated mode of sludge behavior in the LDC would result from the metallic fuel particles settling preferentially toward the bottom of the sludge. As the fuel particles oxidize to produce hydrogen gas, the sludge is postulated to be sufficiently impervious that the hydrogen gas cannot escape upward through the sludge. When the hydrogen gas pressure in the growing volume below the bottom of the sludge increases sufficiently to levitate the sludge, it would slowly drive a slug of sludge upward. If the sludge slug were to be lifted sufficiently high, it would strike the bottom of the Filter Array Assembly. Beyond this point in the scenario, various outcomes have been postulated, including the Filter Array Assembly being partially collapsed by the upward force from the slug or the sludge in the slug being forced up into the Filter Array Assembly so that water and perhaps even sludge would be pushed into the filtered vent system on the LDC. If sludge were forced into the vent system, it could effectively plug the vents, thus allowing the pressure in the LDC to continue to grow.

This range of postulated behavior modes for the metallic fuel particle-bearing sludge has given rise to several concerns that have been addressed during the design and safety analysis efforts for the LDC. These concerns are as follows:

Concern 1: Given the spatial distribution of metallic fuel particles that settle out in the sludge as it is pumped into the LDC,

1) Will the hydrogen gas that will be generated from oxidation of the particles be able to escape the sludge so that the sludge volume remains relatively unchanged, or
2) Will the bubbles be trapped throughout the sludge so that the sludge becomes more and more porous as its overall volume increases, or
3) Will the hydrogen gas be generated preferentially in the bottom of the LDC and not escape the sludge so that it could ultimately drive a slug of sludge upward into the Filter Array Assembly?

Concern 2: If the sludge were indeed to be driven upward as an intact slug by the expanding hydrogen gas volume below it, would the Filter Array Assembly be capable of arresting the slug such that water is not forced out of the LDC and the LDC vent system remains effective?
Background Discussion

The LDCs in which the sludge is to be stored at T-Plant are required to provide for the safe storage of the sludge for a period of up to 30 years, including the various configurations and operating environments in which they will exist from the start of pumping the sludge/water slurry into each LDC at K-East Basin through to storage in a cell at T-Plant. As noted above, the metallic fuel particles present in the sludge are expected to experience more rapid oxidation once they have been disturbed as a result of being vacuumed from the bottom of the Basin into the LDC. This more rapid oxidation will generate both heat and hydrogen gas. In addition, fission product isotopes present in the metallic fuel particles will continue to undergo radioactive decay, resulting in the production of additional heat.

Extensive analyses have been performed to demonstrate that the design of the LDC is such that it will accommodate the consequences of the heat and hydrogen generation during the required 30-year storage mission. The specific functional and design requirements imposed on LDC that address the heat and hydrogen generation phenomena are as follows:

SNF-8166, Rev. 0, Functional Design Criteria for the K Basins Sludge and Water System – Project A-16. (Ref. 1)

Section 3.2.3 – Vessel Performance Requirement – …

- Tank/vessel design shall preclude the possibility of accumulating either more than 25 percent of the lower flammability limit of hydrogen, per the National Fire Protection Association (NFPA™) 69, Explosion Prevention Systems, or a problematic quantity of hydrogen as determined by the fire hazards analysis.
- Tank/Vessel design shall provide for the removal of heat from radiolytic decay and uranium chemical reaction to prevent the hulk sludge temperatures from exceeding 60°C (140°F). The preferred bulk sludge storage temperature is below 20°C (68°F).

SNF 8163, Rev. 4, Performance Spec for the K-East Basin Sludge Transportation System for Project A-16. (Ref. 2)

Section 4.2 – Normal Conditions of KE Operations:

- 4.2.3.2 Thermal [Acceptance Criteria]: The STS [Sludge Transportation System] design shall ensure the maximum temperature of the payload does not reach 100°C (212°F) at any time during loading, transportation and storage.
- 4.2.3.5 Gas Generation: The hydrogen gas generation shall be evaluated to show that during sludge loading and preparation for transportation no accumulation of hydrogen gas exceeds one quarter of the lower flammability limit assuming normal operation of the KE Basin ventilation.

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NFPA™ is a registered trademark of National Fire Protection Association, Inc., Quincy, Massachusetts
Section 4.3 – Accident Conditions of KE Operations:

- 4.3.3.2 Thermal [Acceptance Criteria]: The STS design shall ensure the maximum temperature of the payload does not reach 100°C (212°F) at any time during loading, transportation and storage.

- 4.3.3.5 Gas Generation: The hydrogen gas generation shall be evaluated to show that within the KE Basin no accumulation of hydrogen gas exceeds one-quarter of the lower flammability limit assuming off-normal operation of the KE Basin ventilation.

Section 5.1 – Normal Conditions of Transport:

- 5.1.3.2 Thermal [Acceptance Criteria]: Maximum accessible outside surface temperature of the cask shall be less than 85°C (185°F) in 37.8°C (100°F) air temperature and in the shade. The STS design shall ensure the maximum temperature of the payload does not exceed 100°C (212°F) at any time during loading, transportation and storage.

Section 5.2 – Hypothetical Accident Conditions:

- 5.2.3.3 Thermal [Acceptance Criteria]: The STS design shall ensure the maximum temperature of the payload does not reach 100°C (212°F) at any time during loading, transportation and storage and subjected to the accident conditions.

Section 6.2 – Normal Conditions of T Plant Unloading Operations:

- 6.2.3.2 Thermal [Acceptance Criteria]: The STS design shall ensure the maximum temperature of the payload does not reach 100°C (212°F) at any time during loading, transportation and storage.

- 6.2.3.5 Gas Generation: The hydrogen gas generation shall be evaluated to show that within the T Plant no accumulation of hydrogen gas exceeds one-quarter of the lower flammability limit assuming off-normal operation of the T Plant ventilation.

Section 6.3 – Accident Conditions of T Plant Unloading Operations:

- 6.3.3.2 Thermal [Acceptance Criteria]: The STS design shall ensure the maximum temperature of the payload does not reach 100°C (212°F) at any time during loading, transportation and storage.

- 6.3.3.5 Gas Generation: The hydrogen gas generation shall be evaluated to show that within the T Plant canyon or tunnel no accumulation of hydrogen gas exceeds one-quarter of the lower flammability limit assuming off-normal operation of the T Plant ventilation.
Section 6.4 – Normal Conditions of T Plant Storage Operations:

- 6.4.3.2 Thermal [Acceptance Criteria]: The STS design shall ensure the maximum temperature of the payload does not reach 100°C (212°F) at any time during loading, transportation and storage.

- 6.4.3.5 Gas Generation: The hydrogen gas generation shall be evaluated to show that within the T Plant no accumulation of hydrogen gas exceeds one quarter of the lower flammability limit assuming off-normal operation of the T Plant ventilation.

Section 6.5 – Accident Conditions of T Plant Storage Operations:

- 6.5.3.2 Thermal [Acceptance Criteria]: The STS design shall ensure the maximum temperature of the payload does not reach 100°C (212°F) at any time during loading, transportation and storage.

- 6.5.3.5 Gas Generation: The hydrogen gas generation shall be evaluated to show that within the T Plant no accumulation of hydrogen gas exceeds quarter of the lower flammability limit assuming normal operation of the T Plant ventilation.

Section 7.5 – General Design and Interface Requirements:

- 7.5.6 The Large Container shall be capable of receiving 30 to 90 gpm of sludge slurry transferred to the Large Container. The slurry flow of 30 gpm shall be considered the minimum. The normal flow for which the Large Container is designed shall be identified and be capable of up to 60 gpm continuously. Slurry flow up to 90 gpm shall be acceptable for short duration transfers of high-density material, as needed to ensure adequate transfer velocities are attained. The inlet flow shall be designed to promote uniform mixing of fluid above the settling sludge. The inlet piping shall not penetrate the uniform mixing layer. For example, consider a flat plate with a diameter twice the inlet pipe diameter separated large of one-quarter the pipe diameter or 1/2 in. from the exit of the inlet pipe.

Consideration of Heat and Hydrogen Generation in LDC Design

For a variety of mission-related considerations, it was decided to size the LDC to be approximately 5 ft in diameter and approximately 9 ft in height. Given the thermal and hydrogen gas requirements cited above, the early thermal analyses focused on demonstrating that a payload of 3 m³ of a so-called safety basis mixture of sludge (which was postulated to contain a relatively high proportion of the fuel particle-rich canister sludge) would experience peak temperatures that would remain below the maximum temperatures established in the requirements cited above throughout the various loading, transportation and storage phases. These initial thermal analyses raised concern that if the metallic fuel particles in this safety basis sludge mixture were permitted to concentrate preferentially in the lower portion of the sludge, temperatures that exceeded the requirements could be reached in some configurations.
The LDC was designed to operate in a mode such that it will initially be filled with water, into which the sludge/water slurry will be pumped once sludge pumping has begun. Because the LDC will be completely filled with water when sludge pumping begins, water will be forced through the internal Filter Array Assembly and out through the LDC outlet piping, where it will be discharged back into the K-East Basin. The end of the inlet pipe was located below the Filter Array Assembly lower support grid, and a flat deflector plate was placed below the end of the inlet pipe to deflect the incoming slurry in the radial direction. This was done 1) to minimize the extent to which the sludge that settled out at the bottom of the LDC could become re-suspended by the incoming stream and 2) to deflect the heavy fuel particles in the radial direction to prevent the particles from settling preferentially in the radial center of the LDC. Had the particles been permitted to concentrate in the radial center of the LDC, peak temperatures in the sludge would have been higher and could have exceeded the requirements under some conditions.

Given the concern about the possibility of the metal particles settling preferentially to the lower portion of the sludge, studies were performed to understand the settling characteristics of the sludge (Ref.3). These studies demonstrated that, once the pumping of the sludge/water slurry into the LDC was stopped, the sludge pumped into the LDC during the period of continuous pumping settled out rather quickly. This led to establishment of an operational requirement that, after each period of continuous pumping, pumping would have to be suspended for a period of time to let most of the lighter particles in the sludge settle out on top of the already-settled sludge. This limit was ultimately expressed in a requirement that no more that 0.5 m³ can be pumped without pausing the pumping, and that the subsequent pause would have to be of sufficient duration to permit settling to occur. Imposition of the “0.5 m³ pumped in/ pause” operational requirement would guarantee that the sludge would be formed in several distinct layers (Ref. 3). Within each layer, it was expected that fuel particles would be concentrated in the lower portion of that layer. In actual fact, given the current operational sludge retrieval philosophy, it is anticipated that it will take far more than four pumping sessions to place the required quantity of sludge in a LDC, thus assuring that there will be relatively more layers of sludge, each with the fuel particles settled preferentially toward its lower portion.

The initial scoping thermal analyses assumed that any hydrogen generated in the settled sludge would escape the sludge as it was generated so that the volume occupied by the sludge would not increase perceptibly. Given this assumption, the LDC was designed to store 3 m³ of settled sludge with approximately 10 in of water covering it. As the thermal and hydrogen gas generation studies proceeded, concerns were raised that some of the hydrogen gas that could be generated would be retained in the interstitial volume of the sludge, causing the sludge to increase slowly in volume. These concerns were raised based on surveys of the behavior of analogous materials that also experienced internal hydrogen generation.

Specifically, this mode of behavior was postulated based on observations of the behavior of the caustic waste that is being stored in the Hanford Tank Farms (Ref. 4). The caustic waste consists of the radioactive fission products recovered from the reprocessing of spent fuel from the plutonium production reactors at the Hanford site. The radiation field leads to the production of hydrogen gas from the radiolytic decomposition of water and any other hydrogenous material present in the waste. In at least some of the large tanks, sufficient hydrogen has remained trapped in the waste material to cause it to become somewhat porous and to increase
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significantly in volume. Extrapolating on this observed behavior, it was suggested that this phenomena could lead to a volume increase of up to 54% for the K-East sludge stored in a LDC.

At this point in the ongoing design effort for the LDC, it was decided to limit the volume of sludge in a LDC so as to accommodate this potential volume increase. Reference 5 demonstrates that 2 m³ of as-settled sludge can be accommodated in a LDC under the assumption of this 54% limiting volume increase as well as the volume changes that would occur from complete oxidation of the metallic uranium particles. Thus, the design payload for a LDC became 2 m³ of as-settled sludge. Given a payload of 2 m³ of as-settled sludge, imposition of the “0.5 m³ pumped in/pause” operational requirement would result in a minimum of four distinct layers of sludge in a LDC.

At the same time that the concern regarding the potential significant volumetric expansion of the sludge due to retention of hydrogen gas was being raised and addressed, observations of the behavior of a small sample of actual Basin sludge in a test beaker led to concern being raised regarding another possible mode of behavior. This behavior was observed in a sample of sludge that had been placed in glass graduated cylinders some 3 inches in diameter and thoroughly mixed with a helium sparging hose (Ref. 6). As a result of the mixing, the sludge in the cylinders settled into a stratified layer where the denser fuel particles remained predominately at the bottom of the layer. Approximately 10 days after the sludge was sparged with helium, a gas bubble began to form at the bottom of one of the cylinders. In time, the bubble spanned the diameter of the cylinder, and the pressure buildup was enough to move the sludge layer upward.

After due consideration, it was decided to proceed with an approach in which the adequacy of the LDC design would be based on a design payload of 2 m³ of as-settled sludge that had expanded uniformly to a volume of over 3 m³ (the 54% plus volume change due to oxidation discussed above). Furthermore, it was decided to address the opposite possibility that a vessel-spanning slug of sludge could be levitated upward into the filter bank by demonstrating that such behavior would be very unlikely to occur. As a second “line of defense” to this improbability argument, it was decided to perform analyses to demonstrate that the Filter Array Assembly would “bust” the slug to permit the gas below it to escape before water or sludge could be forced out through the vent or rupture disc.

The sections that follow document the basis that has been used to demonstrate 1) that an acceptable radial and axial distribution of metallic fuel particles will be obtained in the as-settled sludge in the LDC, 2) that the maximum temperatures that would be experienced in the volumetrically expanded 2 m³ of sludge are acceptable in all required modes of operation, and 3) that the “levitating slug” mode of behavior is both very unlikely to occur and, if it did occur, could be accommodated by the design of the LDC and its internal structures.

Basis for Resolution of Concerns

Radial and Axial Distribution of Fuel Particles

As noted above, it was understood at the inception of the design effort for the LDC that it would be necessary to demonstrate that the fuel particles would settle out of the sludge/water slurry
such that acceptable thermal behavior could be demonstrated. This led to the inclusion of a baffle plate with a diameter of 2 in located approximately 1.5 in below the end of the inlet pipe. Both experimental and analytical evidence now exist to demonstrate that an acceptable axial and radial distribution of fuel particles will result.

Fauske & Associates, Inc. (FAI) was commissioned to perform analyses to establish acceptable ranges for these parameters of baffle plate diameter and distanced below the inlet pipe end. The results of the FAI study are documented in Ref. 7. The analyses documented in Ref. 7 assume that the suspended fuel particles behave as a continuum fluid that is blended with the carrier feed liquid. This assumption permits application of the extensive literature that is available on jet mixing in tanks to determine the maximum particle size that will remain well stirred by the LDC inlet pipe flow. Particles remaining well stirred by the liquid feed flow would be deposited in a relatively homogeneous fashion. Particles larger in diameter than this maximum particle size would not remain well stirred.

The FAI analyses lead to the conclusion that the metal fuel particles will not remain well stirred as the particle-bearing slurry strikes the baffle plate, resulting in fuel particles leaving the flowing fluid streamlines and undergoing inertial deposition on the surface of the already-settled sludge. However, since the initial flow of the slurry is radial once it has encountered the baffle plate, the settled sludge will most probably consist of an outer annular region with a higher concentration of metal particles surrounding an inner cylindrical region containing relatively few fuel particles.

The FAI report notes that such a deposition pattern of metal particles should not be a cause for concern. If the sludge is loaded in a number of discrete pumping sessions, each of which is followed by a pause in pumping, the annular region will form a stratified morphology of alternating metal-rich and metal-poor sub-layers, with each pair of sub-layers being formed during a particular loading period. The distance between stratified metal layers should be small enough so that the hydrogen bubbles that form in one layer connect with hydrogen bubbles in an adjacent layer, thereby forming paths for gas to flow to the surface of the sludge. In this respect, annular deposits are not necessarily different from sludge-wide homogeneous deposits. In both cases, vessel-spanning bubbles are not likely to form as long as the discrete metal layers are close to one another.

A Proof of Principle (POP) test (referred to as POP2) was performed on a prototype container in June 2002 by the firm that completed the detailed design of and is fabricating the LDC, including its internals (Ref. 8). This test used surrogate materials to simulate the metallic fuel particle-bearing sludge. Particles of a tungsten/cobalt alloy were used to simulate the metallic fuel particles. The POP2 test was designed to demonstrate that the surrogate material could be pumped into the prototype container at planned flow rates, that the surrogate sludge material would distribute itself as anticipated as it settled out in the container, and that the Filter Array Assembly would function as designed to filter out at least 98% of the particles in the sludge with diameters larger than five microns.

During the POP2 test, 2.1 m$^3$ of sludge surrogate was loaded into the prototype container at flow rates of 60 and 90 gpm. Pumping was periodically ceased for various purposes. After pumping
was ceased for the final time and the sludge surrogate was allowed to settle, the top head of the prototype container was removed and a diaphragm pump was used to remove water and sludge surrogate from the container in a layer-by-layer manner. Visual observations were made and pictures taken during the surrogate sludge offload to evaluate how evenly the sludge was distributed.

Observations during the offload showed that the tungsten/cobalt alloy particles and other surrogate materials were relatively evenly distributed in the radial direction. It was noted that, as the layers of the sludge were removed, a thin layer of fine sludge would periodically be present. This was likely a result of settling that took place while pumping operations were halted overnight and during other test iterations that did not require pumping.

In summary, the combination of the FAI analyses of settling behavior and performance of the baffle plate on the inlet pipe end and the experimental results from the POP2 test strongly support the conclusion that the metallic fuel particles will be distributed throughout the sludge following settling of the sludge particles in the LDC. The distribution of fuel particles in the axial direction will consist of a number of relatively discrete deposition layers, with each layer being the result of a period of continuous pumping of sludge into the LDC followed by a period of several hours of no pumping. With each deposited layer, the fuel particles will be located preferentially toward the bottom of the layer, with the density of fuel particles continuously decreasing at successively higher elevations in the layer and with a fuel particle-free zone of very light particulate material at the top of the layer.

As noted above, the FAI analysis predicted that the distribution of fuel particles in the radial direction at any elevation would be expected to reach a maximum density of particles in an annular region some distance away from the end of the inlet pipe, with the density of fuel particles decreasing to a relatively fuel particle-free zone directly below the baffle plate on the end of the inlet pipe. The POP2 test results suggest that there would be less variation in the radial direction than predicted by the FAI analyses.

These results have provided confirmation that the thermal analyses discussed below have been performed using a conservative approach and the conditions that could possible give rise to the levitating sludge slug scenario are very unlikely to exist.

**Summary of Thermal Analysis Results**

Extensive thermal analyses have been performed on the LDC and the STS in the various conditions cited above to establish that the payload (sludge/water mixture with fuel particles distributed in it) would not experience maximum temperatures that exceed those established in the requirements. These thermal analyses are documented in Ref. 9. The analyses were performed using the conservative safety basis sludge mixture consisting of 40% of fuel particle-rich canister sludge and 60% of floor sludge, which generally has a much lower density of fuel particles. The payload in these analyses was assumed to be 2 m$^3$ of as-settled sludge that had subsequently expanded by 54% in volume because of hydrogen gas bubble formation in the interstitial volume of the sludge. The sludge payload was assumed to have been deposited in four pumping sessions, each followed by a period of no pumping to allow the sludge to settle.
As noted above, this assumption gives rise to the four discrete layers of sludge, with the fuel particles in each being concentrated in the lower portion of the layer.

Reference 9 documents that this payload would not experience temperatures that exceed the requirements. Thus, these analyses establish that the LDC and cask as designed meet the thermal performance criteria cited above for both the case where little hydrogen is retained within the interstitial volume (the sludge expands very little in volume as a result of hydrogen gas generation) and the case where the sludge has expanded in volume due to gas entrainment by 54% (which is the more conservative of the two from a heat transfer perspective and was the configuration actually analyzed).

Unlikelihood of Formation of a Vessel-Spanning Bubble

Both analyses and experiments have been performed to address the related issues of likelihood for formation of a hydrogen gas bubble that would span the LDC and the behavior of the sludge above the bubble as it formed and expanded. Fauske & Associates performed analyses both of the conditions that could give rise to a vessel-spanning bubble and how a sludge slug driven by an expanding vessel spanning bubble would behave (Ref. 10). Regarding the possibility of a vessel-spanning bubble, the FAI report concludes that if the metallic fuel particles on which the hydrogen is being produced are uniformly distributed throughout the sludge column, they are close enough together to enable the product-gas bubbles to connect and form a continuous path to the surface. This same conclusion is stated in the FAI report on baffle plate performance (Ref. 7). Reference 10 goes on to state that the actual sludge morphology is likely to be a stratified one involving many thin horizontal layers of metallic particle-rich sludge “sandwiched” between relatively thick layers of inert material. The stratified morphology is likely to be similar to the uniform metallic uranium particle distribution in that the bubbles that form in one layer are close enough to connect with bubbles in an adjacent layer, thereby forming paths for gas to flow to the surface of the plug. The report notes, however, that this conjecture should be checked by experiment.

The FAI report further states that at least three failure mechanisms could play a role in causing a sludge plug located above a growing hydrogen gas bubble to be disrupted so that the gas below it would escape. The first failure mode examined would result from a spatial variation in plug thickness so that one side of the plug is heavier than the other, leading to a mass imbalance. The report concludes that plug failure by this mass imbalance mechanism is predicted only for very thin plugs as the yield stress of the sludge increases beyond 1,000 Pa.

The second mechanism examined is the well-known Taylor instability. This mechanism results from the fact that the development of buoyancy forces due to the presence of the underlying light gas layer can render the sludge layer laterally unstable to infinitesimal disturbances at the gas/sludge layer interface. Unstable disturbances will grow into gas spikes that penetrate the overlying sludge layer and result in the disintegration of the sludge layer. The report shows that a rising sludge plug would fail by the Taylor instability mechanism if the sludge yield strength is less than about 1,600 Pa. As the sludge shear strength increases above 1,600 Pa, it is possible for a bubble to form and expand radially and axially that could at some point start pushing the sludge plug upward.
The third failure mechanism that would disrupt a rising sludge plug (if it had not already been disrupted by one of the first two mechanisms) would come into play when the sludge plug struck the lower support structure of the Filter Array Assembly. This failure mechanism is addressed in the next section.

The FA1 report highlights the fact that sludge behavior will depend upon the shear strength of the sludge material, among other parameters. All else being equal, sludge mixtures with lower shear strengths are more susceptible to failure by both the mass imbalance and Taylor instability mechanisms. The physical parameters of thermal conductivity and shear strength of the K Basin sludge were studied at PNNL and reported in Ref. 11. Reference 11 reports shear stress values that range from 100 to 8,200 Pa., with most samples having shear strength values in the range of 100 to 500 Pa. The analyses reported in Ref. 10 suggest that a sludge plug comprised of sludge with shear strength in this range would be prone to failure by either of the first two mechanisms. However, for reasons that are not apparent to the authors of Ref. 11, some few samples included in the Ref. 11 study had measured shear strength values that were significantly higher than the 1,600 Pa cited in Ref. 10 as the upper bound on shear strength values that would lead to sludge plug failure by the Taylor instability mechanism.

This rising sludge plug phenomenon could only occur if sufficient uranium fuel particles were initially concentrated at the bottom of the LDC. This was the case in the laboratory experiment cited in Ref. 6, where the helium sparging resulted in the heavy metallic uranium particles settling to the bottom of the container, with the remaining sludge above being relatively free of metallic particles. Thus, in this experimental situation, the hydrogen gas source was located almost exclusively at the bottom of the container.

The sludge loading process planned for the LDC virtually guarantees, in contrast, that the metallic fuel particles will be distributed axially in the “sawtooth” pattern discussed above and observed in the POP2 test (Ref. 8). This distribution of fuel particles, in and of itself, practically precludes this postulated plug-like behavior from occurring in the LDC because, if any significant amount of uranium metal is oxidized, the oxidation process would be occurring throughout the axial extent of the sludge and not concentrated at the bottom of the LDC.

In summary, whereas both analyses and experiments have demonstrated that it would not be physically impossible for a vessel-spanning hydrogen bubble to form that would drive a sludge plug upward as the bubble expands, there is substantial evidence available to suggest that it is beyond extremely unlikely that such a phenomenon would be observed in the LDCs loaded with 2 m$^3$ of K-East Basin sludge using the planned loading process. Factors that, taken together, lead to this conclusion of extremely low probability include, most prominently, 1) the fact that the planned loading sequence will lead to many relatively thin layers of settled sludge and 2) the fact that the bulk of the sludge samples whose shear strength was measured were found to have values well within the range where the Taylor instability mechanism would result in sludge plug failure.
Expected Behavior of Sludge And Adequacy
of Filter Array Assembly Design for LDC

Adequacy of Filter Array Assembly to Disrupt Sludge Slug

As noted above, the third sludge plug failure mechanism would come into play if a vessel-spanning hydrogen bubble were indeed to form and drive a sludge plug upward until the plug came into contact with the lower support grid for the Filter Array Assembly. Fauske & Associates studied these phenomena both analytically and experimentally (Ref. 10). Reference 10 reports on a series of experiments in which mixtures of water and kaolin were used to represent sludge plugs. The starting condition for these experiments was a Plexiglas column in which a gas column was initially trapped under a simulated sludge plug of the water/kaolin mixture. When the pressure in this gas column was increased, the clay slug was driven upward. Various structures were placed at the top of the column above the clay slug. As the clay slug was driven upward, it ultimately came in contact with these structures and was driven through (extruded) whatever opening(s) existed in the structure.

In each experiment, the clay was initially extruded through whatever opening(s) existed. At some point in each experiment, a loud pop signaled the end of the extrusion process. At this point, the underlying gas had penetrated the remaining vertical thickness of the clay plug, which resulted in the rapid depressurization of the driver gas column. In each case, a significant fraction of the clay plug was left behind in the Plexiglas column, pressed up against the lower surface of the structure through which it was being extruded. This same phenomenon occurred when the opening was a simple 1-in diameter hole in a flat plate placed over the top of the column and when the upper structural element was designed to simulate the Filter Array Assembly with its slot.

In this latter case, the structure consisted of a circular grate of diameter equal to the inside of the test column. The grate was suspended from a lid placed on the test section by eight steel rods. A rectangular opening was cut into the grate to represent the actual slot in the lower support grid for the Filter Array Assembly in a LDC. When driven upward by gas pressure below it, the clay extruded through the slot. Gas break-through occurred after about 35% of the clay was extruded through the slot. The failure mechanism was the same as that observed in the initial experiment where the opening was a simple round hole in the lid of the test assembly.

Reference 10 presents an analytical model of slug flow that can be used to predict when failure by gas break-through will occur. The model treats the clay plug as a viscous non-Newtonian fluid. It can be used to predict the thickness (denoted He) of the remaining clay plug (that has not yet been extruded through the opening) at which gas break-through would occur. In this model, the higher the shear strength of the sludge, the sooner that failure by gas break-through will occur. For example, while the model predicts that a sludge plug with shear strength of 1,500 Pa would fail when the sludge plug had been reduced to a thickness of .21 m by extrusion through the slot in the lower support grid. For sludge with shear strength of 10,000 Pa, the critical thickness at which the sludge plug would fail is 0.8 m.

Two issues were identified when these results were used to predict how the Filter Array Assembly would respond to a sludge plug being driven upwards against its lower support grid, with the sludge subsequently being extruded through the slot (which is 10 in wide and stretches from the outer periphery to the centerline of the support grid). The first issue regards the
structural response of the Filter Array Assembly to the sludge plug being driven up against it. The second issue regards the volume that is available above the lower support grid, including volume around the cylindrical filters and the LDC head above the filters. It would be into this volume that the water and extruded sludge would be driven.

Regarding the first issue, it was decided to increase the structural capability of the Filter Array Assembly to resist the upward force of the postulated hydrogen bubble-driven sludge plug. To this end, a design change was implemented to add stainless steel pipe segments around the 14 all-thread tie rods that hold the Filter Array Assembly together. Reference 12 presents a calculation which shows that the re-designed Filter Array Assembly is capable of resisting the force of the sludge plug with a factor of safety of 1.45. This calculation assumed sludge with very high shear strength of 8,200 Pa. If the sludge that formed the plug had lower shear strength, the factor of safety would be correspondingly higher (since the upward force exerted by the sludge plug is directly proportional to its shear strength).

Based on the model presented in Ref. 10, a sludge plug with such high shear strength would fail by gas break-through while the plug was still relatively thick. In this case, relatively little sludge would be extruded through the slot into the volume around the filters. A separate calculation is reported in Ref. 13 that examines the amount of volume that would be displaced in the case where the sludge being extruded had much lower shear strength. This calculation started with a sludge plug some 35 in thick with shear strength of 1,500 Pa (to correspond to the low end of the shear strength range where the sludge plug would not be likely to fail by Taylor instability). In this case, the lower shear strength sludge, the calculation shows that the sludge plug would extrude down to a thickness of 6.7 in before gas break-through would occur. At this point in time, some 45 ft$^3$ of sludge and 32 ft$^3$ of water would have been pushed up into the Filter Array Assembly. Given that the volume around the filters and in the upper head above the Filter Array Assembly is 63 ft$^3$, some of this water would have been forced through the filters and into the exit manifold piping. Because the outlet pipe through which filtered water flowed when the LDC was being loaded in the K-East Basin will have been capped, this outlet piping will contain only a limited amount of water. If this large volume of sludge and water were indeed to be forced into the volume above the Filter Array Assembly lower support grid, excess water in the LDC would be forced out of the LDC onto the floor of the cell in T-Plant. Water would be preferentially expelled because it is lighter than the underlying sludge and would be pushed ahead of the sludge.

The cells in T-Plant have been lined with stainless steel liners with leak detection available. Thus, the ultimate (and very improbable) outcome of the vessel-spanning sludge plug event described here would be that some quantity of contaminated water from the LDC would be forced out of the LDC and into the lined cell, where its presence would be alarmed by the leak detection system. The accident consequences of such a scenario are clearly bounded by the various scenarios analyzed in the T-Plant Documented Safety Analyses that provide a safety basis for the project.

However, it must be kept in mind that the likelihood of formation of a vessel-spanning sludge plug is judged to be a beyond extremely unlikely event for all of the reasons cited above. Therefore, the fact that such an event could possibly lead to a small quantity of water being
expelled from an LDC into a lined cell at T-Plant should not be viewed with any alarm whatsoever.

**Conclusions**

The following conclusions are documented and supported in this White Paper:

1. **Radial and Axial Distribution of Fuel Particles in LDC** Two factors in the design of the LDC and planned sludge-gathering operations combine to provide a high degree of assurance that the radial and axial distribution of metallic fuel particles in the settled sludge is such that heat generated within the sludge can be transported out without exceeding the maximum temperature requirements and hydrogen gas generated in the sludge will “percolate” through the sludge and escape. The design of the LDC inlet pipe, with its attached baffle plate, results in the fuel particles being distributed in an acceptable radial pattern. The operational limitation of requiring a significant pause after each successive 0.5 m$^3$ of sludge is loaded assures an acceptable axial distribution of fuel particles from a heat transfer perspective. The actual expected operation of the sludge retrieval system, which will consist of a large number of pumping sessions, each followed by a pause of sufficient duration to permit the sludge to settle out of the sludge/water slurry, would result in numerous layers of settled sludge, each with a somewhat richer concentration of fuel particles toward the bottom of the layer. This expected configuration is such that hydrogen gas bubbles formed from the oxidation of fuel would be likely to link up vertically such that paths would form through the sludge that would permit the hydrogen to escape the sludge.

2. **Thermal Response of STS** Given the radial distribution of fuel particles assured by the baffle plate and the minimum of four layers of sludge, thermal analyses cited in this white paper demonstrate that the maximum temperature requirements are satisfied in all configurations.

3. **Response of Sludge to Hydrogen Generation** As noted in 1 above, it is expected that hydrogen gas bubbles will link vertically to form escape paths for hydrogen gas generated in the sludge. At most, some gas may be trapped in the interstitial volume of the sludge such that the sludge would expand in volume by some 10% to 15%. The payload of sludge has been limited to 2 m$^3$ in order to accommodate an increase in volume of up to 54 percent.

4. **Potential for Formation of Vessel-Spanning Hydrogen Bubble** As cited above, the metallic uranium fuel particles will be distributed throughout the sludge volume in a large number of relatively thin layers of heavy particles alternating with layers of lighter sludge particles. If any significant oxidation of the fuel particles were to occur, hydrogen would be generated throughout the volume of sludge and not preferentially at the bottom of LDC. This fact leads to the conclusion that the formation of a vessel-spanning sludge plug must be viewed as a beyond extremely unlikely event. Furthermore, analyses and experiments cited in this white paper lead to the conclusion that, unless the sludge collected in a LDC has shear strength significantly in excess of that expected for the sludge, any sludge plug that might (however improbably) form above an expanding
hydrogen gas bubble would break up before it could be driven upward to any significant extent.

5. **Response of LDC to Hydrogen Bubble-Driven Sludge Plug** In the beyond extremely unlikely case where a vessel-spanning hydrogen gas bubble were to form and drive a sludge plug upward, this white paper cites analyses and experiments that show that the consequences of this event could be tolerated by the LDC with at most some water being ejected from the open ports on the LDC as it sits in storage in a T-Plant cell. Such a consequence is judged to be acceptable for such a beyond extremely unlikely event.

References


5. SWS-A-16-G-010, Rev. 2, *Sludge Container Maximum Sludge Loading Calculation*, Fluor Hanford, Inc., *(This is the calc. that needs to be reissued. Sly did the necessary editing before he left.)*


Position Paper

Adequacy of Inlet Deflector Plate Design
To Assure Acceptable Fuel Particle Distribution in SWS Large Diameter Container (LDC)

Issue/Concern

As the sludge/water slurry is being pumped into the Large Diameter Container (LDC) during the loading phase in the K-East Basin, it is desirable to achieve a distribution of fuel particles that is as close to homogeneous as possible throughout the sludge. The more homogeneous the distribution of particles, the less likely it is that a “hot spot” could develop in the sludge where a relatively high concentration of fuel particles gives rise to excessive heat generation from fuel oxidation. Once the LDC has been filled with water, the inlet pipe will discharge the sludge/water slurry under several feet of water at an elevation slightly below the bottom of the lower filter support grating. A deflector plate that will deflect the slurry will be attached to the discharge end of the inlet piping some distance below the end of the pipe. The ability of the deflector plate to deflect the incoming slurry so as to achieve an acceptable distribution of fuel particles in the sludge has given rise to the following concern:

Concern 1: Is the planned size (diameter) and installation location (distance below the end of the inlet pipe) of the deflector plate adequate to assure an acceptable distribution of the fuel particles throughout the sludge?

Background Discussion

It is expected that a substantial amount of heat will be generated throughout the sludge once it has been pumped into the LDC due to the oxidation of the fuel particle that have lost their protective oxide coating during the pumping process. Extensive calculations have been performed to establish that, if the fuel particles are distributed reasonably homogeneously throughout the sludge, maximum temperatures reached would not lead to local boiling in the sludge even under the extremely conservative assumption that complete oxidation of the fuel particles would occur based on an enhanced reaction rate (by a factor of three).

It was recognized that, if the inlet pipe were permitted to discharge the sludge/water slurry without a deflector plate directly down onto the top of the growing pile of sludge mixture on the bottom of the LDC, sludge located directly below the inlet pipe would continue to be disturbed enhancing the potential for oxidation. In addition, the relatively heavy fuel particles would be less likely to be transported to the periphery of the LDC and could concentrate in a pile below the inlet pipe. These considerations led to the inclusion of a deflector plate to be affixed to the end of the inlet pipe that would deflect the inlet sludge/water slurry in the radial direction.

The requirements to design the inlet piping system to achieve an acceptable distribution of fuel particles in the sludge are established in the following documents:
SNF-13268, Rev. 0, *Functional Design Criteria for the K Basins Sludge and Water System - Project A-16.* (Ref. 1)

Section 3.2.3 – Vessel Performance Requirement –

- Tank/Vessel design shall provide for the removal of heat from radiolytic decay and uranium chemical reaction to prevent the bulk sludge temperatures from exceeding 60°C (140°F). The preferred bulk sludge storage temperature is below 20°C (68°F).

SNF 8163, Rev. 4, *Performance Specification for the K-East Basin Sludge Transportation System for Project A-16.* (Ref. 2)

Section 4.2 – Normal Conditions of KE Operations:

- 4.2.3.2 Thermal (Acceptance Criteria): The STS [Sludge Transportation System] design shall ensure the maximum temperature of the payload does not reach 100°C (212°F) at any time during loading, transportation and storage.

Section 4.3 – Accident Conditions of KE Operations:

- 4.3.3.2 Thermal (Acceptance Criteria): The STS design shall ensure the maximum temperature of the payload does not reach 100°C (212°F) at any time during loading, transportation and storage.

Section 5.1 – Normal Conditions of Transport:

- 5.1.3.2 Thermal (Acceptance Criteria): Maximum accessible outside surface temperature of the cask shall be less than 85°C (185°F) in 37.8°C (100°F) air temperature and in the shade. The STS design shall ensure the maximum temperature of the payload does not exceed 100°C (212°F) at any time during loading, transportation and storage.

Section 5.2 – Hypothetical Accident Conditions:

- 5.2.3.3 Thermal (Acceptance Criteria): The STS design shall ensure the maximum temperature of the payload does not reach 100°C (212°F) at any time during loading, transportation and storage and subjected to the accident conditions.

Section 6.2 – Normal Conditions of T Plant Unloading Operations:

- 6.2.3.2 Thermal (Acceptance Criteria): The STS design shall ensure the maximum temperature of the payload does not reach 100°C (212°F) at any time during loading, transportation and storage.
Section 6.3 – Accident Conditions of T Plant Unloading Operations:

- 6.3.3.2 Thermal (Acceptance Criteria): The STS design shall ensure the maximum temperature of the payload does not reach 100°C (212°F) at any time during loading, transportation and storage.

Section 6.4 – Normal Conditions of T Plant Storage Operations:

- 6.4.3.2 Thermal (Acceptance Criteria): The STS design shall ensure the maximum temperature of the payload does not reach 100°C (212°F) at any time during loading, transportation and storage.

Section 6.3 – Accident Conditions of T Plant Storage Operations:

- 6.5.3.2 Thermal (Acceptance Criteria): The STS design shall ensure the maximum temperature of the payload does not reach 100°C (212°F) at any time during loading, transportation and storage.

Section 7.5 – General Design and Interface Requirements:

- 7.5.6 The Large Container shall be capable of receiving 30 to 90 gpm of sludge slurry transferred to the Large Container. The slurry flow of 30 gpm shall be considered the minimum. The normal flow for which the Large Container is designed shall be identified and be capable of up to 60 gpm continuously. Slurry flow up to 90 gpm shall be acceptable for short duration transfers of high-density material, as needed to ensure adequate transfer velocities are attained. The inlet flow shall be designed to promote uniform mixing of fluid above the settling sludge. The inlet piping shall not penetrate the uniform mixing layer. For example, consider a flat plate with a diameter twice the inlet pipe diameter separated large of one-quarter the pipe diameter or ½ in. from the exit of the inlet pipe.

Extensive thermal analyses have been performed on the STS in the various conditions cited above to establish that the payload (sludge/water mixture with fuel particles distributed in it) would not experience maximum temperatures established in the requirements. These thermal analyses are documented in Ref. 3.

These thermal analyses assume that the fuel particles will settle in a reasonably homogeneous distribution radially and into a number of layers axially, where each layer results from a period of continuous pumping followed by a to be specified time of no pumping. Within each layer, the fuel particles are assumed to be concentrated more heavily in the lower regions of the layer due to the different rates of settling of the heavy fuel particles and the other lighter constituents of the sludge during the pumping phase that created that layer.

**Basis for Resolution of Concern**

Given the concern raised regarding deflector plate design parameters, Fauske & Associates, Inc. (FAI) was commissioned to perform analyses to establish acceptable ranges for these parameters.
The FAI analyses lead to the conclusion that the metal fuel particles will not remain well stirred as the particle-bearing slurry strikes the deflector plate, leading to fuel particles leaving the flowing fluid streamlines and undergoing inertial/gravitational deposition on the surface of the already-settled sludge. However, since the initial flow of the slurry is radial once it has encountered the deflector plate, the settled sludge will probably consist of an outer annular region with a higher concentration of metal particles surrounding an inner cylindrical region containing relatively few fuel particles.

The FAI report notes that an annular deposit of metal particles should not be a cause for concern. If the sludge is loaded in a number of discrete operations the annular region will form a stratified morphology of alternating metal-rich and metal-poor sublayers, each pair of sublayers formed during a particular loading period. The distance between stratified metal layers should be small enough so that the hydrogen bubbles that form in one layer would connect with hydrogen bubbles in an adjacent layer, thereby forming paths for gas to flow to the surface of the sludge. In this respect, annular deposits are not necessarily different from sludge-wide homogeneous deposits. In both cases, vessel-spanning bubbles are not likely to form as long as in both cases the discrete metal layers are close to one another.

The FAI report provides a formula for calculating the size of the deflector plate that will accomplish the redirection of the fuel particles in the radial direction. It concludes that a deflector plate with a diameter of 2 in. and placed 1.5 in. below the end of the inlet pipe would satisfy the criteria established by application of this formula. That is, it will deflect the incoming feed mixture in the radial direction, preventing the inlet flow from re-suspending the already-deposited sludge below the inlet pipe and causing the fuel particles to be deposited in the annular fashion discussed above.

Conclusions

The current design of the deflector plate is adequate to accomplish its function.

References


Position Paper

Radiation Hardening For SWS Sludge Containers Filters

**Issue/Concern**

The Filter Array Assembly in the Large Diameter Container (LDC) includes over 50 filters, each some 30 inches in length. These filters will exist in a relatively high radiation field once loading of sludge has begun for an LDC. The concern has been expressed regarding the effect that the radiation could have on the filter media and filter assembly.

Specifically, the following comments were made at the STS 60% Design Review:

1. The filter assembly appears to not be in compliance with the specification in a number of areas. First the materials (PVC, polypropylene) may not meet the 30 year design life requirement for all container components. Radiation degradation over time will most likely lead to the breakdown of the items. (60-CAP-023)

2. Do PVC and Polypropylene meet the design requirement that all container components be compatible with a 30-year service life (SNF-8163, Section 5.4.1). It would seem PVC and Poly might degrade due to radiation exposure. What is the life expectancy of the PVC and Poly filters? Will this degrade over the 30-year storage life? (60-EGE-005C)

**Background Discussion**

The driving requirements were identified in the Functional Design Criteria and the STS Performance Specification.


Section 2.2.8 – The equipment associated with sludge handling, removal, and sludge transport shall have a minimum design life of five (5) years.

Section 3.2.1 – ... The storage containers shall provide long-term (30 years) storage of sludge.

Section 3.2.3 – Vessels shall be compatible with K Basin water and sludge.

Section 2.2.8 addresses shelf life and storage of the LDC and equipment associated with K Basin sludge retrieval operations. Section 3.2.1 requires that LDC maintain its containment boundary for 30 years. Section 3.2.3 also implies that the vessel and all
vessel components are compatible with K Basin conditions. This implies all chemical, thermal, and radiological conditions.


Section 7.6.1 – Process Service: The Large Container during normal KE Basin operations shall be capable of not less than 6 months of full operations within the KE Basin operation segment as defined in Section 4.0. The operation begins once filling of the Large Container begins and ends once the containment boundary of the Cask has been established.

Section 7.6.2 – Storage Service: … The Large Container internal filter has two service life requirements. The first being five (5) years during loading in K Basin (functional). The second being thirty (30) years is related to the decomposition and corrosion of the filter media and assembly (filter physical integrity).

The intent of SNF-8163, Rev. 4, Section 7.6.1 was to ensure that the LDC filter media was capable of performing its intended function in the K Basin. Once the LDC was full and prepared for shipment, this mission was complete.

The intent of SNF-8163, Rev. 4, Section 7.6.2 was to address the pre-filling shelf life of the LDC filter media prior to the loading of any sludge. During this time, the LDC filter media is not exposed to a radiation field. Lastly, the reference to the 30-year life is to ensure that the filter media and assembly dose not degrade to the point that it would impact the removal of sludge in the future.

**Defensible/Defendable Support**

PacTec provided as a response to 60-EGE-005C as follows: “The PVC and poly are used only during the loading of the Large Container. Upon the completion of loading their service life may come to an end. …”

PacTec provided as a response to 60-CAP-023 as follows: “First – the PVC and polypropylene will not degrade significantly during the 30 year design life (90% submittal will include a polymer degradation analysis.)”

In PacTec Con 15, Rev. 2 – Using Sections 6.2 (Table 6-1) and 7.2, and for a 6 month campaign, the expected radiation field is approximately 1.5 E+6 Rad. Using this value and comparing it to Figure 7-1 in Section 7.2 the break point from “Usually always usable” to “Often satisfactory” is approximately 8 E+6. Therefore the value for a 6-month campaign is about a factor of 5 below the limit of minimal concern.
Resolution / Conclusions

From the above requirements and discussion, it can be deduced that the LDC filter media only need to remain functional for a maximum period of six months. During this time, the radiation field will not be sufficiently large or the duration long enough for the radiation to have a significant and damaging effect upon the LDC filter media.

Secondly, in actual operations, the expected K Basin filling mission time is approximately 1 month. If this value were to be used, the expected radiation field would be even less.

Finally, the LDC design was modified between the 60 and 90% design points to eliminate any use of PVC components. This change left polypropylene (filter media and filter housing) as the only component of concern. (If the filter media is changed to the 90% design polyester filter media the radiation hardening values are higher by a factor of 100 greater then a polypropylene filter media).

In either case, polypropylene or polyester filter media is acceptable for the K Basin filling operation. As for long-term storage, the filter media may experience some limited radiation hardening, but at that time it is no longer necessary to perform the filtration function. And any degradation would not change the waste classification or hamper sludge removal.

References

1. 60% STS Design Review Comment – 60-CAP-023 and 60-EGE-005C.

2. SNF-8166, Rev. 0, Functional Design Criteria for the K Basins Sludge and Water System – Project A-16.

3. SNF 8163, Rev. 4, Performance Specification for the K-East Basin Sludge Transportation System for Project A-16.


Position Paper

Prevention of Ignition and Burning of Hydrogen Gas

In

SWS Sludge Container (LDC)

Issue/Concern

Two processes that will produce hydrogen gas will occur in the sludge/water mixture in the Large Diameter Container (LDC) once it is loaded. These processes are 1) oxidation of metal fuel particles (composed predominately of uranium metal) and 2) radiolysis of water in the radiation field that will exist in the LDC. Oxidation of metal fuel particles will be the dominant source of hydrogen gas. The presence of this hydrogen gas gives rise to the following concern:

Concern 1: Could the hydrogen gas concentration in the free space above the liquid/air interface in the LDC build up to the point that it exceeds \( \frac{3}{4} \) of the Lower Flammability Limit (LFL) of 4% at the same time that the oxygen gas concentration in the free space lies within the range that would support burning of the hydrogen gas, given an ignition source?

This White Paper examines this concern during the period in time extending from the start of loading the LDC in KE Basin until the LDC is ready to be placed in a storage cell at T-Plant.

Background Discussion

The potential for hydrogen gas building up in the free space at the top of the LDC was recognized during the development of the requirements for the SWS equipment. The driving requirements are identified in the Functional Design Criteria and the STS Performance Specification.

SNF-8166, Rev. 0, Functional Design Criteria for the K Basins Sludge and Water System – Project A-16.

Section 3.2.3 – Vessel Performance Requirement – …

- Tank/Vessel design shall preclude the possibility of accumulating either more than 25 percent of the lower flammability limit of hydrogen, per the National Fire Protection Association (NFPA)\(^{\text{Tm}}\) 69, Explosion Prevention Systems, or a problematic quantity of hydrogen as determined by the fire hazards analysis.

SNF 8163, Rev. 4, Performance Spec for the K-East Basin Sludge Transportation System for Project A-1 6.

Section 4.2.3.5 – Gas Generation: The hydrogen gas generation shall be evaluated to show that during sludge loading and preparation for transportation no accumulation of hydrogen gas exceeds one quarter of the lower flammability limit assuming normal operation of the KE Basin ventilation.
Section 4.3.3.5 – Gas Generation: The hydrogen gas generation shall be evaluated to show within the KE Basin no accumulation of hydrogen gas exceeds one quarter of the lower flammability limit assuming off-normal operation of the KE Basin ventilation.

Section 6.2.3.5 – Gas Generation: The hydrogen gas generation shall be evaluated to show within T Plant no accumulation of hydrogen gas exceeds one quarter of the lower flammability limit assuming off-normal operation of the T Plant ventilation.

Section 6.3.3.5 – Gas Generation: The hydrogen gas generation shall be evaluated to show within T Plant no accumulation of hydrogen gas exceeds one quarter of the lower flammability limit assuming off-normal operation of the T Plant ventilation.

These requirements regarding limits on accumulation of hydrogen gas in the LDC under various conditions are more succinctly summarized in the following table:

**Condition 1: LFL Hydrogen**

<table>
<thead>
<tr>
<th>Location</th>
<th>Requirement</th>
<th>Ventilation</th>
<th>Requirement Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>KE Basin – Normal</td>
<td>1/4&quot; LFL during loading and staging for transportation or fire hazard analysis</td>
<td>Normal</td>
<td>SNF-8163, Section 4.2.3.5</td>
</tr>
<tr>
<td>KE Basin – Off-Normal</td>
<td>1/4&quot; LFL during loading and staging for transportation or fire hazard analysis</td>
<td>Off-Normal</td>
<td>SNF-8163, Section 4.3.3.5</td>
</tr>
<tr>
<td>Transporation – Normal</td>
<td>Less than 80 psig internal cask Pressure</td>
<td>NA</td>
<td>SNF-8163, Section 5.1.2.6</td>
</tr>
<tr>
<td>Transporation – Off Normal</td>
<td>Less than 80 psig internal cask pressure</td>
<td>NA</td>
<td>SNF-8163, Section 5.2.3.2</td>
</tr>
<tr>
<td>T Plant – Unloading (Normal)</td>
<td>114&quot; LFL during receipt and LDC unloading</td>
<td>Off-Normal</td>
<td>SNF-8163, Section 6.2.3.5</td>
</tr>
<tr>
<td>T Plant – Unloading (Off-Normal)</td>
<td>1/4&quot; LFL during receipt and LDC unloading</td>
<td>Off-Normal</td>
<td>SNF-8163, Section 6.3.3.5</td>
</tr>
</tbody>
</table>

**Basis for Resolution of Concern**

The following table summarizes the passive conditions, design features and administrative controls that exist or will be imposed at the various locations and corresponding operational phases and configurations that will work in concert to prevent the concentration of hydrogen gas from reaching ¼ of LFL in the free space at the top of the LDC:
<table>
<thead>
<tr>
<th>Location/Operational Phase</th>
<th>Configuration</th>
<th>Design Feature/Control</th>
<th>Resulting Condition in LDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>K-East/LDC Filling</td>
<td>Pumps On</td>
<td>Venting through outlet piping</td>
<td>Venting continuously sweeps $H_2$ from the LDC back to the basin through the outlet piping. Any $H_2$ generated is entrained in water in the form of small bubbles and is not flammable. $H_2$ accumulation is not a concern.</td>
</tr>
<tr>
<td></td>
<td>Pumps Off – LDC Solid</td>
<td>Vventing through outlet piping</td>
<td>Passive venting purges $H_2$ from the LDC back to the basin through the outlet piping. Any $H_2$ remaining is entrained in water in the form of small bubbles and is not flammable. $H_2$ accumulation is not a concern.</td>
</tr>
<tr>
<td>K-East/LDC Staging</td>
<td>Pumps Off</td>
<td>He Purge to remove excess liquid from LDC</td>
<td>Helium gas is introduced into the LDC to lower the water level in the LDC to the desired point. This results in a cover gas of helium existing in the free space above the liquid level in the LDC. Any $H_2$ generated during this period cannot be ignited because of the lack of oxygen.</td>
</tr>
<tr>
<td></td>
<td>Pumps Off / Excessive Delay in Shipping</td>
<td>Re-initiation of He purge if necessary</td>
<td>If something occurs such that the LDC cannot be readied for shipment in expected time frame (~8 hrs), provisions have been made in the design to enable the He purge lines to be reconnected to the LDC. Additional purging of the free space in the LDC can be performed as necessary to limit $H_2$ buildup.</td>
</tr>
<tr>
<td>LDC During Transportation to T-Plant</td>
<td>LDC with Helium cover gas/ LDC vented into STS cask</td>
<td>LDC vented to cask that encloses it; Cask has undergone He purge.</td>
<td>Both the cask and the free space in the top of the LDC will be filled with He gas with very low oxygen concentrations. Any $H_2$ generated during this period cannot be ignited because of the lack of oxygen.</td>
</tr>
<tr>
<td>Location/Operational Phase</td>
<td>Configuration</td>
<td>Design Feature/Control</td>
<td>Resulting Condition in LDC</td>
</tr>
<tr>
<td>----------------------------</td>
<td>--------------</td>
<td>------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>T Plant/LDC Receipt</td>
<td>Cask Lid on</td>
<td>He Purge of cask to reestablish He atmosphere in cask and LDC prior to removal of cask lid</td>
<td>The cask containing the LDC is purged with He to re-establish an inert environment prior to removing the cask lid.</td>
</tr>
<tr>
<td>Time period following initial purge of STS cask and LDC</td>
<td>Cask Lid on</td>
<td>He Purge of free space in LDC to reestablish He atmosphere in LDC prior to placing it in T-Plant cell</td>
<td>Following the initial He purge of the cask and LDC, the cask and its contents will be monitored for some time to assure that conditions have stabilized before the cask lid is removed and the LDC removed for placement in a T-Plant cell. The cask will be repurged with He periodically to assure that H₂ is not allowed to build up to unacceptable levels.</td>
</tr>
<tr>
<td>T Plant/LDC Receipt</td>
<td>Cask Lid off</td>
<td>Cask lid will not be removed until it has been established that a sufficient window of time will be available to place the LDC in storage and vented before H₂ could build to unacceptable levels.</td>
<td>When it has been confirmed that the H₂ generation rate is sufficiently low that adequate time will be available to remove the cask lid and “pluck and place” the LDC in storage, that activity can begin with confidence the H₂ will not build up to concentrations greater than the LFL while the LDC is being handled.</td>
</tr>
</tbody>
</table>

**Conclusions**

Information provided in the table above provides the basis for concluding that a combination of design features, modes of operation and administrative controls will preclude the buildup of H₂ in the free space at the top of the LDC to the point that the H₂ could ignite and burn.

**References**

1. 60% STS Design Review Comment – 60-CAP-023 and 60-EGE-005C.
2. SNF-8166, Rev. 0, Functional Design Criteria for the K Basins Sludge and Water System – Project A-16.

3. SNF 8163, Rev. 4, Performance Spec for the K-East Basin Sludge Transportation Sys for Project A-16.

**Problem Statement or Objective of the Calculation:**

The K East Basin sludge properties and the initial cask pressure have changed since the safety basis analysis for the Sludge Transport System (STS) Thermal Analysis [3.1] was issued. The intent of this calculation is to extend the safety basis calculation provided in the [3.1] calculation by evaluating the thermal performance of the Sludge Transport System for the revised sludge properties and initial cask pressure. The evaluation is conducted as a sensitivity analysis using the bounding safety basis load cases for normal and accident conditions of transportation.

Since this calculation extends the analysis conducted under the Reference [3.1] calculation to new sludge properties and revised operational conditions, it is to be View as an addendum to the Reference [3.1] calculation.

<table>
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<th>Document Revision</th>
<th>Affected Pages</th>
<th>Revision Description</th>
<th>Project Engineer Approval/Date</th>
<th>Name of Preparer &amp; Checker</th>
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<tr>
<td>0</td>
<td>All</td>
<td>Initial Release</td>
<td></td>
<td>Preparer: G. J. Banken</td>
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<td>Checker: L. H. Nielsen</td>
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**RECORD OF VERIFICATION**

<table>
<thead>
<tr>
<th>[a) The objective is clear and consistent with the analysis.</th>
<th>Circle:</th>
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<tbody>
<tr>
<td>(b) The inputs are correctly selected and incorporated into the design.</td>
<td>YES NO</td>
</tr>
<tr>
<td>(c) References are complete, accurate, and retrievable.</td>
<td>YES NO N/A</td>
</tr>
<tr>
<td>(d) Basis for engineering judgments is adequately documented.</td>
<td>YES NO N/A</td>
</tr>
<tr>
<td>(e) The assumptions necessary to perform the design activity are adequately described and reasonable.</td>
<td>YES NO N/A</td>
</tr>
<tr>
<td>(f) Assumptions and references, which are preliminary, are noted as being preliminary.</td>
<td>YES NO N/A</td>
</tr>
<tr>
<td>(g) Methods and units are clearly identified.</td>
<td>YES NO N/A</td>
</tr>
<tr>
<td>(h) Any limits of applicability are identified.</td>
<td>YES NO N/A</td>
</tr>
<tr>
<td>(i) Computer calculations are properly identified.</td>
<td>YES NO N/A</td>
</tr>
<tr>
<td>(j) Computer codes used are under configuration control.</td>
<td>YES NO N/A</td>
</tr>
<tr>
<td>(k) Computer codes used are applicable to the calculation.</td>
<td>YES NO N/A</td>
</tr>
<tr>
<td>(l) Input parameters and boundary conditions are appropriate and correct.</td>
<td>YES NO</td>
</tr>
<tr>
<td>(m) An appropriate design method is used.</td>
<td>YES NO</td>
</tr>
<tr>
<td>(n) The output is reasonable compared to the inputs.</td>
<td>YES NO</td>
</tr>
<tr>
<td>(o) Conclusions are clear and consistent with analysis results.</td>
<td>YES NO</td>
</tr>
</tbody>
</table>

**COMMENTS:**

Verifier: Larry H. Nielsen  10/22/02

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1. INTRODUCTION

Objectives:
The K East Basin sludge properties and the initial cask pressure have changed since the safety basis analysis for the Sludge Transport System (STS) Thermal Analysis [3.1] was issued. The intent of this calculation is to extend the safety basis calculation provided in the Reference [3.1] calculation by evaluating the thermal performance of the Sludge Transport System for the revised sludge properties and initial cask pressure. The evaluation is conducted as a sensitivity analysis using the bounding safety basis load cases for normal and accident conditions of transportation developed under the Reference [3.1] calculation.

Purpose:
The purpose of this calculation is to ensure that the safety basis evaluation provided in the STS Thermal Analysis [3.1] is either bounding for the revised sludge properties and initial cask pressure or to provide the bounding thermal and gas generation evaluations within this document. This calculation extends the analysis conducted under the Reference [3.1] calculation to these new sludge properties and revised operational conditions. As such, it is to be viewed as an addendum to the Reference [3.1] calculation.

Scope:
This calculation applies to the Sludge Transportation System during the transportation between the K Basins and T Plant.

2. DESIGN REQUIREMENTS

With the exception of the sludge property revisions provided in Reference [3.5], the design requirements for this calculation are the same as those presented in the Reference [3.1] calculation. The References [3.2] and [3.3] documents are the basis for the design requirements.

3. REFERENCES


3.2. SOW for the Sludge Transportation System - Contract 12329, Attachment 8, Rev. 3, March 2002, Fluor Hanford Inc., Richland, WA.

3.3. SNF-8163, Performance Specification For The K Basin Sludge Transportation System - Project A.16, Rev. 4, March 2002, Fluor Hanford, Richland, WA.

3.4. SNF-9955, Safety-Basis Thermal Analysis For KE Basin Sludge Transport System And Storage At T Plant, Rev. 1, September, 2002, Fluor Hanford, Richland, WA.
4. THERMAL SOURCE TERM

The thermal source term for the packaging is determined by a combination of assumptions for 1) the thermal properties of the various sludge streams to be loaded, 2) the mixture ratio of the various sludge types, 3) the quantity of sludge to be loaded during the fill process, and 4) the assumed settling pattern. The KE Basin sludge stream is comprised of a mixture of sludge released from the fuel canisters holding the spent nuclear fuel (SNF) and from the sludge on the floor or in the basin loadout pit. Each of these sources of sludge represents a non-homogeneous mixture of debris, possibly including some uranium fuel particles. The following sections present the thermal properties and payload configuration assumptions used in this analysis.

4.1. Sludge Thermal Properties

The thermal properties of the sludge are based upon the best available data as documented in Volume 2 of the Spent Fuel Project Technical Databook [3.5]. The Technical Databook provides values for the bounding (i.e., safety basis) and the nominal (i.e., design basis) sludge compositions for the canister and floor sludge sources. Since the issuance of the reference [3.1] thermal analysis, the radiolytic decay heat and the thermal conductivities for the safety and design bases sludge payloads and the composition of the design basis sludge payload have changed. The following paragraphs document the values used in this calculation.

Per the project specification [3.3], the safety basis payload for the Large Container will be comprised of 60% by volume of floor sludge and 40% by volume of KE canister sludge, while the design basis payload will consist of 80% floor sludge and 20% KE canister sludge. The reference [3.4] analysis also assumed a 60%/40% mixture for the safety basis sludge payload, but increased the mixture composition to 75%/25% for the design basis payload. This revised design basis payload mixture is considered in this analysis.

Table 4-1 presents a selection of critical sludge thermal parameters for the safety basis and design basis sludge payloads based on the properties for the individual sludge streams. The blended sludge properties assume a homogeneous mixture on a volumetric basis. For example, the blended density of the safety basis sludge of 1.9 g/cm³ is computed using the volumetric mix ratio of the sludge and the individual mass density of the sludge streams or 40% x 2.5 g/cm³ +
60\%\times 1.5\text{g/cm}^3.\) However, those properties that are expressed on a unit mass basis (i.e., reactive surface area, specific heat, etc.) require the use of a mass weighted averaging approach.

The thermal conductivity of the sludge is based on a porous media modeling approach, while the specific heat for the sludge is computed using a mass weighted average of the constituents making up the sludge. Rather than repeat the calculation of these thermal properties within this document, the reader is directed to [3.4] for a discussion of the calculation methodology used to arrive at these thermal property values.

The transient calculation of the consumption of the metallic uranium due to chemical reaction requires several assumptions. These assumptions are: 1) the initial mass of the metallic uranium present, 2) a relationship between mass and surface area, and 3) that the reaction rate is a function of the local environment. The initial mass is taken from the data in Spent Fuel Project Technical Databook [3.5] and is equal to 0.0638 g U/cm$^3$ for the safety basis sludge and 0.013 g U/cm$^3$ for the design basis sludge (without allowance for gas retention). The relationship between the mass of the metallic uranium and the reaction surface area is provided by the Reference [3.5] assumption that the uranium metal exists in the form of uniform spherical particles with a diameter of 500 microns. This assumption permits the calculation of the initial number of reacting particles based on the initial mass and the determination of an extinction rate by computing the change in particle diameter with the change in mass as the uranium reacts with the surrounding water.

The chemical reaction rate between the metallic uranium in the sludge is the same as that assumed in the Reference [3.1] safety analysis. The reaction rate is conservatively assumed to be unaffected by previous chemical reactions, whereas logic would indicate that the majority of the metallic uranium is covered by a protective layer of oxide layer since the material has existed for years in the KE pool without being consumed by continuing chemical reaction.

4.2. Quantity Of Sludge To Be Loaded

The quantity of as-settled sludge that can be loaded into the Large Container was determined in the Reference [3.1] calculation and this quantity remains bounding for this calculation. The safety basis sludge quantity considered within this calculation is 2 m$^3$ of as-settled sludge without gas retention. The 2 m$^3$ sludge quantity equates to 3.08 m$^3$ after allowance for 35\% gas retention. The mass of the sludge remains constant.

4.3. Assumed Sludge Layering

Layering within the sludge payload assumed for this calculation is the same as that evaluated for the safety basis calculations in the Reference [3.1] and for the Reference [3.4] calculation. A total of four (4) active and four (4) inactive sludge layers are assumed within the sludge container (see Figure 4-1). The chemical reaction between the metallic uranium and the water is considered to occur only within the active sludge layers, while the radiolytic decay heat is distributed equally on a volumetric basis between the active and the inactive sludge layers. The sludge volumes within each active layer are equal to each other and are twice as large as the sludge volumes within each inactive layer.
Table 4-2 and Table 4-3 present the material properties of safety and design basis sludge payloads assuming a sludge layering with 66.7% of the sludge volume in an ‘active’ sludge layer and 33.3% of the sludge volume in an ‘inactive’ sludge layer and with a retention of hydrogen gas equal to 35% by volume.

4.4. Thermal Heat Load

The heat loading from the sludge will arise from a combination of radiolytic decay and chemical reaction heat sources. Per the Reference [3.5] databook, the safety basis decay heat loading is 118 watts per m$^3$ of KE canister sludge and 37 watts per m$^3$ of floor sludge. Based on a sludge mixture of 60% by volume of floor sludge and 40% by volume of KE canister sludge, the safety basis decay heat loading is 69.4 watts per m$^3$. The design basis decay heat loading is 25.9 watts per m$^3$ of KE canister sludge and 3.34 watts per m$^3$ of floor sludge. Based on a sludge mixture of 75% by volume of floor sludge and 25% by volume of KE canister sludge, the design basis decay heat loading is 8.98 watts per m$^3$. The decay heat loading are assumed to be constant throughout the sludge volume.

These radiolytic decay heat loads are 91.3% and 60.7%, respectively, of the safety and design basis decay heat loadings used in the Reference [3.1] calculation.

The heat generation resulting from chemical reactions within the sludge container is a function of the temperature and the reacting surface area. The safety basis for reaction rate and the amount and the distribution of the reacting surface area within the sludge payload is the same as that used in the Reference [3.1] and [3.4] thermal analyses. Due to a change in the mixture ratio for the design basis sludge composition from 80% floor/20% canister to 75% floor/25% canister, the design basis reaction area increases from the 0.0689 cm$^2$/cm$^3$ of gassy sludge assumed for the Reference [3.1] thermal analysis to 0.0800 cm$^2$/cm$^3$ of gassy sludge (see Table 4-3). As such, the change in the composition of the design basis sludge results in a 16% increase in the reaction area over that assumed in the Reference [3.1] thermal analysis.

4.5. Radiolysis of Water

The methodology used to compute the hydrogen and oxygen generation due to radiolysis of the water is the same as that used in the Reference [3.1] and [3.4] thermal analyses. However, based on the latest radioisotopic inventory for the sludge presented in the Reference [3.5] databook, the computed values of $f_\alpha, f_\beta, f_\gamma$ (i.e., alpha, beta, and gamma fractions, respectively, of the decay heat power absorbed by the water) are 0.3217, 0.5146, and 0.1637, respectively. See Reference [3.4] for the development of these factors.
<table>
<thead>
<tr>
<th>Sludge Parameter</th>
<th>Safety Basis</th>
<th>Design Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Floor Sludge / % Canister Sludge</td>
<td>60-vol% / 40-vol% \textsuperscript{A}</td>
<td>75-vol% / 25-vol% \textsuperscript{C} (80-vol% / 20-vol%) \textsuperscript{A,D}</td>
</tr>
<tr>
<td>KE Canister Sludge Density (w/ water) \textsuperscript{B}</td>
<td>2.5 g/cm\textsuperscript{3}</td>
<td>1.9 g/cm\textsuperscript{3}</td>
</tr>
<tr>
<td>Floor Sludge Density (w/ water) \textsuperscript{B}</td>
<td>1.5 g/cm\textsuperscript{3}</td>
<td>1.4 g/cm\textsuperscript{3}</td>
</tr>
<tr>
<td>Blended Density of Wet Sludge</td>
<td>1.9 g/cm\textsuperscript{3}</td>
<td>1.525 g/cm\textsuperscript{3} (1.5 g/cm\textsuperscript{3}) \textsuperscript{D}</td>
</tr>
<tr>
<td>KE Canister Sludge U Metal Fraction \textsuperscript{C}</td>
<td>0.125 g/cm\textsuperscript{3}</td>
<td>0.040 g/cm\textsuperscript{3}</td>
</tr>
<tr>
<td>Floor Sludge U Metal Fraction \textsuperscript{C}</td>
<td>0.023 g/cm\textsuperscript{3}</td>
<td>0.004 g/cm\textsuperscript{3}</td>
</tr>
<tr>
<td>Metallic U Concentration \textsuperscript{C}</td>
<td>0.0638 gm U/cm\textsuperscript{3}</td>
<td>0.013 gm U/cm\textsuperscript{3} (0.0112 gm U/cm\textsuperscript{3}) \textsuperscript{D}</td>
</tr>
<tr>
<td>Reaction Area Based On Metallic U Concentration And 500 micron Spherical Particles \textsuperscript{C}</td>
<td>0.403 cm\textsuperscript{2}/cm\textsuperscript{3}</td>
<td>0.0821 cm\textsuperscript{2}/cm\textsuperscript{3} (0.0707 cm\textsuperscript{2}/cm\textsuperscript{3}) \textsuperscript{D}</td>
</tr>
<tr>
<td>Reaction Enhancement Factor \textsuperscript{C}</td>
<td>\textsuperscript{3}</td>
<td>\textsuperscript{1}</td>
</tr>
<tr>
<td>% Water In KE Canister Sludge \textsuperscript{C}</td>
<td>75%</td>
<td>75% (70%) \textsuperscript{C}</td>
</tr>
<tr>
<td>% Water In Floor Sludge \textsuperscript{C}</td>
<td>75%</td>
<td>75% (65%) \textsuperscript{C}</td>
</tr>
<tr>
<td>Thermal Conductivity of Sludge \textsuperscript{C}</td>
<td>0.70 W/m-K (0.82 W/m-K) \textsuperscript{D}</td>
<td>0.70 W/m-K (0.88 W/m-K) \textsuperscript{D}</td>
</tr>
<tr>
<td>Specific Heat of Sludge \textsuperscript{C}</td>
<td>1.852 J/g-K (1.923 J/g-K) \textsuperscript{D}</td>
<td>2.319 J/g-K (2.186 J/g-K) \textsuperscript{D}</td>
</tr>
<tr>
<td>Total U Content In Sludge \textsuperscript{B}</td>
<td>0.74 gm U/cm\textsuperscript{3} (0.69 gm U/cm\textsuperscript{3}) \textsuperscript{D}</td>
<td>0.238 gm U/cm\textsuperscript{3} (0.202 gm U/cm\textsuperscript{3}) \textsuperscript{D}</td>
</tr>
<tr>
<td>KE Canister Sludge Radiolytic Decay Heat \textsuperscript{B}</td>
<td>118 W/m\textsuperscript{3} (117 W/MTU) \textsuperscript{D}</td>
<td>25.9 W/m\textsuperscript{3} (73.3 W/MTU) \textsuperscript{D}</td>
</tr>
<tr>
<td>Floor Sludge Sludge Radiolytic Decay Heat \textsuperscript{B}</td>
<td>37.0 W/m\textsuperscript{3} (117 W/MTU) \textsuperscript{D}</td>
<td>3.34 W/m\textsuperscript{3} (73.3 W/MTU) \textsuperscript{D}</td>
</tr>
</tbody>
</table>

Table Notes:  
A) Based on values in the project specification [3.3]  
B) Based on values in the Spent Fuel Project Technical Databook [3.5]  
C) Based on values in SNF-9955 [3.4].  
D) Value assumed for the reference 3.1 safety analysis.
<table>
<thead>
<tr>
<th>Sludge Parameter</th>
<th>Homogeneous Sludge w/o Gas Retention</th>
<th>Active Layer (66.7% of volume)</th>
<th>In-Active Layer (33.3% of volume)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blended Density of Wet Sludge</td>
<td>1.9 g/cm³</td>
<td>1.235 g/cm³</td>
<td>1.235 g/cm³</td>
</tr>
<tr>
<td>Metallic U concentration</td>
<td>0.0638 gm U/cm³</td>
<td>0.0622 gm U/cm³</td>
<td>0 gm U/cm³</td>
</tr>
<tr>
<td>Reaction Area Based On Metallic U Concentration And 500 micron Spherical Particles</td>
<td>0.403 cm²/cm³</td>
<td>0.393 cm²/cm³</td>
<td>0 cm²/cm³</td>
</tr>
<tr>
<td>Reaction Enhancement Factor</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Thermal Conductivity of Sludge</td>
<td>0.70 W/m-K</td>
<td>0.512 W/m-K</td>
<td>0.512 W/m-K</td>
</tr>
<tr>
<td>Specific Heat of Sludge</td>
<td>1.852 J/g-K</td>
<td>1.852 J/g-K</td>
<td>1.852 J/g-K</td>
</tr>
<tr>
<td>Total U Content In Sludge</td>
<td>0.74 gm U/cm³</td>
<td>0.481 gm U/cm³</td>
<td>0.481 gm U/cm³</td>
</tr>
<tr>
<td>Sludge Radiolytic Decay Heat</td>
<td>69.4 W/m³</td>
<td>45.11 W/m³</td>
<td>45.11 W/m³</td>
</tr>
</tbody>
</table>
Figure 4-1 - Thermal Model Layout For Large Container (Shell & 'Gassy' Sludge)
5. SUMMARY OF MATERIAL THERMAL PROPERTIES

The material properties for the Sludge Transportation Cask and the Large Diameter Container (LDC) are the same as those presented in the Reference [3.1] analysis. As such, this information will not be repeated within this calculation.

6. CONDITIONS ANALYZED

The conditions considered in this sensitivity analysis are a subset of those evaluated in the Reference [3.1] analysis. Specifically, Load Case 1 (i.e., safety basis NCT), Load Case 3 (i.e., safety basis for NCT cold), and Load Case 4 (i.e., safety basis HAC with minimal water leakage) are used to evaluate the effect of the changes in the sludge properties and the initial cask pressure on the thermal performance of the cask.

The following paragraphs summarizes the principle parameters associated with each of these load cases. See the Reference [3.1] analysis for additional discussion on the development of these load cases.

1. Safety Basis NCT: A transient condition consisting of the safety basis diurnal cycle for ambient temperature and insolation, with safety basis source terms for decay and chemical reaction heat. The sludge payload is 2 m$^3$ of as-settled sludge, plus 35-vol% of retained hydrogen gas, and 10 inches of water cover. The total decay heat load is 138.8 watts. The transport condition begins with the sludge, the cover water, the container, and the transportation cask at an initial temperature of 77°F. This temperature is equal to the maximum K Basin pool water temperature per [3.5]. The transient is evaluated over a 60 hour shipping window (i.e., twice the expected transportation time).

2. Design Basis NCT: Same as Case #1, except with design basis source terms for decay and chemical reaction heat. This load condition provides the basis for assessing the expected thermal performance for the system with a nominal payload. The total decay heat load for the sludge payload is 17.96 watts.

3. NCT Cold: A transient analysis assuming a -27°F steady state ambient temperature with zero decay and chemical reaction heat and zero insolation. The transport condition begins with the 3.08 m$^3$ of ‘gassy’ sludge, the cover water, the container, and the transportation cask at an initial temperature of 50°F. This temperature is equal to the minimum K Basin pool water temperature per [3.5]. The intent of this load condition is to assess the possibility for freezing the water in the payload during the 60 hour shipping window under the worst case Hanford cold day conditions. By assuming a zero heat load, the need to verify the heat loading for each sludge shipment is avoided.

4. HAC Fire Event (hot): The peak system temperature obtained from the Safety Basis NCT (i.e., the Load Case #1) transient analysis serves as the starting condition for the fire event. The fire event consists of a thirty minute transient with an ambient temperature of 1,475°F and the maximum decay heat, and then back to a diurnal cycle in ambient air temperature. Active cooling of the packaging, using water flow from fire hoses, is permitted after the 30 minute fire. This load case evaluates the peak temperature achieved for the various cask components under the HAC fire event and the associated thermal gradients. The packaging
configuration prior to the initiation of the hypothetical fire is the bounding package configuration from the Reference [3.1] analysis (i.e., on its side with the leakage of 0.03 m$^3$ of water into the cask-LDC annulus).

7. ACCEPTANCE CRITERIA

The thermal acceptance criteria for the Sludge Transportation Cask and the Large Diameter Container (LDC) are the same as those presented in the Reference [3.1] analysis. Table 7-1 summarizes the acceptance criteria applied in this calculation. See the Reference [3.1] analysis for the basis for these values.

Table 7-1 Acceptance Criteria Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Acceptance Criteria</th>
</tr>
</thead>
</table>
| Bulk Sludge Temperature | $\leq 212^\circ$F  
$\geq 32^\circ$F |
| Cask Accessible Surface Temperature | $\leq 185^\circ$F for NCT w/o Solar |
| Cask Pressure | - structural calc. to demonstrate a positive design margin |
| Helicoflex$^\text{TM}$ Metallic Seals | -40$^\circ$F to 932$^\circ$F  
- vent & drain ports -40$^\circ$F to 700$^\circ$F |
| Butyl-N Rubber Seals$^1$ | -40$^\circ$F to 285$^\circ$F |
| NucFil$^\text{TM}$ Filter$^2$ | -40$^\circ$F to 180$^\circ$F |
| Betafine$^5$ XL Cartridge Filters$^3$ | -40$^\circ$F to 175$^\circ$F  
< 60 psid @ 77$^\circ$F$^3$  
< 40 psid @ 77$^\circ$F$^4$ |
| Copperized Lead$^5$ | -40$^\circ$F to 620$^\circ$F |
| Type 304 Stainless Steel$^6$ | -40$^\circ$F to 800$^\circ$F for NCT  
-40$^\circ$F to 1000$^\circ$F for HAC |

1) No direct limit on HAC pressure is provided by the SNF-8163 performance specification[3.3]. Instead, the STS Cask structural calculations must demonstrate that the cask design provides a positive design margin in relation to the peak HAC pressure.

2) NITS - Not Important To Safety

3) Maximum forward differential pressure (psid) across filter in pounds per square inch

4) Maximum reverse differential pressure (psid) across filter in pounds per square inch

5) Per the SNF-8163 performance specification[3.3], lead melt can occur, but no net loss of lead can occur.

6) The temperature limitations apply only to structural components. The applicable limit for the non-structural components is the melting point (i.e., approximately 2600°F).
8. CALCULATION METHODOLOGY

The calculation methodology used for this analysis is the same as that described in the Reference [3.1] analysis. The thermal analysis is conducted using the SINDA/FLUINT™ and Thermal Desktop™ computer programs (see [3.6] and [3.7]). These programs are designed to function together to build, exercise, and post-process a thermal model. The codes provide the capability to simulate steady-state and transient temperatures using temperature dependent material properties and heat transfer via conduction, convection, and radiation. Complex algorithms may be programmed into the solution process for the purposes of computing variations to the thermal model as a function of various parameters. Examples include computing the heat transfer coefficients as a function of the local geometry, the heat generation due to the chemical reaction of uranium and water, the decrease in metallic uranium content as it is converted to oxide form, etc. The Thermal Desktop™ and the SINDA/FLUINT™ codes have been validated for use in simulating the thermal response of transportation packages [3.8].

Although the void volume in the STS cask interior and within the LDC will be filled with a combination of helium, hydrogen, oxygen, water vapor, and residual air from the backfill operation, the thermal modeling assumed that the gas mixture in these void volumes can be thermally characterized using the thermophysical properties of helium only. This modeling approach (the same as used in the Reference [3.1] analysis) is justified because of the relative quantities of gas constituents involved, the time frame for the calculations, and the distribution of the gas constituents within the packaging. See Appendix C for the justification of this modeling approach.

9. CALCULATIONS

9.1. Sensitivity Analysis For Normal Conditions

The effect of the sludge thermal property changes and the initial cask pressurization on the thermal performance of the system under normal conditions of transportation (NCT) is evaluated in a series of steps using the Load Case #1 scenario. The first step is to increase the initial cask pressurization from atmospheric to 2 psig, while keeping the thermal sludge properties at the values used in the Reference [3.1] analysis. The second step involved switching to the revised sludge thermal properties presented in Section 4, while assuming the same atmospheric initial cask pressure assumed in the Reference [3.1] analysis. The third and fourth steps involved analyzing the system for the combination of the revised sludge thermal properties presented in Section 4, plus an initial cask pressurization of 2 and 4 psig, respectively. By evaluating the thermal performance in this manner, the sensitivity of the design to these changes can be seen individually and in combination with one another.

Table 9-1 presents the comparison between the thermal performance of the Sludge Transport Cask with an initial pressure of 2 psig and the results obtained from the Reference [3.1] analysis with an initial atmospheric cask pressure. As seen from the table, with the exception of cask pressure, the measured performance parameters after 30 and 60 hours of simulated transport conditions are essentially identical. This is to be expected since cask pressure has no effect on...
the internal heat source loading and only a minor effect on the internal heat transfer rates. The only noted difference in thermal performance is the increase in cask pressure throughout the transport period by the approximately the initial 2 psig differential. The difference is not exactly 2 psig because of the fact there are two gas volumes considered (i.e., one inside the sludge container and one for the annulus between the container and the cask) and because of the difference in the amount of heat added to each gas volume during the simulated transportation period.

Table 9-2 presents the comparison between the thermal performance of the Sludge Transport Cask with the revised sludge thermal properties and the results obtained from the Reference [3.1] analysis. Again, as seen from the table, the measured performance parameters after 30 and 60 hours of simulated transport conditions are essentially identical. The primary difference noted is a slight (i.e., approximately 0.4°F) increase in the maximum container wall/sludge payload temperature. This temperature increase is attributed to the decrease in the sludge conductivity, which decreases the thermal connection between the relatively cool mass of the sludge interior and the container wall. As a result, the relative influence of the hotter inner shell of the cask on the container wall temperature increases slightly and drives the temperature up.

The combination of the reduction in radiolytic decay heat from 152.1 to 138.8 watts and the reduced conductivity with the container wall causes a slight drop in the bulk average temperature in the sludge and a lower level of radiolysis. As such, a slight decrease in the hydrogen and oxygen gas generation occurs due to the reduced chemical reaction (as seen by the noted lower chemical reaction heat) and radiolysis. The slight magnitude of the effect of the revised sludge thermal properties over the simulated 60-hour transportation process is reflected in the predicted 0.06 psi reduction in the maximum cask pressure. A greater effect would be seen had the simulation been carried through to steady-state conditions, as would exist at the T-Plant.

Table 9-3 presents the comparison between the thermal performance of the Sludge Transport Cask with a combination of a 2 psig initial cask pressure and the revised sludge thermal properties versus the results obtained from the Reference [3.1] analysis. The results seen for this combination are essentially those from Table 9-2, with the maximum pressure from Table 9-1. Overall, with the exception of the cask pressure, there is very little impact from this combination. Again, the slight decrease in the hydrogen and oxygen generation is associated with the reduction in the total payload radiolytic heat from 152 to 138.8 watts and the reduced conductivity with the container wall. The change in the cask pressure from that predicted using the Reference [3.1] analysis assumptions reflects the impact of the initial 2 psig cask pressurization. A similar set of results was obtained from the independent analysis presented in Reference [3.4].

The results for the combination of a 4 psig initial cask pressurization and the revised sludge thermal properties presented in Table 9-4 show similar results to those seen with the 2 psig initial pressurization. The only real difference is the higher cask pressure due to the difference in the initial cask pressurization. Again, the difference is not exactly 2 psig or 4 psig because of the fact there are two gas volumes considered (i.e., one inside the sludge container and one for the annulus between the container and the cask) and because the difference in the heating of these two gas volumes during the simulated transportation period.
Since all of the sensitivity cases evaluated herein yield essentially the same cask and sludge temperatures and similar gas generation levels, the transient trends for all of the sensitivity cases can be illustrated using a single case. The transient temperatures, cask pressure and gas constituents, and the heat source loadings for the sensitivity case with an initial 4 psig cask pressurization and with the revised sludge thermal properties are illustrated in Figure 9-1, Figure 9-2, and Figure 9-3, respectively. The 4 psig initial pressurization case bounds the results seen for the 0 and 2 psig initial pressure cases.

9.2. Sensitivity Analysis For NCT Cold

The bounding NCT Cold condition analysis was evaluated in Reference [3.1] as Load Case #3. That analysis conservatively assumed that package transport begins at a uniform package temperature of 50°F and is exposed for 60 hours to a constant ambient temperature of -27°F without insolation. For additional conservatism under bounding cold conditions, the analysis assumes no heat loading from radioactive decay or chemical reaction in the sludge, and therefore no hydrogen gas generation by radiolysis or uranium oxidation (chemical reaction).

Reference [3.1] indicated that negative cask gage pressures down to -1.8 psig at 30 hours and -2.2 psig at 60 hours were theoretically possible under the evaluated NCT Cold conditions. Negative cask gage pressure was not identified as a safety issue in Reference [3.1] for the following reasons:

- First, oxygen levels remain low throughout the 60-hour safety-basis shipping window. Assuming (a) the upper bound of 1% oxygen after the pre-transport helium purge operation and (b) the bounding radiolytic oxygen contribution of 0.515 g-moles from column 2 of Table 9-1 (even though radiolysis is assumed not to occur), and taking the 65.4 g-moles of helium backfill from footnote (2) of Table 9-1, the oxygen level at the end of 60 hours is conservatively estimated as:

\[
0.01 + \frac{0.515 \text{ g-mole}}{65.4 \text{ g-mole}} = 0.018 = 1.8\%
\]

Combustion would not occur at this low oxygen concentration, particularly since the NCT cold conditions will dramatically limit hydrogen generation.

- Second, the NCT Cold case in Reference [3.1] conservatively assumed an initial package fill gas temperature of 77°F, with no time to reach equilibrium with the 50°F overall package temperature prior to sealing the cask. As a result, the package pressure rapidly dropped to -0.7 psig as the fill gas cooled to 50°F, then continued downward under the effect of the extreme cold ambient conditions. An additional 3.3 g-moles of fill gas over the 65.4 g-moles assumed for the Reference [3.1] analysis would be required to achieve an initial 0 psig pressure within the sealed cask at 50°F. This additional fill gas would not affect the overall oxygen concentration since it would be conservatively assumed to contain the same minimum 1% oxygen as the base fill gas quantity. However, initiating the shipping window at true equilibrium atmospheric pressure for the evaluated temperature conditions would limit the minimum package pressure to -1.5 psig at the end of 60 hours, rather than the -2.2 psig as predicted in the Reference [3.1] analysis.
Third, the STS cask is designed and fabricated to meet the leaktight criteria (leakage less than \(1 \times 10^{-7}\) standard cubic centimeters per second [scce/s] for air) of ANSI N14.5-1997, Leakage Tests on Packages for Shipment. Given the maximum differential pressure across the seal at cold conditions of -2.2 psig, the potential ingress of air is negligible over 60 hours at a bounding negative pressure of -1.5 psig.

Therefore, initial pressurization of the cask above 0 psig with helium gas only further enhances the safety margin against flammability due to oxygen buildup during NCT Cold conditions.

The revisions to the sludge thermal properties will have a negligible effect on the predicted temperatures under the NCT cold conditions. Since the Reference [3.1] analysis assumed zero decay heat and no radiolysis, the changes in the sludge properties affected these parameters will not affect the evaluation. The lower sludge thermal conductivity will tend to reduce the heat loss from the sludge to the cold packaging and make the temperature levels presented in Reference [3.1] conservatively low. Therefore, the safety basis for NCT Cold conditions are bounded by the Reference [3.1] results for Load Case #3 (see Table 9-5). The table includes the predicted cask pressure based on the quantity of helium backfill assumed for the Reference [3.1] analysis and estimated pressure if the quantity of helium required to achieve atmospheric conditions at the assumed payload temperature of 50°F had been used instead.

The recommendation of the Reference [3.1] analysis is to limit cask exposure to freezing weather to 24 hours or less when the ambient temperature is below 0°F is still valid. Given the limited number of days at the Hanford site that meet this temperature criteria, the impact of such an administrative control on operations is expected to be minimal.

### 9.3. Sensitivity Analysis For Accident Conditions Of Transportation

Three packaging configurations were evaluated for the Load Case #4 hypothetical accident condition (HAC) under the Reference [3.1] analysis. These configurations were: 1) the cask and container on their sides and with a minimal amount (i.e., 0.03 m\(^3\)) of cover water required to over-pressurize the cask being leaked into the annulus between the cask and the container, 2) the cask and container on their sides and with the entire cover water volume (i.e., 0.43 m\(^3\)) leaked into the annulus, and 3) the cask and container upright and the entire cover water volume leaked into the annulus. In addition, the potential impact of a mixture of sludge and water being leaked into the annulus was addressed.

The Reference [3.1] results demonstrated that the first accident configuration produced the bounding cask pressure results and that the situation where the leakage consisted of pure water bounded the situation where a mixture of water and sludge were leaked. The peak pressure reached during the 30-minute fire and subsequent 11.5 hour cool down period was 123 psia (108.3 psig). As such, the accident configuration with the cask and container on their sides and with 0.03 m\(^3\) of cover water leaked into the annulus between the cask and the container was selected to assess the sensitivity of the HAC simulation to the revised sludge properties and initial cask pressurization.

The thermal model described in Reference [3.1] for this calculation was modified for the revised sludge thermal properties and the system component temperatures and gas constituents were set.
equal to those values existing at the end of the 60 hour transient with an initial 4 psig cask backfill (see Table 9-4). This starting point bounds the results for either the 0 or 2 psig backfill conditions.

Table 9-6 presents a comparison of the peak cask parameters noted between the Reference [3.1] analysis and this HAC simulation based on the revised sludge thermal properties and a 4 psig initial cask pressurization. As seen from the table, with the exception of a peak surface temperature (reached at the cask's fork lift pockets at the bottom of the cask), the temperatures achieved for the various cask components are equal or lower than those reached under the Reference [3.1] analysis. Given the location of the peak surface temperature, the relatively slight 9°F increase in maximum temperature noted in this analysis is not seen as significant as even a slight change in the thermal conductors associated with this low mass region of the cask could produce the noted temperature difference in a 1500°F fire event.

Although the peak lead temperature noted during the fire of 672°F is 52°F above the melting point for lead, the analysis does not account for the heat of fusion for lead. As such, some of the heat energy would have been absorbed in melting the lead. The heat of fusion for lead is approximately 11.3 Btu/lbm, while the specific heat for lead at its melting point is 0.036 Btu/lbm°F. As such, the heat required to melt a pound of lead is over 300 times greater than the heat required to raise the temperature of a pound of lead 1°F. Given this fact, the temperature gradient through the lead shield (see the curves for the lead and the inner shell in Figure 9-5), and the fact that the peak lead temperature occurs at the end of the fire, it can be safely stated that if any lead melt does occur, it will be limited to a very short time period and to a thin layer at the outer diameter of the lead shield and that the lead will quickly re-solidify during the water quench operation. Therefore, no net lead loss is predicted. It should again be noted that lead melt is permitted for this condition per the [3.3] performance specification.

Figure 9-4 to Figure 9-5 present the transient temperature plots for the HAC event and the post-fire cool down. The effectiveness of the water quench operation at the end of the fire can readily be seen from the plotted data. Figure 9-6 presents the pressure and gas generation transients over the same time period. As seen from the plotted data for cask pressure, the internal pressure rises quickly once boiling begins, reaches a peak point shortly after the fire is over, reduces in level as the water quench operation drops the cask temperatures (and hence the internal gas temperatures), and then drops dramatically once the cask inner surface temperatures fall below the condensation temperature.

The peak chemical reaction heat noted during the transient is 1,739 watts, while the radiolytic decay heat remains constant at its safety basis value of 138.8 watts. The peak chemical reaction heat lasts less than 5 minutes before the quenching operation reduces the sludge temperatures and brings the chemical reaction heat level down to a level that is approximately 25% higher than that seen for the pre-fire conditions. As demonstrated by the system temperatures, the cask design is adequate to handle this elevated heat generation rate and maintain the packaging in a safe condition. As seen from Table 9-6, the maximum source terms for both the radiolytic decay and chemical reaction heat are lower than those seen for the Reference [3.1] calculation. While a portion of the lower chemical reaction heat is due to the cooler sludge temperatures achieved as a result of the revised sludge properties, the majority of the change in the source terms is due to the removal of excessive conservatism in the [3.1] calculation HAC routines that compute the volumetric heating rates for radiolytic decay heat and chemical reaction heat. Since the
conservatism resulted in over-estimating the heat loads, the results in the [3.1] calculation are valid for safety analysis purposes.

To assess the sensitivity of the HAC results to the radiolytic and chemical reaction heat loads and in the interest of correctness, this modeling conservatism was removed for the HAC modeling for this calculation. The fact that similar peak cask pressures are achieved demonstrates that, as is expected, the system's thermal performance under HAC conditions is driven primarily by the heating from the fire and not from the sludge payload.

Boiling of the water within the annulus is predicted to begin approximately 21.5 minutes after the start of the fire. At that point in time the steam saturation pressure exceeds the 33 psia pressure existing in the cask cavity due to the presence of gas generation from the assumed 60 hours of NCT transportation that precedes the fire accident event. The 4 psi higher cask pressure at the start of the HAC event raises the saturation temperature of the leaked water by 7°F, and thus delays the onset of boiling by an estimated 1.5 minutes beyond the onset of boiling seen in the Reference [3.1] analysis. Analysis of the temperature of the water in the annulus vs. time indicates that if the initial cask backfill pressurization was atmospheric, boiling would begin at about 17 minutes after the initiation of the fire. As such, no boiling is expected if the fire event lasts 15 minutes or less. Boiling is predicted to cease approximately 5 minutes after the start of the cask quench operations, with a shorter fire exhibiting a corresponding shorter period of boiling within the cask. The analysis further predicts that after approximately 35 minutes of water quenching, the interior surfaces of the cask will have dropped in temperature sufficiently to allow the steam to re-condense, with an associated rapid decrease in the cask pressure.

The increase in cask pressure is due to a combination of mechanisms. First, boiling within the cask is a self-arresting process since the increased cask pressure associated with the conversion of the liquid water to vapor also raises the saturation temperature of the remaining liquid water. As such, an ever-increasing temperature level is required to create boiling conditions within the remaining water. Second, the heat of fusion for water (i.e., the change in enthalpy from a liquid to a vapor state) is approximately 1000 times greater than the sensible heat required to raise the water temperature 1°F. Thus, a significant amount of heat energy can be absorbed with little change in the local temperatures. The third mechanism acting to control the cask pressure is the presence of the relatively cold thermal mass of the sludge payload. Not only does the sludge act as a heat sink, the container's walls remain below the saturation temperature during the fire transient. Therefore, a portion of the water that is boiled off will re-condense on the surfaces of the container and act to moderate the pressure increase with the level of this concurrent condensation process being a complex function of the interior geometry and local temperatures. For simplicity and to avoid the need to justify the configuration of the sludge container following the drop and puncture events that are assumed to precede the fire event, this calculation ignores the potential for concurrent condensation during the boiling phase. This approach will result in a conservative over-prediction of the peak pressures for the HAC event and the rate of condensation during the post-fire cool-down.

The resulting peak pressure seen for this packaging configuration is 124.7 psia (110 psig). The saturated steam temperature associated with this pressure is approximately 345°F, which is indicative of the level of the cask sidewall temperatures reached in the vicinity of the leaked water (the actual sidewall temperature will be approximately 40 to 60°F hotter due to a combination of the heating rate and the heat transfer coefficient between the sidewall and the
The 124.7 psia (110 psig) peak cask pressure predicted under this calculation is 1.4% higher than the 123 psia (108.3 psig) peak pressure predicted under the [3.1] calculation and that pressure level was shown to yield a positive structural margin with respect to the cask structural design criteria.

The Figure 9-7 color-flooded plot illustrates the temperature distribution in the cask shells (lead shield omitted for clarity), and for the bottom and lid plates at the end of the 30-minute fire event. Since the cask is assumed to be horizontal for this simulation, the ‘new bottom’ of the cask is on the right side of the plot. The cooler temperatures seen on the right side of the plot are indicative of the presence of the 4’ water depth along the side, plus the contact between the container and the cask. The relatively cool inner surface of the cask bottom (or end plate) results from the lower elliptical head of the container and the convection and radiative exchange between it and the cask end plate. Although peak cask temperatures in the range of 1130°F are seen at the end of the fire, the Figure 9-7 temperature distribution clearly illustrates that this temperature level is only attained at the corners of the cask lid flange and the cask base where the exposed surface area per unit mass is the greatest.

The Figure 9-8 color-flooded plot illustrates the temperature distribution in the lead shield at the end of the 30-minute fire. Again, the cooler temperatures seen on the right side of the plot are the result of the presence of water along that side (i.e., the bottom of the horizontally oriented cask during the fire event), plus the contact between the container and the cask. Further, as discussed above, the portion of the lead that exceeds the lead's 620°F melting point is limited to the outer surface of the lead away from the location of the water in the annulus. The conservative assumption of no gap between the lead and the outer shell of the cask also contributes to a conservative estimate of the lead temperatures during the HAC event.

Figure 9-9 illustrates the temperature distribution in the container and sludge payload via a color flooded plot at the time point of peak temperatures within the cask interior (approximately 3 minutes after the end of the fire). The right hand side of the plot represents the portion of the container that is in contact with the cask inner shell and with the leaked water. As seen from the figure, the localized peak temperature (approximately 390°F) is limited to a small volume adjacent to the section of the container wall that is in contact with the inner shell of the cask. As such, any localized boiling within the sludge is of no consequence as it will re-condense by the sludge mass above these areas and no net steam vapor production is expected. It should be noted that the thermal model does capture the accelerated chemical reaction heat, gas generation, and the depletion of the metallic uranium metal associated with these areas of the elevated sludge temperatures. Since sludge temperatures everywhere else are well below 212°F, the bulk sludge temperature is clearly demonstrated as remaining within the temperature limit for the sludge payload.

Water quenching of the cask exterior will induce thermal stresses in the cask walls. The color flooded plot presented in Figure 9-10 and the line plot in Figure 9-5 illustrate the predicted temperature gradient between the inner and outer walls of the cask 3 minutes after the start of the quench. At this point, the exterior surface temperatures of the cask have dropped below the boiling point for water used to quench the cask, while the inner shell temperatures are still near their maximum temperature point. Additional information regarding the temperature distribution in the cask shells and at the bottom forging are presented in Appendix B.
The conclusion drawn from this analysis is that the STS cask design is adequate to maintain the system’s safety basis for a regulatory 30-minute fire event. The use of a post-fire quenching operation is critical to this safety basis and must be made part of any recovery response where the fire event has lasted 15 minutes or longer. Further, with the exception of peak pressure, the Reference [3.1] analysis of the HAC conditions remain valid. An extension to this conclusion is that the sensitivity analyses presented in [3.1] as to the cask and sludge container configuration, the amount of water leakage, and the composition of the leakage into the cask annulus also remain valid and the configuration used in this calculation is the bounding configuration. Finally, the fact that the 4 psig initial cask pressurization yields a slightly higher peak pressure than seen for the [3.1] analysis with an initial atmospheric pressure demonstrates that the 4 psig results will bound those seen for either a 2 psig or atmospheric backfill condition.
Table 9-1 - Sensitivity Of NCT Results To Initial Cask Pressure

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ref. [3.1] Analysis</th>
<th>Initial 2psig Cask Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>@ 30 Hours</td>
<td>@ 60 Hours</td>
</tr>
<tr>
<td>Max. Lid Temperature, °F</td>
<td>127.9</td>
<td>137.3</td>
</tr>
<tr>
<td>Max. Outer Shell Temperature, °F</td>
<td>118.4</td>
<td>126.7</td>
</tr>
<tr>
<td>Max. Lead Temperature, °F</td>
<td>117.0</td>
<td>129.2</td>
</tr>
<tr>
<td>Max. Inner Shell Temperature, °F</td>
<td>113.3</td>
<td>127.5</td>
</tr>
<tr>
<td>Seal Temperatures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Cask Closure Seal</td>
<td>122.6</td>
<td>131.7</td>
</tr>
<tr>
<td>- Lid Vent Port</td>
<td>123.2</td>
<td>132.8</td>
</tr>
<tr>
<td>- Cask Drain Port</td>
<td>107.2</td>
<td>119.5</td>
</tr>
<tr>
<td>Max. Container Wall / Sludge Temperature, °F</td>
<td>99.0</td>
<td>114.5</td>
</tr>
<tr>
<td>Metallic U Consumed, kg</td>
<td>2.33</td>
<td>6.17</td>
</tr>
<tr>
<td>Water Consumed, kg</td>
<td>0.367</td>
<td>0.963</td>
</tr>
<tr>
<td>Hydrogen Generated, g-moles</td>
<td>20.397</td>
<td>53.482</td>
</tr>
<tr>
<td>Oxygen Generated, g-moles</td>
<td>0.257</td>
<td>0.515</td>
</tr>
<tr>
<td>Cask Pressure, psia</td>
<td>20.40 2</td>
<td>29.02 2</td>
</tr>
<tr>
<td>Gas Generation Rate, g-moles/hr</td>
<td>0.86</td>
<td>1.38</td>
</tr>
<tr>
<td>Radiolytic Decay Heat, watts</td>
<td>152.1</td>
<td>152.1</td>
</tr>
<tr>
<td>Chemical Reaction Heat, watts</td>
<td>60.7</td>
<td>99.3</td>
</tr>
<tr>
<td>Oxygen Mole Fraction</td>
<td>1.06%</td>
<td>0.98%</td>
</tr>
</tbody>
</table>

Table Notes:
1) Includes hydrogen from radiolysis.
2) Assumes an initial atmospheric cask pressure (i.e., 65.4 g-moles of helium backfill).
3) Assumes an initial 2 psig cask pressure (i.e., 74.5 g-moles of helium backfill).
4) Results for 30 and 60 hours taken from time points of 37 and 67 hours, respectively, in the computer simulation since the analysis conservatively assumes transportation processes start at 7am and 8 hours would represent mid-night for the diurnal cycle of ambient air temperature/solar loading vs. time.
5) Gas generation rate includes 0.0365 g-moles/hr from radiolysis.
6) Assumes an initial 1% oxygen mole fraction at the completion of the cask vent and purge cycle.
Table 9-2 - Sensitivity of NCT Results To Revised Sludge Thermal Properties

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ref. [3.1] Analysis</th>
<th>Revised Sludge Thermal Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>@ 30 Hours 4</td>
<td>@ 60 Hours 4</td>
</tr>
<tr>
<td>Max. Lid Temperature, °F</td>
<td>127.9</td>
<td>137.3</td>
</tr>
<tr>
<td>Max. Outer Shell Temperature, °F</td>
<td>118.4</td>
<td>126.7</td>
</tr>
<tr>
<td>Max. Lead Temperature, °F</td>
<td>117.0</td>
<td>129.2</td>
</tr>
<tr>
<td>Max. Inner Shell Temperature, °F</td>
<td>113.3</td>
<td>127.5</td>
</tr>
<tr>
<td>Seal Temperatures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Cask Closure Seal</td>
<td>122.6</td>
<td>131.7</td>
</tr>
<tr>
<td>- Lid Vent Port</td>
<td>123.2</td>
<td>132.8</td>
</tr>
<tr>
<td>- Cask Drain Port</td>
<td>107.2</td>
<td>119.5</td>
</tr>
<tr>
<td>Max. Container Wall / Sludge Temperature, °F</td>
<td>99.0</td>
<td>114.5</td>
</tr>
<tr>
<td>Metallic U Consumed, kg</td>
<td>2.33</td>
<td>6.17</td>
</tr>
<tr>
<td>Water Consumed, kg</td>
<td>0.367</td>
<td>0.963</td>
</tr>
<tr>
<td>Hydrogen Generated, g-moles ^1</td>
<td>20.397</td>
<td>53.482</td>
</tr>
<tr>
<td>Oxygen Generated, g-moles</td>
<td>0.257</td>
<td>0.515</td>
</tr>
<tr>
<td>Cask Pressure, psia</td>
<td>20.40 ^2</td>
<td>29.02 ^2</td>
</tr>
<tr>
<td>Gas Generation Rate, g-moles/hr</td>
<td>0.86 ^5</td>
<td>1.38 ^5</td>
</tr>
<tr>
<td>Radiolytic Decay Heat, watts</td>
<td>152.1</td>
<td>152.1</td>
</tr>
<tr>
<td>Chemical Reaction Heat, watts</td>
<td>60.7</td>
<td>99.3</td>
</tr>
<tr>
<td>Oxygen Mole Fraction ^7</td>
<td>1.06%</td>
<td>0.98%</td>
</tr>
</tbody>
</table>

Table Notes: 1) Includes hydrogen from radiolysis.
2) Assumes an initial atmospheric cask pressure (i.e., 65.4 g-moles of initial helium backfill).
3) Assumes an initial atmospheric cask pressure.
4) Results for 30 and 60 hours taken from time points of 37 and 67 hours, respectively, in the computer simulation since the analysis conservatively assumes transportation process starts at 7am and 0 hours would represent mid-night for the diurnal cycle of ambient air temperature/solar loading vs. time.
5) Gas generation rate includes 0.0365 g-moles/hr from radiolysis.
6) Gas generation rate includes 0.0328 g-moles/hr from radiolysis.
7) Assumes an initial 1% oxygen mole fraction at the completion of the cask vent and purge cycle
Table 9-3 - Sensitivity Of NCT Results To 2 psig Initial Cask Pressure And Revised Sludge Thermal Properties

<table>
<thead>
<tr>
<th></th>
<th>Ref. [3.1] Analysis</th>
<th>2 psig Cask Fill + Revised Sludge Thermal Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>@ 30 Hours 4</td>
<td>@ 60 Hours 4</td>
</tr>
<tr>
<td>Max. Lid Temperature, °F</td>
<td>127.9</td>
<td>137.3</td>
</tr>
<tr>
<td>Max. Outer Shell Temperature, °F</td>
<td>118.4</td>
<td>126.7</td>
</tr>
<tr>
<td>Max. Lead Temperature, °F</td>
<td>117.0</td>
<td>129.2</td>
</tr>
<tr>
<td>Max. Inner Shell Temperature, °F</td>
<td>113.3</td>
<td>127.5</td>
</tr>
<tr>
<td>Seal Temperatures</td>
<td>122.6</td>
<td>131.7</td>
</tr>
<tr>
<td>- Cask Closure Seal</td>
<td>123.2</td>
<td>132.8</td>
</tr>
<tr>
<td>- Lid Vent Port</td>
<td>107.2</td>
<td>119.5</td>
</tr>
<tr>
<td>- Cask Drain Port</td>
<td>99.0</td>
<td>114.5</td>
</tr>
<tr>
<td>Max. Container Wall /Sludge Temperature, °F</td>
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<td>53.482</td>
</tr>
<tr>
<td>Metallic U Consumed, kg</td>
<td>2.33</td>
<td>6.17</td>
</tr>
<tr>
<td>Water Consumed, kg</td>
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<td>0.963</td>
</tr>
<tr>
<td>Hydrogen Generated, g-moles 1</td>
<td>0.257</td>
<td>0.515</td>
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<tr>
<td>Oxygen Generated, g-moles</td>
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<td>29.02</td>
</tr>
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<td>Cask Pressure, psia</td>
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<td>152.1</td>
</tr>
<tr>
<td>Gas Generation Rate, g-moles/hr</td>
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<td>1.38</td>
</tr>
<tr>
<td>Radiolytic Decay Heat, watts</td>
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<td>99.3</td>
</tr>
<tr>
<td>Chemical Reaction Heat, watts</td>
<td>1.06%</td>
<td>0.98%</td>
</tr>
</tbody>
</table>

Table Notes:
1) Includes hydrogen from radiolysis.
2) Assumes an initial atmospheric cask pressure (i.e., 65.4 g-moles of initial helium backfill).
3) Assumes an initial 2 psig cask pressure (i.e., 74.5 g-moles of initial helium backfill).
4) Results for 30 and 60 hours taken from time points of 37 and 67 hours, respectively. In the computer simulation since the analysis conservatively assumes transportation starts at 7am and 9 hour would represent mid-night for the diurnal cycle of ambient air temperature/solar loading vs. time.
5) Gas generation rate includes 0.0365 g-moles/hr from radiolysis.
6) Gas generation rate includes 0.0328 g-moles/hr from radiolysis.
7) Assumes an initial 1% oxygen mole fraction at the completion of the cask vent and purge cycle.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ref. [3.1] Analysis</th>
<th>4 psig Cask Fill + Revised Sludge Thermal Properties</th>
</tr>
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<td></td>
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<tr>
<td>Max. Lid Temperature, °F</td>
<td>127.9</td>
<td>127.9</td>
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<tr>
<td></td>
<td>137.3</td>
<td>137.2</td>
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<tr>
<td>Max. Outer Shell Temperature, °F</td>
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<td>118.4</td>
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<td>126.8</td>
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<tr>
<td></td>
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<td>132.8</td>
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<td>- Cask Drain Port</td>
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<td>107.2</td>
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<tr>
<td></td>
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<td>119.6</td>
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<td>114.9</td>
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<td>2.32</td>
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<td></td>
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<tr>
<td>Water Consumed, kg</td>
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<td></td>
<td>0.963</td>
<td>0.954</td>
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<tr>
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<td>20.251</td>
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<td></td>
<td>53.482</td>
<td>53.025</td>
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<td>Oxygen Generated, g-moles</td>
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<td></td>
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<td>Cask Pressure, psia</td>
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<td>24.64 ^3</td>
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<tr>
<td></td>
<td>29.02 ^2</td>
<td>33.31 ^3</td>
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<tr>
<td>Gas Generation Rate, g-moles/hr</td>
<td>0.86 ^5</td>
<td>0.85 ^6</td>
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<tr>
<td></td>
<td>1.38 ^5</td>
<td>1.36 ^6</td>
</tr>
<tr>
<td>Radiolytic Decay Heat, watts</td>
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<td></td>
<td>152.1</td>
<td>138.8</td>
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<td>Chemical Reaction Heat, watts</td>
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</tr>
<tr>
<td></td>
<td>99.3</td>
<td>98.4</td>
</tr>
<tr>
<td>Oxygen Mole Fraction</td>
<td>1.06%</td>
<td>1.05%</td>
</tr>
<tr>
<td></td>
<td>0.98%</td>
<td>0.98%</td>
</tr>
</tbody>
</table>

Table Notes:
1) Includes hydrogen from radiolysis.
2) Assumes an initial atmospheric cask pressure (i.e., 65.4 g-moles of initial helium backfill).
3) Assumes an initial 4 psig cask pressure (i.e., 83.5 g-moles of initial helium backfill).
4) Results for 30 and 60 houn taken from time points of 37 and 67 houn, respectively, in the computer simulation since the analysis conservatively assumes transportation process starts at 7am and 0 houn would represent mid-night for the diurnal cycle of ambient air temperature/solar loading, time.
5) Gas generation rate includes 0.0365 g-moles/hr from radiolysis
6) Gas generation rate includes 0.0328 g-moles/hr from radiolysis
7) Assumes an initial 1% oxygen mole fraction at the completion of the cask vent and purge cycle.
Table 9-5 - Bounding Results For NCT Cold (Load Case #3)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Results At 30 Hours ¹, ²</th>
<th>Results At 60 Hours ¹, ²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lid Temperature, °F</td>
<td>-5.4</td>
<td>-14.6</td>
</tr>
<tr>
<td>Outer Shell Temperature, °F</td>
<td>-3.3</td>
<td>-12.4</td>
</tr>
<tr>
<td>Lead Temperature, °F</td>
<td>-2.0</td>
<td>-11.9</td>
</tr>
<tr>
<td>Inner Shell Temperature, °F</td>
<td>-0.5</td>
<td>-10.8</td>
</tr>
<tr>
<td>Seal Temperatures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Cask Closure Seal</td>
<td>-4.4</td>
<td>-13.5</td>
</tr>
<tr>
<td>- Lid Vent Port</td>
<td>-4.5</td>
<td>-13.6</td>
</tr>
<tr>
<td>- Cask Drain Port</td>
<td>5.1</td>
<td>-7.8</td>
</tr>
<tr>
<td>Container Wall / Sludge Temperature, °F</td>
<td>18.0</td>
<td>3.3</td>
</tr>
<tr>
<td>Sludge Centerline Temperature, °F</td>
<td>49.8</td>
<td>46.2</td>
</tr>
<tr>
<td>Metallic U Consumed, kg</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Water Consumed, kg</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Hydrogen Generated, g-moles ²</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Oxygen Generated, g-moles</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cask Pressure, psia</td>
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<td></td>
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<td>12.86 ³</td>
<td>12.51 ³</td>
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<td></td>
<td>13.6 ⁴</td>
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<tr>
<td>Chemical Reaction Heat, watts</td>
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<tr>
<td>Oxygen Mole Fraction ⁷</td>
<td>1%</td>
<td>1%</td>
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¹ Includes hydrogen from radiolysis
² Assumes initial backfill of 65.4 g-moles of helium at 77°F temperature.
³ Assumed initial backfill of 65.4 g-moles of helium at 77°F temperature.
⁴ Estimated cask pressure had the initial backfill quantity been 68.1 g-moles of helium at 77°F temperature.
⁵ Results for 30 and 60 hours taken from time points of 37 and 67 houn., respectively, in the computer simulation since the analysis conservatively assumed the time of the analysis conservatively assumed the time of the ambient air temperature/solar loading vs. time.
⁶ Since decay heat is assumed to be zero, gas generation rate from radiolysis is also zero.
⁷ Assumes an initial 1% oxygen mole fraction at the completion of the cask vent and purge cycle.
Table 9-6 - Sensitivity Results For HAC Load Case #4 (Horizontal Package Configuration w/ 0.03 m³ Water Leakage)

<table>
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<tr>
<th>Parameter</th>
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<th>Peak For 4 psig Cask Fill + Revised Sludge Thermal Properties</th>
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<td>Max. Exterior Temperature, °F</td>
<td>1124</td>
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<td>Max. Outer Shell Temperature, °F</td>
<td>828</td>
<td>823</td>
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<td>Max. Lead Temperature, °F</td>
<td>675</td>
<td>669</td>
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<tr>
<td>Max. Inner Shell Temperature, °F</td>
<td>555</td>
<td>551</td>
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<tr>
<td>Seal Temperatures</td>
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<td></td>
</tr>
<tr>
<td>*Cask Closure Seal</td>
<td>624</td>
<td>623</td>
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<tr>
<td>*Lid Vent Port</td>
<td>545</td>
<td>544</td>
</tr>
<tr>
<td>*Cask Drain Port</td>
<td>69</td>
<td>690</td>
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<tr>
<td>Max./Min LDC Wall Temperature, °F</td>
<td>370 / 114 °F</td>
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<td>Bulk Sludge Temperature, °F</td>
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<td>Metallic U Consumed, kg</td>
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<td>Water Consumed, kg</td>
<td>1.011</td>
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<td>Cask Pressure, osia</td>
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<td>Gas Generation Rate, g-moles/hr *</td>
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<tr>
<td>Time Between Start of Fire &amp; Boiling</td>
<td>15 minutes</td>
<td>21.5 minutes</td>
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Table Notes:

1) Includes hydrogen from radiolysis.

2) Includes 65.4 g-moles of initial helium backfill & 102.57 g-moles of hydrogen equivalent assumed trapped in the predrop accident 'gassy' sludge.

3) Includes 83.5 g-moles of initial helium backfill, 53.02 g-moles of hydrogen from preceding 60 hours of NCT transport, and 123.78 g-moles of hydrogen equivalent assumed trapped in the pre-drop accident 'gassy' sludge.

4) Results for temperatures and pressure are the maximums noted during the 12 hour transient and do not necessarily occur at coincident times. Results for generated gas quantities, etc. are at the end of the 12 hour transient. Initial conditions for the transient are taken from end of 60 hour shipping window for Load Case #1.

5) Gas generation rate includes 0.036 g-moles/hr from radiolysis for the Ref. 31 analysis, but does not include the steam generation rate.

6) Values for Ref. 31 analysis are conservatively high due to the existence of a known error/conservatism in the routines that computed the volumetric heating rates for radiolytic decay heat and chemical reaction heat.

7) Tabulated value presents the time period over which potential boiling conditions exist, but not necessarily the actual length of time boiling occurs.

8) Minimum LDC wall temperature taken at time coincident with the noted maximum temperature and is provided to illustrate the circumferential temperature variation.
Figure 9-1 - Temperature Profiles For Safety Basis NCT 60-Hour Shipping Window
Figure 9-2 - Pressure/Gas Profiles For Safety Basis 60-Hour Shipping Window w/ Initial 4 psig Cask Pressure
Figure 9-3 - Heat Source Comparison Between Original And Revised Sludge Payload Properties Over 60-Hour Shipping Window
Figure 9-4 - HAC Cask Component Temperatures For The Bounding Package Configuration
Figure 9-5 - HAC Cask Component Temperatures For The Bounding Package Configuration (Enlarged View)
Figure 9-6 - HAC Gas/Pressure Transient For The Bounding Package Configuration
Figure 9-7  -Temperature Distribution In Cask Shells At End Of Fire For The Bounding Package Configuration
Figure 9-8 - Temperature Distribution In Lead At End Of Fire For The Bounding Package Configuration
Figure 9-9 - Temperature Distribution In Container & Sludge 3 Minutes After End Of Fire For The Bounding Package Configuration
Figure 9-10 - Temperature Distribution in Cask Shells 3 Minutes After Start Of Water Quench For The Bounding Package Configuration
10. CONCLUSIONS

The K East Basin sludge properties and the initial cask pressure have been changed since the Sludge Transport System (STS) Thermal Analysis [3.1] was issued. This calculation extends the safety basis calculation provided in the Reference [3.1] calculation to cover these changes in sludge properties and operating conditions. The evaluation is conducted as a series of sensitivity analyses using the bounding safety basis load cases for normal and accident conditions of transportation developed under the Reference [3.1] calculation.

The results presented in Section 9 demonstrate that the system's design complies with all thermal and pressure criteria in the performance specification [3.3] and as summarized in Table 7-1. Specifically, all packaging components are shown to remain within their allowable temperature limits for both NCT and HAC conditions. The sludge payload is demonstrated to remain thermally stable throughout the 60-hour simulated period (and is expected to remain stable for an indefinite period -- see the extended analysis presented in the Reference [3.4]). The NCT analyses also demonstrate that, even with insolation applied, the system complies with §5.1.3.2 of [3.3] in that no accessible surface of the package will exceed 185°F.

Analysis of the Load Case #3 results presented in Table 9-5, indicates that freezing along the outer edges of the container can be expected to begin after approximately 16 hours of exposure to the -27°F ambient condition. While the results in Table 9-5 indicates that the edges of the sludge container will below 32°F, the center of the sludge payload is seen as being only marginally decreased from its initial 50°F starting temperature. Further, since the analysis does not account for the latent heat required to freeze water, the predicted minimum sludge temperatures are conservatively low. In reality, the combination of a higher sludge density due to the absence of retained gases, and the latent heat removal required to freeze water will tend to limit the portion of the sludge payload which would actually freeze below that predicted in this analysis. For conservatism, it is recommended that exposure of the cask to ambient conditions of 0°F or less should be limited to 24 hours or less to avoid freezing in the sludge payload.

The maximum normal operating pressure (MNOP) of 33.31 psia (18.6 psig) arises with a 4 psig initial cask pressurization. This peak pressure is well within the 94.7 psia (80 psig) pressure criterion for the cask under normal operating conditions. The maximum oxygen gas mole fraction remains well below 2% (i.e., 50% of the lower flammability limit) throughout the 60-hour simulated period (i.e., twice the expected transportation time) and for cask backfill conditions of 0 psig and higher.

The peak packaging component temperatures noted during the simulated fire event remain within the allowable limits specified in Table 7-1. Although the maximum package temperature of 1133°F is above the 1000°F limit for Type 304 stainless steel under accident conditions specified in Table 7-1, this temperature occurs at the upper and lower corners of the cask and not at the cask's pressure boundary. Temperatures over other portions of the cask remain below the short term limit of 1000°F. Although the peak lead temperature is predicted to exceed 620°F, this occurs only for a thin layer, for a short time period, and only under a conservative set of assumptions. As such, no lead melt is actually expected and no net lead loss will occur.
The peak cask pressure under HAC conditions is conservatively estimated at 124.7 psia (110 psig). This pressure is only 1.3% above the level predicted in the Reference [3.1] calculation, with the difference being primarily related to the increase from 0 to 4 psig in the assumed initial cask pressurization. No boiling is expected within the cask unless the accident condition involves a drop event that damages the LDC container allowing the cover water to escape and unless the fire event lasts more than 15 minutes. The use of the post-fire quench process (see 75.2.2.3 of the performance specification [3.3]) is seen as a critical element in controlling the peak temperatures and gas generation within the sludge payload. As such, any recovery procedure for the HAC event involving a fire should incorporate the quench operation.

Finally, the results of this analysis demonstrate that the conclusions drawn in the Reference [3.1] calculation remain valid for the revised sludge thermal properties. The primary difference between the results presented in this calculation and those presented in the [3.1] calculation is the higher cask pressures predicted due to the assumption of a 2 and 4 psig initial cask pressurization vs. the atmospheric condition assumed in the [3.1] calculation. As such, the conclusion reached in the [3.1] calculation as to the sensitivity to various assumptions, the selection of the bounding HAC configuration, etc. remains valid.
11. APPENDIX A - ELECTRONIC FILE LOGS

The following tables provide a listing of the input and output files used in the thermal simulations for this calculation. All of the computer runs were performed on a Pentium III computer (S/N 1317327-001) running Windows 2000. The spread sheets are generated using Microsoft's EXCEL 2000 program.

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Analysis represents a repeat of Load Case #1 as describe in Reference [3.1], except with the revised sludge thermal properties.
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**Analysis Description:**

Analysis represents a repeat of Case1_TI015R9, except with a 2 psig initial cask pressurization instead of atmospheric pressure.
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- 'frcvhu.f'

Creator: Gregory J Banken

#### Binary Database
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Creator: Gregory J Banken

#### ASCII Output
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Creator: Gregory J Banken

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Creator: Gregory J Banken

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**Analysis Description**

Analysis represents a repeat of the bounding Load Case #4 package configuration as describe in Reference [3.1], except with the revised sludge thermal properties and with a 4 psig initial cask pressurization instead of atmospheric pressure.
12. **APPENDIX B - TEMPERATURE GRADIENT INFORMATION**

To support the structural analysis of the thermal stresses for the fire and the post-fire quench operation, temperatures for 8 points on the bottom forging were extracted from the model. The figure below illustrates the specific thermal model node numbers and the location associated with selected 8 points. As seen from the figure, the temperature points capture the temperature distribution at the end of the inner and outer shells in the vicinity of the drain port. For conservatism, the thermal model assumes that the drain port is oriented towards the top of the horizontal cask (i.e., the left side of Figure 9-7).

![Diagram of temperature distribution](image)

<table>
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<th>SWALL Submodel</th>
<th>CSKB T Submodel</th>
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<tr>
<td></td>
<td>T309</td>
<td>T310</td>
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<tr>
<td>End of Fire</td>
<td>811.7°F</td>
<td>807.9°F</td>
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<tr>
<td>3 Minutes Into Quench</td>
<td>152.0°F</td>
<td>147.7°F</td>
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</table>

The following color flooded plots provide additional information regarding the temperature distribution in the inner and outer shells for the same time points.
Temperature (°F), Time = 60.5 hr

INNER SHELL AT END OF FIRE

OUTER SHELL AT END OF FIRE
INNER SHELL 3 MINUTES INTO THE QUENCH OPERATION

OUTER SWELL 3 MINUTES INTO THE QUENCH OPERATION
13. **APPENDIX C - JUSTIFICATION OF THERMOPHYSICAL PROPERTIES ASSUMED FOR VOID VOLUMES WITHIN THE STS CASK**

Although the void volumes within the STS cask and the Large Diameter Container (LDC) will be filled with a combination of helium, hydrogen, oxygen, water vapor, and residual air from the backfill operation, the thermal modeling assumed that the gases in these void volumes can be characterized using the thermophysical properties of helium. This modeling approach is justified because of the relative quantities of gas constituents involved, the time frame for the calculation, and the distribution of the gas constituents within the packaging.

The cask and LDC void volumes are to be filled with helium gas prior to the start of transportation. The purge and vent cycle to be used has a criteria that the oxygen concentration at the start of transportation must be \( \leq 1\% \). Since this oxygen content will result from the residual air left within the packaging, the minimum helium content will be \( 100\%-1\%/21\% = 95.2\% \), where the 21\% factor represents the relative portion of oxygen in air. Pressurization of the packaging with helium above atmospheric pressure will also increase the relative helium content. Since the thermal conductivity of air is only about 1/5 of that of helium, the thermal conductivity of the gas mixture will also be reduced, with the amount of reduction ranging from about 8\% for conduction, to less than 2\% for heat transfer via convection. The lower impact on convection heat transfer is due the associated changes in gas density, viscosity, and specific heat which tend to increase the buoyancy driven convection forces.

The addition of hydrogen gas to the void volumes from chemical reactions and/or radiolysis will increase the thermal conductivity of the gas mixture. Since the amount of increase is a function of the mole fraction of the gas constituents, the thermal conductivity of the gas mixtures will increase as longer transportation periods result in larger amounts of generated hydrogen gas. Using the gas constituents for the case with a 4 psig initial backfill condition (see Table 9.4), the thermal conductivity of the gas mixture will be approximately 3\% higher than that for pure helium environment after 60 hours of transportation, while the associated convection rate will be approximately 8\% higher.

Given that the sludge payload is assumed to begin the safety basis transportation conditions colder than the ambient, the general flow of heat is from the cask into the sludge container. As such, the use of a pure helium environment will tend to over-estimate this heat transfer rate between the cask sidewall and the container during the initial portion of the simulated 60-hour transportation period. Since this would result in higher sludge temperatures and greater gas generation from chemical reactions, it is conservative to ignore the presence of air in the gas mixture. While the opposite effect is true at the end of the 60-hour period where the thermal conductivity of the gas mixture could be 3\% higher than a pure helium environment, the effect is small and more than offset by the demonstrated conservatisms during the initial portion of the transportation process. Further, the 3\% increase in gas conductivity due to the presence of hydrogen is predicated on a safety basis rate of hydrogen gas generation and the assumption that the initial quantity of helium gas is that for a sludge payload with gas retention (i.e., a greater helium quantity will be required if the gas retention within the sludge is less than 35\% by volume). Per the Reference [3.1] analysis, the design basis sludge will generate less than 6\% of the hydrogen gas generated under the safety basis sludge assumptions. Therefore, overall, the use of a pure helium environment for the NCT analyses will yield conservative results for sludge temperature and gas generation rates.
The same logic applies to the HAC analysis since, of the 32.7 g-moles of hydrogen gas estimated to be generated during the simulated 30-minute fire and 11.5-hour post-fire cool down period (see Table 9-6 and Figure 9-6), less than \(6\) g-moles are generated during the first 45-minutes, whereas up to \(477\) g-moles of steam are generated during the same time frame. As such, the thermal conductivity of the gas mixture during this critical time frame can be expected to be decreased substantially from that of a pure helium environment due to the presence of water vapor with its associated relatively low thermal conductivity. Only after the quench operation has re-condensed the water vapor will the thermal conductivity of the gas mixture rise above that for a pure helium environment. Therefore, the use of a pure helium environment \textbf{will} conservatively increase the heat transfer into the sludge container during the fire event and conservatively restrict the heat flow out of the container during the post fire cool-down period.
Fluor Federal Services

CALCULATION IDENTIFICATION
AND INDEX

Status and description of the attached Calculation Sheets.

Discipline: Criticality & Shielding

Project No. & Title: K East Basin Sludge and Water System - Project A-16

Calculations: Supplemental Report to the STS Process Shield Plate Analysis of PacTeC Calc. 12099-21 Rev. 3

Check applicable box: (when required by project)

- Safety Class
- Safety Significant
- General Service
- Not Determined

These calculations apply to:

Drawing No. ____________________________  Rel. No ____________________________
Drawing No. ____________________________  Rel. No ____________________________

Other (Study, CDR) ____________________________  Rev. No. ____________________________

The status of these calculations is:

- Final Calculations
- Void Calculations (reason voided):

Were calculations incorporated into the final drawings?  Yes  No
 Were calculations verified by independent “check” calculations?  Yes  No

Original and Revised Calculation Approvals

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<td>J. V. Nelson</td>
<td>09/02</td>
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<td>H. Toft &amp; L. Armstrong</td>
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INDEX

Calculation Sheet Page No.  

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7.0 Calculations
7.3 Results
8.0 Conclusion
9.0 References
10.0 Input/Output Files

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7.0 CALCULATIONS ........................................................................................................... 1
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  Penetrations ................................................................................................................ 4

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Figure 7-5. Average Dose Rates (in mrem/hr) for 2.0 m³ of TI-015 Rev 9-60/40 Sludge–Open
  Penetrations .............................................................................................................. 4
1.0 INTRODUCTION

This report simply extends the average dose rate tallies above the process shield plate provided by PacTec (12099-21, Rev.3) to the well area where information was not reported. This task began with a PacTec delivered (11/7/02) CD, which has nearly 1.6 gigabytes of digital records regarding the STS Process Shield Plate (PSP) Analysis. The package included the input and output files for source generation and Monte Carlo geometric model, source tape, restart files, post processing excel data spread sheets, PacTec calculation package (23 pages, Calc. No.12099-21 Rev.3) and LDC cask shielding analysis records. The FFS extended analysis started with two cases best described by the Table 7-3 of the PacTec report. For the purpose of clarification and continuation of work, this table is shown below:

Table 7-3. MCNP Case Identification

<table>
<thead>
<tr>
<th>Case</th>
<th>Shield Penetrations</th>
<th>Source</th>
<th>Source Volume</th>
<th>Total Source Strength</th>
</tr>
</thead>
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<tr>
<td>Psp5zi</td>
<td>NA</td>
<td>Rev 9 of TI-015 60/40 sludge and water</td>
<td>2.0m³ sludge +10” water and 275 g filter</td>
<td>1.2886x10¹⁴ (p/s)</td>
</tr>
<tr>
<td>Psp70zi</td>
<td>Open</td>
<td>Psp5zi tape</td>
<td>Uses Psp5zi</td>
<td>1.2886x10¹⁴ (p/s)</td>
</tr>
<tr>
<td>Psp71zi</td>
<td>Plugged</td>
<td>Psp5zi tape</td>
<td>Uses Psp5zi</td>
<td>1.2886x10¹⁴ (p/s)</td>
</tr>
<tr>
<td>Psp72zi</td>
<td>Open</td>
<td>Rev 9 of TI-015 60/40 sludge</td>
<td>4.15 m³</td>
<td>2.673x10¹⁴ (p/s)</td>
</tr>
<tr>
<td>Psp73zi</td>
<td>Plugged</td>
<td>Rev 9 of TI-015 60/40 sludge</td>
<td>4.15 m³</td>
<td>2.673x10¹⁴ (p/s)</td>
</tr>
</tbody>
</table>

Sections 2.0 through 6.0 (Design Inputs, Material Properties, Condition Analyzed, Acceptance Criteria and Assumptions) are all omitted from this report because they are the same as in the referenced PacTec report. Also Sections 7.1 (Source Terms) and 7.2 (MCNP™ Model Specification), along with associated tables and figures, are omitted for the same reason.

7.0 CALCULATIONS

The calculation preserved all the assumed parameters including the source terms, material densities, material compositions, penetrations and shield plate dimensions. The analysis also retained the source tape and the STS configuration. The only changes to the models were that tally points and the associated problem cells were added. Case psp5zi models only the partial container where the sludge rises and was used to generate the surface source file called rssa (referenced to as “tape” in Table 7-3), which was repeatedly utilized by the follow up calculations. A surface source file allows records of particles crossing a surface in one problem to be used as the source for subsequent problems. The de-coupling of a calculation into several parts allows detailed design or analysis of certain geometrical regions without having to rerun the entire problem from the beginning each time. Consequently, the input files psp70zi and psp71zi, represent the model that starts with a boundary where psp5zi left off.

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7.3 Results

The extended results in the well area, shown in Figure 7-4 and Figure 7-5, were computed using MCNP4C (Johnson, 2002). Cases psp70zi and psp71zi simulate the unplugged and plugged conditions for the inlet/outlet penetrations subject to normal source intensity. Cases psp72zi and psp73zi are the corresponding input files for the accident source condition, which is only a factor of \(-2\) different from that of the normal condition (see the Total Source Strength column of Table 7-3) and was not re-analyzed.

Table 7-7 and Table 7-8 have also been adjusted. The previous dose rates values in those two tables are due to the particle streaming through the penetrations projected at +30 cm vertical location (shown in the figures). The new values reflect the streaming at the plate surface (\(-35\) cm surface mark), the deepest reachable position.

There are many ways of averaging flux distributions over reasonably divided regions. To further simplify the matter, extra tallies in the well area are made on existing surfaces and their extended volumes to prevent any discontinuity from the original dose chart.

8.0 CONCLUSION

It is a common practice to bend penetration paths through a shield such as the ones designed five years ago for the MCO lid (WHC-SD-SNF-CAVR-001) for the SNF project. Straight openings such as the ones in the current design do not attenuate the peak dose rates axially regardless of the thickness of cover material. Since the process shield plate of STS has already been manufactured, it is too late to address design options to reduce the dose rates. Using time-motion analysis to control the access occasions to the high radiation zone with the help of lead blankets is the only alternative to minimize cumulative exposures at this point. The extended well area dose map provided here will assist the crucial ALARA analysis to help minimize the effect of operators' contact doses.

9.0 REFERENCES


PACTEC Calc. No. 12099-21, STS Process Shield Plate Analysis, Rev. 3, 11/01/02.


1 Note that the Figure and Table numbers are taken from the original PacTec report.
<table>
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<tr>
<th>Penetration</th>
<th>HEPA</th>
<th>Rupture Disk</th>
<th>Inlet</th>
<th>Outlet</th>
</tr>
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<tr>
<td>90 cm</td>
<td>12.0±3%</td>
<td>10.5±2%</td>
<td>7.4±1%</td>
<td>3.711%</td>
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<tr>
<td>- 60</td>
<td>17.0±2%</td>
<td>13.7±1%</td>
<td>8.6±1%</td>
<td>3.4±1%</td>
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<tr>
<td>- 30</td>
<td>20.5±2%</td>
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<td>9.1±1%</td>
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<td>- 0</td>
<td>24.3±2%</td>
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<td>9.5±1%</td>
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<tr>
<td>-18 cm</td>
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<td>-35 cm</td>
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<td></td>
<td>82.7±1%</td>
<td>36.9±1%</td>
<td>9.3±1%</td>
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Figure 7-4. Average Dose Rates (in mrem/hr) for 2.0 m³ of TI-015 Rev 9- 60/40 Sludge–Plugged Penetrations

Table 7-7. Dose Rates above Penetrations for 2.0 m³ of TI-015 Rev 9- 60/40 Sludge–Plugged Penetrations

"Centered" refers to the area immediately above the pipe inner diameter (ID) projected upward to the elevation of interest. "Annulus" is the annular area between the PSP penetration ID and the pipe ID.
Figure 7-5. Average Dose Rates (in mrem/hr) for 2.0 m³ of TI-015 Rev 9-60/40 Sludge-Open Penetrations

Table 7-8. Dose Rates above Penetrations for 2.0 m³ of TI-015 Rev 9-60/40 Sludge-Open Penetrations

<table>
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<th>Penetration</th>
<th>HEPA</th>
<th>Rupture Disk</th>
<th>Inlet</th>
<th>Outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>-35 cm Dose rate Centered (mrem/hr)</td>
<td>593±12%</td>
<td>622±7%</td>
<td>297±8%</td>
<td>401±4%</td>
</tr>
<tr>
<td>-35 cm Dose rate Annulus (mrem/hr)</td>
<td>195±3%</td>
<td>195±3%</td>
<td>245±2%</td>
<td>172±2%</td>
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“Centered” refers to the area immediately above the pipe inner diameter (ID) projected upward to the elevation of interest. “Annulus” is the annular area between the PSP penetration ID and the pipe ID.
10.0  INPUT/OUTPUT FILES

The input files PSP80z.i and PSP81z.i listed here were created from the PacTec files PSP70z.i and PSP71z.i referenced in Table 7-3. Due to their large volumes, output files will be stored in a CD and delivered to be contained in the A-16 Project files.

Input file for Case PSP80z.i

PSP plate, 2.0m*3 photon 60/40 sludge source, 10° cover w/o plugs
c                        case with extra cells for optimization
1  6  -7.82  -12 -10  4 (11 :-5 ) $ inner zone
2  51  -11.35  -13 -6  5 12 $ radial lead
3  51  -11.35  -14 -6  5 13 $ radial lead
4  6  -7.82  -15 -10  1 114 :-2 ) $ outer zone
5  6  -7.82  -13 -5  3 (12 : -4 ) $ 2nd axial SS bottom
6  6  -7.82  -13 -10  6 12 $ 2nd axial SS top ring
7  6  -7.82  -14 -5  2 (13 :-3 ) $ 3rd axial SS bottom
8  6  -7.82  -14 -10  6 13 $ 3rd axial SS top ring
c            inside cask
11  71  -1.41  1-31 -22  21 ):(-33 -21 } $ sludge-source 1.33 or 1.41
12  4  -1  1-31 22 -23 ) $ water
14  77  -0.00123  1-31 -24 ):(-35 24 63 64 ) $ air above water
15  6  -7.82  -34 -21  33 $ lower IC
16  6  -7.82  -32 -24  31 21 $ middle IC
17  6  -7.82  -36 24  61 62 63 64 $ top IC
20  77  -0.00123  -11 -21  5 34 $ upper axial air beyond IC
21  77  -0.00123  -11 -22  21 32 $ mid radial air beyond IC
22  77  -0.00123  -11 -24  22 32 $ upper radial air beyond IC
23  77  -0.00123  -11 -34  24 61 62 63 64 #140 #47 #49 #50 #146 $ air above
IC
C            PSP plate
31  6  -7.82  -42 47 -15 41 (10 :-48 ) $ side and top
32  6  -7.82  -44 43 -81 82 83 84 85 151 152 153 55 55 $ bottom 1st layer
      (56 :57 :58 :59 )):(-153 152 -44 43 154)
33  6  -7.82  -45 44 -48 51 52 53 84 55 151 152 85 155 $ bottom 2nd layer
      (56 :57 :58 :59 )):(-85 185 -45 55 53):(-155 185 -45):
      (-84 54 -45 144 57)
34  6  -7.82  -46 45 -48 51 52 53 54 55 151 152 $ bottom 3rd layer
      (56 :57 :58 :59 ))
35  6  -7.82  -47 46 -48 51 52 53 54 55 152 111 113 $ bottom 4th layer
      (56 :57 :58 :59 )):(-112 46 -113 54 57)
37  77  -0.00123  -60 47 -41 61 62 63 64 #47 #49 #150 $ air above
38  77  -0.00123  -11 48 -10 43 $ air gap at annulus
C            Gaps around Penetration top of shield
40  77  -0.00123  -147 44 ((-51 61 ):(-52 62 ):(-53 63 ): $ annulus air
      1-54 64 ):(-55 105 )):(-43 -46 -151):(-47 -152 87):
      143 -87 -86) (146 -144 -84 54 57)
41  77  -0.00123  -47 44 -56 -57 -58 -59 $ annulus around lug
      166 :67 :68 :69
C            Penetration pipes
42  6  -7.82  35 24 -70 ((-61 71 ):(-62 72 )) $ Vent pipes
43  77  -0.00121  35 24 -70 ((-71 101):( -72 102)) $ Vent pipes
# A16-N-002. Rev. 0

## Pipe plugs and Air

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<th>-7.82</th>
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<tr>
<td>Inlet, Outlet pipes</td>
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<td>Pipe caps</td>
<td></td>
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</tr>
<tr>
<td>Air beyond cask</td>
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## Pipe collars in shield plate

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<td>Cask ID-OD</td>
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<tr>
<td>OD-OD+30</td>
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## Gaps around Penetration Bottom of shield

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<td>Pipe caps</td>
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<tr>
<td>Air beyond cask</td>
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<td></td>
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## Air beyond cask

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<th>-7.82</th>
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<tbody>
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<td>Volume centered over p</td>
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<tr>
<td>15&quot;-cask ID</td>
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<tr>
<td>Cask ID-OD</td>
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<tr>
<td>OD-OD+10 cm</td>
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## Added for tally well area

<table>
<thead>
<tr>
<th>Added for tally well area</th>
<th>15&quot;-cask</th>
<th>160</th>
<th>-7.82</th>
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<tbody>
<tr>
<td>One meter above shield</td>
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<tr>
<td>One meter, 30 cm</td>
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</tbody>
</table>

---

Page 9-87
C collar and hole OR

100 1 pz -4.7498 $ Bottom elevation of pipe plugs and collars 0.13-2"
mode  p
tr1 0.0 0.0 279.4 $ bottom of lower PSP 91+19.0\,\text{h} \text{ el}
m4 1000.  0.6667 $MAT
$000.  0.3333

m6  6000.  -0.0008 $MAT
  25055. -0.02 15000. -0.00045 28000. -0.0025
  24000. -0.19  26000. -0.0075 16000. -0.0003
  14000. -0.015  7000. -0.001
m51 $2000. 1  $ lead
c $ 40/60 sludge actinides
  c  95241. -3.62E-03  93237. -1.21E-03  94238. -1.04E-06
  c  94239. -1.21E-03  94240. -1.98E-04  94241. -1.53E-05
  c  94242. -4.18E-06  92235. 0.00204  92238. -0.211

m71 $000.  -0.07833 $MAT
  $000.  -0.95719 14000. -0.29448

m77 $8000.  0.22 $MAT
  7000.  0.78
   
   imp:p 128  32  8  2  32  $1, 6
   128  2   128  16  32  $7, 12
   64  16  512  1r  16  $14, 20
   1r  512  1024  2048  1024  $21, 32
   c  2048  4r  8048  2048  19r  $33, 134
   2048  4r   2048  19r  $33, 134
   1024  2048  1r  8048  15r  $140, 384
   8048  5r
   1024  8   2r   0  $191, 139
   
   prdmp  j j 1 2
   print
   phys:p  j 1
   ctime 800
   
c ssr old=24 new=24
   
c water dose response
   
c ansi/ans-6.1.1-1977 fluence-to-dose, photons (mrem/hr)/(p/cm^2/s)
   de0 0.01 0.03 0.05 0.07 0.10 0.15 0.20 0.25 0.30
   0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.80
   1.00 1.40 1.80 2.20 2.60 2.80 3.25 3.75 4.25
   
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<table>
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<tr>
<th>fdf0</th>
<th>df0</th>
<th>4.75</th>
<th>5.00</th>
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<th>6.25</th>
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<th>7.50</th>
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<td>3.96-3</td>
<td>5.82-4</td>
<td>2.90-4</td>
<td>2.58-4</td>
<td>2.83-4</td>
<td>3.79-4</td>
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<td>6.31-4</td>
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<td>9.85-4</td>
<td>1.08-3</td>
<td>1.17-3</td>
<td>1.27-3</td>
<td>1.36-3</td>
<td>1.44-3</td>
<td>1.52-3</td>
<td>1.68-3</td>
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<td>5.60-3</td>
<td>5.80-3</td>
<td>6.01-3</td>
<td>6.37-3</td>
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<td>7.11-3</td>
<td>7.65-3</td>
<td>8.77-3</td>
<td>1.03-2</td>
<td>1.18-2</td>
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| f112  | 42  |       |       |       |       |       |       |       |       |       |
| f112p | -406 | -407 | -41  | -15  | -408  |       |       |       |       |       |
| f112s | 1297.17 | 3263.2 | 8774.603 | 13115.48 | 20123.3 | 68945.5 |

| f312  | 30  |       |       |       |       |       |       |       |       |       |
| f312p | 400 |       |       |       |       |       |       |       |       |       |
| f312s | 1297.17 | 3263.2 | 8774.603 | 13115.48 | 20123.3 | 0.01 |

| f322  | 60  |       |       |       |       |       |       |       |       |       |
| f322p | 401 |       |       |       |       |       |       |       |       |       |
| f322s | 1297.17 | 3263.2 | 8774.603 | 13115.48 | 20123.3 | 0.01 |

| f332  | 90  |       |       |       |       |       |       |       |       |       |
| f332p | 402 |       |       |       |       |       |       |       |       |       |
| f332s | 1297.17 | 3263.2 | 8774.603 | 13115.48 | 20123.3 | 0.01 |

| f342  | 120 |       |       |       |       |       |       |       |       |       |
| f342p | 403 |       |       |       |       |       |       |       |       |       |
| f342s | 1297.17 | 3263.2 | 8774.603 | 13115.48 | 20123.3 | 0.01 |

| f352  | 180 |       |       |       |       |       |       |       |       |       |
| f352p | 404 |       |       |       |       |       |       |       |       |       |
| f352s | 1297.17 | 3263.2 | 8774.603 | 13115.48 | 20123.3 | 0.01 |

| f362  | 300 |       |       |       |       |       |       |       |       |       |
| f362p | 405 |       |       |       |       |       |       |       |       |       |
| f362s | 1297.17 | 3263.2 | 8774.603 | 13115.48 | 20123.3 | 0.01 |

| f412  | 30  |       |       |       |       |       |       |       |       |       |
| f412p | 406 |       |       |       |       |       |       |       |       |       |
| f412s | 1297.17 | 3263.2 | 8774.603 | 13115.48 | 20123.3 | 0.01 |

| f422  | 60  |       |       |       |       |       |       |       |       |       |
| f422p | 407 |       |       |       |       |       |       |       |       |       |
| f422s | 1297.17 | 3263.2 | 8774.603 | 13115.48 | 20123.3 | 0.01 |

| f432  | 90  |       |       |       |       |       |       |       |       |       |
| f432p | 408 |       |       |       |       |       |       |       |       |       |
| f432s | 1297.17 | 3263.2 | 8774.603 | 13115.48 | 20123.3 | 0.01 |

| f442  | 120 |       |       |       |       |       |       |       |       |       |
| f442p | 409 |       |       |       |       |       |       |       |       |       |
| f442s | 1297.17 | 3263.2 | 8774.603 | 13115.48 | 20123.3 | 0.01 |

| f452  | 300 |       |       |       |       |       |       |       |       |       |
| f452p | 410 |       |       |       |       |       |       |       |       |       |
| f452s | 1297.17 | 3263.2 | 8774.603 | 13115.48 | 20123.3 | 0.01 |

| f462  | 60  |       |       |       |       |       |       |       |       |       |
| f462p | 411 |       |       |       |       |       |       |       |       |       |
| f462s | 1297.17 | 3263.2 | 8774.603 | 13115.48 | 20123.3 | 0.01 |

| f472  | 90  |       |       |       |       |       |       |       |       |       |
| f472p | 412 |       |       |       |       |       |       |       |       |       |
| f472s | 1297.17 | 3263.2 | 8774.603 | 13115.48 | 20123.3 | 0.01 |

| f482  | 120 |       |       |       |       |       |       |       |       |       |
| f482p | 413 |       |       |       |       |       |       |       |       |       |
| f482s | 1297.17 | 3263.2 | 8774.603 | 13115.48 | 20123.3 | 0.01 |

| f492  | 300 |       |       |       |       |       |       |       |       |       |
| f492p | 414 |       |       |       |       |       |       |       |       |       |
| f492s | 1297.17 | 3263.2 | 8774.603 | 13115.48 | 20123.3 | 0.01 |

| f502  | 60  |       |       |       |       |       |       |       |       |       |
| f502p | 415 |       |       |       |       |       |       |       |       |       |
| f502s | 1297.17 | 3263.2 | 8774.603 | 13115.48 | 20123.3 | 0.01 |

| f512  | 90  |       |       |       |       |       |       |       |       |       |
| f512p | 416 |       |       |       |       |       |       |       |       |       |
| f512s | 1297.17 | 3263.2 | 8774.603 | 13115.48 | 20123.3 | 0.01 |

| f522  | 120 |       |       |       |       |       |       |       |       |       |
| f522p | 417 |       |       |       |       |       |       |       |       |       |
| f522s | 1297.17 | 3263.2 | 8774.603 | 13115.48 | 20123.3 | 0.01 |

| f532  | 300 |       |       |       |       |       |       |       |       |       |
| f532p | 418 |       |       |       |       |       |       |       |       |       |
| f532s | 1297.17 | 3263.2 | 8774.603 | 13115.48 | 20123.3 | 0.01 |
fs512:p 60
fs512 -72 -52 -82
sd512 21.649 123.3832 69.05156 115181.
c
fs512 surface 400 axial p dose rate (mrem/hr) Rupture dk at 30 above PSP
fs512:p 400
fs512 -72 -52 -82
sd512 21.649 123.3832 69.05156 46235.
c
fs512 surface 401 axial p dose rate (mrem/hr) Rupture dk at 60 above PSP
fs512:p 401
fs512 -72 -52 -82
sd512 21.649 123.3832 69.05156 46235.
c
fs512 surface 402 axial p dose rate (mrem/hr) Rupture dk at 90 above PSP
fs512:p 402
fs512 -72 -52 -82
sd512 21.649 123.3832 69.05156 46235.
c
fs612:p 60
fs612 -73 -53 -83
sd612 13.1344 111.5238 65.1261 115181.
c
fs612 surface 400 axial p dose rate (mrem/hr) Inlet top of PSP (changed)
fs612:p 400
fs612 -73 -53 -83
sd612 13.1344 111.5238 65.1261 46235.
c
fs612 surface 401 axial p dose rate (mrem/hr) Inlet at 30 above PSP
fs612:p 401
fs612 -73 -53 -83
sd612 13.1344 111.5238 65.1261 46235.
c
fs612 surface 402 axial p dose rate (mrem/hr) Inlet at 60 above PSP
fs612:p 402
fs612 -73 -53 -83
sd612 13.1344 111.5238 65.1261 46235.
c
fs612 surface 402 axial p dose rate (mrem/hr) Inlet at 90 above PSP
fs612:p 402
fs612 -73 -53 -83
sd612 13.1344 111.5238 65.1261 46235.
c
fs712:p 60
fs712 -74 -54 -84
sd712 47.6954 190.7591 98.1133 115181.
c
fs712 surface 400 axial p dose rate (mrem/hr) Outlet top of PSP (changed)
fs712:p 400
fs712 -74 -54 -84
sd712 47.6954 190.7591 98.1133 46235.
c
fs712 surface 401 axial p dose rate (mrem/hr) Outlet at 30 above PSP
fs712:p 401
fs712 -74 -54 -84
sd712 47.6954 190.7591 98.1133 46235.
c
fs712 surface 402 axial p dose rate (mrem/hr) Outlet at 60 above PSP
fs712:p 402
fs712 -74 -54 -84
sd712 47.6954 190.7591 98.1133 46235.
c
fs712 surface 402 axial p dose rate (mrem/hr) Outlet at 90 above PSP
fs712:p 402
fs712 -74 -54 -84
sd712 47.6954 190.7591 98.1133 46235.
c Cell doses

fc114 Cell p dose rate (mrem/hr) 0 to 30 above top of PSP
f114:p 180 181 182 183 184
fc124 Cell p dose rate (mrem/hr) 30 to 60 above top of PSP
f124:p 280 281 282 283 284
fc134 Cell p dose rate (mrem/hr) 60 to 90 above top of PSP
f134:p 380 381 382 383 384

---------------------------------------------

fc144 Cell p dose rate (mrem/hr) 0 to -30 below top of PSP (added)
f144:p 480 481 482
fc154 Cell p dose rate (mrem/hr) -30 to -60 below top of PSP (added)
f154:p 580 581 582
sd154 20845.54 52439.56 141007.87

Input file for Case PSP8lz.i

PSP plate, 2.0m**3 photon 60/40 sludge source, 10" cover w/5 5.5 plugs
c cask with extra cells for optimization:
  1  6  -7.82 -12  -10  4 (11  -5 ) $ inner zone
  2  5 1  -11.35 -13  -6  5 12 $ radial lead
  3  5 1  -11.35 -14  -6  5 13 $ radial lead
  4  6  -7.82 -15  -10  1 (14  -2 ) $ outer zone
  6  6  -7.82 -13  -5  3 (12  -4 ) $ 2nd axial SS bottom
  7  6  -7.82 -13  -10  6 12 $ 2nd axial SS top ring
  6  6  -7.82 -14  -5  2 (13  -3 ) $ 3rd axail SS bottom
  6  6  -7.82 -14  -10  6 13 $ 3rd axial SS top ring

c inside cask:
  11  71  -1.41 (-31  -22  21 ):(-33  -21) $ sludge-source 1.33 or 1.41
  12  4  -1 (-31  -22  -23 ) $ water
  14  77  -0.00123 (-31  -23  -24):(-35  24  63  64 ) $ air above water
  15  6  -7.82 -34  -21  33 $ lower IC
  16  6  -7.82 -32  -24  31 21 $ middle IC
  17  6  -7.82 -36  24  35 61 62 63 64 $ top IC
  20  77  -0.00123 -11  -21  5 34 $ lower air beyond IC
  21  77  -0.00123 -11  -22  21 32 $ mid radial air beyond IC
  22  77  -0.00123 -11  -24  22 32 $ upper radial air beyond IC
  23  77  -0.00123 -11  -43  24 36 61 62 63 64 #140 #47 #49 #50 #146 $ air above IC

PSP plate:
  31  6  -7.82 -42  47  -15  41 (10  -48) $ side and top
  32  6  -7.82 (-44  43  -48  81  82  83) 84  85  151 152 153 55 155 $ bottom 1st layer
  33  6  -7.82 (-45 44  -48  51 52 53 84  55 151 152 85 155 $ bottom 2nd layer
(56 57 :58 :59 ):(-153 152  -44 43 154 )
  34  6  -7.82 (-46 45  -48  51 52 53 54 55 151 152 $ bottom 3rd layer
(56 57 :58 :59 )
  35  6  -7.82 (-47 46  -48  51 52 53 54 55 152 111 113 $ bottom 4th layer
(56 57 :58 :59 ):(-112 46  -111 51 57 ):(-114 46  -113 54 57 )
  37  77  -0.00123 (-60 47  -41 61 62 63 64 ) #47 #49 #150 $ air above annulus
  38  77  -0.00123 -11 48  -10 43 $ air gap at annulus
  39  77  -0.00123 (-42 60  -41 47  #47 #49 #150 $ air above annulus

Gaps around penetration top of shield:
  40  77  -0.00123 (-47 44  (-51 61 ):(-52 62 ):(-53 63 ) $ annulus air
(54 64 ):(-55 1051 11:(43  -46 -151 ):(-47  -152 87 )
(43  -87  -86 ):144 -144 -84 54 57 )
  41  77  -0.00123 (-47 44  -56 57  -58 59 $ annulus around lug
(66 67 68 :69 )
Penetration pipes
42  77 -0.00123 35 24 -70 (-71 101):(-72 102) $ Vent pipes
43  77 -0.00123 35 24 -70 (-71 101):(-72 102) $ Vent pipes
44  77 -0.00123 24 -70 (-63 73);(-64 74) $ Inlet, outlet pipes
45  77 -0.00123 24 -70 (-73 101);(-74 104) $ Inlet, outlet pipes
46  77 -0.00123 36 24 -49 -60 (-66 -67 -68 -69) $ lifting Lug
47  77 -0.00123 79 -78 -76 -77 -66 -67 $ lug hole
48  77 -0.00123 (24 43 -65 75) (-95 43 -1861 $ Level pipe and flange

Pipe plugs and Air
52  77 -0.00123 (-47 43) (-101 -102) $ Vent pipes interior
53  77 -0.00123 135 24 -70 (-101 -102) $ #52 $ Vent pipes void
54  77 -0.00123 (-47 43) (-103 -104) $ Inlet, outlet pipes
55  77 -0.00123 (24 -70 (-103 -104)) $ #54 $ Inlet, outlet pipes
56  77 -0.00123 -47 44 -105 $ level pen

Pipe collars in shield plate
57  77 -0.00123 -44 43 -56 -57 -58 -59 $ annulus around lug
106 :67 :68 :69

Gaps around Penetration Bottom of shield
130 77 -0.00123 (-80 43 (-81 91):(-82 92):(-83 93):$annulus air
(-84 94):(-84 94):(-85 95 63)) $140 #131 #47 #49 #50
131 77 -0.00123 -44 43 -56 -57 -58 -59 $ annulus around lug
166 :67 :68 :69
132 77 -0.00123 (-154 87 152 -153):(-87 43 -153 #148 #6) $ sensor gap
133 77 -0.00123 (44 -185 -85 55 53):(-155 43 -1851 $ level gap
134 77 -0.00123 (-47 112 -111 51 57):(-47 114 -113 54 57) $ top air counter

Penetration pipes
140 6 -7.82 (-80 24 36 100 (-91 61);(-92 62);$Collars in plate
1-93 63};(-94 64 -184}) $111 #47 #49 85
145 77 -0.00123 -44 80 (-81 61);(-82 62);(-83 63); $ gap above col
(-84 64);(-85 63); #131 #47 #49 #50
146 6 -7.82 97 -87 86 -96 56 $sensor puck
150 6 -7.82 (55 -156 -58 -59);(57-157 -58 -59);
(58 -158 -157 -156);
(66 -159 -157 -156) (47 -160);
(96 -156 -157 -156) $ lug cap

Air beyond cask
180 77 -0.00123 -400 42 -406 $ Volume centered over p
181 77 -0.00123 -400 42 406 -407 $ 8-15" annulus
182 77 -0.00123 -400 42 407 -41 $ 15"-cask ID
183 77 -0.00123 -400 42 41 -15 $ Cask ID-OD
184 77 -0.00123 -400 42 15 -408 $ OD-OD+30 cm
280 77 -0.00123 -401 400 -406 $ Volume centered over p
281 77 -0.00123 -401 400 406 -407 $ 8-15" annulus
282 77 -0.00123 -401 400 407 -41 $ 15"-cask ID
283 77 -0.00123 -401 400 41 -15 $ Cask ID-OD
284 77 -0.00123 -401 400 15 -408 $ OD-OD+30 cm
380 77 -0.00123 -402 401 -406 $ Volume centered over p
381 77 -0.00123 -402 401 406 -407 $ 8-15" annulus
382 77 -0.00123 -402 401 407 -41 $ 15"-cask ID
383 77 -0.00123 -402 401 41 -15 $ Cask ID-OD
384 77 -0.00123 -402 401 15 -408 $ OD-OD+30 cm

480 77 -0.00123 -42 161 -406 $ added for tally well area
481 77 -0.00123 -42 161 406 -407 $ added for tally well area
482 77 -0.00123 -42 161 407 -41 $ added for tally well area
580 77 -0.00123 -161 60 -406 #47 #49 #150 $ added for tally well area
581 77 -0.00123 -161 60 406 -407 #47 #49 #150 $ added for tally well area
582 77 -0.00123 -161 60 407 -41 #47 #49 #150 $ added for tally well area
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SNF-13268, Rev. 0

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57  P  1  1  0  2.87368 $ Lift Lug
58  P  -1  1  0  56.5685 $ Lift Lug
59  P  1  -1  0  56.5685 $ Lift Lug
156  P  -1  -1  0  4.22072 $ Lift Lug cover
157  P  1  1  0  4.22072 $ Lift Lug cover
158  P  -1  1  0  57.9155 $ Lift Lug cover
159  P  1  -1  0  57.9155 $ Lift Lug cover
160  P  $ 29.591 +6.25* above top of plate
161  P  $ 34.671 +2* more

60  P  298 $ Top of pipe caps 119"
70  P  298. $ bottom of caps --none

61  c/z  0.0  16.51  3.01625 $ Hepa Vent
62  c/z  0.0  16.51  2.6251  $ Hepa Vent
63  c/z  -16.51  0  2.413 $ Inlet
64  c/z  -16.51  0  2.0447  $ Inlet
65  c/z  16.51  0  4.445 $ Outlet
66  c/z  -33.02  0  5.715 $ Level
67  c/z  -33.02  0  5.4102 $ Level
68  P  -1  1  0  2.245 $ Lift Lug
69  P  1  1  0  2.245 $ Lift Lug
70  P  0.18525  0.18525  0.3242  100.0 $ Lift Lug
71  P  0.18525 -0.18525  0.3242  100.0 $ Lift Lug
72  P  -1  1  0  5.388 $ Lift Lug hole
73  P  1  -1  0  5.388 $ Lift Lug hole
74  P  295.275 $ top of lug hole
75  P  276.86 $ bottom of lug hole
76  P  295.275 $ top of lug hole
77  P  276.86 $ bottom of lug hole

80  P  0.3302 $ top of collars 0.13* inset
81  c/z  0.0  16.51  7.5184  $ Hepa Vent 5.92* dia
82  c/z  0.0  16.51  8.2555  $ Hepa Vent 6.5*
83  c/z  0.0  16.51  10.795 $ Hepa Vent 8.5* od top cb
84  c/z  0.0  16.51  12.7635 $ top counter bore inset 5.4-3/8"
85  c/z  0.0  -16.51  7.5184 $ Rupture Disk 5.92* dia
86  c/z  0.0  -16.51  8.2555 $ Rupture Disk 6.5*
87  c/z  -16.51  0  6.985 $ Inlet 5.5* dia
88  c/z  -16.51  0  7.7724 $ Inlet 3.06 R
89  c/z  16.51  0  9.4488 $ Outlet 7.44 dia
90  c/z  16.51  0  10.3505 $ Outlet 8.15
91  c/z  -4.7498 $ bottom sensor puck OR
184  P  -0.00257163  0.00257163  0.00363683  1.0 $45 deg notch in outlet puck
110.13" el

113  c/z  16.51  0.0  12.3825 $ outlet 9.75* od top cb
114  P  11.811 $ top counter bore inset 5.4-.75"
95  c/z  -33.02  0  12.7 $ Level
85  c/z  -33.02  0  14.605 $ Level 11.5* OD
185  P  4.1402 $ level counter bore depth
186  P  1.27 $ level plate thickness
86  c/z  -39.5564 29.8079  1.3843 $ sensor wash puck hole
87  P  0.3302 $ top of sensor puck (.13")
96  c/z  -39.5564 29.8079  7.493 $ sensor wash puck OR
97  P  -4.7498 $ bottom sensor puck (0.13-2")

100  P  -4.7498 $ Bottom elevation of pipe plugs and collars 0.13-2*"
A16-N-002, Rev. 0

103 c/z -16.51 0 1.5875 $ Inlet 1.25''
104 c/z 16.51 0 3.33375 $ Outlet 2-5/8''
105 c/z -33.02 0 3.816 $ Level

c 162 c 92.7575

104 c/z -16.24

c 163 p 262 c 191.7575

263 p 266 c 432.74

362 c 291.7575

363 p 215.24

366 p 520.04

399 sos 2000 $ outside world

400 p 20400 $ 30 cm Above top of shield

401 p 20402 $ 60 cm Above top of shield

402 p 20406 $ 90 cm Above top of shield

406 cz 20.32 $ 8'' radius

401 cz 38.1 $ 15'' radius

408 cz 121.7575 $ 30 cm beyond outer radius

mode p

t1 0.0 0.0 279.4 $ bottom of lower PSP $1+19.0'' el

m1 1000. 0.6667 $MAT

8000. 0.3333

c $-304

m6 6000. -0.0008 $MAT

25055. -0.02 15000. -0.00045 28000. -0.0525

24000. -0.19 26000. -0.68745 16000. -0.0003

14000. -0.0075 7000. -0.001

m51 82000. -1 $ lead

c $40/60 sludge, assumed to be 30 vol% si02 and 70 vol% water,

m71 1000. -0.07833 $MAT

8000. -0.95714 14000. -0.29448

c $40/60 sludge actinides

c 95241. -3.62E-05 93237. -1.21E-05 94238. -1.04E-06

94239. -1.21E-03 94240. -1.98E-04 94241. -1.53E-05

94242. -4.18E-06 92235. -0.00204 92238. -0.0213

c air

m77 8000. 0.22 $MAT

7000. 0.78

imp:p 128 32 8 2 32 $ 1, 6

128 2 128 16 32 $ 7, 12

64 16 512 1r 16 $ 14, 20

1r 512 1024 2048 1024 $ 21, 32

c 2048 4r 8048 2048 19r $ 33, 134

2048 4r 2048 19r $ 33, 134

1024 2048 1r 8048 15r $ 140, 384

8048 5r $ 480, 582

1024 8 2r 0 $ 191, 199

prdmp j j 1 2

print

phys:p j 1

cpp 800

c $sr old=24 new=24

c water dose response

c ansi/ans-6.1.1-1977 fluence-to-dose, photons (mrem/hr)/(p/cm*2/s)
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| df0 | 3.96x3 5.82x4 2.90x4 2.58x4 2.83x4 3.79x4 5.01x4 6.31x4 7.59x4 |
|     | 8.78x4 9.85x4 1.08x3 1.17x3 1.27x3 1.36x3 1.44x3 1.52x3 1.68x3 |
|     | 1.98x3 2.51x3 2.99x3 3.42x3 3.82x3 4.01x3 4.41x3 4.83x3 5.23x3 |
|     | 5.60x3 5.80x3 6.01x3 6.37x3 6.74x3 7.11x3 7.66x3 8.77x3 1.03x2 |
|     | 1.18x2 1.33x2 |

c  
fc312 | surface 42 axial p dose rate (mrem/hr) at top of PSP  
f312:p 42  
fs312 | -406 -407 -41 -15 -408  
sd312 | 1297.17 3263.2 8774.603 13115.48 20123.3 68945.5  

c  
fc322 | surface 400 axial p dose rate (mrem/hr) at 30 above PSP  
f322:p 400  
fs322 | -406 -407 -41 -15 -408  
sd322 | 1297.17 3263.2 8774.603 13115.48 20123.3 0.01  

c  
fc332 | surface 401 axial p dose rate (mrem/hr) at 60 above PSP  
f332:p 401  
fs332 | -406 -407 -41 -15 -408  
sd332 | 1297.17 3263.2 8774.603 13115.48 20123.3 0.01  

c  
fc342 | surface 402 axial p dose rate (mrem/hr) at 90 above PSP  
f342:p 402  
fs342 | -406 -407 -41 -15 -408  
sd342 | 1297.17 3263.2 8774.603 13115.48 20123.3 0.01  

c  
fc352 | surface 60 axial p dose rate (mrem/hr) at -60 above PSP (added)  
f352:p 60  
fs352 | -406 -407 -41  
sd352 | 1297.17 3263.2 8774.603 0.01  

c  
fc362 | surface 161 axial p dose rate (mrem/hr) at -30 above PSP (added)  
f362:p 161  
fs362 | -406 -407 -41  
sd362 | 1297.17 3263.2 8774.603 0.01  

c  
fc412 | surface 42 axial p dose rate (mrem/hr) HEPA at top of PS? (changed)  
f412:p 60  
fs412 | -71 -51 -81  
sd412 | 21.649 123.3832 69.05156 115181.  

c  
fc422 | surface 400 axial p dose rate (mrem/hr) Hepa at 30 above PSP  
f422:p 400  
fs422 | -71 -51 -81  
sd422 | 21.649 123.3832 69.05156 46235.  

c  
fc432 | surface 401 axial p dose rate (mrem/hr) Hepa at 60 above PSP  
f432:p 401  
fs432 | -71 -51 -81  
sd432 | 21.649 123.3832 69.05156 46235.  

c  
fc442 | surface 402 axial p dose rate (mrem/hr) Hepa at 90 above PSP  
f442:p 402  
fs442 | -71 -51 -81
surface 42 axial p dose rate (mrem/hr) Rupture dk top of PSP (changed)

fc512: 60
fs512: -72 -52 -82
sd512: 21.649 123.3832 69.05156 46235.

c

surface 400 axial p dose rate (mrem/hr) Rupture dk at 30 above PSP

fc522: 400
fs522: -72 -52 -82
sd522: 21.649 123.3832 69.05156 46235.

c

surface 401 axial p dose rate (mrem/hr) Rupture dk at 60 above PSP

fc532: 401
fs532: -72 -52 -82
sd532: 21.649 123.3832 69.05156 46235.

c

surface 402 axial p dose rate (mrem/hr) Rupture dk at 90 above PSP

fc542: 402
fs542: -72 -52 -82
sd542: 21.649 123.3832 69.05156 46235.

c

Inlet top of PSP (changed)

fc612: 60
fs612: -73 -53 -83
sd612: 13.1344 111.5238 65.1261 115181.

c

Inlet at 30 above PSP

fc622: 400
fs622: -73 -53 -83
sd622: 13.1344 111.5238 65.1261 46235.

c

Inlet at 60 above PSP

fc632: 401
fs632: -73 -53 -83
sd632: 13.1344 111.5238 65.1261 46235.

c

Inlet at 90 above PSP

fc642: 402
fs642: -73 -53 -83
sd642: 13.1344 111.5238 65.1261 46235.

c

Outlet top of PSP (changed)

fc712: 60
fs712: -74 -54 -84
sd712: 47.6954 190.7591 98.1133 115181.

c

Outlet at 30 above PSP

fc722: 400
fs722: -74 -54 -84
sd722: 47.6954 190.7591 98.1133 46235.

c

Outlet at 60 above PSP

fc732: 401
fs732: -74 -54 -84
sd732: 47.6954 190.7591 98.1133 46235.

c

Outlet at 90 above PSP

fc742: 402
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CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed – A16-N-002, Rev. 0

Title: Supplemental Report to the STS Process Shield Plate Analysis of PacTec Calc. 12099-21 Rev. 3

Author: J.S. Lan

Date: December 2002

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- Referenced analyses appropriate.
- Problem completely defined and all potential configurations considered.
- Accident scenarios developed in a clear and logical manner.
- Necessary assumptions explicitly stated and supported.
- Computer codes and data files documented.
- Data used in calculations explicitly stated in document.
- Data checked for consistency with original source information as applicable.
- Mathematical derivations checked including dimensional consistency of results.
- Models appropriate and used within range of validity, or use outside range of established validity justified.
- Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
- Software input correct and consistent with document reviewed.
- Software output consistent with input and with results reported in document reviewed.
- Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
- Safety margins consistent with good engineering practices.
- Conclusions consistent with analytical results and applicable limits.
- Results and conclusions address all points required in the problem statement.
- Format consistent with applicable guides or other standards.
- Review calculations, comments, and/or notes are attached.
- Document approved (for example, the reviewer affirms the technical accuracy of the document).

J. V. Nelson  
Technical Peer Reviewer (printed name and signature.)  
13/5/02  
Date

* All "no" responses must be explained below or on an additional sheet.

** Any calculations, comments, or notes generated as part of this review should be signed, dated and attached to this checklist. The material should be labeled and recorded in such a manner as to be understandable to a technically qualified third party.
NOTES, UNLESS OTHERWISE SPECIFIED:

1. FABRICATE IN ACCORDANCE WITH PACKING SPEC OF 005.

2. TORQUE TO 500-700 FT-LB. TORQUE WITH OR WITHOUT LUBRICATION. PLACE A WASHER (ITEM 14) UNDER EACH BOLT HEAD.

3. SLOTS AND SEAL SURFACES SHALL BE LIGHTLY COATED WITH VACUUM GREASE PRIOR TO ASSEMBLY.

4. TORQUE TO 55-50 FT-LB. CLEAN PORT AND BOLT OF DIRT AND DEBRIS PRIOR TO INSTALLATION. USE NO LUBRICATION.

5. CONTAMINATION BOUNDARY SHALL BE HELIUM LEAK TESTED TO DEMONSTRATE A LEAKAGE RATE NOT TO EXCEED 1 X 10^-11 ATMOSPHERE CUBIC CENTIMETERS PER SECOND AIR IN ACCORDANCE WITH ANSI N14.5 and GF-005.

6. CASK ASSEMBLY SHALL BE HYDROSTATIC PRESSURE TESTED IN ACCORDANCE WITH GF-005.

7. LID LIFTING POINTS SHALL BE EACH LOAD TESTED TO 2200 LBS (1000 - 0 LBS). USING A CALIBRATED SCALE, AND HELD FOR 10 MINUTES. INSPECT THREADS PRIOR TO AND AFTER THE TEST. VERIFY THAT NO PERMANENT THREAD DEFORMATION OCCURS BY THREADING A CALIBRATED 3/4-1 DING HOLE THRU AND OUT OF THE LIFT POINT. LOAD TEST PROCEDURE SHALL BE SUBMITTED TO PACIFIC ENGINEERING FOR APPROVAL.

8. CASK LIFTING POINTS SHALL BE EACH LOAD TESTED TO 2000 LBS (500 - 0 LBS). USING A CALIBRATED SCALE, AND HELD FOR 10 MINUTES. INSPECT THREADS PRIOR TO AND AFTER THE LOAD TEST. VERIFY THAT NO PERMANENT THREAD DEFORMATION OCCURS BY THREADING A CALIBRATED 1/2-1 DING HOLE THRU AND OUT OF THE LIFT POINT. LOAD TEST PROCEDURE SHALL BE SUBMITTED TO PACIFIC ENGINEERING FOR APPROVAL.

1. BUTYL RUBBER SEAL MATERIAL PER RR-0405-70, RAINTER RUBBER COMPANY, SEATTLE WA.

2. TORQUE TO 250-200 FT-LB. CLEAN PORT AND BOLT OF DIRT AND DEBRIS PRIOR TO INSTALLATION. USE NO LUBRICATION.

3. TAMPER INDICATING SEAL SHALL BE INSTALLED AT EACH PORT LOCATION.

4. PLACE A 1/2 X 1/2 X 10 ID STRIPE AT THE TOP EDGE OF CASK CENTERED ON THE PLANE OF THE ALIGNMENT KEY. PACKETS TO APPROVE PAINT.

5. USING 3 ADJACENT BOLTS LOCATION Optional) DRILL A 1/4 DIAMETER HOLE THRU EACH HEAD. AFTER INSTALLATION, INSTALL TAMPER INDICATING SEAL ACROSS BOLT HEADS.

6. IDENTIFY CASK ASSEMBLY IN AREA 94 ABOVE DRAIN PORT USING 5/8 HIGH (MAX) BLACK CHARACTERS WITH THE FOLLOWING INFORMATION (STENCILED A)

MFG: PACKAGING TECHNOLOGY, INC.  SACRAMENTO, CA 95820-3350

DATE OF MFG:  
GROSS WEIGHT: 85,000 LBS. 

NOTE: PAINT BLACK AMERICOTE 450HS

INFORMATION ONLY

D-12099-200

CASK ASSEMBLY

PACKAGING TECHNOLOGY, INC.

A Transnuclear Company

CASK ASSEMBLY

SLUDGE TRANSPORTATION SYSTEM

NOTE: MFG NAME IMEI M/1 A

Rev 3
3758 ATLAS L-1/4

SNF-1268 Rev. 0
NOTES, UNLESS OTHERWISE SPECIFIED:

1. FABRICATE IN ACCORDANCE WITH PACTEC SPECIFICATION OF-006.

2. MATERIAL SIZES LISTED IN THE MATERIAL COLUMN ARE FOR REFERENCE ONLY. IT IS THE RESPONSIBILITY OF THE MANUFACTURER TO DETERMINE ACTUAL REQUIREMENTS PRIOR TO FABRICATION.

3. THIS WELD IS MADE AFTER LEAK POUR ACCEPTANCE.

4. OUTER AND INNER SHELLS SHALL COMPLY WITH TOLERANCE REQUIREMENTS OF THE ASME CODE, SECTION II, DIVISION 1, SUBSECTION NB, ARTICLE NB-4200, SUBARTICLE NB-4220, PARAGRAPH NB-4221, SUB-PARAGRAPH NB-4221.1.

5. LEAD POURING SHALL BE IN ACCORDANCE WITH PACTEC LEAD POURS PROCEDURE FP-035 AND LEAD POUR PREPARATION SHALL BE IN ACCORDANCE WITH PACTEC DRAWING 12099-215.

6. PRIOR TO LEAD POUR, THE INNER SHELL OF THE OUTER CASK SHALL BE HELIUM LEAKAGE RATE TESTED TO DEMONSTRATE A LEAKAGE RATE NOT TO EXCEED 1 X 10^(-7) STANDARD CUBIC CENTIMETER PER SECOND AIR, IN ACCORDANCE WITH ANSI N14.5-1987. TESTING SHALL BE PERFORMED IN ACCORDANCE WITH PACTEC LEAKAGE RATE PROCEDURE LT-020, OR APPROVED ALTERNATE.

7. WELD SIZE TO MATCH THICKNESS OF THINNER MATERIAL.

8. NOTE ANGULAR ORIENTATION OF NOTCHES IN BASE (ITEM 2), AND THE ALIGNMENT PIN HOLES IN THE BODY COLLAR (ITEM 1).


INFORMATION ONLY

AS-BUILT DRAWING

Dwg. No. 12099-210

Serial No. 0

Signature

Date

Page 9-113
NOTES, UNLESS OTHERWISE SPECIFIED:

1. FABRICATE IN ACCORDANCE WITH PACTEC SPECIFICATION GF-005.
2. MATERIAL SIZES LISTED IN THE MATERIAL COLUMN ARE FOR REFERENCE ONLY. IT IS THE RESPONSIBILITY OF THE MANUFACTURER TO DETERMINE ACTUAL REQUIREMENTS PRIOR TO FABRICATION.

NOT USED

VERIFY AND MATCH, -0.05 WITH INSIDE DIAMETER OF INNER SHELL, 12099-213-1.

VERIFY AND MATCH, +0.05 WITH OUTSIDE DIAMETER OF INNER SHELL, 12099-213-1.

VERIFY AND MATCH, -0.05 WITH INSIDE DIAMETER OF OUTER SHELL, 12099-214-1.

FINAL MACHINING OF INDICATED SURFACES AND PLACEMENT OF BOLT HOLES MAY BE PERFORMED AFTER WELDING AND LEAD POUR.

OPTIONAL: MATERIAL MAY BE ASME SA240, TYPE 304, EXAMINATION (AND REPAIRS, IF REQUIRED) TO BE PERFORMED ON PLATE, IN ACCORDANCE WITH ASME CODE, SECTION II, DIVISION 1, SUBSECTION NB, ARTICLE NB-2530 AND SECTION X, ARTICLE 5.

EXAMINATION (AND REPAIRS, IF REQUIRED) TO BE PERFORMED ON FORGING IN ACCORDANCE WITH ASME CODE, SECTION III, DIVISION 1, SUBSECTION NB, ARTICLE NB-2540, AND SECTION X, ARTICLES 2 AND 5.


11. INTEGRAL BACKING BAR MAY BE USED. SEE OPTIONAL INTEGRAL BACKING BAR DETAIL.
NOTES, UNLESS OTHERWISE SPECIFIED:
1. FABRICATE IN ACCORDANCE WITH PACTEC SPECIFICATION OF-006.
2. MATERIAL SIZES LISTED IN THE MATERIAL COLUMN ARE FOR RENDITION ONLY.
NOTES, UNLESS OTHERWISE SPECIFIED:

1. FABRICATE IN ACCORDANCE WITH PACTEC SPECIFICATION CF-006.

2. MATERIAL SIZES LISTED IN THE MATERIAL COLUMN ARE FOR REFERENCE ONLY. IT IS THE RESPONSIBILITY OF THE MANUFACTURER TO DETERMINE ACTUAL REQUIREMENTS PRIOR TO FABRICATION.

3. OPTIONAL SHELLS MAY BE OF ONE PIECE CONSTRUCTION, OR HAVE AN OPTIONAL CIRCUMFERENTIAL WELD. WHEN OPTIONAL CIRCUMFERENTIAL WELD IS USED, LONGITUDINAL WELDS SHALL BE STAGGERED A MINIMUM OF 90°.

4. DIMENSIONS ARE FOR INFORMATION ONLY. ACTUAL DIMENSIONS ARE DICTATED BY DWG NO. 1299-210.

5. EXAMINATION AND REPAIR IF REQUIRED ON MATERIAL PROVIDED BY THE FABRICATOR. PERFORM IN ACCORDANCE WITH ASME CODE, SECTION II, DIVISION 1, SUBSECTION NB, ARTICLE NB-2530.

INFORMATION ONLY

SECTION A-A

#72,235.13

#4.00 THRU AS SHOWN

PACKAGING TECHNOLOGY, INC.
A Transnuclear Company
OUTER SHELL CASK
SLUDGE TRANSPORT

DETAIL ITEM 1

33.38

#1.50 BORE THRU OUTER SHELL AS SHOWN

PLATE, 1 1/2 THK, X 115.0 X 223.0 ASME SA-240, TYPE 304
NOTES, UNLESS OTHERWISE SPECIFIED:

1. FABRICATE IN ACCORDANCE WITH PACTEC SPECIFICATION GF-006.

2. LEAD INSTALLATION SHALL BE IN ACCORDANCE WITH PACTEC PROCEDURE FP-035 OR APPROVED ALTERNATE.

3. GAMMA SCAN OF POURED LEAD SHIELDING INTEGRITY SHALL BE PERFORMED IN ACCORDANCE WITH PACTEC SPECIFICATION FP-008 OR APPROVED ALTERNATE.

4. CASK FABRICATOR'S QUALITY ASSURANCE PROGRAM SHALL FULLY DOCUMENT THE INTERIOR DIMENSIONS OF THE OUTER CASK INNER SHELL PRIOR TO AND FOLLOWING LEAD POUR PER PACTEC PROCEDURE FP-035 OR APPROVED ALTERNATE.

5. AFTER LEAD POUR, CASK FABRICATOR SHALL REMOVE PIPE AND TRIM LEAD TO DEPTH SHOWN. GRIND EXTERNAL SURFACE OF PLUG TO CASK CURSOR PRIOR TO INSTALLATION. INSTALL PLUGS AS SHOWN ON DETAILS B, D AND F. PLUG MUST NOT PROTRUDE INTO LEAD CAVITY.

6. ALL LEAD CAVITY PENETRATIONS SHALL BE SEALED PRIOR TO SHIPPING TO AND FROM LEAD POUR FACILITY TO PREVENT GIRT AND WATER FROM ENTERING LEAD CAVITY.

7. DUE TO SEQUENCE IN FABRICATION STEPS AS DEFINED BY THE CASK FABRICATOR, OUTER CASK CONFIGURATION MAY NOT BE EXACTLY AS SHOWN.

SUGGESTED CONFIGURATION OF ROUNDUP RING. IF ALTERNATE DESIGN IS USED, SUBMIT TO PACTEC ENGINEERING FOR REVIEW AND APPROVAL.

D. DIMETRAL CLEARANCE TO BE MINIMIZED AND LIMITED TO .05" MAX BETWEEN PLUG AND HOLE.

SLUDGE SHIPPING CASK W/LEAD POUR FIXTURING

INFORMATION ONLY
NOTES, UNLESS OTHERWISE SPECIFIED:

1. FABRICATE IN ACCORDANCE WITH PACTED SPECIFICATION OP-008.

2. MATERIALS, SIZES, LINES IN THE MATERIAL COLUMN ARE FOR REFERENCE ONLY. IT IS THE RESPONSIBILITY OF THE MANUFACTURER TO DETERMINE ACTUAL REQUIREMENTS PRIOR TO FABRICATION.

3. ALL MACHINED SURFACES, UNLESS OTHERWISE SPECIFIED, SHALL HAVE A MAXIMUM SURFACE FINISH OF 83 RMS PER ANSI B46.1.
NOTES, UNLESS OTHERWISE SPECIFIED:
1. FABRICATE IN ACCORDANCE WITH PACTEC SPECIFICATION CF-006.
2. THREADS PER ANS/ASME B1.11.
3. MATERIAL SIZES LISTED IN THE MATERIAL COLUMN ARE FOR REFERENCE ONLY. MANUFACTURER SHALL CONFIRM ACTUAL REQUIREMENTS PRIOR TO FABRICATION.
4. ELECTROLESS NICKEL PLATE TO A THICKNESS OF 0.005-0.010 IN ACCORDANCE WITH MIL-C-26274 (LATEST REV). CLASS I, GRADE B.
5. REMOVED.
6. EQUIPMENT, COMPONENTS AND/OR SOURCES OF SUPPLY MAY BE SUBSTITUTED UPON APPROVAL OF PACTEC ENGINEERING.
7. LUBRICATE O-RING SEALS ITEM 6) WITH Dow CORNING HIGH VACUUM OIL OR EQUIVALENT.
8. IMPRESSION STAMP OR ENGRAVE THE DRAWING NUMBER AND A TWO DIGIT NUMERIC SERIAL NUMBER. CONTACT PACTEC TO CONFIRM SERIAL NUMBER TO BE PLACED PRIOR TO PLACEMENT.
GENERAL NOTES:

1. ALL MATERIAL SHALL BE AS SPECIFIED OR AN APPROVED EQUAL.
2. ABBREVIATIONS ARE IN ACCORDANCE WITH API 1104.
4. GRIND ALL SHARP EDGES AND REMOVE ALL BURRS.
5. STRUCTURAL WELDING & NOZZLE SHALL BE IN ACCORDANCE WITH AWS D1.1 (CS) AND AWS D1.5 (SS) UNLESS OTHERWISE SPECIFIED. ALL WELDS AT FINAL PASS.

ITEM 3 MAY BE FABRICATED AS FULLY MACHINED, ROLLED OR AS A MULTIPLE WELDMENT WITH FILLER WELDING PER FABRICATIONS PREFERENCES.

UTILIZE ITEM 8 AS REQUIRED TO FABRICATE A SHOULDER TO COMPLETELY COVER GAP BETWEEN ASSEMBLY A1 AND A2. SEAL WELD ALL AROUND SHOULDER AS REQUIRED.

1. PROCESS SHELL PLATE TO BE IDENTIFIED AS "TOL. 12099-400 S/A 632 PROCESS SHELL PLATE, RATED W/10,000 LBS. WT. COLUMNS LST w/ STAMPED LETTERING APPROVED 25 HIGH ALONG OUTER DIAMETER OF ASSEMBLY FLANGE, SERIAL NUMBERING (SSG) TO BEGIN AT 601 AND OHM AT 602.

2. RATED MAXIMUM CAPACITY IS 10,000 LBS.

3. ASSEMBLY SHALL BE PROOF TESTED TO 125% OF ITS RATED CAPACITY FOR A PERIOD NOT LESS THAN 15 MINUTES. AFTER LOAD TESTING, ALL LUG WELDMENT AND ALL LUG WELDMENT TO A1 PROCESS SHELL WELDMENT WELDS SHALL BE SUBJECT TO NDE.

4. VERIFY ASSEMBLY Dry weight (±100 LBS) BY WEIGHING AFTER ASSEMBLY IS COMPLETE.

5. PAINT ALL EXPOSED AND OTHERWISE NON-TRATED CARBON STEEL SURFACES WITH ONE COAT OF ANODIC 400 PRIMER AND TWO COATS OF ANODIC 450 HS OR APPROVED EQUAL. APPLICATION SHALL BE IN ACCORDANCE WITH MANUFACTURER'S INSTRUCTIONS. FINAL COLOR TO BE WHITE. MASK TAPPED HOLES.

INFORMATION ONLY

ASSEMBLY DRAWING

STAMP NO. 12099-400 Rev. 5

FOURTH PRINTING

Sludge transport sys process shield plate ISO

SCALE: none

PacTec Engineering & Manufacturing Co.
INFORMATION ONLY

AS-BUILT DRAWING

No. 12099-400 Rev. 5

DATE: 01/01/2023

INFORMATION ONLY
1. Manufacturer's fabrication standards shall apply.
2. Material sizes listed in the material column are for reference only. Manufacturer shall confirm actual requirements prior to fabrication.
3. All weld procedures and welding operators shall be qualified in accordance with ASME Code, Section IX.

Detail Item 1

Detail Item 2

Information Only

As-Built Drawing

Deg. No.: 12099-612 Rev. 1
Serial No.: 5709
Signature: Date: 1/29/02

Packaging Technology, Inc.
A Transnuclear Company

Operating Lever Weldment
Lid Turning Fixture
Sludge Transportation System
### General Make-up

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Unit</th>
<th>Stream 1</th>
<th>Stream 2</th>
<th>Stream 3</th>
<th>Stream 4</th>
<th>Stream 5</th>
<th>Stream 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Make-up</td>
<td></td>
<td>Sludge/Water Surry</td>
<td>Filtered Water</td>
<td>Water</td>
<td>Sludge/Water Surry</td>
<td>Air</td>
<td>Water</td>
</tr>
<tr>
<td>Insolubles</td>
<td>wt%sol</td>
<td>1-10</td>
<td>1-10</td>
<td>1-10</td>
<td>1-10</td>
<td>1-10</td>
<td>1-10</td>
</tr>
<tr>
<td>Solubles</td>
<td>ppm</td>
<td>TBD</td>
<td>TBD</td>
<td>[demin]</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>Bulk Density</td>
<td>lb/cuft</td>
<td>89.9</td>
<td>62.4</td>
<td>62.4</td>
<td>89.9</td>
<td>89.9</td>
<td>89.9</td>
</tr>
<tr>
<td>Flow (min)</td>
<td>lb/hr</td>
<td>2.20E+04</td>
<td>1.50E+04</td>
<td>[gravity]</td>
<td>2.20E+04</td>
<td>1.00E+06</td>
<td></td>
</tr>
<tr>
<td>Flow (max)</td>
<td>lb/hr</td>
<td>6.50E+04</td>
<td>4.50E+04</td>
<td>[gravity]</td>
<td>4.35E+04</td>
<td>1.25E+06</td>
<td></td>
</tr>
<tr>
<td>Pressure (max)</td>
<td>psig</td>
<td>50</td>
<td>45</td>
<td>atm</td>
<td>atm</td>
<td>atm</td>
<td>40</td>
</tr>
<tr>
<td>Temperature</td>
<td>°F</td>
<td>50</td>
<td>50</td>
<td>77</td>
<td>ambient</td>
<td>ambient</td>
<td>50</td>
</tr>
</tbody>
</table>

**Notes:**
- These values are generally either taken directly or derived from design input parameters found in Specification 8163 Rev. 4 or are simple estimates based on industry standard practices.
- Soluble TBD values for Streams 1 and 2 to be provided by FH.
- Stream 4 are typical initial operating parameters.
- Stream 5 parameters are nominal vessel fill venting.
- Stream 6 is nominal — only operating experience will determine actual values.
- Stream 6 Pressure is max allowed by filter manufacturer.

---

### INFORMATION ONLY

**SIGNATURE COPY ON FILE**

**CUSTOMER PROJECT**

**FLUOR HANFORD**

**PACTEC**

**AVANTech**

**K-East Basin STS**

**Large Container Process Flow Diagram**

---

**Fabrication/Construction Submittal**

A copy of this submittal is tied to the contract requirements. Minor changes to the drawing are permitted by the drawings except where noted.

---

**Signature and Revision**

**Date:** 12/17/2023

**Rev.:** 0
NOTE: WELD GEOMETRY FOR ALL SOCKET WELD CONNECTIONS SHALL BE IDENTIFIED ON A SHOP TRAVELER APPROVED BY AVANTECH PRIOR TO WELDING.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Item Description</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1&quot; PIPE x LG AS REQ'D, SCH 40, 300 SERIES SS</td>
<td>ASTM A-312</td>
</tr>
<tr>
<td>2</td>
<td>1&quot; CROSS, SOCKET, 150 LB, 300 SERIES SS</td>
<td>ASME B16.11</td>
</tr>
<tr>
<td>3</td>
<td>1&quot; PIPE x LG AS REQ'D, SCH 40, 300 SERIES SS</td>
<td>ASTM A-312</td>
</tr>
<tr>
<td>4</td>
<td>1&quot; TEE, SOCKET, 150 LB, 300 SERIES SS</td>
<td>ASME B16.11</td>
</tr>
<tr>
<td>5</td>
<td>1&quot; PIPE x LG AS REQ'D, SCH 40, 300 SERIES SS</td>
<td>ASTM A-312</td>
</tr>
<tr>
<td>6</td>
<td>1&quot; 90 ELBOW, SOCKET, 150 LB, 300 SERIES SS</td>
<td>ASME B16.11</td>
</tr>
<tr>
<td>7</td>
<td>1&quot; PIPE x LG AS REQ'D, SCH 40, 300 SERIES SS</td>
<td>ASTM A-312</td>
</tr>
<tr>
<td>8</td>
<td>REDUCING COUPLING, SHEET 6 6 6</td>
<td></td>
</tr>
</tbody>
</table>

**CUSTOMER/PROJECT**

FLUOR HANFORD
PACTEC

**AVANTECH**

KE BASIN STS: A-170
FILTER ASSEMBLY MANIFOLD
SPOOL-02

**JOB NO. 0126**

FILE ID: 3CG44-0126-0136.DWG

**SIGNATURE COPY ON FILE**

**FABRICATION/CONSTRUCTION SUBMITTAL**

AFC (FABRICATED) INFRARED

Conforms to the Contract Requirements

1. Minor Variations - Approved with
   exceptions - Incorporate and Re-Submit

Date: 12/12/20

**INFORMATION ONLY**

**Rev.**

**Serial No.**

**Dwg. No.**

**Signature**

**Date**
**INFORMATION ONLY**

NOTE: WELD GEOMETRY FOR ALL SOCKET WELD CONNECTIONS SHALL BE IDENTIFIED ON A SHOP TRAINER APPROVED BY AVANTECH PRIOR TO WELDING.

<table>
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<tr>
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<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>1&quot; PIPE x LG AS REQ'D, SCH 40, 300 SERIES SS</td>
</tr>
<tr>
<td>5</td>
<td>1&quot; TEE, SOCKET, 150 LB, 300 SERIES SS</td>
</tr>
<tr>
<td>4</td>
<td>1&quot; PIPE x LG AS REQ'D, SCH 40, 300 SERIES SS</td>
</tr>
<tr>
<td>3</td>
<td>1&quot; 90 ELBOW, SOCKET, 150 LB, 300 SERIES SS</td>
</tr>
<tr>
<td>2</td>
<td>1&quot; PIPE x LG AS REQ'D, SCH 40, 300 SERIES SS</td>
</tr>
<tr>
<td>1</td>
<td>REDUCING COUPLING, 6&quot; OD x 6&quot;</td>
</tr>
</tbody>
</table>
CUT HOLE THRU WALL FOR 1" NPS PIPE, TYP. 9X

NOTE:
1. ALL BUTT WELD CONNECTIONS SHALL BE FULL PENETRATION.
2. FLANGE CONNECTIONS SHALL BE MADE USING 1/16 THICK CARBON FIBER GASKET (ASME B16.1) AND SS HEX HEAD FASTENERS.

INFORMATION ONLY

CUSTOMER/PROJECT

AVANTech

KE BASIN STS: A-170
FILTER ASSEMBLY MANIFOLD
SPOOL-05

FLUOR HANFORD
PACTEC

SPECIALTY AND/or PART Nr.

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INFORMATION ONLY

CUSTOMER/PROJECT

AVANTech

KE BASIN STS: A-170
FILTER ASSEMBLY MANIFOLD
SPOOL-05

FLUOR HANFORD
PACTEC

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INFORMATION ONLY

CUSTOMER/PROJECT

AVANTech

KE BASIN STS: A-170
FILTER ASSEMBLY MANIFOLD
SPOOL-05

FLUOR HANFORD
PACTEC

SPECIALTY AND/or PART Nr.
REDUCING COUPLING
COUNTER BORE
1-1/4" END, AS SHOWN
(DIM IN PARENTHESIS ARE AS PURCHASED)
ATTACHMENT 10

HNF-8513, Rev. 1
CSER 01-002: Criticality Safety Evaluation Report for Loading, Transport, and Storage of K Basin Sludge Containers

Consisting of 1 Pages
Including this cover page.
Retrievable from RMIS
ATTACHMENT 11

SNF-9955, Rev. 1
Safety-Basis Thermal Analysis for KE Basis Sludge Transport and Storage

Consisting of 1 Pages
Including this cover page.

Retrievable from RMIS
ATTACHMENT 12

SNF-10415, Rev. 0

Design-Basis Thermal and Gas Generation Analysis for KE Basis Sludge in Large Diameter Containers

Consisting of 1 Pages
Including this cover page.

Retrievable from RMIS
ATTACHMENT 13

SNF-6470, Rev. 0
Design Verification Plan for the K Basins Sludge and Water System, Project A.16

Consisting of 1 Pages
Including this cover page.

Retrievable from RMIS
ATTACHMENT 14

SNF-13143, Rev. 0
Human Factors Report for the Sludge Water System

Consisting of 1 Pages
Including this cover page.

Retrievable from RMIS
ATTACHMENT 15

SNF-8509, Rev. 0

ALARA Report – Sludge Water System SNF Project A-16

Consisting of 1 Pages
Including this cover page.

Retrievable from RMIS
ATTACHMENT 16

SNF-10020, Rev. 1
Hazard Evaluation for KE Sludge & Water System Project A-16

Consisting of 1 Pages
Including this cover page.

Retrievable from RMIS
ATTACHMENT 17

HNF-3960, Rev. 5, K Basin Hazard Analysis

Consisting of 1 Pages
Including this cover page.

Retrievable from RMIS