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Section 1 of 2

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Conceptual Design Report – Cask Loadout System/Cask Drop Redesign for the Immersion Pail Support Structure and Operator Interface Platform, 105 K West Basin, Project A.5/A.6

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Abstract:

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CONCEPTUAL DESIGN REPORT

CASK LOADOUT SYSTEM/CASK DROP REDESIGN FOR THE IMMERSION PAIL SUPPORT STRUCTURE AND OPERATOR INTERFACE PLATFORM

105 K WEST BASIN

PROJECT A.5/A.6

July 1999

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ABBREVIATIONS/ACRONYMS

ALARA	As low as reasonably achievable
CDR	Conceptual Design Report
CLS	Cask loadout system
DOE	U. S. Department of Energy
FRS	Fuel retrieval system
IPSS	Immersion pail support structure
KE	K East
KW	K West
MCO	Multi-canister overpack
MLS	MCO loading system
OIP	Operator interface platform
RL	Richland Operations Office (DOE)
SNF	Spent nuclear fuel
WBS	Work breakdown structure

CONCEPTUAL DESIGN REPORT
CASK LOADOUT SYSTEM/CASK DROP REDESIGN
FOR THE
IMMERSION PAIL SUPPORT STRUCTURE
AND
OPERATOR INTERFACE PLATFORM
105 K WEST BASIN
PROJECT A.5/A.6

I. INTRODUCTION

The potential for a leak in the 105 KWest (KW) Basin south loadout pit, caused by a postulated cask drop accident, is addressed in this conceptual design report (CDR). A design solution was developed that redesigns the immersion pail support structure (IPSS) and the operator interface platform (OIP), to absorb the energy resulting from a dropped cask.

This CDR documents the redesign of the IPSS and the OIP. Redesign of the cask loadout system (CLS) is required because of additional load condition requirements in HNF-SD-SNF-FRD-025 Rev.2, *Cask Loadout System Function and Requirements*. In general, HNF-SD-SNF-FRD-025, Rev. 2 provides new requirements for seismic evaluation of the equipment and a cask drop scenario into the 105 KW Basin south loadout pit. This CDR covers concentric and off-center cask drops over the south loadout pit, but it does not include seismic analysis (drop loads are assumed to govern over seismic loads). Other Basin components that could be affected by the cask drop scenarios include the multi-canister overpack (MCO) loading system (MLS), the building structure, the transfer area crane, the building floor slabs, and the basin floor under the spent nuclear fuel (SNF). These issues will be covered in future design efforts. This CDR does not include loads due to drops that are not directly over the south loadout pit. These additional drop scenarios will be covered in a future revision to this CDR.

SNF project A.5/A.6, *Canister Transfer Facility Modifications*, will install an IPSS, an immersion pail, and a MLS for removal of the SNF through the KW Basin south loadout pit (see Figure 1). The basic plan for project A.5/A.6 is to transfer loaded baskets of SNF from the fuel retrieval system (FRS) to the MCO basket queue, through the transfer channel, into the south loadout pit, and into the cask-MCO.

The cask-MCO is hoisted off the conveyance, moved to and inserted into the immersion pail by the transfer bay crane. The immersion pail containing the loaded cask-MCO is lowered by the transfer bay crane into the bottom of the south loadout pit and IPSS. The MLS then loads the MCO with the baskets of SNF. When the MCO is loaded, the transfer area crane lifts the immersion pail-cask-MCO to the top of the IPSS where it is pinned and supported

SOUTH LOADOUT PIT PLAN

NOTE: PLATFORM, GRATING, STAIRS, HANDRAIL
ATTACHMENT, AND REMOVABLE CASK
GUIDE NOT SHOWN

Figure 1

by the IPSS. The primary function of the IPSS is to suspend the immersion pail in the upper position, guide the immersion pail when hoisted, and position the immersion pail at the bottom position. The primary function of the immersion pail is to protect the cask-MCO from surface contamination by the basin water, and act as a lifting device for the cask-MCO.

An analysis studied the structural effects on the south loadout pit concrete floor and the slab/wall joint due to a cask-MCO concentric drop into the existing IPSS (SNF-4345, Rev 0, Kanjilal, 1999). The results of that analysis indicated that the forces due to the drop would exceed the capacity of the concrete at the slab/wall interface.

Document HNF-SD-WM-SAR-062, Rev. 3H, *K Basins Safety Analysis Report*, indicates that the safety class function of the basin is to maintain water coverage over the SNF and the sludge. The objective of this CDR effort is to provide a design concept for modifying the CLS as required to reduce the forces on the south loadout pit concrete floor and wall such that the safety class function is maintained. A preliminary concept, identified during a facilitated value engineering session, involved the installation of an integral sleeve in the IPSS (*Cask Loading System Cask Drop, Installation Restart Position Paper*, April 1999). This sleeve, along with the pail, will be designed to work as a piston such that a controlled flow of water will hydraulically dissipate energy. The redesign of the IPSS and OIP, to incorporate this sleeve and other energy absorbing features, is the scope of this CDR effort. Related proof-of-concept studies and Type II scoping calculations are included to substantiate the design concept.

A modification to the conceptual design, which integrates the OIP and the IPSS, was identified during the independent formal design review of this CDR. (See Appendix R.) This integrated structure is to be supported off the top of the south loadout pit walls, rather than on feet at the pit base slab. This option presents some important benefits in that it minimizes potential dose rate impacts, improves operator access, and eliminates the potential gap-causing loads on the slab. Additionally, it is anticipated that many of the uncertainties identified in this CDR can be more easily resolved with the modified design. This modified design option was evaluated and accepted (See Appendix V) and is presented in Appendices T and U. The modified conceptual design incorporates the hydraulic sleeve feature but does not utilize the support feet, base impact absorbers, or sliding tubular legs. The CDR discussion of these items does not apply to the modified design concept. The modified OIP maintains its same function but many of the details as described in this CDR will change. The following table shows which of the CDR appendices are applicable to each of the two design concepts.

APPENDIX	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
ORIGINAL CONCEPT	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x			x
MODIFIED CONCEPT					x	x				x	x				x	x	x	x		x	x	x

II. SUMMARY

This conceptual design report documents the redesign of the IPSS and the OIP in the 105 KW Basin south loadout pit due to a postulated cask drop accident, as part of Project A.5/A.6, *Canister Transfer Facility Modifications*. Project A.5/A.6 involves facility modifications needed to transfer fuel from the basin into the cask-MCO.

The function of the IPSS is to suspend, guide, and position the immersion pail. The immersion pail protects the cask-MCO from contamination by basin water and acts as a lifting device for the cask-MCO. The OIP provides operator access to the south loadout pit.

Previous analyses studied the effects of a cask-MCO drop on the south loadout pit concrete structure and on the IPSS. The most recent analysis considered the resulting loads at the pit slab/wall joint (Kanjilal, 1999). This area had not been modeled previously, and the analysis results indicate that the demand capacity exceeds the allowable at the slab/wall joint.

The energy induced on the south loadout pit must be limited such that the safety class function of the basin is maintained. The solution presented in this CDR redesigns the IPSS and the OIP to include impact-absorbing features that will reduce the induced energy. The impact absorbing features of the new design include:

- Impact-absorbing material at the IPSS base and at the upper portion of the IPSS legs.
- A sleeve which provides a hydraulic means of absorbing energy.
- Designing the OIP to act as an impact absorber.

The existing IPSS structure in 105 KW will be removed.

This conceptual design considers only loads resulting from drops directly over the IPSS and south loadout pit area. Drops in other areas of the basin are not considered, and will be covered as part of a future revision to this CDR.

A modification to the conceptual design, which integrates the OIP and the IPSS, was identified during the independent formal design review of this CDR. This integrated structure is to be supported off the top of the south loadout pit walls, rather than on feet at the pit base slab. This option presents some important benefits in the way of minimizing potential dose rate impacts, improving operator access, and eliminating gap-causing slab loads. Additionally, it is anticipated that many of the uncertainties identified in this CDR can be more easily resolved with the modified design. This modified design option was evaluated and accepted.

The total estimated cost for the redesign is \$6,000,000 (See Appendices A and B). The estimate includes design of the K East OIP and the design/fabrication of the K East IPSS. The K East work is not part of the scope of this CDR. However, because these structures will be almost identical, it is most cost effective to do the selected portions of the work for both basins concurrently. All other costs given are for KW Basin work only. The schedule in Appendix C includes work at both K East and KW.

III. JUSTIFICATION

Analyses were performed for the original IPSS definitive design for several drop scenarios of the immersion pail and cask-MCO. These analyses were combined and issued in SNF-3774, Rev. 0 (Moore 1998). The report was being independently reviewed (Wagenblast 1999) when concerns were raised about the possibility of high stresses in the south loadout pit concrete at the slab/wall junction. These concerns stemmed from the results of additional analysis performed using more detailed boundary conditions in the finite element model.

The analysis results in SNF-4345, Rev. 0 (Kanjilal, 1999), indicate that previous cask drop analyses were non-conservative. This new analysis considered the loads at the south loadout pit slab/wall joint, which was not modeled previously. The demand capacity exceeded the allowables, based on the American Concrete Institute (ACI) 349, *Code Requirements for Nuclear Safety Related Concrete Structures*. Recommendations were made to perform a more detailed evaluation of the drop scenarios on the IPSS and south loadout pit.

This CDR provides an engineered solution that redesigns the CLS equipment to reduce the energy induced on the south loadout pit floor resulting from dropped cask load scenarios. The energy induced on the south loadout pit is to be controlled such that the safety class function of the basin is maintained, that is, adequate water level is maintained over the SNF.

The design solution includes the following:

- Redesign of the IPSS to include an impact absorber under the structure and impact absorbing design features at the feet and upper portion of the tubular legs.
- Provision of a sleeve in the IPSS to hydraulically slow the descent of the immersion pail.
- Accommodating off-center drops by use of the energy-absorbing upper portion of the IPSS and/or the energy-reducing capabilities of the OIP.

The proposed changes involve replacement of the existing IPSS. The supporting hydraulic and structural calculations demonstrate that the redesigned IPSS, immersion pail, and OIP will limit the energy input to the south loadout pit to acceptable levels. An acceptable level of energy transferred to the south loadout pit such that the safety class function of the basin is maintained.

The allowable basin leak rate was established in WHC-SD-WM-SAR-062, K-Basins Safety Analysis Report. The final design will minimize the cracking and associated leak rate to the extent possible. During the development of this conceptual design, a parallel study effort was ongoing to quantify the gap size and leakage rates that would occur due to cask drops using the existing IPSS design. It was thought that by refining the finite element structural model, it could be demonstrated that leakage rates due to a cask-MCO drop were in an acceptable range. At this time, the preliminary analysis results indicate leakage rates to be at unacceptable levels. The study is not part of this conceptual design, but a summary of the results is included in Appendix N. These results help to demonstrate the necessity of the IPSS redesign.

IV. DESCRIPTION OF SCOPE

A. DROP ANALYSIS FOR THE SOUTH LOADOUT PIT

Definition of Drops

The transfer of the cask to/from the transport trailer and to/from the south loadout pit will involve utilization of the crane/trolley/hoist system in the transfer area of the 105 KW Basin. The total mass of the transferred cask containing the MCO and the SNF is 62,000 lb (Values varying from 60,000 lb to 64,000 lb have been used in the CDR analyses, which is acceptable for establishing design concepts). If the cask is dropped during the transfer process, it could threaten the safety class envelope of the south loadout pit and basin pool, affecting the ability to retain required levels of water over the SNF. An interoffice memorandum, with attached calculations defining the drop heights used in the CDR, is included in Appendix E.

A document was prepared to define and describe the possible accident scenarios that might occur as a result of a cask drop accident in the transfer/south loadout pit area (see Appendix D). This document grouped these drops into the following three categories:

1. Worst case accidents in the south loadout pit during which the cask remains vertical during the drop.
2. Drop accidents of the cask onto the transfer area or into the south loadout pit, during which the cask is in an oblique orientation during the drop.
3. Drop accidents of the cask onto the transfer area or into the south loadout pit during which the cask may roll or slide toward the basin pool.

This CDR effort considers only drops directly impacting the south loadout pit area. It does not consider drop actions occurring in other areas of the basin which could potentially create missiles that could impact the south loadout pit. Figure 2 shows the four main drop height

DROP #1

DROP #2

DROP #3
FLUID DAMPING

DROP #4

Figure 2
-7-

scenarios derived from the letter report which were considered in this CDR. The heights vary slightly from the values listed in HNF-SD-SNF-FRD-025, Rev. 2, which was being revised at the time of conceptual design. These changes will be incorporated during definitive design.

- A 3.3-ft high off-center drop. (Drop No. 1)
- A 17-ft cask drop into pail. (Drop No. 2)
- A 15-ft pail and cask drop into bottom of IPSS. (Drop No. 3)
- Cask drops 5 ft into pail at an angle (Drop No. 4). This case is governed by Drop No. 2, so not much consideration was given here.

Structural Analysis of South Loadout Pit Concrete

The vertical static load capacity of the south loadout pit was determined by developing a finite element structural model. The model includes the transfer channel, the south loadout pit, and a portion of the basin. The static capacity of the south loadout pit was established using ACI-349, *Code Requirements for Nuclear Safety Related Concrete Structures*. The drop loading was applied as a distributed floor pressure over the floor/impact absorber interface area. The analysis results show that the equivalent static capacity of the south loadout pit is 600,000 lb. A detailed description of the analysis is provided in Appendix I.

Horizontal loading of the south loadout pit walls can occur during seismic and accidental drop events (off-center Drop No. 1). The horizontal loading is transmitted through bearing pads between the IPSS and the rails. An evaluation of the south loadout pit concrete structure for horizontal loading was performed using the same finite element model used for the vertical loading. Using a design vertical load of 400 kips; the horizontal load becomes 70 kips. The resulting margin of safety for this applied load is larger than 1.0. It is assumed that all floor loads due to drops are distributed uniformly over the slab. This assumption is based on designing lateral restraint such that the IPSS is prevented from rotating, therefore resulting in no uneven floor loads. This will be verified in definitive design.

A geotechnical consultant was tasked to assist in providing soil properties. (See Appendix I.) The soil spring constant value will be incorporated into the definitive design analysis of the south loadout pit.

Acceptance Criteria for Drop Analysis Studies Acceptance criteria are based on ACI 349, the governing design code. Appendix C of this code permits the use of "ductility ratios" which permit load in excess of rebar yield strength. However, ACI cautions that the application of ductility ratios should "not result in the loss of intended function of the structural element nor impair the safety-related function of other systems and components."

Based on that statement, the south loadout pit cask drop loading will be limited to ACI 349 Appendix C limits, using a load factor of 1.0, without the use of ductility ratios (See

Appendix J). The acceptance criteria recommendations are based on the assumption that the south loadout pit concrete and reinforcing steel has experienced no significant in-service degradation. The 105 KW concrete walls are coated with an epoxy coating. Inspections of the 105 KW Basin are documented in WHC-SD-NR-SA-023, released in December 1991 (Winkle, 1991), and Job Control System Package IK-95-01414 in February 1996 (Winkle, 1996). No evidence of reinforcing steel corrosion or concrete degradation was found.

B. IPSS DESIGN AND ANALYSIS

The IPSS and immersion pail are part of the CLS and are installed in the south loadout pit for use in SNF removal operations. The IPSS is the primary load-carrying structure that interfaces directly with the south loadout pit. The immersion pail is used to raise and lower the cask in the south loadout pit and protects the outside surfaces of the cask from contamination when immersed in the basin water. The floor and walls of the south loadout pit perform a safety class function associated with retaining water coverage over the SNF and sludge. A 4-in. drain valve, located at the intersection of the west wall and the floor of the south loadout pit, was identified as performing the same safety class function as the walls and floor.

A new IPSS will be constructed as part of this CDR effort. Initial efforts looked at installing a sleeve in the existing in-place IPSS. However, once the concept development was under way, it was realized that to incorporate all the required energy absorbing features would necessitate the construction of a new IPSS. (See sketches in Appendix S.) In addition, the existing IPSS is radiologically contaminated due to contact with the basin water, which makes modification difficult.

This new IPSS structure incorporates existing design features to the extent possible to minimize redesign efforts, and to minimize the impacts on other auxiliary features and equipment. Significant modifications to the existing immersion pail have not been identified for this conceptual design effort. The finite element analysis of the IPSS is shown in Appendix K.

The important design features of the new IPSS structure include:

- Three main features/devices to absorb the energy released during the drop scenarios (see Figure 3):
 1. Impact absorbing material at the upper portion of the IPSS legs
 2. Impact absorber at the base
 3. Hydraulic piston action of the sleeve with the pail.
- The existing IPSS will be removed. The pit will be utilized as is, with minimal modifications. Portions of some existing rails will be removed as necessary to provide adequate clearance for the new IPSS.

Figure 3

- The existing pin blocks at the top of the pail will be used. The design of the new IPSS at this supporting point location will conform to the existing design. This is subject to verification in definitive design.
- The existing design concept for the leveling feet will be incorporated into the new design. This design uses a shear pin connection to ensure that excessive loads don't transfer to the floor at the foot location. Once the pin shears, the loads are transferred to the floor over the larger area of the IPSS impact absorber base.
- The telescoping tube mechanism, provided as an energy-absorbing feature, can be eliminated by absorbing the Drop No.1 in the foam at the bottom of the IPSS. (See Appendix H.) The floor loading is protected for Drop No. 2, No. 4 and No. 5 by design of the square support pins to fail at an ultimate capacity less than the allowable floor load.
- Everything in this structure is readily fabricated. There is nothing unusual that requires specialized fabrication processes.
- The impact absorber will have a cutout area over the drain valve sump, which is slightly higher than the rest of the floor. This cutout is provided so drop loads are not transmitted to the drain valve area, which is an area of concern. The bottom plate of the IPSS will extend over this sump area with impact-absorbing material above the plate at this location. This feature is a means of protecting the drain valve area from falling tools and debris that may or may not be related to cask drop incidents. This cutout concept, still under development, does not show on the IPSS sketches in Appendix S.
- The immersion pail makes a transition in its usage from a lifting device to a holding device. The IPSS is a holding device designed to ANSI N690, *Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear Facilities*. The pins and pin block area are related to the lifting operation and therefore are designed to ANSI N14.6, *Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 kg) or More*.
- The impact pads under the IPSS are sealed in sheet metal. The closed cell foam material resists water absorption and has been used on commercial, nuclear material, shipping containers and on a number of impact absorbers at the Hanford Site. The anticipated radiation levels are not expected to affect this foam. A dose rate study during definitive design will compare the radiation resistance of the foam against dose rates. If not structurally challenged, the foam has a long life span.
- The pail is not required to be filled with water as the cask-MCO is being lifted out. The upper foam will take the drop in this case. The piston and the foam are not relied on to work at the same time.

- The vent holes in the sleeve minimize peak pressures when the immersion pail falls into the sleeve.
- For Drop No. 1, the off-center drop case, one concern is whether the sliding mechanism will bind. It is being conservatively assumed that binding will occur.

IPSS Structural Analysis using the ANSYS Finite Element Analysis Program

The IPSS was modeled using ANSYS finite element analysis software (see Appendix K).

The model includes the lower cylinder, the 10 by 8 mitered tubes, the 4 by 8 support tubes, and the stiffener plates and cylinders in the upper portion of the structure. All structural members are 3/8-in. thick and are modeled with shell elements that calculate both bending and membrane stresses.

The model was used to determine the stability of the columns. Preliminary results are favorable for a total load of 800 kips at the top of the two columns adjacent to the open section at the top of the structure. The 800 kip load is a conservative value chosen based on exceeding with a comfortable margin, the floor slab capacity of 600 kips used for conceptual design. Definitive design will use loads determined from the drop and seismic analyses for the design of the IPSS structure. Lateral restraints will prevent rotation of the IPSS structure so that the load in all legs will be the same.

Immersion Pail Analysis

The immersion pail components are analyzed in accordance with AISC N690 as a structure under extreme load conditions, and in accordance with ANSI N14.6 as a lifting device. ASME pressure vessel codes are not applicable to this situation, as they apply only to operating pressurized systems. The structural integrity of the immersion pail and its support pins is required to be maintained for the 17-ft drop (Drop No. 2), in order to preclude combining Drops No. 2 and No. 3. During Drop No. 2, the cask free falls until entering the narrow orifice, compressing the air below, and then contacting the water 1 ft above the bottom of the pail. Both the air (inside the pail) and the water resist the free fall of the cask prior to impacting the bottom of the pail. This transient condition is evaluated using the applicable fluid mechanics equations.

An elastic-plastic static finite element analysis assessed the structural integrity of the immersion pail after a drop of a cask-MCO (17-ft). (See Appendix L) An axisymmetric shell model of the lower end (2.5-ft) was analyzed using the ANSYS finite element analysis program. The pail is assumed to contain 1 ft. of water. The loading is by hydrostatic internal pressure loading of 560 psi, as determined by hydraulic analysis, acting over this 1 ft. depth (see Appendix F). Material properties were taken from the vendor material certification reports. Plasticity was modeled with a bilinear kinematic strain-hardening model with a Von Mises yield criterion.

Results show that the initial yielding will occur at about 30% of the peak pressure loading at the discontinuity joint between the cylindrical shell and the flat bottom plate. At peak pressure, maximum equivalent plastic strains of 1.79% (at the joint-weld) and 0.44% (at the center of the bottom plate) were predicted. These strains are acceptable because of the high ductility of the stainless steel used here (ASTM A 240, type 304, with total elongations of 51-65%).

Additional pressure issues that will be considered in definitive design include the effect of the momentum transfer from the bottom of the cask to the mass of the water in the pail. This could locate a high-pressure spike. The use of a rupture disk to mitigate this effect will be considered during definitive design.

C. OPERATOR INTERFACE PLATFORM – DESIGN AND ANALYSIS

The OIP will be located over the south loadout pit. The OIP will provide operator access to the center of the pit during SNF loadout operations without interfering with the installation and removal of the cask. The OIP will be designed to reduce the impact load to the IPSS and the immersion pail to maintain the south loadout pit safety class boundary within code allowances during a cask-MCO off-center drop accident.

The purpose of the OIP system is twofold:

- It provides operator access to the south loadout pit for pin removal and other MLS tasks, serving as a replacement for the existing platform.
- It acts as an impact absorber, preventing damage to the south loadout pit floor that could result from a cask-MCO off-center drop onto the immersion pail or IPSS

The worst case accident scenario acting on the platform is considered to be a cask slap down or tip-over. This could result in the MCO contacting the immersion pail or IPSS with an associated kinetic energy equivalent to a 5-ft high, 64,000-lb cask drop. The OIP design function is to place a fixed energy-absorption system between the falling mass and the potential immersion pail and IPSS targets. The system will absorb all the drop energy and preclude damage to the south loadout pit floor by preventing the MCO from contacting the immersion pail and IPSS.

The system consists of an assembly of steel beams that span the south loadout pit. Crushable foam blocks located on top of the south loadout pit wall support the beams. The beams are configured such that they physically cover the immersion pail and IPSS and present a first point-of-contact from a falling MCO. The beams are sized to transfer the drop energy to the crush blocks. The crush blocks are made from the same foam used in the IPSS structure (see description above) and will similarly be sealed in sheet metal. The resulting crush force on the crush blocks will be absorbed by the bearing capacity of the curb wall. A safety factor

of 2.8 exists between the design load and the allowable wall-bearing load as determined in accordance with ACI 349, Appendix C requirements.

The conceptual design of the OIP incorporates a worst case envelope of off-drop conditions and therefore represents the worst case configuration and specification of components. Definitive design, using more rigorous analytical techniques, is certain to reduce the complexity and size of the system and thereby make it more operator-friendly and more easily erected, given the limited space around the south loadout pit.

Some important design features of the OIP include:

- The original platform design was only to the outside of the pit wall. The new one is much larger, and is elevated 4 ft off the floor (2 ft off the top of the curb).
- As an impact absorber, the OIP physically protects the pail from hits with beams that are attached to the foam at the top of the curb. Currently, the beam is a W18 x119 that is boxed in on the sides with steel plates and tapers down to a 6-in. deep, boxed section at the ends. The taper is required so that there is room for the foam. The frame controls the load path into the crushable material, which is the only sacrificial element.
- The cask guide center section must be removable so that there is clearance for the lifting hooks, for access to the pin area, and for sling removal. It is in place only during the cask-loading operation. The guide is not for drop mitigation and does not take impact loads. It only deflects the cask to get it centered and part way into the pail. (past the pail lip) Then the guides are slid back (possibly this is done remotely).
- Drop scenarios for the platform are straight-down drop and tip-overs from the east and west. Tip-overs from the east is the governing case with highest energy levels. This case governs sizing of the beams and the foam.

D. DEMOLITION

The original design of the IPSS was partially installed in September 1997 in the 105 KW Basin south loadout pit. This structure consists of three main components:

- 1) The lower section, which includes the leveling feet (adjusted to a height of approximately 3-in. off the floor).
- 2) The upper section, which was bolted onto the lower section before both the lower and upper sections were installed in the south loadout pit.
- 3) The four-pail lock pin guide assemblies which are bolted onto the top of the four IPSS columns.

All these components are in a contaminated area, with the upper and lower IPSS sections directly in contact with contaminated basin water. The redesign of the IPSS requires removal of all three components of the existing IPSS. The lower and upper sections will be removed together, decontaminated, and disposed of. The pail lock pin guide assemblies will be reinstalled with the new structure. The demolition sequence is as follows:

- 1) Remove the pin blocks
- 2) Raise the structure up halfway and insert the support cribbing
- 3) Remove the bolts between the upper and lower sections
- 4) Remove, decontaminate, and dispose of the upper section
- 5) Reconfigure the rigging to the lower section and remove the cribbing
- 6) Remove, decontaminate, and dispose of the lower section.

The existing 32-ton crane cannot be used for the IPSS removal because its pick height is too low. A mobile crane must be brought in for this task. Redesign of the OIP to withstand the drop load scenarios will require removing portions of the existing vertical guide rails. Approximately 2 ft of rail will be removed for two rails each at the south, west, and north walls. These rails are contaminated and will require decontamination prior to disposal.

E. DESIGN COMPLIANCE

The design and construction of the IPSS and the OIP will comply with the codes, regulations, and customer technical requirements identified in HNF-SD-SNF-FRD-025, Rev. 2, *Functions and Requirements for K Basins Cask Transportation Facility Modifications - Project A.5/A.6*. The document has been internally reviewed, approved, released under configuration control, and provided to the U. S. Department of Energy, Richland Operations Office (RL) for review and approval.

A design review checklist (Appendix P) was prepared using the applicable requirements of HNF-SD-SNF-FRD-025, Rev. 2. The conceptual design was reviewed against the design review checklist requirements during the independent formal design review. Although the design requirements have not been approved by RL, they are the best available to support the current redesign effort. The adequacy of the design requirements was also evaluated as part of the CDR design review.

The detailed design specification will implement the requirements of HNF-SD-SNF-025, Rev. 2 and will be used by the design agent as the controlling requirements document when preparing designs.

F. MODIFIED IPSS CONCEPTUAL DESIGN IN RESPONSE TO REVIEWER COMMENTS

An independent formal design review was held to assure that the concepts proposed are sufficient to meet the requirements in HNF-SD-SNF-FRD-025, Rev 2. This review is

documented in HNF-4683, Rev 0 (Riesenweber1999). The Review Comment Record and the Design Review Checklists from that report are included here in Appendices P and R. One of the comments resulting from that formal review was the recommendation that a modified design be considered which integrates the OIP and IPSS. This integrated design concept lowers the height of the OIP, suspends the IPSS from the OIP deck, and removes the loads from the south loadout pit floor. This modified concept was evaluated and accepted, as documented in the meeting minutes in Appendix V. The resulting preliminary sketches and analysis are attached in Appendices T and W

V. METHODS OF PERFORMANCE

The methods of performance for the major phases of work to be accomplished, i.e., engineering, procurement, construction, project management, and other activities are listed below.

A. ENGINEERING

Definitive Design

The SNF project contractor will prepare the "design-build" procurement package for the IPSS definitive design; and will provide the definitive design for the OIP and the demolition of the existing IPSS structure. The SNF project contractor will prepare the analysis for the interfacing concrete and other existing interfacing structures for input into the design/build procurement package.

Engineering and Inspection

The construction contractor will provide project support for construction and construction quality control services.

The SNF project contractor will incorporate contractor as-build/vendor submittals into the Hanford Site system, oversee walkthroughs, prepare open items and exceptions lists, and support the contract closing documentation.

RL will provide acceptance inspection services during construction.

B. CONSTRUCTION

The construction contractor will perform the demolition and removal of the existing IPSS, construct the OIP, and install the new IPSS and the modified immersion pail.

C. DESIGN-BUILD WORK

An offsite design-build contractor will provide the definitive design, procurement, and fabrication of the IPSS, including the alignment hardware and the drain valve cover.

D. PROJECT MANAGEMENT

The design-build contractor is directly responsible to the SNF project contractor, performing all activities associated with the design and fabrication of the IPSS.

The SNF project contractor will provide overall project management during design, procurement, and construction on this project.

VI. REQUIREMENTS AND ASSESSMENTS

A. QUALITY ASSURANCE AND SAFETY CLASSIFICATION

SNF project personnel reviewed the procurement quality assurance requirements to determine if components originally purchased as General Services or Safety Significant under the vendor's quality assurance program (Title 10 CFR, Part 71, Subpart H) provide sufficient control during design and fabrication to support a classification upgrade to Safety Class. The components that required this verification were the IPSS, the immersion pail, and the MLS gantry and shuttle. The review concluded that 10 CFR 71, Subpart H, *Quality Assurance Requirements*, was adequate to ensure control of design and fabrication activities by the vendor and the sub-tier suppliers. (EDT – 625960)

Design and fabrication changes to the IPSS, the immersion pail, the MLS shuttle, the MLS gantry, and any new designs initiated after May 1, 1999, shall comply with American Society of Mechanical Engineers (ASME) NQA-1-1994, *Quality Assurance Requirements for Nuclear Facility Applications*.

B. ENVIRONMENTAL COMPLIANCE

The design changes presented in the conceptual design will require evaluation against Washington State air-permitting requirements documented in DOE/RL-97-28, dated April 1997, including revised pages dated December 2, 1997. This evaluation may also include review of SNF Process Standard 408, *Environmental Safety Requirements – KW Basin*, that implements the KW Basin air-permitting requirements. This evaluation will determine if information in the approved air permit and process standard is in conflict with information provided in the conceptual design. Depending on the conceptual design changes, the Washington State Department of Health may be briefed on the changes.

C. ALARA ASSESSMENT

Beginning at the earliest design stage, radiological design reviews are required to ensure that

radiological design requirements are incorporated into the designs for new facilities and equipment and into modifications of existing facilities and equipment. As low as reasonably achievable (ALARA) requirements are required by law in Title 10, CFR, Part 835, Subpart K (10 CFR 835).

The cask drop redesign effort falls within the radiological design review screening criteria under, "*The design of equipment to be installed in a facility that contains, handles, uses or processes radioactive material in any way*", and is required to undergo radiological design reviews. The need for radiological design reviews and other aspects of ALARA planning have been included in *Engineering Work Plan, Cask Loadout System Conceptual Redesign for Immersion Pail Support Structure and Operational Platform 105 K West*, dated May 18, 1999. Subsequent design phases will be covered by a new or revised engineering work plan. Resources will be allocated to support continued radiological design reviews and ALARA planning. An informal design review meeting was held on May 13, 1999, (minutes available in K Basins project files) to obtain early input to the design concept. The review included input by a member of the K Basins Radiological Design Review Team.

Design criteria document HNF-SD-SNF-FRD-025, Rev. 2, *Functions and Requirements for K Basins Cask Transportation Facility Modifications - Project A.5/A.6*, was developed to address the cask drop redesign effort. Requirements for the ALARA and radiological engineering aspects of the design were included and approved by a member of the K Basins Radiological Design Review Team.

Operations

Operational aspects of the original design for the cask loadout system was reviewed for ALARA and is documented in HNF-SD-SNF-FDR-003, *Design Analysis Report for the TN-WHC Cask and Transportation System*. Design changes to the IPSS and immersion pail (as required) are not expected to appreciably affect the overall operational sequence for cask loading; and dose and contamination assessments performed to date are not expected to change significantly.

The IPSS will be raised due to the design, and this will affect current dose assessments. The increased height of the IPSS will cause the fuel baskets to be lifted higher (closer to the surface of the water), before being lowered into the MCO. The increased height increases the dose rate above the IPSS, which will need to be assessed during definitive design. A dose rate calculation applicable to the IPSS redesign is included in Appendix Q.

Time-dose issues related to the OIP will be addressed during definitive design. Issues include reduced accessibility to the immersion pail locking pins and immersion pail rigging attachment points because of additional height requirements needed to accommodate impact-limiting material that may be placed beneath the OIP. The increased elevation requires workers to work in awkward positions, potentially slowing the work process and increasing dose exposure. A comment, from a member of the K Basins Radiological Design Review Team, following the preconceptual design review held on May 13, 1999, has identified the need to evaluate the impact-limiting material for contamination issues.

The interface between the cask and the immersion pail is not expected to change as a result of the redesign effort. The outer surfaces of the cask will continue to be protected from contaminated basin water by the immersion pail, and slightly pressurized demineralized water supplied to the annulus between the cask and the immersion pail.

Operational aspects of the original design for the MLS was reviewed for ALARA and is documented in HNF-SD-SNF-DR-004, *Design Review Report for the Hanford K East and K West Basins MCO Loading System*. Height adjustments to the MLS gantry support structure and gantry are not expected to affect operational dose and contamination ALARA assessments that have been performed to date.

Installation

Installation ALARA aspects are documented in the *Spent Nuclear Fuel Project (SNFP) ALARA Support Team Report for the K West Immersion Pail Support Structure*, dated April 21, 1997, and in the *ALARA Review of 1K-97-3553, Install Multiple Canister Overpack Loading System Components*, dated May 11, 1998. These documents contain an overall discussion of the installation work scope, radiation and contamination surveys of the work area, work steps and estimated dose, photographs, design information, etc. Once installation details are established, re-evaluation of these documents will be required during definitive design.

VII. IDENTIFICATION AND ANALYSIS OF UNCERTAINTIES

This CDR effort is for the conceptual design directly pertaining to the IPSS structure and its OIP, and does not cover design for peripheral structures and equipment. The following items are not part of this effort. It is assumed that the items will be covered in future engineering reports or definitive design efforts. These uncertainties were considered in the evaluation of the modified conceptual design as described in Appendix V. It was determined that the modified concept provides for either elimination or a better resolution of the uncertainties listed here.

Drain Valve Assessment as a Result of the Drops

A 4-in. drain valve located at the intersection of the west wall and the floor of the south loadout pit has been identified as performing the same safety-class function as the walls and floor. The integrity of the drain valve and the surrounding concrete following a drop must be maintained and will require further evaluation during definitive design. (See Appendix E.)

Leak Mitigation Efforts

Appendix B of HNF-SD-SNF-FRD-025, Rev. 2, recommends that regardless of the final safety margins associated with the cask drop accident, administrative procedures should be in place for dealing with a leak in the basin. This recommendation is based upon the fact that a structural acceptance criterion guaranteeing zero leakage is not feasible. One leak

mitigation procedure would involve the application of coated bentonite clay pellets or grout to the bottom of the south loadout pit following a cask-MCO drop.

Another method of leak mitigation would involve applying sealant to the postulated leak area prior to loadout operations. Consideration was given to remote application of a urethane sealant, which cures underwater and is elastic after curing. Although a product was identified which could potentially be shown to be acceptable, this approach was not considered acceptable by itself as a solution to an unmitigated drop.

Some research has been performed regarding the above mitigation efforts. These items are not included as part of this CDR effort and are not included in the estimate. Further research and conceptual design of the leak mitigation efforts should be included in a future engineering report.

Analysis of and Modifications to the Gantry Required Due to Drop Scenarios

An evaluation is being performed to determine the adequacy and the integrity of the existing gantry support structure to withstand dead load, seismic loads, and the impact loads caused by the drop of the cask-MCO during the cask loadout operation. These impact loads are the result of secondary drops (not in the scope of this CDR effort). Preliminary results of the ongoing analysis indicate that the stresses in the gantry support structure exceed the plastic stress limits and that the anchor bolts for the base plates will be overstressed by 300-to-500%. The gantry support structure will probably need to be reinforced or a separate impact resisting structure will need to be provided to protect the basin from cask-MCOs that drop and impact the gantry.

Interface Required if IPSS is Raised

The conceptual design configuration raises the IPSS by 6- to 12- in. to allow space for the installation of the bottom impact absorber. The IPSS will need to be raised an additional amount due to field conditions, such as the uneven floor, and to accommodate installation clearance and tolerance requirements. It may be possible to modify the shape of the impact absorber to accommodate some of these concerns. Raising the IPSS affects the interface between the MCO basket guide and the basket being loaded into the MCO by the gantry.

The current gantry design has a nominal clearance of 4 in. for a scrap basket. This clearance dimension may change because some of the information used to determine the dimension is from draft designs and does not include construction tolerances.

To accommodate the new IPSS, the gantry support structure must be raised. To avoid interference with the 32-ton transfer area crane, a 10-in. total maximum raise is allowed. A redesign of the gantry support structure concrete anchorage most likely will be required. The gantry support structure attachment to the existing building steel will be much more complicated and will probably necessitate the redesign of the walk way platform steel. Modifications to the gantry support structure due to raising the IPSS are not included in this conceptual design effort, and will be addressed in a future engineering report or design effort.

Analysis of and Modifications to 32-Ton Crane Required Due to Drop Scenarios (M. Hall)

For the current design, the limit switches on the existing 32-ton crane will be relied on for limiting the lift height of the cask-MCO and therefor limiting the maximum drop heights.

An administrative control may be used to limit the lift height of the cask-MCO, but an engineered feature must limit the worst case lift height evaluated by analysis. Because the engineered feature is relied on to perform the safety-class function of limiting the lift height, this engineered feature is then safety-class. The function of the Safety Class limit switches is to prevent a cask drop as a result of a two-block and subsequent catastrophic failure of the main hoist. (A two-block is when crane components physically interlock, such as when the lower block engages the trolley wheel.) The system is designed and procured to DOE 6430.1a, Sections 1300-3 and 1660-99.0.1 which requires an NQA-1 Quality Assurance Program, seismic testing, fail-safe electrical design, redundancy and separation in design, special maintenance and repair considerations; and special considerations allowing routine in-place testing of the safety function. The critical system components of the system have a reliability factor such that failure of the system is incredible. These limit switches are currently being reviewed to determine if modifications are required so that they can perform this safety class function. The results of this study will be addressed in a future engineering report.

Seismic Design of the IPSS

The seismic design loads on the IPSS and OIP are not being considered during conceptual design. It has been assumed that the greater magnitude drop impact loads envelop the seismic loads. During definitive design, these loads will need to be analyzed as part of the design of these structures. One area of concern is whether the existing vertical rails in the south loadout pit, which are to be used for lateral support, can take the lateral seismic loads from the IPSS. Currently it is assumed that the existing lateral jack in the south loadout pit will not be used. A concept close to the design of this jack may be utilized. The use of pail guide wedges that are breakaway on drop impact may be part of the lateral restraint system. The seismic design of the structures and the related design features will need to be considered in much greater depth during the definitive design effort.

Additional Cask Drop Scenarios

This conceptual design effort considers loads resulting from primary drops on the IPSS structure only. It does not include drops that are not directly over the IPSS and the south loadout pit. Impacts occurring in other areas of the basin which could create missiles that could then impact the south loadout pit need to be considered. This effort will be covered as part of a future revision to this CDR.

Concrete Curb Removal

Based on the worst case drop scenario and that a 2-foot vertical envelope is required for the impact system, operator head room is limited to slightly under 6 ft under the gantry support structure. It may be advantageous to cut the concrete curb for the design of the platform. This would have the benefit of lowering the final floor height of the OIP. The curb does not have a safety class function even though it is part of a safety class barrier. However this may be an as-low-as-reasonably-achievable (ALARA) issue because it affects shielding, and

therefore, requires further investigation.

Installation of the OIP

Leak mitigation in the south loadout pit may be complicated by the installation of the OIP that covers a large portion of the south loadout pit. This is of concern with the current design, due to the complexity and weight and mass of this "worst case" structure. Additional specialized tools may be required for cask loadout operations planned to be completed from the platform. The system restricts operator access to the IPSS/immersion pail and a remote device for installing and removing the pail support pins will have to be designed. The design of specialized tools is not part of the scope of the CDR effort.

Design of the OIP

Lateral loads have not been evaluated fully and the magnitude of lateral restraint design is unknown. This design has a high probability of function, but represents a quick assessment of the components needed to mitigate the drop. The definitive design should include computer applications to balance the structural members with the crush block components. Multiple points of impact should be considered in the structural model to optimize and complete the system balance. This conceptual design provides good assurance that a design solution is feasible. The design presented includes much conservatism and analyzes an extreme drop scenario in an attempt to show the worst case impact on fabrication, construction, and operations. During definitive design, the complexity of the system can be significantly reduced with the aid of more rigorous analytical techniques. In addition, as the design of the IPSS is more fully developed, its capability to absorb impact may result in reduced requirements for the OIP.

Demineralized Water System Modifications

It is assumed that an upgraded Safety Class demineralized water system will not be required. The primary need for the water delivery system is to maintain clean water surrounding the cask when the cask-MCO is immersed in the basin water. In conjunction with the IPSS and the immersion pail, the water provided by the water delivery system could be used to reduce the impact load to the south loadout pit during a cask-MCO drop accident. Drop energy would then be dissipated by providing a hydraulic cushion between the cask and the immersion pail. The water system would perform a safety class function of delivering water in sufficient quantity to fill the immersion pail during removal of the cask-MCO from the pail. The filled-pail approach was identified and evaluated early in the conceptual design. It is not a preferred approach based on the engineering difficulty.

The current conceptual design does not rely on the water in the immersion pail for dissipation of drop energy. If it becomes necessary during definitive design to utilize the hydraulic capability of the water in the immersion pail to reduce impact load during a drop, additional functions and requirements must be identified and documented prior to proceeding with that design.

Table 3-10, Drop Height vs. Mass for Nonperforation of Basin Floor, Issues (Rodgers)

Table 3-10 of WHC-SD-WM-SAR-062, Rev 3H, *K Basins Safety Analysis Report*, is being

modified, and its requirements may become more stringent. The table shows allowable drop heights for potential missiles at the K Basins. If lifted items do not exceed the table heights; an analysis is not required to prove that the lifted items, if dropped, would not compromise the basin floor. The modifications to Table 3-10 will have minimal impact on the design of the IPSS and the OIP, but could have significant impact on installation of these structures due to the potential missiles resulting from construction activities. Additional analysis may be required and is not included in the scope of this conceptual design.

Fire Protection Issues Due to Large Quantities of Foam

The fire protection issues regarding the use of foam impact-absorbing materials need to be addressed. The foam intended for use is fire-retardant polyurethane that has undergone furnace testing in accordance with 10 CFR 71. The foam used in the impact absorbers at the upper part of the legs is the area of concern because the bottom impact absorber will be underwater at all times. This upper foam impact absorber may need to be replaced with an aluminum absorber if the fire protection issue for the foam can not be resolved. DOE 6430.1A prohibits the use of this material, but it is currently being evaluated as part of the fire loading of WHC-SD-SNF-FHA-001, Rev. 0, *Fire Hazards Analysis*. If a waiver to DOE 6430.1A is obtained to allow the use of the foam, this may potentially interfere with existing waivers obtained for the sprinkler system. In conjunction with the Fire Hazards Analysis revision effort, the expected worst-case quantity of foam is being calculated as part of the K Basin fire loading. The modified conceptual design as presented in Appendices T and U will minimize the use of the foam material.

VIII. REFERENCES

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APPENDIX A

Cost Estimate Summary

IPSS Structure Design and Fabrication (NAC)

ESTIMATED NAC CLS ENGINEERING AND FABRICATION COSTS WITH CONTINGENCY

Source	Scope	Estimate Type	Estimate (\$)	Adders (\$)	Total (\$)
NAC (KE and KW)	Definitive Design of IPSS and IP	Time and Materials	580,000	130,000	710,000
NAC (KE and KW)	Fabrication of two IPSS and mods to IPs	Time and Materials	780,000	180,000	960,000
NAC	Contingency	30%	410,000	90,000	500,000
TOTAL			1,770,000	400,000	2,170,000

Assumptions for NAC Support:

- Scope of work is limited to designing, analyzing, and fabricating the modified immersion pail support structure (IPSS) and lateral support hardware of the K-Basin South Load-Out Pit (SLOP) in order to withstand an accidental cask drop during fuel transfer and lateral seismic loads.
- M&D Professional Services, Inc. (M&D) and HiLine Engineering & Fabrication, Inc. (HiLine) will be on the project team with NAC as directed by DE&S Hanford.
- NAC proposes to perform all tasks described in Scope of Work on a time and materials basis until such time that the actual scope for each of the defined task activities becomes more clearly established. As the actual task items become better defined, NAC will entertain the idea of providing fixed task pricing. At this time, the detailed pricing represents a best effort budget estimate for each task.
- All work will be performed in accordance with the terms and conditions specified in the Request for Proposal.
- NAC will invoice DE&S Hanford on a monthly basis for all work performed together with any travel and direct expenses incurred.
- Direct and Subcontractor (e.g., M&D, HiLine, etc.) costs are budget estimates. Design specification and actual hardware requirements are currently not defined.
- Vendor travel and expenses are included in this cost estimate.
- 10% fee will be added to Direct and Subcontractor costs.

APPENDIX B

Cost Estimate Summary

Operation Interface Platform, Demolition, and IPSS Installation

ESTIMATED OTHER CLS ENGINEERING AND FABRICATION COSTS WITH CONTINGENCY

Source	Scope	Estimate Type	Estimate (\$)	Adders (\$)	Total (\$)
M&D (KE and KW)	Support for SLOP and Secondary Drop Analyses	Time and Materials	170,000	40,000	210,000
Dyncorp Support For Construction (KW)	Equipment at 105 KW	ROM	30,000	10,000	40,000
FDNW Engineering (Shared Resources) (KE and KW)	Support for SLOP and Secondary Drops Analyses	Time and Materials	75,000	20,000	95,000
FDH Project Support for Construction (KW)	HPT Support and Burial	ROM	80,000	20,000	100,000
FDNW Construction (KW)	IPSS Operator Platform Fab and Install at 105 KW	ROM	530,000	160,000	690,000
FDNW Construction (KW)	Remove IPSS from 105 KW	ROM	40,000	10,000	50,000
FDNW Construction (KW)	Demolition at 105 KW	ROM	500,000	150,000	650,000
FDNW Misc. Allowances (KW)	Design Changes, Downtime, Overtime, Newhire training	ROM	80,000	20,000	100,000
Dyncorp Support For Construction (KW)	Dyncorp Light Duty Equipment Usage	ROM	20,000	5,000	25,000
FDNW Engineering (Shared Resources) (KE and KW)	Secondary Drops Design	Preconceptual (Placeholder)	50,000	10,000	60,000
FDNW Construction (KW)	Secondary Drops Construction	Preconceptual (Placeholder)	500,000	150,000	650,000
FDNW Construction (KW)	Crane Safety Class Limit Switch Upgrade	Preconceptual (Placeholder)	150,000	50,000	200,000
Ederer (Engineering) (KE and KW)	Crane Safety Class Limit Switch Upgrade	Preconceptual (Placeholder)	50,000	10,000	60,000
Above Sources	Contingency	30%	680,000	150,000	830,000
TOTAL			2,955,000	805,000	3,760,000

Assumptions for FDNW Support:

- Order of magnitude estimate to be used for budgeting purposes only.
- Bottoms-up/analysis technique has been utilized.
- 8% sales tax has been applied to all materials and equipment.
- 15% factor applied to direct craft labor for general requirements.
- 47% factor applied to all construction, supervision, construction engineering, and industrial safety and health.
- Consumable are estimated at 3.2% of direct craft labor costs.
- Special work procedure (SWP) factors are applied against direct labor for actual time lost due to the personnel protective equipments and procedures. The rates which have been applied are as follows: 25% protective clothing factor has been applied, and 85% mask work plus 15% protective clothing factors have been applied.
- General foreman factor of 7% has been applied to direct craft labor crews.
- Escalation percentages were calculated from the January, 1999 update of the Economic Escalation Price Change indices for DOE Construction Projects as published by the "Office of Project and Fixed Asset Management."
- No design in this estimate. All construction is be onsite contractor FDNW.
- An allowance has been added for potential overtime premium pay based on the assumption that 10% of total labor will be expended on off-shift basis.
- An allowance has been added for potential design changes increasing work scope by 5% of total direct labor dollars.
- An allowance of 5% of direct labor dollars has been added for potential delays due to operational procedures.
- An allowance of 2% of direct labor dollars has been added for potential new hires.
- An allowance has been added for Dyncorp light-duty equipment usage of 10%.

Assumptions for Non-FDNW Support:

- Rough order of magnitude estimate to be used for budgeting purposes only.
- Estimates are based on analysis to similar work performed.

APPENDIX C

Conceptual Project Schedule

Work Pkg	Activity ID	Activity Description	Start	Finish	Pct Cmpl	Rem Dur	Total Float	Resp	FY99					FY00									
									M	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY		
Management									Management														
Facility Upgrades for Transport									Facility Upgrades for Transport														
CLS Budget Change Request									CLS Budget Change Request														
Management 1K-98-BCR FC0002000A Helium Purge - Develop Work Scope / Rqmt's 07JUN99* 18JUN99 0 10 415 HAGMAN 1K-98-BCR FC0002000B Submit DN for Prelim Helium Purge Requirements 21JUN99 0 0 415 HAGMAN									Management Helium Purge - Develop Work Scope / Rqmt's Submit DN for Prelim Helium Purge Requirements														
Cask Drop ReDesign BCR									Cask Drop ReDesign BCR														
Management 1K-98-BCR1 FC00031 ---PREP & APPROVE BCR for DESIGN 20MAY99A 14JUN99 10 10* 29 SUMMARY 1K-98-BCR1 FC00031100 Prepare BCR for Final Design 20MAY99A 07JUN99 10 5* 29 J.WEAMER 1K-98-BCR1 FC00031110 Review and Approve BCR for Final Design 08JUN99 14JUN99 0 5 29 J.WEAMER 1K-98-BCR1 FC00032 ---ESTIMATE & BCR for FABR / INSTALL 04AUG99 08SEP99 0 25* -5 SUMMARY 1K-98-BCR1 FC00032100 FDNW Prep & Issue Estimate for Fab/Instl 04AUG99 10AUG99 0 5 -5 1K-98-BCR1 FC00032110 Review & Approve Est for Fab/Installation 11AUG99 17AUG99 0 5 -5 1K-98-BCR1 FC00032120 Prep & Submit BCR for Fab/Instl 18AUG99 31AUG99 0 10 -5 1K-98-BCR1 FC00032130 Review & Approve BCR for Fab/Instl 01SEP99 08SEP99 0 5 -5									Management ---PREP & APPROVE BCR for DESIGN Prepare BCR for Final Design Review and Approve BCR for Final Design ---ESTIMATE & BCR for FABR / INSTALL FDNW Prep & Issue Estimate for Fab/Instl Review & Approve Est for Fab/Installation Prep & Submit BCR for Fab/Instl Review & Approve BCR for Fab/Instl														
105KW Basin									105KW Basin														
Facility Upgrades for Transport									Facility Upgrades for Transport														
105KW MLS Installations									105KW MLS Installations														
Design 1K-97-3553 FC12551 ---DESIGN NESTING PAIL - IPSS - IP 19APR99A 17AUG99 20 54* 5 SUMMARY 1K-97-3553 FC125511 ---CONCEPTUAL DESIGN 19APR99A 16JUN99 90 12* -5 SUMMARY 1K-97-3553 FC12551101 Definition of Drops 19APR99A 26MAY99A 100 0* 1K-97-3553 FC12551105 Design Upper SLP Platform 10MAY99A 27MAY99A 100 0* 1K-97-3553 FC12551107 Interface Drawing if IPSS is Raised 17MAY99A 07JUN99 10 5 425 1K-97-3553 FC12551108 ALARA Evaluation Assessment 17MAY99A 27MAY99A 100 0* 1K-97-3553 FC12551109 Hazards Classification 24MAY99A 01JUN99 0 1 -5 1K-97-3553 FC12551110 Hydraulics - M&D Structural Analysis 03MAY99A 01JUN99 90 1 -5									Design ---DESIGN NESTING PAIL - PSS - IP ---CONCEPTUAL DESIGN Definition of Drops Design Upper SLP Platform Interface Drawing if IPSS is Raised ALARA Evaluation Assessment Hazards Classification Hydraulics - M&D Structural Analysis														

Project Start 30MAR98
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100K AREA PROJECTS

Cask Transport Facility Mods

May 31, 1999

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Duke Engr Services Hanford, Inc.			
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		FY99												FY00																	
		M	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY																	
Work Pkg	Activity ID	Activity Description												Start	Finish	Pct Cmpht	Rem Dur	Total Float	Resp												
Design																															
1K-97-3553	FC12551112	Upper SLP Platform Analysis												03MAY99A	27MAY99A	100	0"														
1K-97-3553	FC12551113	SLP Concrete Analysis												03MAY99A	01JUN99	90	1	-5													
1K-97-3553	FC12551114	Drop Analysis of IPSS by M&D												10MAY99A	27MAY99A	100	0"														
1K-97-3553	FC12551116	Interface with DOE, SNF, DNFSB & NAC												03MAY99A	03JUN99	75	3"	0													
1K-97-3553	FC12551117	Conceptual Design Report Assembly												10MAY99A	04JUN99	50	4"	-5													
1K-97-3553	FC12551118	Tech Edit Conceptual Design Report												24MAY99A	04JUN99	50	3"	-5													
1K-97-3553	FC12551130	Conceptual Design Review												07JUN99	11JUN99	0	5	-5													
1K-97-3553	FC12551140	Incorp Comments from CDR												14JUN99	16JUN99	0	3	-5													
1K-97-3553	FC12551150	Conduct KR-2													16JUN99	0	0	-5													
1K-97-3553	FC125512	Nesting Palil/PSS/IP - Final Design												14JUN99	03AUG99	0	35	-5													
1K-97-3553	FC12551200	Prepare Definitive Design Work Plan												24MAY99A	04JUN99	10	4"	0													
1K-97-3553	FC12551201	Begin Definitive Design													07JUN99	0	0	0													
1K-97-3553	FC12551290	Nesting Palil/PSS/IP - Final Design Review												04AUG99	10AUG99	0	5	5													
1K-97-3553	FC12551295	Nesting Palil/PSS/IP - Independent Design Review												04AUG99	10AUG99	0	5	5													
1K-97-3553	FC12551297	Nesting Palil/PSS/IP - Incorporate FDR Comments												11AUG99	17AUG99	0	5	5													
1K-97-3553	FC12552	---PROCURE NESTING PAIR - IPSS - IP												21JUL99	31AUG99	0	30"	0	SUMMARY												
1K-97-3553	FC12552100	Nesting Palil/PSS/IP - Prep Procurement Package												21JUL99	03AUG99	0	10	0													
1K-97-3553	FC12552140	Nesting Palil/PSS - Finalize Procurement/Fab Pkg												04AUG99	24AUG99	0	15	0													
1K-97-3553	FC12552150	Nesting Palil/PSS/IP - Negotiate & Award Fab												25AUG99	31AUG99	0	5	0													
1K-97-3553	FC12553	Nesting Palil/PSS/IP - Fabricate & Delv												09SEP99	24NOV99	0	55	-5													
1K-97-3553	FC12602	---PREP / APPROVE DOC for REMOVAL of IPSS												29JUN99	04AUG99	0	25"	74	SUMMARY												
1K-97-3553	FC12602110	Prep Documentation for Removal of IPSS												29JUN99	14JUL99	0	10	74													
1K-97-3553	FC12602120	RL Approve Removal & Disposal of KW&KE IPSS												15JUL99	04AUG99	0	15	74													
1K-97-3553	FC12603	---UPGRADE SAFETY DOCUMENTATION												18AUG99	13OCT99	0	40"	25	SUMMARY												

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Created		Checked		Approved		Approved		Approved	

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Work Pkg	Activity ID	Activity Description	Start	Finish	Pct Cmplt	Rem Dur	Total Float	Resp	FY99					FY00																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			
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1K-97-3553	FC12603110	Revise & Submit Safety Documentation	18AUG99	15SEP99	0	20	25																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																										

Project Start 30MAR98
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	Work Pkg	Activity ID	Activity Description	Start	Finish	Pct Cmpl	Rem Dur	Total Float	Resp	FY99					FY00					
										M	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Construction										Construction										
1K-97-3553	FC14072110	SHUTTLE - STAGE SHUTTLE in BASIN	21JUN99	22JUN99	0	2		66	S.IMHOFF	SHUTTLE - STAGE SHUTTLE in BASIN										
1K-97-3553	FC14072120	SHUTTLE - PLACE CART on SHUTTLE	23JUN99	24JUN99	0	2		67	S.IMHOFF	At Hold Point										
1K-97-3553	FC14072125	SHUTTLE AIR - INSTALL CA TUBE to SHUTTLE PISTON	21JUN99*	25JUN99	0	5		66	S.IMHOFF	SHUTTLE - PLACE CART on SHUTTLE										
1K-97-3553	FC14072130	SHUTTLE - INSTALL DEAD WGT / BRACES / SHUTTLE	28JUN99	08JUL99	0	7		66	S.IMHOFF	SHUTTLE AIR - INSTALL CA TUBE to SHUTTLE PISTON										
1K-97-3553	FC14072205	MOD IMPACT LIMITER for END PLATES	17MAY99A	28MAY99A	100	0			S.IMHOFF	Prior to Shuttle Field Install										
1K-97-3553	FC14072210	IMPACT LIMIT - STAGE EQUIP in BASIN	09JUL99	13JUL99	0	3		66	S.IMHOFF	SHUTTLE - INSTALL DEAD WGT / BRACES / SHUTTLE										
1K-97-3553	FC14072220	IMPACT LIMIT - INSTALL / WELD / FITUP	14JUL99	20JUL99	0	5		66	S.IMHOFF	MOD IMPACT LIMITER for END PLATES										
1K-97-3553	FC140731	---105KW BRIDGE GANTRY SUPPORT STRUC INSTALL	21JUL99	09AUG99	0	14*		66	SUMMARY	IMPACT LIMIT - STAGE EQUIP in BASIN										
1K-97-3553	FC14073105	GANTRY - ANCHOR BOLTS & BEAM PREP	21JUL99	26JUL99	0	4		66	S.IMHOFF	IMPACT LIMIT - INSTALL / WELD / FITUP										
1K-97-3553	FC14073110	GANTRY - INSTALL BRIDGE GANTRY SUPPORT STRUC	27JUL99	05AUG99	0	8		66	S.IMHOFF	---105KW BRIDGE GANTRY SUPPORT STRUC INSTALL										
1K-97-3553	FC14073130	GANTRY - MODIFY MONORAIL	06AUG99	09AUG99	0	2		66	S.IMHOFF	GANTRY - ANCHOR BOLTS & BEAM PREP										
1K-97-3553	FC140732	---105KW IPSS REMOVAL & DISPOSAL	10AUG99	24AUG99	0	11*		65	SUMMARY	GANTRY - INSTALL BRIDGE GANTRY SUPPORT STRUC										
1K-97-3553	FC14073210	SLP - REMOVE & DISPOSE IPSS	10AUG99	23AUG99	0	10		66	S.IMHOFF	At Hold Point / Requires IKM Relocation Cmpl										
1K-97-3553	FC14073215	IPSS - CUT / REMOVE RAIL at SLP	24AUG99*	24AUG99	0	1		82	L.FORMO	GANTRY - MODIFY MONORAIL										
1K-97-3553	FC14074	---105KW IPSS - BRIDGE GANTRY - CASK ALIGNMNT	06DEC99	23FEB00	0	56*		-3	SUMMARY	IPSS - REMOVE & DISPOSE IPSS										
1K-97-3553	FC14074100	IPSS - REINSTALL IPSS	06DEC99	17DEC99	0	10		-5	L.FORMO	IPSS - CUT / REMOVE RAIL at SLP										
1K-97-3553	FC14074105	IPSS - INSTALL PAIL in IPSS	20DEC99	27DEC99	0	5		-5	L.FORMO	Need 32-Ton Crane										
1K-97-3553	FC14074107	GANTRY - INSTALL BRIDGE GANTRY RAILS	28DEC99	05JAN00	0	6		-5	L.FORMO	---105KW IPSS - BRIDGE GANTRY - CASK ALIGNMNT										
1K-97-3553	FC14074110	GANTRY - STAGE BRIDGE GANTRY & GRAPPLE	06JAN00	12JAN00	0	5		-5	L.FORMO	IPSS - REINSTALL IPSS										
1K-97-3553	FC14074120	GANTRY - INSTALL BRIDGE GANTRY	13JAN00	19JAN00	0	5		-5	L.FORMO	IPSS - INSTALL PAIL in IPSS										
1K-97-3553	FC14074130	GANTRY - INSTALL GRAPPLE	20JAN00	26JAN00	0	5		-5	L.FORMO	GANTRY - INSTALL BRIDGE GANTRY RAILS										
1K-97-3553	FC14074170	GANTRY - HAND ALIGN GRAPPLE & PAIL	27JAN00	02FEB00	0	5		-5	L.FORMO	GANTRY - STAGE BRIDGE GANTRY & GRAPPLE										
1K-97-3553	FC14074180	KWMCO - INSTALL CASK / FINAL ALIGNMENTS	03FEB00	16FEB00	0	10		-5	L.FORMO	At Hold Point										
1K-97-3553	FC14074190	KWMCO - TOUCHUP PAINT	17FEB00	23FEB00	0	5		-3	L.FORMO	GANTRY - INSTALL BRIDGE GANTRY										
										GANTRY - INSTALL GRAPPLE										
										GANTRY - HAND ALIGN GRAPPLE &										
										KWMCO - INSTALL CASK / FINAL										
										At Hold Point										
										KWMCO - TOUCHUP PAINT										

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		FY99		FY00																										
		M	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY																
Work Pkg	Activity ID	Activity Description		Start	Finish	Pct Cmpmt	Rem Dur	Total Float	Resp																					
Design																														
1K-98-2387	FC12016100	Work Platform - Prep Procurement Package		12JUL99	23JUL99	0	10	85	KARD																					
1K-98-2387	FC12016110	Work Platform - Prep & Submit Bids		26JUL99	13AUG99	0	15	85	KARD																					
1K-98-2387	FC12016140	Work Platform - Negotiate & Award Fabrication		18AUG99	24AUG99	0	5	83	KARD																					
1K-98-2387	FC12017	Work Platform - Fabricate & Deliver		09SEP99	20OCT99	0	30	73																						
1K-98-2387	FC12018	105KW WORK PLATFORM WRK PKG		05OCT99	02NOV99	0	21*	64	SUMMARY																					
1K-98-2387	FC12018110	WORK PLATFORM - Prep Wk Instructions		05OCT99	18OCT99	0	10	64	T.NUGENT																					
1K-98-2387	FC12018120	WORK PLATFORM - Conduct Job Walkdown			04OCT99*	0	0	64	T.NUGENT																					
1K-98-2387	FC12018130	WORK PLATFORM - Prepare AMW/ RWP		05OCT99	18OCT99	0	10	64	T.NUGENT																					
1K-98-2387	FC12018140	WORK PLATFORM - Prepare Critical Lift Procedures		05OCT99	18OCT99	0	10	64	T.NUGENT																					
1K-98-2387	FC12018150	WORK PLATFORM - Obtain All Required Permits		05OCT99	18OCT99	0	10	64	T.NUGENT																					
1K-98-2387	FC12018160	WORK PLATFORM - Prepare QC Requirements		05OCT99	18OCT99	0	10	64	T.NUGENT																					
1K-98-2387	FC12018170	WORK PLATFORM - Prepare Waste Mgmt Plan		05OCT99	18OCT99	0	10	64	T.NUGENT																					
1K-98-2387	FC12018180	WORK PLATFORM - Incorporate AI Plan		05OCT99	18OCT99	0	10	64	T.NUGENT																					
1K-98-2387	FC12018190	WORK PLATFORM - Prepare / Compile AJHA		05OCT99	18OCT99	0	10	64	T.NUGENT																					
1K-98-2387	FC12018192	WORK PLATFORM - Conduct 95% Cmpmt Job Walkdown			19OCT99	0	0	64	T.NUGENT																					
1K-98-2387	FC12018194	Approve JCS Pkg for WORK PLATFORM		20OCT99	26OCT99	0	5	64	T.NUGENT																					
1K-98-2387	FC12018196	MRB Pkg Review for WORK PLATFORM		27OCT99	02NOV99	0	5	64	OPS																					
1K-98-2387	FC12018199	KR3 Meeting for WORK PLATFORM			02NOV99	0	0	64	JWEAMER																					
Construction																														
1K-98-2387	FC1401	105KW PLATFORM around SLP		22FEB99A	15MAR00	20	200*	-3	SUMMARY																					
1K-98-2387	FC1401110	OPS LOADOUT - INSTALL OPS LOADOUT IFACE SYSTEM		24FEB00	15MAR00	0	15	-3	LFORMO																					
105KW Small Tool / Laydown Area																														
Construction																														
1K-98-2348	FC1408	105KW TOOL STORAGE / DECON AREA INSTALL		02NOV98A	15MAR00	50	200*	-3	SUMMARY																					
1K-98-2348	FC1408110	TOOL AREA - INSTALL SMALL TOOL / LAYDOWN AREA		24FEB00	15MAR00	0	15	-3	LFORMO																					

Project Start
30JAN98
Project Finish
31JUN01
Date Date
02JUN99
Run Date

Project Start
31JUN01
Project Finish
31JUN99
Date Date
02JUN99
Run Date

Project Start
31JUN01
Project Finish
31JUN99
Date Date
02JUN99
Run Date

Early Bar
Progress Bar
Critical Activity

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Work Pkg	Activity ID	Activity Description	Start	Finish	Pct Cmpl	Rem Dur	Total Float	Resp	FY99					FY00							
									M	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Construction									Construction												
1K-98-2348	FC14082	—SMALL TOOLS / EQUIP INSTALL WORK PKG	05OCT99	02NOV99	10	21*	64	SUMMARY	—SMALL TOOLS / EQUIP INSTALL WORK PKG												
1K-98-2348	FC1408210	Tools - Prep Wk Instructions	05OCT99	04OCT99	10	0*	64	K.SHADDIX	Tools - Prep Wk Instructions												
1K-98-2348	FC1408220	Tools - Conduct Job Walkdown		04OCT99*	0	0	64	K.SHADDIX	Tools - Conduct Job Walkdown												
1K-98-2348	FC1408230	Tools - Prepare AMW / RWP	12OCT99	25OCT99	0	10	64	K.SHADDIX	Tools - Prepare AMW / RWP												
1K-98-2348	FC1408250	Tools - Obtain All Required Permits	12OCT99	25OCT99	0	10	64	K.SHADDIX	Tools - Obtain All Required Permits												
1K-98-2348	FC1408260	Tools - Prepare QC Requirements	12OCT99	25OCT99	0	10	64	K.SHADDIX	Tools - Prepare QC Requirements												
1K-98-2348	FC1408270	Tools - Prepare Waste Mgmt Plan	12OCT99	25OCT99	0	10	64	K.SHADDIX	Tools - Prepare Waste Mgmt Plan												
1K-98-2348	FC1408283	Tools - Prepare / Cmpl AJHA	12OCT99	25OCT99	0	10	64	K.SHADDIX	Tools - Prepare / Cmpl AJHA												
1K-98-2348	FC1408286	Tools - Conduct 95% Cmpl Job Walkdown		26OCT99	0	0	64	K.SHADDIX	Tools - Conduct 95% Cmpl Job Walkdown												
1K-98-2348	FC1408290	Approve JCS Pkg for Small Tools / Racks Instl	27OCT99	02NOV99	0	5	64	K.SHADDIX	Approve JCS Pkg for Small Tools / Racks Instl												
105KW Compressed Air Upgrades									105KW Compressed Air Upgrades												
Construction									Construction												
1K-99-0680	FC1420	—105KW INSTALL CA UPGRADES	19MAY99A	14JUN99	20	10*	162	SUMMARY	—105KW INSTALL CA UPGRADES												
1K-99-0680	FC1420110	CA Supply - Install Compressed Air System	19MAY99A	14JUN99	20	10*	162	S.IMHOFF	CA Supply - Install Compressed Air System												
105KW Windbreak Installation									105KW Windbreak Installation												
Construction									Construction												
1K-98-2034	FC1402	—105KW WINDBREAK INSTALLATION	26MAY98A	15JUN99	73	11*	186	SUMMARY	—105KW WINDBREAK INSTALLATION												
1K-98-2034	FC1402135G	WIND - CMPLT WINDBREAK ERECT	02JUN99*	08JUN99	0	5	69	S.IMHOFF	WIND - CMPLT WINDBREAK ERECT												
1K-98-2034	FC1402135H	WIND - CMPLT ELECTRICAL INSTALLATIONS	08JUN99	15JUN99	0	5	186	S.IMHOFF	WIND - CMPLT ELECTRICAL INSTALLATIONS												
1K-98-2034	FC1402135Z	WIND - TIE-IN to BLDG	09JUN99	14JUN99	0	4	69	S.IMHOFF	WIND - TIE-IN to BLDG												
105KW Construction Acceptance Testing									105KW Construction Acceptance Testing												
Construction									Construction												
1K-98-ZAT1	FC1405	—105KW Facility Upgrade for Transport CAT's	20MAR00	14APR00	0	20*	-5	SUMMARY	—105KW Facility Up												
1K-98-ZAT1	FC1405100	KW - FACILITY UPGRADE for TRANSPORT - CAT	20MAR00	14APR00	0	20	-5	L.FORMO	KW - FACILITY UPGR												
1K-98-ZAT1	FC1405110	105KWCLS CONSTRUCTION COMPLETE		07APR00*	0	0	0	J.WEAMER	105KW CLS CO												

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									JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY				
105KE Basin									105KE Basin															
Facility Upgrades for Transport									Facility Upgrades for Transport															
105KE MEI Reroutes									105KE MEI Reroutes															
Construction									Construction															
1K-96-2026	FC2402	105KE MECH - ELEC - INSTR REROUTES INSTALL	12JUL99	27JUL99	10	12*	0	SUMMARY	105KE MECH - ELEC - INSTR REROUTES INSTALL															
1K-96-2026	FC2402200	MEI - REMOVE MEZZ #3 & S.CATWALK LCONDUIT	12JUL99*	14JUL99	0	3	7	L.FORMO	MEI - REMOVE MEZZ #3 & S.CATWALK LCONDUIT															
1K-96-2026	FC2402205	MEI - REMOVE UNIT HEATERS 14,15,16,17	12JUL99*	14JUL99	0	3	0	L.FORMO	MEI - REMOVE UNIT HEATERS 14,15,16,17															
1K-96-2026	FC2402210	MEI - REROUTE GLYCOL HEATER CNTRL / THERMOSTAT	12JUL99*	23JUL99	15	10	0	L.FORMO	MEI - REROUTE GLYCOL HEATER CNTRL / THERMOSTAT															
1K-96-2026	FC2402220	MEI - REROUTE MANUAL FIRE ALARM STATION	12JUL99*	23JUL99	15	10	0	L.FORMO	MEI - REROUTE MANUAL FIRE ALARM STATION															
1K-96-2026	FC2402230	MEI - REROUTE DOOR 156 / 157 SECURITY ALARM	12JUL99*	23JUL99	15	10	0	L.FORMO	MEI - REROUTE DOOR 156 / 157 SECURITY ALARM															
1K-96-2026	FC2402240	MEI - REROUTE HIGH PRESSURE WTR JET PWR / CNTRL	12JUL99*	23JUL99	15	10	0	L.FORMO	MEI - REROUTE HIGH PRESSURE WTR JET PWR / CNTRL															
1K-96-2026	FC2402250	MEI - INSTALL NEW UNIT HTR's 32,33,38,39	22JUL99	23JUL99	0	2	0	L.FORMO	MEI - INSTALL NEW UNIT HTR's 32,33,38,39															
1K-96-2026	FC2402260	MEI - PERFORM CAT / TURNOVER TESTING	26JUL99	27JUL99	0	2	0	L.FORMO	MEI - PERFORM CAT / TURNOVER TESTING															
105KE Demo Center Mezz / Wikwy									105KE Demo Center Mezz / Wikwy															
Construction									Construction															
1K-96-1275	FC2403	105KE DEMO of CTR MEZZANINE / WIKWY INSTALL	22FEB99A	13AUG99	10	52*	5	SUMMARY	105KE DEMO of CTR MEZZANINE / WIKWY INSTALL															
1K-96-1275	FC2403105	KE DEMO - ERECT SCAFFOLD at SOUTH WALL	12JUL99*	12JUL99	0	1	11	L.FORMO	KE DEMO - ERECT SCAFFOLD at SOUTH WALL															
1K-96-1275	FC2403110	KE DEMO - DEMO PLATFORM #4 at SOUTH WALL	13JUL99*	19JUL99	0	5	11	L.FORMO	KE DEMO - DEMO PLATFORM #4 at SOUTH WALL															
1K-96-1275	FC2403200	KE DEMO - ERECT SCAFFOLD at MEZZ #3	28JUL99*	29JUL99	0	2	5	L.FORMO	KE DEMO - ERECT SCAFFOLD at MEZZ #3															
1K-96-1275	FC2403210	KE DEMO - REMOVE HANDRAILS / GRATING at MEZZ #3	30JUL99	03AUG99	0	3	5	L.FORMO	KE DEMO - REMOVE HANDRAILS / GRATING at MEZZ #3															
1K-96-1275	FC2403220	KE DEMO - DEMO STRUCTURE/EXIST PIPING at MEZZ #3	04AUG99	10AUG99	0	5	5	L.FORMO	KE DEMO - DEMO STRUCTURE/EXIST PIPING at MEZZ #3															
1K-96-1275	FC2403230	KE DEMO - INSTALL NEW TRUCK BOLLARDS	11AUG99	13AUG99	0	3	5	L.FORMO	KE DEMO - INSTALL NEW TRUCK BOLLARDS															
105KE Transfer Channel Cleanup									105KE Transfer Channel Cleanup															
Design									Design															
1K-96-1490	FC21024	105KE TRANSFER CHANNEL DEMO WRK PKG	24AUG99	22SEP99	0	21*	101	SUMMARY	105KE TRANSFER CHANNEL DEMO WRK PKG															
1K-96-1490	FC2102410	TRANSFER CHANNEL - Prep Wk Instructions	24AUG99	07SEP99	0	10	101	TBD	TRANSFER CHANNEL - Prep Wk Instructions															
1K-96-1490	FC2102420	TRANSFER CHANNEL - Conduct Job Walkdown		23AUG99*	0	0	101	TBD	TRANSFER CHANNEL - Conduct Job Walkdown															
1K-96-1490	FC2102430	TRANSFER CHANNEL - Prepare AMW / RWP	24AUG99	07SEP99	0	10	101	TBD	TRANSFER CHANNEL - Prepare AMW / RWP															

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										M	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY				
Design										Design																
1K-96-1490	FC2102440	TRANSFER CHAN - Prepare Critical Lift Procedures			24AUG99	07SEP99	0	10	101	TBD	TRANSFER CHAN - Prepare Critical Lift Procedures															
1K-96-1490	FC2102450	TRANSFER CHANNEL - Obtain All Required Permits			24AUG99	07SEP99	0	10	101	TBD	TRANSFER CHANNEL - Obtain All Required Permits															
1K-96-1490	FC2102460	TRANSFER CHANNEL - Prepare QC Requirements			24AUG99	07SEP99	0	10	101	TBD	TRANSFER CHANNEL - Prepare QC Requirements															
1K-96-1490	FC2102470	TRANSFER CHANNEL - Prepare Waste Mgmt Plan			24AUG99	07SEP99	0	10	101	TBD	TRANSFER CHANNEL - Prepare Waste Mgmt Plan															
1K-96-1490	FC2102480	TRANSFER CHANNEL - Incorporate AI Plan			24AUG99	07SEP99	0	10	101	TBD	TRANSFER CHANNEL - Incorporate AI Plan															
1K-96-1490	FC2102490	TRANSFER CHANNEL - Prepare / Complete AJHA			24AUG99	07SEP99	0	10	101	TBD	TRANSFER CHANNEL - Prepare / Complete AJHA															
1K-96-1490	FC2102500	TRANSFER CHANNEL - Conduct 95% Complete Job Walkdown				08SEP99	0	0	101	TBD	TRANSFER CHANNEL - Conduct 95% Complete Job Walkdown															
1K-96-1490	FC2102510	Approve JCS Package for TRANSFER CHANNEL			09SEP99	15SEP99	0	5	101	TBD	Approve JCS Package for TRANSFER CHANNEL															
1K-96-1490	FC2102520	MRB Package Review for TRANSFER CHANNEL			16SEP99	22SEP99	0	5	101	OPS	MRB Package Review for TRANSFER CHANNEL															
1K-96-1490	FC2102530	KR3 Meeting for TRANSFER CHANNEL				22SEP99	0	0	101	J.WEAMER	KR3 Meeting for TRANSFER CHANNEL															
Construction										Construction																
1K-96-1490	FC2404	105KE TRANSFER CHANNEL EQUIPMENT REMOVAL INSTALL			05JAN00	25JAN00	0	15	41	SUMMARY	105KE TRANSFER CHANNEL EQUIPMENT REMOVAL Must Complete Prior to MCO Queue															
105KE Crane Pre-Outage										105KE Crane Pre-Outage																
Construction										Construction																
1K-99-0855	FC2450	105KE TRANSFER BAY CRANE UPGRADE			12JUL99	19APR00	0	198*	0	SUMMARY	105KE TRANSFER BAY CRANE UPGRADE															
1K-99-0855	FC24501	KE CRANE - PREOUTAGE CONSTRUCTION			12JUL99	27OCT99	0	77*	0	SUMMARY	KE CRANE - PREOUTAGE CONSTRUCTION															
1K-99-0855	FC2450110	KE CRANE - COMPLETE CORR-7 CONDUIT RUNS			12JUL99*	06AUG99	0	20	37	L.FORMO	KE CRANE - COMPLETE CORR-7 CONDUIT RUNS Paper Floor Ongoing Activity															
1K-99-0855	FC2450120	KE CRANE - COMPLETE CORR-7 PULL WIRE/TERM to CENTRAL BOX			09AUG99	03SEP99	0	20	37	L.FORMO	KE CRANE - COMPLETE CORR-7 PULL WIRE/TERM to CENTRAL BOX															
1K-99-0855	FC2450200	MEI REROUTES COMPLETE				27JUL99*	0	0	0	L.FORMO	MEI REROUTES COMPLETE Must Be Complete Prior to Scaffold Erection															
1K-99-0855	FC2450205	KE CRANE - ERECT ROLLING SCAFFOLD SOUTH WALL			28JUL99	03AUG99	0	5	0	L.FORMO	KE CRANE - ERECT ROLLING SCAFFOLD SOUTH WALL															
1K-99-0855	FC2450210	KE CRANE - ASBESTOS REMOVAL SOUTH WALL			04AUG99	13AUG99	0	8	2	L.FORMO	KE CRANE - ASBESTOS REMOVAL SOUTH WALL															
1K-99-0855	FC2450220	KE CRANE - DECON SOUTH WALL			04AUG99	17AUG99	0	10	0	L.FORMO	KE CRANE - DECON SOUTH WALL															
1K-99-0855	FC2450230	KE CRANE-MOUNT FESTOON-READER BRD-RADIO CONTROL UNIT			18AUG99	31AUG99	0	10	0	L.FORMO	KE CRANE-MOUNT FESTOON-READER BRD-RADIO CONTROL UNIT															
1K-99-0855	FC2450240	KE CRANE - COMPLETE CONDUIT RUNS SOUTH WALL			18AUG99	31AUG99	0	10	0	L.FORMO	KE CRANE - COMPLETE CONDUIT RUNS SOUTH WALL															
1K-99-0855	FC2450250	KE CRANE - PULL WIRE / TERM to FESTOON BOX			01SEP99	27OCT99	0	40	0	L.FORMO	KE CRANE - PULL WIRE / TERM to FESTOON BOX															

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									M	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY				
Construction									Construction																
1K-99-0519	FC24506220	KE CRNE - PERFORM EAST RAIL REPLACEMENT	02FEB00	22FEB00	0	15	0	L.FORMO	KE CRNE - PERFORM EAST RAIL REPLACEMENT																
1K-99-0519	FC24506225	KE CRNE - EAST RAIL BOLT TORQUE DOWN	23FEB00	07MAR00	0	10	0	L.FORMO	KE CRNE - EAST RAIL BOLT TORQUE DOWN																
1K-99-0519	FC24506230	KE CRNE - EAST RAIL FINAL PAINT	23FEB00	07MAR00	0	10	0	L.FORMO	KE CRNE - EAST RAIL FINAL PAINT																
1K-99-0519	FC24506235	KE CRNE - TROLLEY REPLACEMENT & FINAL ELECTRICAL	08MAR00	04APR00	0	20	0	L.FORMO	KE CRNE - TROLLEY REPLACEMENT & FINAL ELECTRICAL																
1K-99-0519	FC24506240	KE CRNE - ROOF MOD FINAL REPAIRS	15MAR00	28MAR00	0	10	5	L.FORMO	KE CRNE - ROOF MOD FINAL REPAIRS																
1K-99-0519	FC24506243	KE CRNE - FINAL PREP for CATS	05APR00	11APR00	0	5	0	L.FORMO	KE CRNE - FINAL PREP for CATS																
1K-99-0519	FC24506245	KE CRNE - PERFORM CONSTRUCTION ACCEPT TEST	12APR00	18APR00	0	5	0	L.FORMO	KE CRNE - PERFORM CONSTRUCTION ACCEPT TEST																
1K-99-0519	FC24506299	KE CRNE - TURNOVER to OPERATIONS		19APR00	0	0	0	L.FORMO	KE CRNE - TURNOVER to OPERATIONS																
105KE Immersion Pail Support Structure									105KE Immersion Pail Support Structure																
Design									Design																
1K-99-IPSS	FC2140	—IPSS / CONCRETE LUMP DESIGN	01OCT98A	14JUN99	25	10*	115	SUMMARY	—IPSS / CONCRETE LUMP DESIGN																
1K-99-IPSS	FC2140130	KE IPSS - Prepare Procurement Specification	03MAY99A	07JUN99	75	5	115	R.FILKOWSKI	KE IPSS - Prepare Procurement Specification																
1K-99-IPSS	FC2140140	KE IPSS - Approve Procurement Specification	08JUN99	14JUN99	0	5	115	R.FILKOWSKI	KE IPSS - Approve Procurement Specification																
1K-99-IPSS	FC2140150	KE IPSS - Bid / Award Process	15JUN99	14JUN99	0	0*	115	PROCUREMENT	KE IPSS - Bid / Award Process																
1K-99-IPSS	FC2140160	KE IPSS - Award Contract		14JUN99	0	0	115	PROCUREMENT	KE IPSS - Award Contract																
1K-99-IPSS	FC2140500	KE IPSS - Resolve 105KE Drain Valve Path Forward	18AUG99*		0	0	41	OPS	KE IPSS - Resolve 105KE Drain Valve Path Forward																
1K-99-IPSS	FC2140505	KE IPSS - Prepare Hazards Catagory	18AUG99	31AUG99	0	10	41	R.WEBB	KE IPSS - Prepare Hazards Catagory																
1K-99-IPSS	FC2140510	KE IPSS - Prepare ECN	01SEP99	15SEP99	0	10	41	L.RODGERS	KE IPSS - Prepare ECN																
1K-99-IPSS	FC2140520	KE IPSS - ALARA Review	18AUG99	31AUG99	0	10	51	M.NOLAN	KE IPSS - ALARA Review																
1K-99-IPSS	FC2140530	KE IPSS - Conduct / Approve USQ Screen	16SEP99	22SEP99	0	5	41	D.COOLEY	KE IPSS - Conduct / Approve USQ Screen																
1K-99-IPSS	FC21406	—GROUT REMOVAL / IPSS INSTALL WORK PKG	30SEP99	03NOV99	0	25*	41	SUMMARY	—GROUT REMOVAL / IPSS INSTALL WORK PKG																
1K-99-IPSS	FC2140610	GROUT / IPSS - Prep Wtk Instructions	30SEP99*	20OCT99	0	15	41	T.NUGENT	GROUT / IPSS - Prep Wtk Instructions																
1K-99-IPSS	FC2140620	GROUT / IPSS - Conduct Pre-Job Walk		29SEP99*	0	0	41	T.NUGENT	GROUT / IPSS - Conduct Pre-Job Walk																
1K-99-IPSS	FC2140630	GROUT / IPSS - Prepare AMW / RWP	07OCT99	20OCT99	0	10	41	T.NUGENT	GROUT / IPSS - Prepare AMW / RWP																
1K-99-IPSS	FC2140640	GROUT / IPSS - Prepare Critical Lift Procedures	07OCT99	20OCT99	0	10	41	T.NUGENT	GROUT / IPSS - Prepare Critical Lift Procedures																

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1K-99-IPSS	FC2140650	GROUT / IPSS - Obtain All Required Permits	07OCT99	20OCT99	0	10		41	T.NUGENT																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						</

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1K-99-SHTL	FC21088140		SHUTTLE / GAN - Prepare Critical Lift Procedures	02NOV99	15NOV99	0	10	127	TBD																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		

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										M	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB
105KE Windbreak Installation										105KE Windbreak Installation									
Design										Design									
1K-98-2388	FC21033	105KE WINDBREAK WRK PKG	16MAR99A	15JUN99	75	11*		58	SUMMARY										
1K-98-2388	FC2103320	Windbreak - Conduct Job Walkdown		28MAY99*	0	0		64	T.NUGENT										
1K-98-2388	FC2103330	Windbreak - Prepare AMW/RWP	01JUN99	07JUN99	0	5		58	T.NUGENT										
1K-98-2388	FC2103350	Windbreak - Obtain All Required Permits	16MAR99A	07JUN99	75	5		58	T.NUGENT										
1K-98-2388	FC2103355	Windbreak - Prepare QC Requirements	16MAR99A	07JUN99	75	5		58	T.NUGENT										
1K-98-2388	FC2103360	Windbreak - Prepare Waste Mgmt Plan	16MAR99A	07JUN99	75	5		58	T.NUGENT										
1K-98-2388	FC2103365	Windbreak - Incorporate AI Plan	16MAR99A	07JUN99	75	5		58	T.NUGENT										
1K-98-2388	FC2103370	Windbreak - Prepare / Complete AJHA	16MAR99A	07JUN99	75	5		58	T.NUGENT										
1K-98-2388	FC2103375	Windbreak - Conduct 95% Complete Job Walkdown		08JUN99	0	0		58	T.NUGENT										
1K-98-2388	FC2103380	Approve JCS Pkg for Windbreak Install	09JUN99	15JUN99	0	5		58	T.NUGENT										
Construction										Construction									
1K-98-2388	FC2405	105KE WINDBREAK INSTALL	30JUN99	05AUG99	0	25*		58	SUMMARY										
1K-98-2388	FC2405100	WIND - EXCAVATION	30JUN99	15JUL99	0	10		58	L.FORMO										
1K-98-2388	FC2405110	WIND - SET FORMS & POUR CONCRETE	16JUL99	20JUL99	0	3		58	L.FORMO										
1K-98-2388	FC2405120	WIND - CURE CONCRETE (Perform 7-Day Break)	21JUL99	27JUL99	0	5		58	L.FORMO										
1K-98-2388	FC2405130	WIND - ERECT WINDBREAK	28JUL99	04AUG99	0	6		58	L.FORMO										
1K-98-2388	FC2405140	WIND - PERFORM ELECTRICAL INSTALLATIONS	28JUL99	04AUG99	0	6		59	L.FORMO										
1K-98-2388	FC2405150	WIND - TIE-IN to BLDG	02AUG99	05AUG99	0	4		58	L.FORMO										
105KE Platform around SLP										105KE Platform around SLP									
Design										Design									
1K-98-2389	FC2105	105KE PLATFORM around SLP DESIGN	01JUN98A	07JUN99	62	5*		349	SUMMARY										
1K-98-2389	FC2105145	OPS Loadout - Complete ALARA Report	01JUN99*	07JUN99	0	5		349	N.NOLAN										
1K-98-2389	FC21058100	105KE OPS LOADOUT WRK PKG	02MAY00	30MAY00	0	21*		121	SUMMARY										
1K-98-2389	FC21058110	OPS LOADOUT - Prep Work Instructions	02MAY00	15MAY00	0	10		121	TBD										
1K-98-2389	FC21058120	OPS LOADOUT - Conduct Job Walkdown		01MAY00*	0	0		121	TBD										

Project Start
30MAR98

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31MAY99

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02JUN99

Early Bar

Progress Bar

Critical Activity

FE17 E110

100K AREA PROJECTS

Cask Transport Facility Mods

May 31, 1999

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Work Pkg	Activity ID	Activity Description	Start	Finish	Pct Cmpl	Rem Dur	Total Float	Resp	FY99					FY00										
									M	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY			
105KE Tool Storage / Laydown Area									105KE Tool Storage / Laydown Area															
Design									Design															
1K-98-2391	FC2130	105KE TOOL STORAGE / DECON AREA DESIGN	08JUN98A	07JUN99	80	5*		425	SUMMARY															
1K-98-2391	FC2130155	Tool - Perform ALARA Review	01JUN99*	07JUN99	0	5		425	M.NOLAN															
1K-98-2391	FC21303	105KE SMALL TOOL WRK PKG	02MAY00	30MAY00	0	21*		126	SUMMARY															
1K-98-2391	FC21303110	SMALL TOOL - Prep Wk Instructions	02MAY00	15MAY00	0	10		126	TBD															
1K-98-2391	FC21303120	SMALL TOOL - Conduct Job Walkdown		01MAY00*	0	0		126	TBD															
1K-98-2391	FC21303130	SMALL TOOL - Prepare AMW / RWP	02MAY00	15MAY00	0	10		126	TBD															
1K-98-2391	FC21303140	SMALL TOOL - Prepare Critical Lift Procedures	02MAY00	15MAY00	0	10		126	TBD															
1K-98-2391	FC21303150	SMALL TOOL - Obtain All Required Permits	02MAY00	15MAY00	0	10		126	TBD															
1K-98-2391	FC21303160	SMALL TOOL - Prepare QC Requirements	02MAY00	15MAY00	0	10		126	TBD															
1K-98-2391	FC21303170	SMALL TOOL - Prepare Waste Mgmt Plan	02MAY00	15MAY00	0	10		126	TBD															
1K-98-2391	FC21303180	SMALL TOOL - Incorporate AI Plan	02MAY00	15MAY00	0	10		126	TBD															
1K-98-2391	FC21303190	SMALL TOOL - Prepare / Cmpl AI JHA	02MAY00	15MAY00	0	10		126	TBD															
1K-98-2391	FC21303200	SMALL TOOL - Conduct 95% Cmpl Job Walkdown		16MAY00	0	0		126	TBD															
1K-98-2391	FC21303210	Approve JCS Pkg for SMALL TOOL	17MAY00	23MAY00	0	5		126	TBD															
1K-98-2391	FC21303220	MRB Pkg Review for SMALL TOOL	24MAY00	30MAY00	0	5		126	OPS															
1K-98-2391	FC21303230	KR3 Meeting for SMALL TOOL		30MAY00	0	0		126	J.WEAMER															
105KE Corridor 7 Modifications									105KE Corridor 7 Modifications															
Design									Design															
1K-98-2345	FC21043	105KE CORR 7 WRK PKG	20JUL99	17AUG99	0	21*		221	SUMMARY															
1K-98-2345	FC21043110	CORR 7 - Prep Wk Instructions	20JUL99	02AUG99	0	10		221	TBD															
1K-98-2345	FC21043120	CORR 7 - Conduct Job Walkdown		19JUL99*	0	0		221	TBD															
1K-98-2345	FC21043130	CORR 7 - Prepare AMW / RWP	20JUL99	02AUG99	0	10		221	TBD															
1K-98-2345	FC21043140	CORR 7 - Prepare Critical Lift Procedures	20JUL99	02AUG99	0	10		221	TBD															
1K-98-2345	FC21043150	CORR 7 - Obtain All Required Permits	20JUL99	02AUG99	0	10		221	TBD															

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30MAR98

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Early Bar

Progress Bar

Critical Activity

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Cask Transport Facility Mods
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Project Start 30MAR98
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Early Bar
 Progress Bar
 Critical Activity

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HNF-4576, Rev. 0

		Work Pkg	Activity ID	Activity Description	Start	Finish	Pct Cmpltd	Rem Dur	Total Float	Resp	FY99					FY00							
											M	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Design												Design											
	1K-98-2345	FC21043160		CORR 7 - Prepare QC Requirements	20JUL99	02AUG99	0	10	221	TBD													
	1K-98-2345	FC21043170		CORR 7 - Prepare Waste Mgmt Plan	20JUL99	02AUG99	0	10	221	TBD													
	1K-98-2345	FC21043180		CORR 7 - Incorporate AI Plan	20JUL99	02AUG99	0	10	221	TBD													
	1K-98-2345	FC21043190		CORR 7 - Prepare / Complete AJHA	20JUL99	02AUG99	0	10	221	TBD													
	1K-98-2345	FC21043200		CORR 7 - Conduct 95% Complete Job Walkdown		03AUG99	0	0	221	TBD													
	1K-98-2345	FC21043210		Approve JCS Pkg for CORR 7	04AUG99	10AUG99	0	5	221	TBD													
	1K-98-2345	FC21043220		MRB Pkg Review for CORR 7	11AUG99	17AUG99	0	5	221	OPS													
	1K-98-2345	FC21043230		KR3 Meeting for CORR 7		17AUG99	0	0	221	J.WEAMER													
Construction												Construction											
	1K-98-2345	FC2406		105KE CORRIDOR 7 MOD's INSTALL	09SEP99	03NOV99	0	40	216	SUMMARY													

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APPENDIX D

Description of Possible Transportation Cask Drop Accidents in the 105 KW Basin South Loadout Pit Area

***See CD-Rom for Animation**

M & D*Professional Services Inc.*

**Description of Possible Transportation Cask Drop Accidents
In the 105 K Basin South Loadout Pit Area**

**Calculation No. M&D 99-04
Rev 1**

Prepared by

**M&D Professional Services, Inc.
1305 Mansfield, Suite 5
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**Prepared for:
DE&S Hanford, Inc.**

Prepared by:

5/28/99
Marlin Lindquist, P. E.

Checked by:

5-28-99
Milon Meyer

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1.0 INTRODUCTION

Transfer of the cask to or from the transport trailer from or to the south loadout pit (SLOP) will involve utilization of the crane/trolley/hoist system in the Transfer Area of 105 K Basins East and West. The cask being transferred will contain the Multi-Canister Overpack (MCO) with the total mass of the cask plus the MCO and Spent Nuclear Fuel (SNF) being 62,000 lb. If the cask were dropped during the transfer process, it could threaten the safety class envelope of the SLOP and the basin pool.

The purpose of this document is to define the possible accident scenarios that might occur as a result of a cask drop accident in the transfer/SLOP area.

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2.0 SCOPE

The drop accident scenarios presented herein are limited to those that may occur in the transfer area and the SLOP of 105 K Basins East and West. The transfer area lies approximately between column lines A and F in the north-south direction and between column lines 13 and 16 in the east-west direction. The SLOP interior horizontal dimensions are 7 ft. by 9 ft. 2 in. and the pit lies approximately between column lines D and E in the north-south direction and between column lines 13 and 15 in the east-west direction. A concrete curbing 2 ft. higher than the transfer area floor surrounds the pit. This curbing is 1 ft. 5 ¾ in. wide on the west side of the pit and 1 ft. 4 in. wide on the other sides. A transfer slot that is 38 in. wide connects the SLOP to the basin pool.

For the purpose of developing drop accident scenarios for the SNF loadout process, a zone of normal work was defined. The zone of normal work used the proposed cask travel path between the SLOP and the transport trailer as its zero data line. It can be reasonably assumed that during SNF project operations the cask may deviate from the proposed cask travel path by a short distance. The zone of normal work thus is an area expanded around the proposed travel path and physical interfaces.

The crane cannot travel east or west outside of its pick zone between column lines 15 and 13. In the north and south directions there is equipment that an operator would have to evade in order move the cask outside of a bounding area. The south side has the transport trailer beyond which the operator would not normally move the cask. The north side has the cask loadout system equipment laydown area also beyond which the operator would not normally move the crane. This leaves the area between column lines D and E in the north-south direction. To move the cask outside of the zone of normal work thus described would require the operator to deliberately evade the equipment and this is not considered part of normal design requirements.

The safety boundary of interest includes the SLOP and its ability to retain required levels of water. Also considered are movements of a dropped cask that might roll or slide eastward and enter the safety class basin pool.

This document is limited to a description of possible cask drop accident scenarios that may threaten the SLOP safety envelope. Analyses of the probability or potential for accident occurrences is not addressed herein. An analysis of the capacity of adjacent components and structure to absorb cask drop impact loading and thus protect the safety envelope of the SLOP is also not considered.

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			Contract No. 19449

3.0 SUMMARY

Drop accident scenarios that might occur during the transfer of the cask and the Multi-Canister Overpack (MCO) from or to the SLOP to or from the transport trailer have been identified. Only those accidents that would compromise the safety envelope of the SLOP or the basin pool have been considered. The drop accidents that were considered have been grouped as follows.

1. Worst case drop accidents of the cask into the SLOP during which the cask remains vertical or near vertical during the drop.
2. Drop accidents of the cask onto the transfer area or into the SLOP during which the cask is in an oblique orientation during the drop.
3. Drop accidents of the cask onto the transfer area or into the SLOP during which the cask may roll or slide toward the basin pool.

The results of the study are summarized in Tables 3-1 through 3-3. Additional details are presented in Section 5.0. Also shown in Table 3-2 are the identification numbers of the cask drop animations developed using the "Working Model" computer code included in Attachment A and discussed in Section 3.

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Table 3-1
Cask/MCO Drop Scenario Summary, Vertical Drop Accidents into the South Loadout Pit

Drop	Description of Drop	Affected Components or Structure	Elevation of Cask Bottom at Initiation of Drop ⁽¹⁾	Drop Distance	Comments
1	Drop imposes loading onto 2 vertical legs of immersion pail support structure.	Immersion pail/immersion pail support structure vertical legs/loadout pit concrete	+5.33 ft.	3.67 ft.	Cask drops onto immersion pail lip. Load is transmitted to 2 adjacent vertical legs of the immersion pail support structure.
2	Cask drops into empty immersion pail.	Immersion pail/immersion pail support structure/loadout pit concrete	+5.33 ft.	17.25 ft.	Empty immersion pail positioned at top of pit, cask drops and impacts bottom of immersion pail.
3	Cask and immersion pail drop into pit.	Loadout pit concrete	Cask inserted in immersion pail	13.33 ft.	Immersion pail (with cask inserted) stationed at top of pit; cask and pail then drop together and impact bottom of pit.
4	Cask drops into empty immersion pail and jams on the top of the pail internal stiffening ring.	Immersion pail/immersion pail support structure/loadout pit concrete	+5.33 ft.	5.25 ft.	Empty immersion pail positioned at top of pit, cask drops and becomes jammed near the top of immersion pail.
5	Combination of Drop 2 and Drop 3.	Immersion pail/immersion pail support structure/loadout pit concrete	+5.33 ft.	See drops 2 and 3	Empty immersion pail stationed at top of pit, cask drops into immersion pail, cask and pail then drop together and impact bottom of pit.
6	Drop imposes loading onto 1 vertical leg of immersion pail support structure.	Immersion pail/immersion pail support structure vertical legs/loadout pit concrete	+5.33 ft.	3.75 ft.	Cask drops onto immersion pail support lug. Load is transmitted to adjacent vertical leg of immersion pail support structure ⁽²⁾ .

- (1) Five feet four inches is the elevation of the bottom of the cask above the transfer area floor when the crane limit switches cut off power during fuel loadout operations
- (2) It is assumed that the pail support lug (1 1/2 in. plate) has insufficient strength to withstand cask drop load and therefore will deform. It is further assumed that the cask then loads the Immersion Pail Support Structure lock pin guide assembly and in turn loads one of the IPSS vertical legs.

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Table 3-2

Cask/MCO Drop Scenario Summary, Oblique Drop Accidents into Transfer Area and South Loadout Pit

Drop	Description of Drop	Affected Components or Structure	Elevation of Cask Bottom at Initiation of Drop ⁽¹⁾	Comments	"Working Model" Animation No.
7a	Cask drops onto transfer area floor, tips and falls to the north.	Non-safety class components	+5.33 ft.	Loadout pit safety class envelop not affected.	-
7b	Cask drops onto transfer area floor, tips and falls to the east.	Loadout pit curbing/gantry/gantry support structure	+5.33 ft.	Loadout pit safety class envelope could be affected ⁽⁴⁾ .	3
7c	Cask drops onto transfer area floor, tips and falls to the south.	Non-safety class trailer components	+5.33 ft.	Loadout pit safety class envelop not affected.	-
7d	Cask drops onto transfer area floor, tips and falls to the west.	Crane rail support column 15D and non-safety class components.	+5.33 ft.	Loadout pit safety class envelope could be affected if crane support column fails.	2
8a	Cask drops into top of loadout pit, tips and falls to the north.	Gantry support structure/ /pit curbing/TXM #4 (at KW)	+5.33 ft.	Loadout pit safety class envelop not affected ⁽²⁾ .	6
8b	Cask drops into or onto top of loadout pit, tips and falls to the east.	Gantry/operations platform/shuttle impact limiter ⁽³⁾ /pit curbing	+5.33 ft.	Loadout pit safety class envelope not expected to be affected ⁽²⁾⁽⁴⁾ Cask cannot fall into the transfer channel.	4,5
8c	Cask drops into or onto top of loadout pit, tips and falls to the northeast.	Gantry rail support structure/secondary gantry structure/crane rail support column/pit curbing.	+5.33 ft.	Loadout pit safety class envelope not expected to be affected ⁽²⁾⁽⁴⁾ .	7
8d	Cask drops into or onto top of loadout pit, tips and falls to the southeast.	Gantry rail support structure/secondary gantry structure/crane rail support/column pit curbing.	+5.33 ft.	Loadout pit safety class envelope not expected to be affected ⁽²⁾⁽⁴⁾ .	-
8e	Cask drops into or onto top of loadout pit, tips and falls to the south.	Gantry support structure/pit curbing/roof support column/non-safety class trailer components	+5.33 ft.	Loadout pit safety class envelop not affected ⁽²⁾ .	1
8f	Cask drops into or onto top of loadout pit, tips and falls to the west.	Pit curbing/transfer area floor.	+5.33 ft.	Loadout pit safety class envelope could be affected. See also Drop 7d and 9	-

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Notes for Table 3-2

- (1) Five feet four inches is the elevation of the bottom of the cask above the transfer area floor when the crane limit switches cut off power during fuel loadout operations
- (2) This assumes that the gantry or other structure is protected or shown through analysis to withstand the cask drop impact loading.
- (3) The Shuttle Impact Limiter is a safety class item, however it is not required to perform its safety function during cask/pail movement. The shuttle will not have a basket in place nor shall the gantry be in use during cask/pail operations.
- (4) Gantry protective bumper will absorb energy.

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Table 3-3

Cask/MCO Drop Scenario Summary, Drop Accidents That May Allow Cask to Move into Basin Pool

Drop	Description of Drop	Further Movement of Cask	Affected Components or Structure	Comments
9	Cask rolls or slides on the transfer area floor.	Rolls/slides east or west	Crane rail support column 15D	Enveloped by Drop 10 if cask moves east. If cask moves west, see Drop 7d
10a	Cask drops into top of loadout pit, tips and falls to the north.	Rolls/slides east after impacting IXM or other non-safety components.	Gantry support structure/IXM (at KW)/walkway platform	If cask penetrates all components and structure, it may roll/slide into the basin pool.
10b	Cask drops into top of loadout pit, tips and falls to the east.	Rolls/slides east	Gantry/operations platform/shuttle impact limiter	If cask penetrates all components and structure, it is not expected that the cask will roll/slide into the basin pool.
10c	Cask drops into top of loadout pit, tips and falls to the northeast.	Rolls/slides east	Gantry rail support structure and secondary gantry structure.	If cask penetrates all components and structure, it is not expected that the cask will roll/slide into the basin pool.
10d	Cask drops into top of loadout pit, tips and falls to the southeast.	Rolls/slides east	Gantry rail support structure and secondary gantry structure.	If cask penetrates all components and structure, it is not expected that the cask will roll/slide into the basin pool.
10e	Cask drops into top of loadout pit, tips and falls to the south.	Rolls/slides east	Gantry support structure/ non-safety class trailer components	If cask penetrates all components and structure and continues to move east, it will impact the rail car stop. If it passes the rail car stop, it can roll/slide into the basin pool.
10f	Cask drops into top of loadout pit, tips and falls to the west.	Rolls/slides west	crane rail support column 15D	Cask falls into transfer area. Cannot move into basin pool. If cask rolls west, could impact crane rail support column 15D

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4.0 CRANE DESCRIPTION

The rated load of the current 105 KE facility transfer bay bridge crane is 30 tons. The rated load of the 105 KW facility transfer bay bridge crane is 32 tons. The crane in 105 KW is a traveling bridge-type crane with motorized trolley bridge and hoist. The 105 KW facility transfer bay bridge crane design includes a number of features to ensure safe unloading of casks containing the SNF. The 105 KE crane will be replaced with a new crane with the same features as the crane currently installed in 105 KW.

Significant features of the cranes are shown in the table below.

Feature	Value
Hoist Capacity	32 tons
Hoist Lift*	39 ft. 6 in.
Hoist Speed	Zero to 10.5 ft./min.
Trolley Speed	Zero to 20.5 ft./min.
Bridge Speed	Zero to 17 ft./min.
Bridge Span	36 ft. 3 in.
Crane Runway Length	69 ft. 6 in.

*The 32 ton transfer area crane limit switch limits the crane hook hoist elevation to 20 ft. 6 in.

The ideal path of the cask as it moves from the SLOP to the transport trailer is 9 ft. 11 in. to the west followed by 11 ft. 9 in. to the south.

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5.0 DROP ACCIDENTS

A number of cask/MCO drop accident scenarios have been identified for the K Basins transfer area and SLOP. These scenarios are described below and summarized in Tables 3-1 through 3-3. These drops involve the loaded cask as it is being transferred from or to the SLOP to or from the transport trailer. The drop accidents identified are limited to those that affect the safety envelope of the SLOP itself or that could result in the cask rolling or sliding into the basin pool. Since both the empty and loaded casks are moved along the same paths during transfer, all drop load scenarios conservatively use the loaded cask/MCO mass.

Detailed calculations of the drop heights for the various scenarios are presented in the Appendix "Drop Height Definition Memorandum" (Calculation CTFM-M-0001, Rev 0).

Animated visualizations of a number of the drop scenarios have been developed using the "Working Model" computer code. These are described in Attachment A. The cases developed were those involving tipping of the cask/MCO after impact. Table 3-2 indicates those cases for which Working Model animations have been developed.

The datum elevation of the floor in the transfer area is +0.0 ft. The elevation of the water in the SLOP/basin pool is

K Basin East	Minus 3 ft. 5 in., Maximum
	Minus 3 ft. 9 in., Minimum
K Basin West	Minus 4 ft. 3 in., Maximum
	Minus 4 ft. 9 in., Minimum

The height that the crane can lift the cask/MCO is defined by either the limit switches or the to-blocking limit. The to-blocking limit results in a greater possible cask/MCO drop height, however the limit switches are safety class, therefore the to-block condition is not considered further herein. The 32 ton crane limit switch limits the cask bottom elevation to a nominal +5 ft. 4 in. (+5.33 ft.).

A plan view sketch showing possible cask drop locations in the transfer area/SLOP is shown in Figure 5-1.

5.1 DROP ACCIDENT SCENARIO 1 (VERTICAL DROP OVER LOADOUT PIT)

Drop accident scenario 1 involves a vertical drop that results in loading on two vertical legs of the immersion pail support structure. This drop scenario is illustrated in Figure 5-2 and 5-3.

The loaded cask/MCO mass is 62,000 lb. and it is in the SLOP where the elevation of the top of the immersion pail is +1.67 ft (transfer area floor surface = zero elevation datum). It is raised and lifted out of the Immersion Pail and Immersion Pail Support Structure (IPSS), and is maintained at a nominal elevation of +4.33 ft. in order to clear the work platform on the west edge of the pit. The crane limit switch elevation, however, is the controlling worst case (bottom of cask at elevation +5.33 ft.). A drop

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occurs while the cask is over the pit and the cask maintains a vertical orientation as it falls and impacts the immersion pail lip midway between two vertical legs of the immersion pail support structure. The immersion pail transfers one half of the load equally through each of two pail support lugs to two adjacent vertical immersion pail support structure legs.

The total drop distance is 3.67 ft.

5.2 DROP ACCIDENT SCENARIO 2 (VERTICAL DROP OVER LOADOUT PIT)

Drop accident scenario 2 involves a vertical drop into an empty immersion pail positioned at the top of the pit. This drop scenario is illustrated in Figures 5-4 and 5-5.

The cask/MCO mass is 62,000 lb. and it is raised over the SLOP with the bottom of the cask at a nominal elevation of +4.33 ft. The crane limit switch elevation is the controlling worst case (bottom of cask at elevation +5.33 ft.).

The immersion pail is positioned at the top of the pit and supported by the pail support pins. The elevation of the bottom of the inside of the pail is -11.92 ft.

A drop occurs while the cask is over the center of the pail, and as the cask drops, it is assumed that the cask (1) remains centered (2) remains vertical and (3) drops freely into the immersion pail and impacts the bottom of the pail.

The total drop distance is 17.25 ft.

5.3 DROP ACCIDENT SCENARIO 3 (VERTICAL DROP OVER LOADOUT PIT)

Drop accident scenario 3 involves a vertical drop of a combined cask and immersion pail into the pit. This drop scenario is illustrated in Figures 5-6 and 5-7.

The cask/MCO mass is 62,000 lb. and is inserted into the immersion pail (mass of pail plus hardware and miscellaneous equipment is 8,000 lb.) at the top of the SLOP.

It is assumed that the pail support pins/lugs fail and a drop accident occurs. The cask and the pail drop downward into the pit as a single unit. As the cask and pail fall, it is assumed that the unit remains centered and vertical and that it impacts the bottom plate of the immersion pail support structure.

The foam surrounding the immersion pail will influence the drop characteristics of the pail. This foam provides buoyancy that is conservatively assumed to be 6353 lb. when the pail is pinned in place at the top of the pit and 10,500 lb. when the pail is fully submerged.

The total drop distance is 13.33 ft.

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5.4 DROP ACCIDENT SCENARIO 4 (VERTICAL DROP OVER LOADOUT PIT)

Drop accident scenario 4 involves a vertical drop into an empty immersion pail positioned at the top of the pit. This drop scenario is illustrated in Figures 5-8 and 5-9.

The cask/MCO mass is 62,000 lb. and it is raised over the SLOP with the bottom of the cask at a nominal elevation of +4.33 ft. The crane limit switch elevation is the controlling worst case (bottom of cask at elevation +5.33 ft.).

The immersion pail is positioned at the top of the pit and supported by the pail support pins. The elevation of the top of the immersion pail is +1.67 ft.

A drop occurs while the cask is over the pail, and as the cask drops, it is assumed that the cask falls freely in a near vertical orientation until a corner of the bottom of the cask strikes the top of the internal stiffening guide ring of the immersion pail and stops. The cask moves no further. The top of the stiffening ring is 19.44 in. below the upper lip of the immersion pail.

Total drop distance is 5.25 ft.

5.5 DROP ACCIDENT SCENARIO 5 (VERTICAL DROP OVER LOADOUT PIT)

Drop accident scenario 5 is a combination of drop accident scenarios 2 and 3 and involves a vertical drop into an empty immersion pail located at the top of the SLOP. After the cask impacts the bottom of the pail, the combined cask/MCO and immersion pail drop into the pit. This drop scenario is illustrated in Figures 5-10 and 5-11.

The cask/MCO mass is 62,000 lb. and is raised over the south loadout area with the bottom of the cask at a nominal elevation of +4.33 ft. The empty immersion pail (mass of pail plus hardware is approximately 8,000 lb.) is at the top of the loadout pit. The crane limit switch elevation is the controlling worst case (bottom of cask at elevation +5.33 ft.).

A drop occurs while over the pit. As the cask drops, it is assumed that the cask remains centered and vertical and that it drops freely into the immersion pail and impacts the bottom of the pail. At this point, the pail support pins/lugs fail and the cask/MCO and the pail fall downward into the pit as a single unit. As the cask and pail drop, it is assumed that the unit remains centered and vertical and that it impacts the bottom plate of the immersion pail support structure with the mass of both the pail and the cask.

As in drop accident scenario 3, the buoyancy of the foam surrounding the immersion pail influences the drop characteristics of the pail

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5.6 DROP ACCIDENT SCENARIO 6 (VERTICAL DROP OVER LOADOUT PIT)

Drop accident scenario 6 involves a vertical drop that results in loading on one leg of the immersion pail support structure. This scenario is similar to drop accident scenario 1 and is illustrated in Figure 5-12.

The cask/MCO mass is 62,000 lb. and it is raised over the SLOP, with the bottom of the cask at a nominal elevation of +4.33 ft. The crane limit switch elevation is the controlling worst case (bottom of cask at elevation +5.33 ft.).

A drop occurs while the cask/MCO is over the pit and the cask maintains a vertical orientation as it falls and impacts one of the immersion pail support lugs. The lug deforms and the cask further impacts the top of the IPSS pin block. The pin block transfers the load to one of the immersion pail vertical support structure legs.

The total drop distance is 3.75 ft.

5.7 DROP ACCIDENT SCENARIO 7 (OBLIQUE DROP OVER TRANSFER AREA)

Drop accident scenario 7 involves an oblique drop onto the transfer area floor surface that results in tipping of the cask/MCO. This scenario is limited to the effects of the tipping only. Rolling or sliding of the cask/MCO after impact is considered in drop accident scenario 9.

The cask/MCO mass is 62,000 lb. and it is raised and lifted toward the transport trailer. As it is moved horizontally, it is nominally at +4.33 ft. above the transfer area floor surface. As the cask is being transferred horizontally over the transfer area floor, a drop occurs. The crane limit switch elevation is the controlling worst case (bottom of cask at elevation +5.33 ft.).

The cask orientation as it drops is at an angle to the vertical. The cask impacts the floor surface of the transfer area on a corner of the cask and the rotational energy of the cask causes it to fall and tip on its side. Depending upon the location and the direction of the tip, the cask may impact adjacent components or structure or it may "slapdown" directly on the floor surface.

5.7.1 Oblique Drop Over Transfer Area and Tip to the North (7a)

An oblique drop in the transfer area that falls and tips in a northerly direction can strike and impact non-safety class components. Since this does not affect the SLOP safety class envelope, it will not be considered further.

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5.7.2 Oblique Drop Over Transfer Area and Tip to the East (7b)

An oblique drop in the transfer area that falls and tips in an easterly direction may strike and impact components and structure in the SLOP area. The affected area from a tip will depend upon the location at which the tip occurs (see also scenarios 8b, 8c, and 8d).

If the drop and tipping of the cask occurs with the center of percussion of the cask outside of the SLOP envelope, the cask will remain in the transfer area. The cask will slap down and could impact and damage the curbing and wall that is on the west side of the SLOP.

If the drop and tipping of the cask occurs with the center of percussion of the cask inside of the SLOP envelope, the cask may tip into the loadout pit. The height of the cask is such that it could tip into the gantry structure and/or gantry support structure. A moveable gantry protective bumper is currently being considered to absorb some of the energy of a cask tip toward the east. This bumper will consist of a sliding crossbar that is supported by the gantry support rails. It will span the space over the SLOP between opposite gantry support rails.

This scenario is illustrated in Figure 5-13.

5.7.3 Oblique Drop Over Transfer Area and Tip to the South (7c)

An oblique drop in the transfer area that falls and tips in a southerly direction can strike and impact non-safety transport trailer components. Since this does not affect the SLOP safety class envelope, it will not be considered further.

5.7.4 Oblique Drop Over Transfer Area and Tip to the West (7d)

An oblique drop in the transfer area that falls and tips in a westerly direction can strike and impact non-safety class components.

However, another potential target that the cask may strike is crane rail support column 15D. This column is located approximately 14 ft. from the center of the transfer area and thus the possibility for a dropped cask to move into that area and damage the column is remote. However, if this column were to fail, the overhead crane and trolley assembly could collapse. This failure could result in the crane and trolley assembly dropping onto the top of the SLOP.

This scenario is illustrated in Figure 5-14.

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5.8 DROP ACCIDENT SCENARIO 8 (OBLIQUE DROP OVER LOADOUT PIT)

Drop accident scenario 8 involves an oblique drop over the SLOP. This scenario is limited to the effects of cask tipping only. The effects of direct drops into the SLOP are covered by scenarios 1-6. Rolling or sliding of the cask after tipping is considered in drop accident scenario 10.

The cask mass is 62,000 lb. and it is raised above the pit with the bottom of the cask at a nominal elevation of +4.33 ft. As the cask is being transferred horizontally over the pit, a drop occurs. The crane limit switch elevation is the controlling worst case (bottom of cask at elevation +5.33 ft.).

The cask orientation as it drops is at an angle to the vertical. The cask impacts structure at or near the top of the SLOP on a corner of the cask. The rotational energy of the cask causes it to tend to tip on its side. Depending upon the location and the direction of the tip, the cask may impact adjacent components or structure.

5.8.1 Oblique Drop Over Loadout Pit and Tip to the North (8a)

An oblique drop of the cask into the SLOP that results in the cask tipping in a northerly direction will cause the cask to strike and impact the gantry support structure. If the cask proceeds beyond the gantry rail support structure (W12 wide flange beam), it will impact the ion exchange module (IXM) in the KW Area. If the cask proceeds beyond the gantry rail support structure in the KE Area, it will impact various non-safety class items.

This scenario is illustrated in Figure 5-15.

5.8.2 Oblique Drop Over Loadout Pit and Tip to the East (8b)

An oblique drop of the cask into the SLOP that results in the cask tipping in an easterly direction will be caused by the cask bottom striking (1) the top of the immersion pail structure or (2) the top of the curbing on the side of the pit. If the cask falls directly east, it will strike and impact the main gantry structure. If the cask passes through the gantry structure, it will impact the east operations platform and supporting steel structure. If the cask proceeds further, it will impact the shuttle impact limiter. As discussed in scenario 7b, a gantry protective bumper will absorb some of the energy from a tip to the east.

The transfer channel between the SLOP and the basin pool is 38 in. wide. If the dropped cask were to penetrate all of the structure noted above, it would not fall into the transfer channel, since the cask diameter (40 in.) is wider than the width of the transfer channel.

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Figure 5-16 shows the envelope of the cask center of percussion for a tip in an eastward direction. If the cask strikes a resisting object (such as the pit curbing) at a radius less than the center of percussion, further rotation could occur. The point of rotation is assumed to be the west curbing of the pit. As can be seen from Figure 5-16, the cask will not fall into the transfer channel even if all structures and components are penetrated.

This scenario is illustrated in Figure 5-17.

5.8.3 Oblique Drop Over Loadout Pit and Tip to the Northeast (8c)

If a drop occurs that results in the cask tipping to the east as described in Drop Scenario 8b, the cask may fall to the left of the main gantry structure. In this case, the cask will impact portions of the gantry rail support structure and the secondary gantry support structure. This structure consists of 4 in. tube steel and 4 in. by 4 in. angle members. Further movement of the cask could impact the crane rail support column.

As discussed in scenario 7b, a gantry protective bumper will absorb some of the energy from a tip to the east.

This scenario is illustrated in Figure 5-18.

5.8.4 Oblique Drop Over Loadout Pit and Tip to the Southeast (8d)

If a drop occurs that results in the cask tipping to the east as described in drop scenario 8b, the cask may fall to the right of the main gantry structure. As in drop accident scenario 8c, the cask will impact portions of the gantry rail support structure and the secondary gantry support structure. Further movement of the cask could impact the crane rail support column.

As discussed in scenario 7b, a gantry protective bumper will absorb some of the energy from a tip to the east.

This scenario is illustrated in Figure 5-19.

5.8.5 Oblique Drop Over Loadout Pit and Tip to the South (8e)

An oblique drop of the cask into the SLOP that results in the cask tipping in a southerly direction will cause the cask to strike and impact the gantry rail support structure. If the cask proceeds beyond the gantry rail support structure (W12 wide flange beam), it may impact a roof support column and non-safety trailer components.

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5.8.6 Oblique Drop Over Loadout Pit and Tip to the West (8f)

An oblique drop of the cask into the SLOP that results in the cask tipping in an westerly direction will cause the cask to strike and impact the transfer area floor. This is covered by drop accident scenario 7d.

5.9 DROP ACCIDENT SCENARIO 9 (CASK MOVEMENT AFTER DROP OVER TRANSFER AREA)

Drop accident scenario 9 involves movement (rolling or sliding) after a drop onto the transfer area floor surface. This scenario assumes that the oblique drops of drop accident scenario 7 have occurred and that further movement occurs. The concern is the potential for the cask to roll or slide eastward and enter the main basin pool and damage components therein or to roll to the west and impact crane rail support column 15D. The latter case is discussed in drop accident scenario 7d.

If the cask were to move eastward and enter the basin pool from a drop in the transfer area, it would have to pass structure and components in or adjacent to the SLOP. The interference that these items present is discussed below regarding potential cask movement after drops over the loadout pit area. Potential entry of the cask into the basin pool as a result of drops and resulting movement of the cask in the transfer area are thus covered by the loadout pit drop scenarios.

5.10 DROP ACCIDENT SCENARIO 10 (CASK MOVEMENT AFTER DROP OVER LOADOUT PIT)

Drop accident scenario 10 involves movement (rolling or sliding) after a drop into the SLOP. This scenario assumes that the oblique drops of drop accident scenario 8 have occurred and that further movement occurs. The concern is the potential for the cask to move to the east and enter the main basin pool.

5.10.1 Cask Movement to the North After Drop Over Loadout Pit (10a)

An oblique cask drop into the SLOP in which the cask tips in a northerly direction will strike and impact the gantry rail support structure and the ion exchange module in KW Area or other non-safety class components in KE Area as discussed above. If the cask penetrates these components and continues to move in an easterly direction, it would impact the walkway platform and then could roll into the basin pool.

This scenario is illustrated in Figure 5-20.

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5.10.2 Cask Movement to the East After Drop Over Loadout Pit (10b)

An oblique cask drop into the SLOP in which the cask tips in an easterly direction will strike and impact the gantry structure, the east operations platform, and the shuttle impact limiter. If the cask penetrates these components, it not expected that the cask would continue to move into the basin pool, based upon the discussion of 5.8.2.

As discussed in scenario 7b, a gantry protective bumper will absorb some of the energy from a tip to the east.

5.10.3 Cask Movement to the Northeast After Drop Over Loadout Pit (10c)

If a drop occurs that results in the cask tipping to the east as described in Drop Scenario 8b, the cask may fall to the left of the main gantry and impact portions of the gantry rail support structure and the secondary gantry support structure. If the cask penetrates this structure, it not expected that the cask would continue to move into the basin pool, based upon the discussion of 5.8.2.

As discussed in scenario 7b, a gantry protective bumper will absorb some of the energy from a tip to the east.

This scenario is illustrated in Figure 5-21.

5.10.4 Cask Movement to the Southeast After Drop Over Loadout Pit (10d)

If a drop occurs that results in the cask tipping to the east as described in Drop Scenario 8b, the cask may fall to the right of the main gantry and impact portions of the gantry rail support structure and the secondary gantry support structure. If the cask penetrates this structure, it not expected that the cask would continue to move into the basin pool, based upon the discussion of 5.8.2.

As discussed in scenario 7b, a gantry protective bumper will absorb some of the energy from a tip to the east.

5.10.5 Cask Movement to the South After Drop Over Loadout Pit (10e)

An oblique cask drop into the SLOP in which the cask tips in a southerly direction will strike and impact the gantry rail support structure and non-safety transport trailer components. If the cask were to roll off the east end of the trailer and continue to move in an easterly direction it would impact the rail car stop. If it moved past the rail car stop, it could pass into the basin pool.

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5.10.6 Cask Movement to the West After Drop Over Loadout Pit (10f)

An oblique cask drop into the SLOP in which the cask tips in a westerly direction may strike and impact the transfer area floor and other non-safety components. Other drop scenarios as discussed drop accident scenario 9 cover rolling or sliding into the basin pool or potential damage to crane rail support column 15D.

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		Milon Meyer 5/28/99

Figure 5-1

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Figure 5-2, Vertical Drop Accident Scenario 1
 (Two Legs of Immersion Pail Support Structure Absorb Load)

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SOUTH LOADOUT PIT ELEVATION
IMMERSION PAIL DROP SCENARIO #1

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Figure 5-4, Vertical Drop Accident Scenario 2
 (Cask Drops into Empty Immersion Pail)

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SOUTH LOADOUT PIT ELEVATION
IMMERSION PAIL DROP SCENERIO #2

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Figure 5-6, Vertical Drop Accident Scenario 3
 (Cask and Immersion Pail Drop Loadout Pit)

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SOUTH LOADOUT PIT ELEVATION
IMMERSION PAIL DROP SCENARIO #3

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Figure 5-8, Vertical Drop Accident Scenario 4
Cask Drop and Jams at Top of Immersion Pail)

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SOUTH LOADOUT PIT ELEVATION
IMMERSION PAIL DROP SCENARIO #4

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Figure 5-10, Vertical Drop Accident Scenario 5
 (Combination of Scenarios 2+3)

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Milon Meyer 5/28/99

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1

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SOUTH LOADOUT PIT ELEVATION
IMMERSION PAIL DROP SCENERIO #5

Figure 5-11
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Figure 5-12, Vertical Drop Accident Scenario 6
 (Same as Scenario 1 Except Drop on One Leg of Immersion Pail Support Structure)

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SOUTH LOADOUT PIT ELEVATION
IMMERSION PAIL DROP SCENERIO #7b

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SOUTH LOADOUT PIT ELEVATION
IMMERSION PAIL DROP SCENERIO #7d

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SOUTH LOADOUT PIT ELEVATION
IMMERSION PAIL DROP SCENERIO #8a
(LOOKING WEST)

Figure 5-15
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Figure 5-16, Location of Cask Center of Percussion After Eastward Tip Off of the West Curbing

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SOUTH LOADOUT PIT ELEVATION
 IMMERSION PAIL DROP SCENERIO #8b

Figure 5-17
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SOUTH LOADOUT PIT ELEVATION
 IMMERSION PAIL DROP SCENERIO #8c
 (LOOKING WEST)

Figure 5-18
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Milon Meyer 5/28/99

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SOUTH LOADOUT PIT ELEVATION
IMMERSION PAIL DROP SCENARIO #8d

Figure 5-19

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Marlin Lindquist 5/28/99

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Milon Meyer 5/28/99

SOUTH LOADOUT PIT ELEVATION
IMMERSION PAIL DROP SCENARIO #100
(LOOKING WEST)

Figure 5-20

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SOUTH LOADOUT PIT ELEVATION
IMMERSION PAIL DROP SCENERIO #10c
(LOOKING WEST)

Figure 5-21

ATTACHMENT A

CONCEPTUAL DESIGN REPORT

DROP ANALYSIS MODELS

Internal Memorandum

To: Milon Meyer	Date: May 28, 1999
From: Phil Noss	kbasin7.doc
cc:	
Subject: Conceptual Design Report – Drop Analysis Models	

Introduction

A hypothetical drop of the MCO transfer cask has been postulated to occur at some point during the loadout process in the K-East and K-West basins. Ultimately, the consequences of such a drop and the required measures which must be taken to mitigate such a drop are sought. As a preliminary step, all of the possible drop scenarios have been evaluated for their potential to cause significant damage to the safety class structures that could be affected. To perform this evaluation, a three dimensional, solid, impact/collision model was developed which shows the behavior of the cask during the hypothetical accident drop.

Analysis Model

The model of the transfer area was built using Working Model 3D, Version 4.0.1, from Knowledge Revolution, Inc. This program models all objects as three dimensional, rigid bodies, and models collisions using an elastic coefficient of restitution. The coefficient is typically set at a relatively low value (about 0.1) to model the significant energy losses associated with plastic deformation of impacted components. The model is capable of showing the complex geometric relationships between the system components as they fall, tip, collide, and roll, and also of evaluating the kinetic energy of the components, which can be used to design energy absorbing structures.

The model includes the transfer area floor, the South Loadout Pit stem wall, the transfer trailer, the gantry crane and support structures and part of the nearby platforms, the bridge crane support columns, and the IXM. When relevant, a simplified model of the upper geometry of the IPSS is included. The principal dynamic behavior is that of the transfer cask, and its mass and inertia are carefully modeled. The weight of the cask is 60,000 lb. The center of gravity is located 84.738 inches above the cask bottom, and the mass moment of inertia about a transverse, centroidal axis is 389,389 in-lb-s².

The crush deformation of the initial impacted structure (trailer, floor, stem wall, etc.) is neglected. This is conservative since the subsequent tipover occurs from a higher

initial position (from an undamaged structure) than would be the case if the damage were considered. Additionally, the initial drop orientation of the cask is vertical, but tipover in the most damaging direction is considered. This is conservative compared to an initial oblique drop, since the cask tipover "reach" is greater.

Analysis Parameters

The potential drop accidents considered in the analysis are based on the standard travel path given on drawing TN-3035-2, but modest deviations from the path are considered if a cask drop at such locations would endanger safety class equipment or structures. The drop events assume that the cask is lowered in an uncontrolled manner, such as would occur from failure of the drum, cables, or hooks. The bridge crane components themselves are not assumed to fall. The drop height of the cask is 5 ft, 4 inches. All of the primary drop energy is absorbed in the primary impact event, due to the large cask mass and the highly damped nature of the structural responses. Therefore, the secondary behavior of the cask is driven by a quasi-static tipover event in each case¹.

Analysis Descriptions

The analyses performed are described as follows. Table 1 summarizes the descriptions, results, and cask energy at relevant points. Each analysis is also given in the form of a video clip, supplied separately. The video files can be correlated to the drop descriptions using the file name, which in each case is Drop X.avi, where X is the drop number.

Drop 1. Tipover Impact From Trailer Against the South Roof Support Column.

The cask has been lifted out of the well in the transfer trailer and moved a few inches to the north, at which point the cask drops, and tips directly towards the nearby roof support column at location F14. (Such a tip could occur either because the cask center of gravity is still located over the trailer well, leading to a tip to the south, or because of the particular manner in which the trailer structure might deform during impact.) The cask strikes the column well above the floor with an energy of $1.49 (10^6)$ in-lb. The consequence of this impact could be to cause loss of roof support in the area local to the column.

Drop 2. Tipover Impact Against the West Bridge Crane Support Column.

The cask has been moved as far north as necessary, but has not traveled east, at which point the cask drops, and tips directly towards the nearby bridge crane support column at location D.c15. (Such a tip could occur due to uneven crush of the floor.) The cask strikes the column well above the floor with an energy of $2.14 (10^6)$ in-lb. The consequence of this impact could be to dislodge the bridge crane such that west side of the crane falls.

¹ In some cases, the cask does not naturally tip over, and needs to be "encouraged". This is done by applying a force near the top of the cask in the desired direction, just enough to get the cask beyond the point of instability for tipover. This technique also ensures that the cask falls in the worst case direction as desired.

Drop 3. Tipover Impact Onto the Stem Wall.

This drop is similar to drop 2, but instead of tipping west-northwest toward the bridge crane support column, it tips due east toward the pit west stem wall. The worst case impact would occur if the center of percussion of the cask were to strike the wall. For this to occur, it requires that the cask vertical axis be transported as much as five feet too far to the west. Otherwise, using the standard transport path, the center of percussion falls somewhere over the loadout pit, and the impact force on the wall is smaller. This analysis conservatively assumes the former, worst case hit. The energy of the cask at the point of impact is $3.09 (10^6)$ in-lb. The consequences of this impact could be to damage the SLOP, such that water leakage occurs.

Drop 4. Direct Impact on Stem Wall.

The cask has been moved along the standard path until it is directly over the pit west stem wall, and drops. The energy upon impact with the wall is $2.35 (10^6)$ in-lb. This impact could have consequences similar to those from Drop no. 3.

Drop 5. Tipover Impact From West Stem Wall Towards East.

The cask has been moved over the west stem wall, but before it fully clears the wall, it drops, and tips to the east, toward the gantry crane. The particular position considered is an overlap between the cask and the wall of 3 inches. The energy of the cask at the point of contact with the gantry crane is $3.75 (10^5)$ in-lb. The consequence of this impact is likely to destroy the crane, since it weighs only approximately 7% as much as the cask, and is of relatively light construction. The platform support structure behind the gantry crane is relatively strong compared to the crane, and therefore the remains of the crane will probably be trapped by this structure, which itself will be crushed by the tipping cask at a later moment. It is therefore not likely that a significant weight of material will fall into the basin, but it cannot be ruled out. Since the top of the gantry crane is in line with the east bridge crane rail, some impact with the crane rail could occur, leading to a drop of the bridge crane. When the cask finally strikes the ground, it will most likely be fairly well cushioned by debris, but it could strike the east gap wall of the SLOP, with the potential for damage similar to Drop nos. 3 and 4. Although highly unlikely, it could slide off of a debris pile into the basin.

Drop 6. Tipover Impact From South Wall of SLOP to the North.

The cask has been brought to the IPSS centerline in the east-west direction. Then the cask drops and hits the south stem wall of the SLOP. Since the cask normally clears this wall, the impact could be the result either of the cask being moved off of the standard path, too far to the south, or, the cask could fall obliquely, in which case the bottom of the cask would swing to the south. In any case, the overlap between the cask and the wall is considered for purposes of illustration to be 3 inches, and the cask tips over to the north. The cask has minor impact with a strut of the gantry crane, and then hits the north gantry crane support beam and rail. The energy at contact is $7.63 (10^5)$ in-lb. The consequence of this impact is to cause collapse of the north support of the gantry crane. The cask will continue tipping, with negligible loss of energy due to impact, until it hits the ion exchange module (IXM). The IXM is a massive concrete structure, but could crack open or spall. The gantry crane will fall to the north and west, and not endanger safety class items. The cask could roll

to the east towards the basin, but this is considered unlikely, unless a large chunk of the IXM spalls off in such a way as to impart eastward motion to the cask.

Drop 7. Tipover Impact From Southeast Corner of SLOP to the Northeast.

This scenario is very similar to Drop no. 6, except the cask bottom overlaps both the south and west pit stem walls. Consequently, it falls diagonally to the northeast. The cask strikes both the gantry crane and the north gantry support at about the same time, with an energy of $2.36 (10^5)$ in-lb. The consequence to the gantry crane and the support structure would be about the same as for Drop no. 6. The cask would strike the IXM and be reoriented to have its longitudinal axis more or less east-west, thus precluding rolling to the east, towards the basin. It would strike the north pit stem wall. From this position, impact with the east bridge crane support columns is unlikely due to their distance away. However, if the cask were to tip from a nearer position, for example, the top of the IPSS, some contact with the columns might be possible. The consequence of this might be the same as for Drop no. 2 (falling of the bridge crane), but it is noted that, since the east side would be dislodged first, the momentum of the bridge crane would tend to be away from the basin.

Some of the worst consequences of the drops involving the SLOP can be mitigated through the use of a protective crossbar, supported across the path of the cask on stout upright columns. The crossbar is made from a solid, seven inch diameter mild steel bar. Its length depends on the location of the uprights, but is about 128 inches. The bar can bend through the equivalent of several diameters while resisting the cask with the force associated with its plastic moment, or a central force of about 70,000 lb. This is capable of stopping the cask from the worst case position (the most distant location) within a deflection of about 2 – 3 diameters, or about 15 – 20 inches. The uprights can be made from heavy section I beams and anchored to the floor.

The arrangement is depicted in the video file Drop 5GP.avi, which is similar to Drop 5. The crossbar is shown in the operating (protective) position, located between the gantry crane and the cask. There is clearance for the cask to be lowered into the IPSS without disturbing the crossbar. The bar rests on stout supports attached to the uprights. The weight of the bar, however, is supported by hangars attached to the lower flange of the gantry support I-beams. Before the gantry crane is used, the crossbar is slid out to the west on flange rollers, allowing plenty of room for the gantry crane to be operated. Before lifting the cask out of the pit, the bar is slid back to the east, onto the supporting upright columns.

Some contact between the cask and gantry crane cannot be avoided due to the necessity to keep the crossbar close to the crane. The expected maximum collision interference would be approximately equal to half the gantry crane width, or about 12 inches. However, the amount of energy transferred to the gantry by the partial collision is likely to be relatively small. If desired, a backstop can be located behind the gantry to prevent significant motion from a cask collision. This feature is also shown in the video.

Another video file is provided (Drop 7GP.avi) which shows the behavior in an oblique impact. The cask is reoriented to point more or less to the north, and rolling towards the basin is prevented by the stout crossbar upright column.

APPENDIX E

Interoffice Correspondence

- 1. Authority to Proceed with Cask Transfer Modification Sub-project Design and Construction Activities**
- 2. Clarification – Authority to Proceed with Cask Transfer Modification Sub-project Design and Construction Activities**
- 3. Drop Weights for Cask-MCO and Pail Around the South Loadout Pit**

H-5/11-6

1.1.3

INTEROFFICE

CORRESPONDENCE

98-SNF/NHW-079

To: R. W. Rasmussen X3-85

Date: December 10, 1998

From: N. H. Williams R3-11

Telephone: 373-6307

cc: W. M. Funderburke X3-71
S. H. Harrington R3-26
J. J. Klos R3-86
R. G. Morgan R3-26
S. H. Peck X3-79
C. A. Thompson X3-72
J. E. Truax R3-26
J. L. Weamer X3-85
J. H. Wicks X3-74

Subject: AUTHORITY TO PROCEED WITH CASK TRANSFER MODIFICATION
SUB-PROJECT DESIGN AND CONSTRUCTION ACTIVITIES

This memo documents the conditions and decision to proceed with the Cask Transfer Facility Modification (CTFM) design and construction activities.

You are requested to provide two CTFM design changes. These changes are to provide a cover over the South Load Out Pit (SLOP) four inch drain line bonnet and to provide lateral support for the West Immersion Pail Support Structure (IPSS) support block. The modification safety classification is safety significant.

The drain valve cover should be designed to provide impact protection for a 100 pound object falling from a height of 30 feet and having an impact area of one square inch. It should also be able to withstand a 30 foot drop of the cask handling fixture (approximately 550 pounds) with an impact area appropriate for this device. This protection criteria is appropriate for the following reasons: The most likely object to be dropped into the area above the drain valve is a small tool less than 100 pounds. Most tools above 50 pounds are handled via qualified lifting devices (standard industrial practices limit hand lifting to less than 50 pounds). The lifting devices provide some increased assurance that the tooling or device would not be inadvertently dropped. One square inch is a reasonable small impact area for tooling. Using 100 pounds and one square inch is therefore a reasonable impact design for dropped small tools. The cask handling fixture is the heaviest of the normal tools to be routinely used over the drain valve area. Using this fixture as the second criteria provides assurance that the heaviest device, used in repetitive fashion, will not impact the valve if it should be dropped. SNF-2671, "Risk Assessment of Drain Valve Failure in the K-West Basin South Loadout Pit, Rev. 1," will be revised to reflect the new risk of valve damage assuming these design modifications are installed.

R. W. Rasmussen
Page 2
December 10, 1998

98-SNF/NHW-079

You are requested to provide an engineering evaluation on the SLOP guide rails. This evaluation will determine the likelihood that the SLOP guide rails stay in place during a design seismic event. This is believed to be a reasonable assumption due to having mainly compressive loads on the guide rails during the event.

The IPSS support bloc should be physically restrained from impacting the drain valve during a design seismic event.

The normal safety and design review process should be followed to review and approve these physical modifications. No feedback is requested unless the additional project cost is greater than \$145K or the project recovery schedule will impact the present CTFM construction completion date.

If there are any questions, please contact John Truax at 521-5316.

jre

INTEROFFICE

CORRESPONDENCE

98-SNF/RWR

To: N. H. Williams R3-11

Date: December 17, 1998

From: R. W. Rasmussen *for 12/15/98* X3-85

Telephone: 372-0021

cc: W. M. Funderburke X3-71
S. H. Harrington R3-26
J. J. Klos R3-86
R. G. Morgan R3-26
S. H. Peck X3-79
C. A. Thompson X3-72

J. E. Truax R3-26
J. L. Weamer X3-85
J. H. Wicks X3-74
RWR LB/file
Project Files X3-85

Subject: CLARIFICATION – AUTHORITY TO PROCEED WITH CASK TRANSFER
MODIFICATION SUB-PROJECT DESIGN AND CONSTRUCTION ACTIVITIES

Reference: Interoffice Memorandum 98-SNF/NHW-079, N. H. Williams, FDH to
R. W. Rasmussen, DESH, Authority to Proceed with Cask Transfer Modification
Sub-Project Design and Construction Activities, dated December 10, 1998.

The following clarifications are provided in response to the memorandum referenced above. These
clarifications have been discussed with Mr. John Truax, and he is in agreement with these clarifications.

Page 1, 3rd Paragraph

*...It should also be able to withstand a 30-foot drop of the cask handling fixture (approximately
550 pounds) with an impact area appropriate for this device.*

Clarification: The impact limiter will be sized for a maximum drop height of 45 feet in lieu of a
30-foot drop height. This will bound the maximum height that the cask-handling
fixture can be raised above the south load out pit.

Page 2, 1st Paragraph.

*You are requested to provide an engineering evaluation on the SLOP guide rails. This
evaluation will determine the likelihood that the SLOP guide rails stay in place during a design
seismic event. This is believed to be a reasonable assumption due to having mainly compressive
loads on the guide rails during the event.*

N. H. Williams
Page 2
December 17, 1998

98-SNF/RWR

Clarification: An engineering evaluation for the SLOP guide rails will be performed. This evaluation will determine the likelihood that the SLOP guide rails stay in place during a design seismic event under their own inertia loading. The evaluation of the SLOP guide rails will assume compressive loads resulting from the mass of the IPSS, pail and cask/MCO. No other seismic conditions will be evaluated during this effort.

Page 2, 2nd Paragraph (sentence)

The IPSS support block should be physically restrained from impacting the drain valve during a design seismic event.

Clarification: The IPSS west support block will be restrained against the west SLOP guide rails to restrict the west support block from sliding into the drain valve.

Design efforts will not involve seismic qualification of the cask load out equipment or the support blocks that align the IPSS. Engineering evaluations and design activities authorized by the referenced memorandum will provide some assurance that the drain valve will not be damaged during a seismic event, and that the drain valve will be protected against tools and equipment that are used routinely over the SLOP. Engineering evaluations and design modifications will be available for incorporation into SNF-2671, "Risk Assessment of Drain Valve Failure in the K-West Basin South Loadout Pit", Rev. 1. The CTFM subproject understands that it has not been tasked with revising SNF-2671.

If you have questions, please contact Joni Weamer on 372-0688.

rlf

INTEROFFICE

CORRESPONDENCE

99-SNF/LAR-006

To: J. L. Weamer X3-85 Date: May 26, 1999

From: L. A. Rodgers X3-85 Telephone: 373-0728

cc: K. E. Ard X3-85 Project Files A.5/A.6 X3-85
A. S. Langevin X3-85 LAR LB/file

Subject: DROP WEIGHTS FOR CASK-MCO AND PAIL AROUND THE SOUTH
LOADOUT PIT

The Spent Nuclear Fuel (SNF) Project will use the 32 ton transfer area crane in K West (KW) and K East (KE) Basins to hoist and move the cask multi canister overpack (cask-MCO) and the immersion pail (IP). The crane moves the cask-MCO from the cask conveyance to the south load out pit (SLOP) and inserts it into the IP. The IP is suspended by the immersion pail support structure (IPSS) in the SLOP. The crane is also used to lower the IP, with the cask-MCO, to the bottom of the SLOP inside of the IPSS. After loading of SNF the process is reversed. It has been postulated statistically that it is credible to have a drop accident when performing these hoisting operations. The KE and KW water basins including the SLOP are safety class structures. In order to evaluate the consequence of these drop accidents the height of the drop has been determined for several targets. The targets of concern are the IPSS and the IP. If these targets were hit in a drop accident, the impact energy would be transmitted to the SLOP floor.

For drop accidents, the maximum height the crane is assumed to hoist the cask-MCO is the second limit switch at a nominal 20 ft above the basin work floor. For these calculations a drop from a crane two-block accident is not considered.

The attached calculations use the design drawings for the SLOP, 32-ton crane, cask, MCO, IPSS and the IP to determine drop heights to the targets. Several worst case scenarios were postulated. The scenarios use worst case to bound the drop accident impact load into the SLOP.

Design changes to any of the components can change the drop height for the drop accident scenarios in the attached calculations. The drop heights presented in the attachment will need to be re-calculated if there is redesign of any components.

rlf

Attachments

CTPM-M-0001 Rev. 0

1. DETERMINE THE DROP HEIGHT OF THE CASK

BASED ON 32 Ton CRANE UPPER LIMIT SWITCH

CRANE

PER PA-2109 Rev 8 EDERER

Ø OF HOOK IS 19'-6" FROM FLOOR

PER C-35256 Rev - EDERER

HOOK HAS A 2 1/8" CENTER CUTOUT

AFTER INSTALL - IT WAS REQUIRED THAT THE

HOOK HEIGHT BE RAISED TO 20'-0" AND

20'-6" FOR FIRST & SECOND LIMIT SWITCHES, (TXM).

CASK PER 3035-3 Rev 7 1/6 TRANSNUCLEAR, INC

CASK IS 190.25" CAL.

PER 3035-3 Rev 7 1/6 TRANSNUCLEAR, INC

CASK TRANSMISSIONS ARE 15" FROM BOTTOM

OF LIFTING BRACKET 20" TAIL

TRANSMISSIONS ARE 4" Ø, PART # 11.

CALCULATE & TRANSMISSION TO BOTTOM OF CASK

$$190.25" - (20" - 15") = 185.25" (15'-5 1/4")$$

DROP HEIGHT BETWEEN CASK BOTTOM

$$20'-6" \text{ SECOND. LIMIT SWITCH}$$

$$- 15'-5 1/4"$$

$$5'-1 1/4" \rightarrow$$

BASED ON THE FLOOR BEING 0'-0" EL THE

DROP ELEVATION IS 5'-1 1/4" EL @ LIMIT SWITCH E-6

CTFM-M-000/Rev. 0

PER HNF-SD-SNF-ATR-037, Rev. 0 SECTION 8.2.3.1.13
THE LOWER LIMIT SWITCH STOP @ $235\frac{3}{4}"$. IT WAS SET
AT $19'-6"$ PER EDERER DRWG. PA-2109 Rev. B. THEREFORE
THE TRAVEL AFTER CONTACT WAS $1\frac{3}{4}"$.

PER SECTION 8.2.3.1.16 THE SECOND LIMIT SWITCH
STOP @ $20' - 3\frac{7}{8}"$, IT WAS SET @ $20'-0"$. THEREFORE
THE TRAVEL AFTER CONTACT WAS $3\frac{7}{8}"$

THEREFORE THE MAX DROP FOR ANALYSIS
IS TO BE TAKEN AS $5'-4"$.

2. DETERMINE THE DROP HEIGHT OF THE CASK
BASED ON 32 TON TO BLOCKING.

CRANE

PER EDERER DRWG. D-35221 Rev. A THE DISTANCE
FROM Φ HOOK Φ ^{BOTTOM OF} TROLLEY WHEEL IS $10'-4'\frac{5}{16}"$.

WHEN THE Φ HOOK TO FLOOR IS $19'-6"$ PER EDERER
DRWG, PA-2109 Rev. B, THE HOOK WAS RAISED
 $6"$ FOR THE WATER PROJECT IXM MOVES AT
KW. THEREFORE:

Φ HOOK Φ BOTTOM OF TROLLEY WHEEL IS $9'-10'\frac{15}{16}"$

AND Φ HOOK Φ FLOOR IS $20'-0"$ @ FIRST LIMIT SWITCH.

PER EDERER DRWG C-35250 Rev. - THE Φ SHEAVE

TO Φ HOOK DIMENSION IS $28" + 24\frac{3}{4}" = 52\frac{3}{4}"$ ($4'-4\frac{3}{4}"$)

CTFM-M-0006 Rev. 0

HNF-4576, Rev. 0

3

THE BOTTOM OF TROLLEY STEEL FROM TROLLEY
WHEEL IS NEEDED. PER GOLDER DUB D-35221 Rev. A
THE TOP OF TROLLEY RAIL TO & OF TROLLEY WHEEL
IS 5". PER D-34985 Rev. B $\frac{1}{2}$ & WHEEL TO BOTTOM
OF TROLLEY DECK IS $11\frac{5}{8}" - 4" = 7\frac{5}{8}"$.

PER D-34985 Rev. A $\frac{1}{2}$ & OF LOAD CELL BOSS TO BOTTOM
OF TROLLEY DECK IS $12\frac{1}{2}" - 2\frac{1}{4}" = 10\frac{1}{4}"$.

PER C-35462, THE LOAD CELL TAKE OUT

IS TWO $1\frac{1}{8}$ CHAIN SHACKLES & LOAD CELL, OR & BOSS

TO ROVER PIN ON LOAD CELL $8\frac{3}{8}" + 9.696" = 18.065"$
($1\frac{1}{2} 6\frac{1}{8}"$)

PER GOLDER DUB B-35280 THE SHEAVE IS

20" O.D.

PER GOLDER DUB B-35236 Rev. - THE ROPE IS ATTACHED
TO THE LOAD CELL BY A DEAD END - OPEN END SWAGED
SOCKET PER CAT ROPE TO PIN IS 13.38"

THERE ARE TWO POSSIBLE TO BLOCK ENDS. ONE
WHEN THE SHEAVE & DEAD END INTERACT AND
TWO WHEN THE SHEAVE IS SUCKED UPWARD TO

E-8

CTPM-M-0001 Rev D

$$\begin{array}{r} 9'-10\frac{1}{2}" \\ - 4'-4\frac{3}{4}" \\ \hline 5'-6\frac{3}{16}" \end{array} \quad \begin{array}{l} \text{BOTTOM TROLLEY WHEEL \& HOOR} \\ \text{\& HOOR \& \& SHEAVE} \end{array}$$

$$\begin{array}{r} 1'-6\frac{1}{16}" \\ - 1'-1\frac{3}{8}" \\ \hline 2'-7\frac{9}{16}" \end{array} \quad \begin{array}{l} \text{LOAD CELL PIN TO PIN \&} \\ \text{SWAGE} \end{array}$$

$$\begin{array}{r} 5'-6\frac{3}{16}" \\ - 5" \\ \hline 5'-6\frac{13}{16}" \end{array} \quad \begin{array}{r} 1'-6\frac{1}{16}" \\ - 2'-7\frac{9}{16}" \\ \hline 3'-5\frac{1}{16}" \end{array} \quad \begin{array}{r} 6'-6\frac{1}{2}" \\ - 3'-5\frac{1}{16}" \\ \hline 3'-1\frac{1}{16}" \end{array}$$

CASE ONE

DROP HEIGHT IS $(5'-1\frac{1}{4}" + (3'-1\frac{1}{8}" - (6" - \text{DIP LIMIT SWITCH LOWER TO SECOND}))$

$= 7'-7\frac{3}{8}"$

CTFM-17-0001 Rev. 0

CASE TWO

CASE ONE TO TROLLEY 1/2 Ø SHEAVE

$$(7' - 7\frac{3}{8}") + (3' - 5\frac{1}{16}") - (10") = \underline{10' - 3\frac{1}{16}"}$$

THIS CASE IS NOT TRULY POSSIBLE AS IT WOULD
REQUIRE THE HOOK ASSEMBLY TO ROTATE ALMOST
HORIZONTAL AFTER THE LOAD CELL WEDGED INTO
THE SHEAVE.

CTFM-M-0001 Rev. 0

FOR THE TARGETS LISTED BELOW THE STARTING
OF THE DROP IS THE SECOND LIMIT SWITCH WITH
CASK BOTTOM 5'-4" ABOVE K-BASIN FLOOR OF
0'-0" EL.

THE ZP IS SHOWN
PINNED IN THE
UPPER POSITION
IN THE ZPSS.
ALL IMPACTS
START FROM
THIS CONFIGURATION.

SLOD GENERAL
ELEVATION

DROP LOAD SCENARIOS
SCENARIO 1

CASK IMPACT ON "PAIL LIP"

FIND HEIGHT OF ZPSS FROM SLOD BOTTOM TO PIN
NOMINAL FOOT HEIGHT IS 3" CLEAR

PER NAC DRAWING 457-102 Rev 3 V2

BOTTOM	1.5"	R THICKNESS	TOP	156.5"
	166"	R-R TOP to TOS		
	-6"	TOS to SEAT		
	<u>161.5"</u>			

NOTE: NAC DWS 457-110 Rev 1 SHOW THIS TO BE
161" FIELD DIM. AGREE WITH 161.5"

CTFM-M-0001 Rev 0

PER NAC DRWG 457-109 Rev 3

0.50" BOTTOM R
 3.75" R to BOTTOM OF PIN HOLE
4.25"

1.50" PIN ϕ

PER NAC DRWG 457-101 Rev 2

2.79" LIP PAIL to TOP OF PIN HOLE IN LIFTING
 LUG

THE 'PAIL LIP' HEIGHT FROM FLOOR IS

3.0" CLEAR (FOOT HEIGHT)
 161.5" ZPSS BOT. R to SEAT
 156.5" ZPSS TOP SEAT to PIN R
 4.25" TO BOT. OF PIN (PIN GUIDE)
 1.5" PIN
 2.79" PAIL LUG TOP PIN HOLE to TOP PAIL or LIP.
329.54" TOT CONCRETE FLOOR SLOP TO LIP

329.54" ZPSS BOT FOOT to PAIL LIP

-25'-9" EL SLOP

20.54" DISTANCE ABOVE BASIN FLOOR 0'-0" EL

DROP DISTANCE

5'-4" CASK/MCO to FLOOR
 -20.54" FLOOR to PAIL LIP
3'-7.46" SCENARIO 1
 CASK/MCO BOT. to PAIL LIP

SCENARIO 2

CASK IMPACT ON PAIL BOTTOM R

PER NAC DRWG 457-101 Rev 2

163.5" PAIL LIP TO PAIL BOT. R.

163.5" PAIL LIP TO PAIL BOT. R
 3'-7.46" CASK/MCO BOT. to PAIL LIP
17'-2 15/16" SCENARIO 2
 CASK/MCO BOT. to PAIL BOT. R

Labels 5/1/55

CTFM-M-0001 Rev 0

SCENARIO 3

DOOR HEIGHT FOR
CASK/MCO & ZP

HNF-4576, Rev. 0

CASK/MCO IN PAIL DEEP AS UNIT FROM PINNED
EL.

PET NAC DRAWING 459-101 Rev 2

2.00" PAIL BOT. R

329.54" CONCRETE FLOOR SLOP & LIP
-163.5" PAIL LIP & PAIL BOT. R
-2.0" PAIL BOT. R
164.04" CONCRETE FLOOR & PAIL BOT

164.04" CONCRETE FLOOR & PAIL BOT.
-3.00" FOOT CLEAR.
-1.5" ZPSS BOT. R
159.54" PAIL BOT & TOP ZPSS BOT. R

SCENARIO 3

131-3.54"

CASK/MCO IMPACT INTO PAIL JAMS ON TOP
OF PAIL INTERNAL GUIDE RING

PAIL LIP

PET NAC DRAWING 459-101 Rev 2

73" LIP & BOT. OF RING
-1.73" SLOP OF RING
-1.83" RING
19.44" LIP & POINT B

23" LIP & BOT. OF RING.
-5.3" GUIDE DEPTH
17.9" LIP & POINT A

SCENARIO 1
CASE A

31-7.46"
+17.9"
51-1.16"

SCENARIO 4A

E-13

CTFM-M-0001 Rev 0

3'-7.46" SCENARIO 1

+19.44" CASE 8

5'-2.9" SCENARIO 4BSCENARIO 5

COMBINE SCENARIO 2 & 3 DROPS

17'-2 $\frac{15}{16}$ " SCENARIO 213'-3.54" SCENARIO 330'-6 $\frac{7}{16}$ " SCENARIO 5SCENARIO 6CASK/MCO DROP ON ONE ZPSS LEG THIS
IS AN OFF CENTER DROPTHE FIRST CONTACT IS THE LUG OF THE
PAIL (IP) AS THIS IS A VERY SMALL ROUNDED
AREA THE TOTAL DROP IS CONSERVATIVELY
ASSUMED ON THE PIN GUIDE BODY,

PER NAC DRAWING 457-109 Rev 3

6.89" PIN BLOCK TOT. HEIGHT

3.0"	CLEAR (FOOT HEIGHT)
161.5"	ZPSS BOT. FT. TO SEAT
156.5"	ZPSS TOP SEAT TO TOP
0.5"	PIN GUIDE FT THICKNESS
6.89"	PIN GUIDE BLOCK HEIGHT
<u>328.39"</u>	

SEE P. 667
FOR Ref.

328.39	ZPSS BOT. FOOT TO TOP OF BLOCK
<u>-25'-9" EL</u>	SLOP EL
19.39"	EL ABOVE BASION FLOOR

5'-4"	CASK/MCO TO FLOOR
<u>-19.39"</u>	FLOOR TO TOP BLOCK

3'-8.61" SCENARIO 6

CASK/MCO BOT. TO PIN BLOCK

LARoyers 5/4/99

DROP HEIGHT FOR
CASK/MCO & ZP

HNF-4576, Rev. 0

10/

CTFM-M-0001 Rev 0

NOTE: THIS IS LESS THAN SCENARIO 1 IMPACT
TO PAIL LIP BY

$$\begin{array}{r}
 329.54'' \quad P. 7 \\
 - 328.39'' \quad P. 9 \\
 \hline
 1.15'' \quad .
 \end{array}$$

THIS SCENARIO IS AN OFF CENTER DROP ON TO
THE IP LUG & A SMALL LENGTH OF ZP LIP. BECAUSE THE
CONTACT AREA IS SMALL THE ZP LUG & LIP WILL DEFORM
SO PART OF THE LOAD WILL DIRECTLY LOAD ^{THE} PIN GUIDE,
WITHOUT EXTENSIVE MODEL THE LOAD DISTRIBUTION
TO OTHER ZPS LEGS IS UNKNOWN, NOR THE DROP
ENERGY AT CASK/MCO - GUIDE IMPACT KNOWN. TO BE
CONSERVATIVE THE FULL DROP IS ASSUMED ON BLOCK ONLY.

CTEM-M-0001 Rev 0

LIST OF DRAWINGS USED

ENGINE CRANE

NAC IMMERSION PAIL
& IMMERSION PAIL SUPPORT STRUCT.

- PA-2109
- C-35256
- D-35221
- C-35250
- D-34985
- C-35462
- B-35280
- B-35236

- 457-104
- 457-109
- 457-102
- 457-110
- 457-101

TRANSNUCLEAR

3035-3 (CASH)

RECORD COPY OF

HNF-SD-SNF-ATD-037
SD-SNF-ATR-037

DROP HEIGHTS FOR CASK/MCO & IP CALCULATION

SCENARIO #	DIMENSION	DROP DISTANCE	DESCRIPTION
1	'A'	3'-7.46"	CASK'S BOTTOM TO PAIL LIP
2	'B'	17'-2 15/16"	CASK IMPACT ON PAIL'S BOTTOM PLATE
3	'C'	13'-3.54"	CASK IN PAIL DROPPED FROM PINNED ELEVATION
4a	'D1'	5'-1.16"	CASK IMPACT INTO PAIL, JAMS ON INTERNAL GUIDE
4b	'D2'	5'-2.9"	
5	'E'	30'-6 7/16"	COMBINED IMPACT OF 2 & 3
6	'F'	3'-8.61"	CASK DROPPED ON ONE IPSS LEG (OFF CENTER)

ATTACHMENT A

Appendix F

Hypothetical Cask Drop Analysis

- 1) Hypothetical Cask Drop Analysis Considering Immersion Pail Motion (calculated pressure is 39 atm = $[39-1]14.7 = 560$ psi)**
- 2) Review of Hypothetical Cask Drop Analysis Considering Immersion Pail Motion**
- 3) Hypothetical Cask Drop into Immersion Pail Drop Analysis (calculated pressure is 150 psid with 1.14 sq ft opening)**

Fauske & Associates, Inc.

DATE: June 18, 1999

TO: George Abatt and Milon Meyer, M&D

FROM: Marty Plys *M. Plys*

SUBJECT: Hypothetical Cask Drop Analysis Considering Immersion Pail Motion

1.0 SUMMARY

Peak pail over-pressures, pail and cask accelerations, and strike velocities are calculated here for hypothetical cask drop accidents at the K-basins. Two limiting scenarios are calculated, one for a rigid integrated pail support structure (IPSS), and one for a sliding IPSS but neglecting the beneficial impact of crushable foam. Results are:

	Rigid, Wet Pail	Non-Rigid, Wet Pail
Maximum Pressure (atm)	39	39*
Strike Velocity (m/s)	1.5	N/A
* Reduces to 15 atm in < 5 ms.		

2.0 KEY ASSUMPTIONS

Key assumptions are summarized here for convenience, and are discussed as they are implemented.

1. Gas pressure is uniform in the pail and is determined by assuming adiabatic, isentropic compression from the initial state accounting for outflow.
2. Pressure drop from the gas to ambient occurs primarily across the pail restrictor ring.

3. Water is incompressible, although its inertia is considered for acceleration. This assumption couples the water velocity in the pail-cask annulus to the relative cask and pail velocities.
4. The initial water level is low enough so that water flow through the pail restrictor ring will not occur for cases considered; the model is capable of analyzing these cases.
5. When pail motion is considered, the pail itself is rigid (strain is neglected) and opposing forces from crushable foam are neglected to create a bounding case.
6. Parameters values are summarized in Table 1.

3.0 SCOPE

In the current IPSS design, the pail is held on its supports with shear pins which fail at an off-normal load. When the shear pins fail, the pail and upper portion of the IPSS slide downward and lose energy to crushable foam. The height of the crushable foam is designed to absorb the impact energy of the transient considered here, a free cask fall from 4 feet above the pail restrictor ring into the pail, as described above. The design is in progress and these details, communicated through meetings and conversation with spent fuel project personnel, suffice to establish a modeling basis for the selected transients.

Transients to be analyzed bound loads on the pail and IPSS. First, a transient with a rigid pail provides a high bounding pail pressure and IPSS load history. Second, a transient which assumes pail acceleration uninhibited by crushable foam provides a low bounding pail pressure history, but a high bounding acceleration and load on moving upper portion of the IPSS, in particular the support pins which attach the pail to the IPSS after the shear pins fail. Note that the peak pressure in the pail occurs at the moment of water impact and is the same in both cases because the cask velocity at impact is the same and the pail has zero velocity at the moment of impact. In the moving pail case, however, the pressure is reduced quickly after the peak, compared to the rigid pail case.

4.0 TRANSIENT DESCRIPTION

Figure 1 illustrates a hypothetical transient for the free, concentric drop of a shipping cask plus its contents into the immersion pail at the K-basins. Here the immersion pail is partly water-filled and the cask enters the flow restrictor orifice of the pail. Key features of the geometry are the narrow top orifice, which is about 0.19 inches diameter difference or 0.095 inches radial gap, the 1.0 inch radial gap between cask and pail, and a variable water height. Key dimensions and parameter values are contained in Table 1.

When the cask enters the pail orifice, gas beneath it in the cylindrical pail cavity must exit via the orifice. This causes a pressure increase in the pail cavity which acts to decelerate the cask. The transient drop is swift enough (on the order of a second) so that heat transfer may be neglected and pressurization of the cavity is based on the standard isentropic formula.

When the cask contacts water, water is displaced into the annulus and accelerated upwards. Since the water may be considered incompressible, the annular water slug depth and velocity may be related to the instantaneous position and velocity of the cask. The pressure at the top of the water slug is equal to the pressure of gas in the annulus. The water pressure below the cask is related to the gas pressure by the pressure rise required to accelerate the water slug. This water pressure below the cask also acts to decelerate the cask.

Finally, given enough water initially present, the water slug eventually reaches the orifice when the last of the gas is exhausted. At this point, the pressure of the water immediately inside the orifice, i.e., the pressure at the top of the annular slug, must make a step change from whatever value existed when gas was present, to a new value which is sufficient to accelerate the water flow through the orifice. The water pressure below the cask is still related to the water pressure at the top of the slug (now defined just below the orifice) by the acceleration pressure rise for water entering the annulus. This scenario leads to very high pressure in the pail and is not analyzed here.

Pail motion is assumed to begin at the instant of cask impact with water because shear pins will easily fail. The pail accelerates based upon the same pressure drop which drives water up the annulus; the mass which is accelerated is actually that of the pail plus the sliding portion of the IPSS, but for simplicity this is referred to as the pail mass here. Because the pail mass is much less than the cask mass, its velocity can soon exceed that of the cask.

Pressure drop to accelerate water in the pail-cask annulus is based upon relative velocity, so it continually decreases from its peak upon cask impact with water (when the pail velocity is zero), and the pressure drop changes sign when the pail velocity exceeds the cask velocity. When this occurs, water is drawn back from the annulus and into the region underneath the cask. It is possible that, as the pail continues to accelerate while the cask continues to decelerate, the pail plus water eventually move ahead of the cask, and the cask emerges from the water. Whether or not cask emergence occurs depends upon the travel distance of the sliding structure, the initial drop height, cask and pail masses, and neglect or inclusion of energy absorption by crushable foam.

5.0 GEOMETRY DEFINITIONS

Figures 2A through 2D define geometric notation to analyze the transient cask drop into the immersion pail. Key distances are:

- L = Total length for fall inside pail below the orifice elevation, i.e., distance from pail bottom inside to orifice,
- H = Initial water depth in pail,
- x = Distance of cask penetration into pail, measured from the initial position of the top inside of the pail orifice,
- s = Distance of cask penetration below original water level,
- d = Depth of annular water column relative to bottom of cask, and
- y = Pail displacement from its original position.

Key areas and volumes are defined by other cask and pail dimensions:

- D_p = Cask (piston) outer diameter,
- $A_p = \frac{\pi}{4} D_p^2$ = Piston area (constant),
- δ_g = Gap thickness, cask to pail,

$$A_c = \frac{\pi}{4} (D_p + 2\delta_g)^2 = \text{Pail cavity area,}$$

$$A_g = A_c - A_p = \text{Gap area,}$$

$$\delta_o = \text{Orifice gap thickness, and}$$

$$A_o = \frac{\pi}{4} (D_p + 2\delta_o)^2 - A_p \approx \pi D_p \delta_o = \text{Orifice area.}$$

Initial and instantaneous gas volumes are given by:

$$V_{go} = A_c (L - H) \quad (1)$$

$$V_g = V_{go} - A_p (x - y) \quad (2)$$

because $x - y$ is the distance the cask penetrates into the pail.

Cask contact with water occurs when

$$x > L - (H + y) \quad (3)$$

and $y = 0$ at the moment of first water contact. Water reaches the orifice (gas is depleted) when

$$x > \frac{A_c}{A_p} (L - H) + y \quad (4)$$

The displaced water volume is given by the term

$$A_p [(x - y) - (L - H)] = A_p s \quad (5)$$

Water in the annular column consists of the displaced water, plus water outside the cask beneath the original water level:

$$A_g d = A_p s + A_g s = A_c s \quad (6)$$

so that the length of a moving water column is

$$d = \frac{A_c}{A_g} [(x - y) - (L - H)] \quad (7)$$

6.0 GAS SPACE MODEL

The pressure in the gas space is, for practical purpose, uniform, because pressure losses through the restrictor orifice greatly exceed (by two orders of magnitude) those in the cask-pail annulus. The gas pressure is given by the law for adiabatic compression

$$P_g = P_o \left(\frac{v_o}{v_g} \right)^\gamma \quad (8)$$

where P_o = Initial ambient pressure, 10^5 Pa,

P_g = Gas pressure in pail, Pa,

v_o = Initial ambient specific volume, m^3/kg ,

v_g = Gas specific volume in pail, m^3/kg , and

$\gamma = C_p / C_v = 1.4$.

because heat transfer is negligible during the transient. The initial specific volume is given by the ideal gas law

$$v_o = \frac{R_a T_o}{P_o} = 0.865 \text{ m}^3 / \text{kg} \quad (9)$$

where R_a = Gas constant for air, $8314 / 29 = 286.7$, and

T_o = Ambient temperature, $70^\circ\text{F} \approx 294 \text{ K}$.

During the transient, the instantaneous specific volume is given by its definition

$$v_g = \frac{V_g}{m_g} \quad (10)$$

where V_g = Gas volume, m^3 , and

m_g = Gas mass, kg.

and both V_g and m_g evolve dynamically as discussed below.

The compressible flow rate is given by:

$$w_g = C_D A_o \left[\frac{2P_g}{v_g} \frac{\gamma}{\gamma-1} r^{2/\gamma} \left(1 - r^{\frac{(\gamma-1)}{\gamma}} \right) \right]^{1/2} \quad (11)$$

$$\text{where } r = \max \left(r_c, \frac{P_o}{P_g} \right), \quad (12)$$

$$r_c = \left(\frac{2}{1+\gamma} \right)^{\frac{\gamma}{(\gamma-1)}} = 0.528 \quad (13)$$

C_D = Loss coefficient,

A_o = Area of orifice, m^2 ,

r = Pressure ratio,

r_c = Critical pressure ratio, and

$\max(a, b)$ = Use the larger of the two values.

The formula automatically makes the transition to choked flow when the gas pressure is about 2 atm absolute in the pail. The loss coefficient is given by

$$C_D = \left(1 + K_e + f \frac{L}{D_h} \right)^{-1/2} \quad (14)$$

- where K_e = Overall form coefficient for entrance (contraction) and exit (expansion) losses,
 f = Friction factor through orifice,
 L = Length of orifice, and
 D_h = Hydraulic diameter of orifice.
 = 2δ , δ = gap thickness.

7.0 CASK, IPSS, AND WATER MOTION

7.1 Cask and IPSS Motion

The equation of motion for the cask is

$$m_p \frac{d^2 x}{dt^2} = m_p a_x = m_p g - A_p (P_c - P_o) \quad (15)$$

- where m_p = Piston (cask + contents) mass, kg,
 a_x = Cask acceleration, m^2/s ,
 g = Acceleration of gravity, 9.81 m/s,
 P_c = Pressure in cavity below cask, Pa, and
 P_o = Ambient pressure (above cask), Pa.

The equation of motion of the pail plus slidable IPSS structure is

$$m_{ps} \frac{d^2 y}{dt^2} = m_{ps} a_y = A_c (P_c - P_o) - K_f \quad (16)$$

where m_{ps} = Pail mass, kg,
 a_y = Pail acceleration, m^2/s , and
 K_f = Constant damping force of crushable foam, N.

7.2 Cavity Pressure and Water Motion

Before the cask contacts water, the cavity pressure is the gas pressure:

$$P_c = P_g \quad (x - y < L - H) \quad (17)$$

After the cask makes contact with water, the transient Bernoulli equation may be used to deduce P_c . This will include inertial terms which will be shown to be of second order importance. From [Todreas and Kazimi, 1990], between two points in a system,

$$\left(\frac{\ell}{A}\right)_T \frac{d \dot{m}}{d t} - (P_1 - P_2) + \rho g (z_2 - z_1) + \frac{\dot{m}^2}{2\rho} \left(\frac{1}{A_2} - \frac{1}{A_1}\right) - \Delta P_{\text{loss}} = 0 \quad (18)$$

The inertial term is expanded as:

$$\Delta P_I \equiv \left(\frac{\ell}{A}\right)_T \frac{d \dot{m}}{d t} = \frac{d}{A_g} \left(\rho A_c \frac{d^2 (x - y)}{d t^2} \right) = \rho d \alpha \frac{d^2 (x - y)}{d t^2} = \rho d \alpha (a_x - a_y) \quad (19)$$

where the area ratio $\alpha = A_c / A_g$ is introduced. In the above equation, $(\ell / A)_T$ is the total inertial length to area ratio, which equals the annulus depth over the gap area, and $\dot{m}$ is the rate-of-change of flow, equal to the rate of water addition to the flowing slug. Note that the total area A_c is used and not the piston area A_p because water outside the displaced volume is also accelerated, as seen in the formula for d above, i.e.,

$$\frac{d \dot{m}}{d t} = \rho A_g \frac{d}{d t} \left(\frac{d(d)}{d t} \right) = \rho A_c \frac{d^2 (x-y)}{d t^2} \quad (20)$$

The pressure drop is simply

$$P_1 - P_2 = P_c - P_g = (P_c - P_o) - (P_g - P_o) = (P_c - P_o) - \Delta P_g \quad (21)$$

where the pressure drop due to gas flow ΔP_g is defined as $P_g - P_o$. The static head term may be neglected, and the acceleration pressure drop may be found by neglecting initial velocity ($A_1 \rightarrow \infty$):

$$\Delta P_a = \frac{\dot{m}^2}{2\rho} \left(\frac{1}{A_2^2} - \frac{1}{A_1^2} \right) = (\rho A_c)^2 \frac{d(x-y)}{d t} \left| \frac{d(x-y)}{d t} \right| \frac{1}{2\rho A_g^2} = \frac{1}{2} \rho \alpha^2 |v-u| (v-u) \quad (22)$$

where the velocities $v = dx / dt$ and $u = dy / dt$ are introduced. Note that in equation (22) $\dot{m}$ may be either positive ($v > u$) or negative ($v < u$), so the acceleration pressure drop must have the proper sign. In other words, when $v < u$, the pressure in the gas space must exceed the pressure below the cask in order to drive water from the annulus to the cavity. Friction pressure loss may be neglected in the annulus, but the term is retained for further use.

Combining terms of the Bernoulli equation, i.e., combining equations (18), (19), (21), and (22):

$$(P_c - P_o) - \Delta P_g + \Delta P_{\text{loss}} = \rho d \alpha (a_x - a_y) + \frac{1}{2} \rho \alpha^2 |v-u| (v-u) \quad (23)$$

which may also be rearranged as:

$$P_c - P_o = \Delta P_l + \Delta P_a + \Delta P_g - \Delta P_{\text{loss}} \quad (24)$$

Equations (15), (16), and (23) provide linear relations between the three unknowns a_x , a_y , and $P_c - P_o$. Eliminating the accelerations yields the pressure drop:

$$P_c - P_o = \frac{\Delta P_g + \Delta P_a - \Delta P_{loss} + \rho d \alpha \left(g - \frac{K_f}{m_{ps}} \right)}{1 + \rho d \alpha \left(\frac{A_p}{m_p} + \frac{A_c}{m_{ps}} \right)} \quad (25)$$

The pressure drop from equation (25) may be evaluated first from known quantities and used in equations (15) and (16) to evaluate the accelerations. Note that if the inertial pressure drop of ΔP_I is neglected, the last term in the numerator of equation (25) disappears. Quantifying this term, $\rho \approx 10^3 \text{ kg/m}^3$, $d \approx 0.01 \text{ to } 0.1 \text{ m}$, $\alpha = 10$, and $g \approx 10 \text{ m/s}^2$, so the maximum value of the term is 10^4 Pa , which is a factor of 100 less than the value of ΔP_g at the moment of water impact. The inertial pressure drop is manifest in the denominator. Given $A_p \approx A_c \approx 1 \text{ m}^2$ and $m_p \approx 3 \times 10^4$, $m_{ps} \approx 3 \times 10^3$, the inertial term value is a maximum of about 0.03 for a rigid pail, but about 0.03 to 0.3 for a moving pail.

When the gas volume is exhausted, the pressure drop ΔP_g is replaced by the pressure drop for water flow through the orifice. Still using the symbol P_g for the pressure at the top of the water slug, and just inside the orifice,

$$P_g - P_o = \frac{\dot{m}^2}{2\rho} \left(\frac{1}{A_o^2} - \frac{1}{A_g^2} \right) + \Delta P_{loss} \quad (26)$$

$$\text{defining } \Delta P_{loss} = K_e \frac{1}{2} \rho U_o^2 = K_e \frac{1}{2} \rho \beta^2 \left(\frac{dx}{dt} \right)^2, \text{ and} \quad (27)$$

$$\beta = \frac{A_c}{A_o} \quad (28)$$

$$\text{yields } \Delta P_g = \frac{\rho}{2} \left[(1 + K_e) \beta^2 - \alpha^2 \right] \left(\frac{dx}{dt} \right)^2 \approx \frac{\rho}{2} (1 + K_e) \beta^2 \left(\frac{dx}{dt} \right)^2 \quad (29)$$

8.0 RESULTS: Cask Drop Into Rigid Pail

The solution to the equations of motion is contained in the MATHCAD file included here as Attachment 1. Two rigid pail cases were analyzed: A cask drop into a dry pail cavity was calculated to provide a comparison to past calculations and indicate strike velocity without water (Figure 3), and a cask drop into a pail cavity with just enough water to expel all gas upon strike (Figure 4). For each case, the upper portion of the figure provides the cask distance, velocity, and acceleration in G's, with either the cask bottom or water impact line noted, and the bottom portion of the figure provides the pressure in atmospheres.

In the rigid pail case with water, the pressure at the time of cask impact with water increases from the value for the gas space to the value required to force water into the annulus at a velocity consistent with the cask velocity. A value of 39 atm attained at water impact is the sum of the gas space pressure at the moment of impact, about 12 atm, and the acceleration pressure drop of the water which makes up the difference. High pressures are sustained at values between about 25 and 28 atm as the cask displaces water, but its final strike velocity is reduced to about 1.5 m/s, compared with over 7 m/s in the dry case.

9.0 RESULTS: Cask Drop Into Non-Rigid Pail

Results for the case with a moving pail and upper IPSS are shown in Figures 5 through 8. Figures 5 and 6 contain the same cask dynamics and pressure histories as Figures 3 and 4 discussed above; Figure 6 shows details during the 10 millisecond period of cask impact with water. Figure 7 displays pail position, velocity, and acceleration on long and brief time scales, and Figure 8 displays relative cask and pail position and velocity.

While the same peak pail cavity pressure is attained in this case as in the rigid pail case, high pressure is sustained for less than about 5 milliseconds due to acceleration of the pail. Within 10 milliseconds, the cavity pressure is below 10 atm. The maximum acceleration of the moving pail plus structure mass is about 95 g's, but this decays to about 20 g's in 10 milliseconds.

Because the pail plus structure mass is about an order of magnitude smaller than the cask mass, it is "bounced" ahead of the cask. From Figure 8, it is seen that the cask water penetration distance attains a maximum and then goes back to zero in about 80 milliseconds.

MGP:vdl
Attachment

References:

Todreas, N.E., and Kazimi, M.S., (MIT) "Nuclear Systems I," Thermal Hydraulic Fundamentals, Hemisphere Publishing Corp., 1990.

Table 1: Parameter Values for Cask Drop into Immersion Pail. (Values in British units given, values in metric derived and used.)				
1.0	<u>Geometry</u>			
	Pail interior height below orifice	L	144 in.	3.66 m
	Pail interior height above orifice	L_r	18.78 in.	0.477 m
	Cask outer diameter	D_p	39.81 in.	1.011 m
	Nominal pail radial gap	δ_g	1.095 in.	0.0278 m
	Pail orifice gap	δ_o	0.095 in.	2.4 mm
	Orifice length	L_o	2.0 in.	0.0508 m
	Piston (cask cross-section) area	A_p	-	0.803 m ²
	Cavity (pail interior cross-section) area	A_c	-	0.894 m ²
	Gap area	A_g	-	0.091 m ²
	Orifice area	A_o	-	0.00768 m ²
2.0	<u>Masses</u>			
	MCO plus contents mass	-	20,160 lbs.	9,164 kg
	Cask plus water gap mass	-	36,820 lbs.	16,740 kg
	Total piston mass	m_p	-	25,900 kg
3.0	<u>Parameters</u>			
	Water height in pail that fills cask- pail gap when cask inserted	-	-	0.371 m
	Air initial specific volume	v_a	-	0.843 m ³ /kg
	Water density	ρ_w	-	1,000 kg/m ³
	Friction factor	f	-	0.02
	Orifice coefficient	K_e	-	1.5
	Acceleration of gravity	g	-	9.81 m/s
	Polytropic exponent	γ	-	1.4
	Ambient pressure	P_a	-	10 ⁵ Pa

Figure 1: Cask Drop Into Partially Water-Filled Immersion Pail.

Figure 2A:
Key Dimension Definitions for Cask Drop Into Immersion Pail:
Before Impact, Rigid Pail.

L = Total length

H = Initial water depth

x = Penetration distance

~~~~~ = Water level in pail

Figure 2B:
Key Dimension Definitions for Cask Drop Into Immersion Pail:
After Impact, Rigid Pail.

L = Total length

d = Depth in annulus

H = Initial water depth

s = Water penetration depth

x = Penetration distance

..... = Original water level

~~~~~ = Current water level

Figure 2C:
Key Dimension Definitions for Cask Drop Into Immersion Pail:
After Impact, Non-Rigid Pail.

L = Total length	d = Depth in annulus
H = Initial water depth	s = Water penetration depth
x = Penetration distance	y = Pail Displacement
= Water level without cask penetration	----- = Initial pail position
~~ = Current water level	-.-.-.- = Reference line of zero pail displacement

Figure 2D:
Key Dimension Definitions for Cask Drop Into Immersion Pail:
After Impact, Non-Rigid Pail, Pail Moves Ahead of Cask.

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L = Total length

x = Penetration distance

H = Initial water depth

y = Pail Displacement

~~~~~ = Water level in pail

----- = Initial pail position

-.-.-.- = Reference line of zero
pail displacement

Figure 3: MCO + Cask Drop into Dry Immersion Pail, 5 ft free fall above Orifice

Figure 4: MCO + Cask Drop into Minimally Wet Immersion Pail, 5 ft free fall above Orifice

MCO + Cask Drop into Mimimally Wet Immersion Pail - 5 ft free fall

Figure 5: MCO + Cask Drop into Minimally Wet Immersion Pail, 5 ft free fall above Orifice - Moving Pail + IPSS Upper; Cask Dynamics and Pressure History

MCO + Cask Drop into Mimimally Wet Immersion Pail - 5 ft free fall - Moving Pail + IPSS Upper:
Cask Dynamics and Pressure History

Figure 6: MCO + Cask Drop into Minimally Wet Immersion Pail, 5 ft free fall above Orifice - Moving Pail + IPSS Upper; Cask Dynamics and Pressure History at Moment of Impact

Figure 7: MCO + Cask Drop into Minimally Wet Immersion Pail, 5 ft free fall above Orifice - Moving Pail + IPSS Upper; Pail Dynamics

MCO + Cask Drop into Mimimally Wet Immersion Pail - 5 ft free fall - Moving Pail + IPSS Upper:
Pail Dynamics

Figure 8: MCO + Cask Drop into Minimally Wet Immersion Pail, 5 ft free fall above Orifice – Moving Pail + IPSS Upper; Relative Cask and Pail Dynamics

MCO + Cask Drop into Minimally Wet Immersion Pail - 5 ft free fall - Moving Pail + IPSS Upper:
Relative Cask and Pail Dynamics. Solid line: Relative velocity, Cask - Pail, m/s; Dotted line:
Relative displacement, Cask - Pail, m; Dashed line: Penetration distance into water, cm.

ATTACHMENT 1

MCO+Cask Drop into Immersion Pail - Pail Motion

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For: Joe Swenson Duke Engineering & Services Hanford, March 1999

Extension & update of equations from M.G. Plys 4/2/99 memo to Joe Swenson & Dave Bergmann
Pail motion considered with Hooke's law

1. Input data & Simple functions =====

Nomenclature: "p"=piston=cask+contents, "g"=gap or gas, "o"=orifice, "c"=cylinder

Dimensions and MCO+Cask mass: -----

$$\begin{aligned}
 L_p &:= 144 \cdot 0.0254 & L &= 3.658 & D_p &:= 39.81 \cdot 0.0254 & D_p &= 1.011 \\
 \delta_g &:= 1.095 \cdot 0.0254 & \delta_g &= 0.028 & \delta_o &:= 0.095 \cdot 0.0254 & \delta_o &= 2.413 \cdot 10^{-3} \\
 A_p &:= \frac{\pi}{4} \cdot D_p^2 & A_p &= 0.803 & A_c &:= \frac{\pi}{4} \cdot (D_p + 2 \cdot \delta_g)^2 & A_c &= 0.894 \\
 A_g &:= A_c - A_p & A_g &= 0.091 & A_o &:= \frac{\pi}{4} \cdot (D_p + 2 \cdot \delta_o)^2 - A_p & A_o &= 7.684 \cdot 10^{-3} \\
 M_p &:= \frac{20160 + 36820}{2.2} & M_p &= 2.59 \cdot 10^4 \\
 L_o &:= 4 \cdot 0.025 & L_o &= 0.1 & Dh_o &:= 2 \cdot \delta_o & Dh_o &= 4.826 \cdot 10^{-3}
 \end{aligned}$$

Acceleration of gravity, air gas constant, ambient temperature, and friction factor -----

$$\begin{aligned}
 R_a &:= 8314 \cdot 29^{-1} & T_a &:= 294 & P_a &:= 10^5 & v_a &:= R_a \cdot T_a \cdot P_a^{-1} & v_a &= 0.843 \\
 g &:= 9.81 & \rho_w &:= 1000 & f &:= 0.02 & K_e &:= 1.5 & \gamma &:= 1.4
 \end{aligned}$$

Note K_e is based on 0.5 for contraction and 1.0 for expansion, i.e. large area changes.

Water height which will exhaust all gas: $H_{fill} := \frac{A_g}{A_c} \cdot L \quad H_{fill} = 0.371$

2.0 Compressible Flow Function

Ratio of specific heats:

$\gamma := 1.4$

Critical pressure ratio:

$$R_c := \left(\frac{2}{1 + \gamma} \right)^{\frac{\gamma}{\gamma - 1}} \quad R_c = 0.528$$

 $fG(P_2, P_1, C, \rho_2, \rho_1) :=$
 $P_{up} \leftarrow \text{if}(P_2 > P_1, P_2, P_1)$
 $P_{dn} \leftarrow \text{if}(P_2 > P_1, P_1, P_2)$
 $\rho \leftarrow \text{if}(P_2 > P_1, \rho_2, \rho_1)$
 $s \leftarrow \text{if}(P_2 > P_1, 1, -1)$
 $R \leftarrow \frac{P_{dn}}{P_{up}}$
 $R \leftarrow R_c \text{ if } R < R_c$
 $s \cdot C \cdot \left[2 \cdot \frac{\gamma}{\gamma - 1} \cdot P_{up} \cdot \rho \cdot R^{\frac{2}{\gamma}} \cdot \left(1 - R^{\frac{\gamma - 1}{\gamma}} \right) \right]^{0.5}$
Compressible flow given:

Pressure at points 2 and 1,

Orifice coefficient,

Density of gas at points 2 and 1

Function returns mass flux kg/m²/s

Sign has sense of flow:

from point 2 to point 1 has $G > 0$ Note: the orifice coefficient is found as
 $C = \sqrt{1 / (K + f \cdot L / d)}$ Example: compare flowrates for $C=1$ with incompressible formula, for a few pressures:

$$fGI(P_{up}, P_{dn}, C, \rho) := C \cdot \sqrt{2 \cdot (P_{up} - P_{dn}) \cdot \rho}$$

$$i := 0..20 \quad P_i := P_a \cdot \left(1 + \frac{i}{20} \right) \quad vg_i := v_a \cdot \left(\frac{P_a}{P_i} \right)^{\frac{1}{\gamma}}$$

$$G_i := fG[P_i, P_a, 1, (vg_i)^{-1}, v_a^{-1}]$$

$$GI_i := fGI[P_i, P_a, 1, (vg_i)^{-1}]$$

Compressible flow (line) vs Incompressible (dots) in kg/m²/s as function of $(P_{up}/P_{atm} - 1)$ Of course incompressible is conservative for drop analysis, but use compressible if $P \gg 2$ atm.

3.0 Functions for pressure drop, flowrates, etc. used by derivative function =====

Note parameters not found in arguments are assigned above - must reassign functions to run cases where those values change!

Parameters used here include: H=initial water height, x=cask penetration distance, m=gas mass

Initial air mass: $fMa(H) := A_c \cdot (L - H) \cdot v_a^{-1}$

Current air volume: $fVa(x, y, H) := A_c \cdot (L - H) - A_p \cdot (x - y)$

Is there air left (1=yes, 0=no): $fair(m, H) := \text{if}(m > 0.001 \cdot fMa(H), 1, 0)$

Penetration depth into water: $fs(x, y, H) := \begin{cases} s \leftarrow (x - y) - (L - H) \\ s \leftarrow \text{if}(s > 0, s, 0) \end{cases}$

Water depth in annulus relative to cask bottom; max value is x

$$fd(x, y, H) := \begin{cases} s \leftarrow fs(x, y, H) \\ x - y \text{ if } s \geq \frac{A_g}{A_p} \cdot (L - H) \\ \frac{A_c}{A_g} \cdot s \text{ otherwise} \end{cases}$$

Gas pressure given mass & geometry using adiabatic polytropic formula

$$fPg(x, y, m, H) := \begin{cases} \text{if } fair(m, H) \\ \begin{cases} v_g \leftarrow fVa(x, y, H) \cdot m^{-1} \\ P_g \leftarrow P_a \cdot (v_a \cdot v_g^{-1})^\gamma \end{cases} \\ P_g \leftarrow P_a \text{ otherwise} \\ P_g \end{cases}$$

Gas flowrate:

$$fwg(x, y, m, H, f, K_e) := \begin{cases} \text{if } fair(m, H) \\ \begin{cases} v_g \leftarrow fVa(x, y, H) \cdot m^{-1} \\ P_g \leftarrow P_a \cdot (v_a \cdot v_g^{-1})^\gamma \\ C_o \leftarrow \left(K_e + f \cdot \frac{L_o}{Dh_o} \right)^{-0.5} \\ w_g \leftarrow A_o \cdot fG(P_g, P_a, C_o, v_g^{-1}, v_a^{-1}) \end{cases} \\ w_g \leftarrow 0 \text{ otherwise} \\ w_g \end{cases}$$

Pressure function: Output value is P_g from gas flow before water contact, P_g plus acceleration head after contact and before water-solid, and acceleration head plus water head loss through orifice after solid.

$$fP(x, y, v, vp, m, H, f, K_e, M_p, M_{ps}, K_{ps}) := \begin{cases} P \leftarrow fPg(x, y, m, H) & \text{if } (x - y) < (L - H) \\ \text{otherwise} \\ dPg \leftarrow fPg(x, y, m, H) - P_a & \text{if } \text{fair}(m, H) \\ \text{otherwise} \\ K \leftarrow \left(K_e + f \cdot \frac{L_o}{Dh_o} \right) \cdot \left(\frac{A_c}{A_o} \right)^2 \\ dPg \leftarrow \frac{\rho_w}{2} \cdot K \cdot |v - vp| \cdot (v - vp) \\ dPa \leftarrow \frac{1}{2} \cdot \rho_w \cdot \left(\frac{A_c}{A_g} \right)^2 \cdot |v - vp| \cdot (v - vp) \\ \mu \leftarrow \rho_w \cdot fd(x, y, H) \cdot \frac{A_c}{A_g} \\ dPi \leftarrow \mu \cdot (g - K_{ps} \cdot M_{ps}^{-1}) \\ P \leftarrow \frac{dPg + dPa + dPi}{1 + \mu \cdot (A_p \cdot M_p^{-1} + A_c \cdot M_{ps}^{-1})} + P_a \end{cases}$$

Cask + MCO equation of motion:

$$fa(x, M_p, P) := g - A_p \cdot M_p^{-1} \cdot (P - P_a)$$

IPSS equation of motion with foam resistance force; logic branch turns on accel after first water contact

$$fap(x, H, M_{ps}, K_{ps}, P) := \begin{cases} 0 & \text{if } x < (L - H) \\ A_c \cdot (P - P_a) \cdot M_{ps}^{-1} - K_{ps} & \text{otherwise} \end{cases}$$

$$fI(S, L) := \begin{cases} \text{Imax} \leftarrow \text{length}(S) - 1 \\ i \leftarrow 0 \\ \text{while } S_i < L \\ \quad i \leftarrow i + 1 \\ i \end{cases}$$

Handy function to find index where $x=L$.
Input vector S of distances, assume
monotonic increase.

4.0 Derivative function for integration =====

Parameters are input with state variables to allow more cases.

State variables are:

0= distance, 1= velocity, 2= air mass
3= pail distance, 4=pail velocity

Auxiliary inputs are:

5= water height, 6=piston mass
7= fric. factor, 8= exit coefficient
9=IPSS mass, 10=IPSS Hooke
11=distance to stop calc.

Handy zero vectors:

N := 11

i := 0.. N   ZY_i := 0i := 0.. 6   ZA_i := 0

```

F(t, X) :=
  x ← X0
  v ← X1
  m ← X2
  y ← X3
  vp ← X4
  H ← X5
  Mp ← X6
  f ← X7
  Ke ← X8
  Mps ← X9
  Kps ← X10
  Lend ← X11
  F ← ZY if x > 0.999·Lend
  otherwise
    w ← fwg(x, y, m, H, f, Ke)
    P ← fP(x, y, v, vp, m, H, f, Ke, Mp, Mps, Kps)
    a ← fa(x, Mp, P)
    ap ← fap(x, H, Mps, Kps, P)
    F ← stack((v a w vp ap)T, ZA)
  F

```

Case 1: Cask+MCO into dry pail

Initial position and velocity, 5 ft free fall: $x_o := 0$ $v_o := \sqrt{2 \cdot g \cdot 60 \cdot 0.0254}$ $v_o = 5.468$

IPSS position and velocity: $y_o := 0$ $vp_o := 0$

IPSS mass and Hooke constant: $M_{ps} := 10^{10}$ $K_{ps} := 0$

Initial water depth, derived air mass: $H := 0$
 $Ma := fMa(H)$ $Ma = 3.879$

Restate piston mass, fric factor, loss coef: $M_p = 2.59 \cdot 10^4$ $f = 0.02$ $K_e = 1.5$

End distance for this calc: $L_{end} := L$

State vector and integration: $X := [x_o \ v_o \ Ma \ y_o \ vp_o \ H \ M_p \ f \ K_e \ M_{ps} \ K_{ps} \ L_{end}]^T$

$Imax := 500$ $Y := Rkadapt(X, 0, 1, Imax, F)$ $i := 0.. Imax$

Rename outputs for convenience: $t_i := (Y^{<0>})_i$ $S_i := (Y^{<1>})_i$ $U_i := (Y^{<2>})_i$ $MG_i := (Y^{<3>})_i$

Acceleration in G's: $j := 0.. N$ $XX_{j,i} := Y_{i,j+1}$ $A_i := -F(t_i, XX^{<i>})_1 \cdot \frac{1}{g}$

Pressure in atm: $PG_i := fP(S_i, 0, U_i, 0, MG_i, H, f, K_e, M_p, M_{ps}, K_{ps}) \cdot 10^{-5}$

Bottom location: $SL_i := L$

Maximum pressure, acceleration, and final strike velocity, SI (top) and BR units (bottom):

$\max(PG) = 12.764$ $\max(A) = 2.681$ $U_{Imax} = 7.536$

$\max(PG) \cdot 14.6 = 186.361$ $U_{Imax} \cdot 3.28 = 24.719$

Unit note: Pressure in atm (psi), acceleration in G's, velocity in m/s (ft/s).

For plots limit index to strike time: $lend := fl(S, 0.999 \cdot L_{end})$ $i := 0.. lend$

MCO + Cask Drop into Dry Immersion Pail, 5 ft free fall above Orifice

Case 2: Cask+MCO into minimally-filled pail: Just enough water to fill gap - Rigid Pail

Initial position and velocity, 5 ft free fall: $x_o := 0$ $v_o := \sqrt{2 \cdot g \cdot 60 \cdot 0.0254}$ $v_o = 5.468$

IPSS position and velocity: $y_o := 0$ $vp_o := 0$

IPSS mass and Hooke constant: $M_{ps} := 10^{10}$ $K_{ps} := 0$

Initial water depth, derived air mass: $H := 0.999 \cdot H_{fill}$ $H = 0.371$
 $Ma := fMa(H)$ $Ma = 3.485$

Restate piston mass, fric factor, loss coef: $M_p = 2.59 \cdot 10^4$ $f = 0.02$ $K_e = 1.5$

Integration Phase 1: Up to water contact

End calculation when bottom struck: $Lend := L - H$

State vector and integration: $X := [x_o \ v_o \ Ma \ y_o \ vp_o \ H \ M_p \ f \ K_e \ M_{ps} \ K_{ps} \ Lend]^T$

$Imax := 500$ $Y := Rkadapt(X, 0, 1, Imax, F)$ $i := 0.. Imax$

Rename outputs for convenience: $t_i := (Y^{<0>})_i$ $S_i := (Y^{<1>})_i$ $U_i := (Y^{<2>})_i$ $MG_i := (Y^{<3>})_i$

Acceleration in G's: $j := 0.. N$ $XX_{j,i} := Y_{i,j+1}$ $A_i := -F(t_i, XX^{<i>})_1 \cdot \frac{1}{g}$

Pressure in atm: $PG_i := fP(S_i, 0, U_i, 0, MG_i, H, f, K_e, M_p, M_{ps}, K_{ps}) \cdot 10^{-5}$

For plots limit index to strike time: $Iend1 := fI(S, 0.999 \cdot Lend)$ $PG_{Iend1} = 12.487$ $Iend1 = 228$

$i := 0.. Iend1 - 1$ $t1_i := t_i$ $S1_i := S_i$ $U1_i := U_i$ $A1_i := A_i$ $PG1_i := PG_i$

Integration phase 2: Water Impact

$j := 0.. N$ $X_j := XX_{j,Iend1}$ $t0 := t_{Iend1}$

$S_{Iend1} = 3.284$ $L - H = 3.286$ $(L - H - S_{Iend1}) \cdot (U_{Iend1})^{-1} = 3.577 \cdot 10^{-4}$ $te := t0 + 0.001$

$Lend := L$ $X_N := Lend$ $Imax := 10$ $Y := rkfixed(X, t0, te, Imax, F)$ $i := 0.. Imax$

Rename outputs for convenience: $t_i := (Y^{<0>})_i$ $S_i := (Y^{<1>})_i$ $U_i := (Y^{<2>})_i$ $MG_i := (Y^{<3>})_i$

Acceleration in G's: $j := 0.. N$ $XX_{j,i} := Y_{i,j+1}$ $A_i := -F(t_i, XX^{<i>})_1 \cdot \frac{1}{g}$

Pail params's: $SP_i := (Y^{<4>})_i$ $UP_i := (Y^{<5>})_i$ $AP_i := -F(t_i, XX^{<i>})_4 \cdot \frac{1}{g}$

Pressure in atm: $PG_i := fP(S_i, SP_i, U_i, UP_i, MG_i, H, f, K_e, M_p, M_{ps}, K_{ps}) \cdot 10^{-5}$

Plots for this group: $Iend2 := Imax$ $PG_{Iend2} = 38.204$

$$i := 0.. \text{lend2} - 1 \quad t_{2i} := t_i \quad S_{2i} := S_i \quad U_{2i} := U_i \quad A_{2i} := A_i \quad PG_{2i} := PG_i$$

Integration phase 3: Post-Impact

$$j := 0.. N \quad X_j := XX_{j, \text{lend2}} \quad t_0 := t_{\text{lend2}}$$

$$\text{lend} := L \quad X_N := \text{lend} \quad \text{Imax} := 500 \quad Y := \text{Rkadapt}(X, t_0, 1, \text{Imax}, F) \quad i := 0.. \text{Imax}$$

$$\text{Rename outputs for convenience:} \quad t_i := (Y^{<0>})_i \quad S_i := (Y^{<1>})_i \quad U_i := (Y^{<2>})_i \quad MG_i := (Y^{<3>})_i$$

$$\text{Acceleration in G's:} \quad j := 0.. N \quad XX_{j,i} := Y_{i,j+1} \quad A_i := -F(t_i, XX^{<i>})_1 \cdot \frac{1}{g}$$

$$\text{Pail params's:} \quad SP_i := (Y^{<4>})_i \quad UP_i := (Y^{<5>})_i \quad AP_i := -F(t_i, XX^{<i>})_4 \cdot \frac{1}{g}$$

$$\text{Pressure in atm:} \quad PG_i := fP(S_i, SP_i, U_i, UP_i, MG_i, H, f, K_e, M_p, M_{ps}, K_{ps}) \cdot 10^{-5}$$

$$\text{Plots for this group:} \quad \text{lend3} := f1(S, 0.999 \cdot \text{lend}) \quad \text{lend3} = 81 \quad PG_{\text{lend3}} = 9.945$$

$$i := 0.. \text{lend3} \quad t_{3i} := t_i \quad S_{3i} := S_i \quad U_{3i} := U_i \quad A_{3i} := A_i \quad PG_{3i} := PG_i$$

Assemble Plot Vectors:

$$t := \text{stack}(\text{stack}(t_1, t_2), t_3) \quad S := \text{stack}(\text{stack}(S_1, S_2), S_3) \quad U := \text{stack}(\text{stack}(U_1, U_2), U_3)$$

$$A := \text{stack}(\text{stack}(A_1, A_2), A_3) \quad PG := \text{stack}(\text{stack}(PG_1, PG_2), PG_3)$$

$$\text{Imax} := \text{lend1} + \text{lend2} + \text{lend3} \quad i := 0.. \text{Imax} \quad SW_i := L - H$$

Maximum pressure, acceleration, and final strike velocity, SI (top) and BR units (bottom):

$$\max(PG) = 38.955 \quad \max(A) = 10.996 \quad U_{\text{Imax}} = 1.39$$

$$\max(PG) \cdot 14.6 = 568.747 \quad U_{\text{Imax}} \cdot 3.28 = 4.558$$

Unit note: Pressure in atm (psi), acceleration in G's, velocity in m/s (ft/s).

$$\text{Time of contact:} \quad I_{\text{con}} := f1(S - 0, L - H) \quad I_{\text{con}} = 232 \quad L - H = 3.286 \quad S_{I_{\text{con}}} = 3.287 \quad t_{I_{\text{con}}} = 0.456$$

$$\text{Pressure at contact:} \quad PG_{I_{\text{con}} - 1} = 12.563 \quad PG_{I_{\text{con}}} = 38.955 \quad U_{I_{\text{con}}} = 7.38$$

$$fPg(S_{I_{\text{con}}}, 0, MG_{I_{\text{con}}}, H) \cdot 10^{-5} = 0.028 \quad A_c \cdot A_g^{-1} = 9.846$$

$$\frac{1}{2} \cdot \rho \cdot w \cdot \left(\frac{A_c}{A_g} \right)^2 \cdot (U_{I_{\text{con}}} - 0)^2 \cdot 10^{-5} = 26.399$$

MCO + Cask Drop into Minimally Wet Immersion Pail - 5 ft free fall

Case 3: Cask+MCO into minimally-filled pail: Just enough water to fill gap - 5 ft - Moving Pail

Initial position and velocity, 4 ft free fall: $x_o := 0$ $v_o := \sqrt{2 \cdot g \cdot 60 \cdot 0.0254}$ $v_o = 5.468$

IPSS position and velocity: $y_o := 0$ $vp_o := 0$

IPSS mass and Hooke constant: $M_{ps} := 3600$ $K_{ps} := 0$

Initial water depth, derived air mass: $H := 0.999 \cdot H_{fill}$ $H = 0.371$

$Ma := fMa(H)$ $Ma = 3.485$

Restate piston mass, fric factor, loss coef: $M_p = 2.59 \cdot 10^4$ $f = 0.02$ $K_e = 1.5$

Integration Phase 1: Up to water contact

End calculation when bottom struck: $Lend := L - H$

State vector and integration: $X := [x_o \ v_o \ Ma \ y_o \ vp_o \ H \ M_p \ f \ K_e \ M_{ps} \ K_{ps} \ Lend]^T$

$Imax := 500$ $Y := Rkadapt(X, 0, 1, Imax, F)$ $i := 0.. Imax$

Rename outputs for convenience: $t_i := (Y^{<0>})_i$ $S_i := (Y^{<1>})_i$ $U_i := (Y^{<2>})_i$ $MG_i := (Y^{<3>})_i$

Acceleration in G's: $j := 0.. N$ $XX_{j,i} := Y_{i,j+1}$ $A_i := -F(t_i, XX^{<i>})_1 \cdot \frac{1}{g}$

Pressure in atm, and gas flow: $PG_i := fP(S_i, 0, U_i, 0, MG_i, H, f, K_e, M_p, M_{ps} W_i := F(t_i, XX^{<i>})_2$

For plots limit index to strike time: $Iend1 := fl(S, 0.999 \cdot Lend)$ $PG_{Iend} = 12.487$ $Iend1 = 228$

Initialize: $t1 := 0$ $S1 := 0$ $U1 := 0$ $A1 := 0$ $PG1 := 0$ $SP1 := 0$ $UP1 := 0$ $AP1 := 0$

$i := 0.. Iend1 - 1$ $t1_i := t_i$ $S1_i := S_i$ $U1_i := U_i$ $A1_i := A_i$ $PG1_i := PG_i$ $W1 := 0$
 $SP1_i := 0$ $UP1_i := 0$ $AP1_i := 0$ $W1_i := W_i$

Integration phase 2: Water Impact

$$j := 0..N \quad X_j := XX_{j, \text{lend1}} \quad t0 := t_{\text{lend1}}$$

$$S_{\text{lend1}} = 3.284 \quad L - H = 3.286 \quad (L - H - S_{\text{lend1}}) \cdot (U_{\text{lend1}})^{-1} = 3.577 \cdot 10^{-4} \quad te := t0 + 0.001$$

$$\text{lend} := L \quad X_N := \text{lend} \quad \text{Imax} := 10 \quad Y := \text{rkfixed}(X, t0, te, \text{Imax}, F) \quad i := 0.. \text{Imax}$$

$$\text{Rename outputs for convenience:} \quad t_i := (Y^{0>})_i \quad S_i := (Y^{1>})_i \quad U_i := (Y^{2>})_i \quad MG_i := (Y^{3>})_i$$

$$\text{Acceleration in G's:} \quad j := 0..N \quad XX_{j,i} := Y_{i,j+1} \quad A_i := -F(t_i, XX^{<i>})_1 \cdot \frac{1}{g}$$

$$\text{Pail params's:} \quad SP_i := (Y^{4>})_i \quad UP_i := (Y^{5>})_i \quad AP_i := F(t_i, XX^{<i>})_4 \cdot \frac{1}{g}$$

$$\text{Pressure in atm:} \quad PG_i := fP(S_i, SP_i, U_i, UP_i, MG_i, H, f, K_e, M_p, M_{ps}, K_{ps}) \cdot 10^{-5} \quad W_i := F(t_i, XX^{<i>})_2$$

$$\text{Plots for this group:} \quad \text{lend2} := \text{Imax} \quad PG_{\text{lend2}} = 31.463$$

$$\text{Initialize:} \quad t2 := 0 \quad S2 := 0 \quad U2 := 0 \quad A2 := 0 \quad PG2 := 0 \quad SP2 := 0 \quad UP2 := 0 \quad AP2 := 0$$

$$i := 0.. \text{lend2} - 1 \quad t2_i := t_i \quad S2_i := S_i \quad U2_i := U_i \quad A2_i := A_i \quad PG2_i := PG_i \quad W2 := 0$$

$$SP2_i := SP_i \quad UP2_i := UP_i \quad AP2_i := AP_i \quad W2_i := W_i$$

Integration phase 3: Post-Impact

$$j := 0..N \quad X_j := XX_{j, \text{lend2}} \quad t0 := t_{\text{lend2}}$$

$$\text{lend} := L + 0.3 \quad X_N := \text{lend} \quad \text{Imax} := 500 \quad Y := \text{Rkadapt}(X, t0, 1, \text{Imax}, F) \quad i := 0.. \text{Imax}$$

$$\text{Rename outputs for convenience:} \quad t_i := (Y^{0>})_i \quad S_i := (Y^{1>})_i \quad U_i := (Y^{2>})_i \quad MG_i := (Y^{3>})_i$$

$$\text{Acceleration in G's:} \quad j := 0..N \quad XX_{j,i} := Y_{i,j+1} \quad A_i := -F(t_i, XX^{<i>})_1 \cdot \frac{1}{g}$$

$$\text{Pail params's:} \quad SP_i := (Y^{4>})_i \quad UP_i := (Y^{5>})_i \quad AP_i := F(t_i, XX^{<i>})_4 \cdot \frac{1}{g}$$

$$\text{Pressure in atm:} \quad PG_i := fP(S_i, SP_i, U_i, UP_i, MG_i, H, f, K_e, M_p, M_{ps}, K_{ps}) \cdot 10^{-5} \quad W_i := F(t_i, XX^{<i>})_2$$

$$\text{Plots for this group:} \quad \text{lend3} := \text{fl}(S, 0.999 \cdot \text{lend}) \quad \text{lend3} = 89 \quad PG_{\text{lend3}} = 4.304$$

$$\text{Initialize:} \quad t3 := 0 \quad S3 := 0 \quad U3 := 0 \quad A3 := 0 \quad PG3 := 0 \quad SP3 := 0 \quad UP3 := 0 \quad AP3 := 0$$

$$i := 0.. \text{lend3} \quad t3_i := t_i \quad S3_i := S_i \quad U3_i := U_i \quad A3_i := A_i \quad PG3_i := PG_i \quad W3 := 0$$

$$SP3_i := SP_i \quad UP3_i := UP_i \quad AP3_i := AP_i \quad W3_i := W_i$$

Assemble Plot Vectors:

$t := \text{stack}(\text{stack}(t1, t2), t3)$ $S := \text{stack}(\text{stack}(S1, S2), S3)$ $U := \text{stack}(\text{stack}(U1, U2), U3)$
 $A := \text{stack}(\text{stack}(A1, A2), A3)$ $PG := \text{stack}(\text{stack}(PG1, PG2), PG3)$ $W := \text{stack}(\text{stack}(W1, W2), W3)$
 $SP := \text{stack}(\text{stack}(SP1, SP2), SP3)$ $UP := \text{stack}(\text{stack}(UP1, UP2), UP3)$ $AP := \text{stack}(\text{stack}(AP1, AP2), AP3)$
 $I_{\max} := I_{\text{end}1} + I_{\text{end}2} + I_{\text{end}3}$ $i := 0.. I_{\max}$ $SW_i := L - H$

Maximum pressure, acceleration, and final strike velocity, SI (top) and BR units (bottom):

$\max(PG) = 38.564$ $\max(A) = 10.872$ $U_{I_{\max}} = 6.826$
 $\max(PG) \cdot 14.6 = 563.027$ $U_{I_{\max}} \cdot 3.28 = 22.388$

Unit note: Pressure in atm (psi), acceleration in G's, velocity in m/s (ft/s).

Time of contact: $I_{\text{con}} := \text{fl}(S - 0, L - H)$ $I_{\text{con}} = 232$ $L - H = 3.286$ $S_{I_{\text{con}}} = 3.287$ $t_{I_{\text{con}}} = 0.456$

Pressure at contact:

$PG_{I_{\text{con}}-1} = 12.563$ $PG_{I_{\text{con}}} = 38.564$ $U_{I_{\text{con}}} = 7.38$
 $fPg(S_{I_{\text{con}}}, 0, MG_{I_{\text{con}}}, H) \cdot 10^{-5} = 5.752$ $A_c \cdot A_g^{-1} = 9.846$
 $\frac{1}{2} \cdot \rho_w \left(\frac{A_c}{A_g} \right)^2 \cdot (U_{I_{\text{con}}} - 0)^2 \cdot 10^{-5} = 26.399$

MCO + Cask Drop into Minimally Wet Immersion Pail - 5 ft free fall - Moving Pail + IPSS Upper:
Cask Dynamics and Pressure History

MCO + Cask Drop into Minimally Wet Immersion Pail - 5 ft free fall - Moving Pail + IPSS Upper:
Cask Dynamics and Pressure History - Moment of water impact detail

MCO + Cask Drop into Mimimally Wet Immersion Pail - 5 ft free fall - Moving Pail + IPSS Upper:
Pail Dynamics

$$Z_i := S_i - SP_i \quad VR_i := U_i - UP_i \quad s_i := \text{if}(fs(S_i, SP_i, H) > 0, fs(S_i, SP_i, H), 0)$$

MCO + Cask Drop into Minimally Wet Immersion Pail - 5 ft free fall - Moving Pail + IPSS Upper:
Relative Cask and Pail Dynamics. Solid line: Relative velocity, Cask - Pail, m/s; Dotted line:
Relative displacement, Cask - Pail, m; Dashed line: Penetration distance into water, cm.

Fauske & Associates, Inc.

DATE: June 18, 1999

TO: George Abhatt and Milon Meyer, M&D

CC: M. G. Plys

FROM: Boro Malinovic *BM*

SUBJECT: Review of "Hypothetical Cask Drop Analysis Considering Immersion Pail Motion"

This memorandum documents independent review of "Hypothetical Cask Drop Analysis Considering Immersion Pail Motion," an FAI memorandum from Plys, to Swenson (DESH), Abatt (M&D) and Meyer (M&D), dated June 18, 1999.

The review consisted of first checking that the equations of motion were derived correctly. The solution scheme (MATHCAD files) was independently checked by alternate means. Essentially, the equations of motion were solved again using a spreadsheet.

Derivations are correct within the stated assumptions. Solution of the equations of motion has been implemented properly with one exception. The discharge coefficient for gas flow was properly described as

$$C = [1 + K_e + fL/D]^{1/2}$$

in the text (C goes to one for inviscid flow), but $C = [K_e + fL/D]^{1/2}$ was used in the MATHCAD solution. This is not a serious error and leads to slightly conservative results for strike velocity.

The solution is otherwise correct. I integrated the equations of motion independent of the MATHCAD file as a check. Case 1 (MCO + Cask Drop into Dry Immersion Pail, 5ft free fall above Orifice) was reproduced. Independent check results for velocity, acceleration and pressure are shown here as Figures 1 and 2. This ensures that the before water contact solution scheme is correct. Case 2 (MCO + Cask Drop into Wet Immersion Pail, 5ft free fall above Orifice) was also reproduced. Independent check results for velocity, acceleration and pressure are shown here as Figures 3 and 4. This ensures that the solution scheme after impact is correct.

The results shown here are generally in good agreement with Plys results, although there are some differences in the pressure traces after the cask contacts the water. Nevertheless, the Figures 1 through 4 serve as an independent check of Plys calculation.

Figure 1: Case 1 Distance and velocity.

Figure 2: Case 1 Pressure.

Case 3: Case 2 Velocity and distance.

Figure 4: Case 2 Pressure.

Fauske & Associates, Inc.

DATE: April 7, 1999
 TO: Dave Bergmann and Joe Swenson, DE&SH
 FROM: Marty Plys *Marty*
 SUBJECT: Hypothetical Cask into Immersion Pail Drop Analysis

1.0 SUMMARY

Hypothetical drop accidents for a fully loaded cask and MCO into the immersion pail at the K basins are considered here for a pail design with bottom relief venting, and with operational constraints on the maximum free fall before water impact.

Bottom relief venting is required to keep the pressure difference across the pail wall upon water impact below a value which could cause pail failure. An equation is provided that relates the allowable pressure difference and impact velocity to the required relief area. For a free fall height of 4 feet (1.2 m) the impact velocity is 4.9 m/s, and for an allowed pressure difference of 100 psi (6.8 atm approximately) the required vent area is 0.13 m² (1.4 square feet). Other examples are given below. The greater the allowable pressure, the smaller the required vent area and the smaller the strike velocity. The steady-state pressure under a falling cask in the pail is about 3.2 atm.

The strike velocity is equal to the terminal velocity for sufficient depth of water penetration, and the required depth will be discussed below. The strike velocity is directly proportional to the relief area. For the example relief area of 1.4 square feet the strike velocity is 3.4 m/s or 11 ft/s, which is not much smaller than the impact velocity used above.

The difference between free-fall impact velocity and strike velocity in the example is small, only 1.5 m/s. Acceleration of the cask upon impact is -11.1 m/s², or just over one G, and using an average acceleration of 3.3 m/s² (a time average over the transient) the cask will slow to its terminal velocity within 0.34 m or just over 1 foot of water penetration. Thus a cask dropped from 4 feet over a full immersion pail would decelerate to terminal velocity by the time it encountered the restrictor ring inside the pail.

2.0 HYPOTHETICAL TRANSIENT DESCRIPTION

For the present analysis, the immersion pail is assumed to be full or nearly full of water underneath the shipping cask, so that the maximum free fall distance of a shipping cask and its contents is limited. Whether the cask bottom initial position is above the pail interior restrictor ring or below the restrictor ring, gas flow around the cask may be neglected for short fall heights, and the velocity of the cask upon impact with water is conservatively approximated by the free-fall value.

Upon cask impact with water, the pressure in the pail will instantly increase to the value needed to expel water from the pail cavity beneath the cask at a rate demanded by the cask water impact velocity. That is, the cask water impact velocity times its cross-sectional area is a volumetric flowrate of water that must be removed either through the annular gap between cask and pail, or through a relief area. A relief area on the pail bottom is the baseline design for this analysis. If the initial position of the cask bottom is below the restrictor ring, then the annular gap area for upward water relief is the orifice area at the restrictor ring, and this area is very small. For practical purposes, only the relief area need be considered for drops with an initial cask position beneath the restrictor ring, and the relief area must be designed for this limiting scenario.

After impact with water, the cask will decelerate until either its terminal velocity is attained or it impacts upon the pail wall or bottom. The strike velocity for the cask is thus equal to the terminal velocity for sufficient water depth, and the water depth to decelerate to terminal velocity is of interest.

3.0 ANALYSIS

The equation of motion for the cask is

$$a = g - \frac{A_p}{M_p} \Delta P \quad (1)$$

where a = Acceleration, m/s^2 ,

g = Acceleration of gravity 9.81 m/s^2 ,

A_p = Piston (cask cross-sectional) area, 0.8 m^2 ,

M_p = Piston (cask) mass, $26,000 \text{ kg}$, and

ΔP = Pressure difference across pail, Pa .

The pressure difference is given by:

$$\Delta P = (1 + K_e) \frac{\rho}{2} \alpha^2 U^2 = C_o \frac{\rho}{2} \alpha^2 U_p^2 \quad (2)$$

- ρ = Water density, 1000 kg/ m³,
 α = Ratio of cask area to relief area, A_p / A_R ,
 U_p = Cask velocity, m/s, and
 C_o = Overall loss coefficient,

And the free fall velocity of the cask from height H is simply

$$U_i = \sqrt{2gH} \quad (3)$$

So for a 4 foot (1.22 m) free drop, the free fall velocity is $U_p = 4.9$ m/s.

The corresponding pressure at impact is found by (2), which is more conveniently rearranged to yield the relief area required by a given impact pressure ΔP_i :

$$A_R \geq \frac{A_p U_i}{\sqrt{2\Delta P_i / \rho C_o}} \quad (4)$$

For a range various possible pressure differences the required relief area is:

Pressure difference, ΔP_i Psi (atm)	Relief area, A_R m ² (ft ²)
50 (3.4)	0.184 (2.0)
100 (6.8)	0.13 (1.40)
150 (10.2)	0.106 (1.14)

Cask terminal (strike) velocity is found by setting the acceleration equal to zero in Eq. (1) and combining the result with Eq. (2):

$$U_s = \frac{A_R}{A_p} \sqrt{2M_p g / \rho C_o A_p} \quad (5)$$

This relationship may be conveniently combined with (4) to yield a design curve for the tradeoff between strike velocity and pressure difference across the pail:

$$U_s^2 = \frac{M_p g}{A_p \Delta P_i} U_i^2 = \frac{3.2}{\Delta P_i} U_i^2 = \frac{80}{\Delta P_i} \quad (6)$$

where ΔP_i is expressed in atmospheres, the strike velocity is expressed in m/s, and an impact velocity of 4.9 m/s from a 4 foot free fall are used in Eq. (6) above. For the impact pressures used above, corresponding strike velocities are:

Pressure difference, ΔP_i Psi (atm)	Strike (terminal) velocity, U_i m/s (ft/s)
50 (3.4)	4.85 (15.9 ft/s)
100 (6.8)	3.43 (11.3 ft/s)
150 (10.2)	2.80 (9.2 ft/s)

It is notable that for the chosen water impact velocity of 4.9 m/s and the range of allowed pail pressure differences that the terminal velocity is not much below the impact velocity, and in fact for the lower pressure difference the two are practically equal. This implies that a small water depth is required to decelerate the cask to its terminal velocity. The depth can be quickly estimated from a time-average value of cask acceleration during this period. A suitable average value is the square root of the initial acceleration. From Eq. (1) the initial acceleration is $a = 9.81 - 20.9 = -11.1 \text{ m/s}^2$, so an average value is -3.3 m/s^2 . The duration of the deceleration period is given by the required change in velocity and the average acceleration, $\Delta v = a \Delta t$. For the 100 psi case, $\Delta v = 3.4 - 4.9 = -1.5 \text{ m/s}$, so $\Delta t = 0.45$ seconds. The distance traveled is $\Delta x = 1/2 a \Delta t^2$ so $\Delta x = 0.34 \text{ m}$ or about 1 foot.

Note that the analysis above is conservative because only the relief area was used. This is a good approach for drops with the cask initially below the restrictor ring. For drops initially above the restrictor ring, the cask-gap area of about 0.09 m^2 or about 1 ft^2 is comparable to the relief area, so pressure in the pail upon impact will be lower than given here, and the relief area may not open up depending upon the pressure set point.

Appendix G

Hypothetical Immersion Pail Drop Into Pail Shell Analysis

Fauske & Associates, Inc.

DATE: April 7, 1999
 TO: Dave Bergmann and Joe Swenson, DE&SH
 FROM: Marty Plys
 SUBJECT: Hypothetical Immersion Pail Drop into Pail Shell Analysis

1.0 SUMMARY

Hypothetical drop accidents for the immersion pail containing a fully loaded cask and MCO in the K basins were analyzed for a design currently being considered that minimizes both the maximum pressure drop across the pail the pail strike velocity at touchdown. A bottom vent area equivalent to a gap of 1.5 inches around the sleeve perimeter meets these criteria. Results for the range of potential pail-to-sleeve gap distances are:

Parameter	1/4" Gap	1/2" Gap
Strike Velocity	2.4 m/s	2.6 m/s
Maximum delta-P	2.7 atm	2.4 atm
Maximum acceleration	0.14 G	0.02 G
Maximum velocity	2.7 m/s	2.8 m/s

2.0 GEOMETRY AND HYPOTHETICAL TRANSIENT DESCRIPTION

The immersion pail has a constant cross-sectional area in the form of an extended octagon along most of its length. Near the top of the pail, the octagonal portions taper into a cylindrical cross-section and handling appurtenances are found closer to its top. For present purposes, the pail may be considered to be a piston of constant cross-section whose shape is not important.

In its fully ascended position, the bottom six inches of the pail are engaged in the immersion pail sleeve. The sleeve has the same extended octagonal cross section as the pail to maintain a constant gap thickness along this length, with the exception that the upper portion of the sleeve has slots, described next, to accommodate appurtenances. In its fully descended position, the pail fits into the sleeve uniformly along its length and pail appurtenances protrude through slots and cutouts. Four 2-inch slots extending 18.4 inches from the sleeve top are located on the octagon diagonals, and two 18-inch cutouts extending 24 inches from the sleeve

top are located on the long octagon flats. The bottom of the pail shell has existing gaps by which water will be expelled when the pail is lowered (or it drops). The total area for venting of water from the shell is a free parameter for design basis and hypothetical accident consideration.

A hypothetical drop transient begins with the pail in its fully ascended position and zero initial velocity. The pail accelerates downward and displaces water from the sleeve to the basin primarily through the side vents (the slots and cutouts) and any bottom vent at first. As the pail moves downward, however, the side vent area becomes covered and only the pail-shell gap and bottom vent remain for water expulsion. After 18 inches of travel (24 inches of side cutout length minus 6 inches of initial pail engagement in the sleeve) water displaced by the pail must all flow through the gap between pail and sleeve. Pressure builds up under the pail when it first begins to move downward, and the value of the pressure is equal to the driving pressure required to displace water through the combination of gap, side, and bottom vent areas. Thus the pressure beneath the pail depends upon the pail velocity, which sets the rate of water displacement, and total vent area, which sets the velocity of water being displaced. The driving pressure is also proportional to the friction and form loss coefficients along the flow path of displaced water.

Table 1 contains geometry and parameter data used in this analysis.

A design feature to reduce the maximum pressure, and yet maintain a sufficiently low strike velocity, is to tailor the side and bottom vent area of the sleeve. As the transient description above implies, side venting can decrease the pressure beneath the pail, but at the expense of allowing a larger velocity. Side vent areas become blocked as the pail falls, but any side vent reduces the distance that gap water must travel, and thereby reducing the friction pressure drop contribution. Bottom vent area is only occluded just before touchdown. These factors will be balanced in the calculations below to arrive at suitable values and distributions of side vent and bottom area.

After analysis of several possible geometries, the apparently easiest design requires no change in the planned side venting (i.e., retain existing slots for appurtenances) but addition of bottom ventilation only. This merely requires the pail sleeve to be supported by feet at its bottom so as to provide the vent area employed in the present analysis. This design solution is not unique and other designs could accomplish the same goals, i.e. simultaneous minimization of overpressure across the sleeve and strike velocity.

3.0 MODEL DESCRIPTION

The equation of motion for the pail is

$$a = g - \frac{A_p}{M_p} \Delta P \quad (1)$$

where a = Acceleration, m/s^2 ,

g = Acceleration of gravity $9.81 m/s^2$,

A_p = Piston (pail) area, m^2 ,

M_p = Piston (pail) mass, kg, and

ΔP = Pressure difference across sleeve, Pa.

The pressure in the cavity beneath the pail is determined by a momentum balance on water displaced from the pail as described above. The pressure drop between the pail and basin ambient is very nearly the same for gap, side vent, and bottom vent flowpaths, with the only difference being the static head of water which varies along the length of the pail shell. This term (about 0.4 atm or 6 psig) is small compared with pressure drops resulting from fluid acceleration as will be seen below, and can be neglected in the formulation. The pressure drop across each flow area is given by:

$$\Delta P_g = (1 + f \frac{x}{D} + K_e) \frac{\rho}{2} U_g^2 = C_g \frac{\rho}{2} U_g^2 \quad (2)$$

$$\Delta P_s = (1 + K_e) \frac{\rho}{2} U_s^2 = C_s \frac{\rho}{2} U_s^2 \quad (3)$$

$$\Delta P_b = (1 + K_e) \frac{\rho}{2} U_b^2 = C_b \frac{\rho}{2} U_b^2 \quad (4)$$

where f = Friction factor,

D_h = Hydraulic diameter, m,

K_e = Exit coefficient,

ρ = Water density, kg/m³,

U = Velocity, m/s,

C = Overall loss coefficient, and

g,s,b = Gap, side, and bottom vent respectively.

A mass balance on water displaced by the piston, equal to the total vented flow, yields:

$$A_p U_p = A_g U_g + A_s(x) U_s + A_b U_b \quad (5)$$

where A is the flow area and x is the downward penetration distance of the pail. The pail velocity is dx/dt and the acceleration a is the time derivative of pail velocity.

Equations (2) to (5) are rearranged to solve for the gap flow velocity:

$$U_g = \frac{A_p U_p}{A_g + (A_s + A_b) \sqrt{C_g / C_b}} \quad (6)$$

The position and velocity of the pail are known quantities at all times, and are equal to zero at the beginning of the drop. Given the pail velocity, the gap velocity is found via (6) and substituted into (2) to yield the pressure drop. The pressure drop in turn is substituted into (1) to yield the acceleration. The time derivative of position is velocity, and the time derivative of velocity is acceleration, and these are integrated to update position and velocity until the pail strikes bottom.

4.0 TRANSIENT RESULTS

Results are presented here for a bottom vent area equivalent to a gap of 1.5 inches around the periphery of the pail sleeve. This design was found to minimize the pressure increase in the sleeve when the pail accelerates after its release and decelerates when side vents are covered. Extending side vents and tailoring area versus distance was found to prolong the acceleration phase and increase pail maximum velocities without reducing maximum pressure as much as simply adding extra bottom ventilation alone. Bottom ventilation alone was chosen as the easiest possible alternative. Two pail-sleeve gap thicknesses, 1/4" and 1/2", are investigated to bound the possible range in fabrication.

Key output parameters are the strike velocity when the pail contacts the bottom of the sleeve, because this determines the dynamic load of impact, and the maximum pressure difference between across the sleeve, because this may lead to sleeve deformation. Numerical results are listed in the summary section at the beginning of this memorandum.

Detailed graphical results are presented in Figures 1 and 2 for the 1/4" and 1/2" gap cases respectively. Two plots are shown per figure, with the upper plot containing position in meters (dotted line), velocity in meters per second (solid line), and acceleration in negative G's (multiples of -9.81 m/s^2 , dashed line); the sign for acceleration is chosen for ease of plotting. The lower plot contains the pail cavity pressure in atmospheres and includes the gauge reference value at the top of the sleeve.

The pail and contents accelerate after release while water is vented out the side, but acceleration decreases continually as the cavity pressure increases. The cavity pressure initially increases because the pail velocity increases and the flow area decreases. Cavity pressure and pail acceleration pass through a maximum before the side vents are completely cleared, and about when the side vents are covered, a quasi-steady velocity is attained. In the quasi-steady phase, pail velocity decreases somewhat with time as friction along the pail-sleeve gap increases with penetration distance.

The design objective, to minimize overpressure of the sleeve and maintain a relatively low bottom strike velocity, is met by the bottom ventilation area investigated here.

MEMO: Immersion Pail
Drop Into Pail Nest/Sleeve

Table 1: Parameter Values for Cask Drop into Pail Nest. (Values in British units given, values in SI used.)			
1.0 Geometry			
Sleeve interior height below pail	L	159 in.	4.039m
Piston (pail) cross-sectional area	A _p	1934 sq. in.	1.248 m ²
Gap thickness nominal	g	1/4 in.	6.35mm
Gap hydraulic diameter (nominal)	D _h	1/2 in.	13mm
Slot height (6" engagement)	L ₁	12.4 in.	0.315m
Slot width		2 in.	0.05m
Cutout height (6" engagement)	L ₂	22 in.	0.559m
Cutout width		18 in.	0.457m
Initial total vent area	A _v		0.575m ²
Bottom vent area (1.5" gap)	A _b		0.157m ²
2.0 Masses			
MCO plus contents		20,160 lbs.	9,164 kg
Cask plus water gap		38,260 lbs.	16,740 kg
Total piston mass	m _p		29,500 kg
3.0 Parameters			
Water density	p _w		1,000 kg/m ³
Friction factor	f		0.02
Loss coefficient	K _a		0.05
Acceleration of gravity	g		9.81 m/s ²

Figure 1:
Transient pail drop results, 1/4 inch gap, 1.5 inch bottom vent

Pail + MCO + Cask Drop into Pail Shell; 1/4" Perimeter Gap, 1.5" Bottom Gap.

Figure 2
Transient pail drop results, 1/2 inch gap, 1.5 inch bottom vent.

Pail + MCO + Cask Drop into Pail Shell: 1/2" Perimeter Gap, 1.5" Bottom Gap.

Case 3: Cask+MCO into minimally-filled pail: Just enough water to fill gap - 5 ft - Moving Pail

Initial position and velocity, 4 ft free fall: $x_o := 0$ $v_o := \sqrt{2 \cdot g \cdot 60 \cdot 0.0254}$ $v_o = 5.468$

Initial water depth, derived air mass: $H := 0.999 \cdot H_{fill}$ $H = 0.371$
 $Ma := fMa(H)$ $Ma = 3.485$

Restate piston mass, fric factor, loss coef: $M_p = 2.59 \cdot 10^4$ $f = 0.02$ $K_e = 1.5$

Integration Phase 1: Up to water contact

End calculation when bottom struck: $Lend := L - H$

State vector and integration: $X := [x_o \ v_o \ Ma \ 0 \ 0 \ H \ M_p \ f \ K_e \ 3600 \ 0 \ Lend]^T$

$Imax := 500$ $Y := Rkadapt(X, 0, 1, Imax, F)$ $i := 0..Imax$

Rename outputs for convenience: $t_i := (Y^{<0>})_i$ $S_i := (Y^{<1>})_i$ $U_i := (Y^{<2>})_i$ $MG_i := (Y^{<3>})_i$

Acceleration in G's: $j := 0..N$ $XX_{j,i} := Y_{i,j+1}$ $A_i := -F(t_i, XX^{<i>})_1 \cdot \frac{1}{g}$

Pressure in atm: $PG_i := fP(S_i, 0, U_i, 0, MG_i, H, f, K_e) \cdot 10^{-5}$

For plots limit index to strike time: $lendl := fl(S, 0.999 \cdot Lend)$ $PG_{lendl} = 12.487$ $lendl = 228$

Initialize: $t1 := 0$ $S1 := 0$ $U1 := 0$ $A1 := 0$ $PG1 := 0$ $SP1 := 0$ $UP1 := 0$ $AP1 := 0$

$i := 0..lendl - 1$ $t1_i := t_i$ $S1_i := S_i$ $U1_i := U_i$ $A1_i := A_i$ $PG1_i := PG_i$
 $SP1_i := 0$ $UP1_i := 0$ $AP1_i := 0$

Integration phase 2: Water Impact $j := 0..N$ $X_j := XX_{j,lendl}$ $t0 := t_{lendl}$

$S_{lendl} = 3.284$ $L - H = 3.286$ $(L - H - S_{lendl}) \cdot (U_{lendl})^{-1} = 3.577 \cdot 10^{-4}$ $te := t0 + 0.001$

$Lend := L$ $X_N := Lend$ $Imax := 10$ $Y := rkfixed(X, t0, te, Imax, F)$ $i := 0..Imax$

Rename outputs for convenience: $t_i := (Y^{<0>})_i$ $S_i := (Y^{<1>})_i$ $U_i := (Y^{<2>})_i$ $MG_i := (Y^{<3>})_i$

Acceleration in G's: $j := 0..N$ $XX_{j,i} := Y_{i,j+1}$ $A_i := -F(t_i, XX^{<i>})_1 \cdot \frac{1}{g}$

Pail params's: $SP_i := (Y^{<4>})_i$ $UP_i := (Y^{<5>})_i$ $AP_i := F(t_i, XX^{<i>})_4 \cdot \frac{1}{g}$

Pressure in atm: $PG_i := fP(S_i, SP_i, U_i, UP_i, MG_i, H, f, K_e) \cdot 10^{-5}$

Plots for this group: $lendl2 := Imax$ $PG_{lendl2} = 34.95$

Initialize: $t2 := 0$ $S2 := 0$ $U2 := 0$ $A2 := 0$ $PG2 := 0$ $SP2 := 0$ $UP2 := 0$ $AP2 := 0$

File: drop-caskinpail-C.mcd Date:
5/26/99 Page: 12

Hanford SNFP

$i := 0..lend2 - 1$ $t2_i := t_i$ $S2_i := S_i$ $U2_i := U_i$ $A2_i := A_i$ $PG2_i := PG_i$
 $SP2_i := SP_i$ $UP2_i := UP_i$ $AP2_i := AP_i$

Integration phase 3: Post-Impact

$j := 0..N$ $X_j := XX_{j,lend2}$ $t0 := t_{lend2}$

$Lend := L$ $X_N := Lend$ $Imax := 500$ $Y := Rkadapt(X, t0, 1, Imax, F)$ $i := 0..Imax$

Rename outputs for convenience: $t_i := (Y^{<0>})_i$ $S_i := (Y^{<1>})_i$ $U_i := (Y^{<2>})_i$ $MG_i := (Y^{<3>})_i$

Acceleration in G's: $j := 0..N$ $XX_{j,i} := Y_{i,j+1}$ $A_i := -F(t_i, XX^{<1>})_1 \cdot \frac{1}{g}$

Pail params's: $SP_i := (Y^{<4>})_i$ $UP_i := (Y^{<5>})_i$ $AP_i := F(t_i, XX^{<1>})_4 \cdot \frac{1}{g}$

Pressure in atm: $PG_i := fP(S_i, SP_i, U_i, UP_i, MG_i, H, f, K_e) \cdot 10^{-5}$

Plots for this group: $lend3 := fl(S, 0.999 \cdot Lend)$ $lend3 = 53$ $PG_{lend3} = 4.099$

Initialize: $t3 := 0$ $S3 := 0$ $U3 := 0$ $A3 := 0$ $PG3 := 0$ $SP3 := 0$ $UP3 := 0$ $AP3 := 0$

$i := 0..lend3$ $t3_i := t_i$ $S3_i := S_i$ $U3_i := U_i$ $A3_i := A_i$ $PG3_i := PG_i$
 $SP3_i := SP_i$ $UP3_i := UP_i$ $AP3_i := AP_i$

Assemble Plot Vectors:

$t := \text{stack}(\text{stack}(t1, t2), t3)$ $S := \text{stack}(\text{stack}(S1, S2), S3)$ $U := \text{stack}(\text{stack}(U1, U2), U3)$

$A := \text{stack}(\text{stack}(A1, A2), A3)$ $PG := \text{stack}(\text{stack}(PG1, PG2), PG3)$

$SP := \text{stack}(\text{stack}(SP1, SP2), SP3)$ $UP := \text{stack}(\text{stack}(UP1, UP2), UP3)$ $AP := \text{stack}(\text{stack}(AP1, AP2), AP3)$

$Imax := lendl + lend2 + lend3$ $i := 0..Imax$ $SW_i := L - H$

Maximum pressure, acceleration, and final strike velocity, SI (top) and BR units (bottom):

$\max(PG) = 38.875$ $\max(A) = 10.961$ $U_{Imax} = 5.945$

$\max(PG) \cdot 14.6 = 567.581$ $U_{Imax} \cdot 3.28 = 19.501$

Unit note: Pressure in atm (psi), acceleration in G's, velocity in m/s (ft/s).

Time of contact: $Icon := fl(S - 0, L - H)$ $Icon = 232$ $L - H = 3.286$ $S_{Icon} = 3.287$ $t_{Icon} = 0.456$

Pressure at contact: $PG_{Icon-1} = 12.563$ $PG_{Icon} = 38.875$ $U_{Icon} = 7.38$

$fPg(S_{Icon}, 0, MG_{Icon}, H) \cdot 10^{-5} = 8.545$ $A_c \cdot A_g^{-1} = 9.846$

$\frac{1}{2} \cdot \rho \cdot w \cdot \left(\frac{A_c}{A_g}\right)^2 \cdot (U_{Icon} - 0)^2 \cdot 10^{-5} = 26.399$

MCO + Cask Drop into Minimally Wet Immersion Pail - 5 ft free fall - Moving Pail + IPSS[†] Upper:
Cask Dynamics and Pressure History

MCO + Cask Drop into Minimally Wet Immersion Pail - 5 ft free fall - Moving Pail + IPSS Upper:
Pail Dynamics

$$\begin{array}{r}
 2462.5853 \\
 1935.2320 \\
 140.7956(2) \\
 \hline
 245.7621 = 1.7067 \text{ SQ FT}
 \end{array}$$

APPENDIX H

IPSS Impact Limiter Scoping Calculations

PURPOSEBY D.L. KOREIS 6/17/99
CHECKED: D. Wood 6/18/99

THIS CALC DETERMINES THE SIZE OF CRUSHABLE FOAM UNDER THE IPSS. THIS FOAM IS SIZED TO TAKE A 62000# CASK DROP ONTO TWO LEGS OF THE IPSS FROM A DISTANCE OF 3.67 FT. (SEE APPENDIX D PP 6-41 TABLE 3-1)

SUMMARY OF RESULTS

THE 62000# CASK DROP OF 3.67' ON TO TWO LEGS OF THE IPSS REQUIRES 11 1/2" OF FOAM ^{DEPTH} TO KEEP THE FLOOR LOAD ON THE SLOP TO LESS THAN 600 KIPS.

THE 11 1/2" OF FOAM DEPTH GIVES A "G" DECELERATION OF 8.8 G'S WHICH RESULTS IN A 545 KIP FLOOR LOAD.

THEREFORE THE FLOOR LOAD IS WITHIN ACCEPTABLE LEVELS FOR A TWO LEG IPSS CASK DROP

DAY 6/18/99

DISCUSSION

THE FOLLOWING FIG. #1 SHOWS THE ORIENTATION OF THE FOAM UNDER THE IPSS WHICH IS LOCATED IN THE 10SK SLOP.

FIGURE 1.0

THE 62000# CASK DROPS ON TWO LEGS OF THE IPSS. THIS CALC ASSUMES A UNIFORM CRUSH OVER THE SURFACE OF THE FOAM SINCE THE IPSS IS ESSENTIALLY GUIDE BY THE SLOP CASK RAILS.

THIS CALC IS BASED ON THE "GENERAL PLASTICS CAT. FOR {FR-3700
LAST-A-FOAM }

APPROPRIATE CAT. DATA IS ATTACHED TO THIS CALC.

LAST-A-FOAM® FR-3700 DYNAMIC IMPACT APPLICATIONS

The designer of impact absorbing devices who wishes to use LAST-A-FOAM® FR-3700 can quickly determine a target foam density by using conservation of energy equations combined with packaging constraints and the energy absorbing efficiency (J) of the foam to arrive at the required foam volume and density. A typical approach is to focus on the peak acceleration (or deceleration) experienced during the design impact. This acceleration is frequently expressed in terms of a multiple of the acceleration of gravity (g) and labeled (G). Allowing for the energy absorbing efficiency of the foam (J) produces (G') the predicted peak acceleration. The following example was developed from an actual application:

A 10 in. diameter, 700 lb object falls 30 ft. onto a 5 in. foam pad.

What foam density would be recommended?

What is the maximum predicted G?

h1=30'

LAST-A-FOAM

h2=5"

From conservation of energy;

$$m \cdot g \cdot h_1 = m \cdot G \cdot h_2$$

$$G = h_1/h_2 \cdot g \text{ (theoretical)}$$

$$G' = J \cdot G$$

$$G' = 3 \times \frac{30(12)}{5} = 216g$$

Where G' is actual and J is deceleration efficiency factor of foam (from 2.5 to 3 for FR-3700).¹

Next determine volume of foam absorbing the impact. In this illustration simply assume that the area of the falling mass will be stopped by a like area of foam times thickness. The kinetic energy at point of impact is:

$$700 \text{ lb} \times 30 \text{ ft} = 21,000 \text{ lb-ft} \text{ Which will be absorbed by;}$$

$$\pi (5'')(5'')(5'') = 392.7 \text{ cu in. of foam at an energy density of;}$$

$$\epsilon p = 21,000 / 392.7 = 53.5 \text{ lb-ft/cu in.}$$

Entering the chart next page at $\epsilon p = 53.5 \text{ lb-ft/cu in}$ we find density possibilities range from

10.8 to 16.7 lb/cu ft with 13 lb/cu ft expected to give optimum performance.

The data and chart on the following page were derived from empirical test results of FR-3700 falling pendulum impact tests. The tests were designed to exercise the foam to a reasonable level to avoid "lock up" (foam density approaching that of the solid polymer).. The column displaying strain (%) shows an inverse relationship between strain and density and represents General Plastics best estimate of the optimum levels of strain for the given density. The chart can be used to choose trial densities of LAST-A-FOAM® FR-3700 for impact absorbing applications. Around the optimum there is a wide range of impact situations where the foam will perform satisfactorily although we would expect G' to be higher.

10/9/90
F. HENRY

The upper and lower bounds of the chart are an estimate of the useable range of foam densities to absorb a particular impact. All tests were conducted on unconfined samples with equal aspect ratios ($H=L=W$). Other conditions may produce different results. Confined samples could be expected to absorb more energy per unit volume with subsequently higher G . The term "energy density" is the kinetic energy per unit volume absorbed by the foam.

LAST-A-FOAM FR-3700 DENSITY SELECTION
CHART FOR IMPACT PROTECTION APPLICATIONS

ρ	$\epsilon \rho$	J	STRAIN %
3	5.3	1.9	75
4	8.1	1.8	72
6	15.4	2.8	68
8	20.6	2.5	65.7
11	36.8	2.8	65.7
18	84.1	3	59.2
25	120	2.8	47.5

The "J" factor provide a comparison of the G measured from the sample to a perfect cushion which would have a J of one (1). In general the J factor increases with density. It is also possible to have a high J at any density if the system is improperly designed. For example a too soft foam may bottom out producing extremely high G. A too firm foam may not crush thereby producing high G and significant rebound. The same effect would be produced by having the load spread over too large an area of soft foam.

Dwy 6/11/89

CALC DROP ENERGY:

$$\text{DROP HEIGHT} \times \text{DASK WEIGHT} \pm \text{ENERGY OF DROP} \\ 3.67' \times 62000 \# = 227540 \text{ FT} \#$$

CALC. FOAM VOLUME

{ SEE DET: # 96 / # 97
OF 457-202
ATTACHED

$$\begin{aligned} \text{AREA DF FOAM} \\ &= 21.4 \times 26.3 - 11" \times 11" \\ &= 562.82 - 121 \\ &= 441.8 \text{ IN}^2 \end{aligned}$$

ASSUME FOAM DEPTH
OF - 11 1/2"

$$\begin{aligned} \text{VOL. FOAM} &= 441.8 \times 11.5 \\ &= 5080.7 \text{ IN}^3 \end{aligned}$$

$$\begin{aligned} 4 \text{ FOAM BLOCKS} &\rightarrow 4 \times 5080.7 \\ &= 20322 \text{ IN}^3 \end{aligned}$$

CALC ENERGY DENSITY

$$\text{EP} = \text{ENERGY DENSITY} = \frac{\text{DROP ENERGY}}{\text{VOLUME}}$$

$$\begin{aligned} \text{EP} &= \frac{227540 \text{ FT} \#}{4 \times 5080.7 \text{ IN}^3} \\ \text{EP} &= 11.2 \text{ FT} \# / \text{IN}^3 \end{aligned}$$

TARGET DENSITY FROM "GENERAL PLASTICS
CAT"

$$\begin{aligned} \rho &= 5 \# / \text{ft}^3 @ \text{EP} = 11.2 \text{ FT} \# / \text{IN}^3 \\ &(\text{SEE ATTACHED CHART}) \end{aligned}$$

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS

H-6

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NEW IPSS
RE-DESIGN

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THE CORRESPONDING "J" FACTOR
IS $\approx 1.8 + (2.8 - 1.8)/2 = 2.3$

THE RESULTING $G' = J \times \frac{\text{DROP HEIGHT}}{\text{FOAM HEIGHT}}$

$$G' = 2.3 \times \frac{3.67(12)}{11.5}$$

$$G' = 8.81$$

°° RESULTING FLOOR LOAD IS

$G' \times \text{CASK WEIGHT}$

$$= 8.81 \times 62000 = 546 \text{ KIPS}$$

$$546 \text{ KIPS} < 600 \text{ KIP} \begin{cases} \text{ALLOWABLE} \\ \text{SLOP FLOOR LOAD} \end{cases}$$

This document was too large to scan as a single document; therefore, it has been divided into smaller sections.

Section 2 of 2

Document Information

Document #	HNF-4576	Revision	0
Title	CONCEPTUAL DESIGN REPORT CASK LOADOUT SYS CASK DROP REDESIGN FOR THE IMMERSION PAIL SUPPORT STRUCTURE & OPERATOR INTERFACE PLATFORM 105K WEST BASIN PROJECT A-5 & A-6		
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Projects	K BASIN, A-5, A-6, SNF		
Other Information			

APPENDIX I

Structural Analysis of South Loadout Pit Reinforced Concrete

M & D

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Structural Analysis of the South Load Out Pit

Reinforced Concrete

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M&D Professional		CALCULATION SHEET		HNF-4576, Rev. 0	
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STRUCTURAL ANALYSIS OF THE SOUTH LOADOUT PIT REINFORCED CONCRETE

1.0 INTRODUCTION

The South Load Out Pit (SLOP) of the 100-KE and 100-KW fuel storage facilities is the staging area for loading the MCO spent fuel baskets into the Multi-Canister Overpack (MCO). For all operations within the SLOP, the MCO is contained inside the MCO Cask. The bounding weight of a fully loaded MCO/Cask combination is 62,000 lbs. If a cask drop accident should occur when the cask is over the SLOP, significant damage to the floor region of the SLOP could occur, accompanied by undesirable leakage of the basin shielding water.

Prior to lowering the MCO Cask to the bottom of the SLOP, the cask is inserted inside an immersion pail. The combined MCO/Cask and immersion pail are then lowered together to the bottom of the SLOP (combined bounding weight of 70,000 lbs.). Thus, bounding drop weights of both 62,000 and 70,000 lbs. are possible during MCO-related operations within the SLOP.

To avoid unacceptable damage to the SLOP from a drop accident, design efforts are currently underway to reduce the magnitude of the drop accident loading to the floor, using impact limiters and hydraulic dampers. The purpose of this calculation is to establish structural capacity limits for MCO-related drop accidents onto the SLOP floor. These structural capacity limits will be used as design input into the impact limiter/hydraulic damper design effort.

Although, as demonstrated below, the primary drop accident concern is the SLOP floor region, significant loading can be imparted to the SLOP walls from an eccentric drop onto one side of the immersion pail/immersion pail support structure (IPSS) assembly. The resulting horizontal loads would be transmitted to the SLOP walls through shims placed between the IPSS and the rails mounted to the SLOP walls. These horizontal drop loads could potentially combine with lateral seismic loads. The structural adequacy of the SLOP for the potential horizontal wall loads is addressed in Section 5.4 below.

2.0 SUMMARY AND CONCLUSIONS

The current drop load capacities of the SLOP reinforced concrete structure are based upon the assumption that the vertical drop loads will be transmitted to the floor through an impact limiter located between the IPSS bottom plate and SLOP floor (dimensions approximately 46" by 58"). The horizontal drop loads, associated with a seismic event and/or an eccentric drop, are assumed to be transmitted to the walls through shim plates placed between the IPSS and SLOP rails. The shims are assumed to be located at elevation 0'-0" (2' below the top of the curb), elevation -12'-6" (mid-height), and elevation -25'-0" (bottom of the pit).

Based upon the above assumptions, and other assumptions and design input described in Section 3.0, the structural capacities summarized in Table 2-1. As indicated, the calculated capacities are 450 kips for drop loads transmitted to the SLOP floor, and 117 kips for horizontal loads transmitted to the SLOP walls.

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Table 2-1 - SLOP Drop Load Capacity Summary

External Load Category	Critical Internal Load Category	Critical Location	Calculated Capacity (kips)
SLOP Floor Vertical Load	Floor/Wall Joint Vertical Load	South Wall, Adjacent to Loaded Area	450
SLOP Walls Horizontal Loads	Wall Bending Moment	South Wall, Top Center	117

3.0 DESIGN INPUT/ASSUMPTIONS

The SLOP geometry and rebar definitions are given in Drawing H-1-21072. The structural acceptance criteria is specified in Appendix B of Reference 7. The remainder of this section addresses loads, load combinations, material properties, and assumptions associated with the structural evaluations.

3.1 LOAD CONDITIONS AND LOAD COMBINATIONS

At the time of this report writing, the load path for the critical drop loads onto the SLOP floor was transferred from the Immersion Pail Support Structure (IPSS) through an impact limiter to be placed between the immersion pail bottom plate and the SLOP floor. Therefore, for establishing SLOP floor capacity limits, a uniform pressure over the foot print of the immersion pail base plate is assumed. The uniform pressure assumption is justified, in part, by the fact that tipping of the IPSS will be prevented by the addition of shim plates between the IPSS and the SLOP wall rails.

Sections C.1.1 and C.8 of Appendix C of ACI-349 state that impact loads must be combined with other loads in accordance with Section 9.1 of ACI-349. However, Section 9.1 does not include a drop load in any of the load combination equations given in Section 9.2.1. A reasonable approach is to place the cask drop accident in the same category as a safe shutdown earthquake (E_{ss}). This results in load factors of 1.0 for all loads in combination with a cask drop (ACI-349, Section 9.2.1, Equations 4 and 8). The only significant loads in Section 9.2.1 of ACI-349 to be considered in combination with a cask drop are dead weight, water pressure, and soil pressure.

Based upon experience with soil pressure on the basin walls, the wall external soil pressure loading exceeds the internal wall water pressure, resulting in bending compression on the inside surfaces at the floor/wall interface. Since the drop loading bending moments result in tension on the inside surfaces, it is conservative to ignore the resultant loading from the soil and water pressures on the pit walls. On the other hand, the water pressure on the floor adds to the drop loading bending moments and floor/wall joint tensile forces. Following the above rationale, the following load combination is used for establishing the drop load capacity:

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$$U = 1.0D + 1.0L + 1.0I,$$

where, U is the required ACI load resistance, D is the dead weight of the hardware and pit walls resting on the pit floor, L is the floor water pressure, and I is the cask drop impact loading. It is noted that it is conservative to ignore the dead weight contribution from the pit walls since the wall loading places the wall/floor joint in compression.

Notice that the above load combination for the SLOP floor does not include a seismic load contribution. The specified peak vertical ground acceleration for the 100K area is $(2/3)(0.2) = 0.133$ g's. As indicated below, the allowable drop loading g levels are an order of magnitude higher (about 7 g's) and probabilistically, the peak seismic loading would not coincide with the peak drop loading. Assuming a root-sum-square load combination for seismic and drop loading increases the 7g drop loading to only 7.002 g's. Therefore, the seismic contribution can be ignored for establishing the floor load capacity.

Lateral seismic loading to the SLOP walls are more significant than the vertical seismic loading to the floor. As mentioned in Section 1.0, lateral loading can also occur from eccentric drops. The seismic and eccentric combined lateral loads are evaluated in Section 5.4.

3.2 MATERIAL PROPERTIES

The side walls and floor of both the fuel storage basin and SLOP are encased in soil, which adds significant complexity to the SLOP structural analysis. The drop load reaction load path is sensitive to the relative stiffness of the concrete and soil. For example, for a very stiff SLOP foundation soil, a relatively high portion of the drop load would be reacted directly through the floor to the SLOP foundation soil. For a softer SLOP foundation soil, more of the drop load would be reacted at the SLOP floor/wall connection. As indicated below, the SLOP floor/wall connection is the governing location for establishing the SLOP drop load capacity. Therefore, significant attention was given to addressing the uncertainties in the soil and reinforced concrete stiffness properties, as indicated in the design input parameters discussed below.

The material properties used in the SLOP capacity calculations are listed in Table 3-1. Some explanations are in order to provide the basis for some of the material properties listed. For the concrete elastic modulus range, the lower value of 1.6×10^6 psi was obtained from the lower bound, cracked-section, 28-day design strength of 3000 psi ($E = 57,000[f_c']^{0.5}$) per Section 8.5.1 of Reference 1). An approximate cracked-section modulus reduction factor of 1/2 was used per Section 8.6.1 of the ACI Commentary (Reference 2). The upper value of concrete compressive strength of 6000 psi is based upon relatively recent limited non-destructive testing of the basin concrete (Reference 3). The upper value of 20,000 psi for the soil modulus was taken from Table 2-7 of Reference 4 for a mixture of dense sand and gravel. The lower modulus of 10,000 psi represents dense sand, taken from the same reference. The upper subgrade modulus of 250 psi/in is typical of dense sands (e.g. Table 9-1 of Reference 4) for a footing size equal to the SLOP floor. The lower value of 50 psi/in was used to provide comparable results with a solid soil model discussed in Section 4.0.

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In accordance with Appendix C of ACI 349 (Reference 1), a dynamic strength increase factor (DIF) was applied to the concrete compressive strength and reinforcing bar yield strength. From Section C.2.1 of Reference 1, DIF values of 1.25 and 1.2 were used for the concrete compressive strength and rebar yield strength, respectively.

Table 3-1 - Material Properties Used in the SLOP Capacity Calculations

Material	Property	Values Used
Concrete	Density	150 lb/ft ³
	Elastic Modulus	1.6x10 ⁶ - 4.4x10 ⁶ psi
	Poisson's Ratio	0.2
	Compressive Strength	3000 - 6000 psi
Soil	Elastic Modulus	10,000 – 20,000 psi
	Poisson's Ratio	0.3
	Subgrade Modulus	50 psi/in – 250 psi/in
Reinforcing Bar	Yield Strength	40,000 psi

3.3 ASSUMPTIONS

The following assumptions were used in the SLOP structural calculations:

1. The soil surrounding the SLOP is assumed to behave in a linearly-elastic manner. The adequacy of soil springs was justified by selecting a soil spring stiffness which bounded the results from a more rigorous model using solid soil elements.
2. For analysis simplification, the reinforced concrete structure is assumed to behave in a linear manner. The effects of concrete cracking on the section stiffness is assumed to be the same for all load levels and at all locations within the structure. The one exception to the linear behavior is the inelastic analysis using a model with elastic/plastic rebar elements at the floor/wall joint and elastic/plastic floor elements.
3. For the cask drop problem, the static capacity is assumed to be an adequate measure of the dynamic drop capacity. This position is justified, in part, by the dynamic load factor of 1.0 derived in Section 5.1. The effect of soil inertia on the SLOP structural capacity is assumed to be insignificant.

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4. SLOP geometry and rebar definitions taken from Drawing No. H-1-21072. It is assumed that the rebar has not experienced significant corrosion. This assumption is primarily based upon the fact that basin inspections have revealed no evidence of rebar corrosion (Reference 3, Table 1).

4.0 ANALYSIS APPROACH

The static capacity of the SLOP was determined by developing finite element models of the SLOP facility. The models shown in Figures 1 and 2 were developed using the ANSYS computer code. Note that both models include the transfer channel between the basin and the pit, as well as a portion of the basin. The full SLOP was modeled, due to the asymmetry created by the floor sump and also the different lengths of the basin walls modeled (to the first intersecting wall on either side of the SLOP). The Figure 1 model included the surrounding soil as an attempt to model the structural interaction of the soil and pit structure. This model was used to "bench mark" the accuracy of a simpler model using soil springs. It was also used to perform a modal analysis of the SLOP structural assembly which was used in calculating a dynamic load factor for the drop accidents.

Modeling of the soil with three-dimensional solid elements results in a relatively large model (~15,000 elements). Therefore, a second model was developed (Figure 2) which approximated the effect of the soil using soil springs on both the pit walls and floor elements. Using the Figure 1 model as a measure of adequacy in the use of soil springs, it was found that the soil spring model gave comparable results in the critical locations if a relatively low soil spring constant is used (lower bound subgrade modulus of 50 psi/in.). Having bench marked the soil spring model, the faster-running Figure 2 model was used to establish the static capacity of the SLOP for both the vertical floor loading and the horizontal wall loading. Using the simpler soil spring model permitted more refined modeling of the SLOP structure. Note, for example, the Figure 2 model includes the sump in the west end of the pit floor.

The static capacity of the SLOP was established using the American Concrete Institute (ACI) design code for reinforced concrete nuclear safety structures (ACI-349, Reference 1), as described in the acceptance criteria document reported in Reference 7. The drop loading was applied as a distributed floor pressure over the IPSS/floor impact limiter interface area.

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Figure 4-1 - SLOP Model Including Surrounding Soil Elements

Figure 4-2 - SLOP Model Using Soil Springs

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A third model of the SLOP was developed to predict deformations in the floor/wall joint. The model is similar to the Figure 4-2 model but focuses on the floor/wall joint rebar, using an elastic/plastic spar element at each rebar location in the floor/wall joint, as shown in Figure 4-3. This model was used to quantify the joint opening size versus load magnitude as input to post accident leak rate calculations.

The relatively simple ANSYS model shown in Figure 4-4 was developed to evaluate the dynamic amplification of the impact loading being transmitted to the floor through the impact limiter. Note that the eccentricity of the cask is modeled to eliminate the rotational energy portion of the energy being transmitted to the impact limiter and SLOP floor for an eccentric drop. Note also that the natural frequency of the SLOP is accounted for with an appropriate combination of mass and spring constant.

The four models introduced above were used to perform structural capacity calculations for both vertical floor loads and horizontal wall loads. Model details, including boundary conditions and loading details are described in the calculations below. The SLOP capacity for a particular loading was obtained by comparing the predicted member forces/moments with the section capacities derived in Appendix A. The section capacities are based upon standard methodology for reinforced concrete described in Chapters 10 and 11 of Reference 1.

Figure 4-3 SLOP Finite Element Model with Wall/Floor Joint Rebar Modeling

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Figure 4-4 - Eccentric Drop Model of Cask and IPSS

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5.0 CALCULATIONS

5.1 DYNAMIC DROP ANALYSIS

5.1.1 Modal Analysis

Using the embedded structure/soil model shown in Figure 4-1, a modal analysis was performed to obtain the fundamental frequency of the SLOP associated with a drop event. The first 24 frequencies were calculated. The mode shape for the lowest frequency of 10.87 hz involves the basin and SLOP moving vertically together, which would not be excited by a drop event into the SLOP. The mode shape for the second frequency of 14.8 hz is shown in Figure 5-1. Note that the mode shape is associated with a relative SLOP vertical motion ("cantilever mode"), which compares to the deformation pattern due to a drop onto the SLOP floor.

By applying a unit load to the SLOP floor in the Figure 4-1 model, an effective drop load pit stiffness of 3.6×10^6 lb/in was obtained. Using the natural frequency equation for a single degree of freedom oscillator:

$$f = \frac{1}{2\pi} \sqrt{\frac{k}{m}},$$

X

an "effective mass" of the SLOP can be obtained to match the fundamental frequency of 14.8 hz:

$$m = \frac{k}{(2\pi f)^2} = \frac{3.6 \cdot 10^6}{(2\pi \cdot 14.8)^2} = 416.3 \text{ lb} - \text{sec}^2/\text{in},$$

which corresponds to an effective weight of 161,000 lbs.

The above derived spring stiffness and mass values for the SLOP were incorporated into the simplified drop model shown in Figure 4-4. The Figure 4-4 eccentric drop model also includes a non-linear spring which represents a layer of impact limiter (structural foam) to be placed between the IPSS and SLOP floor. The structural foam was assumed to correspond to a "Last-A-Foam" material (Reference 5), which has an elastic modulus of 4900 psi. Selecting a crushing strength of 450,000 lbs (approximate floor capacity, as derived below) and a length of nine inches, an elastic stiffness of 544,000 lb/in was obtained for the non-linear spring representing the foam. A third spring, with a stiffness of 2.5×10^6 lb/in, represents two legs of the IPSS, as shown in Figure 4-4.

The Figure 4-4 model was used to obtain the dynamic response to a two-foot eccentric drop of a 60,000-lb cask. The resulting floor reaction load response is shown in Figure 5-2. Note that the peak force is only slightly higher than the 450,000 lb crushing strength of the foam, represented by the non-linear spring. This

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dynamic load factor of approximately 1.0 is consistent with the one degree of freedom oscillator response to a step function with a rise time of t_1 . Note from Figure 5-2, the rise time, t_1 , is about 0.2 sec., which is significantly longer than the fundamental period of the SLOP ($T = 1/f_n = 1/15.8 = 0.063$ sec.) For a t_1/T ratio of $0.2/0.063 = 3.2$, a dynamic load factor of about 1.1 is expected. See, for example, Figure 4.5-1 of Reference 6. Although this particular drop analysis is not necessarily representative of all of the cask drop cases, it demonstrates that the relatively soft impact limiter stiffness (elastic modulus = 4500 psi) results in relatively low dynamic load factors for cask drop loading onto the SLOP floor. For the remainder of this report, a dynamic load factor of 1.0 is assumed.

Another conclusion of interest is the percentage of drop energy going to the SLOP floor. By comparing the total drop energy (120,000 ft-lbs) with the energy transmitted to the floor spring, it was found that only 70% of the drop energy was transmitted to the floor. The remaining drop energy of remains with the cask as rotational energy.

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Figure 5-1 - SLOP Fundamental Frequency Mode Shape for Drop Loading

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Figure 5-2 - SLOP Floor Reaction Response to a Two-Foot Eccentric Drop

5.2 SLOP FLOOR CAPACITY FOR DROP LOADS—ELASTIC ANALYSIS

The structural model used for estimating the SLOP capacity for drop loads transmitted to the floor is the Figure 4-2 soil spring model. The width of the basin walls corresponds to the distance to the adjacent intersecting walls (north loadout pit and south basin wall). Thus, it is reasonably conservative to assume total horizontal fixity (x and y directions) at the edges of the basin walls. The only fixity in the vertical direction is soil springs under the basin and SLOP floors. Soil springs were also used on the basin walls and the west SLOP wall because the westward movement of these walls is resisted by the adjacent soil.

Various combinations of the material property extremes shown in Table 3-1 were run for the case of a floor pressure applied to the IPSS foot print area. For the critical location and internal load category (floor/wall joint, vertical force) the results are summarized in Table 5-1. Note that, as expected, the maximum joint force is associated with the minimum support under the floor and the maximum stiffnesses elsewhere. The

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soil and concrete stiffness values shown for the maximum case (1st case) were used for the remaining computer runs in this section to establish the drop load capacity.

Table 5-1 - Results of Structural & Soil Stiffness Variations on Wall/Floor Joint Forces

Concrete Elastic Modulus, psi	Soil Subgrade Modulus, psi/in	Soil Spring Location	Peak Joint Vertical Force, kips/in.
4.4×10^6	50	All Locations (walls & floors)	2208
1.6×10^6	250	All Locations (walls & floors)	1875

As discussed in Section 3.1, the appropriate floor load combination for establishing the floor capacity for drop loads is water pressure + dead load + drop loading. Each of these load cases were run separately. The drop loading considered was a 400 kip load applied as a pressure over the foot print area of the IPSS. The dominant loading is the drop load case, which was used to determine the critical location and internal load category.

The results for a 400 kip drop load to the SLOP floor are summarized in the contour plots shown in Figure 5-3 and Figure 5-4. Note that the higher contours occur in the floor and walls adjacent to the floor. The critical safety margins for each internal force/moment category, for drop loads alone, are shown in Table 5-2. Note that the vertical forces (TY) in the floor/wall joint (south wall) has the smallest safety margin, and is the governing category/location. The corresponding TY forces for the water pressure and dead weight loading are 126.7 lb/in and 86.9 lb/in, respectively, which correspondingly reduces the drop load capacity:

$$DropLoadCapacity = \frac{1840 - 126.7 - 86.9}{1739.2} (400) = 374 \text{ kips.}$$

Thus, the SLOP capacity for drop loads transmitted to the floor is about 370 kips.

The above capacity considers in-plane forces and moments only. A bearing stress and transverse shear check follows to assure that these stress categories do not control the capacity. Assuming a rectangular impact limiter foot print of 46 in. by 58 in., the bearing stress for a 457 kip load is

$$\sigma_{bearing} = \frac{374,000}{46(58)} = 140 \text{ psi.}$$

From Section 10.15 of Reference 1, the allowable bearing stress is

$$\sigma_{allow} = \phi(0.85)f'_c = 0.7(0.85)(3000) = 1785 \text{ psi,}$$

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which is well above the bearing stress for a 374 kip load. The punching shear stress is

$$v = \frac{F}{2(w + d + h + d)d} = \frac{374,000}{2(46 + 16.69 + 58 + 16.69)(16.69)} = 81.5 \text{ psi,}$$

which is less than the minimum allowable from Section 11.3 of Reference 1:

$$v_{allow} = 2\sqrt{f'_c} = 2\sqrt{3000} = 109.5 \text{ psi.}$$

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Figure 5-3 - Vertical Force (TY) Contours for 400 Kip Drop Load

ANSYS 5.5.1
MAY 28 1999
09:15:06
AVG ELEMENT SOLUTION
STEP=1
SUB =1
TIME=1
TY (AVG)
TOP
DMX =.178441
SMN =-1508
SMX =2163
A =-1304
B =-896.126
C =-488.227
D =-80.327
E =327.572
F =735.471
G =1143
H =1551
I =1959

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Figure 5-4 - MX (North/South Rebar) Contours for 400 Kip Drop Load

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Table 5-2 - Comparison of Design Margins for Various Internal Load Categories

Internal Load Category	Critical Location	Calculated Value ¹	Allowable ²	Design Margin ³
TX (Horizontal Forces)	Top of Channel Walls Adjacent to Basin Walls	701 lb/in	2250 lb/in	+2.21
TY (Vertical Forces)	Wall/Floor Joint in West Wall	1739 lb/in	1840 lb/in	+0.06
MX (North/South Rebar)	Under Drop Load	25,839 in-lb/in	29,400 in-lb/in	+0.14
MY (East/West Rebar)	Under Drop Load	25,948 in-lb/in	31,000 in-lb/in	+0.19

Notes:

1. Based upon an average value over four times the section thickness, in accordance with Appendix B of Reference 7.
2. From section capacity calculations provided in Appendix A.
3. Design Margin defined as (Allowable)/(Calculated Value) - 1.

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5.3 INELASTIC ANALYSIS OF THE SLOP FLOOR/WALL JOINT

The primary purpose of this section is to demonstrate the adequacy of the SLOP structural acceptance criteria (Appendix B of Reference 7) which specifies that the floor/wall joint moments can be treated as secondary due to the displacement limited response of the joint moments. This purpose is achieved by showing that the joint deformations and rebar plastic strains are very small for the drop load capacity of 450 kips calculated in Section 5.2. Loading is applied well beyond the 450 kip capacity to demonstrate the conservatism associated with the 450 kip capacity. It is also noted that the axial forces in the joint are also secondary, in the sense that as axial load yielding occurs, a redistribution of the loading occurs (wall-to-ground).

5.3.1 Finite Element Model/Loading Discussion

The finite element model used to obtain the elastic/plastic response of the floor/wall joint is shown in Figure 4-3. Elastic/plastic link elements are used to model each reinforcing bar which spans the floor/wall joint. The effective length of the joint rebar increases with load magnitude, and can be quantified by using the simplifying assumption that the rebar stress is balanced by a uniform shear stress at the O.D. of the rebar equal to the bond strength. An approximate "effective length" of rebar of 8.15 inches is used for the #5 bars in the joint, which is derived below.

Based upon the testing at the University of Illinois (Reference 8), a reasonable estimate of the bond strength of deformed bars is

$$\sigma_{bond} = 14\sqrt{f_c'},$$

where f_c' is the concrete design strength and σ_{bond} is the ultimate bond strength.

When the rebar reaches the material yield strength, the length of the distributed ultimate bond stress can be estimated by assuming that the rebar stress is balanced by a uniform shear/bond stress at the rebar periphery, equal to the above bond strength. For the uniform bond stress assumption, the rebar stress would be transferred in a linear fashion from the yield stress at the joint down to zero at the end of the balanced rebar bond strength stress. The associated length of rebar achieving the bond ultimate strength is

$$l_{eff} = \frac{\sigma_y d}{4(14\sqrt{f_c'})} = \frac{40,000(0.625)}{56\sqrt{3,000}} = 8.15 \text{ in.},$$

where σ_y is the rebar yield strength, d is the rebar diameter, and f_c' is the concrete design strength.

The actual effective rebar length varies with load magnitude, due to a progressive bond slip, which is highest near the construction joint. The higher bond slip near the joint results in a bond stress of near zero, adjacent

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to the joint, which means that upon yielding, the rebar stress does not drop below the yield stress for some finite distance from the joint. Based upon comparisons with rebar bond test load/deflection data, it is reasonable to assume an effective length of half of l_{eff} on each side of the joint, for a total effective length of l_{eff} . This approach to selecting an effective rebar modeling length at the construction joint was bench-marked by comparing the rebar model, with a constant effective length of l_{eff} deformation predictions with actual rebar bond test data, as shown in Figure 5-5. The "model" prediction shown was based upon the same geometry and material properties used in the test program (#7 rebar, $f_y = 42$ ksi, $f_c' = 5000$ psi). Note that the constant length model over predicted the rebar deformations for stresses less than 70% of the rebar yield strength, but was close when the stresses exceeded the yield strength. Thus, the effective length, l_{eff} , developed above, was used for the elastic/plastic rebar elements in the finite element model shown in Figure 4-3.

Figure 5-5 - Evaluation of Construction Joint Rebar Model Adequacy

To account for local bending moments in excess of the floor bending moment capacities, elastic/plastic plate elements were used to model the floor of the SLOP. A pseudo plate yield stress was used to simulate plastic moment achievement when the section ultimate moment, M_n , was achieved.

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Using the inelastic elements described above, the finite element model shown in Figure 4-3 was incrementally loaded with a pressure loading over an area equal to the IPSS foot print area, to various load levels, and then unloaded to obtain the residual joint opening deformations.

Inelastic Model Boundary Conditions

The load reaction path for the drop loading onto the SLOP floor is a function of the relative stiffness of the SLOP walls and the soil beneath the floor. The stiffness of the walls is influenced by the soil friction associated with the soil surrounding the SLOP walls. The approach used for modeling the soil friction follows below.

The evaluation of the SLOP wall/soil friction problem is similar to the problem of a concrete caisson in sand. See, for example, page 348 in Reference 10. The soil friction force per unit width of wall is estimated by the following formula:

$$F_f = \frac{\gamma h^2 K_o \tan \phi}{2},$$

where γ = the unit weight of the soil, h = the soil surrounding soil depth, K_o = Rankine soil pressure coefficient, and ϕ = soil friction coefficient.

To obtain a conservative estimate of the wall/floor joint opening for a given drop load, an upper bound soil friction estimate is needed. From communications with Shannon and Wilson (geotech firm, see Appendix B memo), the following upper bound values were used: $\gamma = 135 \text{ lbs/ft}^3$, $K_o = 0.5$, $\phi = 44^\circ$. The soil depth values, h , are 24.75 and 19.75 feet for the SLOP and basin, respectively. Substituting these values into the above equation yields the following friction force for the SLOP walls:

$$F_f = \frac{135(24.75)^2(0.5)\tan(44^\circ)}{2} = 19,965 \text{ lbs/ft.}$$

For the shallower basin walls, the corresponding friction force is 12,713 lbs/ft. Using frictions elements available in ANSYS (COMBIN40), the above friction forces were used to calculate the element breakaway friction (FSLIDE) values. The friction elements were placed at the resultant friction force elevation ($h/3$), as illustrated in Figure 5-6. Analysis results indicated that using the bounding soil friction approach resulted in a small percentage of the reaction load reaching the basin portion of the model. Thus, the basin model and associated boundary conditions did not have a significant effect on the results.

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Figure 5-6 - Inelastic Model Boundary Conditions

Using the inelastic model and the boundary conditions described above, the finite element model shown in Figure 4-3 was incrementally loaded with a pressure loading over an area equal to the IPSS foot print area, to various load levels, and then unloaded to obtain the residual joint opening deformations. The predicted joint deformations were used as input to the post accident leakage calculations.

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5.3.2 Elastic/Plastic Joint Analysis Results

As the floor load increases, a corresponding increase in the number of rebar yielding is predicted, as shown in Figure 5-7. Note that 87% of the rebar has yielded at a load of about 850 kips. At the 87% point, all but the eastern most line of rebar has yielded. The 850 kip load is considered to be the limit load for the wall/floor joint because loads beyond this point result in pivoting about the east re Using a strength reduction factor of 0.9, the ACI allowable "limit load" is 760 kips. The joint deformation pattern for this loading is qualitatively illustrated in Figure 5-8. Note that the maximum deformations occur near the center of the south and north walls and the minimum deformation is on the outside of the east wall. Although the maximum rebar strains are less than 1%, it is necessary to check the leak rate associated with the joint deformations to assure that allowable leak rates are not exceeded, which is addressed below.

Figure 5-7 - Joint Rebar Yielding Versus Floor Load

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The predicted joint deformation pattern is illustrated in Figure 5-8.

Figure 5-8 - Floor/Wall Joint Deformation Pattern

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The maximum and average joint opening size versus load is shown in Figure 5-9. Note that for loads in excess of 600 kips the slope of the opening/load curve significantly increases. Based upon the As shown in Reference TBD, joint leak rates allow floor loading greater than 700 kips, but a reasonable floor design limit is 600 kips.

Figure 5-9 - Wall/Joint Opening Size Versus Floor Load

Some yielding of the floor bottom rebar is predicted at the 600 k loading, indicating a potential for through cracks in the floor. However, if the reverse bending, upon unloading, does not result in yielding of the top rebar, then significant through-wall cracking is not expected. Following unloading, the residual floor moments were reviewed, and the moments producing tension on the top of the floor were found to be well below capacity. Thus, top rebar yielding is not expected.

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5.4 SLOP WALL CAPACITIES FOR HORIZONTAL LOADING

Horizontal loading to the South Load Out Pit (SLOP) walls can occur during seismic and accidental drop events. The horizontal loading is transmitted through bearing pads between the Immersion Pail Support Structure (IPSS) and the SLOP rails. The load path continues through the rails to the SLOP walls at the rail support anchor bolt/pad locations. The purpose of this section of the report is to provide a summary of the results from horizontal load prediction calculations and the corresponding SLOP wall structural calculations.

Although current plans are to provide load pads at three elevations (top, bottom, and mid-height), it was conservatively assumed that seismic horizontal reactions occur only at the top and bottom of the IPSS. The top load pads are assumed to be located at elevation 0.0 (two feet below the top of the SLOP walls), since the top few feet of the rails curve outward towards the walls.

The maximum seismic loading occurs with the fully-loaded cask and Immersion Pail (IP) positioned at the top of the SLOP, with the IP/IPSS support pins in place. The seismic horizontal loads are calculated by assuming that the cask/Immersion Pail/IPSS assembly, supported at the rail bearing pads, is relatively rigid ($f_n > 30$ Hz) resulting in a maximum horizontal acceleration equal to the maximum design basis earthquake (DBE) horizontal ground acceleration of 0.2 g's.

The bounding horizontal loads from a drop accident were obtained by assuming a maximum drop position eccentricity, which is associated with a drop onto an edge of the IP (46-inch O.D.). With the IPSS rotation prevented by the rail support pads, the IPSS will move vertically downward, with a bottom reaction centered in the middle of the IPSS, resulting in a load eccentricity of 23 inches. This load eccentricity is conservatively assumed to be reacted with a corresponding horizontal reaction couple at the top and mid-height IPSS/rail support pads.

The SLOP structural adequacy calculations were performed using the SLOP finite element model used in previous drop accident analyses (Figure 4-2). It was conservatively assumed that the seismic and drop loading coincide in direction, using a root-sum-square combination, to account for non-coinciding peak loading timing. Three load cases were considered: 1) outward load at the top of the west wall and corresponding load at the mid-height location of the east walls, 2) outward load at the top of the east walls and corresponding load at the mid-height of the west wall, and 3) outward load at the top of the south wall and corresponding load at the mid-height of the north wall. The north/south wall reverse case was not needed, i.e. the results would be the same as load case 3, due to symmetry.

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5.4.1 Load Definitions

Seismic Loading

The seismic load calculation is based upon the free body diagram shown below. Note that bounding weights of 70 kips and 12 kips are used for the cask/IP and IPSS, respectively. The top support pad reaction is obtained by taking moments about the base:

$$F_r = \frac{14(252) + 2.4(157)}{290} = 13.5 \text{ kips.}$$

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Drop Event Horizontal Loading

From the free body diagram shown below, the horizontal reaction due to an eccentric drop is

$$F_r = \frac{23(450)}{290 - 157} = 77.8 \text{ kips.}$$

Combined Loading

From the above horizontal loads, the combined seismic and drop horizontal loading at the top support pad is

$$F_{total} = \sqrt{(13.5)^2 + (77.8)^2} = 79.0 \text{ kips.}$$

5.4.2 Horizontal Load Capacity

The above load pairs were applied for the three load cases described in Section 5.4.1. The critical load case was found to be an eccentric drop load on the south edge. The critical bending moment contours for this load case are shown in Figure 1. The margin of safety for this critical load case is

$$MS = \frac{21230}{14352} - 1 = 0.48.$$

Thus, the horizontal load capacity is about $(1.48)(79) = 117$ kips.

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Figure 5-10 - Moment Contours (MX) for Horizontal Loading on the South Wall

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APPENDIX A

SLOP REINFORCED CONCRETE SECTION CAPACITIES

Objective: 1) Calculate the K Basin South Load Out Pit (SLOP) dynamic section capacities using ACI 349, Appendix C, Section C.2.1 and Drawing H-1-21072.

Input Parameters:

$f_c := 3000 \cdot \frac{\text{lb}}{\text{in}^2}$	28 day concrete design strength
$f_y := 40000 \cdot \frac{\text{lb}}{\text{in}^2}$	Minimum reinforcing bar yield strength
$\text{cov} := 2 \cdot \text{in}$	Concrete cover thickness, except pit floor bottom
$\text{cov}_b := 3 \cdot \text{in}$	Concrete cover thickness, bottom of pit floor
$\text{DIF}_c := 1.00$	Concrete dynamic increase factor for impact loading
$\text{DIF}_s := 1.00$	Reinforcing steel dynamic increase factor for impact loading
$\phi := 0.9$	ACI Code strength reduction factor, bending and tension

North, East, and South SLOP Walls (Including Basin Channel Walls):**Vertical Steel (#5 @ 12", both faces):****Bending Capacity**

$$d_b := 0.625 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.307 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{wall}} := 16 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - d_b - \frac{d_b}{2} \quad d = 13.063 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.401 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right)$$

$$M_{\text{cap}} = 1.184 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Tension Capacity:

$$d_{bi} := 0.625 \cdot \text{in}$$

$$A_s := 2 \cdot \pi \cdot \frac{d_{bi}^2}{4 \cdot \text{ft}}$$

$$A_s = 0.614 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$T_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s$$

$$T_{\text{cap}} = 2.209 \cdot 10^4 \cdot \frac{\text{lb}}{\text{ft}} \quad T_{\text{cap}} = 1.841 \cdot 10^3 \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Bottom 7.5 feet of Inside Surface (#6@12"): Bending Capacity

$$d_b := 0.75 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.442 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{wall}} := 16 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - \frac{d_b}{2} \quad d = 13.625 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.577 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right) \quad M_{\text{cap}} = 1.768 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Remaining 20'-3" of Inside Surface (#5@12"): Bending Capacity

$$d_b := 0.625 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.307 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{wall}} := 16 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - \frac{d_b}{2} \quad d = 13.688 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.401 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right) \quad M_{\text{cap}} = 1.241 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Bottom 7.5 feet of Outside Surface (#8@12"): Bending Capacity

$$d_b := 1.00 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.785 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{wall}} := 16 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - \frac{d_b}{2} \quad d = 13.5 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 1.027 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right) \quad M_{\text{cap}} = 3.06 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Middle 8-ft. of Outside Surface (#7@12"): Bending Capacity

$$d_b := 0.875 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.601 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{wall}} := 16 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - \frac{d_b}{2} \quad d = 13.563 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.786 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right) \quad M_{\text{cap}} = 2.376 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Top 10'-3" of Outside Surface (#6@12"): Bending Capacity

$$d_b := 0.75 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.442 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{wall}} := 16 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - \frac{d_b}{2} \quad d = 13.625 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.577 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right) \quad M_{\text{cap}} = 1.768 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Bottom 7.5 ft., Both Surfaces, Tension Capacity (#6 & #8 @ 12"):

$$d_{bi} := 0.75 \cdot \text{in}$$

$$d_{bo} := 1.00 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_{bi}^2}{4 \cdot \text{ft}} + \frac{\pi \cdot d_{bo}^2}{4 \cdot \text{ft}}$$

$$A_s = 1.227 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$T_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s$$

$$T_{\text{cap}} = 4.418 \cdot 10^4 \cdot \frac{\text{lb}}{\text{ft}} \quad T_{\text{cap}} = 3.682 \cdot 10^3 \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Middle 8.0 ft., Both Surfaces, Tension Capacity (#5 & #7 @ 12"):

$$d_{bi} := 0.625 \cdot \text{in}$$

$$d_{bo} := 0.875 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_{bi}^2}{4 \cdot \text{ft}} + \frac{\pi \cdot d_{bo}^2}{4 \cdot \text{ft}}$$

$$A_s = 0.908 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$T_{cap} := \phi \cdot A_s \cdot f_y \cdot DIF_s$$

$$T_{cap} = 3.269 \cdot 10^4 \cdot \frac{\text{lb}}{\text{ft}} \quad T_{cap} = 2.724 \cdot 10^3 \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Top 10'-3", Both Surfaces, Tension Capacity (#5 & #6 @ 12"):

$$d_{bi} := 0.625 \cdot \text{in}$$

$$d_{bo} := 0.75 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_{bi}^2}{4 \cdot \text{ft}} + \frac{\pi \cdot d_{bo}^2}{4 \cdot \text{ft}}$$

$$A_s = 0.749 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$T_{cap} := \phi \cdot A_s \cdot f_y \cdot DIF_s$$

$$T_{cap} = 2.695 \cdot 10^4 \cdot \frac{\text{lb}}{\text{ft}} \quad T_{cap} = 2.246 \cdot 10^3 \cdot \frac{\text{lb}}{\text{in}}$$

West Wall:**Vertical Steel (#5 @ 12", both faces):****Bending Capacity**

$$d_b := 0.625 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.307 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{wall}} := 17.75 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - d_b - \frac{d_b}{2} \quad d = 14.813 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.401 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right)$$

$$M_{\text{cap}} = 1.345 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Tension Capacity:

$$d_{bi} := 0.625 \cdot \text{in}$$

$$A_s := 2 \cdot \pi \cdot \frac{d_{bi}^2}{4 \cdot \text{ft}}$$

$$A_s = 0.614 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$T_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s$$

$$T_{\text{cap}} = 2.209 \cdot 10^4 \cdot \frac{\text{lb}}{\text{ft}} \quad T_{\text{cap}} = 1.841 \cdot 10^3 \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Bottom 7.5 feet of Inside Surface (#6@12"): Bending Capacity

$$d_b := 0.75 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.442 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{wall}} := 17.75 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - \frac{d_b}{2} \quad d = 15.375 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.577 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right) \quad M_{\text{cap}} = 1.999 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Remaining 20'-3" of Inside Surface (#5@12"): Bending Capacity

$$d_b := 0.625 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.307 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{wall}} := 17.75 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - \frac{d_b}{2} \quad d = 15.438 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.401 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right) \quad M_{\text{cap}} = 1.402 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Bottom 7.5 feet of Outside Surface (#8@12"): Bending Capacity

$$d_b := 1.00 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.785 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{wall}} := 17.75 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - \frac{d_b}{2} \quad d = 15.25 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 1.027 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right) \quad M_{\text{cap}} = 3.472 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Middle 8-ft. of Outside Surface (#7@12"): Bending Capacity

$$d_b := 0.875 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.601 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{wall}} := 17.75 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - \frac{d_b}{2} \quad d = 15.313 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.786 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right) \quad M_{\text{cap}} = 2.691 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Top 10'-3" of Outside Surface (#6@12"): Bending Capacity

$$d_b := 0.75 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.442 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{wall}} := 17.75 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - \frac{d_b}{2} \quad d = 15.375 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.577 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right) \quad M_{\text{cap}} = 1.999 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Bottom 7.5 ft., Both Surfaces, Tension Capacity (#6 & #8 @ 12"):

$$d_{bi} := 0.75 \cdot \text{in}$$

$$d_{bo} := 1.00 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_{bi}^2}{4 \cdot \text{ft}} + \frac{\pi \cdot d_{bo}^2}{4 \cdot \text{ft}}$$

$$A_s = 1.227 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$T_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s$$

$$T_{\text{cap}} = 4.418 \cdot 10^4 \cdot \frac{\text{lb}}{\text{ft}} \quad T_{\text{cap}} = 3.682 \cdot 10^3 \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Middle 8.0 ft., Both Surfaces, Tension Capacity (#5 & #7 @ 12"):

$$d_{bi} := 0.625 \cdot \text{in}$$

$$d_{bo} := 0.875 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_{bi}^2}{4 \cdot \text{ft}} + \frac{\pi \cdot d_{bo}^2}{4 \cdot \text{ft}}$$

$$A_s = 0.908 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$T_{cap} := \phi \cdot A_s \cdot f_y \cdot DIF_s$$

$$T_{cap} = 3.269 \cdot 10^4 \cdot \frac{\text{lb}}{\text{ft}} \quad T_{cap} = 2.724 \cdot 10^3 \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Top 10'-3", Both Surfaces, Tension Capacity (#5 & #6 @ 12"):

$$d_{bi} := 0.625 \cdot \text{in}$$

$$d_{bo} := 0.75 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_{bi}^2}{4 \cdot \text{ft}} + \frac{\pi \cdot d_{bo}^2}{4 \cdot \text{ft}}$$

$$A_s = 0.749 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$T_{cap} := \phi \cdot A_s \cdot f_y \cdot DIF_s$$

$$T_{cap} = 2.695 \cdot 10^4 \cdot \frac{\text{lb}}{\text{ft}} \quad T_{cap} = 2.246 \cdot 10^3 \cdot \frac{\text{lb}}{\text{in}}$$

Pit Floor Slab:

Steel Definition: #7 @ 12" each way, each face

Bending Capacity, tension @ top, north/south steel:

$$d_b := 0.875 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.601 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{floor}} := 21 \cdot \text{in}$$

$$d := t_{\text{floor}} - \text{cov} - d_b - \frac{d_b}{2} \quad d = 17.688 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.786 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right)$$

$$M_{\text{cap}} = 3.12 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Bending Capacity, tension @ bottom, north/south steel:

$$d_b := 0.875 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.601 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{floor}} := 21 \cdot \text{in}$$

$$d := t_{\text{floor}} - \text{cov}_b - d_b - \frac{d_b}{2} \quad d = 16.688 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.786 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right)$$

$$M_{\text{cap}} = 2.939 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Bending Capacity, tension @ top, east/west steel:

$$d_b := 0.875 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.601 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{floor}} := 21 \cdot \text{in}$$

$$d := t_{\text{floor}} - \text{cov} - \frac{d_b}{2} \quad d = 18.563 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.786 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right)$$

$$M_{\text{cap}} = 3.278 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Bending Capacity, tension @ bottom, east/west steel:

$$d_b := 0.875 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.601 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{floor}} := 21 \cdot \text{in}$$

$$d := t_{\text{floor}} - \text{cov}_b - \frac{d_b}{2} \quad d = 17.563 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.786 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right)$$

$$M_{\text{cap}} = 3.097 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Stub Wall Between Channel Floor and SLOP Floor:

Steel Definition: #7 @ 12", each way, each face

Bending Capacity, horizontal steel:

$$d_b := 0.875 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.601 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{wall}} := 24 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - d_b - \frac{d_b}{2} \quad d = 20.688 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.786 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right) \quad M_{\text{cap}} = 3.661 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Bending Capacity, vertical steel:

$$d_b := 0.875 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot ft} \quad A_s = 0.601 \cdot \frac{in^2}{ft}$$

$$t_{wall} := 24 \cdot in$$

$$d := t_{wall} - cov - \frac{d_b}{2} \quad d = 21.563 \cdot in$$

$$a := \frac{A_s \cdot f_y \cdot DIF_s}{0.85 \cdot f_c \cdot DIF_c} \quad a = 0.786 \cdot in$$

$$M_{cap} := \phi \cdot A_s \cdot f_y \cdot DIF_s \cdot \left(d - \frac{a}{2} \right) \quad M_{cap} = 3.819 \cdot 10^4 \cdot in \cdot \frac{lb}{in}$$

Tension Capacity, vertical & horizontal steel:

$$T_{cap} := \phi \cdot 2 \cdot A_s \cdot f_y \cdot DIF_s$$

$$T_{cap} = 4.33 \cdot 10^4 \cdot \frac{lb}{ft} \quad T_{cap} = 3.608 \cdot 10^3 \cdot \frac{lb}{in}$$

Channel Floor Slab:

Steel Definition: #6 @ 12" each face (north/south), #8 @ 6.5" (east/west top),
#7 @ 12" (east/west bottom)

Bending Capacity, tension @ top, north/south steel:

$$d_b := 0.75 \cdot in$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot ft} \quad A_s = 0.442 \cdot \frac{in^2}{ft}$$

$$t_{floor} := 24 \cdot in$$

$$d := t_{floor} - cov - d_b - \frac{d_b}{2} \quad d = 20.875 \cdot in$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.577 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right)$$

$$M_{\text{cap}} = 2.728 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Bending Capacity, tension @ bottom, north/south steel:

$$d_b := 0.75 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.442 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{floor}} := 24 \cdot \text{in}$$

$$d := t_{\text{floor}} - \text{cov}_b - d_b - \frac{d_b}{2} \quad d = 19.875 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.577 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right)$$

$$M_{\text{cap}} = 2.596 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Bending Capacity, tension @ top, east/west steel:

$$d_b := 1.00 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.785 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{floor}} := 24 \cdot \text{in}$$

$$d := t_{\text{floor}} - \text{cov} - \frac{d_b}{2} \quad d = 21.5 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 1.027 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right)$$

$$M_{\text{cap}} = 4.945 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Bending Capacity, tension @ bottom, east/west steel:

Conservatively ignore increased floor thickness at tapered section.

$$d_b := 0.875 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.601 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{floor}} := 24 \cdot \text{in}$$

$$d := t_{\text{floor}} - \text{cov}_b - \frac{d_b}{2} \quad d = 20.562 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.786 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right)$$

$$M_{\text{cap}} = 3.638 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Notched Wall Capacities:**West Wall Notch (8" wide, 7" deep)****Horizontal Steel, Bottom 7.5 feet of Inside Surface (#6@12"):****Bending Capacity**

$$d_b := 0.75 \cdot \text{in}$$

$$A_s := \frac{2 \cdot \pi \cdot d_b^2}{4 \cdot \text{ft}}$$

$$A_s = 0.884 \cdot \frac{\text{in}^2}{\text{ft}}$$

Note: Double area used to account for rebar overlap at notch > 2 times the bar development length.

$$t_{\text{wall}} := 17.75 \cdot \text{in} - 7 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - \frac{d_b}{2} \quad d = 8.375 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 1.155 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right) \quad M_{\text{cap}} = 2.067 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Remaining 20'-3" of Inside Surface (#5@12"):**Bending Capacity**

$$d_b := 0.625 \cdot \text{in}$$

$$A_s := \frac{2 \cdot \pi \cdot d_b^2}{4 \cdot \text{ft}}$$

$$A_s = 0.614 \cdot \frac{\text{in}^2}{\text{ft}}$$

Note: Double area used to account for rebar overlap at notch > 2 times the bar development length.

$$t_{\text{wall}} := 17.75 \cdot \text{in} - 7 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - \frac{d_b}{2} \quad d = 8.438 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.802 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right) \quad M_{\text{cap}} = 1.479 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Bottom 7.5 feet of Outside Surface (#8@12"): Bending Capacity

$$d_b := 1.00 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.785 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{wall}} := 17.75 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - \frac{d_b}{2} \quad d = 15.25 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 1.027 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right) \quad M_{\text{cap}} = 3.472 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Middle 8-ft. of Outside Surface (#7@12"): Bending Capacity

$$d_b := 0.875 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.601 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{wall}} := 17.75 \cdot \text{in} - 7 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - \frac{d_b}{2} \quad d = 8.312 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.786 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right) \quad M_{\text{cap}} = 1.429 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Top 10'-3" of Outside Surface (#6@12"): Bending Capacity

$$d_b := 0.75 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.442 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{wall}} := 17.75 \cdot \text{in} - 7 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - \frac{d_b}{2} \quad d = 8.375 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.577 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right) \quad M_{\text{cap}} = 1.072 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

North/South Walls Notch (6" wide, 4" deep)**Horizontal Steel, Bottom 7.5 feet of Inside Surface (#6@12"):****Bending Capacity**

$$d_b := 0.75 \cdot \text{in}$$

$$A_s := \frac{2 \cdot \pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.884 \cdot \frac{\text{in}^2}{\text{ft}}$$

Note: Double area used to account for rebar overlap at notch > 2 times the bar development length.

$$t_{\text{wall}} := 16 \cdot \text{in} - 4 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - \frac{d_b}{2} \quad d = 9.625 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 1.155 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right) \quad M_{\text{cap}} = 2.398 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Remaining 20'-3" of Inside Surface (#5@12"):**Bending Capacity**

$$d_b := 0.625 \cdot \text{in}$$

$$A_s := \frac{2 \cdot \pi \cdot d_b^2}{4 \cdot \text{ft}} \quad A_s = 0.614 \cdot \frac{\text{in}^2}{\text{ft}}$$

Note: Double area used to account for rebar overlap at notch > 2 times the bar development length.

$$t_{\text{wall}} := 16 \cdot \text{in} - 4 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - \frac{d_b}{2} \quad d = 9.688 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c} \quad a = 0.802 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right) \quad M_{\text{cap}} = 1.709 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Bottom 7.5 feet of Outside Surface (#8@12"): Bending Capacity

$$d_b := 1.00 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}}$$

$$A_s = 0.785 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{wall}} := 16 \cdot \text{in} - 4 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - \frac{d_b}{2}$$

$$d = 9.5 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c}$$

$$a = 1.027 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right)$$

$$M_{\text{cap}} = 2.117 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Middle 8-ft. of Outside Surface (#7@12"): Bending Capacity

$$d_b := 0.875 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}}$$

$$A_s = 0.601 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{wall}} := 16 \cdot \text{in} - 4 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - \frac{d_b}{2}$$

$$d = 9.562 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c}$$

$$a = 0.786 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right)$$

$$M_{\text{cap}} = 1.654 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

Horizontal Steel, Top 10'-3" of Outside Surface (#6@12"): Bending Capacity

$$d_b := 0.75 \cdot \text{in}$$

$$A_s := \frac{\pi \cdot d_b^2}{4 \cdot \text{ft}}$$

$$A_s = 0.442 \cdot \frac{\text{in}^2}{\text{ft}}$$

$$t_{\text{wall}} := 16 \cdot \text{in} - 4 \cdot \text{in}$$

$$d := t_{\text{wall}} - \text{cov} - \frac{d_b}{2}$$

$$d = 9.625 \cdot \text{in}$$

$$a := \frac{A_s \cdot f_y \cdot \text{DIF}_s}{0.85 \cdot f_c \cdot \text{DIF}_c}$$

$$a = 0.577 \cdot \text{in}$$

$$M_{\text{cap}} := \phi \cdot A_s \cdot f_y \cdot \text{DIF}_s \cdot \left(d - \frac{a}{2} \right) \quad M_{\text{cap}} = 1.237 \cdot 10^4 \cdot \text{in} \cdot \frac{\text{lb}}{\text{in}}$$

APPENDIX B

SHANNON & WILSON SOIL PROPERTIES MEMO

SEATTLE
RICHLAND
TACOMA
FAIRBANKS
ANCHORAGE
SAINT LOUIS
BOSTON

June 9, 1999

M & D Professional Services, Inc.
1305 Mansfield, Suite 5
Richland, Washington 99352

Attn: Mr. Bob Winkler, P.E., Ph. D.

**RE: GEOTECHNICAL ENGINEERING REVIEW OF K BASINS SOIL PROPERTIES;
100 K AREA, HANFORD SITE, WASHINGTON**

At your request and in response to our meeting of June 4, 1999, Shannon & Wilson has performed a review of available subsurface information for the 100 K Areas located at the Hanford Site near Richland, Washington. This letter discusses our review and analysis of available data, presents data for use as initial baseline data for analysis, and provides recommendations for additional review that will be required by the Defense Nuclear Facilities Safety Board (DNFSB) in approval of the analyses.

During the June 4, 1999 meeting, you requested that we provide the following data to support your analysis:

- a) Coefficient of Subgrade Reaction for the 10-foot by 14-foot base slab currently being analyzed;
- b) A range of shear strength ("Phi Angle") for the subgrade soils;
- c) Young's Modulus for the subgrade soils;
- d) Winkler springs for the subgrade soils;
- e) An estimate of the unconfined compressive strength of the subgrade soils; and
- f) An estimate of Poisson's ratio.

M & D Professional Services, Inc.
Attn: Mr. Bob Winkler, P.E., Ph. D.
June 9, 1999
Page 2

BACKGROUND

The currently available geotechnical data for the 100 K Basins at the 100 K West and 100 K East Areas is very limited. The data consists primarily of 6 documented plate load tests performed in 1953 (5 tests at the 105 K West and 1 test at the 105 K East), along with a report of 1 downhole geophysical survey performed in 1994. Shannon & Wilson performed a geotechnical study for the Cold Vacuum Drying Facility in the 100 K West Area in 1997. That study, at the request of the client, included only shallow borings (above the elevation of the basins) and included no seismic or dynamic soil evaluations.

As we discussed during our June 4 meeting, the existing soils data is insufficient to support a DNFSB-defensible study that defines mean and upper/lower boundary soil properties, as are required for an evaluation such as this. However, the plate load test data and the previous (limited) geophysical studies could be used to develop soil properties for use in a preliminary analysis. As such, the analyses and soil properties discussed below are to be considered as preliminary only. Definition of actual soil properties will require an extensive subsurface exploration program. We will prepare a proposed scope of services and costs for that program in a separate letter.

ANALYSIS OF EXISTING DATA

The existing data consists primarily of plate load tests. Plate load tests are considered to model large-strain soil properties, which may actually be larger than the strains that will occur during the model loading conditions (such as canister impact on the base slab). However, with the lack of any other data, our analyses used the plate load tests to estimate the modulus of subgrade reaction, the Winkler spring, and Young's modulus for the subgrade soils at the site.

The Winkler spring is usually defined as the modulus value for a 1-foot-square plate with a normalized 1-inch vertical deflection. The coefficient of subgrade reaction is then calculated from the modulus value for the 1-foot-square plate by the equation

M & D Professional Services, Inc.
Attn: Mr. Bob Winkler, P.E., Ph. D.
June 9, 1999
Page 3

$$K_B = K_{S1} * ((B+1)/2B)^2; \text{ where}$$

K_B is the coefficient of subgrade reaction (modulus) for a footing/slab with the average dimension of "B";

K_{S1} is the coefficient of subgrade reaction (modulus) for the 1-foot-square plate; and
B is the average dimension of the footing or slab under consideration.

For the given plate load tests, the results were first adjusted to a 1-foot-square plate and then normalized to 1-inch deflection.

From the values for K_B , Young's Modulus can be back-calculated using the conventional calculation for elastic settlement. This equation is $dH = q*B*((1-\gamma^2)/E)* I$, where

dH is the settlement, in this case the normalized 1 inch;
 q is the applied bearing pressure, in this case, the K_{S1} pressure;
B is the average footing or slab width, in this case about 11.8 feet;
 γ is Poisson's Ratio, in this case 0.3;
E is Young's Modulus; and
I is a shape factor, in this case 0.82.

The average values for the moduli, based solely on plate load tests, are summarized in Table 1. Our review of the moduli data indicates that one of the plate load tests for the 100 K West Area was probably performed on disturbed soil, and the one plate load test for the 100 K East Area was probably performed on looser soils within the upper 20 to 25 feet of the section, given the low modulus values. Interestingly, when the previous geophysical data (for the soil layer below 25 feet at the 100 K East Area) is normalized to large strains (i.e., 10^0 to 10^1 percent strains), that modulus value of about 20,000 pounds per square inch (psi) correlates well with the data below. The shear wave velocity data for the upper soils also correlates well with the plate-load derived modulus data for the 100 K East Area, indicating, in our opinion, that this plate load test was probably performed in the upper 25 feet of the section at 100 K East.

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 Attn: Mr. Bob Winkler, P.E., Ph. D.
 June 9, 1999
 Page 4

Table 1. Subgrade Moduli and Young's Modulus			
Location	K_{SI}, lb/in²/in. (Winkler Spring)	K_{11.8}, lb./in²/in. (Coefficient of Subgrade Reaction)	Young's Modulus, lb./in²
105 K West	620	182	19,100
105 K East	126	37	3,900

ANALYSIS OF OTHER DATA

The other soil properties requested for your analysis are derived from previous studies we have performed in the 200 Areas. These properties include density, Phi angle, and Poisson's Ratio (Table 2). We have included no estimate for unconfined compressive strength, because granular soils such as these do not have the property classically defined as "unconfined compressive strength." Unconfined compressive strength is a property of cohesive soils only. In granular soils, a property similar to unconfined compressive strength, i.e., an apparent "unconfined compressive strength," can be assumed based on the degree of cementation present in the soils. However, this property is very difficult to measure, and our experience indicates that this property is, practically, non-existent in most of the slightly cemented soils at the Hanford Site. Therefore, we recommend that unless the degree of cementation of the on-site soils can be established, no "unconfined compressive strength" be assigned to the soils in your modeling.

Table 2. Density, Friction Angle, and Poisson's Ratio		
Moist Density, pcf	Friction Angle, degrees	Poisson's Ratio
125 ± 10	40 ± 4	0.3 ± .3

M & D Professional Services, Inc.
Attn: Mr. Bob Winkler, P.E., Ph. D.
June 9, 1999
Page 5

LIMITATIONS

The analyses, conclusions, and recommendation contained in this report are based upon limited existing data and data obtained from other sites with similar soil characteristics. These data are intended for use in **preliminary** analysis only, and are not intended for final analysis of soil-structure interaction. Because of the basis for these data, the data do not satisfy the requirements of a geotechnical study usually conducted to provide site-specific, strain-dependant modulus and other soil properties.

We appreciated the opportunity to work with you on this project. If you have questions regarding this letter report, please contact our office.

Sincerely,

SHANNON & WILSON, INC.

Brian J. Williams, P.E., P.G.
Principal Engineer

BJW:DJB/bjw

Enclosures: Calculations and Backup Information (7 pages)

06-09-99/h1606-01.gtl/H-1606-01/cvm

- Based on discussions w/ Bob Winkel (M&D), Joe Swenson (Duke), and Bob Kennedy (Independent Reviewer, "RPK Structural Mechanical Consulting, Inc.") on June 4, we have been asked to provide assistance in providing soil properties for use in their analysis of part of the K Basins in the 105 KW and KE areas.

The properties they need for their analysis include:

- i) Coefficient of Subgrade Reaction for the 10' x 14' base slab in the area where fuel assemblies will be lifted;
- ii) A range of ϕ angle for the subgrade soils below the above-referenced slab;
- iii) Young's Modulus, which needs to be compatible with the coefficient of Subgrade Reaction, above;
- iv) Winkler Springs. This is the same thing as the coefficient of Subgrade Reaction for 'x' size of feature.
- v) Estimate of Unconfined Compressive Strength. This is easy, since for purely granular soils, it is zero. At larger deflections, any cementation will be lost so I'll recommend they use zero. This is in contrast to some previous models, which have used unconfined compressive strengths of over 50 psi (7,200 psf).
- vi) Poisson's Ratio.

- The current basis for determining subsurface soil properties is very slim in the 100-K areas. We have records of plate load tests from 1953, and we have some down-hole shear-wave data done by Redpath in 1994 in K east. This paucity of data would never pass a formal DNFSB review, but our clients need some basis for their current analyses. So, I'll base my analysis on the plate load tests first, then check with the Redpath data for the K East. I will also supplement with data from the 200 Areas.

We will need to advise them that the data we develop has limitations, and that it is not entirely based on site-specific measurements. We will also recommend that they perform site-specific studies, including down hole S-P-wave studies.

- I'll start with the plate-load tests. There are records for five plate load tests at the 105 kW reactor floor (about 23' below grade) and one test at 105 KE, but the east test does not indicate any elevation.

The tests were reportedly conducted using 2' by 2' square plates. Loads & deflections are shown on the attached sheets.

I'll first calculate subgrade modulus based on the first test table. At this point, I should define the concept of subgrade modulus.

- The definition of Modulus of Subgrade Reaction is the load required to cause a 1' square plate to settle 1" into the ground. This value is then related to different size footings (or slabs) by the relationship:

$$K_x = K_{s1} ((B+1)/2B)^2, \text{ where}$$

K_{s1} is the subgrade modulus for a 1' square plate.
 B is the width of the slab/footing
 K_x is the subgrade modulus for the width of " B ".

- So, we need to relate the results of the 2'x2' plates to a 1' square plate, and to a deflection of 1 inch.

Assumption 1. Soil response is linear. Strictly speaking, this isn't true, but I'll assume so for the limited data we have.

Assumption 2. The soil is consistent over the depths being considered. Again, without other data, we're not really sure about this (thus the need for drilling).

Plate I settled .023', or .276", under a load of 12,000 psf. For the 4' square plate, the total load is then 48,000 lb.

What is the equivalent load to get 1" of settlement?

$$\frac{48,000 \text{ lb.}}{.276"} \sim \frac{x' \text{ lb.}}{1"}; x = 173,913 \text{ lb.}$$

What is the 4' subgrade modulus? $173,913 \text{ lb.} \div 4 \text{ ft.}^2 = 43,478 \text{ lb./ft.}^2$ or, 302 (Say 300) lb./in.², per inch of settlement.

so, 301 lb./in.²/in is our subgrade modulus for a 4' square (a 2' by 2') plate

What, then, is K_{s1} ?

$$K_4 = K_{s1} ((4+1)/(2 \times 4))^{.390}, \text{ or,}$$

$$300 = K_{s1} (.390)$$

$K_{s1} = 768$, say 770 lb./in.²/in., which is our Winkler spring.

Next, calculate equivalent subgrade modulus for the 10' by 14' basin slab. The equivalent square size is 11.8' by 11.8', (or the square root of 10' by 14').

$$K_{11.8} = 770 ((11.8+1)/2 \times 11.8)^{.294}$$

$$\underline{\underline{K_{11.8} = 226 \text{ lb./in.}^2/\text{in.}}}$$

Now, calculate the equivalent Young's Modulus with the elastic deformation equation

$$dH = q \cdot B \cdot \left(\frac{1-\gamma^2}{E} \right) \times I, \text{ where}$$

q = the load, in this case 226 lb./in.²

dH = the deformation, which we're assuming is 1" (to be numerically consistent)

B = the width of the footing/slab; in this case 11.8' $\times$ 12"/ft. = 141 inches

γ = Poisson's Ratio - I'll use 0.3 (see elsewhere in these calc's).

I is a shape factor (see NAVFAC 7.1-212), which equals 0.82 for a square (essentially square) shape.

$$1" = 226 \text{ lb./in.}^2 \times 141 \text{ in.} \times \left(\frac{1-.3^2}{E} \right) \times .82$$

$$E = 23,780 \text{ psi} = 1,700 \text{ tons/ft.}^2$$

Are these values reasonable? Yes. Refer to the attached Table 4 from the StW Cross-Side Pipeline Report, attached. For the high-strain parameters, for which the 1" deflection is appropriate, E_{vib} from 17,000 to 42,000 psi, for the sand-gravel layer across 200 West + 200 East.

The table below will summarize the results of those same calcs on the rest of the plate load tests.

Test	Location	K_{SL} , lb/in. ³	K_{SB} , lb/in. ³	E' , psi
1	105KW	770	226	23,780
2	105KW	590	174	18,300
3	105KW	740	218	22,940
5	105KW	790	230	24,200
6	105KW	205	60	6,300
8	105 KE	126	37	3,900 *
* Probably in upper loose - med. dense sands; corresponds to 3,000 psi derived from Redpath velocity in upper sands				
K West Mean		620	182	19,100
S. Dev.		294	72	7,500
Cv		.47	.40	.39

Test #6 looks like the ground surface was probably disturbed, although 46 years later, it's very hard to say.

Test #8 was almost certainly performed in the upper sands at the side, where the velocities are much lower. The 3,900 psi Young's Modulus correlates fairly well with a back-calculated E' of 3,000 psi for the 650 fps shear wave velocity of Redpath's.

As far as the other properties, I'll just give them the results for the gravel/sand layer for the 200 area. Since we don't really have any other data, and since the modulus values for Redpath's one data set are similar, the 200 gravel data are probably as good as it gets without doing any subsurface data.

As far as establishing any real data,

**Final Report for
Task Order ICF KH-8008-3
Project W-058, Replacement of the
Cross-Site Transfer System
Hanford Site
Richland, Washington**

March 1995

**ICF Kaiser Hanford Company
c/o Mr. Richard Sober
P.O. Box 888
Richland, Washington 99352**

SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

1354 N. Grandridge Boulevard
Kennewick, Washington 99336-1037
509-735-1280

TABLE 4

SUMMARY OF DYNAMIC SOIL PROPERTIES

Material	Moist Density (pcf)	Friction Angle (degree)	Poisson's Ratio (ν)	Low Strain ¹ Parameters				High Strain ² Parameters	
				V_i (fps)	V_p (fps)	G (ksi)	E (ksi)	G (ksi)	E (ksi)
Stratum 1 Sand	—	—	—	—	—	—	—	—	—
Stratum 2 Sand/Gravel	—	41 ± 4	.21 - .33	1100 $\pm$ 200	2000 $\pm$ 550	20 - 45	48 - 120	7 - 16	17 - 42
Stratum 3 Sand	—	—	—	—	—	—	—	—	—
Backfill Sand	—	—	—	—	—	—	—	—	—

¹Corresponds to strains at a level of 10^{-4} %.

²Corresponds to strains at a level of 10^{-1} %.

For design of machine foundations, use low-strain parameters, density, and friction angle.

6 of 7 11-1112-51

Job: K-Basins
Project Number: H-1606-01
Date: 08-Jun-99

Seismic Wave/Shear Modulus Calculations

This analysis is based on the S-wave velocities obtained by Redpath in 1994.
The velocity below is from a depth below 25 feet, from an east-west orientation.

Depth, Feet	Vs, Ft./Sec.	Poisson's Ratio	Density, Lbs./Ft.3	Rho	G' max, ksi, 10 E -4	E max, ksi, 10 E -4	E ksi, 10 E -1	E tsf, 10 E -1	Comments
0-3.2	1625	0.30	125	3.88	71	185	20	1466	
3.2-6.4	1625	0.27	125	3.88	71	181	20	1432	
6.4-9.7	1625	0.33	125	3.88	71	189	21	1500	
9.7-13.0	0	0.30	110	3.42	0	0	0	0	
13.0-16.3	0	0.30	110	3.42	0	0	0	0	
16.3-19.6	0	0.30	110	3.42	0	0	0	0	
19.6-22.9	0	0.30	110	3.42	0	0	0	0	
22.9-26.2	0	0.30	110	3.42	0	0	0	0	
26.2-29.4	0	0.30	110	3.42	0	0	0	0	

Input Vs from ECPT is achieved at 10-5% to 10-4% strain. Since the difference between the two is less than 5%, G' is calculated using the input Vs and Rho, where $G' = \text{Rho} \cdot V_s^2$. E max at 10-4% is then calculated by the equation $2 \cdot (1 + \text{Poisson's Ratio}) \cdot G'_{\text{max}}$. G'max is then reduced from 10-4% to 10-1% strains using the Seed and Idriss curve for that soil type. E at 10-1% is then used in the settlement calculations.

For use in dynamic calculations or as input in most dynamic analyses programs, use G' at 10-4% strains.

APPENDIX C

ANSYS INPUT FILES

Elastic Soil Springs Model

```

/prep7
/title, Load Out Pit Model
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et,1,63
!real constants, Ks=50 (to match solid soil results)
r,1,17.75,,,,50 !West Pit Wall
r,2,16,,,,0 !Remaining Pit Walls
r,3,27,,,,50 !Basin Walls (Conserv.)
r,4,21,,,,50 !Pit Floor
r,5,24,,,,50 !Basin Floor/Pit E. Wall (bottom)
!material prop.
mp,ex,1,4.4e6
mp,nuxy,1,0.2

!Keypoints
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a,34,51,52,47
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amesh,9,15
esize,15
amesh,16,48

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n,2916,64,48.66
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fill,108,2908,3,2905,1
fill,109,2912,3,2909,1
fill,110,2916,3,2913,1
fill,2904,174,2,2919,1
fill,2916,177,2,2917,1
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e,2901,2902,2906,2905
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e,3056,178,179,3057
egen,10,1,-7
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k,104,64,24.075,-18
k,201,89,24.075,0
k,202,89,48.66,0
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amesh,49,53
nummrg,all

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0.364688184224
/ANG, 1, 74.8562934399

eplo

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d,all,uy,,,,ux
nsel,s,loc,x,249,251
d,all,uy,,,,ux
nall

fini
/solu
alls
!Drop Loading
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eplo
nsle
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nsel,r,loc,x,37,96
nsel,r,loc,z,0
esln,,1

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alls
solve
!Dead Weight Loading
sfedele,all,all,all
esel,s,real,,4
eplo
nsle
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nsel,r,loc,x,37,96
nsel,r,loc,z,0
esln,,1
sfe,all,,pres,,-8.45  !20k, IPPS + IP
alls
acel,,,1.0  !1g vertical loading
solve
!Water Pressure Loading
sfedele,all,all,all
esel,s,real,,4
eplo
nsle
nsel,s,loc,y,15.8,147.1
nsel,r,loc,x,13.9,114.1

```

```

nsel,r,loc,z,0
esln,,1
sfe,all,,pres,,-9.1  !pit floor water pressure
nsel,s,loc,y,216,335
esln
sfe,all,,pres,,-6.93  !basin water pressure
alls
solve

```

```

FINISH
/POST1
/output,post,out
SET,1,1
esel,s,elem,,450,457  !4t element width
ETABLE,ty,SMISC,2
pretab,ty
set,2,1
etable,ty,smisc,2
pretab,ty
set,3,1
etable,ty,smisc,2
pretab,ty

```

Solid Soil Elements Model

```

/prep7
/title, Load Out Pit Model
!element types
et,1,63
et,2,45
!real constants
r,1,17.75,,,,,0
r,2,16,,,,,0
r,3,27,,,,,0
r,4,21,,,,,0
r,5,24,,,,,0 ! Basin Floor Mat
r,6,40,,,,,0 ! Tapered Channel Floor, A45
r,7,32,,,,,0 ! Tapered Channel Floor, A44
!material prop.
mp,ex,1,4e6 ! Basin/Pit Concrete
mp,nuxy,1,0.2
mp,ex,2,1e4 ! Soil
mp,nuxy,1,0.3
mp,ex,3,1e6 ! Lean Concrete
mp,nuxy,3,0.2

!Keypoints
k,1,0,0,0
k,2,14,0,0
k,3,114,0,0
k,4,128,0,0
k,5,0,18.8
k,6,14,18.8
k,7,114,18.8
k,8,128,18.8
k,9,0,147
k,10,14,147
k,11,37.5,147
k,12,90.5,147
k,13,114,147
k,14,128,147
k,15,0,166,
k,16,14,166
k,17,37.5,166
k,18,90.5,166
k,19,114,166
k,20,128,166
k,21,14,18.8,63
k,22,114,18.8,63
k,23,14,147,63
k,24,37.5,147,63
k,25,90.5,147,63
k,26,114,147,63
k,27,14,18.8,324
k,28,114,18.8,324
k,29,14,147,324
k,30,37.5,147,324
k,31,90.5,147,324
k,32,114,147,324
k,33,37.5,215,63
k,34,90.5,215,63
k,35,37.5,215,324
k,36,90.5,215,324
k,37,37.5,0
k,38,90.5,0
k,39,37.5,18.8
k,40,90.5,18.8
k,41,37.5,18.8,63
k,42,90.5,18.8,63
k,43,37.5,18.8,324
k,44,90.5,18.8,324
k,45,-200,215,63
k,46,-200,215,324
k,47,250,215,63
k,48,250,215,324
k,49,-200,153.5,63
k,50,37.5,153.5,63
k,51,90.5,153.5,63
k,52,250,153.5,63
k,53,37.5,153.5,324
k,54,90.5,153.5,324
k,55,-200,335,63
k,56,37.5,335,63
k,57,90.5,335,63
k,58,250,335,63
k,59,14,18.8,348
k,60,37.5,18.8,348
k,61,90.5,18.8,348
k,62,114,18.8,348
k,63,14,147,348
k,64,37.5,147,348
k,65,90.5,147,348
k,66,114,147,348
k,67,-200,147,63
k,68,-200,147,324
k,69,-200,153.5,324
k,70,14,153.5,324
k,71,14,215,324
k,72,14,215,63
k,73,14,153.5,63
k,74,-200,18.8,324
k,75,-200,18.8,63
k,76,-200,-200,324
k,77,-200,-200,63
k,78,14,-200,324
k,79,14,-200,63
k,80,37.5,-200,324
k,81,37.5,-200,63
k,82,90.5,-200,324
k,83,90.5,-200,63
k,84,114,-200,324
k,85,114,-200,63
k,86,250,-200,324
k,87,250,-200,63
k,88,250,18.8,324
k,89,250,18.8,63
k,90,250,147,324
k,91,250,147,63
k,92,250,153.5,324
k,93,114,153.5,324
k,94,114,153.5,63
k,95,114,215,324
k,96,114,215,63

```

k,97,114,335,63
 k,98,14,335,63
 k,155,-200,335,0
 k,198,14,335,0
 k,156,37.5,335,0
 k,157,90.5,335,0
 k,197,114,335,0
 k,158,250,335,0
 k,145,-200,215,0
 k,172,14,215,0
 k,133,37.5,215,0
 k,134,90.5,215,0
 k,196,114,215,0
 k,147,250,215,0
 k,149,-200,153.5,0
 k,173,14,153.5,0
 k,150,37.5,153.5,0
 k,151,90.5,153.5,0
 k,194,114,153.5,0
 k,152,250,153.5,0
 k,167,-200,147,0
 k,123,14,147,0
 k,124,37.5,147,0
 k,125,90.5,147,0
 k,126,114,147,0
 k,191,250,147,0
 k,149,-200,153.5,0
 k,150,37.5,153.5,0
 k,151,90.5,153.5,0
 k,152,250,153.5,0
 k,173,14,153.5,0
 k,194,114,153.5,0
 k,167,-200,147,0
 k,191,250,147,0
 k,167,-200,147,0
 k,191,250,147,0
 k,175,-200,18.8,0
 k,189,250,18.8,0
 k,177,-200,-200,0
 k,179,14,-200,0
 k,181,37.5,-200,0
 k,183,90.5,-200,0
 k,185,114,-200,0
 k,187,250,-200,0

!Areas

a,1,2,6,5
 a,2,37,39,6
 a,37,38,40,39
 a,38,3,7,40
 a,3,4,8,7
 a,5,6,10,9
 a,6,39,11,10
 a,39,40,12,11
 a,40,7,13,12
 a,7,8,14,13
 a,9,10,16,15
 a,10,11,17,16
 a,11,12,18,17
 a,12,13,19,18
 a,13,14,20,19
 aatt,,4

asel,none
 a,6,39,41,21
 a,39,40,42,41
 a,40,7,22,42
 a,27,43,60,59
 a,43,44,61,60
 a,44,28,62,61
 aatt,,1
 asel,none
 a,6,21,23,10
 a,7,22,26,13
 a,10,11,24,23
 a,11,12,25,24
 a,12,13,26,25
 a,29,27,59,63
 a,32,28,62,66
 aatt,,2
 asel,none
 a,21,41,43,27
 a,41,42,44,43
 a,42,22,28,44
 aatt,,1
 asel,none
 a,23,21,27,29
 a,26,22,28,32
 a,23,24,30,29
 a,25,26,32,31
 a,34,51,54,36
 a,51,25,31,54
 aatt,,2
 asel,none
 a,45,33,35,46
 a,34,96,95,36
 a,96,47,48,95
 aatt,,3
 asel,none
 a,33,50,53,35 !Tapered Channel Floor, A44
 aatt,,7
 asel,none
 a,50,24,30,53 !Tapered Channel Floor, A45
 aatt,,6
 asel,none
 a,45,49,50,33
 a,33,50,51,34
 a,50,24,25,51
 a,34,51,52,47
 a,55,45,72,98
 a,98,72,33,56
 a,56,33,34,57
 a,57,34,96,97
 a,97,96,47,58
 aatt,,5
 alls
 esize,18
 amesh,all
 !volumes
 v,72,73,50,33,71,70,53,35
 v,73,23,24,50,70,29,30,53
 v,45,49,73,72,46,69,70,71
 v,49,67,23,73,69,68,29,70
 v,67,75,21,23,68,74,27,29


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v,75,77,79,21,74,76,78,27
v,21,79,81,41,27,78,80,43
v,41,81,83,42,43,80,82,44
v,42,83,85,22,44,82,84,28
v,22,85,87,89,28,84,86,88
v,26,22,89,91,32,28,88,90
v,94,26,91,52,93,32,90,92
v,51,25,26,94,54,31,32,93
v,34,51,94,96,36,54,93,95
v,96,94,52,47,95,93,92,48
v,155,145,172,198,55,45,72,98
v,198,172,133,156,98,72,33,56
v,156,133,134,157,56,33,34,57
v,157,134,196,197,57,34,96,97
v,197,196,147,158,97,96,47,58
vatt,2,,2
vsel,none
!lean concrete
v,172,173,149,145,72,73,49,45
v,133,150,173,172,33,50,73,72
v,134,151,150,133,34,51,50,33
v,196,194,151,134,96,94,51,34
v,147,152,194,196,47,52,94,96
v,173,10,167,149,73,23,67,49
v,150,11,10,173,50,24,23,73
v,151,12,11,150,51,25,24,50
v,194,13,12,151,94,26,25,51
v,152,191,13,194,52,91,26,94
vatt,3,,2
vsel,none
v,10,6,175,167,23,21,75,67
v,191,189,7,13,91,89,22,26
v,6,179,177,175,21,79,77,75
v,39,181,179,6,41,81,79,21
v,40,183,181,39,42,83,81,41
v,7,185,183,40,22,85,83,42
v,189,187,185,7,89,87,85,22

v,155,145,172,198,55,45,72,98
v,198,172,133,156,98,72,33,56
v,156,133,134,157,56,33,34,57
v,157,134,196,197,57,34,96,97
v,197,196,147,158,97,96,47,58

!Generate keypoints at soil bottom
!aslv,,1
!lsla
!ksll
ksel,r,loc,z,0
kgen,2,all,,,,,-200,100
!Generate soil volumes below pit
v,255,245,272,298,155,145,172,198
v,298,272,233,256,198,172,133,156
v,256,233,234,257,156,133,134,157
v,257,234,296,297,157,134,196,197
v,297,296,247,258,197,196,147,158

v,272,273,249,245,172,173,149,145
v,233,250,273,272,133,150,173,172
v,234,251,250,233,134,151,150,133
v,296,294,251,234,196,194,151,134
v,247,252,294,296,147,152,194,196
v,273,110,267,249,173,10,167,149
v,250,111,110,273,150,11,10,173
v,251,112,111,250,151,12,11,150
v,294,113,112,251,194,13,12,151
v,252,291,113,294,152,191,13,194
v,110,106,275,267,10,6,175,167
v,291,289,107,113,191,189,7,13
v,106,279,277,275,6,179,177,175
v,139,281,279,106,39,181,179,6
v,140,283,281,139,40,183,181,39
v,107,285,283,140,7,185,183,40
v,289,287,285,107,189,187,185,7
v,111,139,106,110,11,39,6,10
v,112,140,139,111,12,40,39,11
v,113,107,140,112,13,7,40,12
vatt,2,,2
alls
!type,2
vmesh,all

/VIEW, 1, -0.739216348626 , -0.566181700703 ,
0.364688184224
/ANG, 1, 74.8562934399
eplot
!aplot

nsel,s,loc,x,-200
d,all,ux
nsel,r,loc,y,214,400
nsel,r,loc,z,62,325
d,all,uy
nsel,s,loc,x,250
d,all,ux
nsel,r,loc,y,214,400
nsel,r,loc,z,62,325
d,all,uy
nsel,s,loc,y,-200
d,all,uy
nsel,s,loc,z,-200
d,all,uz

nall
fini
/solu
nsel,s,loc,x,30,100
nsel,r,loc,z,0
nsel,r,loc,y,30,120
esln,,1
sfe,all,,pres,, -277 !277 psi = wall tensile capacity
alls
solve

```

Modal Analysis

/prep7	k,35,37.5,215,324
/title, Load Out Pit Model	k,36,90.5,215,324
!element types	k,37,37.5,0
et,1,63	k,38,90.5,0
et,2,45	k,39,37.5,18.8
!real constants	k,40,90.5,18.8
r,1,17.75,,,,,0	k,41,37.5,18.8,63
r,2,16,,,,,0	k,42,90.5,18.8,63
r,3,27,,,,,0	k,43,37.5,18.8,324
r,4,21,,,,,0	k,44,90.5,18.8,324
r,5,24,,,,,0 ! Basin Floor Mat	k,45,-200,215,63
r,6,40,,,,,0 ! Tapered Channel Floor, A45	k,46,-200,215,324
r,7,32,,,,,0 ! Tapered Channel Floor, A44	k,47,250,215,63
!material prop.	k,48,250,215,324
mp,ex,1,4e6 ! Basin/Pit Concrete	k,49,-200,153.5,63
mp,nuxy,1,0.2	k,50,37.5,153.5,63
mp,dens,1,2.25e-4	k,51,90.5,153.5,63
mp,ex,2,1e4 ! Soil	k,52,250,153.5,63
mp,nuxy,1,0.3	k,53,37.5,153.5,324
mp,dens,1,1.65e-4	k,54,90.5,153.5,324
mp,ex,3,1e6 ! Lean Concrete	k,55,-200,335,63
mp,nuxy,3,0.2	k,56,37.5,335,63
mp,dens,1,2.25e-4	k,57,90.5,335,63
	k,58,250,335,63
!Keypoints	k,59,14,18.8,348
k,1,0,0,0	k,60,37.5,18.8,348
k,2,14,0,0	k,61,90.5,18.8,348
k,3,114,0,0	k,62,114,18.8,348
k,4,128,0,0	k,63,14,147,348
k,5,0,18.8	k,64,37.5,147,348
k,6,14,18.8	k,65,90.5,147,348
k,7,114,18.8	k,66,114,147,348
k,8,128,18.8	k,67,-200,147,63
k,9,0,147	k,68,-200,147,324
k,10,14,147	k,69,-200,153.5,324
k,11,37.5,147	k,70,14,153.5,324
k,12,90.5,147	k,71,14,215,324
k,13,114,147	k,72,14,215,63
k,14,128,147	k,73,14,153.5,63
k,15,0,166,	k,74,-200,18.8,324
k,16,14,166	k,75,-200,18.8,63
k,17,37.5,166	k,76,-200,-200,324
k,18,90.5,166	k,77,-200,-200,63
k,19,114,166	k,78,14,-200,324
k,20,128,166	k,79,14,-200,63
k,21,14,18.8,63	k,80,37.5,-200,324
k,22,114,18.8,63	k,81,37.5,-200,63
k,23,14,147,63	k,82,90.5,-200,324
k,24,37.5,147,63	k,83,90.5,-200,63
k,25,90.5,147,63	k,84,114,-200,324
k,26,114,147,63	k,85,114,-200,63
k,27,14,18.8,324	k,86,250,-200,324
k,28,114,18.8,324	k,87,250,-200,63
k,29,14,147,324	k,88,250,18.8,324
k,30,37.5,147,324	k,89,250,18.8,63
k,31,90.5,147,324	k,90,250,147,324
k,32,114,147,324	k,91,250,147,63
k,33,37.5,215,63	k,92,250,153.5,324
k,34,90.5,215,63	k,93,114,153.5,324

k,94,114,153.5,63
 k,95,114,215,324
 k,96,114,215,63
 k,97,114,335,63
 k,98,14,335,63
 k,155,-200,335,0
 k,198,14,335,0
 k,156,37.5,335,0
 k,157,90.5,335,0
 k,197,114,335,0
 k,158,250,335,0
 k,145,-200,215,0
 k,172,14,215,0
 k,133,37.5,215,0
 k,134,90.5,215,0
 k,196,114,215,0
 k,147,250,215,0
 k,149,-200,153.5,0
 k,173,14,153.5,0
 k,150,37.5,153.5,0
 k,151,90.5,153.5,0
 k,194,114,153.5,0
 k,152,250,153.5,0
 k,167,-200,147,0
 k,123,14,147,0
 k,124,37.5,147,0
 k,125,90.5,147,0
 k,126,114,147,0
 k,191,250,147,0
 k,149,-200,153.5,0
 k,150,37.5,153.5,0
 k,151,90.5,153.5,0
 k,152,250,153.5,0
 k,173,14,153.5,0
 k,194,114,153.5,0
 k,167,-200,147,0
 k,191,250,147,0
 k,167,-200,147,0
 k,191,250,147,0
 k,175,-200,18.8,0
 k,189,250,18.8,0
 k,177,-200,-200,0
 k,179,14,-200,0
 k,181,37.5,-200,0
 k,183,90.5,-200,0
 k,185,114,-200,0
 k,187,250,-200,0

!Areas

a,1,2,6,5
 a,2,37,39,6
 a,37,38,40,39
 a,38,3,7,40
 a,3,4,8,7
 a,5,6,10,9
 a,6,39,11,10
 a,39,40,12,11
 a,40,7,13,12
 a,7,8,14,13
 a,9,10,16,15
 a,10,11,17,16
 a,11,12,18,17

a,12,13,19,18
 a,13,14,20,19
 aatt,,4
 asel,none
 a,6,39,41,21
 a,39,40,42,41
 a,40,7,22,42
 a,27,43,60,59
 a,43,44,61,60
 a,44,28,62,61
 aatt,,1
 asel,none
 a,6,21,23,10
 a,7,22,26,13
 a,10,11,24,23
 a,11,12,25,24
 a,12,13,26,25
 a,29,27,59,63
 a,32,28,62,66
 aatt,,2
 asel,none
 a,21,41,43,27
 a,41,42,44,43
 a,42,22,28,44
 aatt,,1
 asel,none
 a,23,21,27,29
 a,26,22,28,32
 a,23,24,30,29
 a,25,26,32,31
 a,34,51,54,36
 a,51,25,31,54
 aatt,,2
 asel,none
 a,45,33,35,46
 a,34,96,95,36
 a,96,47,48,95
 aatt,,3
 asel,none
 a,33,50,53,35 !Tapered Channel Floor, A44
 aatt,,7
 asel,none
 a,50,24,30,53 !Tapered Channel Floor, A45
 aatt,,6
 asel,none
 a,45,49,50,33
 a,33,50,51,34
 a,50,24,25,51
 a,34,51,52,47
 a,55,45,72,98
 a,98,72,33,56
 a,56,33,34,57
 a,57,34,96,97
 a,97,96,47,58
 aatt,,5
 alls
 esize,24
 amesh,all
 !volumes
 v,72,73,50,33,71,70,53,35
 v,73,23,24,50,70,29,30,53

```

v,45,49,73,72,46,69,70,71
v,49,67,23,73,69,68,29,70
v,67,75,21,23,68,74,27,29
v,75,77,79,21,74,76,78,27
v,21,79,81,41,27,78,80,43
v,41,81,83,42,43,80,82,44
v,42,83,85,22,44,82,84,28
v,22,85,87,89,28,84,86,88
v,26,22,89,91,32,28,88,90
v,94,26,91,52,93,32,90,92
v,51,25,26,94,54,31,32,93
v,34,51,94,96,36,54,93,95
v,96,94,52,47,95,93,92,48
v,155,145,172,198,55,45,72,98
v,198,172,133,156,98,72,33,56
v,156,133,134,157,56,33,34,57
v,157,134,196,197,57,34,96,97
v,197,196,147,158,97,96,47,58
vatt,2,,2
vsel,none
!lean concrete
v,172,173,149,145,72,73,49,45
v,133,150,173,172,33,50,73,72
v,134,151,150,133,34,51,50,33
v,196,194,151,134,96,94,51,34
v,147,152,194,196,47,52,94,96
v,173,10,167,149,73,23,67,49
v,150,11,10,173,50,24,23,73
v,151,12,11,150,51,25,24,50
v,194,13,12,151,94,26,25,51
v,152,191,13,194,52,91,26,94
vatt,3,,2
vsel,none
v,10,6,175,167,23,21,75,67
v,191,189,7,13,91,89,22,26
v,6,179,177,175,21,79,77,75
v,39,181,179,6,41,81,79,21
v,40,183,181,39,42,83,81,41
v,7,185,183,40,22,85,83,42
v,189,187,185,7,89,87,85,22

v,155,145,172,198,55,45,72,98
v,198,172,133,156,98,72,33,56
v,156,133,134,157,56,33,34,57
v,157,134,196,197,57,34,96,97
v,197,196,147,158,97,96,47,58

!Generate keypoints at soil bottom
!aslv,,1
!lsla
!ksll
ksel,r,loc,z,0
kgen,2,all,,,,,-200,100
!Generate soil volumes below pit
v,255,245,272,298,155,145,172,198
v,298,272,233,256,198,172,133,156
v,256,233,234,257,156,133,134,157

```

```

v,257,234,296,297,157,134,196,197
v,297,296,247,258,197,196,147,158
v,272,273,249,245,172,173,149,145
v,233,250,273,272,133,150,173,172
v,234,251,250,233,134,151,150,133
v,296,294,251,234,196,194,151,134
v,247,252,294,296,147,152,194,196
v,273,110,267,249,173,10,167,149
v,250,111,110,273,150,11,10,173
v,251,112,111,250,151,12,11,150
v,294,113,112,251,194,13,12,151
v,252,291,113,294,152,191,13,194
v,110,106,275,267,10,6,175,167
v,291,289,107,113,191,189,7,13
v,106,279,277,275,6,179,177,175
v,139,281,279,106,39,181,179,6
v,140,283,281,139,40,183,181,39
v,107,285,283,140,7,185,183,40
v,289,287,285,107,189,187,185,7
v,111,139,106,110,11,39,6,10
v,112,140,139,111,12,40,39,11
v,113,107,140,112,13,7,40,12
vatt,2,,2
alls
!type,2
vmesh,all

/VIEW, 1, -0.739216348626 , -0.566181700703 ,
0.364688184224
/ANG, 1, 74.8562934399
eplot
!aplot

nsel,s,loc,x,-200
d,all,ux
nsel,r,loc,y,214,400
nsel,r,loc,z,62,325
d,all,uy
nsel,s,loc,x,250
d,all,ux
nsel,r,loc,y,214,400
nsel,r,loc,z,62,325
d,all,uy
nsel,s,loc,y,-200
d,all,uy
nsel,s,loc,z,-200
d,all,uz

nall
fini
/solu
antype,modal
modopt,subsp,20
/output,modal,out
mxpand,20
solve

```

Time History Drop Analysis

```

/prep7
/title, Load Out Pit, 24" Cask Drop, 5 pcf, 1000 sq. in
foam
!element types
et,1,42,,,3 !cask model
et,2,12,,, !gap element
et,3,39,,,2 !nonlinear spring(foam)
et,4,21,,,4 !mass elem.
et,5,14 !pit spring
!real constants
r,1,1 !cask thickness
r,2,0,2.5e6,-24 !gap elem. spring, 24" drop height
r,3,0,0,.826,450000,4.5,450000 !nonlinear spring
(39)
rmore,5.4,585000,6.3,887000
r,4,365 !pit mass
r,5,3.6e6 !pit stiffness
!material prop.
mp,ex,1,30e6
mp,nuxy,1,0.3
mp,dens,1,9.4754 !wt./in^3

!Nodes
k,1,0,0,0
k,2,39.8,0
k,3,39.8,159.1
k,4,0,159.1
a,1,2,3,4
esize,10
type,1
real,2
amesh,all

n,301,39.8,-1
n,302,39.8,-2
n,303,39.8,-3

type,2
real,2
e,301,2

type,3
real,3
e,301,302

```

```

type,4
real,4
e,302

type,5
real,5
e,302,303

d,303,all
d,2,ux,0
d,301,ux,0
d,302,ux,0

fini

/solu
nlgeom,on
timint,off
d,3,all
d,4,all
time,1e-8
acel,,1
kbc,1
nsubst,2
solve
timint,on
!autots,on
!solcon,on
nsubst,100
ddelete,3,all
ddelete,4,all
outres,all,1
time,6.7
solve
nsubst,400
!autots,off
time,10.0
solve
fini
/post26
nsol,2,2,u,y
!sol,3,65,301,F,y
rforce,3,303,f,y
plvar,3

```

Inelastic Model

```

/prep7
/title, Load Out Pit Model
!element types
et,1,63 !concrete
et,2,8 !rebar
et,3,52 !gap elements (outside rebar)
et,4,43 !inelas. floor element
!real constants
r,1,17.75,,,100 !West Pit Wall
r,2,16,,,0 !Remaining Pit Walls
r,3,27,,,100 !Basin Walls
r,4,21,,,100 !Pit Floor
r,5,24,,,100 !Basin Floor/Pit E. Wall (bottom)
r,6,18,,,100 !Sump Bottom Thickness
r,7,0.31 !#5 rebar
r,8,0.60 !#7 rebar
r,9,17 !rigid plate, floor/wall conn.
r,10,1e9 !gap element spring
!material prop.
!concrete
mp,ex,1,4.4e6
mp,nuxy,1,0.2
!rebar, elas./plas.
mp,ex,2,29e6
mp,nuxy,2,0.3
Tb,Bkin,2,1
Tbdata,1,40e3,8e5
!rigid plates, wall-to-floor conn.
mp,ex,3,4.0e6
mp,nuxy,3,0.2
!inelas. floor
mp,ex,4,4.4e6
mp,nuxy,4,0.2
Tb,Bkin,4,1
Tbdata,1,457,8e5 !pseudo yield strength, floor eles.

n,1,0,0,0
n,3,9.32
fill
n,21,118.68
fill,3,21
n,23,128
fill,21,23
ngen,3,23,1,23,,,5.16
ngen,3,23,47,69,,,5.685
ngen,2,23,93,115,,,5.83
ngen,2,23,116,118,,,5.83
n,143,18.94,33.35
fill,141,143
n,157,109.06,33.35
fill,143,157
n,159,118.68,33.35
fill,157,159
n,161,128,33.35
fill,159,161
ngen,17,23,139,161,,,5.831
ngen,2,414,116,138,,,104.96
ngen,2,460,93,115,,,116.62

ngen,4,23,553,575,,,6.083
ngen,3,23,622,644,,,4.72
!modify nodes @ sump boundary
n,126,58,24.75
n,130,82,24.75
fill
n,218,58,48.75
n,222,82,48.75
fill
fill,126,218,3
fill,130,222,3
!n,103,57.93,20.7
!n,107,82.2,20.7
!fill
n,241,57.6,56.2
n,245,83.4,56.2
fill
!generate floor elements
real,4
type,4
mat,4
e,1,2,25,24
egen,22,1,-1
egen,29,23,-23
!delete eles. in sump hole
edele,121,124
edele,143,146
edele,165,168
edele,187,190
!generate sump elements
real,6
ngen,2,700,126,130,,, -16.5
ngen,2,700,218,222,,, -16.5
ngen,2,700,149,195,23,,, -16.5
ngen,2,700,153,199,23,,, -16.5
fill,849,853
fill,872,876
fill,895,899
e,826,827,850,849
egen,4,1,-1
egen,4,23,-4
e,126,127,827,826
egen,4,1,-1
e,149,126,826,849
egen,4,23,-1
e,130,153,853,830
egen,4,23,-1
e,219,218,918,919
egen,4,1,-1
!generate rebar eles.
ngen,2,700,49,67,2,,,8.15
ngen,2,700,95,113,2,,,8.15
ngen,2,700,141,509,46,,,8.15
ngen,2,700,143,511,46,,,8.15
ngen,2,700,157,525,46,,,8.15
ngen,2,700,159,527,46,,,8.15
ngen,2,700,555,573,2,,,8.15
ngen,2,700,624,642,2,,,8.15

```

real,7	k,39,37.5,15.88,8.15
type,2	k,40,89.0,15.88,8.15
mat,2	k,41,37.5,15.88,63
e,49,749	k,42,90.5,15.88,63
egen,10,2,-1	k,43,37.5,15.88,324
e,95,795	k,44,90.5,15.88,324
egen,10,2,-1	k,45,-200,215,63
e,141,841	k,46,-200,215,324
egen,9,46,-1	k,47,250,215,63
e,143,843	k,48,250,215,324
egen,9,46,-1	k,49,-200,153.5,63
e,157,857	k,50,37.5,153.5,63
egen,9,46,-1	k,51,90.5,153.5,63
e,159,859	k,52,250,153.5,63
egen,9,46,-1	k,53,37.5,153.5,324
e,555,1255	k,54,90.5,153.5,324
egen,10,2,-1	k,55,-200,335,63
e,624,1324	k,56,37.5,335,63
egen,10,2,-1	k,57,90.5,335,63
type,1	k,58,250,335,63
mat,1	k,59,14,15.88,348
	k,60,37.5,15.88,348
!Keypoints	k,61,90.5,15.88,348
k,1,0,0,0	k,62,114,15.88,348
k,2,14,0,0	k,63,14,147,348
k,3,114,0,0	k,64,37.5,147,348
k,4,128,0,0	k,65,90.5,147,348
k,5,0,15.88	k,66,114,147,348
k,6,14,15.88,8.15	!Areas
k,7,114,15.88,8.15	a,1,2,6,5
k,8,128,15.88	a,2,37,39,6
k,9,0,147	a,37,38,40,39
k,10,14,147,8.15	a,38,3,7,40
k,11,37.5,147,8.15	a,3,4,8,7
k,12,89.0,147,8.15	a,5,6,10,9
k,13,114,147,8.15	a,6,39,11,10
k,14,128,147,8.15	a,39,40,12,11
k,15,0,166	a,40,7,13,12
k,16,14,166	a,7,8,14,13
k,17,37.5,166	a,9,10,16,15
k,18,89.0,166	a,10,11,17,16
k,19,114,166	a,11,12,18,17
k,20,128,166	a,12,13,19,18
k,21,14,15.88,63	a,13,14,20,19
k,22,114,15.88,63	!Area 15
k,23,14,147,63	aatt,,4
k,24,37.5,147,63	asel,none
k,25,90.5,147,63	a,6,39,41,21
k,26,114,147,63	a,39,40,42,41
k,27,14,15.88,324	a,40,7,22,42
k,28,114,15.88,324	a,27,43,60,59
k,29,14,147,324	a,43,44,61,60
k,30,37.5,147,324	a,44,28,62,61
k,31,90.5,147,324	!Area 21
k,32,114,147,324	aatt,,1
k,33,37.5,215,63	asel,none
k,34,90.5,215,63	a,10,6,21,23
k,35,37.5,215,324	a,13,7,22,26
k,36,90.5,215,324	a,29,27,59,63
k,37,37.5,0	a,32,28,62,66
k,38,89.0,0	!Area 25
!sump edge loca.	aatt,,2
	asel,none
	a,21,41,43,27

a,41,42,44,43	e,1255,1443,1433,1324
a,42,22,28,44	e,1326,1324,1433,3328
aatt,,1	e,1328,1326,3328,3327
asel,none	e,1330,1328,3327,3341
a,23,21,27,29	e,1332,1330,3341,3340
a,26,22,28,32	e,1334,1332,3340,3339
a,24,23,29,30	e,1336,1334,3339,3338
a,26,25,31,32	e,1338,1336,3338,3337
a,33,50,53,35	e,1340,1338,3337,3366
a,50,24,30,53	e,1342,1340,3366,1499
a,34,51,54,36	e,1273,1342,1499,1509
a,51,25,31,54 !Area 36	e,1273,1509,1508,1227
aatt,,2	e,1227,1508,1507,1181
asel,none	e,1181,1507,1506,1135
a,45,33,35,46	e,1135,1506,1505,1089
a,34,47,48,36	e,1089,1505,1504,1043
aatt,,3	e,1043,1504,1503,997
asel,none	e,997,1503,1502,951
a,11,10,23,24	e,951,1502,1501,905
a,12,11,24,25	e,905,1501,1500,859
a,13,12,25,26	e,859,1500,1391,813
a,45,49,50,33	e,767,813,1391,1391
a,33,50,51,34	e,1344,1345,797,797
a,50,24,25,51	e,1345,1343,799,797
a,34,51,52,47	e,1343,1365,801,799
a,55,45,33,56	e,1365,1364,803,801
a,56,33,34,57	e,1364,1363,805,803
a,57,34,47,58 !Area 48	e,1363,1362,807,805
aatt,,5	e,1362,1361,809,807
alls	e,1361,1392,811,809
esize,8.3	e,1392,1391,811,811
eshape,2	
!amesh,1,7	e,1344,797,843,1434
!amesh,9,15	e,1434,843,889,1435
!sel,s,loc,z,8.15	e,1435,889,935,1436
!lesize,all,6.5	e,1436,935,981,1437
alls	e,1437,981,1027,1438
esize,13	e,1438,1027,1073,1439
amesh,16,48	e,1439,1073,1119,1440
!wall/floor connection plates	e,1440,1119,1165,1441
real,9	e,1441,1165,1211,1442
mat,3	e,1442,1211,1257,1443
e,749,751,1345,1344	e,1443,1257,3328,1433
e,751,753,1343,1345	e,1257,1259,3327,3328
e,753,755,1365,1343	e,1259,1261,3341,3327
e,755,757,1364,1365	e,1261,1263,3340,3341
e,757,759,1363,1364	e,1263,1265,3339,3340
e,759,761,1362,1363	e,1265,1267,3338,3339
e,761,763,1361,1362	e,1267,1269,3337,3338
e,763,765,1392,1361	e,1269,1271,3366,3337
e,765,767,1391,1392	e,1271,1509,1499,3366
e,795,749,1344,1344	e,1271,1225,1508,1509
e,841,795,1344,1434	e,1225,1179,1507,1508
e,887,841,1434,1435	e,1179,1133,1506,1507
e,933,887,1435,1436	e,1133,1087,1505,1506
e,979,933,1436,1437	e,1087,1041,1504,1505
e,1025,979,1437,1438	e,1041,995,1503,1504
e,1071,1025,1438,1439	e,995,949,1502,1503
e,1117,1071,1439,1440	e,949,903,1501,1502
e,1163,1117,1440,1441	e,903,857,1500,1501
e,1209,1163,1441,1442	e,857,811,1391,1500
e,1255,1209,1442,1443	

!Gap elements on outside rebar

```
real,10
type,3
e,49,749
egen,10,2,-1
e,624,1324
egen,10,2,-1
e,95,795
egen,11,46,-1
e,113,813
egen,11,46,-1
```

nummrg,all

```
/VIEW, 1, -0.739216348626 , -0.566181700703 ,
0.364688184224
/ANG, 1, 74.8562934399
```

```
!nsel,s,loc,z,8.15
!esln,,1
!/pnum,node,1
eplot
```

```
nsel,s,loc,x,-201,-199
d,all,uy,,,,ux,uz
nsel,s,loc,x,249,251
d,all,uy,,,,ux,uz
nall
```

```
cp,1,uy,49,749
cp,2,ux,49,749
cp,3,ux,67,767
cp,4,uy,67,767
```

```
fini
/solu
```

!Soil Friction Forces

```
alls
nsel,s,loc,y,0,148
nsel,r,loc,z,100.2,100.4
f,all,fz,7260
alls
```

```
nsel,s,loc,x,38,90
nsel,r,loc,z,0
nsel,r,loc,y,48,98
esln,,1
!load under IPSS
sfe,all,2,pres,,270 !667 kip load (600/0.9)
alls
```

```
outr,all,1
solcon,on
nsubst,30
solve
fdelete,all,all
sfdelete,all,all,all
nsubst,30
solve !unloading
```

```
FINISH
/POST1
/output,post,out
```

!Calculate Joint Openings

```
set,2,last
*dim,dwest,,10
*dim,dnorth,,10
*dim,dsouth,,10
*dim,deast,,10

*do,i,1,8 !west wall
ntop=797+2*i-2
nbot=ntop-700
dwest(i)=uz(ntop)-uz(nbot)
*enddo
```

```
*do,i,1,8 !east wall
ntop=1257+2*i-2
nbot=ntop-700
deast(i)=uz(ntop)-uz(nbot)
*enddo
```

```
*do,i,1,9 !south wall
ntop=857+46*i-46
nbot=ntop-700
dsouth(i)=uz(ntop)-uz(nbot)
*enddo
```

```
*do,i,1,9 !north wall
ntop=843+46*i-46
nbot=ntop-700
dnorth(i)=uz(ntop)-uz(nbot)
*enddo
```

```
/output,post,out
*status,dwest(1),1,8
*status,dsouth(1),1,9
*status,dnorth(1),1,9
*status,deast(1),1,8
/output
```

APPENDIX J

Recommended Structural Acceptance Criteria for MCO Cask Accidents in the 105 K South Loadout Pit

**Recommendations for Hardware Handling Operations Near
Exterior Walls in the 105-K Fuel Storage Basins**

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SLOP Structural Acceptance Criteria, Cask Drop Accident

1 Cracking/Leakage Issues

To begin a discussion on the South Load Out Pit (SLOP) drop accident acceptance criteria, it is important to emphasize that a structural acceptance criteria guaranteeing zero leakage is not feasible. Due to the low tensile strength of concrete, the design of reinforced concrete structures is based upon the assumption of tensile cracking, i.e. the internal tensile loading is assumed to be carried entirely by the reinforcing steel. Reinforced concrete structures designed to the ACI Code (Reference 1) and subjected to normal service level bending moments, typically exhibit hairline cracking. Even with no mechanical loading, differential shrinkage and settlement cracks frequently occur. However, the maximum service level crack widths are generally less than 0.01 inches (Reference: Section 6.2 of *Design of Concrete Structures* by Nilson, et al).

For accident load conditions, with the less restrictive accident-level ACI Code limits, crack sizes should remain relatively small, but greater than the normal service level crack sizes. For impact type loading, e.g. cask drop loads, Appendix C of the Code emphasizes that “maximum deformations shall not result in the loss of intended function of the structural element nor impair the safety related function of other systems and components”. The “safety-related function” at issue for cask drops into the SLOP is loss of shielding water. Therefore, in addition to the structural limits imposed by the ACI Code, it is necessary to demonstrate that leakage rates, associated with cask drop damage, does not exceed allowable leak rates imposed by the K Basin SAR.

2 ACI Code Criteria Discussion

For nuclear safety reinforced concrete structures, the governing design code is ACI 349, *Code Requirements for Nuclear Safety Related Concrete Structures*. Section 9.2 of ACI 349 specifies load combinations and load factors for typical nuclear structures. For low probability loads, such as a safe shutdown earthquake (E_{ss}) or tornado (W_t), load factors of 1.0 are prescribed. However, Section 9.2 of ACI 349 does not include drop accidents in the list of load combinations.

Impact accidents, including “fuel cask drops” are addressed in Appendix C of ACI 349. Appendix C provides some special provisions for impact accidents, including “dynamic increase factors (DIF’s) for both the rebar and concrete strengths (20% increase for Grade 40 rebar and 25% increase for concrete). The DIF values are based upon the increased strength observed at the higher strain rates associated with impact accidents.

Appendix C also permits the use of “ductility ratios” which permit loads in excess of the rebar yield strength. However, as discussed above, the Code cautions that the application of ductility ratios should not impair the safety related functions of the components.

Concerning the use of detailed stress results, such as that obtained from a finite element analysis, it is noted that ACI 349 is based upon load factors and ultimate strength design. It is common practice in ACI Code design to use average, rather than peak member

loading for ACI structures. For example, in Section 14.2.4 of ACI 349, it is permissible to use an effective wall length of four times the wall thickness plus the bearing width in designing for a concentrated load. Thus, applying ACI 349 limits to local peak values is overly conservative. The conservatism of using peak internal forces and moments is further emphasized by the ACI Commentary to Section 13.3.1, which allows “yield line analyses” (limit analysis) for the design of slab systems.

Based upon the above discussion, it is recommended that the SLOP cask drop loading be limited to the ACI 349 Appendix C limits using a load factor of 1.0, without the use of ductility ratios. Applying the ACI Code strength reduction factors (ϕ factors), loads up to 85 to 90% of the limit load capacity would be permitted. However, allowing local peak internal loading to go much beyond section capacities must demonstrate conformance to leak rate limitations.

It is also recommended that regardless of the final safety margins associated with the cask drop accident, that administrative procedures be in place for dealing with a leak in the basin. This recommendation is based upon the beginning paragraph of this acceptance criteria, which emphasizes the impractical nature of a leak-proof acceptance criteria. The administrative procedure could be as simple as a provision for applying coated bentonite clay pellets to the bottom of the SLOP.

The above recommendation addressing the need to deal with a post accident minor leak also applies to the sump pit/drain valve region. Although the sump geometry will be modeled in the SLOP finite element models, in our judgement, it is not feasible to prove that zero leakage would occur in the sump region following a cask drop. Therefore, the administrative procedures addressing post accident leakage should include the sump pit/drain valve region.

The above recommendations are based upon the assumption that the SLOP concrete and reinforcing has experienced no significant in-service degradation. That is, there has been no significant degradation in concrete strength or reduction in slab thickness, nor has there been any significant rebar corrosion. K Basin inspections, to date, support this position.

3 Load Combination Discussion

Sections C.1.1 and C.8 of Appendix C of ACI-349 state that impact loads must be combined with other loads in accordance with Section 9.1 of ACI-349. However, Section 9.1 does not include a drop load in any of the load combination equations given in Section 9.2.1. A reasonable approach is to place the cask drop accident in the same category as a safe shutdown earthquake (E_{ss}). This results in load factors of 1.0 for all loads in combination with a cask drop (ACI-349, Section 9.2.1, Equations 4 and 8). The only significant loads in Section 9.2.1 of ACI-349 to be considered in combination with a cask drop are dead weight, water pressure, and soil pressure.

Based upon experience with soil pressure on the basin walls, the wall external soil pressure loading exceeds the internal wall water pressure, resulting in bending compression on the inside surfaces at the floor/wall interface. Since the drop loading bending moments result in tension on the inside surfaces, it is conservative to ignore the soil and water pressures on the pit walls. On the other hand, the water pressure on the floor adds to the drop loading bending moments and floor/wall joint tensile forces. Following the above rationale, the following load combination is recommended for the cask drop analysis:

$$U = D + L + C.D. ,$$

where, U is the required strength, D is the pit dead weight, L is the floor water pressure, and $C.D.$ is the cask drop loading. It is noted that it may be conservative to ignore the dead weight and/or the water pressure contribution, because they may actually reduce the response at the floor/wall joint area.

Another load combination issue is the potential for combining the drop loading with seismic loading. In the floor/wall joint area, the seismic contribution is small. The vertical inertia of the design basis earthquake is an order of magnitude less than the drop loading. Using an SRSS combination of the seismic with the drop loading reduces the seismic loading to a negligible value for the floor/wall joint. However, the lateral seismic loading to the pit walls is more significant and should be combined with the drop loading when evaluating other areas, such as the pit channel/basin interface.

4 SLOP Analysis/Acceptance Criteria Discussion

This section addresses specific concerns related to the application of the ACI 349 limits to the SLOP drop accident. Based upon preliminary analyses performed by both FDNW and M&D, the drop accident load limit will be governed by the ACI Code limits at the wall/floor joint. Therefore, by minimizing the conservatisms associated with the demand/capacity ratios at this location, the maximum capacity can be obtained.

By developing a model which focusses on predicting reasonably conservative deformations in the wall/floor joint, it is possible to correlate drop accident loading with leakage rates. Using leakage rate limits, the drop load capacity can be established which is based upon allowable leak rates.

5 References

1. ACI 1995, *Code Requirements for Nuclear Safety Related Concrete Structures*, ACI 349, American Concrete Institute, Detroit, Michigan.

APPENDIX K

Immersion Pail Support Structure Impact Analysis

M & D

Professional Services Inc.

**Immersion Pail Support Structure
Impact Analysis**

Prepared by:

M&D Professional Services, Inc.

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Phone: (509) 943-1625 ext 231

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Prepared for:

Joni L. Weamer

DE&S Hanford, Inc.

Prepared By:

Michael D. Nothey

Michael D. Nothey 6/23/99

Reviewed By:

Milon Meyer

Milon Meyer 6/23/99

M&D Professional Services		CALCULATION SHEET	Page No. 1 of 3
Client / Location DE&S Hanford, Inc.			Calculation No.
Subject Immersion Pail Support Structure Impact Analysis		Prepared By / Date M.D. Northey-06/23/99	Revision No. 0
Ref. Drawing(s)		Checked By / Date M.J. Meyer-06/23/99	Contract No.
		Revised By / Date	

1. INTRODUCTION

The Immersion Pail Support Structure (IPSS) and immersion pail are part of the Cask Loadout System and are installed in the south loadout pit for use in Spent Nuclear Fuel removal operation. The IPSS is the primary load-carrying structure that interfaces directly with the south loadout pit. This analysis addresses the postulated cask drop accident onto the IPSS to determine the relative displacements and buckling capacity of the structural members. This analysis assumes that the impact limiters are rigid and that all the load is reacted through the structural members.

2. SUMMARY OF RESULTS

The preliminary results show that the columns are stable for a load of 800 kips. Further analysis will determine the actual buckling capacity of the structure. The stresses at the juncture of the 4x8 support tubes to the lower cylinder are above yield but these stresses are local and will not have significant effect on the overall results. The maximum displacement of about 1-inch occurs at the load in the east direction.

3. MODEL DESCRIPTION

The immersion pail support structure has been modeled using the ANSYS finite element analysis software. The model includes the lower cylinder, the 10x8 mitered tubes, the 4x8 support tubes and the stiffener plates located in the upper portion of the structure. All structural members are 3/8" thick and are modeled with shell elements that calculate both bending and membrane stresses.

4. LOAD CASES

This analysis considers two accident scenarios, a 3.3-ft off-center drop (Drop No. 1) and a cask in pail, lined-up drop (Drop No. 2). For Drop No. 1, the two east columns are loaded with a total force of 800 kips. For Drop No. 2, all four columns are loaded with a total force of 800 kips. Drop No. 1 is considered to be the worst case and this preliminary analysis addressed this load case. The 800 kips criteria is conservatively derived by doubling the allowable load of the concrete floor at the base of the IPSS.

M&D Professional Services	CALCULATION SHEET		Page No. 2 of 3
			Calculation No.
Client / Location DE&S Hanford, Inc.	Prepared By / Date M.D. Northey-06/02/99	Revision No. 0	
Subject Immersion Pail Support Structure Impact Analysis	Checked By / Date M.J. Meyer-06/02/99	Contract No.	
Ref. Drawing(s)	Revised By / Date		

5. RESULTS

The following plot shows the stress intensity throughout the structure. The maximum stress of 76000 psi is local and occurs where the support tubes meet the lower cylinder.

ANSYS 5.5.1
 JUN 1 1999
 14:07:26
 NODAL SOLUTION
 STEP=1
 SUB =1
 TIME=1
 SINT (AVG)
 PowerGraphics
 EFACET=1
 AVRES=Mat
 DMX =.921066
 SMN =60.414
 SMX =75518
 0
 5111
 10222
 15333
 20444
 25556
 30667
 35778
 40889
 46000

Immersion Pail Support Structure, Hydraulic Damper Design

M&D Professional Services		CALCULATION SHEET		Page No. 3 of 3
Client / Location DE&S Hanford, Inc.		Prepared By / Date M.D. Northey-06/02/99		Calculation No.
Subject Immersion Pail Support Structure Impact Analysis		Checked By / Date M.J. Meyer-06/02/99		Revision No. 0
Ref. Drawing(s)		Revised By / Date		Contract No.

The following plot shows the relative displacements at the top of the structure. Note how the structure moves east (positive Y-direction) and slightly out.

ANSYS 5.5.1
JUN 2 1999
10:07:05
PLOT NO. 1
DISPLACEMENT
STEP=1
SUB =1
TIME=1
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.9203

6. SCOPE OF WORK

Capacity of connections to carry load in six degrees of freedom, assumption is full strength connections.

Displacement of tops of columns relative to pail connection. Pin tolerances.

Displaced shape of support tubes. Possible interference with sliding tubes.

The intent is to show that the IPSS can sustain the applied load without buckling and without causing excessive deformation such that interference or binding occurs in the structure. The initial results presented here indicated that this is a reasonable approach.

APPENDIX L

Structural Evaluation of the Immersion Pail for Pressure Loading During A Postulated MCO/Cask Drop Accident

STRUCTURAL EVALUATION OF THE IMMERSION PAIL FOR PRESSURE LOADING DURING A POSTULATED MCO/CASK DROP ACCIDENT

S. L. Hecht
DE&S Hanford, Inc
June 1999

Prepared by: [Signature] 6-18-99
S. L. Hecht

Reviewed by: L. P. Shrivastava 6/18/99
H. Shrivastava, M&D

INTRODUCTION

A redesign effort of the Immersion Pail Support Structure (IPSS) is in progress to mitigate the detrimental effects of potential MCO/CASK drop accidents in the South Load Out Pit (SLOP). One design loading condition considers the MCO/Cask dropping 17 feet into the Immersion Pail (IP), when it is pinned to the IPSS. The IP is designed to have a tight annular clearance with the MCO/CASK and will have approximately one foot of water in it during normal operations. Hence, when the MCO/CASK drops into the IP, it will impact the water surface generating a pressure pulse. Hydraulic analysis has predicted this pressure to peak at 560 psi at initial impact (Appendix F). It is a design goal that the IP maintain its structural integrity during this event.

The IP is basically a circular cylinder 42 inches in diameter with a flat bottom plate and attachment ears at the top which pin to the IPSS. Both the 3/8 inch thick cylindrical shell and the 2 inch thick bottom plate are constructed of type 304 stainless steel (Ref drawing H-1-81544).

ANALYSIS AND RESULTS

Initial hand calculations predicted that stresses would exceed the yield strength of the 304 SST in both the bottom plate and in the cylinder at the junction with the bottom plate (discontinuity- secondary stress) when subjected to 560 psi internal pressure. Hence, to show, by analysis, that this component is acceptable, an elastic-plastic static finite element analysis was made to assess the structural integrity of the Immersion Pail after a drop of a MCO/Cask (17 ft.). An axisymmetric shell model of the lower end (2.5 feet) was utilized using the ANSYS^{TM} finite element analysis program. The pail is assumed to have 1 ft. of water in it. Loading is by a hydrostatic internal pressure loading of 560 psi, acting over this 1 ft. depth. (Note: at 560 psi internal pressure, the axial force transmitted to the IPSS is 776 Kips. Hence, it may not be possible for this pressure to be realized in an assumed static mode.) Material properties were taken from the vendor material certification reports. Plasticity was modeled with a Bilinear Kinematic Strain Hardening model with a Von Mises yield criterion.

Figure 1 shows a schematic of the finite-element model giving element numbers. Modeled are the bottom plate and the cylindrical wall to a height of 30 inches. All elements are ANSYS SHELL51 - Axisymmetric Structural Shell which have 4 degree of freedom per node, i.e., -all translations and rotation about the hoop axis (out of plane). The elements have 9 integration points through the thickness and three along the length. The model has a finer "mesh" in the region of the plate-to-cylinder joint. Elements 1 through 14 represent the bottom plate, the other elements representing the cylinder wall. The internal pressure of 560 psi is applied as surface loads to elements 1 through 24 (1 ft. location). Elements 25 through 34 are used to provide more than adequate flexibility for the shell pressure discontinuity. The translation at the upper node on element 34 was constrained in the y direction, to conservatively bound the vertical constraint from

the IPSS. Inelastic stress-strain relationships were specified for both (material) the bottom plate and cylindrical shell. For the bottom plate: $S_y = 41,600$ psi; $S_u = 81,400$ psi and T.E. = 51%. For the cylinder: $S_y = 32,600$ psi; $S_u = 81,400$ psi; T.E. = 65%. Small deformation theory was assumed. The plastic tangent modulus is treated in a conservative manner with respect to plastic strain. Here, $E_p = (S_u - S_y)/T.E.$

Results show that some localized initial yielding will occur at about 30% of the peak pressure loading at the discontinuity joint between the cylindrical shell and the flat bottom plate. Table 1 gives the equivalent plastic strains on the inside (top), center and outside of each element, for the peak pressure of 560 psi. At this peak pressure, the maximum equivalent plastic strains of 1.79% (at the joint-weld) and 0.44% (at the center of the bottom plate) were predicted. The maximum primary stress intensity (for ASME code evaluation) is calculated at 48,100 psi. For the hoop membrane stress in the cylinder wall to exceed the yield strength, would require an internal pressure greater than 582 psi. A maximum permanent deformation of 0.37 inches was predicted at the center of the bottom plate.

CONCLUSION

The IP will retain structural integrity after the postulated drop cask accident. Here, the calculated strains are acceptable as the ductility of the 304 SST used here are high (total elongation's of 51-65%). Furthermore, this peak pressure load is dynamic in nature, and it is likely that the structure may not fully respond. For conservatism, the loading is assumed to be static.

Allowable strain limits based on ANSI/AISC N690 Ductility Factors for Extreme and Abnormal Loads (Table Q1.5.8.1) range from 10% (tension member) to 2.2% (flexural member). The N690 criteria reduces allowable stresses (but not explicitly strains) to 0.75 of the base metal allowable for the type of weld and QA in the IP (Tables QB2 and QB3). Hence, for the 1.79% strain in the weld the allowable value is 7.5% (secondary stress - bending will self mitigate). The calculated plastic strain in the bottom plate of 0.44% is less than the allowable value of 2.2%, when conservatively considering the bottom plate as a bending member,

The use of the N690 criteria on a "pressure vessel" may be overly conservative. Other estimate of allowable strains (without reduction for weld quality factors) based on other industry acceptance criteria are 27% nominal plastic strain when using the RDT F9-7 standard (WHC-SD-DGS-00002). The ASME B&PV Section III Code for Level D Service Loading (Appendix F) specifies an allowable Primary Stress Intensity Limit of $0.9 S_u$, or 73,300 psi, for plastic analysis. This is considerably greater than the 48,100 psi calculated value.

Figure 1. Schematic of Finite Element Model of Immersion Pail Bottom (showing element numbers)

Table 1. Predicted Equivalent Plastic Strain: Immersion Pail at 560 psi internal pressure.
(given for inside, middle and outside surfaces)

STAT ELEM	CURRENT EPEQ-TOP	CURRENT EPEQ-MID	CURRENT EPEQ-BOT
1	0.42323E-02	0.0000	0.44404E-02
2	0.37320E-02	0.0000	0.39397E-02
3	0.30606E-02	0.0000	0.32487E-02
4	0.24000E-02	0.0000	0.25687E-02
5	0.18532E-02	0.0000	0.19912E-02
6	0.14244E-02	0.0000	0.15429E-02
7	0.10555E-02	0.0000	0.11666E-02
8	0.75157E-03	0.0000	0.85397E-03
9	0.51209E-03	0.0000	0.60456E-03
10	0.32660E-03	0.0000	0.41138E-03
11	0.19103E-03	0.0000	0.26425E-03
12	0.91764E-04	0.0000	0.15576E-03
13	0.24439E-04	0.0000	0.79525E-04
14	0.0000	0.0000	0.30624E-04
15	0.17910E-01	0.47267E-02	0.57733E-02
16	0.51181E-03	0.0000	0.0000
17	0.0000	0.0000	0.0000
18	0.0000	0.0000	0.0000
19	0.0000	0.0000	0.0000
20	0.0000	0.0000	0.0000
21	0.0000	0.0000	0.0000
22	0.0000	0.0000	0.0000
23	0.0000	0.0000	0.0000
24	0.0000	0.0000	0.0000
25	0.0000	0.0000	0.0000
26	0.0000	0.0000	0.0000
27	0.0000	0.0000	0.0000
28	0.0000	0.0000	0.0000
29	0.0000	0.0000	0.0000
30	0.0000	0.0000	0.0000
31	0.0000	0.0000	0.0000
32	0.0000	0.0000	0.0000
33	0.0000	0.0000	0.0000
34	0.0000	0.0000	0.0000

MINIMUM VALUES

ELEM	14	1	16
VALUE	0.0000	0.0000	0.0000

MAXIMUM VALUES

ELEM	15	15	15
VALUE	0.17910E-01	0.47267E-02	0.57733E-02

APPENDIX M

Conceptual Design, Operator Interface Platform

INTEROFFICE

CORRESPONDENCE

99-SNF/DAM-007

To: J. L. Weamer X3-85

From: D. A. Moody *D. A. Moody* X3-85

cc: K. E. Ard X3-85
R. W. Rasmussen X3-85
DAM LB/file

Date: May 27, 1999

Telephone: 376-6491

Subject: CONCEPTUAL DESIGN, OPERATOR INTERFACE PLATFORM

1.0 INTRODUCTION

The purpose of this report is to present a conceptual design of an impact limiting system to be installed above the 105 KW building South Load Out Pit (SLOP). The purpose of the system is to prevent damage to the SLOP floor that could result from a Multi-Canister Overpack (MCO) off-center drop or drop and tip over onto the Immersion Pail (IP) or Immersion Pail Support Structure (IPSS). The system will also serve as a replacement operator interface platform for Multi-Canister Overpack Loading System (MLS) operations. The conceptual design includes drawings and supporting calculations as an attachment. The drawings (Attachment A) depict the major components and features of the impact limiting system and also show by scale the anticipated extent of the operator platform grating and access stairways. Calculations (Attachment B) necessary to provide proof of concept are provided herein.

2.0 DESIGN DESCRIPTION

The worst case accident scenario is considered to be a cask tip over. This could result in the MCO contacting the IP or IPSS with an associated kinetic energy equivalent to a 60,000-pound cask falling from a height of five feet six inches. The concept of this design is to place a fixed energy absorption system between the falling mass and the potential IP and IPSS targets. The system will absorb all of the drop energy and precluding damage to the SLOP floor by preventing the MCO from contacting the protected targets.

The system (Attachment A, Sheet 2) consists of an assembly of steel beams that span the SLOP and are supported by crushable foam blocks located on top of the SLOP wall. The beams are configured such that they physically cover the IP and IPSS and present a first point of contact from a falling MCO. The beams are sized to transfer the drop energy (within the elastic plastic stress range of the beam) to crush-blocks where the kinetic energy from impact will be absorbed by the work (plastic strain energy) in uniformly deforming the blocks.¹ Resulting crush forces will be absorbed by the bearing capacity of the curb wall. A factor of safety of 2.8 exists between the

¹The crush blocks are a crushable plastic foam material (General Plastic Last-A-Foam TM) used on commercial nuclear material shipping containers and a number of impact limiters here at Hanford.

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design load and the allowable wall bearing load as determine in accordance with the requirements of ACI 349, Appendix C, *Code Requirements for Nuclear Safety Related Concrete Structures*.

Four lateral restraint systems are required at each beam, crush block, and wall interface (Attachment A, Sheets 2 & 5). In a tip over scenario, MCO contact with the impact beam will be at an angle other than perpendicular. This will result in both vertical and horizontal loads on the impact system. Consequently, a horizontal support system is required to resist the horizontal loads and allow the blocks to absorb the vertical drop energy without being pushed aside. The calculated horizontal loads associated with the postulated tip over were too large to allow design of a practical anchorage system. Therefore, a horizontal foam crush system (Attachment A, Sheet 4, Section B) is designed to reduce the lateral impact loads to the horizontal restraint system. Even with the use of a lateral crush foam system the loads are significant, requiring extensive anchorage. The lateral system may interfere with operator access on the north side of the SLOP, therefore the platform grating (Attachment A, Sheet 1) is extended beyond the edges of the SLOP to include this area as part of the working surface.

The area directly above the IP/IPSS assembly or center section (Attachment A, Sheets 1 & 3) of the impact limiting system is covered by ancillary cross members to prevent physical contact of the MCO with the CLS components. This center section is designed, not to absorb the load from a vertical drop, but to deflect slightly off-center MCO drops away from the IPSS/IP and into the center of the IP. This center section is used only during cask insert and removal operations. Therefore, this center section is removable to allow installation of the cask lid, to raise and lower the IP, and to perform other CLS operations. The center section can be removed as one assembly using the overhead crane once the cask has been placed in the IP pail in the SLOP.

The center section (Attachment A, Sheets 1 & 3) features a set of guide-rails used to guide the MCO during its travel over the SLOP to only those areas that are protected from a drop. These guide rails prevent movement of the MCO in the north/south direction. The guide rails are adjustable such that they can be move out of the way during insertion of the MCO into the IP. This is necessary because the MCO lifting lug assembly protrudes beyond the outside diameter of the MCO body and would interfere with the full insertion of the MCO into the IP. Additionally, a travel-stop is positioned on the backside of the center section to limit MCO travel, in an easterly direction, past the center of the IP.

3.0 DISCUSSION OF ANALYSIS AND DETAILED COMPONENT DESIGN

3.1 DROP SCENARIO'S:

Three drop scenarios were considered in this conceptual design to envelop the worst case impact loads as follows:

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Drop # 1

MCO drop resulting in a tip over and rotation about its bottom corner through a full 90 degrees until it impacts the IPSS. The energy associated with this drop is equal to a 60,000-pound cask drop of 5.62 feet or 337,200 ft. lbs. of kinetic energy.

Drop # 2

Cask drops vertically from a height of five feet above the floor and impacts the IP/IPSS. With the OPS Interface Platform in place, the associated drop energy is equal to a 60,000-pound cask drop of approximately 2.02 feet or 123,000 ft. lbs. of kinetic energy.

Drop # 3

Cask drops from the west and outside of the SLOP curb wall resulting in a tip-over to the east until impact occurs with the IP/IPSS. The energy associated with this drop is equal to a total of a 60,000-pound cask drop of 1.688 feet or 127,800 ft. lbs. of kinetic energy. This resolves into vertical and horizontal components of approximately 90,300-ft. lbs. of kinetic energy. At several potential drop locations to the west of the curb wall, the falling cask may contact the curb wall before contacting the IP/IPSS. However, after contact with the curb, the cask could continue to tip toward the east and result in a secondary impact on the IP/IPSS. This scenario is considered because of the potential for large lateral loads that could be created by the angular impact. The lateral loads are of concern, because if the system were to be ineffective laterally, it could not be expected to dissipate the vertical energies either, resulting in possible vertical impact with the IP/IPSS.

Summary

Drop scenario # 1 produced the highest vertical drop energies and therefore was used as the governing load case for design. Drop # 3 produced horizontal loads and therefore is used to design the lateral support system.

3.2 DETAILED DESIGN:

The available amount of elastic energy in the beam compared to the overall drop energy was assumed to be insignificant and although it may be feasible to design a beam to dissipate the energy plastically, the resulting support loads would be unacceptable. Therefore, it was necessary to design a beam that transfers the load to a crushable foam system without development of a plastic hinge in the beam. Based on the available SLOP wall bearing capacity, availability of surface area to bear the crush blocks, and the required kinetic energy capacity, a range of foam densities and crush forces were calculated. A maximum crush block size of 36 inches by 36 inches by 18 inches deep was considered. However, a 24-inch long by 16 inch wide by 18 inch deep crush block with a foam density of eight pounds per cubic inch will provided the lowest crush force. The crush force determines the maximum load that the beam will see during an impact. Assuming a dynamic impact factor of one, this load was used to calculate the minimum required beam section modulus for the worst case vertical load from Drop #1. W18 by 119 steel beams were selected and require

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modification to create closed or boxed in sections. The beam material, A-441, high strength, low alloy steel, has a minimum yield strength of 50,000 pounds per square inch (psi). The beam must be tapered down to a six-inch high boxed in "W" shape at the ends to allow for the greatest crush block depth. The tapering is also necessary to avoid contacting existing cask rails during the crush process. The existing rails are located on the inside of and just below the SLOP curb walls, and even with the tapering a portion of the rail lengths must be removed.

The lateral restraint system design is governed by drop scenario 3. Resistance of the lateral loads requires a structure of 5 x 5 x 5/8-inch A500 GR. B welded tube steel members. The structure anchorage to the floor may require several base plates with a minimum of six one-inch anchor bolts for each plate. In order to reduce the horizontal loads to an acceptable level, 24 x 48 x 30 inch deep crush blocks (plastic foam, FR3700, 5 LB/cu. in) are placed on top of the SLOP curb wall in front of the platform impact beams. Additional, crush material is placed in front of the curb wall and underneath the platform access stairway to minimize any tip over impact load to the floor and curb wall.

The combination of the six inch deep modified "W" end beams and the eighteen inch deep crush blocks results in an operator interface platform height of two feet above the SLOP curb wall (four feet above the floor).

4.0 DESIGN ADVANTAGES AND DISADVANTAGES, RISKS AND OPPORTUNITIES

Advantages:

The properties and testing information on the foam are very predictable and well known. The manufacturer has the means to manufacture and dynamically test special order foam designs. The manufacturer can implement an NQA-1 program for fabrication.

All of the design components are commercially available, however a special design and fabrication of the long beam will be required.

The design incorporates a worst case envelope of drop conditions and therefore represents the worst case configuration and specification of components. Definitive design using more rigorous analytical techniques are certain to reduce the complexity and size of the system and thereby make it more operator friendly and more easily erectable given the limited space around the SLOP.

New system may provide a larger grating area than is currently designed for personnel performing MLS operations.

Disadvantages:

Based on the worst case drop scenario and that a two foot vertical envelope is required for the impact system, operator head room is limited to slightly under six feet under the gantry support structure. Additional specialized tools may be required for cask load-out operations planned to be completed from the platform.

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System restricts operator access to the IPSS/IP and a remote device for installing and removing the pail support pins will have to be designed.

The opportunity for leak mitigation in the SLOP is complicated by the installation of a system that covers a large portion of the SLOP. This is of concern with the current design, but is further complicated by the complexity, weight, and size of this "worst case" structure.

May require redesign of fall protection equipment required for access to the operator platform, and will certainly result in a fall protection system that is less user-friendly.

Risks and Opportunities:

This conceptual design is based on a dynamic impact factor of 1. In definitive design, this factor should be confirmed either through dynamic testing or by performing a transient dynamic analysis using computer structural codes such as ANSYS.

Lateral anchorage loads have not been evaluated fully and the magnitude of lateral restraint anchorage is unknown. This design has a high probability of function, but represents a quick assessment of the components needed to mitigate the drop. The definitive design should include computer applications to balance the structural members with the crush block components. Multiple points of impact should be considered in the structural model to optimize and complete the system balance.

An alternate approach to placing the crush blocks on top of the curb wall is to cut out a 24 inch wide by two-foot deep section of the curb wall at each crush-block location. Placing the crush blocks in this cutout will lower the platform to a more operator friendly elevation. Additionally, the cut out may reduce or eliminate the need for such a massive lateral restraint system by placing the impact limiting system in a position where it would only be impacted at angles closer to ninety degrees. Also the cutout in the wall could function as a lateral restraint system. This approach may require modification to lower the IPSS and pail pinned elevation. This option is left to definitive design to evaluate.

5.0 CONCLUSIONS

This conceptual design contains many features that would complicate or constrict MLS operations; however, it provides good assurance that a design solution is feasible. The conceptual design includes much conservatism and analyzes extreme drop scenarios in an attempt to show the worst case impact on fabrication, construction and operations. It is felt that in the definitive design phase, the complexity of the system can be significantly reduced with the aid of more rigorous analytical techniques.

rlf

Attachments (2)

99-SNF/DAM-007

ATTACHMENT A

CONCEPTUAL DESIGN DRAWINGS
OPERATOR INTERFACE PLATFORM

6 total pages (including coversheet)

GRATING PLAN

PAIL SHOWN IN THE UPPER POSITION (PINNED),
CASK (WITHOUT LID) SHOWN IN THE PAIL

NOTE: OPS PLATFORM AND CASK GUIDE, SHOWN; ALL OTHER
MISCELLANEOUS EQUIPMENT REMOVED FOR CLARITY.

REMOVABLE CASK GUIDE IMPACT LIMITER

CASK TRANSPORTATION FACILITY MODIFICATIONS

TITLE: CONCEPTUAL DESIGN OPS INTERFACE PLATFORM	BY: Wm ZICKUHR
	DATE: 5/27/99

PLAN

IMPACT LIMITER

NOTE: GRATING OVER PIT, HANDRAIL ATTACHMENT
REMOVABLE CASK GUIDE, AND PLATFORM
SUPPORT SYSTEM NOT SHOWN

CASK TRANSPORTATION FACILITY MODIFICATIONS

TITLE:	CONCEPTUAL DESIGN OPS INTERFACE PLATFORM		BY:	Wm ZICKUHR	
	DATE:	5/27/99	PAGE:	2	

CONCEPTUAL REMOVABLE CASK GUIDE IMPACT LIMITER

CASK TRANSPORTATION FACILITY MODIFICATIONS			
m.c.	CONCEPTUAL DESIGN OPS INTERFACE PLATFORM		By Wm ZICKUHR
			DATE: 5/27/99 PAGE: 3

PLAN

NOTE: GRATING, STAIRS, HANDRAIL
ATTACHMENT AND PLATFORM/GRATING
SUPPORT SYSTEM NOT SHOWN

MISCELLANEOUS CRUSH MATERIAL

CASK TRANSPORTATION FACILITY MODIFICATIONS			
TITLE:	CONCEPTUAL DESIGN OPS INTERFACE PLATFORM		
	BY: Wm ZICKUHR		
	DATE: 5/27/99	PAGE: 4	

HNF-4576, Rev. 0

NOTE: PLATFORM HANDRAILS AND MISCELLANEOUS ATTACHMENTS NOT SHOWN

C SECTION
NTS

CASK TRANSPORTATION FACILITY MODIFICATIONS

TITLE: CONCEPTUAL DESIGN OPS INTERFACE PLATFORM	BY: Wm ZICKUHR
	DATE: 5/27/99 PAGE: 5

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ATTACHMENT B

CONCEPTUAL DESIGN CALCULATIONS
OPERATOR INTERFACE PLATFORM

29 total pages (including coversheet)

Doc. No. CTFM-C-0006

Revision 0

Page No. / of 28

DESIGN ANALYSIS

Client SNF FACILITY PROJECTS

WO/Job No. 65100300

Subject Conceptual Design/Structural Analysis, OPS
Impact Limiter/Interface Platform

Date 5-27-99

By DA Moody DAH

Checked 6/2/99

By MA Islam

Location 105 KW

Revised

By

I. OBJECTIVE

Provide proof of concept for the conceptual design of an operator interface platform (OIP) to be installed above the 105 KW building South Load Out Pit (SLOP).

The purpose of the platform is two fold:

1. Provide operator access to the center of the SLOP during SNF load out operations without interfering with the installation and removal of the Multi-Canister Overpack (MCO).
2. Perform a safety-class function as an impact limiting device, to reduce or eliminate impact loads to the Immersion Pail (IP) or Immersion Pail Support Structure (IPSS) during a cask-MCO drop/tip over accident.

Note:

The efforts of this conceptual design have concentrated primarily on the technical features of the impact limiting system. The basic operator platform requirements are met, however satisfaction/optomization of the system to meet the operator interface functions are left to definitive design.

II. DESIGN INPUTS

A. FUNCTIONS AND REQUIREMENTS:

Functions and requirements for the OPS Impact Limiter/Interface Platform are specified in HNF-SD-SNF-FRD-025, Rev. 2, *Functions and Requirements for K Basins Cask Transportation Facility Modifications - Project A.5/A.6.*

Key Criteria specified by the F & R document that were considered in the conceptual "proof of concept" design include the following:

1. ANSI/AISC N690 (Ref 1) defines the loading conditions (Section Q1.3) and load combinations (Section Q1.3.6 and Table Q1.5.7.1) used in the conceptual design.
2. SLOP Concrete Wall bearing the impact limiting system is evaluated for impact loads using ACI 349, Appencix C.

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DESIGN ANALYSIS

Client SNF FACILITY PROJECTS

WO/Job No. 65100300

Subject Conceptual Design/Structural Analysis, OPS
Impact Limiter/Interface Platform

Date 5-27-99

By DA Moody DM

Checked 6/2/99

By MA Islam

Location 105 KW

Revised

By

B. ASSUMPTIONS:

1. Maximum vertical Cask Drop Height = Bottom of cask is five feet above the 105K Building operating floor.
2. Maximum Cask weight for drop scenario = 60,000 lbf.
3. Trolley speed of crane = 20.5 ft/min laterally
4. Cask Geometry:
  - Body diameter = 39.82 in
  - Lid diameter = 31.50 in
  - Length = 170.25 in
  - Height C.G. = 85.00 in
5. Elevation of the Top of Platform must not exceed four feet above the floor.
6. Loads used to size impact beams are based on FR3700 crush values provided in General Plastics Catalog for FR foam material. A dynamic impact factor of "1" is assumed ~~##~~ with these crush values.

DM 5-27-99

C. METHODS TO BE USED:

1. Hand calculations using classic text book solutions are used to structurally evaluate all applicable items in accordance with applicable criteria defined above.

D. REFERENCES:

1. ANSI/AISC N690-1984, *Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures For Nuclear Facilities*, American Institute of Steel Construction, Inc. 400 North Michigan Avenue, Chicago, IL 60611.
2. Catalog, *General Plastics Last - A - Foam FR-3700 for Crash & Fire Protection of Nuclear Material Shipping Containers*, GPMC, Tacoma Wa.
3. Kleinlogel, *Rigid Frame Formulas, Twelfth Edition*, Frederick Ungar Publishing Co., New York.
4. SDC- 4.1, *STANDARD ARCH-CIVIL DESIGN CRITERIA*, DESIGN LOAD FOR FACILITIES, Rev. 12, September 3, 1993.
5. SNF-2555, *Drop Analysis of the Loaded Multi-Canister Overpack Transport Cask on the K Basin South Loadout Pit Curb*, Rev. 0, DESH, Richland, Wa.

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WO/Job No. 65100300

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Impact Limiter/Interface PlatformDate: 5-27-99 By: D'A Moody *DM*

Checked: 6/2/99 By: MA-Islam

Location: 105 KW

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E. CALCULATIONS:

1.0 DROP SCENARIOS/ENERGIES

At the initiation of this analysis, specific drop scenario's had not been defined. A review of potential scenario's was completed as a part of this conceptual design and the following three drop scenarios are considered to envelope the worst case impact loads.

- a. DROP 1: Cask drop resulting in a tip over and rotation about its bottom corner through a full 90 degrees until it impacts the IPSS.
- b. DROP 2: Cask drops vertically from a height of 5 feet above floor and impacts the IP/IPSS.
- c. DROP 3: Cask drop from west and from outside of the SLOP curb wall resulting in a tipover to the east until impact (Impact angles from vertical ranging from 40 to 55 degrees) occurs with the IP/IPSS. The Cask may contact the curb wall before contacting the IP/IPSS but the cask could continue to travel toward the east with a secondary impact on the IP/IPSS. This scenario is considered because of the potential for large lateral loads that could be created by the angular impact. The lateral loads are of concern because, if the system were to be ineffective laterally, it could not be expected to dissipate the vertical energies either, resulting in possible vertical impact with the IP/IPSS.

(10)

SKETCH (TIP OVER)

$$W = \text{CASK WIDTH} = 39.82 \text{ in}$$

Diagram illustrating the stability of a cask during tipping. The diagram shows a cask in its initial position (upright) and its final position (tipped at an angle α). Key parameters include:

- CASK INITIAL POSITION
- CASK FINAL POSITION?
- C.G. (Center of Gravity)
- C.G. max
- C.G. min
- width w
- height difference Δh
- tipping velocity V_t
- tipping angle α

$$CG = \frac{L}{2} = \frac{170.25}{2} = 85.125'$$

$$c.g. min = \frac{\omega}{2} = \frac{39.82}{2} = 1.66'$$

$$C.G. MAX = \left[\left(\frac{W}{2} \right)^2 + C_G^2 \right]^{1/2} = (1.66^2 + 7.09^2)^{1/2} = 7.28'$$

$$\Delta h = C_{G_{max}} - C_{G_{min}} = 7.28 - 1.66' = 5.62'$$

DESIGN CALCULATION

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 (9) Checker MA ISLAM Date 6/2/99

(10)

DROP ENERGY:

$$KE = \frac{1}{2} MV^2$$

$$CASK WEIGHT = 60,000 \text{ lb}_f$$

$$V = \sqrt{2gh}$$

$$h = 5.62'$$

$$\therefore KE = \frac{1}{2} M \cancel{V^2} gh = mgh \quad \text{Now } W = mg$$

$$\therefore KE = Wh$$

$$KE = 60,000 (5.62') = 337,200 \text{ ft} \cdot \text{lb}_f$$

IMPACT VELOCITIES/ACCELERATIONS

REF. SCHAUM'S OUTLINE SERIES, ENG. MECH, STATICS & DYNAMICS, 4th ED., P. 330.

$$\alpha = \sin^{-1} \left(\frac{C.G. \text{ min}}{C.G. \text{ Max}} \right) = \sin^{-1} \left(\frac{1.66}{7.28} \right) = 0.228 \text{ Rad}$$

$$= 13.06^\circ$$

$$\theta = 90 - \alpha = 76.94^\circ$$

$$\omega = \text{ANGULAR SPEED} = \sqrt{\frac{3g}{l} (1 - \cos \theta)}$$

$$V_t = \text{tang. Velocity} = \omega \bar{r}, \quad \bar{r} = C.G. \text{ MAX}$$

$$= \sqrt{\frac{3g}{l} (1 - \cos 76.94^\circ)} (7.28') = 16.71 \text{ ft/sec}$$

$$V_x = \text{HORIZ VELOCITY} = V_t \cos \theta = 3.78 \text{ ft/sec}$$

$$V_y = \text{VERTICAL VELOCITY} = V_t \sin \theta = 16.28 \text{ ft/sec}$$

DESIGN CALCULATION

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 (8) Originator DA Moody Date 5-27-99
 (9) Checker MA Islam Date 6/2/99

(10)

DROP # 2

STRAIGHT DROP FROM BOTTOM OF CASK HEIGHT = 5'-0"

DETERMINE MAX Δh :

$$h = \text{BOTTOM OF CASK} = 5'-0''$$

$$h_1 = \text{INITIAL DIST ABOVE PLATFORM STEEL} = h - (h_2 + h_3 + h_4) = 1'-0''$$

$$h_2 = \text{ASSUMED STEEL DEPTH} = 0'-6''$$

$$h_3 = \text{INITIAL CRUSH BLOCK HEIGHT} = 1'-6''$$

$$h_4 = \text{CURB WALL HEIGHT} = 2'-0''$$

$$h_5 = \text{FINAL CRUSH BLOCK HEIGHT} = 0.3 h_3 = 0'-5.4''$$

$$\Delta h = \text{DROP HEIGHT} = h - (h_2 + h_5 + h_4) = 2.05'$$

$$KE = \text{DROP ENERGY} = W \Delta h = 60,000(2.05) = 123,000 \text{ ft} \cdot \text{lb}_f$$

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DROP # 3

Cask Drop and Tip over from the West:

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Determine at what angle the MCO will contact the impact limiter:

 $i := 1..8$ $x_i :=$

Cask center line distance to the east from point of removal from truck

0
.5
1
1.5
2
2.5
3
3.5

 $y_{IL} := 4$ Top of impact limiter distance from the floor $l_{IL} := 6.9167$ Horizontal distance from point of MCO removal from truck to impact limiter $l_G := 12.5$ Vertical distance to first point of contact with gantry lower cross brace. $y_G := 12.0833$ Horizontal distance to first point of contact with gantry lower cross brace. $l_{CW} := 5.4167$ Vertical distance from point of MCO removal from truck to curb wall $y_{CW} := 2$ Horizontal distance from point of MCO removal from truck to curb wall

$$\theta_{IL_i} := \text{atan} \left[\frac{l_{IL} - (x_i + 1.65875)}{y_{IL}} \right]$$

$\theta_{IL} =$	0	
	52.738	
	49.946	
	46.789	
	43.213	deg
	39.162	
	34.586	
	29.444	
	23.725	

Vertical angle to MCO at point of contact with impact limiter during a cask drop and tip over scenario. Drop is postulated to drop in area to the west of the south load out pit curb wall. X represents the distance from the trailer offload position to the postulated drop position. When X equals 3' - 9", the cask will contact the curb wall during the vertical fall. At this point the cask is assumed to tip to the west.

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Determine MCO/Impact limiter contact distance from point of rotation on corner of MCO:

$$L_{\text{contact, IL}_i} := \left[\left[1_{\text{IL}} - (x_i + 1.65875) \right]^2 + y_{\text{IL}}^2 \right]^{\frac{1}{2}}$$

$$L_{\text{contact, IL}} = \begin{bmatrix} 0 \\ 6.607 \\ 6.216 \\ 5.842 \\ 5.488 \\ 5.159 \\ 4.859 \\ 4.593 \\ 4.369 \end{bmatrix}$$

Contact point distance from point of rotation**Determine vertical angle to MCO at point of contact with curb wall:**

$$\theta_{\text{CW}_i} := \text{atan} \left[\frac{1_{\text{CW}} - (x_i + 1.65875)}{y_{\text{CW}}} \right]$$

$$\theta_{\text{CW}} = \begin{bmatrix} 0 \\ 61.978 \\ 58.455 \\ 54.051 \\ 48.467 \\ 41.315 \\ 32.169 \\ 20.755 \\ 7.349 \end{bmatrix} \cdot \text{deg}$$

**Vertical angel to MCO at point
of contact with curb wall during
a cask drop and tip over scenario**

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Location 105 KW

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Determine MCO/Curb Wall contact distance from point of rotation on corner of MCO:

$$L_{\text{contact.CW}_i} := \left[\left[1_{\text{CW}} - (x_i + 1.65875) \right]^2 + y_{\text{CW}}^2 \right]^{\frac{1}{2}}$$

$$L_{\text{contact.CW}} = \begin{bmatrix} 0 \\ 4.257 \\ 3.823 \\ 3.407 \\ 3.016 \\ 2.663 \\ 2.363 \\ 2.139 \\ 2.017 \end{bmatrix}$$

Contact point distance from point of rotation

Determine vertical angle to MCO at point of contact with gantry:

$$\theta G_i := \text{atan} \left[\frac{1_G - (x_i + 1.65875)}{y_G} \right] + 0.0873$$

$$\theta G = \begin{bmatrix} 0 \\ 46.901 \\ 45.56 \\ 44.163 \\ 42.708 \\ 41.195 \\ 39.62 \\ 37.983 \\ 36.283 \end{bmatrix} \cdot \text{deg}$$

Vertical angel to MCO at point of contact with gantry
cross beam during a cask drop and tip over scenario

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Date 5-27-99 By DA Moody

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Location 105 KW Determine MCO/Gantry contact distance from point of rotation on corner of MCO:
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$$L_{\text{contact.G}_i} := \left[\left[1 - G - (x_i + 1.65875) \right]^2 + y_G^2 \right]^{\frac{1}{2}}$$

$$L_{\text{contact.G}} = \begin{bmatrix} 0 \\ 16.234 \\ 15.904 \\ 15.584 \\ 15.273 \\ 14.972 \\ 14.683 \\ 14.405 \\ 14.139 \end{bmatrix}$$

Distance from point of pivot to gantry cross beam. Contact will take place when this length is 15.854 feet or less.

Summary:

The MCO can contact the impact limiter at vertical angles ranging from approx. 40 deg. to 53 deg. The MCO will hit the gantry cross beam first at "X" equals 1.5 to 2.5 feet (angles 42 to 44 deg.). The MCO will contact the curb wall first at "X" equals 2.5 to 3.5 feet (angles 7 to 33 deg.)

The worst case vertical drop energy is therefore at theta = 53 deg. The worst case horizontal load is at theta = 45 degrees.

For all drop points & impact angles, the cask c.g. is beyond the impact point

Determine vertical drop energy/vertical change in Cask C.G. (Ref. Page 7)

$$\theta_1 := \text{atan}\left(\frac{1.65875}{7.09}\right) \quad \theta_1 = 13.168 \cdot \text{deg} \quad \theta_{\text{impact}} := 53 \cdot \text{deg} - \theta_1 \quad \theta_{\text{impact}} = 39.832 \cdot \text{deg}$$

$$\Delta_{h.CG} := (7.28 \cdot \text{ft}) - \left[(7.09^2 + 1.6587^2)^{\frac{1}{2}} \cdot \sin(90 \cdot \text{deg} - \theta_{\text{impact}}) \right] \cdot \text{ft} \quad \Delta_{h.CG} = 1.688 \cdot \text{ft}$$

$$KE_{\text{tip}} := \Delta_{h.CG} \cdot 60000 \cdot \text{lb} \cdot \text{ft} \quad KE_{\text{tip}} = 1.013 \cdot 10^5 \cdot \text{ft} \cdot \text{lb} \cdot \text{ft}$$

Therefore Drop # 1 has highest vertical drop energy, and therefore it is governing for the vertical case, and Drop # 2 has a higher vertical drop energy than Drop # 3.

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By DA Moody *DA*

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By MA Islam *MA*

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Size Crush Blocks based on Drop # 1 vertical energy: Two surface areas will be considered based on available space on the SLOP curb wall. Surface area 1 is 24" x 16". Surface area 2 is 36" x 16". For each area, two crush block depths will also be considered. These depths are based on the maximum depth of 2 feet that is available to place the crush blocks and impact beam.

Crush Volumes:

 $i := 1..2$ $A_i :=$ Crush block areas, 1 & 2

384
576

 $T_{k12} := 12$ $T_{k18} := 18$ Crush block thicknesses, 1 and 2

Crush block volumes for areas 1 and 2, and thicknesses 1 and 2:

 $Vol12_i := T_{k12} \cdot A_i$ $Vol12_i$ $Vol18_i := T_{k18} \cdot A_i$ $Vol18_i$

$4.608 \cdot 10^3$
$6.912 \cdot 10^3$

$6.912 \cdot 10^3$
$1.037 \cdot 10^4$

 $L := 102$

Impact Beam Length, from center lines of crush blocks:

 $W := 60000$

Cask Weight

 $h := 5.62$

Drop Height

 $KE := W \cdot h$ $KE = 3.372 \cdot 10^5$

Drop Energy

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Determine required foam densitys for each area/volume based on target equations developed by General Plastics for FR-3700 crush materials.

$$\rho_{12_i} := 3.75 + 0.17 \cdot \left(\frac{KE}{2 \cdot Vol_{12_i}} \right) \quad \rho_{12} = \begin{pmatrix} 0 \\ 9.97 \\ 7.897 \end{pmatrix} \quad (\text{Therefore, } J \cong 2.5 \text{ \& } e = 66 \%)$$

$$\rho_{18_i} := 3.75 + 0.17 \cdot \left(\frac{KE}{2 \cdot Vol_{18_i}} \right) \quad \rho_{18} = \begin{pmatrix} 0 \\ 7.897 \\ 6.514 \end{pmatrix} \quad (\text{Therefore, } J \cong 2.5 \text{ \& } e = 66 \%)$$

Last-A-Foam FR-3700 Paralell to Rise Crush Strengths for 6 thru 10 pound densities.

n := 1..8   P6_n :=   P7_n :=   P8_n :=   P9_n :=   P10_n :=

159	193	228	264	301
148	183	221	261	302
153	192	234	278	325
164	208	256	308	362
185	240	300	365	435
231	307	393	488	594
277	373	484	609	747
359	492	647	823	1022

Crush Averages (PSI) for 6, 7, 8, 9, and 10 lb/cu in. densities:

$$P6_{crushave} := \frac{P6_1 + P6_2 + P6_3 + P6_4 + P6_5 + P6_6 + P6_7 + P6_8}{8}$$

P6crushave = 209.5

$$P7_{crushave} := \frac{P7_1 + P7_2 + P7_3 + P7_4 + P7_5 + P7_6 + P7_7 + P7_8}{8}$$

P7crushave = 273.5

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Checked 6/2/99

By MA Islam

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$$P8_{crushave} := \frac{P8_1 + P8_2 + P8_3 + P8_4 + P8_5 + P8_6 + P8_7 + P8_8}{8}$$

$$P8_{crushave} = 345.375$$

$$P9_{crushave} := \frac{P9_1 + P9_2 + P9_3 + P9_4 + P9_5 + P9_6 + P9_7 + P9_8}{8}$$

$$P9_{crushave} = 424.5$$

$$P10_{crushave} := \frac{P10_1 + P10_2 + P10_3 + P10_4 + P10_5 + P10_6 + P10_7 + P10_8}{8}$$

$$P10_{crushave} = 511$$

Crush Averages for selected densities (LBf):

$$F718_{crushave} := P7_{crushave} \cdot A_2 \quad F718_{crushave} = 1.575 \cdot 10^5 \quad (\text{Applies to } A2, V2, 18)$$

$$F812_{crushave} := P8_{crushave} \cdot A_2 \quad F812_{crushave} = 1.989 \cdot 10^5 \quad (\text{Applies to } A2, V2, 12)$$

$$F818_{crushave} := P8_{crushave} \cdot A_1 \quad F818_{crushave} = 1.326 \cdot 10^5 \quad (\text{Applies to } A1, V1, 18)$$

$$F1012_{crushave} := P10_{crushave} \cdot A_1 \quad F1012_{crushave} = 1.962 \cdot 10^5 \quad (\text{Applies to } A1, V1, 12)$$

Maximum Crush Values in LBf based on largest crush pressures for selected block densities:

$$F718_{crushmax} := P7_8 \cdot A_2 \quad F718_{crushmax} = 2.834 \cdot 10^5 \quad (\text{Applies to } A2, V2, 18)$$

$$F812_{crushmax} := P8_8 \cdot A_2 \quad F812_{crushmax} = 3.727 \cdot 10^5 \quad (\text{Applies to } A2, V2, 12)$$

$$F818_{crushmax} := P8_8 \cdot A_1 \quad F818_{crushmax} = 2.484 \cdot 10^5 \quad (\text{Applies to } A1, V1, 18)$$

$$F1012_{crushmax} := P10_8 \cdot A_1 \quad F1012_{crushmax} = 3.924 \cdot 10^5 \quad (\text{Applies to } A1, V1, 12)$$

Summary:

Eight lb/cu ft. density foam, 18" thick x 24" long x 16" wide has the lowest maximum crush force. This force will set the beam size since for a simply support beam, the maximum force acting in the center is equal to 2 times the equal reaction forces at the end points.

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Date 5-27-99

By DA Moody *DM*

Checked 6/2/99

By MA Islaw

Location 105 KW

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Size Beam based on Yield Stress and lowest maximum crush strength. Assume use of A441, Grade 50 Steel.

$$\sigma_y := 50000$$

$$L := 102$$

Impact Beam Length, from center lines of crush blocks:

$$\sigma = M/S$$

$$M = PL/4$$

Simply Supported Beam

$$P := 2 \cdot F818_{\text{crushmax}}$$

$$P = 4.969 \cdot 10^5$$

Therefore: $\sigma = PL/2S$ And $S := \frac{P \cdot L}{4 \cdot \sigma_y}$ $S = 253.417$

Consider Plastic Moment Capacity: Ref. Gaylord and Gaylord, Structural Engineers Handbook Section 7-3, Table 1.

The plastic moment shape factor for Wide Flange and Tube Steel shapes is approximately 1.12,
 $f := 1.12$

S = Member Cross Section

f = Plastic Shape Factor

$Z = S \times f$ (Plastic Section)

Now: $M_p = \sigma_y \times Z$ (Plastic Moment Capacity)

and Elastic Moment, $M_e = PL/4$ (Actual Elastic Moment)

and Plastic Moment, $M_p = 1.1M_e$ (Actual Plastic Moment per N690).

So: $1.1PL/4$ must be less than $\sigma_y \times Z$

Therefore:
$$S_{\min} := \frac{1.1 \cdot \left(\frac{P \cdot L}{4} \right)}{\sigma_y \cdot f}$$
  $S_{\min} = 248.892$

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 Checker MA Islam Date 6/2/99

CHECK WALL BEARING, CRUSH LOAD:

$$F_{ALLOW} = \phi (0.85 f'_c A)$$

$$\phi = 0.7$$

$$f'_c = 3000 \text{ lb/in}^2$$

$$A = 24 \times 16 = 384 \text{ in}^2$$

$$\therefore F_A = 1785 A$$

$$= 1785(384)$$

$$= 685,440 \text{ lbf}$$

$$F_{ACTUAL} = 248,450 \text{ lbf} < 685,440 \text{ OK.}$$

$$\text{Factor of Safety} = F.S. = \frac{685,440}{248,450} = 2.8$$

DESIGN ANALYSIS

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Date

By DA Moody

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By MA Islam

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Determine required section properties along length of beam based on moment distribution of a simply supported beam with load in the center:

$$\sigma_y := 50000 \quad f := 1.12$$

$$\sigma = Mx/S \quad Mx = PX/2 \quad \text{Simply Supported Beam}$$

$$P := 2 \cdot F818_{\text{crushmax}} \quad P = 4.969 \cdot 10^5$$

$$\text{Therefore: } \sigma = PX/2S \quad \text{And} \quad S = PX/2\sigma$$

$$i := 1..11$$

$$X_i := \frac{F818_{\text{crushmax}} \cdot X_i}{S818_i} \quad \text{Neglects Plastic Capacity}$$

1	
5	
10	0
15	0
20	1 4.969
25	2 24.845
30	3 49.69
35	4 74.534
40	5 99.379
45	6 124.224
50	7 149.069
	8 173.914
	9 198.758
	10 223.603
	11 248.448

$$\text{and } Z818_i := \frac{1.1 \cdot (F818_{\text{crushmax}} \cdot X_i)}{1.12 \cdot \sigma_y}$$

$$Z818_i \quad \text{Considers Plastic Capacity}$$

4.88
24.401
48.802
73.203
97.605
122.006
146.407
170.808
195.209
219.61
244.011

Summary:

Impact beam requires a center section modulus of approximately $S = 249$ and at the ends where the depth is reduced ($X = 10$) $S = 49$.

ANALYTICAL CALCULATIONS

Page 18 of 28Subject CONCEPTUAL DESIGN: OPS PLATFORM, CFEM-C-0006Originator D.A. MooreDate 5-27-99Checker MA IslamDate 6/2/99BEAM SECTION PROPERTIES

A) W18 X 119, BOXED IN:

$$W = 11.265''$$

$$d = 18.97$$

$$t_f = 1.060$$

$$t_w = 0.655$$

$$t_p = 1''$$

$$T = 16.85$$

$$C_x = d/2 = 9.485''$$

$$C_y = w/2 = 5.6325''$$

$$\textcircled{1} = W18 \times 119$$

$$\textcircled{2} = 1'' \text{ PLATE}$$

$$I_x = I_{1x} + I_{2x}$$

$$I_{1x} = 2190 \text{ in}^4$$

$$I_{2x} = \frac{t_p T^3}{12} = \frac{1 (16.85)^3}{12} = 398.7 \text{ in}^4$$

$$\therefore I_x = 2190 + (398.7) 2 = 2987 \text{ in}^4$$

$$S_x = \frac{I_x}{C_x} = \frac{2987}{9.485} = 314.9 \text{ in}^3$$

$$I_y = I_{1y} + I_{2y}$$

$$I_{1y} = 253 \text{ in}^4$$

$$I_{2y} = 2 \left[\frac{T t_p^3}{12} + T t_p \left(\frac{w}{2} - \frac{t_p}{2} \right)^2 \right]$$

$$= 2 \left[\frac{(16.85)(1.00)^3}{12} + 16.85(1.00) \left(\frac{11.265}{2} - \frac{1.00}{2} \right)^2 \right]$$

$$= 891 \text{ in}^4$$

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ANALYTICAL CALCULATIONS

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$$I_{1y} + I_{2y} = 253 + 891 = 1144 \text{ in}^4$$

$$S_y = \frac{I_y}{c_y} = \frac{1144}{5.6325} = 203 \text{ in}^3$$

$$\begin{aligned} \text{AREA} &= A_1 + A_2 \\ &= 35.1 + 2(1)(16.85) \\ &= 68.8 \text{ in}^2 \end{aligned}$$

TORSIONAL PROPERTIES

ASSUME BOX SECTION, NEGLECTING W SECTION WEB

$$\begin{aligned} R &= \frac{2t_p w^2 d^2}{w+d} \\ &= \frac{2(1)(11.265)^2 (18.97)^2}{11.265 + 18.97} \\ &= 3021 \text{ in}^4 \end{aligned}$$

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ANALYTICAL CALCULATIONS

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B.) 6" HIGH SECTION @ END OF BEAM

$$W = 11.265$$

$$d = 6"$$

$$t_f = 1.06$$

$$t_w = 0.655$$

$$t_p = 1"$$

$$T = 4"$$

$$C_x = 3$$

$$C_y = W/2 = 5.6325"$$

$$\textcircled{1} = \text{MODIFIED } W18 \times 119$$

$$\textcircled{2} = 1" \text{ PLATE}$$

$$\begin{aligned} I_{1x} &= 2 \left(\frac{W t_f^3}{12} + t_f W \left(\frac{d}{2} - \frac{t_f}{2} \right)^2 \right) + \frac{t_w T^3}{12} \\ &= 2 \left(\frac{11.265 (1.06)^3}{12} + (1.06)(11.265) \left(\frac{6}{2} - \frac{1.06}{2} \right)^2 \right) + \frac{0.655 (4)^3}{12} \\ &= 151.43 \end{aligned}$$

$$I_{2x} = \frac{t_p (T)^3}{12} = \frac{1 (4)^3}{12} = 5.33 \text{ in}^4$$

$$I_x = 151.4 + 2(5.33) = 162.09$$

$$S_x = \frac{162.09}{3} = 54.0 \text{ in}^3$$

$$\begin{aligned} I_{1y} &= \frac{T_f (W)^3}{12} (2) + \frac{T (t_w)^3}{12} \\ &= \frac{1.06 (11.265)^3}{12} (2) + \frac{4 (0.655)^3}{12} \\ &= 238.3 + 0.562 \\ &= 253 \text{ in}^4 \end{aligned}$$

$$\begin{aligned} I_{2y} &= \left[\frac{T t_p^3}{12} + T t_p \left(\frac{W}{2} - \frac{t_p}{2} \right)^2 \right] 2 \\ &= \left[\frac{4 (1)^3}{12} + 4 (1) \left(\frac{11.265}{2} - \frac{1.0}{2} \right)^2 \right] 2 \\ &= 211.41 \end{aligned}$$

ANALYTICAL CALCULATIONS

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$$I_y = 253 + 211.41$$

$$= 464.4 \text{ in}^4$$

$$S_y = \frac{464.4}{5.6325} = 82.45 \text{ in}^3$$

$$\text{AREA} = A_1 + A_2$$

$$A = 2(t_p T) + 2(w t_f) + T t_w$$

$$= 2(1)(4) + 2(11.265)(1.06) + 4(0.655)$$

$$= 34.5 \text{ in}^2$$

TORSION:

$$R = \frac{2(1)(11.265)^2(6)^2}{11.265 + 6} = 529.21 \text{ in}^4$$

ANALYTICAL CALCULATIONS

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LATERAL SYSTEM DESIGN: (HORIZ. FORCES FROM DROP #3).

ASSUMPTION:

WORST CASE LATERAL LOAD OCCURS @ $\theta = 45^\circ$ $l = \text{CASK LENGTH} = 14.1875'$ $c_w = \text{CASK WIDTH} = 3.3175'$ $W = \text{CASK WEIGHT} = 60,000 \text{ lb}$
LOADED $C.G. = 14.1875/2 = 7.09' = \bar{r}$ $H_{max} = 7.09' - \frac{c_w}{2} = 5.435'$ $a_t = \bar{r} \alpha$ $\bar{a}_n = \bar{r} \omega^2$

$$\Sigma M_O = I_O \alpha$$

$$Mgd = I_O \alpha$$

 $\omega = \text{ANGULAR VELOCITY}$ $\alpha = \text{ANGULAR ACCELERATION}$ $I_O = \text{MOMENT OF INERTIA OF CASK}$
ABOUT AXIS OF ROTATION.

$$d = \frac{1}{2} l \sin \theta$$

$$I_O = \frac{1}{3} M l^2$$

$$\omega = \sqrt{\frac{3g}{l} (1 - \cos \theta)}$$

REF SCHAUM'S OUTLINE, PROB 17.3
Pg. 331.

$$\alpha = \frac{3g}{2l} \sin \theta$$

"

$$\therefore @ \theta = 45^\circ, \omega = 1.412 \frac{\text{RAD}}{\text{SEC}} \quad \& \quad \alpha = 2.407 \frac{\text{RAD}}{\text{SEC}^2}$$

$$\therefore \bar{a}_t = 7.09' (2.407) \frac{\text{RAD}}{\text{SEC}^2} = 17.067 \text{ ft/SEC}$$

$$\bar{a}_n = 7.09' (1.412)^2 = 14.14 \text{ ft/SEC}^2$$

DESIGN CALCULATION

HNF-4576, Rev. 0

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(10)

$$V_t = WF = 10.01 \text{ ft/sec}$$

$$V_x = 0.707 V_t = 7.07 \text{ ft/sec} = 84.84 \text{ in/sec}$$

ESTIMATE FORCE ON BEAM: (REF. BLODGETT, Pg. 68)
 SUPPLEMENTAL SOLUTIONS
 TO WELDMENTS.

$$F_{1a} = F_{1b} = \frac{1}{2} F_2$$

BEAM STIFFNESS (HORIZONTAL, REF Pg. 17-20)

$$K = \frac{48EI}{L^3}$$

$$I_y = 1144 \text{ in}^4$$

$$S_y = 208.3 \text{ in}^3$$

$$A = 66.1 \text{ in}^2$$

$$E = 29 \times 10^6$$

$$\therefore K = 5.6 \times 10^5$$

$$\text{IMPACT FORCE: } F = W_1 \left[1 + \sqrt{1 + \frac{K_2 V_1^2}{g(W_1 + W_2)}} \right]$$

$$W_1 = \text{CASK WT.} = 60,000 \text{ lb}_f$$

$$W_2 = \text{BEAM WT.} \approx 120 \text{ lb} \left(\frac{142}{12} \right) = 1,420 \text{ lb}_f$$

$$\therefore F_2 = 60,000 \left[1 + \sqrt{1 + \frac{5.6 \times 10^5 (84.84)^2}{386.4 (61,420)}} \right]$$

$$F_2 = 8.4 \times 10^5 \text{ lb}_f$$

$$\therefore F_{1a/b} = 4.2 \times 10^5 \text{ lb}_f \quad \left(\text{LOAD IS OBVIOUSLY TOO LARGE FOR LATERAL SYSTEM ANCHORAGE} \right)$$

DESIGN CALCULATION

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(10)

END SUPPORTS: (REF KLEINLOGAL, CASE 41/8)

$$K = \frac{J_2}{J_1} \cdot \frac{h}{l}$$

$$N_1 = K + 2$$

$$N_2 = 6K + 1$$

$$h = 4'$$

$$l = 3'$$

$$M_A = M_D = \pm \frac{Ph}{2} \cdot \frac{3K+1}{N_2}$$

$$V_D = -V_A$$

$$M_B = M_C = \pm \frac{Ph}{2} \cdot \frac{3K}{N_2}$$

$$H_D = -H_A = \frac{P}{2}$$

$$M_{y_1} = M_A + \frac{P}{2} y$$

$$M_x = \frac{x' - x}{l} M_B$$

$$M_{y_2} = M_D - \frac{P}{2} y_2$$

SEE NEXT PAGE FOR CALCULATIONS & MEMBER SIZES.

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DESIGN ANALYSIS

Client SNF FACILITY PROJECTS

WO/Job No. 65100300

Subject Conceptual Design/Structural Analysis, OPS
Impact Limiter/Interface Platform

Date 5-27-99

By DA Moody

Checked 6/2/99

By MA Islam

Location 105 KW

Revised

By

End Supports, Calculate reactions, moments, and stresses:

$$P := 420000 \cdot \text{lbf} \quad h := 48 \cdot \text{in} \quad l := 36 \cdot \text{in} \quad i_1 := 1.4 \quad j_1 := 27 \cdot \text{in}^4 \quad j_2 := 27 \cdot \text{in}^4$$

$$S_i :=$$

$.88 \cdot \text{in}^3$	(2 x 2 x 5/16 T.S.)
$2.39 \cdot \text{in}^3$	(3 x 3 x 5/16 T.S.)
$6.13 \cdot \text{in}^3$	(4 x 4 x 1/2 T.S.)
$10.18 \cdot \text{in}^3$	(5 x 5 x 1/2 T.S.)

$$k := \frac{j_1 h}{j_2 l}$$

$$k = 1.333$$

$$N_1 := k + 2$$

$$N_1 = 3.333$$

$$N_2 := 6 \cdot k + 1$$

$$N_2 = 9$$

$$M_A := \frac{P \cdot h}{2} \cdot \left(\frac{3 \cdot k + 1}{N_2} \right)$$

$$M_A = 5.6 \cdot 10^6 \cdot \text{in} \cdot \text{lbf}$$

$$M_B := \frac{P \cdot h}{2} \cdot \left(\frac{3 \cdot k}{N_2} \right)$$

$$M_B = 4.48 \cdot 10^6 \cdot \text{in} \cdot \text{lbf}$$

$$V_D := \frac{2 \cdot M_B}{l}$$

$$V_D = 2.489 \cdot 10^5 \cdot \text{lbf}$$

$$H_D := \frac{P}{2}$$

$$H_D = 2.1 \cdot 10^5 \cdot \text{lbf}$$

$$\sigma_i := \frac{M_A}{S_i}$$

$$\sigma = \begin{bmatrix} 0 \\ 6.364 \cdot 10^6 \\ 2.343 \cdot 10^6 \\ 9.135 \cdot 10^5 \\ 5.501 \cdot 10^5 \end{bmatrix} \cdot \frac{\text{lbf}}{\text{in}^2}$$

Summary:

Allowable stresses are exceeded for all members selected. Also reactions and moments at the anchorage points are very large requiring a base plate and concrete anchorage system that is not feasible for the space available in the field.

Recommendation: Use foam impact material to reduce the load on the lateral support system.

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 (9) Checker MA IBlaun Date 6/2/99

(10)

SIZE FOAM FOR LATERAL IMPACT LOADS:

PLACE FOAM IN FRONT OF & ON TOP OF CURB SUCH THAT IT BEARS Laterally AGAINST THE CURB WALL & THE IMPACT BEAM.

ASSUMPTIONS:

- 2'-6" CRUSH DEPTH (HORIZ.) AVAILABLE
- 1/2 WIDTH OF CASK & 2'-0" OF CRUSH DEPTH IS EFFECTIVE IN THE CRUSH.

CRUSH BLOCK VOLUME:

$$\begin{aligned}
 Vol &= \frac{\text{CASK WIDTH}}{2} (\text{CRUSH DEPTH}_{\text{HORIZ}}) (\text{CRUSH DEPTH}_{\text{VERT}}) \\
 &= \frac{39.81}{2} (24)^2 \\
 &= 11,465 \text{ in}^3
 \end{aligned}$$

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(10)

DROP ENERGY:

$$\text{FROM PAGE 11, } \Delta h_{c.g.} = 7.28 - \left[(7.09^2 + 1.6587^2)^{1/2} \sin(90 - \theta_{imp}) \right]$$

ASSUME C.G. WILL ROTATE TO 45° @ IMPACT

$$\therefore \Delta h_{c.g.} = 2.13'$$

$$\therefore KE = 60,000(2.13) = 127,800 \text{ ft. lb}_f$$

RESOLVE HORIZ & VERT. COMPONENTS,

$$KE_x = KE_y = 0.707 KE = 90,354 \text{ ft. lb}_f$$

FOAM SIZE:

$$\begin{aligned} \rho_{\text{TARGET}} &= 3.75 + 0.17 \frac{KE}{\text{Vol}} \\ &= 3.75 + 0.17 \left(\frac{90,354}{11,465} \right) \\ &= 5.09 \frac{\text{ft. lb}}{\text{in}^3} \end{aligned}$$

USE 5 lb/in^3 DENSITY

CRUSH AVERAGE: (PARALLEL TO CRUSH RISE) FR-3700
FOAM

$$\rho_{\text{ave}} = \frac{127 + 115 + 117 + 123 + 136 + 164 + 194 + 247}{8} = 153 \text{ lb/in}^2$$

$$F_{\text{ave}} = 153(\text{AREA}) = 153 \left(\frac{39.81}{2}(24) \right) = 73,091 \text{ lb}_f$$

$$R_1 = R_2 = \text{REACTION @ END SUPPORT} = \frac{73,091}{2} = 36,546 \text{ lb}_f$$

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DESIGN ANALYSIS

Client SNF FACILITY PROJECTS

WO/Job No. 65100300

Subject Conceptual Design/Structural Analysis, OPS
Impact Limiter/Interface Platform

Date 5-27-99

By DA Moody *DA Moody*

Checked 6/2/99

By MA Islam *MA Islam*

Location 105 KW

Revised

By

Consider average crush force on end supports: Using this approach, the horizontal drop energy should be dissipated once the crush is complete. Therefore the impact beam will bear only the crush force and will not see the load from a direct contact or impact of the cask.

Using Mathcad equations from previous pages, input the new reaction force:
Consider only the 5 x 5 tube steel.

$$P := 36546 \cdot \text{lbf} \quad h := 48 \cdot \text{in} \quad l := 36 \cdot \text{in} \quad i := 1.4 \quad j_1 := 27 \cdot \text{in}^4 \quad j_2 := 27 \cdot \text{in}^4$$

$$S := 10.18 \cdot \text{in}^3 \quad (5 \times 5 \times 1/2 \text{ T.S.}) \quad k := \frac{j_1 h}{j_2 l} \quad k = 1.333$$

$$N_1 := k + 2 \quad N_1 = 3.333 \quad N_2 := 6 \cdot k + 1 \quad N_2 = 9$$

$$M_A := \frac{P \cdot h}{2} \left(\frac{3 \cdot k + 1}{N_2} \right) \quad M_A = 4.873 \cdot 10^5 \cdot \text{in} \cdot \text{lbf}$$

$$M_B := \frac{P \cdot h}{2} \left(\frac{3 \cdot k}{N_2} \right) \quad M_B = 3.898 \cdot 10^5 \cdot \text{in} \cdot \text{lbf}$$

$$V_D := \frac{2 \cdot M_B}{l} \quad V_D = 2.166 \cdot 10^4 \cdot \text{lbf}$$

$$H_D := \frac{P}{2} \quad H_D = 1.827 \cdot 10^4 \cdot \text{lbf}$$

$$\sigma := \frac{M_A}{S} \quad \sigma = 4.787 \cdot 10^4 \cdot \frac{\text{lbf}}{\text{in}^2}$$

This stress level is within the plastic moment capacity of 42 ksi tube steel. However, the moments at anchorages are still very high and will require a structure that is optimized to reduce moments at its anchorages ~~anchorage~~

APPENDIX N

Summary of Analyses and Results

Basin Water Leak Rate After an MCO Cask Drop Into the K Basin South Loadout Pit for the Current Design

SUMMARY OF ANALYSES AND RESULTS: BASIN WATER LEAK RATE AFTER A MCO/CASK DROP INTO THE K-BASIN SOUTH LOAD-OUT PIT FOR THE CURRENT DESIGN

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June 1999

Prepared by:

S. L. Hecht

6-18-99

[Note: The intent of this effort was to support the current design, and hence much of the information presented herein does not apply to the new design, which is the focus of this conceptual design. Specifically, the structural analyses, much of which is unchecked, is presented for information only as it relates specifically to the current design. Furthermore, only a summary of structural analysis is presented here. The hydraulic analyses do, however, apply to both the current and the new designs. Hence, hydraulic analyses are presented in detail and was independently verified (pipe flow) by an alternative calculation as it is a potential basis for the new IPSS design. Unreviewed porous media flow analysis are also presented for information.]

INTRODUCTION

Analyses were made to determine the damage, i.e., the wall-floor joint separation (gap), and the associated leak rate, resulting from a postulated MCO/CASK drop into the K-Basin South Load-Out Pit (SLOP). Only one analysis (Peterson 1996) existed prior to this effort, that quantified the size of the gap(s) and associated flow area(s). This analysis was, however, ultra-conservative as it did not include a number of energy absorbing feature, e.g., plasticity in the structure, concrete and soil. Recently, a number of structural analyses were made which basically modified or expanded on prior models. These prior models (Moore 1997 and Tu 1999) were focused on obtaining loads, stress and strains, and hence for simplicity and conservatism did not have features which explicitly addressed the gap size.

SUMMARY OF STRUCTURAL ANALYSES

The updated structural models (see Table 1) are very complex, state-of-the-art, finite element structural analyses. These dynamic drop analyses include a large amount of non-linear characteristics through the modeling of such features as physical clearances, and plasticity in the rebar, concrete, soil and the IPSS structure. Both the concrete crushing model and the soil energy-absorbing feature were based on constitutive relationships that have been benchmarked with data (some Hanford). Hence, predictions from these structural analyses are intended to be a "best estimate" or nominal. The 14 ft (later expanded to 17) drop into the pinned Immersion Pail was chosen as the most severe drop based on the calculated concrete displacements for various drop conditions as determined by Moore 1997. An evaluation was also made for

a combined 30 ft. drop, which assumes that the shear pins that attach the pail to the IPSS fail, and then the combined pail and MCO/CASK continue to drop another 13 ft.

Table 1, gives a description of analysis and results, to date. A number of cases were run, and generally represent a progression in model development, based on a heuristic process from review of past analysis shortcomings (Cases 1-8), and a update in loading conditions (Case 9). An evaluation was also made for a potential in-situ design retrofits, i.e., an impact limiter under IPSS bottom plate (Case 10). Case 9 in Table 1 is most representative of the most severe drop, using the most complete model. Here a floor-to-wall gap of 0.210 inches is predicted. The use of an impact limiter under the IPSS alone will reduce the gap by about 30%. A permanent opening of the joint of 0.08 inches is predicted for a 3 ft. drop using the best model (Case 11). The analysis of the combined 30 ft. drop indicated that there would be extensive and unacceptable concrete floor slab damage (cracking), and the joint gap size determination was uncertain.

HYDRAULIC ANALYSIS

To determine the basin water leak (flow) rate, the gap size calculated in the structural analysis is used to calculate a flow area. The flow area model is based on that used in the Peterson analysis which assumes that a wedge shape opening occurs (end of the SLOP where the transfer channel is a pivot point, max displacement at loaded end). This simple model seems reasonable based on detailed structural analysis. Flow rates were calculated based on hydraulic resistance from both a "pipe" model and a porous media model. The assumptions that the soil does not provide any hydraulic resistance, and act as an infinite sink; and that the rubber waterstop is totally ineffective were conservatively used in the hydraulic calculations. Furthermore, for the pipe flow model, the loss coefficient for inlet/exist loses is chosen to be on the low end of the literature values (conservative). This "pipe flow" model, the Fortran program GAPFLOW, is shown in Exhibit 1. Here, the pressure drop at given flow rates are calculated for various gap sizes. The leak rate for a given gap size is the calculated flow rate when the pressure drop is equal to the basin water head of 16 ft. (998 lb/ft²). Figure 1, shows the leak flow rate as a function of gap size based on a pipe flow model. An independent pipe flow analysis (Plys - memo 4/28/99) was made and basically confirms the values given in figure 1 (slightly lower flow for gap > .05; slightly higher for gaps < 0.05). The porous media flow results (Plys - memos 5/7/99 & 6/14/99) show significantly lower flow rates, but may be non-conservative. Figure 1, also show the SAR flow rate limits for reference.

CONCLUSION

The predicted gap size of 0.21 inches for the most severe drop would give a flow rate of approximately 4500 GPM. This is above the SAR allowable limits, and hence this drop is unacceptable. Another calculations was made to determine what the maximum gap would be under a "no rebar yield criteria", as is proposed for the redesigned IPSS. Here a maximum elastic gap is estimated to be 0.0012 inches. Assuming that this drop would fail the waterstop, a flow rate of 0.005 GPM, an acceptable value, is predicted. Porous media flow analysis indicate, that for the redesigned IPSS, the SLOP floor can tolerate loadings up to 700 Kips.

REFERENCES

- Peterson, W. S., 1996, *SNF Cask Drop Analysis for K-Basin Loadout Pits*, MCE Engineering
- Moore, C. J. 1998, *Structural Evaluation of Cask-MCO Drop into K Basin South Loadout Pit*, Document SNF-3774, Rev. 0, with all appendices. Duke Engineering and Services Hanford, Richland, Washington.
- Tu, K. C. and S. Kanjilal, 1999, Engineering Report, *105-K Basins South Loadout Pit Concrete Results for The Concentric Multi-Canister Overpack/Cask Drop Into the Pinned Immersion Pail*, SNF-4345, Rev. 0, prepared for Duke Engineering Services Hanford by Fluor Daniel Northwest

ANALYSIS AND RESULTS FOR FLOOR WALL GAP AFTER 14-17 FT MCO/CASK DROP INTO PAIL PINNED TO IPSS

CASE/ANALYSIS	DROP HEIGHT (FT)	DESCRIPTION	CONCRETE	SOIL	REBAR (WALL TO FLOOR)	GAP SIZE (IN)	FLOW * (GPM)
(1) SNF CASK DROP (MCE- PETERSON 96) - floor/wall sep. dr tension	14.15	ELASTIC FEA - PSUEDO PLASTIC REBAR - STATIC WITH ENERGY BALANCE - RIGID CASK NO IPSS	ELASTIC $F_c = 3000$	ELASTIC (350 PCI)	ELASTIC-PLASTIC ($S_y = 40\text{KSI}$)	<1.85 (EST)	>10,000
(2) LIKE 1 EXCEPT SOIL MOD.	14.15	ELASTIC FEA - PSUEDO PLASTIC REBAR - STATIC WITH ENERGY BALANCE - RIGID CASK NO IPSS	ELASTIC $F_c = 3000$	ELASTIC (133 PCI)	ELASTIC-PLASTIC ($S_y = 40\text{KSI}$)	<2.51 (EST)	>10,000
(3) SNF-3774, APEND A1 (C. MOORE 97)	14.15	ELASTIC-PLASTIC FEA - DYNAMIC. CASK-PAIL IPSS - TWO PHASE (UPPER BOUND LOAD); AXISYMMETRIC APPROXIMATION	ELASTIC-PLASTIC (DRUCKER-PRAGER - 3000 PSI CRUSH - TUNED TO TEST DATA)	ELASTIC-PLASTIC (D-P) TUNED TO TEST DATA - SOIL DEPTH BASED ON INFLUENCE DEPTH FOR SLAB	NONE	0.1	1030
(4) 3-D INELASTIC (MOD FDMV DRAFT REPORT (K.C. TU 99)	14.15	3-D 1/4 SYM - SLAB TO INNER WALL - NO REBAR - ELASTIC PLASTIC - DYNAMIC ALL STRUCTURAL STEEL COMPONENTS - SINGLE PHASE ANA.	ELASTIC-PLASTIC (DRUCKER-PRAGER - 3000 PSI CRUSH - TUNED TO TEST DATA)	ELASTIC-PLASTIC (D-P) TUNED TO TEST DATA - SOIL DEPTH BASED ON INFLUENCE DEPTH FOR SLAB -250 PCI SOIL MOD. - 12 FT OF SOIL TO RIGID B.C.	NONE		
(5) - LIKE CASE 4 FLOOR EXPANDED TO OUTER WALL	14.15	3-D 1/4 SYM - SLAB TO OUTER WALL - NO REBAR - ELASTIC PLASTIC - DYNAMIC ALL STRUCTURAL STEEL COMPONENTS - SINGLE PHASE ANA.	ELASTIC-PLASTIC (DRUCKER-PRAGER - 3000 PSI CRUSH - TUNED TO TEST DATA)	ELASTIC-PLASTIC (D-P) TUNED TO TEST DATA - SOIL DEPTH BASED ON INFLUENCE DEPTH FOR SLAB -250 PCI SOIL MOD. - 12 FT OF SOIL TO RIGID B.C.	NONE	0.14	2500
(6) LIKE CASE 5 WITH WALL REBAR	14.15	3-D 1/4 SYM - SLAB TO OUTER WALL - REBAR - ELASTIC PLASTIC - DYNAMIC ALL STRUCTURAL STEEL COMPONENTS - SINGLE PHASE ANA.	ELASTIC-PLASTIC (DRUCKER-PRAGER - 3000 PSI CRUSH - TUNED TO TEST DATA)	ELASTIC-PLASTIC (D-P) TUNED TO TEST DATA - SOIL DEPTH BASED ON INFLUENCE DEPTH FOR SLAB -250 PCI SOIL MOD. - 12 FT OF SOIL TO RIGID B.C.	ELASTIC-PLASTIC ($S_y = 40\text{KSI}$) - 12 in left length	0.07	900
(7) LIKE CASE 5 - WITH INFINITE SOIL ELEMENTS - NO REBA	14.15	3-D 1/4 SYM - SLAB TO OUTER WALL - NO REBAR - ELASTIC PLASTIC - DYNAMIC ALL STRUCTURAL STEEL COMPONENTS - SINGLE PHASE ANA - INFINITE SOIL	ELASTIC-PLASTIC (DRUCKER-PRAGER - 3000 PSI CRUSH - TUNED TO TEST DATA)	ELASTIC-PLASTIC (D-P) TUNED TO TEST DATA - INELASTIC SOIL DEPTH BASED ON INFLUENCE DEPTH FOR SLAB -250 PCI SOIL MOD. - 12 FT OF SOIL TO INFINITE ELEMENT	NONE	0.31	7500
(8) LIKE CASE 7 WITH REBAR	14.15	3-D 1/4 SYM - SLAB TO OUTER WALL - REBAR - ELASTIC PLASTIC - DYNAMIC ALL STRUCTURAL STEEL COMPONENTS - SINGLE PHASE ANA - INFINITE SOIL	ELASTIC-PLASTIC (DRUCKER-PRAGER - 3000 PSI CRUSH - TUNED TO TEST DATA)	ELASTIC-PLASTIC (D-P) TUNED TO TEST DATA - INELASTIC SOIL DEPTH BASED ON INFLUENCE DEPTH FOR SLAB -250 PCI SOIL MOD. - 12 FT OF SOIL TO INFINITE ELEMENT	ELASTIC-PLASTIC ($S_y = 40\text{KSI}$) - 8 in left length	0.17	3000
(9) LIKE CASE 8 BUT FOR A 17 FT DROP	17	3-D 1/4 SYM - SLAB TO OUTER WALL - REBAR - ELASTIC PLASTIC - DYNAMIC ALL STRUCTURAL STEEL COMPONENTS - SINGLE PHASE ANA - INFINITE SOIL	ELASTIC-PLASTIC (DRUCKER-PRAGER - 3000 PSI CRUSH - TUNED TO TEST DATA)	ELASTIC-PLASTIC (D-P) TUNED TO TEST DATA - INELASTIC SOIL DEPTH BASED ON INFLUENCE DEPTH FOR SLAB -250 PCI SOIL MOD. - 12 FT OF SOIL TO INFINITE ELEMENT	ELASTIC-PLASTIC ($S_y = 40\text{KSI}$) - 8 in left length	0.21	4500
(10) LIKE CASE 8 + IMPACT LIMITER (6 IN FOAM) UNDER IPSS BOTTOM PLATE	17	3-D 1/4 SYM - SLAB TO OUTER WALL - REBAR - ELASTIC PLASTIC - DYNAMIC ALL STRUCTURAL STEEL COMPONENTS - SINGLE PHASE ANA - INFINITE SOIL + IMPACT LIMITER UNDER IPSS	ELASTIC-PLASTIC (DRUCKER-PRAGER - 3000 PSI CRUSH - TUNED TO TEST DATA)	ELASTIC-PLASTIC (D-P) TUNED TO TEST DATA - INELASTIC SOIL DEPTH BASED ON INFLUENCE DEPTH FOR SLAB -250 PCI SOIL MOD. - 12 FT OF SOIL TO INFINITE ELEMENT	ELASTIC-PLASTIC ($S_y = 40\text{KSI}$) - 8 in left length	0.16	2800
(11) LIKE CASE 8 BUT FOR A 3 FT DROP	3	3-D 1/4 SYM - SLAB TO OUTER WALL - REBAR - ELASTIC PLASTIC - DYNAMIC ALL STRUCTURAL STEEL COMPONENTS - SINGLE PHASE ANA - INFINITE SOIL	ELASTIC-PLASTIC (DRUCKER-PRAGER - 3000 PSI CRUSH - TUNED TO TEST DATA)	ELASTIC-PLASTIC (D-P) TUNED TO TEST DATA - INELASTIC SOIL DEPTH BASED ON INFLUENCE DEPTH FOR SLAB -250 PCI SOIL MOD. - 12 FT OF SOIL TO INFINITE ELEMENT	ELASTIC-PLASTIC ($S_y = 40\text{KSI}$) - 8 in left length	0.08	950

EXHIBIT 1

```

      program gapflow
c
c  a simple program for hydraulics of flow through small gap
c  calculated delta P for various clearances at a given velocities
c  length, fluid is water at 50 F
c
c  *** unit are in ft -sec -lbs
      real len,pi,k
c
c  *** constants and initialize **
      pi = 3.1416
      g = 32.2      ! ft/sec^2
      len1 = 1.33    ! wall thick
      tl = 300./12.  ! opening length
      k = 0.5        ! inlet-outlet loss coef
c
c  *** water properties at 50 F
      rho = 62.5
      vis = 2.5e-4    ! lb-sec/ft^2
c
c  *** read in input
10  write(6,*) 'gap size (ft), rough/dia '
      read (5,*) dc,rou
c
      aa = dc*tl
      wp = 2.*(tl+dc)
      dh = 4.*aa/wp
c
      write(6,*) 'enter initial, final and increment velocity f/s '
      read(5,*) vint,vfin,vinc
      v = vint

      write (6,201)
c
c  *** loop through velocity -calculate stuff -
50  continue

      re = v*rho*dh/(vis*g)
c
c  *** adjust lenght for not being fully developed flow
      if(re.gt.2300.) go to 70
      xl = .03*re*dh
      go to 80
70  continue
      xl = 4.*dh
80  continue
      len = len1-xl
      if(len.lt.0.) len = 0.
c
c  *** pipe fiction in gap
      if (re.gt.2000.) go to 100
      ff = 64./re      ! laminar fiction fac
      go to 200

```

```

100  continue
    if(rou.lt.1.e-6.and.re.lt.1.e5.and.re.gt.3000.) go to 150
    call frifac (re,rou,ff)
    go to 200
150  ff = .316*re**(-.25)
    c
200  continue
    c
c *** calculate delta p and other and print results
    delp = (len*ff/dh +k)*(rho*v**2)/(2.*g) ! lb/ft^2
    flow = v*aa ! flow ft^3/s
    fgpm = flow*60/.133 ! flow in gpm
    c
    write (6,202) v,re,ff,delp,fgpm
201  format (' velocity      Re      fri-fac    delta P    flow ',/,
+ ' ft/s                lb/ft^2      gpm ',/)
202  format (5(1pe10.2))
    c
c *** increment
    v = v + vinc
    if(v.gt.vfin) stop
    go to 50
end

subroutine frifac (re,rou,f)
C-----CALCULATE FRICTION FACTOR - COLEBROOK EQN.
    IF(RE.GT.2100.) GO TO 9
    F=64./RE
    GO TO 15
9  F=.007
    IF(RE.LT.1.E5) F=.017
    IF(ROU.GE..002) F=.02
    IF(RE.LT.2.E4) F=.025
    IF(ROU.GE..015) F=.04
    DF= .0005
    XF= .25
10 F=F+ DF
    A=1./SQRT(F)
    BP=2.51/(RE* SQRT(F)) + ROU/3.7
    B=-2.*ALOG10(BP)
    X=ABS(A-B)
    IF(F.GT..08) GO TO 11
    IF(X.GT.XF) GO TO 10
    IF(DF.LT..0005) GO TO 15
    DF=DF/3.
    XF=XF/3.
    GO TO 10
11 WRITE (6,12)
12 FORMAT (/, ' NO FRICTION FACTOR FOUND ',/)
    STOP
15 RETURN
    END

```

Fauske & Associates, Inc.

DATE: April 28, 1999

TO: Dave Bergmann, Darrel Duncan, and Joe Swenson, DE&SH

FROM: Marty Plys

SUBJECT: Estimated Leakage Rate through a Cracked Load Out Pit Floor Joint

This quick note summarizes estimated leakage rates from one of the K-basins that could occur after a drop accident in the load out pit. The assumed leak path is a crack at the floor joint with the load out pit based upon approximate displacements provided by finite element model results.

First, the area must be estimated given the displacement. Based on finite element model results which may be conservative, the failure opens like a hinge with zero displacement at the open side of the pit and maximum displacement at the opposite end, so that the area consists of two triangular shapes along the length of the pit in this direction plus a rectangular shape along the width of the pit. Since two triangular areas are summed, the total flow area is simply given by $A = (w + l) d$ where w = pit width = 128 inches, l = pit length = 166 inches, and d = maximum displacement. Converting to SI units, $A = 7.47 d$ where A is in square meters and d is in meters.

The volumetric flowrate Q (m^3/s) is given by the standard expression

$$Q / A = C_D \sqrt{2 g H} \quad (1)$$

where C_D = Loss coefficient,

g = Acceleration of gravity, $9.81 \text{ m}^2/\text{s}$, and

H = Water depth, approximately 25 ft or 7.6 m.

To convert the result from m^3/s to gpm, multiply the value in m^3/s by 15870. The challenge in using the equation is specification of the loss coefficient, which is estimated by:

$$C_D = 1 / \sqrt{K + 4 f L / D} \quad (2)$$

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where K = Sum of acceleration, contraction, and expansion loss coefficients, 2.5,

f = Friction factor,

L = Length of flowpath, 16 inches, and

D = Hydraulic diameter = twice gap thickness = $2d$.

Note that the gap thickness does vary along the length of the hinged opening, but because the flow areas in these two directions are nearly equal, this value is appropriate.

Now the range of openings of interest is on the order of 0.1 inches, so the value of L/D is on the order of 80. The openings will be very rough; for example, concrete roughness values in textbooks range from $\epsilon = 0.001$ to 0.01 ft, or 0.012 to 0.12 inches. Friction factors from typical Fanning charts "top out" at roughness/diameter ratios of about $\epsilon/D = 0.05$, and here ϵ/D is on the order of 1.0. Also, we expect turbulent flow or at least flow in the transitional range between laminar and turbulent. The largest friction factor value from Perry's Handbook, for $\epsilon/D = 0.05$, is 0.02. A value no more than 50% higher is difficult to defend a priori. Putting these values together for an example, a gap thickness of 0.1 inches would yield $C_D = 1/\sqrt{(2.5 + 6.4)} = 0.34$.

A set of flow rates using this approach for various gap distances are:

d (inches)	C_D	A (in ²)	A (m ²)	Q (m ³ /s)	Q (gpm)
0.025	0.19	7.35	0.0047	0.0109	173
0.05	0.26	14.7	0.0095	0.0302	480
0.10	0.34	29.4	0.019	0.0789	1250
0.15	0.38	44.1	0.028	0.1300	2060

These estimated flow rates could be reduced if credit could be taken for flow resistance in the gravel bed drainage region beneath the basins. However, this is expected to be fairly porous, and the flow can essentially expand in three dimensions after leaving the crack, so this may be difficult to pursue. Also, the effective friction factor used above is probably low by a factor of two. We could pursue literature data on flow through rough cracks to improve the estimate.

Fauske & Associates, Inc.

DATE: May 7, 1999

TO: Dave Bergmann, Darrel Duncan, and Joe Swenson, DE&SH

FROM: Marty Plys

SUBJECT: Revised Leakage Rate through a Cracked Load Out Pit Floor Joint:
Porous Medium Approach

In my April 28 memorandum on leakage through a cracked load out pit floor joint after a hypothetical drop accident, I employed a pipe flow model to estimate the flow rate as a function of open gap thickness. At the time I noted that the roughness length scale of the crack might be about the same as the crack thickness itself, and that this was "off the scale" of friction factor charts. An implication of this feature is that we should consider treating the leakage path as a porous medium, and this approach is pursued herein.

A typical crack thickness is about $D = 0.1$ in. or 2.5 mm from finite element calculations we have discussed recently. We intuitively expect the break in the joint to be rough. Concrete roughness values in Perry's Handbook range from $\epsilon = 0.3$ to $\epsilon = 3$ mm, and we would expect a crack to be at the high end of this range, hence the roughness and thickness are for practical purposes equal. Friction factors from typical Fanning charts "top out" at roughness/diameter ratios of about $\epsilon / D = 0.05$, but here ϵ / D is on the order of 1.0. Also, we expect turbulent flow or at least flow in the transitional range between laminar and turbulent. For later use, the largest friction factor value from Perry's Handbook, for $\epsilon / D = 0.05$, is $f = 0.02$.

Imagine looking into the crack in the direction of flow. You would see obstacles whose height is about equal to the crack thickness, as if they were stalactites and stalagmites emerging from the upper and lower surfaces. These obstacles would be pieces of aggregate and an irregular surface of concrete where the floor and wall materials partly adhered. There would not be a direct line of sight through the crack because the distance through the crack (the wall thickness) is 16 inches or 400 mm, about 160 times the crack thickness and roughness scale. If you agree with this picture of the crack morphology, then the crack should rightly be modeled as a porous medium. The porosity should reflect the open area fraction.

The pressure gradient in a porous medium is given by [Macdonald, et al., 1979]:

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$$\frac{\Delta P}{L} = \frac{180(1-\epsilon)^2}{D_e^2 \epsilon^3} \mu U + \frac{B(1-\epsilon)}{D_e \epsilon^3} \rho U^2 \quad (1)$$

where ΔP = Pressure drop, $\Delta P = \rho g H$, Pa,
 L = Length for flow through crack, m,
 ρ = Water density, kg/m³,
 g = Acceleration of gravity, 9.81 m/s²,
 H = Basin water height, ≈ 7.6 m,
 D_e = Equivalent average channel diameter, m,
 ϵ = Porosity,
 μ = Viscosity, $\approx 10^{-3}$ kg/m · s,
 U = Superficial velocity, $= Q / A$, m/s,
 Q = Volumetric flow rate, m³/s,
 A = Flow area, m², and
 B = Roughness parameter; $B = 1.8$ for smooth particles to $B = 4.0$ for rough particles in a porous medium.

Equation (1) is recommended by the cited authors after review of literature models and comparison with data sets representing a wide variety of media. Please note that the standard symbol for porosity ϵ used above should not be confused with the standard symbol used for pipe roughness. The first term is viscous pressure drop and the second represents inertial pressure drop. For values of present interest, the ratio of these terms is:

$$\frac{\left(\frac{\Delta P}{L}\right)_{\text{viscous}}}{\left(\frac{\Delta P}{L}\right)_{\text{inertial}}} = \frac{180(1-\epsilon)}{B D_e} \frac{\mu}{\rho U} \quad (2)$$

where p = 294" ≈ 7.5 m,
 D_e = 0.1" = 0.00254 m,
 A = $p D_e = 0.019$ m²,
 B ≈ 2.5 , and

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$$\begin{aligned}
 U &= Q/A \approx \frac{400 \text{ gpm} / 15870 \text{ gpm} / (\text{m}^3 / \text{s})}{0.019 \text{ m}^2} \\
 &\approx (0.025 \text{ m}^3/\text{s}) / (0.019 \text{ m}^2) \\
 &\approx 1.3 \text{ m/s.}
 \end{aligned}$$

$$\frac{\left(\frac{\Delta P}{L}\right)_{\text{viscous}}}{\left(\frac{\Delta P}{L}\right)_{\text{inertial}}} = 0.016$$

Note that a value closer to smooth than rough was chosen for the roughness parameter B, and that a provisional value of porosity $\epsilon = 0.7$ is used to be conservative; this represents a rather open medium. From the comparison of terms, the viscous term may be dropped, leaving a term proportional to velocity squared.

The pressure drop in pipe flow used in earlier calculations may be compared to the pressure drop in the porous medium approach because both are now proportional to velocity squared:

$$\left(\frac{\Delta P}{L}\right)_{\text{pipe}} = \frac{4f}{D_e} \frac{1}{2} \rho U^2 \quad (3)$$

$$\frac{U_{\text{pipe}}}{U_{\text{porous}}} = \sqrt{\frac{B(1-\epsilon)/\epsilon^3}{2f}} \approx 6$$

where again a provisional, conservative value of porosity $\epsilon = 0.7$ is used. Therefore, we expect a significant reduction in flow rate using the porous medium approach.

The volumetric flow through the crack treated as a porous medium is given by:

$$Q = A \sqrt{\frac{gH}{L} \frac{\epsilon^3}{1-\epsilon} \frac{D_e}{B}} \quad (4)$$

Results are presented for select values of the crack thickness in the range of interest, using $\epsilon = 0.7$, $B = 2.5$, and taking the equivalent diameter equal to the hydraulic diameter of a slit, which is probably an overestimate (and hence, overestimates the flow).

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d (inches)	A (in ²)	A (m ²)	Q (m ³ /s)	Q (gpm)
0.025	7.35	0.0047	0.0019	30
0.05	14.7	0.0095	0.0054	85
0.075	22.1	0.014	0.0097	154
0.10	29.4	0.019	0.0152	241

An intuitive case is presented to prefer the porous medium approach over the pipe flow approach. An experimental basis exists for application of this approach to correlate flow through cracks in reinforced concrete reactor containments in a reference case [Rizkalla, Simmonds, and MacGregor, 1979]. A similar experimental basis could be sought for the present application.

MGP:vdI

References

- I. F. Macdonald, et al., "Flow Through Porous Media - the Ergun Equation Revisited," Ind. Chem. Fundam., Vol. 18, No. 3, pp. 199-207, 1979.
- S. H. Rizkalla, S. H. Simmonds, and J. G. MacGregor, "Leakage Tests of wall Segments of Reactor Containments," Structural Engineering Report No. 80, Dept. Civil Engineering, U. of Alberta, Technical Report of the Atomic Energy Control Board Nuclear Plant Licensing Directorate, Ottawa, Ontario, October, 1979.

Fauske & Associates, Inc.

DATE: June 14, 1999

TO: Rich Sexton, Sam Hecht, Joe Swenson, and Joni Weamer, DE&SH
Milon Meyer and Bob Winkel, M&D Professional Services

CC: Darrel Duncan, DE&SH

FROM: Marty Plys

SUBJECT: Leakage Rate Through a Cracked Load Out Pit Floor Joint Using a Porous Medium Approach

This memorandum presents estimated leakage rates through a cracked K basin load out pit floor joint using a porous medium approach given crack opening profiles for various cases. A porous medium approach is used for the flow because the roughness length scale of the crack is larger than the given crack thicknesses. Pipe flow models are deemed not applicable.

The given range of average crack size is 0.0038 to 0.0376 inches depending upon the load imposed, which translates to 0.097 to 0.96 mm. We intuitively expect the break in the joint to be rough. Concrete roughness values in Perry's Handbook range from $\epsilon = 0.3$ to $\epsilon = 3$ mm, and we would expect a crack to be at the high end of this range. Hence, the roughness will typically exceed the crack size. Friction factors from typical Fanning charts "top out" at roughness/diameter ratios of about $\epsilon / D = 0.05$, but here ϵ / D is greater than 1.0. Also, we expect turbulent flow or at least flow in the transitional range between laminar and turbulent. For later use, the largest friction factor value from Perry's Handbook, for $\epsilon / D = 0.05$, is $f = 0.02$. An experimental basis exists for application of the porous medium approach to correlate flow through cracks in reinforced concrete reactor containments in a reference case [Rizkalla, Simmonds, and MacGregor, 1979].

Imagine looking into the crack in the direction of flow. You would see obstacles whose height is about equal to the crack thickness, as if they were stalactites and stalagmites emerging from the upper and lower surfaces. These obstacles would be pieces of aggregate and an irregular surface of concrete where the floor and wall materials partly adhered. There would not be a direct line of sight through the crack because the distance through the crack (the wall thickness) is 16 inches or 400 mm, about 160 times the crack thickness and roughness scale. If you agree with this picture of the crack morphology, then the crack should rightly be modeled as a porous medium. The porosity should reflect the open area fraction.

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The pressure gradient in a porous medium is given by [Macdonald, et al., 1979]:

$$\frac{\Delta P}{L} = \frac{180(1-\epsilon)^2}{D_e^2 \epsilon^3} \mu U + \frac{B(1-\epsilon)}{D_e \epsilon^3} \rho U^2 \quad (1)$$

where ΔP = Pressure drop, $\Delta P = \rho g H$, Pa,
 L = Length for flow through crack, m,
 ρ = Water density, kg/m^3 ,
 g = Acceleration of gravity, 9.81 m/s^2 ,
 H = Basin water height, $\approx 7.6 \text{ m}$,
 D_e = Equivalent average channel diameter, m,
 ϵ = Porosity,
 μ = Viscosity, $\approx 10^{-3} \text{ kg/m} \cdot \text{s}$,
 U = Superficial velocity, $= Q / A$, m/s,
 Q = Volumetric flow rate, m^3/s ,
 A = Flow area, m^2 , and
 B = Roughness parameter; $B = 1.8$ for smooth particles to $B = 4.0$ for rough particles in a porous medium.

Equation (1) is recommended by the cited authors after review of literature models and comparison with data sets representing a wide variety of media. Please note that the standard symbol for porosity ϵ used above should not be confused with the standard symbol used for pipe roughness. The first term is viscous pressure drop and the second represents inertial pressure drop. For values of present interest, the ratio of these terms is:

$$\frac{\left(\frac{\Delta P}{L}\right)_{\text{viscous}}}{\left(\frac{\Delta P}{L}\right)_{\text{inertial}}} = \frac{180(1-\epsilon)}{B D_e} \frac{\mu}{\rho U} \quad (2)$$

where p = $294'' \approx 7.5 \text{ m}$,
 D_e = $0.1'' = 0.00254 \text{ m}$,
 A = $p D_e = 0.019 \text{ m}^2$,

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$$B \approx 2.5, \text{ and}$$

$$\begin{aligned} U &= Q/A \approx \frac{400 \text{ gpm} / 15870 \text{ gpm} / (\text{m}^3 / \text{s})}{0.019 \text{ m}^2} \\ &\approx (0.025 \text{ m}^3/\text{s}) / (0.019 \text{ m}^2) \\ &\approx 1.3 \text{ m/s.} \end{aligned}$$

$$\frac{\left(\frac{\Delta P}{L}\right)_{\text{viscous}}}{\left(\frac{\Delta P}{L}\right)_{\text{inertial}}} = 0.016$$

Note that a value closer to smooth than rough was chosen for the roughness parameter B , and that a provisional value of porosity $\epsilon = 0.7$ is used to be conservative; this represents a rather open medium. From the comparison of terms, the viscous term may be dropped, leaving a term proportional to velocity squared.

The pressure drop in pipe flow used in earlier calculations may be compared to the pressure drop in the porous medium approach because both are now proportional to velocity squared:

$$\left(\frac{\Delta P}{L}\right)_{\text{pipe}} = \frac{4f}{D_e} \frac{1}{2} \rho U^2 \quad (3)$$

$$\frac{U_{\text{pipe}}}{U_{\text{porous}}} = \sqrt{\frac{B(1-\epsilon)/\epsilon^3}{2f}} \approx 6$$

where again a provisional, conservative value of porosity $\epsilon = 0.7$ is used. Therefore, we expect a significant reduction in flow rate using the porous medium approach.

The volumetric flow through the crack treated as a porous medium is given by:

$$Q = A \sqrt{\frac{gH}{L} \frac{\epsilon^3}{1-\epsilon} \frac{D_e}{B}} \quad (4)$$

Note that the area is simply the product of crack thickness and perimeter, so equation (4) may be written as:

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$$Q = K \left(\frac{1}{N} \sum D_i^{1.5} \right) \quad (5a)$$

$$K = P \sqrt{\frac{g H}{L} \frac{\epsilon^3}{1-\epsilon} \frac{1}{B}} \quad (5b)$$

where P = 32' = 9.76 m,
L = 16" = 0.4 m,
g = 9.81 m/s²,
ε = 0.7,
H = 7.6 m,
B = 2.5, and
K = 90.1.

where the term in parentheses indicates the average value of the thickness to the 1.5 power, and is written for application to equally spaced thicknesses along the perimeter.

Values for the crack thickness profile and for the thickness to the 1.5 power were provided by personal communication with Bob Winkel of M&D Engineering for this analysis as listed below; inside (I), midpoint average (M), and outside (O) crack thicknesses are listed for completeness. Other values required are listed above. Results for the three cases provided for this analysis are:

Flow Rate Through Cracked Floor Joint					
Case	D (in)	D ^{1.5} (in) ^{1.5}	m ^{1.5}	Q (m ³ /s)	Q (gpm)
500 kip	I: 3.81E-3 M: 2.53E-3 O: 1.26E-3	1.42E-4	5.75E-7	5.18E-5	0.82
600 kip	I: 1.07E-2 M: 8.65E-3 O: 6.62E-3	9.04E-4	3.66E-6	3.30E-4	5.2
700 kip	I: 0.029 M: 0.025 O: 0.02	0.00438	1.77E-5	1.60E-3	25

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- I. F. Macdonald, et al., "Flow Through Porous Media - the Ergun Equation Revisited," Ind. Chem. Fundam., Vol. 18, No. 3, pp. 199-207, 1979.
- S. H. Rizkalla, S. H. Simmonds, and J. G. MacGregor, "Leakage Tests of wall Segments of Reactor Containments," Structural Engineering Report No. 80, Dept. Civil Engineering, U. of Alberta, Technical Report of the Atomic Energy Control Board Nuclear Plant Licensing Directorate, Ottawa, Ontario, October, 1979.

APPENDIX O

Hydraulically Damped Cask Drop

Hydraulically Damped Cask Drop

Prepared by:

**M&D Professional Services, Inc.
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Milon Meyer

M&D Professional Services		CALCULATION SHEET		Page No. 1 of 10
				Calculation No. M&D 99-09
Client / Location DE&SH		Prepared By / Date M. D. Northey <i>M.D. 6/2/99</i>		Revision No. 0
Subject Hydraulically Damped Cask Drop		Checked By / Date Milon Meyer		Contract No.
Ref. Drawing(s)		Revised By / Date		

1.0 INTRODUCTION

This analysis calculates the pressure transient in the IPSS lower cylinder during drop scenario number 5, which combines drop number 2 and number 3 in a worst case. The intent is to show that the damping force of the water will reduce the kinetic energy of the cask/pail to an acceptable level at the time that it hits the bottom of the cylinder. Also considered is the reaction force in the floor due to the pressure in the cylinder. This pressure is due primarily to the velocity head of the water as it is forced out of the cylinder through a specified flow area.

2.0 SUMMARY

The results show that by strategically locating holes on either side of the cylinder, the drop can be controlled such that the resultant force in the floor does not exceed 207 kips. The results also show that the remaining kinetic energy in the cask/pail does not exceed 177 ft-kips when it hits the bottom of the cylinder.

3.0 INPUT PARAMETERS

Following are the input parameters that were used in this analysis. Figure 3-1 is a schematic of the drop scenario analyzed. A detailed layout of the holes is shown in Figure 5-3

Weight of Cask = 62000 lbs
 Weight of Cask and Pail = 66000 lbs
 Bottom of Pail Area = 13.44 ft²
 Bottom of Cylinder Base Area = 17.10 ft²
 Minimum Area for Flow = 3.66 ft²
 Free Fall Distance for Cask = 17 feet
 Damped Fall Distance for Cask and Pail = 15 feet
 Density of Water = 62.4 lbs/ft³
 Acceleration of Gravity = 32.2 ft/sec²
 Cylinder Thickness = 0.375 in

Figure 3-1

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4.0 METHODOLOGY

The 62,000-pound cask free falls for 17 feet before it contacts the pail and then the cask and the pail fall together for a distance of 15 feet to the bottom of the cylinder. The last 15 feet of drop is in a cylinder filled with water. Holes are situated in the cylinder to regulate the flow during the drop and control the pressure in the cylinder. This pressure is used to calculate both the load in the floor and the damping force for the falling cask and pail. For this analysis, the drop is divided into 0.1-foot increments. The total work done by all forces acting on the cask/pail during this interval of travel equals the corresponding change in kinetic energy of the cask/pail as it drops.

For the first part of the drop, the cask is free falling and the velocity at the end of the 17-foot drop is calculated from:

$$V = \sqrt{2 \cdot g \cdot h} \quad \text{Equation 4-1}$$

where: $g = 32.2 \text{ ft/sec}^2$
 $h = 17 \text{ feet}$

The energy required to accelerate the pail to the velocity of the cask is conservatively ignored. At contact, a pressure spike develops that is conservatively taken to correspond to a flow area equal to the clearance between the pail and the cylinder. The pressure wave will not see the additional flow area at the instant of impact as the wave travels at a finite velocity.

To characterize the relationship between the cask drop velocity, the area available for the flow of water, and the pressure in the cylinder, the Bernoulli Equation between two points in the system is used:

$$Z_1 + \frac{P_1}{\rho} + \frac{Vel_1^2}{2 \cdot g} = Z_2 + \frac{P_2}{\rho} + \frac{Vel_2^2}{2 \cdot g} + h_L \quad \text{Equation 4-2}$$

where: Z_1 = Elevation head (in), ignored
 $\frac{P_1}{\rho}$ = Pressure head (lbf/in²)/(lbf/in³) (in), P_1 is pressure in the cylinder, P_2 is ignored.
 $\frac{Vel^2}{2 \cdot g}$ = Velocity head (in/sec)²/(in/sec²) (in), Vel_1 , velocity in the cylinder is 0, Vel_2 is a function of the cask velocity and the flow area and developed pressure.
 h_L = Head loss (in)

The head loss term ignores friction losses because the majority of the flow area is through the holes and the L/d term is very small. To account for the interaction of the flow with the surrounding water, an exit loss is included using a resistance coefficient of 0.5:

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$$h_L = K \frac{Vel_2^2}{2 \cdot g} \quad \text{Equation 4-3}$$

Where: K = Resistance coefficient

And the Bernoulli equation simplifies to:

$$P_1 = \frac{\rho \cdot Vel_2^2}{2 \cdot g} (1 + K) \quad \text{Equation 4-4}$$

The water velocity is related to the cask velocity by dividing the volumetric flow by the flow area term. The volumetric flow is the cask velocity times the area at the base of the cylinder.

$$Vel_2 = \frac{Vel_{cask} \cdot Base Area}{Flow Area} \quad \text{Equation 4-5}$$

The developed pressure is used to calculate the force on the floor and the damping force on the cask/pail. The damping force on the pail is used to calculate the work done on the pail over a distance of 0.1 feet. The mass of the cask and pail are used to calculate the increase in kinetic energy due to gravity over a drop distance of 0.1 feet. Summing these two terms with the kinetic energy from the previous interval gives the kinetic energy of the cask/pail at the end of the present interval. Using this calculated energy, a new cask velocity is calculated which in turn yields a new damping force. Because the final kinetic energy is a function of the damping force, which is a function of the pressure, which is determined from the velocity, an iterative solution is performed. For the first guess, the present interval uses the velocity from the previous interval then converges on the present interval solution.

The equations for each interval of drop are entered in a spreadsheet with enough intervals to achieve a total drop height of 32 feet. For the first 17 feet of drop, the energy and velocity are solely a linear function of the drop distance and one interval could be used to calculate the final velocity and kinetic energy. For the sake of plotting purposes, (see Figure 5-2), the first part of the drop is divided into 2 foot intervals. For the last 15 feet of drop, the change in energy is a function of the damping force and an iterative solution is performed for each interval. The damping force is a function of the flow area, which at a minimum is the clearance between the pail and the cylinder. Additional flow area is added by including holes down the side of the cylinder. The size and location of the holes was determined by trial and error to achieve a minimum reaction force in the floor yet keep to a minimum the remaining energy of the cask/pail when it hits the bottom of the cylinder.

The hoop stress in the cylinder due to the developed pressure is calculated using:

$$\sigma = \frac{Pressure \cdot radius}{thickness}$$

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5.0 RESULTS

The results are shown Table 5-1. A plot of the energy and the reaction force in the floor are shown in Figure 5-1

Figure 5-1

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Figure 5-2 shows the flow area and cask velocity as a function of drop distance.

Figure 5-2

The damped fall for the cask and pail starts at 17 feet and the flow area is constant for the first six inches of drop. The flow area reduces from a drop distance of 17.5 feet to a drop distance of 28 feet as the falling pail covers the holes in the cylinder that provide additional flow. The flow area is at a minimum for the last four feet of fall and equals the clearance between the pail and the cylinder.

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Table 5-1 shows the flow area for each interval. This required flow is reduced by the minimum flow area and listed as additional flow area. To simplify application, the size of the hole required to provide the necessary additional area for each 1 foot interval is calculated and listed in the table. Figure 5-3 shows the hole size and spacing needed to achieve the required added area. Two hole patterns are needed, one on each side of the cylinder.

The maximum pressure developed in the cylinder during the fall is 12116 lb/ft² and the stress in the cylinder is:

$$\sigma = \frac{(12116/144)(28)}{0.375} = 6282 \text{ psi}$$

The holes in the cylinder will lead to stress concentrations. This is the reason for staggering the holes laterally. Using a peak stress-concentration factor of 3, the stress becomes:

$$\sigma = 3(6282 \text{ psi}) = 18846 \text{ psi}$$

Figure 5-3, Hole Pattern, Two Sides

The following table shows the results for each interval. From the 17.1 foot interval to the 32 foot interval, the calculation uses an iterative solution.

Table 5-1

Drop Distance (ft)	Total Distance (ft)	Cask Velocity (ft/s)	Water Velocity (ft/s)	Area Water Flow (ft ²)	Water Flow (ft ³ /s)	Area Base (ft ²)	Area Pail (ft ²)	Pressure Cylinder (lb/ft ²)	Force Floor (lb)	Cask Energy (ft-lb)	Additional Flow Area (ft ²)	Hole dia. each side, every 1 ft (inches)	Hole dia. each side, every 2 ft (inches)
	0.0	0.01							0	0			
1.0	1.0	8.02							0	62000			
2.0	3.0	13.90							0	186000			
2.0	5.0	17.94							0	310000			
2.0	7.0	21.23							0	434000			
2.0	9.0	24.07							0	558000			
2.0	11.0	26.62							0	682000			
2.0	13.0	28.93							0	806000			
2.0	15.0	31.08							0	930000			
2.0	17.0	33.09							0	1054000			
0.1	17.1	33.07	62.85	9.000	565.64	17.10	13.44	5741	98195	1052885	5.34		
0.1	17.2	33.05	62.82	9.000	565.34	17.10	13.44	5735	98092	1051777	5.34		
0.1	17.3	33.05	62.82	9.000	565.34	17.10	13.44	5735	98092	1050670	5.34		

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Drop Distance (ft)	Total Distance (ft)	Cask Velocity (ft/s)	Water Velocity (ft/s)	Area Water Flow (ft ²)	Water Flow (ft ³ /s)	Area Base (ft ²)	Area Pail (ft ²)	Pressure Cylinder (lb/ft ²)	Force Floor (lb)	Cask Energy (ft-lb)	Additional Flow Area (ft ²)	Hole dia. each side, every 1 ft (inches)	Hole dia. each side, every 2 ft (inches)
0.1	17.4	33.04	62.78	9.000	565.05	17.10	13.44	5729	97989	1049571	5.34		
0.1	17.5	33.02	62.75	9.000	564.75	17.10	13.44	5723	97886	1048480	5.34	8.25	11.43
0.1	17.6	33.00	63.26	8.923	564.46	17.10	13.44	5816	99485	1047263	5.26		
0.1	17.7	32.98	63.77	8.846	564.13	17.10	13.44	5911	101097	1045920	5.19		
0.1	17.8	32.96	64.28	8.770	563.77	17.10	13.44	6006	102723	1044449	5.11		
0.1	17.9	32.94	64.79	8.695	563.37	17.10	13.44	6102	104362	1042849	5.04		
0.1	18.0	32.91	65.30	8.620	562.94	17.10	13.44	6198	106013	1041119	4.96		
0.1	18.1	32.88	65.81	8.546	562.47	17.10	13.44	6295	107678	1039259	4.89		
0.1	18.2	32.86	66.32	8.473	561.97	17.10	13.44	6393	109354	1037267	4.81		
0.1	18.3	32.82	66.83	8.400	561.43	17.10	13.44	6492	111042	1035142	4.74		
0.1	18.4	32.79	67.34	8.328	560.85	17.10	13.44	6591	112741	1032883	4.67		
0.1	18.5	32.75	67.85	8.257	560.24	17.10	13.44	6691	114451	1030491	4.60	7.91	
0.1	18.6	32.72	68.36	8.186	559.59	17.10	13.44	6792	116171	1027963	4.53		
0.1	18.7	32.68	68.87	8.116	558.91	17.10	13.44	6893	117901	1025299	4.46		
0.1	18.8	32.63	69.37	8.046	558.18	17.10	13.44	6995	119640	1022499	4.39		
0.1	18.9	32.59	69.88	7.977	557.42	17.10	13.44	7097	121388	1019561	4.32		
0.1	19.0	32.54	70.38	7.909	556.62	17.10	13.44	7200	123144	1016486	4.25		
0.1	19.1	32.49	70.88	7.841	555.78	17.10	13.44	7303	124907	1013271	4.18		
0.1	19.2	32.44	71.38	7.773	554.90	17.10	13.44	7406	126677	1009918	4.11		
0.1	19.3	32.39	71.88	7.707	553.98	17.10	13.44	7510	128453	1006425	4.05		
0.1	19.4	32.33	72.38	7.641	553.02	17.10	13.44	7614	130234	1002793	3.98		
0.1	19.5	32.27	72.87	7.575	552.02	17.10	13.44	7719	132020	999020	3.92	7.57	10.49
0.1	19.6	32.21	73.37	7.510	550.98	17.10	13.44	7823	133810	995106	3.85		
0.1	19.7	32.15	73.86	7.446	549.90	17.10	13.44	7928	135603	991051	3.79		
0.1	19.8	32.08	74.34	7.382	548.78	17.10	13.44	8033	137399	986856	3.72		
0.1	19.9	32.02	74.83	7.318	547.62	17.10	13.44	8138	139196	982519	3.66		
0.1	20.0	31.95	75.31	7.256	546.41	17.10	13.44	8243	140994	978041	3.60		
0.1	20.1	31.87	75.79	7.193	545.17	17.10	13.44	8348	142791	973421	3.53		
0.1	20.2	31.80	76.26	7.132	543.88	17.10	13.44	8453	144588	968661	3.47		
0.1	20.3	31.72	76.74	7.070	542.55	17.10	13.44	8558	146382	963759	3.41		
0.1	20.4	31.64	77.20	7.010	541.17	17.10	13.44	8663	148174	958717	3.35		
0.1	20.5	31.56	77.67	6.949	539.75	17.10	13.44	8767	149961	953534	3.29	7.25	
0.1	20.6	31.47	78.13	6.890	538.29	17.10	13.44	8872	151744	948211	3.23		
0.1	20.7	31.38	78.58	6.831	536.79	17.10	13.44	8976	153520	942749	3.17		
0.1	20.8	31.29	79.04	6.772	535.24	17.10	13.44	9079	155290	937148	3.11		
0.1	20.9	31.20	79.48	6.714	533.65	17.10	13.44	9182	157051	931408	3.05		
0.1	21.0	31.10	79.92	6.656	532.01	17.10	13.44	9284	158803	925530	3.00		
0.1	21.1	31.01	80.36	6.599	530.33	17.10	13.44	9386	160544	919516	2.94		
0.1	21.2	30.90	80.79	6.543	528.60	17.10	13.44	9487	162274	913366	2.88		
0.1	21.3	30.80	81.22	6.486	526.83	17.10	13.44	9588	163991	907081	2.83		
0.1	21.4	30.70	81.64	6.431	525.02	17.10	13.44	9687	165695	900662	2.77		
0.1	21.5	30.59	82.06	6.376	523.16	17.10	13.44	9786	167383	894110	2.72	6.95	9.62
0.1	21.6	30.47	82.46	6.321	521.25	17.10	13.44	9884	169054	887427	2.66		
0.1	21.7	30.36	82.87	6.267	519.30	17.10	13.44	9980	170708	880615	2.61		
0.1	21.8	30.24	83.26	6.213	517.30	17.10	13.44	10076	172342	873673	2.55		

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Drop Distance (ft)	Total Distance (ft)	Cask Velocity (ft/s)	Water Velocity (ft/s)	Area Water Flow (ft ²)	Water Flow (ft ³ /s)	Area Base (ft ²)	Area Pail (ft ²)	Pressure Cylinder (lb/ft ²)	Force Floor (lb)	Cask Energy (ft-lb)	Additional Flow Area (ft ²)	Hole dia. each side, every 1 ft (inches)	Hole dia. each side, every 2 ft (inches)
0.1	21.9	30.12	83.65	6.160	515.26	17.10	13.44	10170	173957	866605	2.50		
0.1	22.0	30.00	84.03	6.107	513.17	17.10	13.44	10264	175549	859412	2.45		
0.1	22.1	29.88	84.41	6.054	511.04	17.10	13.44	10355	177119	852095	2.39		
0.1	22.2	29.75	84.78	6.002	508.86	17.10	13.44	10446	178665	844657	2.34		
0.1	22.3	29.62	85.14	5.951	506.63	17.10	13.44	10534	180184	837100	2.29		
0.1	22.4	29.49	85.49	5.900	504.36	17.10	13.44	10622	181677	829425	2.24		
0.1	22.5	29.35	85.83	5.849	502.04	17.10	13.44	10707	183141	821636	2.19	6.65	
0.1	22.6	29.21	86.17	5.799	499.68	17.10	13.44	10791	184575	813733	2.14		
0.1	22.7	29.07	86.49	5.749	497.27	17.10	13.44	10873	185978	805720	2.09		
0.1	22.8	28.93	86.81	5.700	494.81	17.10	13.44	10953	187349	797600	2.04		
0.1	22.9	28.78	87.12	5.651	492.32	17.10	13.44	11031	188685	789375	1.99		
0.1	23.0	28.63	87.42	5.602	489.77	17.10	13.44	11108	189986	781047	1.94		
0.1	23.1	28.48	87.71	5.554	487.18	17.10	13.44	11181	191250	772620	1.89		
0.1	23.2	28.33	87.99	5.507	484.54	17.10	13.44	11253	192476	764097	1.85		
0.1	23.3	28.17	88.26	5.459	481.86	17.10	13.44	11322	193662	755481	1.80		
0.1	23.4	28.01	88.52	5.413	479.14	17.10	13.44	11389	194807	746774	1.75		
0.1	23.5	27.85	88.77	5.366	476.37	17.10	13.44	11454	195910	737981	1.71	6.37	8.83
0.1	23.6	27.69	89.01	5.320	473.56	17.10	13.44	11516	196970	729105	1.66		
0.1	23.7	27.52	89.24	5.274	470.70	17.10	13.44	11575	197984	720149	1.61		
0.1	23.8	27.35	89.46	5.229	467.80	17.10	13.44	11632	198952	711117	1.57		
0.1	23.9	27.18	89.67	5.184	464.86	17.10	13.44	11686	199872	702013	1.52		
0.1	24.0	27.00	89.86	5.140	461.87	17.10	13.44	11737	200744	692840	1.48		
0.1	24.1	26.83	90.05	5.096	458.85	17.10	13.44	11785	201566	683603	1.44		
0.1	24.2	26.65	90.22	5.052	455.78	17.10	13.44	11830	202336	674305	1.39		
0.1	24.3	26.47	90.38	5.009	452.67	17.10	13.44	11872	203054	664950	1.35		
0.1	24.4	26.28	90.53	4.966	449.52	17.10	13.44	11910	203719	655544	1.31		
0.1	24.5	26.09	90.66	4.923	446.33	17.10	13.44	11946	204329	646089	1.26	6.10	
0.1	24.6	25.91	90.78	4.881	443.09	17.10	13.44	11979	204883	636591	1.22		
0.1	24.7	25.71	90.89	4.839	439.83	17.10	13.44	12008	205381	627054	1.18		
0.1	24.8	25.52	90.99	4.797	436.52	17.10	13.44	12033	205821	617482	1.14		
0.1	24.9	25.33	91.08	4.756	433.17	17.10	13.44	12056	206203	607881	1.10		
0.1	25.0	25.13	91.15	4.715	429.79	17.10	13.44	12075	206526	598253	1.06		
0.1	25.1	24.93	91.20	4.675	426.38	17.10	13.44	12090	206789	588606	1.01		
0.1	25.2	24.73	91.25	4.635	422.92	17.10	13.44	12102	206992	578942	0.97		
0.1	25.3	24.52	91.28	4.595	419.44	17.10	13.44	12110	207133	569267	0.94		
0.1	25.4	24.32	91.30	4.556	415.92	17.10	13.44	12115	207213	559586	0.90		
0.1	25.5	24.11	91.30	4.517	412.37	17.10	13.44	12116	207231	549903	0.86	5.85	8.10
0.1	25.6	23.90	91.29	4.478	408.78	17.10	13.44	12113	207186	540224	0.82		
0.1	25.7	23.69	91.27	4.439	405.17	17.10	13.44	12107	207078	530554	0.78		
0.1	25.8	23.48	91.23	4.401	401.53	17.10	13.44	12097	206907	520897	0.74		
0.1	25.9	23.26	91.18	4.363	397.86	17.10	13.44	12083	206673	511258	0.70		
0.1	26.0	23.04	91.11	4.326	394.16	17.10	13.44	12066	206375	501643	0.67		
0.1	26.1	22.83	91.03	4.289	390.43	17.10	13.44	12045	206014	492056	0.63		
0.1	26.2	22.61	90.94	4.252	386.69	17.10	13.44	12020	205591	482502	0.59		
0.1	26.3	22.39	90.83	4.216	382.91	17.10	13.44	11991	205104	472987	0.56		

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Drop Distance (ft)	Total Distance (ft)	Cask Velocity (ft/s)	Water Velocity (ft/s)	Area Water Flow (ft ²)	Water Flow (ft ³ /s)	Area Base (ft ²)	Area Pail (ft ²)	Pressure Cylinder (lb/ft ²)	Force Floor (lb)	Cask Energy (ft-lb)	Additional Flow Area (ft ²)	Hole dia. each side, every 1 ft (inches)	Hole dia. each side, every 2 ft (inches)
0.1	26.4	22.17	90.71	4.179	379.12	17.10	13.44	11959	204555	463515	0.52		
0.1	26.5	21.94	90.58	4.144	375.30	17.10	13.44	11924	203944	454090	0.48	5.60	
0.1	26.6	21.72	90.43	4.108	371.47	17.10	13.44	11884	203271	444719	0.45		
0.1	26.7	21.49	90.26	4.073	367.62	17.10	13.44	11841	202537	435405	0.41		
0.1	26.8	21.27	90.09	4.038	363.75	17.10	13.44	11795	201743	426154	0.38		
0.1	26.9	21.04	89.89	4.003	359.86	17.10	13.44	11745	200890	416970	0.34		
0.1	27.0	20.81	89.69	3.969	355.96	17.10	13.44	11692	199978	407857	0.31		
0.1	27.1	20.58	89.47	3.935	352.05	17.10	13.44	11635	199008	398821	0.27		
0.1	27.2	20.35	89.24	3.901	348.13	17.10	13.44	11575	197982	389865	0.24		
0.1	27.3	20.12	89.00	3.867	344.20	17.10	13.44	11512	196901	380994	0.21		
0.1	27.4	19.89	88.74	3.834	340.26	17.10	13.44	11446	195767	372212	0.17		
0.1	27.5	19.66	88.47	3.801	336.31	17.10	13.44	11376	194580	363524	0.14	3.60	3.60
0.1	27.6	19.43	88.19	3.769	332.37	17.10	13.44	11304	193342	354932	0.11		
0.1	27.7	19.20	87.90	3.736	328.42	17.10	13.44	11228	192054	346442	0.08		
0.1	27.8	18.97	87.59	3.704	324.46	17.10	13.44	11150	190720	338057	0.04		
0.1	27.9	18.74	87.27	3.673	320.51	17.10	13.44	11070	189339	329780	0.01		
0.1	28.0	18.51	86.49	3.66	316.57	17.10	13.44	10873	185976	321768	0.00		
0.1	28.1	18.28	85.44	3.66	312.70	17.10	13.44	10609	181458	314110	0.00		
0.1	28.2	18.06	84.41	3.66	308.95	17.10	13.44	10356	177139	306792	0.00		
0.1	28.3	17.85	83.42	3.66	305.33	17.10	13.44	10115	173012	299798	0.00		
0.1	28.4	17.65	82.47	3.66	301.83	17.10	13.44	9885	169068	293114	0.00		
0.1	28.5	17.45	81.54	3.66	298.45	17.10	13.44	9664	165299	286727	0.00		
0.1	28.6	17.26	80.65	3.66	295.18	17.10	13.44	9454	161696	280622	0.00		
0.1	28.7	17.07	79.79	3.66	292.02	17.10	13.44	9252	158254	274788	0.00		
0.1	28.8	16.89	78.95	3.66	288.97	17.10	13.44	9060	154963	269212	0.00		
0.1	28.9	16.72	78.15	3.66	286.02	17.10	13.44	8876	151819	263883	0.00		
0.1	29.0	16.56	77.37	3.66	283.18	17.10	13.44	8700	148814	258790	0.00		
0.1	29.1	16.40	76.62	3.66	280.43	17.10	13.44	8533	145942	253924	0.00		
0.1	29.2	16.24	75.90	3.66	277.78	17.10	13.44	8372	143197	249272	0.00		
0.1	29.3	16.09	75.20	3.66	275.22	17.10	13.44	8219	140574	244827	0.00		
0.1	29.4	15.95	74.52	3.66	272.76	17.10	13.44	8072	138068	240579	0.00		
0.1	29.5	15.81	73.88	3.66	270.38	17.10	13.44	7932	135672	236519	0.00		
0.1	29.6	15.67	73.25	3.66	268.09	17.10	13.44	7798	133382	232639	0.00		
0.1	29.7	15.54	72.65	3.66	265.88	17.10	13.44	7670	131194	228931	0.00		
0.1	29.8	15.42	72.06	3.66	263.76	17.10	13.44	7548	129103	225387	0.00		
0.1	29.9	15.30	71.50	3.66	261.71	17.10	13.44	7431	127104	222000	0.00		
0.1	30.0	15.19	70.97	3.66	259.73	17.10	13.44	7320	125194	218763	0.00		
0.1	30.1	15.07	70.45	3.66	257.83	17.10	13.44	7213	123369	215670	0.00		
0.1	30.2	14.97	69.95	3.66	256.00	17.10	13.44	7111	121625	212713	0.00		
0.1	30.3	14.86	69.47	3.66	254.24	17.10	13.44	7013	119957	209888	0.00		
0.1	30.4	14.77	69.00	3.66	252.55	17.10	13.44	6920	118364	207188	0.00		
0.1	30.5	14.67	68.56	3.66	250.92	17.10	13.44	6831	116842	204608	0.00		
0.1	30.6	14.58	68.13	3.66	249.35	17.10	13.44	6746	115386	202142	0.00		
0.1	30.7	14.49	67.72	3.66	247.84	17.10	13.44	6665	113996	199785	0.00		
0.1	30.8	14.41	67.32	3.66	246.39	17.10	13.44	6587	112666	197532	0.00		

M&D Professional Services		CALCULATION SHEET		Page No. 10 of 10	
				Calculation No. M&D 99-09	
Client / Location DE&SH		Prepared By / Date M. D. Northey 6/22/99		Revision No. 0	
Subject Hydraulically Damped Cask Drop		Checked By / Date Milon Meyer		Contract No.	
Ref. Drawing(s)		Revised By / Date			

Drop Distance (ft)	Total Distance (ft)	Cask Velocity (ft/s)	Water Velocity (ft/s)	Area Water Flow (ft ²)	Water Flow (ft ³ /s)	Area Base (ft ²)	Area Pail (ft ²)	Pressure Cylinder (lb/ft ²)	Force Floor (lb)	Cask Energy (ft-lb)	Additional Flow Area (ft ²)	Hole dia. each side, every 1 ft (inches)	Hole dia. each side, every 2 ft (inches)
0.1	30.9	14.32	66.94	3.66	245.00	17.10	13.44	6513	111396	195380	0.00		
0.1	31.0	14.25	66.57	3.66	243.66	17.10	13.44	6442	110182	193322	0.00		
0.1	31.1	14.17	66.22	3.66	242.38	17.10	13.44	6374	109022	191356	0.00		
0.1	31.2	14.10	65.89	3.66	241.14	17.10	13.44	6309	107913	189477	0.00		
0.1	31.3	14.03	65.56	3.66	239.95	17.10	13.44	6247	106854	187682	0.00		
0.1	31.4	13.96	65.25	3.66	238.81	17.10	13.44	6188	105841	185966	0.00		
0.1	31.5	13.90	64.95	3.66	237.72	17.10	13.44	6131	104873	184325	0.00		
0.1	31.6	13.84	64.66	3.66	236.67	17.10	13.44	6077	103948	182758	0.00		
0.1	31.7	13.78	64.39	3.66	235.66	17.10	13.44	6026	103064	181260	0.00		
0.1	31.8	13.72	64.12	3.66	234.69	17.10	13.44	5976	102220	179829	0.00		
0.1	31.9	13.67	63.87	3.66	233.77	17.10	13.44	5929	101412	178460	0.00		
0.1	32.0	13.62	63.63	3.66	232.87	17.10	13.44	5884	100641	177153	0.00		

APPENDIX P

Design Review Checklist

IMMERSION PAIL SUPPORT STRUCTURE AND IMMERSION PAIL DESIGN REVIEW CHECKLIST

DESCRIPTIONS	YES	NO	N/A	COMMENTS
FUNCTION:				
1. Perform a safety-class function of maintaining the south loadout pit safety-class function (floor, walls, and drain valve) during a cask-MCO drop, as well as other postulated operational drops.	X			Scenarios evaluated to date indicate that the safety function is being met. However, additional drop evaluations are planned.
2. The IPSS shall function as a guide for raising and lowering the IP.	X			
3. The IPSS shall function as a support for the IP and cask-MCO in the upper pinned position to facilitate installation and removal of the cask-MCO.	X			
4. The IP shall function as a barrier for isolating the outer surfaces of the cask from contaminated K Basin water.	X			
5. The IP shall function as a device for raising and lowering the cask-MCO.	X			Acts as a carrier to which the crane is attached.
REQUIREMENTS:				
1. The IP shall provide buoyancy when raising and lowering the cask-MCO to assure that the transfer bay crane does not lift over 64,000 lb. (DESH 1997).			X	Calculations not provided as a part of this review.
2. The IP shall permit loading MCO baskets into the MCO, using the MLS gantry/grapple, when the IP and cask-MCO are lowered to the bottom of the south loadout pit.	X			
3. For lifted load conditions, the IP shall be designed and fabricated in accordance with ANSI N14.6, <i>American National Standard for Radioactive Materials-Special Lifting Devices for Shipping Containers Weighting 10,000 Pounds (4500 kg) or More</i> (ANSI N14.6).	X			
4. The IP is not required to be designed as a pressure vessel.	X			

**IMMERSION PAIL SUPPORT STRUCTURE AND IMMERSION PAIL
DESIGN REVIEW CHECKLIST, CONT.**

DESCRIPTIONS	YES	NO	N/A	COMMENTS
5. The IPSS shall preclude loaded MCO baskets from falling between the IPSS and the MLS shuttle, while the MCO basket is suspended from the MLS grapple.			X	Not within the scope of this review.
6. The IPSS pin blocks and pins shall be designed for lifting loads in accordance with ANSI N14.6.	X			Provisions need to be provided for in-service testing and/or inspections.
7. The IPSS shall be designed for the dead weight, operational and seismic loads listed in SDC-4.1 (DOE 1993) for safety-class 1 non reactor equipment. Note: Hanford Site standard SDC-4.1 (DOE 1993) references ANSI/AISC N690, UCRL-15910 (Kennedy 1990), and ACI 349.	X			
8. Modifications to the IPSS and IP shall not change the design or operability of the MLS shuttle.	X			
9. The IPSS and IP shall provide repeatable positioning to facilitate insertion and removal of the cask-MCO into the IP (approximately 100 cycles per year for two years).		X		Orifice configuration, close IP/Cask tolerances, and crane positioning tolerance (1/4") make this uncertain.
10. The IPSS and IP shall provide repeatable positioning of the cask-MCO to facilitate loading MCO baskets using the MLS gantry/grapple.			X	Not in scope of this review. However, some concern remains (see comment on number 9, above).
11. The IP and IPSS are not required to be operational after a design basis load drop accident.	X			
12. Seismic evaluation of the IP and IPSS shall include guidance from UCRL-15910 (Kennedy 1990).	X			
13. The IP and IPSS, with exception to crushable impact limiting materials and shear pins designed to fail on impact, shall be designed using ANSI/AISC N690 for dead weight, operational loads, seismic loads, and drop loads (Y_m) as defined as in ANSI/AISC N690 for load case summations.	X			
14. The south loadout pit concrete shall be evaluated using guidance from ACI 349 for dead weight, operational, and seismic loads.	X			

**IMMERSION PAIL SUPPORT STRUCTURE AND IMMERSION PAIL
DESIGN REVIEW CHECKLIST, CONT.**

DESCRIPTIONS	YES	NO	N/A	COMMENTS
15. The south loadout pit concrete shall be evaluated using guidance from ACI 349, Appendix C for load drop accidents (Reference Appendix B of this document for ACI code criteria discussion). Note: The magnitude of impact load reduction will be determined in conjunction with the impact load reduction capability that is designed into the OIP.	X			Meets this requirement. However, the requirement is not considered acceptable. Follow the code to its fullest extent or provide justification for alternate criteria.
16. Acceptance of the concrete surrounding the 4 in. drain valve using guidance from ACI 349, Appendix C shall be deemed adequate justification for acceptance of drain valve integrity after a design basis load drop.			X	Not within the scope of this review, no calculations provided.
17. Overhead drops associated with equipment and tools that are routinely handled over the 4 in. drain valve shall be identified, and protective features designed to accommodate the worst case credible drop(s).			X	Not within the scope of this review.
18. The cask-MCO drop scenarios (Appendix A of this document) for the SNF load out operations shall include the primary impact and any secondary impact(s) with equipment and/or structures until the cask-MCO comes to rest after a drop.		X		Primary impacts have been evaluated, secondary impacts remain to be completed.
19. The drop scenarios shall include the drop of a cask-MCO (empty or loaded) anywhere along the cask-MCO travel path between the CTS and the south loadout pit.		X		See comment to Item 18.
20. Human factors shall be evaluated during design in accordance with UCRL-15673 (Bongarra 1985).			X	Formal evaluation, not part of this preliminary conceptual design.
21. Load drops shall consider the parameters listed below.				
a. The maximum drop height for a cask-MCO shall be 5 ft. 4 in. EL above the floor of the transfer bay as controlled by engineered features provided by the transfer bay crane (WHC 1996) Note: The 0 ft. EL is referenced from the transfer bay floor.	X			
b. The maximum weight of the cask-MCO when empty is 45,000 lb. (DESH 1997, DESH 1998a)			X	No evaluations for empty cask included.

**IMMERSION PAIL SUPPORT STRUCTURE AND IMMERSION PAIL
DESIGN REVIEW CHECKLIST, CONT.**

DESCRIPTIONS	YES	NO	N/A	COMMENTS
c. The maximum weight of the cask-MCO in the loaded condition is 62,000 lb. (DESH 1997, DESH 1998a).		X		Calculations show varying weights (i.e., 60,000 lbs, 62,000 lbs., 64,000 lbs.).
d. The minimum weight of a dropped load in the south loadout pit, consisting of the IP, water in the IP, the cask, cask lid, a 20,457 lb. MCO (DESH 1998a), and cask lid torque tool in the raised, pinned position shall be 70,000 lb. (DESH 1997).	X			
e. The maximum acceleration of the MCO inside the cask during a design basis accident drop shall not exceed 27 g for a vertical drop, 101 g for a horizontal drop, 33.5 g for a corner drop (cask lid up), and 27.4 g for a corner drop (cask lid down) (DESH 1998a).		X		No calculations provided.
22. Cask-MCO drop analysis shall not rely on the water in the IP for reduction of the impact force on the safety-class basin walls and floor.	X			
23. Safety-class components shall be designed to allow inspection, maintenance, and testing to ensure their continued functioning, readiness for operation, and accuracy.		X		Maintenance and inspection provisions for the crush limiters, shear pins, etc., below the slop water level were not apparent.

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OPERATOR INTERFACE PLATFORM DESIGN REVIEW CHECKLIST

DESCRIPTIONS				YES	NO	N/A	COMMENTS
FUNCTION:							
1. The OIP shall function as a work area for operations personnel to perform tasks associated with cask loadout operation.	X						Human factors should be considered for gaining access to Cask/MCO lid, pins, etc.
2. The OIP shall function as a tool storage location for four long handled tools and IP lifting slings.				X			Not part of the preliminary CDR review. A definitive design feature.
3. The OIP shall perform a safety-class function as an impact limiting device, as required, that reduces the impact load to the IPSS.	X						
REQUIREMENTS:							
1. The OIP shall incorporate safety-class design features that reduce the impact load to the IPSS and IP, as required, to maintain the south loadout pit safety-class function (floor, walls, and drain valve) as evaluated using guidance from ACI 349, Appendix C for load drop accidents (Reference Appendix B of this document for ACI code criteria discussion). Note: The magnitude of impact load reduction will be determined in conjunction with the impact load reduction capability that is designed into the IPSS and IP.	X						Meets this requirement. However, the requirement is not considered acceptable. Follow the code to its fullest extent or provide justification for alternate criteria.
2. The OIP is not required to be operational after a design basis load drop accident.	X						
3. The platform shall provide storage for the IP lifting slings and four long handled tools.				X			Not reviewed. See Function Item 2.
4. The platform shall permit access to provide support to the MLS underwater cameras.				X			Not in scope for this review.
5. The platform shall accommodate the loose ends of the IP lifting slings when the IP is in the lowered position.				X			Not in scope for this review.
6. The platform shall accommodate a maximum of two operators with fall arrest protection for each.				X			Not in scope for this review.
7. The platform shall have a load rating of 60 lb./ft ² (minimum).				X			Not in scope for this review.

OPERATOR INTERFACE PLATFORM DESIGN REVIEW CHECKLIST, CONT.

DESCRIPTIONS	YES	NO	N/A	COMMENTS
8. Human factors shall be evaluated during design of the operator platform in accordance with UCRL-15673, <i>Human Factors Design Guidelines for Maintainability of DOE Nuclear Facilities</i> (Bongarra 1985).			X	Formal evaluation not part of this preliminary CDR.
9. Designs shall facilitate safe operation in accordance with the requirements of Title 29, Code of Federal Regulations (CFR), Part 1910, Subparts D and E, and Part 1926, Subparts C, M, and X., as applicable.			X	Formal evaluation not part of this preliminary CDR.
10. Safety-class components shall be designed to allow inspection, maintenance, and testing to ensure their continued functioning, readiness for operation, and accuracy.	X			
11. The OIP shall permit access to the cask load out equipment within the south loadout pit on the north, south, and west sides to accommodate the manual tasks listed below.				
a. Insertion and removal of the IP pail locking pins.	X			Requires specialty tooling – could be ALARA concern.
b. Installation and removal of the IP lid.			X	Not within the scope of this review.
c. Inspection and inflation of the IP lid seals.			X	Not within the scope of this review.
d. Attachment of the cask lid and cask lid torque tool.			X	Not within the scope of this review.
e. Installation of the MCO shield plug, locking ring, and locking ring torque tool.			X	Not within the scope of this review.
f. Installation and removal of IP basket guide/guard			X	Not within the scope of this review.
g. Air bleed for the IP. Initial water fill of MCO.			X	Not within the scope of this review.
h. Initial water fill of MCO.			X	Not within the scope of this review.
i. Decontamination of the platform, equipment, and tools.			X	Not within the scope of this review.
12. The OIP shall not interfere with the following cask load out operations.				
a. Insertion and removal of the IP locking pins	X			See 11a.

**OPERATOR INTERFACE PLATFORM
DESIGN REVIEW CHECKLIST, CONT.**

DESCRIPTIONS	YES	NO	N/A	COMMENTS
b. Installation and removal of the IP lid.			X	Not within the scope of this review.
c. Inspection and inflation of the IP lid seals.			X	Not within the scope of this review.
d. Attachment of the cask lid and cask lid torque tool.			X	Not within the scope of this review.
e. Installation of the MCO shield plug, locking ring, and locking ring torque tool.			X	Not within the scope of this review.
f. Installation and removal of IP basket guide/guard.			X	Not within the scope of this review.
g. Initial water fill of MCO.			X	Not within the scope of this review.
h. Operation of the water reservoir hose connecting to the IP while raising and lowering the IP.			X	Not within the scope of this review.
i. Use of personnel fall arrest protection.			X	Not within the scope of this review.
j. Operation of the MLS.			X	Not within the scope of this review.
k. Operation of the CLS components.			X	Not within the scope of this review.
13. Design and analysis shall be performed in accordance with the requirements of SDC-4.1 (DOE 1993) for safety-class 1 non-reactor equipment. Note: Hanford Site standard SDC-4.1 (DOE 1993) references ANSI/AISC N690, UCRL-15910 (Kennedy 1990), and American Concrete Institute (ACI) 349.	X			
14. Seismic evaluation shall include guidance from UCRL-15910 (Kennedy 1990).	X			
15. The operator platform, with exception to crushable impact limiting materials, shall be designed using ANSI/AISC N690 for dead weight, operational loads, seismic loads, and drop loads (Y_m) as defined as in ANSI/AISC N690 for load case summations.	X			Meets this requirement. However, the requirement is not considered acceptable. Evaluate the scope in full accordance with ACI-349, including Appendix C.
16. The south loadout pit concrete shall be evaluated using guidance from ACI 349 for dead weight, operational, and seismic loads.	X			

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OPERATOR INTERFACE PLATFORM
DESIGN REVIEW CHECKLIST, CONT.

DESCRIPTIONS	YES	NO	N/A	COMMENTS
17. The south loadout pit concrete shall be evaluated using guidance from ACI 349, Appendix C for load drop accidents (Reference Appendix B of this document for ACI code criteria discussion).	X			Same as IP number 15.
18. Drop scenarios are defined in Appendix A of this document. Note: Other drop scenarios may be identified during the course of the design.	X			

APPENDIX Q

Dose Rates at the Operator Interface Platform

INTEROFFICE

CORRESPONDENCE

99-SNF/CAB-022

To: K. E. Ard X3-85

From: C. A. Bullock *CAB* X3-68

cc: W. A. Decker X3-68
 P. G. Huntley X3-68
 J. E. Kurtz X3-68
 D. T. Southerland X3-68
 CAB LB/ File X3-68

Date: June 23, 1999

Telephone: 376-2473

Subject: DOSE RATES AT THE OPERATOR INTERFACE PLATFORM

As requested, I have performed an analysis of the dose rates at the operator interface platform (OIP) associated with the proposed changes to the Immersion Pail Support Structure. Your concern was the dose rates on the OIP due to the decreased water coverage during movement of the Multi-Canister Overpack (MCO) fuel basket. I performed a simple shielding calculation based on existing dose calculations (WHC-SD-SNF-CAVR-001, Rev 0). The document, WHC-SD-SNF-CAVR-001, Rev 0, was issued in November 1996; I was unable to determine if there were any subsequent revisions to this document.

The initial request was for dose rates at the OIP taking into account 1) 4' 0" water coverage and seven feet of air, and 2) 3' 3" of water coverage and seven feet of air. The results indicate a dose rate of 31 mrem/hr for scenario 1, and 199 mrem/hr for scenario 2. Additionally, you requested a graph of the dose rates associated with varying the water coverage in one-inch increments. The attached graph shows the dose rates for 2' 9" to 4' 0" water coverage at the water surface. Based on the source geometry and the results from scenario 1 and scenario 2, air provides negligible shielding, it is conservative to use the water surface dose rates. The dose rates range from 700 mrem/hr to 31 mrem/hr. This is a purely calculational method and no modeling was performed.

These results indicate that there is a great concern about creating a High Radiation Area (HRA) on the OIP. AHRA situation would be unacceptable to the ALARA organization and the Radiological Controls Organization. Attached are the calculation sheets used and checked for this work. Please retain these as part of your project files.

If you have any questions please give me a call at 376-2473.

bag

Attachments 2

99-SNF/CAB-022

ATTACHMENT 1

Dose Rates at the Operator Interface Platform

Consisting of 3 pages
including cover

Analytical Calculation

Date: 6-21-99Building: 105 KWSystem: Cask Load-out SystemPage 1 of 2Calculation Title: Dose to South Load-out Pit Operator Interface
Platform (4' water, 7' air) (3'3" water, 7' air)Performed by: CA Bullock Date: 6-21-99Checked by: G-E. 11/8 Date: 6-21-99Dose at platform

assuming: 4ft (121.92cm) of water over MCO basket

7ft (213.36cm) of air between water level and OIP

Known dose calculations (WHC-SD-SNF-CAVR-001 Rev 0, 11/96)

water thickness

2' 9"

3' 9"

Maximum dose rate at top of water

701 mrem/hr

59 mrem/hr

determine μ_{H_2O}

$$I = I_0 e^{-\mu x}$$

$$59 \text{ mrem/hr} = 701 \text{ mrem/hr} e^{-\mu (30.48 \text{ cm})}$$

$$0.081 = \mu_{H_2O}$$

determine μ_{air} for Cs-137 (0.66 MeV)

linear extrapolation Table 5.1 (Rad Health Handbook @ 1992)

$$\mu/\rho = 0.0799 \quad \rho = 0.00123$$

$$\mu = 0.000098$$

Analytical Calculation: Supplemental Sheet

Page 2 of 32Calculation Title: Dose to SLOP OIPdetermine maximum dose rate at top of ^{4'}water

$$R = R_0 e^{-\mu x}$$

$$R = 59 \text{ mrem/hr } e^{-0.081(7.62 \text{ cm})}$$

$$R = 31.82 \text{ mrem/hr}$$

determine maximum dose rate at OIP (7' air)

$$R = R_0 e^{-\mu x}$$

$$R = 31.82 \text{ mrem/hr } e^{-(0.000098)(213.36 \text{ cm})}$$

$$R = 31.1 \text{ mrem/hr}$$

determine maximum dose rate at top of 3'3" water

$$R = R_0 e^{-\mu x}$$

$$R = 701 \text{ mrem/hr } e^{-0.081(15.24 \text{ cm})}$$

$$R = 204 \text{ mrem/hr}$$

determine maximum ^{cb} dose rate at OIP (7' air)

$$R = R_0 e^{-\mu x}$$

$$R = 204 \text{ mrem/hr } e^{-0.000098(213.36 \text{ cm})}$$

$$R = 199 \text{ mrem/hr}$$

99-SNF/CAB-022

ATTACHMENT 2

Dose Rates at the Operator Interface Platform

Consisting of 2 pages
including cover

Maximum Dose Rate at Surface of Water

APPENDIX R

Review Comment Record

(1) Comment Resolution Report (by Item No)

HNF-4576, Rev. 0

Conceptual Design Report - Cask Loadout System/Cask Drop Redesign for the Immersion Pail Support

Item No.	Subsystem	Commentor	Document Section	Page No.	Category	Priority	Disposition	Disp Date	Reviewer Final Disposition
001	ALARA	Bullock, C		16	Technical	Med. Priority		6/9/99	Accept
		ALARA Assessment/Operations - Based on the uncertainty of actual height, the IPSS will be raised due to new design, it cannot be said that the changes are not expected to appreciably affect the overall operations, and, thereby, not affect the current dose assessments. The increased height of the IPSS will cause the fuel baskets to be lifted higher (closer to surface of water) before being lowered into the MCO. The increase height could lead to the loss of 1/4 to 1/3 shielding from water. This would be a significant increase in dose rate above IP/IPSS.					ALARA assessments performed to date will be evaluated in the final design phase.		
002	ALARA	Bullock, C	OIP	12	Technical	Low Priority			Accept
		OIP foam same design as IPSS. Need to ensure that this foam is also encased.					The Design Team will evaluate the comment during preparation of the final conceptual design report.		
003	ALARA	Bullock, C			Technical	Med. Priority		6/9/99	Accept
		As designed, the OIP significantly interferes with the Operator's access to basic tasks (pin removal, cask lid removal). The increased elevation requires the operators to work in awkward positions which slows the work process. This has the potential to increase the amount of time in the area and increase dose exposure.					This will be evaluated in final design.		
004	M Appendi Conceptual Design, Operator Interface Platform	Bullock, C		4	Technical	Low Priority			Accept
		Paragraph 2 says 24x48x30 inch deep crush blocks are placed on top of the SLOP curb wall. Paragraph 3 says 6 inch deep modified "W" end beams and the 18 inch deep crush blocks.... Which is correct?					The Design Team will evaluate the comment during preparation of the final conceptual design report.		
005	S Appendix Sketches	McDaniel, P	Sketch 6 of the Lower IPSS Structure		Fabrication	Med. Priority			Accept
		Referring to Sketch 6 of the lower IPSS Structure - Fabrication of this hydraulic sleeve and telescoping guide tubes appears to be unnecessarily complicated. The process of rolling the sleeve or individually rolling the panels and welding to the guide tubes will be extremely difficult to maintain layout and tolerances. Although this reviewer does not have all necessary geometry information present, it appears that a one piece rolled hydraulic sleeve and the use of round guide tubes would accomplish objectives and be far easier to fabricate. The round hydraulic sleeve fabricated as a single pipe would simplify pressure quality analysis by allowing it to be modeled as a pipe, using an appropriate pipe code with water hammer. Also a single sleeve will dramatically increase buckling stability.					Fabrication details and economics will be evaluated as the design progresses.		

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(1) Comment Resolution Report (by Item No)

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Item No.	Subsystem	Commentor	Document Section	Page No.	Category	Priority	Disposition	Disp Date	Reviewer Final Disposition
006	S Appendix	McDaniel, P			Safety	High Priority			Accept
	Sketches	The height of the operating platform could and probably should be reduced for two primary reasons. First, it increases the free-fall distance in an accident and causes structural members to be very large; second, it makes it very difficult for operators to access the top of the cask for cask and MCO lid removal and pin removal installation. The best way to reduce the energy of a drop would be to limit the height of the drop. The additional height imposed by the current approach to protecting the operator interface area is in contradiction to this approach. Given the importance of this project, this reviewer suggests removing or lowering the curb/retaining wall and designing and constructing a protective structure without adding additional height. It is also suggested that the crane height be administratively controlled to maintain the bottom of the cask no more than 6" above the elevation of any object it must clear. This could be accomplished by cutting down the SLOP wall, capping the remaining wall with steel, and recessing the platform down into the pit as necessary.				The drop height is predicated on the height of crane limit switches, not the height of the OIP.			
007	General	McDaniel, P			Operational	High Priority		6/9/99	Accept
	CDR General	According to design documentation, the "orifice lip" on the immersion pail has a .095" gap between the cask and pail. This is in contradiction to the supposedly 1/4" positioning accuracy of the crane. Eliminating this orifice should facilitate operations and also could provide energy absorbing benefits. If the gap was larger and the immersion pail was filled with water before use, an effective hydraulic damper would result.				The orifice/crane interface was reviewed in previous design reviews for the Cask Transportation System and is not part of the cask drop redesign effort. The comment will be forwarded to the K Basins Project Manager for consideration. The water-filled approach was identified early in the design and was evaluated. It is not the preferred approach based on the engineering difficulty associated with a safety-class water delivery system, interlocks with the rate of cask removal, and the difficulty of maintaining safety-class control systems. The use of administrative controls for the water delivery has not been well received. However, because of the drop height and difficulties associated with designing for this drop height, the use of a hydraulic cushion is still considered as a fall back alternative as discussed in Section 17.2 of HNF-SD-SNF-FRD-025.			
008	General	McDaniel, P			General	Med. Priority			Accept
	CDR General	It appears that the vertical drop scenarios presented are: a) not possible due to the nature of the rigging system (i.e., double cable arrangement, and b) may not be worse case. Might it be possible to review the lifting equipment and processes and improve design such that a drop becomes incredible?				(a) This has been evaluated to be a credible event. Reference WHC-SD-SNF-FRD-023. (b) Additional drops, such as those identified in M&D Calculation M&D 99-04, Rev. 1, will be evaluated as part of CDR II.			

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(1) Comment Resolution Report (by Item No)

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Item No.	Subsystem	Commentor	Document Section	Page No.	Category	Priority	Disposition	Disp Date	Reviewer Final Disposition
009	CDR	McDaniel, P			Design	Med. Priority		6/9/99	Accept
		I recognize that the Conceptual Design Report suggests that the current IPSS cannot be modified to provide required energy-absorbing characteristics, the justification for this statement is not provided in the report. It is likely that it can be realigned. I have roughed out a concept that could address the problem.				Scoping analysis and concepts were attempted to salvage the existing IPSS. These attempts failed and the decision was made to move on with a replacement structure.			
010	CDR	Besser, R	1	2	Safety	High Priority			Accept
		Pg. 2 Section 1 indicates that the "safety function of the basin is to maintain water coverage over the SNF and sludge" and that the CLS safety function is to "not cause a condition that would challenge the basin's ability to maintain water over the SNF and sludge. In reality, it appears that the safety function has evolved to keeping the South Loadout Pit from leaking since there are many (far less costly ways to keep the fuel and sludge covered with water. The CDR wording should be revised.				The use of the word challenge will be revised. Several leak mitigation methods were identified during a value engineering session. The use of a grout was identified as the preferred alternative. The grout idea was developed and presented to RL on at least two occasions without acceptance.			
		Considering that several of the systems analyzed are based on "unknown" or "not well defined" characteristics [(i.e., concrete/rebar, failure mechanisms, soil backing (compacted sand/gravel composition) and failure mode loads], it appears that the water loss prevention/mitigation (the basic safety function) should focus on stopping water loss after a cask-MCO drop event. See water leakage mitigation options.							
011	CDR	Riesenweber, S	IV B	10	Technical	Low Priority			Accept
		Pg. 10, Section IV B states that "the anticipated radiation levels are not expected to affect this foam". This is too soft a statement for foam that is required to assure that the safety function is met. The adequacy should be verified during conceptual design and stated conclusively.				The Design Team will evaluate the comment during preparation of the final conceptual design report.			
012	General	McDaniel, P			Technical	Med. Priority			Accept
	CDR General	It will be impossible to insert the cask into the IP without contact due to the tight orifice clearance. If 100 cycles per year for two years is considered, this will result in wear on the shear bolts on the IPS. This could result in a premature failure of the IPS.				This will be considered in the final design.			
013	E Appendix	Strehlow, J			Technical	Med. Priority			Accept
	Interoffice Correspondence	Appendix E With the current design of the IP and the method of operation, the water in the annulus will go "solid" when it reaches the orifice during a cask drop. This situation may produce unacceptable loads on the IP. Either design the IP for these loads or remove the orifice.				These issues will be resolved during final design. If pressure becomes a problem, a rupture disk may be installed.			

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(1) Comment Resolution Report (by Item No)

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Item No.	Subsystem	Commentor	Document Section	Page No.	Category	Priority	Disposition	Reviewer Final Disposition
014	CDR	Riesenweber, S	IV B	10	Editorial	Low Priority	The Design Team will evaluate the comment during preparation of the final conceptual design report.	Accept
		The statement, "It is assumed that the bottom of the pail will always be engaged in the bottom of the IPSS sleeve." does not make sense in light of the fact that the IP will be moved up to an intermediate position for installation of the cask-MCO.						
015	CDR	Riesenweber, S	VI A	15	Editorial	Low Priority	The Design Team will evaluate the comment during preparation of the final conceptual design report.	Accept
		Refers to NQA-I-1944. Date is incorrect. Should be 1997.						
016	CDR	Riesenweber, S	VII	21	Administrative	Low Priority	The Design Team will evaluate the comment during preparation of the final conceptual design report.	Accept
		This section refers to a waiver that may be necessary to the FHA because of the impact absorbing foam. It seems that a DCN to the FHA is more appropriate to evaluate the fire related implications of foam.						
017	D Appendix	Riesenweber, S		1	Technical	Med. Priority	Calculations in the Conceptual Design Report will be reviewed by the Design Team to assure that the purpose and scope of the calculations are identified, that the calculations have been checked and signed in accordance with SNF Project procedures. The weight of 62,000 lb. will be used.	Accept
	Description of Possible Transportation Cask Drop Accidents in the 105-KW Basin SLOP	This states that the total mass of the cask-MCO plus SNF is 62,000 lbs. Section IV page 5 states the mass is 64,000 lbs. Attachment A of Appendix D states that the MCO cask weight is 60,000 lbs. This is less than two other weights found in Appendix D, Page, 1 and will affect the resulting forces. These should be made consistent; it is recommended that 64,000 lbs. Be the consistent value to match the crane capacity. Ensure that material weights, plus water is considered when calculating weights.						
018	D Appendix	Riesenweber, S		6	Technical	Low Priority	The Design Team will evaluate the comment during preparation of the final conceptual design report.	Accept
	Description of Possible Transportation Cask Drop Accidents in the 105-KW Basin SLOP	Why does scenario 1 have a shorter drop distance (3.67 ft) than scenario 6 (3.75 ft)? From the sketches, it appears that the support lug is higher in elevation than the pail lip.						

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Item No.	Subsystem	Commentor	Document Section	Page No.	Category	Priority	Disposition	Reviewer	Final Disposition
019	F Appendix	Riesenweber, S	Technical	Med. Priority	This approach was identified early in the design and was evaluated. It is not the preferred approach based on the engineering difficulty associated a safety-class water delivery system, interlocks with the rate of cask removal, and the difficulty of maintaining safety-class control systems. The use of administrative controls for the water delivery has not been well received. However, because of the drop height and difficulties associated with designing for this drop height, the use of a hydraulic cushion is still considered as fall back alternative as discussed in Section 17.2 of HNF-SD-SNF-FRD-025				
020	F Appendix	Riesenweber, S	Technical	High Priority	6/9/99	Accept	This was reviewed in previous design reviews for the Cask Transportation System and is not part of the cask drop redesign effort. The project will reevaluate documentation associated with testing this interface.		
021	F Appendix	Stretchow, J	Technical	High Priority	6/9/99	Accept	The filled pail approach was identified early in the design and was evaluated. It is not the preferred approach based on the engineering difficulty associated a safety-class water delivery system, interlocks with the rate of cask removal, and the difficulty of maintaining safety-class control systems. The use of administrative controls for the water delivery has not been well received. However, because of the drop height and difficulties associated with designing for this drop height, the use of a hydraulic cushion is still considered as fall back alternative as discussed in Section 17.2 of HNF-SD-SNF-FRD-025		
The cask drop into a minimally wet pail results in high pressure spikes caused by first the pail contacting the water and second the water contacting the orifice when all of the air is expelled. The effective mass of the fluid under the cask and the effect of the momentum transfer will induce additional pressure under the cask, which needs to be accounted for in the structural evaluation of the IF. This phenomenon could be addressed by assuming no fluid moves up the annulus, i.e., a solid impact. The over-pressure would then be based on the peak impact force from the cask which depends on the effective stiffness and mass of the IF and IPSS system.									
A filled pail would not result in the orifice spike and would have a lower initial contact pressure spike since the cask is not allowed to accelerate nearly as long before it reaches the water. The lower pressure spike condition is preferred since construction of the pail to withstand the spike will be less costly. This should be done in conjunction with removal of the orifice.									
The water displaced during initial insertion of the cask (in normal operation) could be forced via hose(s) at the bottom of the pail, into an atmospheric tank. The water would be pulled (and gravity fed) back into the pail as the filled cask-M/CO is removed via crane. This serves to minimize the amount of make-up water required, provides the maximized energy absorption over a longer period of time (reducing the impact loads) during both cask insertion and retrieval accidents, and would be used to maintain the slightly pressurized annular space (desired between cask and pail) through static head in the tank.									

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Item No.	Subsystem	Commentor	Document Section	Page No.	Category	Priority	Disposition	Disp Date	Reviewer Final Disposition
022	F Appendix Shipping Cask Into Immersion Pail Drop Analysis	Strehlow, J	Appendix F Make sure the piston energy absorption systems will work properly given the dimensional tolerances specified for the critical parts.		Technical	Low Priority	This will be evaluated during final design.	6/9/99	Accept
023	G Appendix Hypothetical Immersion Pail into Pail Shell Analysis	Riesenweber, S	What is the value in allowing the pail to accelerate with side vents. It appears that the energy resulting from this acceleration will either have to be taken by higher maximum pressures (to slow the pail down) or higher impact velocity. Remove the vents in the side of the IPSS structure and design the piston so that the cask has a minimal velocity when it impacts the bottom of the IPSS. The maximum over-pressure that would occur without these holes would be no more than twice the pressure required to balance the weight of the cask.		Technical	Med. Priority	The vent holes prevent peak pressures when the IP falls into the cylinder. Details will be refined in final design.	6/9/99	Accept
024	General CDR General	Riesenweber, S	Many of the calculations are not checked or signed by the reviewer. At this stage of design, this should be done. Some calculations do not even identify the preparer.		Design Criteria	High Priority	Calculations in the Conceptual Design Report will be reviewed by the Design Team to assure that the purpose and scope of the calculations are identified, that the calculations have been checked and signed in accordance with SNF Project procedures.	6/9/99	Accept
025	General CDR General	Riesenweber, S	Has the design considered suspending the IPSS from the pit walls? This would remove point loading on the SLOP floor and could reduce the likelihood of floor wall separation. This would result in all crush materials up out of the water.		Technical	Med. Priority	This was considered during preconceptual stages of the original cask transportation design and was abandoned due to the load bearing capability of the wall. This idea was also revisited during the value engineering session held on March 11, 1999. The concept will be readdressed with project management.	6/9/99	Accept
026	M Appendi Conceptual Design, Operator Interface Platform	Riesenweber, S	The idea of a guide funnel for inserting the cask is good. It reduces the likelihood of damage to components and/or wedging the cask due to misalignment.		Technical	Low Priority	Acknowledge. Will fully evaluate its use in final design.	6/9/99	Accept
027	M Appendi Conceptual Design, Operator Interface Platform	Riesenweber, S	It is not clear why crush material is placed under the stairs. It creates a substantial amount of fire loading. Instead, consider making the stairs break away if necessary.		Technical	Low Priority	The crush material beneath the stairs is relied upon to protect the SLOP wall during cask tip. Efforts will be made during final design to reduce reliance on the OIP as an impact limiting device.	6/9/99	Accept

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(1) Comment Resolution Report (by Item No)

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Item No.	Subsystem	Commentor	Document Section	Page No.	Category	Priority	Disposition	Disp Date	Reviewer Final Disposition
028	I Appendix	Strehlow, J			Technical	Med. Priority		6/9/99	Accept
	Structural Analysis of SLOP Reinforced Concrete	Appendix I Use direct sum for combining the drop impact load with the seismic load. The duration of the impact load (approximately 2.4-sec for the two-foot eccentric drop) will span several periods for the fundamental vertical oscillation of the SLOP structure (approximately 0.063-sec).					Accepted. Load combinations will be revisited and performed in accordance with code requirements during final design.		
029	J Appendix	Riesenweber, S			Design Criteria	High Priority		6/9/99	Accept
	Recommended Structural Acceptance Criteria for MCO Cask Drop Accidents in the I05-K SLOP	Neither this document or the F&R define: 1) What is an acceptable leak rate? Without this criteria, how can real acceptance criteria for energy absorption system be established? Remember, at least small cracks are inevitable with or without impact loads. 2) This appendix appears to establish a predicted deformation at the floor/wall construction joint; however it does not identify what impact load results in this deflection or reference a calculation that models the deformation. Thus, the criteria (if that is what this is) is questionable.					(1) The leak rate is established in the K Basins SAR. The final design will minimize the cracking and associated leak rate to the extent possible. Analysis is being attempted to quantify a maximum expected leak rate. (2) Current calculations (6/9/99) are quantifying joint deformation and corresponding leak rates, which will be incorporated into final design calculations.		
030	K Appendix	Riesenweber, S			Technical	Low Priority			Accept
	Immersion Pail Support Structure Impact Analysis	This calculation does not contain a clear problem statement, assumption, or sufficient detail to evaluate. Are impact absorbers part of the model?					Calculations in the Conceptual Design Report will be reviewed by the Design Team to assure that the purpose and scope of the calculations are identified, that the calculations have been checked and signed in accordance with SNF Project procedures.		
031	L Appendix	Riesenweber, S			Editorial	Low Priority			Accept
	Structural Evaluation of the Immersion Pail for Pressure Loading During a Postulated MCO/Cask Drop Accident	The figure 1 diagram is missing. This calculation does not contain a clear problem statement, assumption, or sufficient detail to evaluate. Are impact absorbers part of the model?					Calculations in the Conceptual Design Report will be reviewed by the Design Team to assure that the purpose and scope of the calculations are identified, that the calculations have been checked and signed in accordance with SNF Project procedures.		
032	L Appendix	Riesenweber, S			Technical	Low Priority			Accept
	Structural Evaluation of the Immersion Pail for Pressure Loading During a Postulated MCO/Cask Drop Accident	This calculation does not contain sufficient information to evaluate it.					Calculations in the Conceptual Design Report will be reviewed by the Design Team to assure that the purpose and scope of the calculations are identified, that the calculations have been checked and signed in accordance with SNF Project procedures.		

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(1) Comment Resolution Report (by Item No)

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Item No.	Subsystem	Commentor	Document Section	Page No.	Category	Priority	Disposition	Reviewer Final Disposition
033	L Appendix	Riesenweber, S	Technical	Med. Priority	Accept	(1), (2) These calculations were performed for scoping purposes. This will be re-evaluated during final design. A rupture disk will be used if required. (3) This comment will be considered during final design.		
034	M Appendix	Riesenweber, S	Technical	Med. Priority	Accept	The calculation evaluates the affect on the pail of a hydrostatic pressure of 560 psi. (1) Isn't the pressure too low? Appendix F indicates 640 psi, or maybe 3800 psi. (2) The calculation appears to only analyze the pail at the maximum pressure when the cask hits the water. This works for the wall stresses, but an momentum term needs to be added to the pressure for momentum translated from the water to the cask bottom and welds at the time of impact. (3) Our code expert recommends that the IP be evaluated as a pipe with a water hammer condition occurring, rather than looking at it as a pressure vessel.		
034	M Appendix	Riesenweber, S	Technical	Med. Priority	Accept	The level of protection provided by the OIP will be more fully defined during CDR II and the final design phase.		
035	I Appendix	Stretchow, J	Technical	Med. Priority	Accept	The modal analysis did not include the water. Will be incorporated into final design calculations.		
036	I Appendix	Stretchow, J	Technical	Med. Priority	Accept	The level of detail is consistent with Type II calculation requirements. Based upon R. Kennedy's review and recommendations, the solid soil model will not be used. The effect of soil adjacent to vertical walls is being addressed using upper bound friction values, which will be incorporated into final design calculations.		
037	S Appendix	Riesenweber, S	Sketch 1	ALARA	Med. Priority	Accept	This will be evaluated as part of final design.	
038	General	Riesenweber, S	Fabrication	Med. Priority	Accept	The office/crane interface was reviewed in previous design reviews for the Cask Transportation System and is not part of the cask drop redesign effort. The comment will be forwarded to the K Basins Project Manager for consideration.		
	CDR General					There is an potential interface tolerance problem between the pail (office ring ID 40.00" +/- ??? and the cask (OD 39.81" +/- .12"). If the pail tolerance is .07" or more, the pail could be a press fit. In any case, with this close of tolerance on a relatively small office surface, problems in terms of galling or sticking are likely to occur during installation.		

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Item No.	Subsystem	Commentor	Document Section	Page No.	Category	Priority	Disposition	Disp Date	Reviewer Final Disposition
039	S Appendix	Riesenweber, S				Med. Priority		6/9/99	Accept
	Sketches	How will the MCO shield plug be lowered into the MCO (with ____ it in the lowered position) in the SLOP without damaging the locking ring threads?				This interface is outside the scope of this redesign effort, however, there are guides that are used to prevent contact between the shield plug and the locking ring threads.			
040	CDR	Besser, R			Editorial	Low Priority		6/9/99	Accept
		1) The floor/wall interaction used several different terms: - "slab/wall interface" (pg. 2) - "wall/floor connection": (pg. 3) - "floor/wall interface" (pg. 3) - "slab/wall function: (pg. 3)				The Design Team will evaluate the comment during preparation of the final conceptual design report.			
		2) Conclusion of Appendix I that the joint is not a problem does not match the statement made in CDR Pg. 4 that the wall floor connection is a concern. Suggest using consistent term (floor/wall joint).							
041	CDR	Frier, W			Editorial	Low Priority		6/9/99	Accept
		Revise title to include "105 KE Basin." (Project A.5/A.6 is identified which is for both 105 KE and 105 KW).				Although the concept will basically apply to 105 KE as well as 105 KW, the design of the IPSS and IP cannot be well defined until resolution of the concrete lump in the bottom of the SLOP.			
042	CDR	Frier, W	I		Technical	Low Priority		6/9/99	Accept
		Section I, 2nd paragraph, 4th sentence—Provide rationale why a simplified seismic analysis is not provided. (Seems like one would want reasonable confidence in conceptual design cost estimate, which is to become the cost baseline. Section IV, Section A, Structural Analysis of SLOP concrete and Appendix K discusses finite element structural model and analysis).				Current plans are to increase the analytical rigor in the seismic contribution in establishing the SLOP capacity for the drop loads used as IPSS design input.			
043	CDR	Frier, W	I		Technical	Low Priority			Accept
		Section I, last paragraph—Round the CDR cost estimate to the nearest \$10,000 for item costs and \$100,000 for total costs. (Project Data Sheet Guidelines WHC-CM-6-2, PM-3 or predecessor documents).				The Design Team will evaluate the comment during preparation of the final conceptual design report.			
044	CDR	Frier, W	II		Editorial	Low Priority			Accept
		Section II, 5th paragraph—Add "in 105 KW." (Provides clarification about 105 KE to the novice reader).				Although the concept will be similar, the design does not cover 105 KE.			
045	CDR	Frier, W	II		Technical	Low Priority			Accept
		Section II, last paragraph—Round the CDR cost estimate in accordance with cost estimating guidelines.				The Design Team will evaluate the comment during preparation of the final conceptual design report.			

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Item No.	Subsystem	Commentor	Document Section	Page No.	Category	Priority	Disposition	Disp Date	Reviewer Final Disposition
046	CDR	Frier, W	III		Editorial	Low Priority	The Design Team will evaluate the comment during preparation of the final conceptual design report.		Accept
		Section III, 1st paragraph, 1st sentence—Insert “for the definitive design.” (Clarifies to the reader the project phase).							
047	CDR	Frier, W	III		Editorial	Low Priority	The Design Team will evaluate the comment during preparation of the final conceptual design report.		Accept
		Section III, 1st paragraph, 2nd sentence—Identify the independent review report. (Is that SNF-4345?)							
048	CDR	Frier, W	III		Technical	Low Priority	The Design Team will evaluate the comment during preparation of the final conceptual design report.		Accept
		Section III, 2nd paragraph—Provide rationale for “new basin leak criteria.” (Provides credibility).							
049	CDR	Frier, W	III		Editorial	Low Priority	Not accepted.	6/9/99	Accept
		Section III, last paragraph—Delete. (No value added to a final CDR; info is good for the independent review team for background understanding).							
050	CDR	Frier, W	IV B		Technical	Med. Priority	(1), (3), (4), (5) Compliance with the code will be evaluated during final design. (2) Existing pin blocks and pins are SST.	6/9/99	Accept
		Section IV, B, design features discussion—(1) Add “Safety class structures, systems, and components require in service inspection or other means to demonstrate safety class functions” or words to that effect. (For example, ANSI N14.6, Section 6.3.1 requires annually a test load equal to 150% maximum service or if cleanliness conditions permit, dimensional testing, visual inspection, and NDT of major load-carrying welds. Even impact limiters under the base will require cameras for inspections). (2) 3rd bullet—Replace pin blocks with stainless steel. (Existing pin blocks welds will have to have paint removed so that annual NDE inspections and measurements can be made. (ANSI N 14.6, 6.3.1 requirement). (3) Add previous so that pins and welds can be accessed for annual inspection per the ANSI N14.6, 6.3.1 requirement. (4) Provide discussion that shear pins can be replaced or removed for testing if necessary. (Shear pins SSCs require in service inspection or other means to demonstrate safety class functions). (5) 2nd to last bullet—Provide calculations to confirm the assumption that the pail will always be engaged in the bottom of the IPSS. (Maybe it is buoyant and floats).							
051	CDR	Frier, W	IV B		Technical	Med. Priority	The pressure vessel code applies to pressure vessels. This is a structural component and is not a pressure vessel. Additionally, the ASME pressure vessel code applies to operating, pressurized systems. N690 applies to extreme load conditions and is applicable to structures. The CDR will be revised to reflect this position.		Accept
		Section IV, B, Immersion Pail Analysis, 2nd paragraph, 4th sentence—Provide a applicable code requirement or provide rationale why no pressure vessel code applies. (If a pressure code applies, than some type of annual inspection would be required on a periodic basis for safety class SSC's).							

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052	CDR	Frier, W	IV C	SAR	Low Priority	The Design Team will evaluate the comment during preparation of the final conceptual design report.	Accept		
053	CDR	Frier, W	IV C	Technical	Low Priority	The Design Team will evaluate the comment during preparation of the final conceptual design report.	Accept		
054	(General)	Strehlow, J	Technical	Med. Priority	This comment will be addressed during the final design.	Accept			
055	CDR	Frier, W	IV D	Editorial	Low Priority	The Design Team will evaluate the comment during preparation of the final conceptual design report.	Accept		
056	CDR	Frier, W	VI A	Editorial	Low Priority	The Design Team will evaluate the comment during preparation of the final conceptual design report.	Accept		
057	CDR	Frier, W	VII	Technical	Low Priority	The Design Team will evaluate the comment during preparation of the final conceptual design report.	Accept		
058	CDR	Frier, W	VII	Technical	Med. Priority	An administrative control may be used to limit the lift height of the cask to a minimum height, but the worst case lift height, evaluated by analysts, must be limited by an engineered feature. Because the engineered feature is relied upon to perform a safety-class function of limiting the cask lift height, the feature is safety-class.	Accept		

Section VII, Leak Mitigation Efforts, Analysis of and Modifications to 32-Ton Crane required due to drop scenarios, 2nd paragraph—Delete. (Commercial nuclear power plants restrict load pick heights to X inches off the floor and follow a designated pathway. A lower height, in my opinion, would lessen cost impact to the SNF project).

Section VII, Leak Mitigation Efforts—Strongly recommend evaluation of grout material that was used to repair the removed anchor bolt from the weasel pit floor. (As the K Basin cognizant engineer, the Five-Star Structural Concrete Underwater III, 1-800-203-2206, Joe Rizzo, (phone number, 718-921-3167) should be the first material that should be considered for testing).

(1) Comment Resolution Report (by Item No)

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Conceptual Design Report - Cask Loadout System/Cask Drop Redesign for the Immersion Pail Support

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Item No.	Subsystem	Commentor	Document Section	Page No.	Category	Priority	Disposition	Reviewer Final Disposition
059	CDR	Frier, W	VII		Editorial	Low Priority		Accept
		Section VII, Leak Mitigation Efforts, Seismic Design of the IPSS 5th sentence—Reference the design document for the existing lateral jack. (I did not remember that it is installed).				The Design Team will evaluate the comment during preparation of the final conceptual design report.		
060	CDR	Frier, W	VII		Editorial	Low Priority		Accept
		Section VII, DOE 6430.1A requirements—Delete. (This is an activity of definitive design. No value is added with its discussion in the CDR).				The Design Team will evaluate the comment during preparation of the final conceptual design report.		
061	CDR	Frier, W	VII		Technical	Med. Priority		Accept
		Section VII, OIP Cask Drop Scenarios, last sentence—How many CDRs are associated with the MLS redesign? (If I were DOE, I would want to know the impact of this scope change at one time). It is recommended that this CDR be revised rather than issuing a second new one.				The CDR will be revised to include additional cask drops.		
062	CDR	Frier, W	VII, Table 3-10		SAR	Med. Priority		Accept
		Section VII, Table 3-10 discussion—Delete. (I know of no changes contemplated to Table 3-10. If IPSS and OIP are pushing Table 3-10, then I would recommend a similar table for work around SLOP, IPSS, and OIP).				During final design, interfaces with Table 3-10 of the K Basins SAR will be evaluated. The results of the effort will be dependant on the outcome of Table 3-10, JCO resolution.		
063	General	Frier, W	References		Editorial	Low Priority		Accept
	CDR General	References—Revise Drawing "H-2-21120" to "H-1-21120."				Accept.		
064	A Appendix	Frier, W			Technical	Low Priority		Accept
	Cost Estimate Summary - IPSS Structure Design & Fab.	Appendix A—(1) Provide Cost estimate summary sheets stating assumptions, etc., for deriving the cost estimate. Also, add appropriate estimator's signature and cost estimating managers approval. (2) Round off cost estimates.				The Design Team will evaluate the comment during preparation of the final conceptual design report.		
065	C Appendix	Frier, W			Editorial	Low Priority		Accept
	Conceptual Project Schedule	Appendix C—Delete schedule as presented and replace with a level 3 schedule. (Schedule as presented is to detailed for CDR. Remember to include schedule contingencies. RL is publicizing that they want things done right. Publishing a schedule as presented in my opinion is dangerous).				The Design Team will evaluate the comment during preparation of the final conceptual design report.		

(1) Comment Resolution Report (by Item No)

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Conceptual Design Report - Cask Loadout System/Cask Drop Redesign for the Immersion Pail Support

Item No.	Subsystem	Commentor	Document Section	Page No.	Category	Priority	Disposition	Reviewer	Final Disposition
066	D Appendix	Frier, W			Editorial	Low Priority			Accept
	Description of Possible Transportation Cask Drop Accidents in the 105-KW Basin SLOP	Appendix D, Section 4, 1st sentence—Replace “30” with “24” tons. (Previous USQ and subsequent analysis (WHIC-SD-SNF-DA-020 by Kanjilal and WHIC-SD-SNF-SA-002, Rev 0-A by Winkel) rerated existing crane from 30 tons to 24 tons due to structural problems with existing structural steel).					The Design Team will evaluate the comment during preparation of the final conceptual design report.		
067	D Appendix	Frier, W			Technical	Med. Priority			Accept
	Description of Possible Transportation Cask Drop Accidents in the 105-KW Basin SLOP	Appendix D—Table 3-1—Revise 5 ft-4 in drop height of the bottom of the cask above the transfer floor to either “a 2-in” height above the cask transport deck or X” inches above the OIP. (The 5 ft-4-in requirement is adding safety class limit switches with added costs. Commercial nuclear power plants restrict load pick heights to X inches off the floor and follow a designated pathway. A lower height, in my opinion, would lower redesign and fabrication costs especially on the 32-ton crane).					An administrative control may be used to limit the lift height of the cask to a minimum height, but the worst case lift height, evaluated by analysis, must be limited by an engineered feature. Because the engineered feature is relied upon to perform a safety-class function of limiting the cask lift height, the feature is safety-class.		
068	F Appendix	Frier, W			Technical	High Priority			Accept
	Shipping Cask Into Immersion Pail Drop Analysis	Appendixes F & G—Provide appropriate model validation and design reviews. (This is a SC SSC's and requires appropriate QC and engineering controls as per SNF AP 6-027 , Design Verification Process).					Calculations in the Conceptual Design Report will be reviewed by the Design Team to assure that the purpose and scope of the calculations are identified, that the calculations have been checked and signed in accordance with SNF Project procedures.		
069	I. Appendix	Frier, W			Editorial	Med. Priority			Accept
	Structural Evaluation of the Immersion Pail for Pressure Loading During a Postulated MCO/Cask Drop Accident	Appendix I.—(1) Add appropriate author of analysis and QA validation of the models used. (SNF Design Verification administrative procedure (AP-06-027 and QA). (2) 3rd paragraph, 2nd to last sentences—Insert “from” between “taken” and “the.” (Missing word). (3) Last paragraph, last sentence--Provide basis for .37-in prediction. (Can't see how it is arrived at based upon Table I values).					(1) Calculations in the Conceptual Design Report will be reviewed by the Design Team to assure that the purpose and scope of the calculations are identified, that the calculations have been checked and signed in accordance with SNF Project procedures. (2) Accept (3) Full documentation will be provided with the final design.		
070	CDR	Frier, W			Technical	Med. Priority			Accept
		Provide discussion on analysis of the bridge, trolley, and heat impacts if a load is dropped instantly.					This will be evaluated in the revised CDR.		

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Conceptual Design Report - Cask Loadout System/Cask Drop Redesign for the Immersion Pail Support

Item No.	Subsystem	Commentor	Document Section	Page No.	Category	Priority	Disposition	Reviewer Final Disposition
071	I Appendix Structural Analysis of SI.OP Reinforced Concrete	Strehlow, J		13	Technical	Low Priority	As discussed in Comment 038, the soil/SI.OP interaction approach has changed. The modified approach will be incorporated into final design calculations.	Accept
072	I Appendix Structural Analysis of SI.OP Reinforced Concrete	Strehlow, J			Technical	Low Priority	Accepted. Details will be incorporated into final design.	Accept
073	I Appendix Structural Analysis of SI.OP Reinforced Concrete	Strehlow, J			Technical	High Priority	Accepted. C.3.2 requirements will be specifically addressed in the final calculation package (both floor and IPSS).	Accept
074	I Appendix Structural Analysis of SI.OP Reinforced Concrete	Strehlow, J			Editorial	Low Priority	Per Kennedy recommendation, a geotech firm (Shannon and Wilson) has been given the task of providing an appropriate elastic spring constant for the soil strain levels associated with the drop accident. Our calculations will reference the Shannon and Wilson values.	Accept
075	I Appendix Structural Analysis of SI.OP Reinforced Concrete	Strehlow, J			Editorial	Low Priority	Floor capacity is based upon maximum SI.OP stiffness (uncracked). This will be clarified in the final calculation package.	Accept

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Conceptual Design Report - Cask Loadout System/Cask Drop Redesign for the Immersion Pail Support

Item No.	Subsystem	Commentor	Document Section	Page No.	Category	Priority	Disposition	Disp Date	Reviewer Final Disposition
076	I Appendix	Strehlow, J			Technical	Med. Priority		6/9/99	Accept
	Structural Analysis of SLOP Reinforced Concrete	If the cracked concrete section modulus was used in the modal analysis of the SLOP, the effective stiffness of the SLOP may be too low for use in determining the effective mass of the SLOP. The resulting effective mass would be under predicted. In addition, if the fluid mass was not included in the modal analysis the first fundamental frequency for the SLOP would be too high, and again the effective mass of the SLOP would be under predicted. If the effective mass of the SLOP is under predicted it could affect other impact load calculations.				Final calculations will include final impact limiter design, appropriate masses, and range of SLOP stiffness.			
077	I Appendix	Strehlow, J			Technical	Med. Priority		6/9/99	Accept
	Structural Analysis of SLOP Reinforced Concrete	Would an off-center drop on top of the IPSS affect the SLOP floor capacity because of potentially uneven load distribution on the floor?				Current position is that IPSS/rail shims will prevent IPSS rotation, which would result in uniform foam deformation/loading. Thus, there should be no uneven floor load distribution. This will be verified during final design.			
078	J Appendix	Strehlow, J			Technical	Med. Priority		6/9/99	Accept
	Recommended Structural Acceptance Criteria for MCO Cask Drop Accidents in the 105-K SLOP	Averaging local peak stresses does not seem to be acceptable based on ACI 349, Appendix C. Section C.7.1, which states that "Design for impactive loads shall satisfy the criteria (in Appendix C) for both local effects and for overall structural response."				As pointed out by R. Kennedy (primary author of ACI 349, App. C), ACI 349 does permit limit design as an acceptable design tool for slabs. See commentary for Section 13.3.1 which permits "yield line analysis" (reinforced concrete equivalence to limit analysis). The averaging approach referred to in Appendix J is conservative relative to the limit analysis approach. In accordance with Kennedy's recommendations, the acceptance criteria and calculations are being modified to reflect this more liberal approach permitted by ACI code. The controlling criteria will be deformation limits/leak rate. Note that ACI 349, C.3.1 states that max. deformations "shall not result in the loss of intended function of the structural element".			
079	J Appendix	Strehlow, J			Technical	Med. Priority		6/9/99	Accept
	Recommended Structural Acceptance Criteria for MCO Cask Drop Accidents in the 105-K SLOP	Reference the K-Basin inspections that support the stated position that there is no significant reduction in the strength of the reinforced concrete due to in-service degradation. Would these inspections also indicate that no in-service degradation has occurred to the concrete or rebar at the wall-to-floor interface?				Final calculation package will reference inspection reports which have found no evidence of degradation.			

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(1) Comment Resolution Report (by Item No)

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Conceptual Design Report - Cask Loadout System/Cask Drop Redesign for the Immersion Pail Support

Item No.	Subsystem	Commentor	Document Section	Page No.	Category	Priority	Disposition	Disp Date	Reviewer Final Disposition
080	J Appendix	Strehlow, J			Technical	High Priority		6/9/99	Accept
	Recommended Structural Acceptance Criteria for MCO Cask Drop Accidents in the 105-K SLOP	Do not mix the requirements of different design codes (ACI-349 and ASME Section III). The basis for demonstrating that the safety class function is not adversely affected by impact loads is the application of ACI-349 and Appendix C, but without taking advantage of ductility ratios, i.e., no rebar yielding. Apply the requirements of ACI-349 and Appendix C as they are without modification, including Section C.4 "Requirements to assure ductility." Provisions for allowing secondary stresses to redistribute by yielding of the rebar are not included in ACI-349. Further, this approach violates the key aspect of the criteria used to demonstrate that the safety class function.				Per Kennedy's recommendations, current plans are to permit up to 90% of the limit load capacity, as discussed in Comment 80, coupled with deformation requirements, which are more restrictive. Acceptance criteria will be modified. Agree that ASME III reference is not appropriate, and will remove. HNF-SD-SNF-FRD-025, Rev. 2 document will require change as well.			
081	K Appendix	Strehlow, J			Technical	Med. Priority		6/9/99	Accept
	Immersion Pail Support Structure Impact Analysis	There is insufficient information in this Appendix to provide an adequate review. However here are some quotations that I need to be answered. Why was an 800 kip load used when the SLOP floor can only take 450 kips? How would the crushing of the impact absorbing material inside two legs of the IPSS affect the stresses and stability of the IPSS? Was crushing accounted for in the analysis. Does the maximum stress of 76,000 psi pass ANSI N690 requirements? Was a non-linear buckling analysis performed to determine the actual buckling load? Does the buckling load have an adequate design margin per N690 requirements for axially loaded members?				(1) 800 kip loading used to demonstrate that IPSS has adequate margin relative to the allowable floor loading. (2) Lateral constraints (shims) will prevent rotation of the IPSS, i.e., foam will be crushed equally in all legs. (3) Most appropriate criteria for IPSS drop loads is N690 which permits up to 70% of the calculated instability/buckling load. (4) A non-linear buckling/instability analysis was used to determine the capacity of the IPSS. (5) See part #3 above.			

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(1) Comment Resolution Report (by Item No)

HNF-4576, Rev. 0

Conceptual Design Report - Cask Loadout System/Cask Drop Redesign for the Immersion Pail Support

Item No.	Subsystem	Commentor	Document Section	Page No.	Category	Priority	Disposition	Disp Date	Reviewer Final Disposition
082	L Appendix	Strehlow, J			Technical	Med. Priority		6/9/99	Accept
	Structural Evaluation of the Immersion Pail for Pressure Loading During a Postulated MCO/Cask Drop Accident	The calculation evaluates the IP for an over pressure of 560 psi. But the initial impact pressure from Appendix F is 640 psi, which is still low because it dose not include a term for the momentum transferred from the bottom of the cask to the effective mass of the water. After this initial impact, the water that moves up the annulus will go "solid" when it reaches the orifice, creating a water hammer effect. The over pressure associated with this condition form Appendix F is 3800 psi. The IP and the welds in the IP need to be qualified for these over pressures as a water hammer effect. Note: the strain in the weld between the bottom of the IP and the side wall will experience significantly more strain than either the wall of the bottom plate due to the localized structural discontinuity and stress intensification caused by the weld configuration. The effect of the stress intensification is not included in the shell model analysis performed in Appendix L				This work is scoping and nature and pressure issues will be considered during final design. A rupture disk may be used as required.			
083	General	Strehlow, J			Technical	Med. Priority		6/9/99	Accept
	CDR General	Calculations for upper bound loads need to be based on either the actual material yield strength or an adequate estimate for the upper bound yield strength for the material. If the material plastically deforms, appropriate strain hardening must also be included so that the final upper bound load is correct. Insufficient detail is provided in the analyses to verify this approach.				Accepted. This will be incorporated into final design calculations.			
084	F Appendix	Strehlow, J			Technical	Med. Priority			Accept
	Shipping Cask Into Immersion Pail Drop Analysis	Hand corrections to calculations need to be incorporated and the affected results revised.				Calculations in the Conceptual Design Report will be reviewed by the Design Team to assure that the purpose and scope of the calculations are identified, that the calculations have been checked and signed in accordance with SNF Project procedures.			
085	General	Strehlow, J			Technical	Low Priority		6/9/99	Accept
	CDR General	Use A490 bolts for shear pins. This material has a specified maximum strength value.				Existing shear pin calculations are feasibility calculations. The final shear pin/bolt design will carefully quantify the maximum strength.			

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APPENDIX S

Sketches

IPSS Conceptual Design

SOUTH LOADOUT PIT - SECTION
SKETCH 1

SOUTH LOADOUT PIT - PLAN
SKETCH 2

S-3

IMMERSION PAIL
SKETCH 3

ADDED TO INCREASE
BOTTOM AREA OF PAIL
TYPICAL BOTH SIDES
PLATE 1" THICK

IPSS ASSEMBLY
SKETCH 4

UPPER IPSS STRUCTURE
SKETCH 5

LOWER IPSS STRUCTURE
SKETCH 6

IPSS BOTTOM FOAM ARRANGEMENT
SKETCH 7

TYPICAL TELESCOPING COLUMN OF UPPER STRUCTURE
SKETCH 8

APPENDIX T

**Alternative Design Concept,
Wall Mounted IPSS-
Description and Sketches**

Alternate Design Concept, Wall Mounted IPSS

Alternate Concept Description

The wall mounted IPSS will replace the current SLOP work platform and IPSS with an integrated unit that is supported from the top of the pit by means of supports bearing on the existing concrete stem walls and building concrete floor structure. The design will improve access to the upper work area and remove some congestion from that area.

The work area will be provided by a horizontal flat plate at approximately the current floor level. This plate will cover the entire SLOP with a circular cutout for access to and support of the IPSS. Pin blocks (with local reinforcing) will be integrated into the edge of the cutout in the plate. Approximately 2 ft. of crushable foam will be placed under the top work platform plating. This foam will be supported by another lower horizontal flat plate underneath the 2 ft. thickness of foam. The purpose of the foam is to absorb the energy related to cask drops on the periphery of the IPSS.

Vertical telescoping tubes located under the area of the pin blocks will span the 2 ft. distance between the plates. Shear pins will maintain the integrity of the tubes. The purpose of the telescoping tubes and shear pins is to carry operational loading on the work platform level. In the event of a cask drop, the shear pins will fail and the energy of the drop will be absorbed by the foam.

Below the lower plate, the IPSS will consist of a circular cylinder that accepts the cask in the lowered position. In the event of a cask drop, this cylinder provides hydraulic damping to absorb energy.

All of the structure discussed above will be supported by wide flange beams that span the SLOP in an east-west direction. The beam configuration will be an inverted "U" shape. Horizontal extensions will rest on the concrete of the stem walls of the SLOP. The lower horizontal portion of the structural support system will carry the loads from the lower horizontal plate described above.

The wall mounted IPSS is shown conceptually in appendix T.

Response to Cask Drop Scenarios

The following table describes the wall mounted IPSS response for the various direct cask drop scenarios into the SLOP.

Drop	Description of Drop	Comments	Energy Absorption by Wall Mounted IPSS Concept
1	Drop imposes loading onto 2 vertical legs of immersion pail support structure.	This scenario is combined with drop 6 and includes drop on the pail lip and on the work platform around the periphery of the pail. The geometry of the upper pit area is such that all drops will engage the pail lip.	If the drop occurs, the shear pins will fail and the telescoping tubes will collapse. Energy will then be absorbed by the foam.
2	Cask drops into empty immersion pail.	Empty immersion pail positioned at top of pit, cask drops and impacts bottom of immersion pail.	Energy will be absorbed by the telescoping tube shear pins and foam as described above. The pail support pins will fail and additional energy will be absorbed by controlled hydraulic action of the cask falling into the lower cylinder.
3	Cask and immersion pail drop into pit.	Immersion pail (with cask inserted) stationed at top of pit; cask and pail then drop together and impact bottom of pit.	Energy will be absorbed by the telescoping tube shear pins and foam as described above. Additional energy will be absorbed by controlled hydraulic action of the cask falling into the lower cylinder.
4	Cask drops into empty immersion pail and jams on the top of the pail internal stiffening ring.	Empty immersion pail positioned at top of pit, cask drops and becomes jammed near the top of immersion pail.	Energy will be absorbed by the telescoping tube shear pins and foam as described above.
5	Combination of Drop 2 and Drop 3.	Empty immersion pail stationed at top of pit, cask drops into immersion pail, cask and pail then drop together and impact bottom of pit.	Energy will be absorbed by the failure of the pail support pins and pin blocks. Energy will further be absorbed by the telescoping tube shear pins and foam as described above. Additional energy will be absorbed by controlled hydraulic action of the cask falling into the lower cylinder.
6	Drop imposes loading onto 1 vertical leg of immersion pail support structure.	This scenario becomes part of scenario 1.	

Load Path Through Concrete

See attached M&D calculation for wall loading capacities.

Advantages/disadvantages

The wall mounted IPSS has a number of advantages over the present design concept. Disadvantages also exist. These advantages/disadvantages are summarized below.

Advantages

1. No wall cutting.
2. No gantry modifications.
3. No water level changes (ALARA).
4. Better accessibility of pin by raising pins/pin blocks.
5. Wall loading instead of floor loading (water stops in compression).
6. No midpoint lateral support.
7. No sliding upper section.
8. Head room increase for operators.
9. Eliminates Operations Interface Platform.
10. Can include slapdown loads on SLOP structure.
11. Majority of structural work can be done above the water.
12. Drain valve clearance.
13. Foam is above the water.
14. No pin redesign.
15. Provides added shielding.

Disadvantages

1. Must remove rails and other structure.
2. Shuttle support redesign.
3. Crane load increase.
4. Access to the pit is blocked.
5. Must redesign long handled tools and camera.

Open Issues

1. Wall protection against drops.
2. Gantry protection.
3. Combustion.
4. Slapdown loading.
5. Seismic loading.

INTEGRATED OIP/IPSS - DESIGN 1
SKETCH 1

INTEGRATED OIP/IPSS - DESIGN 2
SKETCH 2

APPENDIX U

Structural Analysis

Of The South Loadout Pit

Preliminary Capacity Calculations

For Wall Supported IPSS

M & D

Professional Services Inc.

Structural Analysis of the South Load Out Pit

Preliminary Capacity Calculations for Wall-Supported IPSS

Calculation No. M&D 99-11

Prepared by:

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Prepared for:

Joni L. Weamer

DE&S Hanford, Inc.

Prepared By:

Bob Winkel, Ph.D., P.E.

B. V. Winkel 6-29-99

Checked By:

Gary Wagenblast, P.E.

GR Wagenblast 6-30-99

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Subject SLOP Structural Capacity for Cask Drop Loading		Checked By / Date G. Wagenblast		Revision No. 0	
Ref. Drawing(s) H-1-21072		Revised By / Date		Contract No.	

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2.0 SUMMARY AND CONCLUSIONS	4
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3.1 LOAD CONDITIONS AND LOAD COMBINATIONS.....	4
3.2 MATERIAL PROPERTIES.....	7
3.3 ASSUMPTIONS	7
4.0 ANALYSIS APPROACH.....	8
5.0 ANALYSIS RESULTS.....	10
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Appendix A: PREDICTED SECTION MOMENTS AND FORCES	
Appendix B: ANSYS INPUT LISTINGS	

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FIGURES

Figure 3-1 - Load Configurations Considered for Wall-Supported IPSS	5
Figure 4-1 - SLOP Model Using Soil Springs	9
Figure 5-1 - Wall Top Loading Evaluation Sections	11

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TABLES

Table 5-1 - SLOP Drop Load Capacity Summary	10

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Subject SLOP Structural Capacity for Cask Drop Loading		Checked By / Date G. Wagenblast		Revision No. 0	
Ref. Drawing(s) H-1-21072		Revised By / Date		Contract No.	

STRUCTURAL ANALYSIS OF THE SOUTH LOADOUT PIT REINFORCED CONCRETE

PRELIMINARY CAPACITY CALCULATIONS FOR WALL-SUPPORTED IPSS

1.0 INTRODUCTION

The South Load Out Pit (SLOP) of the 100-KE and 100-KW fuel storage facilities is the staging area for loading the MCO spent fuel baskets into the Multi-Canister Overpack (MCO). One of the concepts under evaluation for the design of the Immersion Pail Support Structure (IPSS) involves supporting the IPSS on the top of the SLOP walls. The purpose of this report is to provide SLOP load capacity estimates for cask drop loads transmitted to the top of the SLOP walls.

2.0 SUMMARY AND CONCLUSIONS

The SLOP structural capacity for drop loads transmitted to the top of the wall is a function of the location of loading. The four load cases illustrated in Figure 3-1 were considered for the current evaluation. The SLOP capacities for the four load configurations shown are as follows: Load Case (a)—0.9 million lbs., Load Case (b)—1.4 million lbs., Load Case (c)—1.5 million lbs, and (d) 0.33 million lbs.

3.0 DESIGN INPUT/ASSUMPTIONS

The SLOP geometry and rebar definitions are given in Drawing H-1-21072. The structural acceptance criteria is specified in Appendix B of Reference 7. The remainder of this section addresses loads, load combinations, material properties, and assumptions associated with the structural evaluations.

3.1 LOAD CONDITIONS AND LOAD COMBINATIONS

Various concepts are under consideration for a "wall-supported" IPSS. The capacity of the SLOP walls are sensitive to the position and location of the wall loading. For the current evaluation, the four load configurations shown in Figure 3-1 were evaluated. It is assumed that the bearing area of the load is sufficient to avoid significant local crushing of the wall. For example, for a million pound load, the bearing area should not be smaller than a 16-in. square area. It is also assumed that appropriately placed impact limiters will result in relatively low load rate applications which allow a dynamic load factor assumption of 1.0.

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(a) Single Vertical Load at Southwest Corner

(b) Two Equal Vertical Loads Near West Corners

Figure 3-1 - Load Configurations Considered for Wall-Supported IPSS

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(c) Four Equal Vertical Loads Near Four Corners

(d) Two Equal Horizontal Loads at West Corners

Figure 3-1 (Continued).

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Sections C.1.1 and C.8 of Appendix C of ACI-349 state that impact loads must be combined with other loads in accordance with Section 9.1 of ACI-349. However, Section 9.1 does not include a drop load in any of the load combination equations given in Section 9.2.1. A reasonable approach is to place the cask drop accident in the same category as a safe shutdown earthquake (E_{ss}). This results in load factors of 1.0 for all loads in combination with a cask drop (ACI-349, Section 9.2.1, Equations 4 and 8). The only significant loads in Section 9.2.1 of ACI-349 to be considered in combination with a cask drop are dead weight, water pressure, and soil pressure.

Based upon experience with soil pressure on the basin walls, the wall external soil pressure loading exceeds the internal wall water pressure, resulting in bending compression on the inside surfaces at the floor/wall interface. For these preliminary calculations, the soil pressure and the lateral water pressure are assumed to balance and the effects of both are disregarded. The following load combination is used for establishing the drop load capacity:

$$U = 1.0D + 1.0I + 1.0H + 1.0F,$$

where, U is the required ACI load resistance, D is the dead weight of the hardware and pit walls resting on the pit floor, I is the cask drop impact loading, H is the lateral soil pressure, and F is the water pressure.

Note that the above load combination for the SLOP floor does not include a seismic load contribution, and, as mentioned above, H and F are assumed to balance one another, and are ignored. The specified peak horizontal ground acceleration for the 100K area is 0.2 g's. As indicated below, the preliminary drop loading capacity g levels range from 4 to 24 g's. Thus, for these preliminary calculations, the seismic loading is ignored. The capacity calculations below are limited to drop loads and water pressure on the floor. The effects of soil resistance, including wall/soil friction are also included in the evaluation.

3.2 MATERIAL PROPERTIES

The material properties of interest are the SLOP concrete stiffness (elastic modulus and gross versus cracked section properties), soil stiffness, and friction between the SLOP walls and the surrounding soil. For the current calculations, the conservative material combination is to use the maximum concrete stiffness (upper bound elastic modulus and gross section properties), minimum soil stiffness, and minimum soil friction. The upper bound concrete elastic modulus used is 4.4×10^6 psi. The lower bound soil stiffness is modeled as elastic springs using a subgrade modulus of 100 psi/in. The minimum wall/soil friction is derived in Section 4.0.

3.3 ASSUMPTIONS

The following assumptions apply to the calculations in the remaining sections of this report.

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- The resultant outward wall force due to water pressure is approximately balanced by the inward soil pressure. Therefore, for this preliminary calculation, the water and soil pressures on the walls are ignored.
- The seismic loading is small relative to the drop loading and the peak seismic and drop stresses would not coincide in time. Therefore, the seismic loading is ignored for the preliminary capacity calculations.
- An upper bound, gross section, concrete stiffness is conservatively assumed for modeling the SLOP and adjacent basin concrete structures ($f'_c = 6000$ psi, $E = 4.4 \times 10^6$ psi).
- A lower bound soil subgrade modulus of 100 psi/in is conservatively assumed.
- A conservative lower bound wall/soil friction coefficient of 0.31 is assumed.
- A lower bound at rest pressure coefficient of 0.31 is conservatively assumed.

4.0 ANALYSIS APPROACH

The static capacity of the SLOP for top loading was determined using the finite element model shown in Figure 4-1. The basic structural element is ANSYS SHELL63. SHELL63 permits a direct input of the subgrade modulus as a real constant. The 100 psi/in subgrade modulus was prescribed as input for the SLOP floor and west-moving walls (SLOP west wall and basin walls). The edges of the basin portion of the model were conservatively constrained in all three translational degrees of freedom.

Assuming a linear-with-depth soil pressure, the soil friction per unit width of wall can be expressed as

$$F_f = \frac{\gamma h^2}{2} K_o \tan \delta,$$

To obtain a lower bound wall/soil friction estimate, the following soil properties were assumed:

Parameter	Minimum Value	Reference
At Rest Pressure Coefficient, K_o	$1 - \sin \phi = 1 - \sin(44^\circ) = 0.31$	Max. friction angle from Table 2, Reference 11
Soil Unit Weight, γ	115 lbs/ft ³	Reference 11, Table 2 minimum
Adjacent Soil Depth, h	24.75 ft. (pit walls), 19.75 ft. (basin and channel walls)	Drawing H-1-21072
Wall/Soil Friction Value, $\tan \delta$	$\tan \delta = \tan(17^\circ) = 0.31$	Reference 12, Table 11-6

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Using the above minimum parameter values, wall/soil friction forces of 3381 and 2153 lbs/ft were calculated for the pit and basin walls, respectively. Using a friction element available in ANSYS (COMBIN40), the above friction forces were used to calculate the maximum element friction values. The friction elements were placed at the resultant friction force elevation ($h/3$).

Figure 4-1 - SLOP Model Using Soil Springs

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5.0 ANALYSIS RESULTS

Using the minimum soil friction parameters listed in Section 4.0, section forces and moments were calculated at the four sections shown in Figure 5-1. The section results, from ANSYS post-processing, are provided in Appendix A. Due to the presence of friction elements, the results are non-linear. Therefore, the results in the Appendix A are presented for three different load levels. Load capacity estimates were made by scaling the results from the load case nearest to the calculated capacity.

For a concentric drop, the drop loading was assumed to be equally applied at four locations (west and east walls, near the pit corners). For the two eccentric load configurations, the critical load locations were found to be the west wall location, as shown in Figure 3-1. A brief summary of the results is provided in Table 5-1 below. The section capacities were taken from Appendix A of Reference 13.

Load Condition	Critical Section No.	Internal Load Category	Capacity, lbs.
(a) Single Vertical Load @ Southwest Corner	1	Horizontal Steel Bending Moment	895,000
(b) Two Equal Vertical Loads Near West Pit Corners	1	In-Plane Shear	1,380,000
(c) Four Equal Vertical Loads Near Each Pit Corner	4	In-Plane Shear	1,500,000
(d) Two Equal Horizontal Loads At West Pit Corners	4	Horizontal Steel Bending Moment	330,000

TABLE 5-1 – SLOP DROP LOAD CAPACITY SUMMARY

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Figure 5-1 - Wall Top Loading Evaluation Sections

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Example calculations, associated with the critical sections and internal load categories listed above, follow below.

Load Condition (a):

From Section 1, Load Run 1 (0.9e6 lbs) in Appendix A-1, the resultant moment about a vertical axis is:

$$MZ = 4,232,440 \text{ in-lbs} = 12,162 \text{ in-lbs/in. (model wall height} = 348 \text{ in.)}$$

From Appendix A of Reference 13, the horizontal steel ACI moment capacity at Section 1 is 12,400 in-lbs/in. The resulting capacity for horizontal steel moments is

$$\text{Capacity} = (12,400/12,162)(0.9e6) = 920,000 \text{ lbs.}$$

This capacity is based upon the average moment over the full height of the wall, which raises a potential cracking/leakage concern. A more conservative approach is to use an average moment over a distance of four times the wall thickness, starting at the water line and working downward. The following ANSYS results are for the four elements (approximately four times the wall thickness) immediately below the water line at Section 1.

***** POST1 ELEMENT TABLE LISTING *****

ELEM	MX
1304	-13312.
1320	-16082.
1336	-19149.
1352	-22487.

The average moment for the above four elements is 17,800 in-lbs/in., resulting in a capacity of

$$\text{Capacity} = (17,700/17,800)(0.9e6) = 895,000 \text{ lbs.}$$

Load Condition (b):

From Section 1, Load Run 2 (1.5e6 lbs.) in Appendix A-2, the section resultant shear and normal forces are

$$FZ = 680,073 \text{ lbs.} = V_u$$

$$FY = 180,323 \text{ lbs.} = N_u$$

The ACI allowable shear loading is governed by Eq. 11-32 of Reference 1:

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$$V_c = 3.3\sqrt{f_c'}hd + \frac{N_u d}{4\ell_w} = 3.3\sqrt{3000}(16)(0.8 \cdot 333) + \frac{-180,323(0.8 \cdot 333)}{4(333)} = 734,360 \text{ lbs.}$$

Conservatively ignoring the shear contribution from the steel (V_s),

$$\phi V_n = 0.85V_c = 0.85(734,360) = 624,200 \text{ lbs.}$$

$$Capacity = \frac{\phi V_n}{V_u} = \frac{624,200}{680,100}(1.5e6) = 1.381e6 \text{ lbs.}$$

Load Condition (c):

From Section 4, Load Run 2 (1.6e6 lbs.) in Appendix A-3, the section resultant shear and normal forces are

$$FZ = 487,239 \text{ lbs.} = V_u$$

$$FY = 177,957 \text{ lbs.} = N_u$$

The ACI allowable shear loading is governed by Eq. 11-32 of Reference 1:

$$V_c = 3.3\sqrt{f_c'}hd + \frac{N_u d}{4\ell_w} = 3.3\sqrt{3000}(16)(0.8 \cdot 249) + \frac{-177,956(0.8 \cdot 249)}{4(249)} = 540,490 \text{ lbs.}$$

Conservatively ignoring the shear contribution from the steel (V_s),

$$\phi V_n = 0.85V_c = 0.85(540,490) = 459,417 \text{ lbs.}$$

$$Capacity = \frac{\phi V_n}{V_u} = \frac{459,417}{487,239}(1.6e6) = 1.51e6 \text{ lbs.}$$

Load Condition (d):

From Section 4, Load Run 2 (0.4e6 lbs) in Appendix A-1, the resultant moment about a vertical axis is:

$$MZ = 3,185,070 \text{ in-lbs} = 12,203 \text{ in-lbs/in. (model wall height} = 261 \text{ in.)}$$

From Appendix A of Reference 13, the horizontal steel ACI moment capacity at Section 4 is 12,400 in-lbs/in. The resulting capacity for horizontal steel moments is

$$Capacity = (12,400/12,203)(0.4e6) = 407,000 \text{ lbs.}$$

This capacity is based upon the average moment over the full height of the wall, which raises a potential cracking/leakage concern. A more conservative approach is to use an average moment over a distance of

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four times the wall thickness, starting at the water line and working downward. The following ANSYS results are for the four elements (approximately four times the wall thickness) below the water line at Section 4.

***** POST1 ELEMENT TABLE LISTING *****

ELEM	MX
1701	12266.
1706	13888.
1711	15659.
1716	17627.

The average moment for the above four elements is 14,800 in-lbs/in., resulting in a capacity of

$$\text{Capacity} = (12,400/14,800)(0.4e6) = 330,000 \text{ lbs.}$$

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6.0 REFERENCES

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APPENDIX A

PREDICTED SECTION MOMENTS AND FORCES

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A-1

SECTION RESULTS FOR SINGLE LOAD AT SOUTHWEST PIT CORNER

Note: For each section, force and moment resultants are listed for three load cases. Load Magnitudes: 0.9e6 (I = 1), 1.0e6 (I = 2), and 1.1e6 lbs (I = 3). Coordinate system: X axis: south, Y axis: east, Z axis: Up.

Section 1

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -17628.41
FY = -202805.6
FZ = 605186.8
MX = 0.2406187E+08
MY = -6367538.
MZ = 4235667.

SUMMATION POINT= 114.00 15.880 174.00

*ENDDO INDEX=I

Section 1

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -18969.47
FY = -226431.3
FZ = 674087.8
MX = 0.2691903E+08
MY = -7094708.
MZ = 4691170.

SUMMATION POINT= 114.00 15.880 174.00

Section 1

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -20310.53
FY = -250057.1
FZ = 742988.8
MX = 0.2977619E+08
MY = -7821877.
MZ = 5146673.

SUMMATION POINT= 114.00 15.880 174.00

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*DO LOOP ON PARAMETER= I FROM 1.0000 TO 3.0000 BY 1.0000

MOMENT SUMMATION LOCATION= 114.000 81.4000 174.000

Section 2

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -16929.26
FY = -165414.9
FZ = 549385.8
MX = -7356535.
MY = -6397911.
MZ = 2950947.

SUMMATION POINT= 114.00 81.400 174.00

*ENDDO INDEX= I

Section 2

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -18499.54
FY = -184772.0
FZ = 612836.7
MX = -8119588.
MY = -7086637.
MZ = 3293470.

SUMMATION POINT= 114.00 81.400 174.00

Section 2

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -20069.82
FY = -204129.1
FZ = 676287.7
MX = -8882640.
MY = -7775362.
MZ = 3635993.

SUMMATION POINT= 114.00 81.400 174.00

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Section 3

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -2891.515
 FY = 104753.1
 FZ = -518986.7
 MX = 0.3183332E+08
 MY = 9582125.
 MZ = -2407671.

SUMMATION POINT= 114.00 147.00 174.00

*ENDDO INDEX= I

Section 3

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -3282.197
 FY = 117298.8
 FZ = -579944.2
 MX = 0.3547534E+08
 MY = 0.1059244E+08
 MZ = -2703553.

SUMMATION POINT= 114.00 147.00 174.00

Section 3

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -3672.879
 FY = 129844.5
 FZ = -640901.6
 MX = 0.3911736E+08
 MY = 0.1160276E+08
 MZ = -2999435.

SUMMATION POINT= 114.00 147.00 174.00

Section 4

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = 59196.95
 FY = -165191.4
 FZ = -200580.9
 MX = 0.1801138E+08
 MY = 9641563.
 MZ = 1880223.

SUMMATION POINT= 90.500 215.00 193.50

*ENDDO INDEX= I

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Section 4

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = 65921.00
 FY = -182202.0
 FZ = -227178.2
 MX = 0.2049074E+08
 MY = 0.1072184E+08
 MZ = 2065646.

SUMMATION POINT= 90.500 215.00 193.50

Section 4

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = 72645.05
 FY = -199212.6
 FZ = -253775.6
 MX = 0.2297010E+08
 MY = 0.1180212E+08
 MZ = 2251068.

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A-2

SECTION RESULTS FOR TWO EQUAL LOADS AT WEST PIT CORNERS

Note: For each section, force and moment resultants are listed for three load cases. Load Magnitudes: 1.0e6 (I = 1), 1.5e6 (I = 2), and 2.0e6 lbs (I = 3). Coordinate system: X axis: south, Y axis: east, Z axis: Up.

MOMENT SUMMATION LOCATION= 114.000 15.8800 174.000

Section 1

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = 12970.53
 FY = -117094.4
 FZ = 448377.1
 MX = 0.1277121E+08
 MY = 163213.4
 MZ = -219646.4

SUMMATION POINT= 114.00 15.880 174.00

*ENDDO INDEX= I

Section 1

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = 22232.19
 FY = -180323.4
 FZ = 680073.2
 MX = 0.1996367E+08
 MY = 160889.8
 MZ = -396853.6

SUMMATION POINT= 114.00 15.880 174.00

Section 1

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = 31493.85
 FY = -243552.3
 FZ = 911769.3
 MX = 0.2715613E+08
 MY = 158566.2
 MZ = -574060.8

SUMMATION POINT= 114.00 15.880 174.00

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MOMENT SUMMATION LOCATION= 114.000 81.4000 174.000

Section 2

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = 15714.74
 FY = -111650.8
 FZ = 401596.2
 MX = -0.1426035E+08
 MY = -192108.5
 MZ = 639368.0

SUMMATION POINT= 114.00 81.400 174.00

*ENDDO INDEX= I

Section 2

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = 24970.44
 FY = -171632.7
 FZ = 613336.8
 MX = -0.2116796E+08
 MY = -184322.2
 MZ = 1025542.

SUMMATION POINT= 114.00 81.400 174.00

Section 2

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = 34226.15
 FY = -231614.5
 FZ = 825077.4
 MX = -0.2807556E+08
 MY = -176535.9
 MZ = 1411716.

SUMMATION POINT= 114.00 81.400 174.00

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MOMENT SUMMATION LOCATION= 114.000 147.000 174.000

Section 3

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -33290.35
FY = 86086.76
FZ = -370480.1
MX = 0.3515382E+08
MY = 3027095.
MZ = -2173569.

SUMMATION POINT= 114.00 147.00 174.00

*ENDDO INDEX= I

Section 3

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -50255.06
FY = 132985.2
FZ = -570694.2
MX = 0.5323728E+08
MY = 4292931.
MZ = -3388746.

SUMMATION POINT= 114.00 147.00 174.00

Section 3

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -67219.76
FY = 179883.6
FZ = -770908.3
MX = 0.7132073E+08
MY = 5558767.
MZ = -4603924.

SUMMATION POINT= 114.00 147.00 174.00

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MOMENT SUMMATION LOCATION= 90.5000 215.000 193.500

Section 4

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -16026.22

FY = -175244.3

FZ = -212735.5

MX = 0.1620590E+08

MY = 5347687.

MZ = -2850033.

SUMMATION POINT= 90.500 215.00 193.50

*ENDDO INDEX=1

Section 4

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -23311.30

FY = -256427.9

FZ = -338862.0

MX = 0.2644233E+08

MY = 8058253.

MZ = -4377010.

SUMMATION POINT= 90.500 215.00 193.50

Section 4

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -30596.38

FY = -337611.5

FZ = -464988.6

MX = 0.3667876E+08

MY = 0.1076882E+08

MZ = -5903986.

SUMMATION POINT= 90.500 215.00 193.50

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MOMENT SUMMATION LOCATION= 114.000 81.4000 174.000

Section 2

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = 14039.78
FY = -76225.85
FZ = 174464.9
MX = -5156179.
MY = 1424909.
MZ = 551385.3

SUMMATION POINT= 114.00 81.400 174.00

*ENDDO INDEX= I

Section 2

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = 24141.66
FY = -126949.1
FZ = 292274.9
MX = -7982803.
MY = 2404463.
MZ = 962004.3

SUMMATION POINT= 114.00 81.400 174.00

Section 2

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = 30876.24
FY = -160764.6
FZ = 370814.9
MX = -9867218.
MY = 3057499.
MZ = 1235750.

SUMMATION POINT= 114.00 81.400 174.00

*DO LOOP ON PARAMETER= I FROM 1.0000 TO 3.0000 BY 1.0000

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MOMENT SUMMATION LOCATION= 114.000 147.000 174.000

Section 3

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -22610.64
 FY = 59305.43
 FZ = -147057.5
 MX = 0.1280873E+08
 MY = -51838.49
 MZ = -1719828.

SUMMATION POINT= 114.00 147.00 174.00

*ENDDO INDEX= I

Section 3

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -36560.45
 FY = 99514.72
 FZ = -253260.8
 MX = 0.2110183E+08
 MY = -380195.1
 MZ = -2905797.

SUMMATION POINT= 114.00 147.00 174.00

Section 3

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -45860.33
 FY = 126320.9
 FZ = -324063.0
 MX = 0.2663055E+08
 MY = -599099.6
 MZ = -3696442.

SUMMATION POINT= 114.00 147.00 174.00

*DO LOOP ON PARAMETER= I FROM 1.0000 TO 3.0000 BY 1.0000

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MOMENT SUMMATION LOCATION= 90.5000 215.000 193.500

Section 4

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -17533.85
 FY = -116051.7
 FZ = -289705.0
 MX = 0.1020026E+08
 MY = 4280251.
 MZ = -1792321.

SUMMATION POINT= 90.500 215.00 193.50

*ENDDO INDEX= I

Section 4

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -27180.53
 FY = -177956.5
 FZ = -487238.6
 MX = 0.1888058E+08
 MY = 6892469.
 MZ = -2990065.

SUMMATION POINT= 90.500 215.00 193.50

Section 4

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -33611.65
 FY = -219226.3
 FZ = -618927.6
 MX = 0.2466747E+08
 MY = 8633948.
 MZ = -3788561.

SUMMATION POINT= 90.500 215.00 193.50

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A-4

SECTION RESULTS FOR TWO EQUAL HORIZONTAL LOADS ON WEST PIT CORNERS

Note: For each section, force and moment resultants are listed for three load cases. Load Magnitudes: 2.0e5 (I = 1), 4.0e5 (I = 2), and 6.0e5 lbs (I = 3).

*DO LOOP ON PARAMETER= I FROM 1.0000 TO 3.0000 BY 1.0000

MOMENT SUMMATION LOCATION= 114.000 15.8800 174.000

Section I

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -42.19682

FY = -106057.1

FZ = 43551.45

MX = 0.1714328E+08

MY = 689502.8

MZ = 201286.2

SUMMATION POINT= 114.00 15.880 174.00

*ENDDO INDEX= I

Section I

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = 1559.353

FY = -208049.4

FZ = 67213.01

MX = 0.3454798E+08

MY = 1115206.

MZ = 463928.5

SUMMATION POINT= 114.00 15.880 174.00

Section I

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = 3160.903

FY = -310041.8

FZ = 90874.57

MX = 0.5195267E+08

MY = 1540909.

MZ = 726570.9

SUMMATION POINT= 114.00 15.880 174.00

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MOMENT SUMMATION LOCATION= 114.000 81.4000 174.000

Section 2

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = 5292.818
FY = -89514.60
FZ = 94474.67
MX = 0.1388520E+08
MY = 636397.1
MZ = 348770.6

SUMMATION POINT= 114.00 81.400 174.00

*ENDDO INDEX= I

Section 2

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = 9314.270
FY = -193887.0
FZ = 138025.2
MX = 0.2880621E+08
MY = 1011726.
MZ = 790606.8

SUMMATION POINT= 114.00 81.400 174.00

Section 2

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = 13335.72
FY = -298259.4
FZ = 181575.8
MX = 0.4372721E+08
MY = 1387055.
MZ = 1232443.

SUMMATION POINT= 114.00 81.400 174.00

MOMENT SUMMATION LOCATION= 114.000 147.000 174.000

Section 3

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -10449.54
FY = 69008.16
FZ = -134603.7
MX = -8054360.
MY = -890188.7
MZ = -881978.9

SUMMATION POINT= 114.00 147.00 174.00

*ENDDO INDEX= I

Section 3

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***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -12789.90
 FY = 175158.2
 FZ = -190334.9
 MX = -0.1934606E+08
 MY = -1185941.
 MZ = -1577925.

SUMMATION POINT= 114.00 147.00 174.00
 Section 3

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -15130.25
 FY = 281308.2
 FZ = -246066.2
 MX = -0.3063775E+08
 MY = -1481693.
 MZ = -2273871.

SUMMATION POINT= 114.00 147.00 174.00
 Section 4

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = 1696.750
 FY = -3615.496
 FZ = -146332.5
 MX = -2029138.
 MY = 1144975.
 MZ = 900785.8

SUMMATION POINT= 90.500 215.00 193.50

*ENDDO INDEX= I
 Section 4

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = 24467.08
 FY = 52923.38
 FZ = -236024.2
 MX = -3575248.
 MY = 581122.1
 MZ = 3185072.

SUMMATION POINT= 90.500 215.00 193.50
 Section 4

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = 47237.40
 FY = 109462.3
 FZ = -325715.8
 MX = -5121359.

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MY = 17268.99

MZ = 5469359.

SUMMATION POINT= 90.500 215.00 193.50

MOMENT SUMMATION LOCATION= 114.000 81.440 336.000

Section 5

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -7263.845

FY = 63344.09

FZ = -10667.19

MX = -28703.51

MY = -81559.50

MZ = -360955.4

SUMMATION POINT= 114.00 81.440 336.00

*ENDDO INDEX= I

Section 5

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -14328.68

FY = 124650.8

FZ = -21670.15

MX = -66958.05

MY = -164711.1

MZ = -699197.8

SUMMATION POINT= 114.00 81.440 336.00

Section 5

***** SUMMATION OF TOTAL FORCES AND MOMENTS IN GLOBAL COORDINATES *****

FX = -21393.51

FY = 185957.5

FZ = -32673.10

MX = -105212.6

MY = -247862.7

MZ = -1037440.

SUMMATION POINT= 114.00 81.440 336.00

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APPENDIX B

ANSYS INPUT LISTINGS

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Vertical Loading Model

/prep7

/title, Load Out Pit Model, Top Drops

!element types

et,1,63

et,2,40,,,3 !soil friction elements

!real constants, Ks=50 (to match solid soil results)

r,1,17.75,,,100 !West Pit Wall

r,2,16,,,0 !Remaining Pit Walls

r,3,27,,,100 !Basin Walls (Conserv.)

r,4,21,,,100 !Pit Floor

r,5,24,,,100 !Basin Floor/Pit E. Wall (bottom)

r,6,1e8,,,0.0,3599 !pit walls friction

r,7,1e8,,,2116 !basin/channel walls friction

!material prop.

mp,ex,1,4.4e6

mp,nuxy,1,0.2

!Keypoints

k,1,0,0,0

k,2,14,0,0

k,3,114,0,0

k,4,128,0,0

k,5,0,15.88

k,6,14,15.88

k,7,114,15.88

k,8,128,15.88

k,9,0,147

k,10,14,147

k,11,37.5,147

k,12,89.0,147

k,13,114,147

k,14,128,147

k,15,0,166,

k,16,14,166

k,17,37.5,166

k,18,89.0,166

k,19,114,166

k,20,128,166

k,21,14,15.88,63

k,22,114,15.88,63

k,23,14,147,63

k,24,37.5,147,63

k,25,90.5,147,63

k,26,114,147,63

k,27,14,15.88,324

k,28,114,15.88,324

k,29,14,147,324

k,30,37.5,147,324

k,31,90.5,147,324

k,32,114,147,324

k,33,37.5,215,63

k,34,90.5,215,63

k,35,37.5,215,324

k,36,90.5,215,324

k,37,37.5,0

k,38,89.0,0 !sump edge loca.

k,39,37.5,15.88

k,40,89.0,15.88

k,41,37.5,15.88,63

k,42,90.5,15.88,63

k,43,37.5,15.88,324

k,44,90.5,15.88,324

k,45,-200,215,63

k,46,-200,215,324

k,47,250,215,63

k,48,250,215,324

k,49,-200,153.5,63

k,50,37.5,153.5,63

k,51,90.5,153.5,63

k,52,250,153.5,63

k,53,37.5,153.5,324

k,54,90.5,153.5,324

k,55,-200,335,63

k,56,37.5,335,63

k,57,90.5,335,63

k,58,250,335,63

k,59,14,15.88,348

k,60,37.5,15.88,348

k,61,90.5,15.88,348

k,62,114,15.88,348

k,63,14,147,348

k,64,37.5,147,348

k,65,90.5,147,348

k,66,114,147,348

k,67,90.5,147,348

k,68,37.5,147,348

!Areas

a,1,2,6,5

a,2,37,39,6

a,37,38,40,39

a,38,3,7,40

a,3,4,8,7

a,5,6,10,9

a,6,39,11,10

a,39,40,12,11

a,40,7,13,12

a,7,8,14,13

a,9,10,16,15

a,10,11,17,16

a,11,12,18,17

a,12,13,19,18

a,13,14,20,19 !Area 15

aatt,,4

asel,none

a,6,39,41,21

a,39,40,42,41

a,40,7,22,42

a,27,43,60,59

a,43,44,61,60

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a,44,28,62,61 !Area 21

aatt,,1

asel,none

a,10,6,21,23

a,13,7,22,26

a,29,27,59,63

a,32,28,62,66 !Area 25

aatt,,2

asel,none

a,21,41,43,27

a,41,42,44,43

a,42,22,28,44

aatt,,1

asel,none

a,23,21,27,29

a,26,22,28,32

a,24,23,29,30

a,26,25,31,32

a,33,50,53,35

a,50,24,30,53

a,34,51,54,36

a,51,25,31,54 !Area 36

aatt,,2

asel,none

a,45,33,35,46

a,34,47,48,36

aatt,,3

asel,none

a,11,10,23,24

a,12,11,24,25

a,13,12,25,26

a,45,49,50,33

a,33,50,51,34

a,50,24,25,51

a,34,51,52,47

a,55,45,33,56

a,56,33,34,57

a,57,34,47,58 !Area 48

aatt,,5

alls

esize,8.3

eshape,2

amesh,1,7

amesh,9,15

esize,15

amesh,16,48

!model sump area (area 8)

fini

/prep7

*do,i,1,11

fill,110+i,177+i,6,3000+i,11

*enddo

n,2904,64,24.075

n,2916,64,48.66

fill,2904,2916,2,2908,4

fill,107,2904,3,2901,1

fill,108,2908,3,2905,1

fill,109,2912,3,2909,1

fill,110,2916,3,2913,1

fill,2904,174,2,2919,1

fill,2916,177,2,2917,1

real,4

e,13,33,2901,107

e,33,32,2902,2901

e,32,31,2903,2902

e,31,30,2904,2903

e,30,29,2919,2904

e,29,28,2920,2919

e,28,26,174,2920

e,107,2901,2905,108

e,2901,2902,2906,2905

egen,3,1,-1

egen,3,4,-3

e,108,2905,2909,109

e,109,2909,2913,110

e,110,2913,3001,111

e,2913,2914,3012,3001

e,2914,2915,3023,3012

e,2915,2916,3034,3023

e,2916,2917,3045,3034

e,2917,2918,3056,3045

e,2918,177,178,3056

e,111,3001,3002,112

e,3001,3012,3013,3002

egen,5,11,-1

e,3056,178,179,3057

egen,10,1,-7

e,121,3011,289,106

e,3011,3022,288,289

e,3022,3033,287,288

e,3033,3044,286,287

e,3044,3055,285,286

e,3055,3066,284,285

e,3066,188,170,284

k,101,89,24.075,-18

k,102,89,48.66,-18

k,103,64,48.66,-18

k,104,64,24.075,-18

k,201,89,24.075,0

k,202,89,48.66,0

k,203,64,48.66,0

k,204,64,24.075,0

a,101,102,103,104 !area 49

a,104,101,201,204

a,101,102,202,201

a,102,103,203,202

a,103,104,204,203

esize,9

amesh,49,53

aatt,,5

esize,15

eshape,2

a,32,31,67,66

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a,30,29,63,68

amesh,54,55

nummrg,all

!Soil Friction Elements

nsl,s,loc,y,0,148

nsl,r,loc,z,91,93

ngen,2,4000,all,,,,,2.0

type,2

real,6

!pit friction elements

ndi=1

*do,i,1,54

ndi=ndnext(ndi)

e,ndi,ndi+4000

*enddo

!channel/basin friction eles.

real,7

nsl,s,loc,y,148,300

nsl,r,loc,z,149,151

ngen,2,4000,all,,,,,2.0

ndi=1

*do,i,1,39

ndi=ndnext(ndi)

e,ndi,ndi+4000

*enddo

!constrain end of friction eles.

nsl,s,node,,4300,8000

d,all,all

/VIEW, 1, -0.739216348626 , -0.566181700703 ,
0.364688184224

/ANG, 1, 74.8562934399

eplo

nsl,s,loc,x,-201,-199

d,all,uy,,,,,ux,uz

nsl,s,loc,x,249,251

d,all,uy,,,,,ux,uz

nall

fini

/solu

alls

!Drop Loading

fdele,all,all

!f,426,fz,-33333.3,,428 !100k load

f,412,fz,-250000

f,443,fz,-250000

f,3111,fz,-250000

f,3116,fz,-250000

!Water Pressure Loading

esl,s,real,,4

eplo

nsle

nsl,s,loc,y,15.8,147.1

nsl,r,loc,x,13.9,114.1

nsl,r,loc,z,0

esln,,1

sfe,all,,pres,, -9.1 !pit floor water pressure

nsl,s,loc,y,216,335

esln

sfe,all,,pres,, -6.93 !basin water pressure

alls

solve

f,412,fz,-400000

f,443,fz,-400000

f,3111,fz,-400000

f,3116,fz,-400000

solve

f,412,fz,-500000

f,443,fz,-500000

f,3111,fz,-500000

f,3116,fz,-500000

solve

fini

/postl

/output,postall,out

*do,i,1,3

set,i,last

nsl,s,loc,x,113,115

nsl,r,loc,y,15,25

nsl,r,loc,z,0,348 !full height

esln,,1

nsl,r,loc,y,15,16

spoint,,114,15.88,174 !west edge of south wall

/com, Section 1

fsum

*enddo

*do,i,1,3

set,i,last

nsl,s,loc,x,113,115

nsl,r,loc,y,81,90

nsl,r,loc,z,0,348 !full height

esln,,1

nsl,r,loc,y,81,82

spoint,,114,81.4,174 !section midpoint

/com, Section 2

fsum

*enddo

*do,i,1,3

set,i,last

nsl,s,loc,x,113,115

nsl,r,loc,y,138,148

nsl,r,loc,z,0,348 !full height

esln,,1

nsl,r,loc,y,146,148

spoint,,114,147,174 !section midpoint

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/com, Section 3

fsum

*enddo

*do,i,1,3

set,i,last

nset,s,loc,x,90,91

nset,r,loc,y,202,215

nset,r,loc,z,63,324 !full height

esln,,1

nset,r,loc,y,214,216

spoint,,90.5,215,193.5 !section midpoint

/com, Section 4

fsum

*enddo

etable,tx,smisc,1

etable,ty,smisc,2

etable,txy,smisc,3

etable,mx,smisc,4

etable,my,smisc,5

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Horizontal Loading Model

/prep7

/title, Load Out Pit Model, Top Drops

!element types

et,1,63

et,2,40,,,3 !soil friction elements

!real constants, Ks=100 (to match solid soil results)

r,1,17.75,,,0 !West Pit Wall

r,2,16,,,100 !Remaining Pit Walls

r,3,27,,,0 !Basin Walls (Conserv.)

r,4,21,,,100 !Pit Floor

r,5,24,,,100 !Basin Floor/Pit E. Wall (bottom)

r,6,1e8,,,0.0,3599 !pit walls friction

r,7,1e8,,,2116 !basin/channel walls friction

!material prop.

mp,ex,1,4.4e6

mp,nuxy,1,0.2

!Keypoints

k,1,0,0,0

k,2,14,0,0

k,3,114,0,0

k,4,128,0,0

k,5,0,15.88

k,6,14,15.88

k,7,114,15.88

k,8,128,15.88

k,9,0,147

k,10,14,147

k,11,37.5,147

k,12,89.0,147

k,13,114,147

k,14,128,147

k,15,0,166,

k,16,14,166

k,17,37.5,166

k,18,89.0,166

k,19,114,166

k,20,128,166

k,21,14,15.88,63

k,22,114,15.88,63

k,23,14,147,63

k,24,37.5,147,63

k,25,90.5,147,63

k,26,114,147,63

k,27,14,15.88,324

k,28,114,15.88,324

k,29,14,147,324

k,30,37.5,147,324

k,31,90.5,147,324

k,32,114,147,324

k,33,37.5,215,63

k,34,90.5,215,63

k,35,37.5,215,324

k,36,90.5,215,324

k,37,37.5,0

k,38,89.0,0 !sump edge loca.

k,39,37.5,15.88

k,40,89.0,15.88

k,41,37.5,15.88,63

k,42,90.5,15.88,63

k,43,37.5,15.88,324

k,44,90.5,15.88,324

k,45,-200,215,63

k,46,-200,215,324

k,47,312.5,215,63

k,48,312.5,215,324

k,49,-200,153.5,63

k,50,37.5,153.5,63

k,51,90.5,153.5,63

k,52,312.5,153.5,63

k,53,37.5,153.5,324

k,54,90.5,153.5,324

k,55,-200,335,63

k,56,37.5,335,63

k,57,90.5,335,63

k,58,312.5,335,63

k,59,14,15.88,348

k,60,37.5,15.88,348

k,61,90.5,15.88,348

k,62,114,15.88,348

k,63,14,147,348

k,64,37.5,147,348

k,65,90.5,147,348

k,66,114,147,348

k,67,90.5,147,348

k,68,37.5,147,348

!Areas

a,1,2,6,5

a,2,37,39,6

a,37,38,40,39

a,38,3,7,40

a,3,4,8,7

a,5,6,10,9

a,6,39,11,10

a,39,40,12,11

a,40,7,13,12

a,7,8,14,13

a,9,10,16,15

a,10,11,17,16

a,11,12,18,17

a,12,13,19,18

a,13,14,20,19 !Area 15

aatt,,4

asel,none

a,6,39,41,21

a,39,40,42,41

a,40,7,22,42

a,27,43,60,59

a,43,44,61,60

a,44,28,62,61 !Area 21

aatt,,1

asel,none

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a,10,6,21,23 a,13,7,22,26 a,29,27,59,63 a,32,28,62,66 !Area 25 aatt,,2 asel,none a,21,41,43,27 a,41,42,44,43 a,42,22,28,44 aatt,,1 asel,none a,23,21,27,29 a,26,22,28,32 a,24,23,29,30 a,26,25,31,32 a,33,50,53,35 a,50,24,30,53 a,34,51,54,36 a,51,25,31,54 !Area 36 aatt,,2 asel,none a,45,33,35,46 a,34,47,48,36 aatt,,3 asel,none a,11,10,23,24 a,12,11,24,25 a,13,12,25,26 a,45,49,50,33 a,33,50,51,34 a,50,24,25,51 a,34,51,52,47 a,55,45,33,56 a,56,33,34,57 a,57,34,47,58 !Area 48 aatt,,5 alls esize,8.3 eshape,2 amesh,1,7 amesh,9,15 esize,15 !amesh,16,48 amesh,16,44 !amesh,39,44 amesh,46,47 !model sump area (area 8) fini /prep7 *do,i,1,11 fill,110+i,177+i,6,3000+i,11 *enddo n,2904,64,24.075 n,2916,64,48.66 fill,2904,2916,2,2908,4 fill,107,2904,3,2901,1	fill,108,2908,3,2905,1 fill,109,2912,3,2909,1 fill,110,2916,3,2913,1 fill,2904,174,2,2919,1 fill,2916,177,2,2917,1 real,4 e,13,33,2901,107 e,33,32,2902,2901 e,32,31,2903,2902 e,31,30,2904,2903 e,30,29,2919,2904 e,29,28,2920,2919 e,28,26,174,2920 e,107,2901,2905,108 e,2901,2902,2906,2905 egen,3,1,-1 egen,3,4,-3 e,108,2905,2909,109 e,109,2909,2913,110 e,110,2913,3001,111 e,2913,2914,3012,3001 e,2914,2915,3023,3012 e,2915,2916,3034,3023 e,2916,2917,3045,3034 e,2917,2918,3056,3045 e,2918,177,178,3056 e,111,3001,3002,112 e,3001,3012,3013,3002 egen,5,11,-1 e,3056,178,179,3057 egen,10,1,-7 e,121,3011,289,106 e,3011,3022,288,289 e,3022,3033,287,288 e,3033,3044,286,287 e,3044,3055,285,286 e,3055,3066,284,285 e,3066,188,170,284 k,101,89,24.075,-18 k,102,89,48.66,-18 k,103,64,48.66,-18 k,104,64,24.075,-18 k,201,89,24.075,0 k,202,89,48.66,0 k,203,64,48.66,0 k,204,64,24.075,0 aatt,,2 a,101,102,103,104 !area 49 a,104,101,201,204 a,101,102,202,201 a,102,103,203,202 a,103,104,204,203 esize,9 amesh,49,53 esize,15 amesh,45 amesh,48

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aatt,,5
esize,15
eshape,2
a,32,31,67,66
a,30,29,63,68
amesh,54,55
nummrg,all

!Soil Friction Elements

nsel,s,loc,y,0,148
nsel,r,loc,z,91,93
ngen,2,4000,all,,,,,2.0
type,2
real,6

!pit friction elements
ndi=1

*do,i,1,54
ndi=ndnext(ndi)
e,ndi,ndi+4000
*enddo

!channel/basin friction eles.

real,7
nsel,s,loc,y,148,300
nsel,r,loc,z,149,151
ngen,2,4000,all,,,,,2.0
ndi=1

*do,i,1,43
ndi=ndnext(ndi)
e,ndi,ndi+4000
*enddo

!constrain end of friction eles.

nsel,s,node,,4300,8000
d,all,all

/VIEW, 1, -0.739216348626 , -0.566181700703 ,
0.364688184224
/ANG, 1, 74.8562934399

nsel,s,loc,x,-201,-199
d,all,uy,,,,,ux,uz
nsel,s,loc,x,312,313
d,all,uy,,,,,ux,uz
nall

fini
/solu
alls

eplot

!Drop Loading

nsel,s,loc,y,23,139
nsel,r,loc,z,91,93
f,all,fy,-2705 !pit hor. friction
nsel,s,loc,y,153,203
nsel,r,loc,z,149,151
f,all,fy,-1292 !channel hor. friction
alls

f,412,fy,100000
f,443,fy,100000

!Water Pressure Loading

escl,s,real,,4
eplo
nsle
nsel,s,loc,y,15.8,147.1
nsel,r,loc,x,13.9,114.1
nsel,r,loc,z,0
esln,,1

sfe,all,,pres,, -9.1 !pit floor water pressure
nsel,s,loc,y,216,335

esln
sfe,all,,pres,, -6.93 !basin water pressure

alls
solve
f,412,fy,200000
f,443,fy,200000

solve
f,412,fy,300000
f,443,fy,300000

solve
fini
/post1
/output,postall,out

*do,i,1,3
set,i,last
nsel,s,loc,x,113,115
nsel,r,loc,y,15,25
nsel,r,loc,z,0,348 !full height
esln,,1
nsel,r,loc,y,15,16
spoint,,114,15.88,174 !west edge of south wall
/com, Section 1
fsum
*enddo

*do,i,1,3
set,i,last
nsel,s,loc,x,113,115
nsel,r,loc,y,81,90
nsel,r,loc,z,0,348 !full height
esln,,1
nsel,r,loc,y,81,82
spoint,,114,81.4,174 !section midpoint
/com, Section 2
fsum
*enddo

*do,i,1,3
set,i,last
nsel,s,loc,x,113,115
nsel,r,loc,y,138,148
nsel,r,loc,z,0,348 !full height

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esln,,1
 nsel,r,loc,y,146,148
 spoint,,114,147,174 !section midpoint
 /com, Section 3
 fsum
 *enddo

*do,i,1,3
 set,i,last
 nsel,s,loc,x,90,91
 nsel,r,loc,y,202,215
 nsel,r,loc,z,63,324 !full height
 esln,,1
 nsel,r,loc,y,214,216
 spoint,,90.5,215,193.5 !section midpoint
 /com, Section 4
 fsum
 *enddo

*do,i,1,3
 set,i,last
 nsel,s,loc,x,113,115
 nsel,r,loc,z,335,349
 esln,,1
 nsel,r,loc,z,335,337
 spoint,,114,81.44,336
 /com, Section 5
 fsum
 *enddo

alls
 etable,tx,smisc,1
 etable,ty,smisc,2
 etable,txy,smisc,3
 etable,mx,smisc,4
 etable,my,smisc,5

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APPENDIX V

Meeting Minutes

**Interoffice Correspondence
CLS Redesign – Operator Interface Platform Options
Meeting Minutes
(Without Attachments)**

INTEROFFICE**CORRESPONDENCE**

99-SNF/JLW

To: Distribution

Date: June 23, 1999

From: J. L. Weamer X3-85

Telephone: 372-0688

cc:

K. E. Ard	X3-85	L. A. Rodgers	X3-85
T. B. Bergman	R3-11	T. J. Ruane	X3-61
R. L. Boyleston	R3-26	L. S. Semmens	X3-85
C. A. Bullock	X3-67	D. W. Siddoway	X3-85
K. C. Conrad	X3-80	J. B. Sullivan	S7-41
G. M. Davis	X3-80	J. A. Swenson	X3-79
W. A. Frier	X3-76	C. B. Thomas	R3-86
E. F. Herbert	S7-41	C. A. Thompson	R3-86
A. S. Langevin	E6-46	R. H. Webb	R3-26
C. B. Loftis	S7-41	J. H. Wicks	X3-74
J. D. Mathews	R3-86	R. B. Wilkinson	R3-11
W. C. Miller	R3-11		
D. A. Moody	X3-85	SNF Project A.5/A.6 Files	X3-85
		(scan)	
S. H. Peck	X3-79	JLW LB/file	
R. W. Rasmussen	X3-85		

Subject: **CLS REDESIGN - OPERATOR INTERFACE PLATFORM OPTIONS
MEETING MINUTES**

Attendees		
Name	Company	Phone
Milon Meyer	M&D	943-1625 ext. 231
Sam Hecht	DESH	376-4193
Kevin Ard	DESH/E2	376-8712
Norman Eng	NAC, International	(408) 453-3900 ext. 14
Bob Rasmussen	DESH	372-0021
Lynn Semmens	DESH/FDNW	373-9099
Theresa Bergman	DESH	376-1669
Joni Weamer	DESH	372-0688
Joe Swenson	DESH	373-1083

The Cask Loadout System (CLS) conceptual design review team suggested an alternative to the design presented in the conceptual design package as a result of their review. The purpose of this meeting was to determine the justification for acceptance or rejection of this comment.

This meeting followed a technical discussion (6/21/99) held at the M&D office with the integrated engineering team (DESH, FDNW, M&D, NAC, Intl.) about two operator interface platform (OIP) options;

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1. Proceed with design identified in the conceptual design report i.e. separate components. This conceptual design includes placement of the immersion pail support structure (IPSS) on the floor of the south loadout pit (SLOP). The conceptual design sketches are included in Attachment 1.
2. Integrate the OIP and the IPSS. This alternative does not include setting the IPSS on the floor. The upper walls of the SLOP provide the bearing surface for the integrated system. The preliminary conceptual design sketches are included in Attachment 2.

The attendees discussed risks associated with the Option 1 design and addressed the question of whether or not the Option 1 design will work. Attendees agreed that many of these issues could be resolved with further study. They also agreed that the study conclusion could result in possible redesign. The attendees then discussed the advantages of staying on course with the current conceptual design described in Option 1. Following the discussion about Option 1, the attendees listed some advantages of the Option 2 design with respect to Option 1 as well as some additional advantage specific to Option 2. Risks associated with Option 2 were also identified. The results are detailed in Table 1.

Norman Eng (NAC, Intl.) responded favorably to Option 2. NAC, International's technical issues are incorporated into Table 1. Mr. Eng placed special emphasis on the following items:

- Very low confidence that the slider mechanism would work
- NAC experience with underwater impact limiting foam has shown that integrity is difficult to assure
- Fabrication complexities with Option 1 may force the fabricator to fabricate it twice when the first does not meet tolerances thus increasing schedule risk
- Option 2 fabrication may reduce risk to schedule due to simplicity and possible parallel fabrication of the upper and lower sections
- The integrated design simplifies the interface between the OIP and the IPSS
- Final design can begin today
- Detailed design report may not meet current schedule due to the addition of the OIP scope but overall schedule risk may be reduced due to the simpler fabrication

Risks and advantages were carefully evaluated during this session. The attendees concluded that the CLS redesign effort would ultimately benefit by the acceptance of the design review comment and are currently proceeding with Option 2.

The following actions resulted;

1. Bob Rasmussen, Joni Weamer, Theresa Bergman, Kevin Ard – Discuss decision with Senior Management (Complete)
2. Bob Rasmussen, Joni Weamer – Brief RL on concept and plans
3. NAC, Intl – Determine ideal impact limiting material which includes an assessment of longterm radiation exposure and fire hazard.
4. Kevin Ard – Determine allowable increase in total crane loading if the IPSS pin blocks were raised. Do not exceed 31 tons.
5. Joni Weamer – Discuss changes in the CDR that result from this decision with Ann Langevin (Complete)

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6. Kevin Ard – Assess changes required to the functional requirements document. (Complete – no changes required.)
7. Theresa Bergman – Revise design specification and NAC, Intl contract as necessary.
8. NAC, Intl, Milon Meyer – Revise plan/schedule to accommodate new scope. (Will be included in Norman's weekly report)

Table 1

OPTION 1 RISKS		OPTION 2 ADVANTAGES	OPTION 1 ADVANTAGES	OPTION 2 RISKS
a)			Many of the technical issues are known and the analytical basis has been reviewed by outside agencies.	All the technical issues have not been identified and outside agencies have not been exposed to the Option 2 design.
b)			No change in scope for design/fabricate contractor (NAC, Intl).	Scope change requires modification the current design specification and increase risk to schedule and cost.
c)			Current shuttle impact limiter design is acceptable.	Shuttle impact limiter design may be impacted.
d)	If the slider mechanism is not successful, additional impact limiting material (foam) will be required under the IPSS thus increasing the height from 3-6 in. to approximately 12 in..	Increased allowable loading (~2X) on the walls of the SLOP will allow the stroke distance required by the system to be cut in half. No under-IPSS foam required. The bottom of the hydraulic cylinder does not touch the floor and will have minimal impact.		
e)	A preliminary estimate of the radiation dose increase during basket loading due to raising of the structure indicates that the dose rate would raise from 39 mR/hr to 200 mR/hr. This could necessitate the raising of the basin water level.	A lower, inset OIP offers the opportunity to reduce the requirement for raising the IPSS and thus increasing the height at which a basket would be raised and subsequent dose.		
f)	Gantry modifications may be required to accommodate the necessary increased height of the IPSS.	Low risk of required gantry modification.		
g)	Underwater foam integrity over time is difficult to validate and verify.	No underwater foam required.		

Table 1

OPTION 1 RISKS		OPTION 2 ADVANTAGES	OPTION 1 ADVANTAGES	OPTION 2 RISKS
h)	OIP/IPSS interfaces are a challenge due to different design agent responsibility. NAC, Intl. – IPSS, DESH/FDNW - OIP	A single design agent and integrated design simplifies the interfaces.		
i)	Vertical rail friction loads that will occur when the IPSS translates down during a drop event may be difficult to accommodate and defend.	No vertical rail loading will occur		
j)	Accessibility of IPSS pins and pin blocks because the OIP is required to be over the inside edge of the pail	New design offers opportunity for improved accessibility and design		Immersion pail may require the addition of foam for buoyancy to accommodate the higher lift height requirement
k)		Beam and plate upper section offers additional radiation shielding		
l)		Existing SLOP/Basin analytical model can be used to evaluate the different loading conditions.		
m)	The design is complex. Several serial energy-absorbing mechanisms are required for the most complex drop scenario i.e. IPSS pin deformation/failure, IPSS leg shear pin failure, IPSS leg foam crushing, hydraulic dampening, IPSS foot failure, and final under-IPSS foam crushing. Fabrication complexity include; welding and alignment of many separate pieces within tight tolerances.	The design is simpler. Energy absorption mechanisms include upper section impact limiting material deformation and hydraulic dampening. Some fabrication simplification avoids the welding and alignment of many separate pieces of the lower section and replaces it with cylinder sections. The upper section is integrated with the lower section and uses a similar beam/foam arrangement as the Option 1 design.		Beam and impact limiting material sizing has not been fully developed.

Table 1

OPTION 1 RISKS		OPTION 2 ADVANTAGES	OPTION 1 ADVANTAGES	OPTION 2 RISKS
n)	The Option 1 OIP may require that the SLOP walls be notched or removed to accommodate the stroke required to fully engage the energy absorption (foam) mechanism following an off-center or secondary drop.	There may be an opportunity to avoid notching or reducing the height of the walls due to increased allowable loading.		Beam and impact limiting material sizing has not been fully developed so design details have not been identified. Lowering or notching the walls may provide an opportunity to improve operational interfaces.
o)	Installation difficulty of midpoint seismic restraint required to ensure that the slider mechanisms engage properly. Also, underwater demolition of rail cross-tie beams required.	No midpoint restraint required.		Installation details of the integrated structure have not been detailed. A larger, heavier, bulkier component presents installation challenges.
p)	Concern with drain valve damage following a drop accident due to unknown existing integrity.	No apparent impact to drain valve.		Loads transmitted through the walls to the drain valve will have to be evaluated to ensure that there are no significant loads on the drain valve but it is not expected to be a technical challenge.
q)	The IPSS alone will not accommodate the secondary drops.	The integrated design may accommodate the off-center and the secondary drops. Guides will be required to perform this function.		Off-center and secondary drops will have to be reevaluated for impact on the integrated design.
r)	Concern with floor/wall gap and following a drop and subsequent leakage (currently evaluated to be less than SAR allowable).	No floor/wall gap will occur. Floor/wall joint and rubber waterstop will be loaded in compression rather than tension. Less risk of basin leakage.		Shear loading on the wall/wall connections will have to be evaluated but is not expected to be a technical challenge.

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Table 1

OPTION 1 RISKS		OPTION 2 ADVANTAGES		OPTION 1 ADVANTAGES		OPTION 2 RISKS	
s)	The telescoping slider mechanism in the legs of the IPSS may not work due to the side-loading that would occur during an off-center drop.	No telescoping slider mechanism required.				Upper impact limiting material requirements and beam sizes have not been fully developed.	
t)						Yearly underwater inspection challenges exist.	

DISTRIBUTION SHEET

To: Distribution	From: J. L. Weamer	Page 1 of 1
Project Title/Work Order Conceptual Design Report – Cask Loadout System/Cask Drop Redesign for the Immersion Pail Support Structure and Operator Interface Platform, 105 K West Basin Project A.5/A.6 – HNF-4576		Date: July 6, 1999
		EDT No. 626743
		ECN No. N/A

Name	MSIN	Text With All Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only
K. E. Ard	X3-85	X			
C. A. Bullock	X3-68		X		
K. C. Conrad	X3-80		X		
P. T. Day	R3-11	X			
W. A. Frier	S1-53		X		
E. F. Herbert	S7-41		X		
J. E. Kurtz	X3-68		X		
A. S. Langevin	X3-85		X		
R. A. Larson	R3-86		X		
P. L. Lingle	S2-51	X			
C. B. Loftis	S7-41		X		
J. D. Mathews	X3-65		X		
D. C. Mobley	X3-73		X		
D. A. Moody	X3-85		X		
L. A. Rodgers	X3-85		X		
L. S. Semmens	X3-85		X		
J. A. Swenson	R3-11	X	~~X~~		
J. L. Weamer	X3-85	X	~~X~~		
K Basin Project Files A.5/A.6	X3-85	X			
DOE/RL Reading Room	H2-53	X			