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B J Craig	R3-26	X			
W A Frier	X3-76	X			
R L Garrett	R3-26	X			
K D Gibson	R3-26	X			
L H Goldmann	R3-86	X			
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S F Kessler	R3-26	X			
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S H Peck	R3-26	X			
J A Swenson	R3-11	X			
SNF Project Files	R3-11	X			
M & D Professional Services, Inc Milon Meyer 1305 Mansfield, Suite 5 Richland, WA 99352		X			

Evaluation of Cask Drop Criticality Issues at K Basin

M & D Professional Services, Inc. for

Fluor Daniel Hanford, Incorporated, Richland, WA 99352 U S Department of Energy Contract DE-AC06-96RL13200

EDT 628129

UC 940

Org Code 2F200

Charge Code 105350/CB80

B&R Code EW31354040

Total Pages 50

Key Words K Basin, Multi-Canister Overpack, MCO Spent Nuclear Fuel SNF criticality cask drop

Abstract An analysis of ability of Multi-Canister Overpack (MCO) to withstand drops at K Basin without exceeding the criticality design requirements. Report concludes the MCO will function acceptably

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UNREVIEWED	SAFETY QUESTION SCR	EENING FORM
Document Number EDT 628129	USQ Tracking Number K 00 0077	Page 1 of 2
SNF 5557 Rev 0 Title Evaluation of Cask Drop Criti	Page 1	

Description This activity involves the issuance of SNF 5557 Evaluation of Cask Drop Criticality Issues at K Basin Revision 0 by EDT 628129 This document evaluates the effects of cask drops on the MCO internal criticality design features to demonstrate they will function properly

It should be noted that SNF 5557 is not used as an input for the currently implemented K Basin SAR/TSR authorization basis SNF 5557 is a supporting document associated with the MCO CSER (HNF SD SNF CSER 005 Rev 5) which is referenced by Revision 4 of the K Basin SAR Revision 4 of the K Basin SAR will be approved by DOE prior to implementation of the fuel removal activities

SNF 5557 will be reviewed as required by Desk Instruction NDSI 02 Review of Design Changes to SNF Project Safety Basis Documents for impact to future AB s for CVDF and CSB. Its issuance is not expected to result in a need for any change. The changes resulting from issuance of SNF 5557 have already been incorporated into Rev 4 of the K Basin SAR and does not impact Rev 1 of the K Basin TSRs.

The authorization bases reviewed

K Basin SAR WHC SD WM SAR 062 Rev 3K K Basin TSR WHC SD SNF TSR 001 Rev 0 G

USQ Screening Questions

Note Respond to each question and provide basis/justification for each response An adequate justification provides sufficient explanation such that an independent reviewer could reach the same conclusion

Does the Proposed Activity Result in a Permanent or Temporary Change in the Facility as Described in the Existing Authorization Basis?

[] N/A [X] NO [] YES/MAYBE

Basis SNF 5557 is being issued to address the acceptability of criticality design features for cask drop accidents for the spent nuclear fuel removal activities. These changes do not change the description of the K Basins depicted in the current SAR or TSRs. The facility has not changed as a result of the issuance of SNF 5557.

Does the Proposed Activity Result in a Temporary or Permanent Change in the Procedure(s) as Described Outlined or Summarized in the Existing Authorization Basis?

[N/A [X] NO [YES/MAYBE

Basis See Question 1 above The issuance of SNF 5557 will not result in changes to procedures for existing operation as referenced in the existing authorization basis

Does the Proposed Activity Result in a Test or Experiment Not Described in the Existing Authorization Basis?

[] N/A [X] NO [] YES/MAYBE

Basis Issuance of SNF 5557 is not a test or experiment

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[] N/A	YBE
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Does the Reportable Occurrence or Issue Basis?	Have Any Potential for Impacting the Authorization
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CHECKLIST FOR PEER REVIEW

Document Reviewed Evaluation of Cask Drop Criticality Issues at K Basin SNF-5557 Rev 0

Scope of Review Independent Check of Calculations

Author B V Winkel

Yes No NA	
[][][X]*	Previous reviews complete and cover analysis up to scope of this review with no gaps
[X] [] []	Problem completely defined
[X] [] []	Accident scenarios developed in a clear and logical manner
[X] [] [X]	Necessary assumptions explicitly stated and supported
[X] [] []	Computer codes and data files documented
[X] [] []	Data used in calculations explicitly stated in document
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[X] [] []	Mathematical derivations checked including dimensional consistency of results
[X] [] []	Models appropriate and used within range of validity or use outside range of established validity justified
[X] [] []	Hand calculations checked for errors Spreadsheet results should be treated exactly the same as hand calculations
[X] [] []	Software input correct and consistent with document reviewed
[X] [] []	Software output consistent with input and with results reported in document reviewed
[X] [] []	Limits/criteria/guidelines applied to analysis results are appropriate and referenced Limits/criteria/guidelines checked against references
[X] [] []	Safety margins consistent with good engineering practices
[X] [] []	Conclusions consistent with analytical results and applicable limits
[X] [] []	Results and conclusions address all points required in the problem statement
[] [] [X]	Format consistent with appropriate NRC Regulatory Guide or other standards
[] [X] *	Review calculations, comments, and/or notes are attached
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1 0 INTRODUCTION

The spent fuel currently residing in the 105 KE and 105 KW storage basins will be placed in fuel storage baskets which will be loaded into the MCO cask assembly. During the basket loading operations, the MCO cask assembly will be positioned near the bottom of the south load out pit (SLOP). The loaded MCO cask will be lifted from the SLOP transferred to the transport trailer, and delivered to the Cold Vacuum Drying Facility (CVDF). In the wet condition, there is a potential for criticality problems if significant changes in the designed fuel configurations occur. The purpose of this report is to address structural issues associated with criticality design features for MCO cask drop accidents in the 105 KE and 105 KW facilities.

2 0 SUMMARY AND CONCLUSIONS

A structural evaluation of MCO cask drops within the 105 KW and 105 KE facilities has been made relative to limitations imposed by criticality considerations for spent fuel contained in the MCO baskets. The evaluation began with a comprehensive review of the existing MCO cask drop analyses. This was followed by an evaluation of the potential cask drops associated with a loaded MCO cask within the K Basin facilities. Bounding K Basin cask drops were identified and the corresponding peak deceleration levels were quantified. The bounding deceleration levels were estimated using a combination of target hardness methodology from EPRI (1993). Impact loading ultimate strength calculations, and comparisons with existing drop calculations.

The structural limits imposed on the MCO by criticality considerations are

- 1) The lateral deformation of the Mark 1A basket center posts is limited to a 2 in lateral shift relative to the MCO shell centerline
- 2) The circumference of the inner surface of the MCO shell cannot increase by more than 0 8325 in This limit applies to both the Mark 1A and Mark IV MCO assemblies
- 3) The MCO basket bottom plates must remain in place to separate the fuel masses but distortion or minor movement of the plates is acceptable

Based upon a review of the existing drop analyses and engineering judgement—seven damage mechanisms were identified for further study—Each mechanism was evaluated relative to the bounding cask drop deceleration levels—The following conclusions result from this analysis

- The bounding vertical drop is a 36 ft drop inside the SLOP
- The bounding horizontal impact is a drop on the SLOP west curb wall
- The critical mechanism for inducing lateral deflections of the Mark 1A basket center post is a shear failure of the center post coupling nipple during a horizontal impact

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- The ultimate shear capacity of the coupling nipple was calculated to be at least 153 g The deceleration associated with the bounding horizontal drop was calculated to be 52 g
- The critical mechanism for increasing the circumference of the MCO shell is internal pressure introduced by the fuel during a vertical cask drop containing Mark IV fuel baskets
- The MCO shell hoop stresses associated with the internal pressure of the bounding vertical drop are below the yield strength of the MCO material
- The resulting circumferential increase of the inner surface of the MCO shell is 0.09 in which is well below the limit of 0.8325 in
- Although the basket bottom plates may experience some minor distortion no mechanism can be established to cause major movement of the plates. The MCO bottom plates remain effective in separating the fuel masses.

Although the methods used in this evaluation were approximate and relied significantly on engineering judgement sufficient safety margins exist to conclude that the MCO criticality design features will perform their functions for the bounding MCO cask drops in the K Basin facilities

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3 0 SYSTEM DESCRIPTION AND CRITICALITY LIMITATIONS

The next two sections contain a description of the loading operations and a listing of the structural limits imposed by criticality considerations

3 1 SYSTEM DESCRIPTION

The Spent Nuclear Fuel Project will remove spent nuclear fuel from the K Basins in a Multi-Canister Overpack (MCO) contained in a shipping cask. Fuel canisters containing fuel stored in the K Basins will be washed in a cleaning machine to remove fuel sludge prior to removing fuel from the canisters. Following washing the spent fuel will be removed from the canisters and will be loaded into MCO baskets. The MCO baskets have a center post designed to couple with and support the bottom of the next basket loaded. The center post of the Mark IA MCO basket is a criticality protection feature designed to prevent fuel from accumulating near the center of the MCO basket. The baskets also have support posts around the basket periphery that support the bottom plate of the next basket up the stack. The bottom plate center post and support posts carry the MCO basket loads and transfer the load to the bottom of the MCO.

The MCO baskets containing spent fuel are loaded into an MCO contained in a cask in the K Basin south loadout pit (SLOP) The MCO will be loaded with up to six MCO baskets. After being loaded the MCO shield plug will be placed on the MCO but it will not be secured. All of these activities are performed underwater in the K Basins.

While inside the SLOP the cask assembly sits inside an immersion pail to prevent contamination of the cask outer surface. The immersion pail containing the cask and loaded MCO is lifted with the transfer bay crane until the top of the cask and MCO are slightly above the basin water surface. The immersion pail is secured in this position by pinning it to the immersion pail support structure (IPSS). After the immersion pail is pinned the MCO shield plug is secured to the MCO and the cask lid is secured on the cask. Some process valves on the MCO shield plug are open to vent the MCO to the cask.

The cask is lifted from the immersion pail with the transfer bay crane and moved to the cask transport trailer. The cask is secured to the transport trailer and then taken to the Cold Vacuum Drying Facility (CVDF)

3 2 CRITICALITY LIMITATIONS AND ACCEPTANCE CRITERIA

Administrative controls and MCO design features are intended to prevent MCO criticality accidents. The MCO criticality analysis (FDNW 1999) credits these design features in demonstrating that the MCO cask drop accidents will not result in exceeding the criticality limits. The MCO design features are

MCO shell which limits the maximum diameter that accumulated fuel scrap could achieve

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- Mark IA basket center post which prevents fuel accumulation near the center of the MCO
- MCO Basket bottom plate which provides spacing of fuel and provides support for the Mark IA basket center post
- MCO shield plug assembly which acts to center the top Mark IA basket center post

FDNW (1999) demonstrates that under normal and drop conditions the loaded MCO does not exceed criticality limits provided the design features continue to function to control fuel geometry. In order to demonstrate that the MCO meets criticality imposed structural limits, the present analysis must demonstrate compliance with the following criteria.

- The maximum MCO inner circumference shall not exceed the circumference of a circle with a diameter of 23 25 in
- The center post of the Mark IA MCO basket shall not displace more than 2 in relative to the center of the MCO shell centerline
- The individual basket fuel masses shall maintain a vertical separation at least as great as the basket bottom plate thickness. Failure of the basket bottoms resulting in significant bending of the bottom plate is not acceptable.

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4 0 DROP DEFINITIONS

This section discusses drops along the travel path of a loaded MCO cask at K Basins. The cask containing an empty MCO arrives at K Basin on the transport trailer. The empty MCO cask assembly is placed into an immersion pail and lowered to the bottom of the SLOP for fuel loading. MCO baskets containing fuel are placed in the MCO. The shield plug with the long process tube is then placed in the top of the MCO. The shield plug is not secured for the first lift and the cask lid is not placed on the cask for the first lift.

The first lift raises the immersion pail containing the uncovered cask and loaded MCO with loose shield plug to the upper position in the IPSS. This positions the top of the cask and MCO just above the basin water surface. The immersion pail is secured in this position by pins in the IPSS. The MCO shield plug is secured and the cask cover is installed. The cask containing the loaded MCO is then lifted from the immersion pail and moved to the transport trailer. The cask is secured to the transport trailer prior to movement of the trailer.

The MCO is always in the cask while at K Basins. With one exception, all postulated drops in the K Basin occur with a completely assembled MCO vented to the assembled and sealed cask. The one exception is a drop that occurs during the first lift described above. The MCO cannot tip over following this drop because even if the transfer bay crane two blocked, not enough vertical clearance exists to raise the cask above the IPSS.

The following assumptions were made when defining the potential drops in the K Basin

- Lifts involving vertical movement of the crane hook are assumed to occur from the two block height of the crane hook. Adjustments to the drop height are made to account for rigging. Since the rigging for the cask and immersion pail differ the drops heights are different.
- Lifts not involving vertical movement are assumed to occur from the second limit switch height of the crane hook. Adjustments to the drop height are made to account for rigging.

Potential drops in the K Basin are summarized in Table 4 1

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Table 4 1 Drop Definitions

Drop	Description	Drop Height	Comments
1	Loaded MCO with loose shield plug inside open cask The cask and immersion pail assembly is lifted to the transfer bay crane two block position and dropped back into load out pit	16 feet	Since the shield plug is not secured it is assumed that the shield plug does not support the upper end of the upper MCO basket Rebound due to the drop is not assumed to cause the MCO baskets to leave the MCO or to totally disengage the center post inserts between each basket
2	Sealed cask containing loaded MCO with secured shield plug is lifted to the transfer bay crane two-block position and dropped back into load out pit	36 feet	Assumes immersion pail pins are sheared and immersion pail with integral impact limiter and cask fall to basin floor
3	Sealed cask containing loaded MCO with secured shield plug is lifted to the transfer bay crane two-block position and dropped onto IPSS/ loadout pit wall or other structure then slaps down to transfer bay floor loadout pit wall or transfer channel	8 25 feet to curb wall or 10 25 ft for transfer bay floor	Highest energy impact occurs with slap down all the way to the transfer bay floor Hardest impact surface is the load out pit wall Impacts to miscellaneous equipment are ignored
4	Sealed cask containing loaded MCO with secured shield plug is lifted to the transfer bay crane second limit switch position and dropped onto transfer bay floor then slaps down to transfer bay floor or loadout pit wall	4 feet	Highest energy impact occurs with slap down all the way to the transfer bay floor. Hardest impact surface is the load out pit wall. Impacts to miscellaneous equipment are ignored. Bounded by drop 3.
5	Sealed cask containing loaded MCO with secured shield plug is lifted to the transfer bay crane two block position and dropped onto trailer then slaps down to transfer bay floor	7 25 feet to trailer or 10 25 ft to transfer bay floor	Trailer height is assumed to be 3 feet off the transfer bay floor

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50 K BASIN DROP LOAD CALCULATIONS

The purpose of the following sections is to define the impact forces and accelerations acting on the cask during drops in the K Basin. For the purpose of establishing impact accelerations, the drops are divided into the 36 ft vertical drop into the south loadout pit (SLOP) drops onto the basin floor, and drops onto the west curb wall of the SLOP. The cask accelerations for the 36 ft drop into the SLOP have been calculated using a finite element model of the SLOP. Cask accelerations associated with drops onto the K Basin floor have been estimated using methodology presented in EPRI (1993). Cask accelerations associated with drops onto the west curb wall have been conservatively estimated using simple hand calculations based on the ultimate strength of the concrete and the impact area.

5 1 VERTICAL DROP INTO THE SOUTH LOADOUT PIT (SLOP)

MCO cask drops into the SLOP were addressed in M&D (1999) The same structural model and methodology used in M&D (1999) were used here to calculate the structural response to the bounding 36 ft high drop described in Section 4.0 The following conservative assumptions were applied to the evaluation of the vertical drop into the SLOP

- No credit was taken for energy absorbed for impact loading on any of the Immersion Pail Support Structure (IPSS) or Immersion Pail (IP) structures
- The relatively thin impact absorber at the bottom of the IPSS was ignored
- The impact velocity reductions associated with the SLOP water (buoyancy and drag forces) were ignored

The dynamic finite element analysis utilized the ANSYS¹ computer code. The finite element model used in the drop analysis is shown in Figure 5.1. The details of the structural model are discussed in M&D (1999). The missile impacting the bottom of the SLOP was modeled as a rigid body (no energy absorbed by missile deformations). A bounding MCO Cask/IP mass of 70 000 lbf was assumed. The SLOP floor impact velocity consistent with the above assumptions is

$$v = \sqrt{2gh} = \sqrt{2(32\ 2)(36)} = 48\ 2ft/\sec = 578\ in/\sec$$

The predicted deceleration of the model rigid mass is shown in Figure 5-2 Note that a peak deceleration of 87 g is predicted. Also note that the deceleration duration is approximately 44 milliseconds (ms)

¹ ANSYS is a registered trademark of ANSYS Inc

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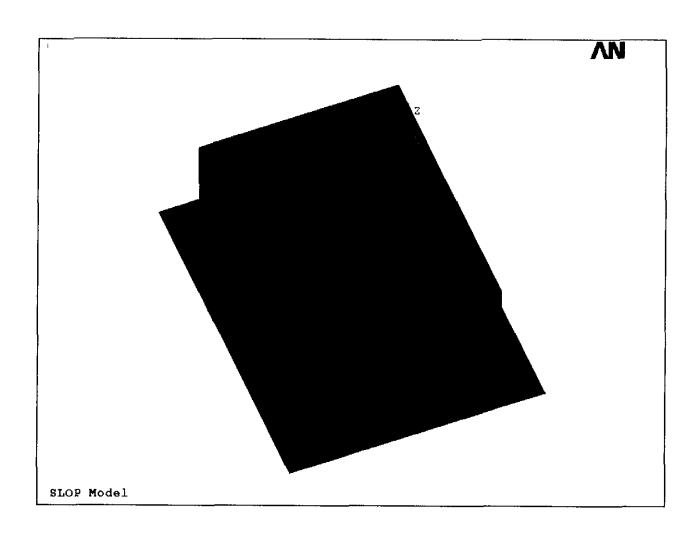


Figure 5 1 Finite Element Model of the Bottom Portion of the South Loadout Pit (SLOP)

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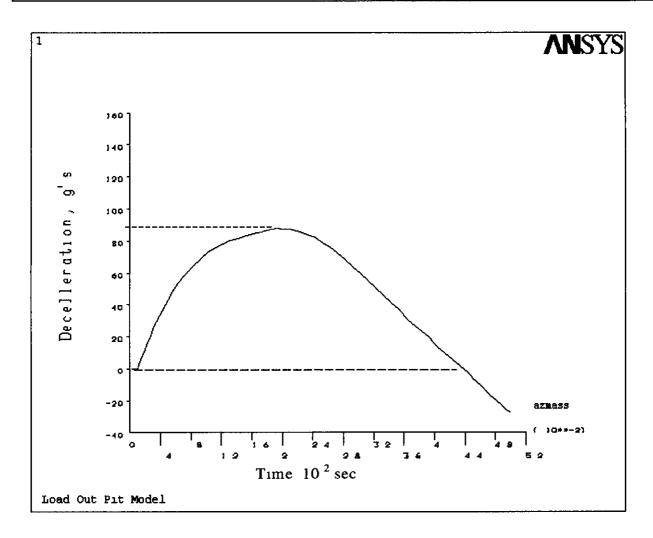


Figure 5-2 MCO Cask Acceleration Time History, SLOP Floor Impact

5 2 DROPS ONTO THE K BASIN FLOOR

EPRI (1993) provides a method of calculating accelerations acting on shipping casks when subjected to accidental drops onto concrete storage pads. The concrete targets are characterized with a target hardness number that accounts for the concrete properties, the underlying soil properties, and the cask weight and dimensions. Table 5-1 shows the parameters used for the determination of the K Basin floor target hardness along with the range of variables used in EPRI (1993). It is recognized that uncertainty exists when applying the methodology of EPRI (1993) to drops in the K Basin. Sources of uncertainty include proper scaling of the results based on cask size, extrapolating target hardness variables outside the range used in the EPRI.

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study and the assumption of constant acceleration inherent in the EPRI study methodology. On the other hand, the target hardness numbers calculated for the K Basin drops are well within the range considered in the EPRI study, the cask accelerations predicted by the EPRI methodology provide at least a rough estimate of expected accelerations, and significant margins exist between predicted and allowable accelerations.

Table 5 1 Comparison of K Basin Floor Impact Parameters to EPRI Study Parameters

Design Parameter	Value used for K-Basın Floor	Range of Values used in EPRI Study
Concrete Elastic Modulus (lbf/in²)	3 8 x 10 ⁶	$2.5 \times 10^6 - 3.6 \times 10^6$
Concrete Ultimate Strength (lbf/in²)	4 500 ¹	2 000 – 4 000
Poisson s Ratio for Concrete	0 17	0 17
Soil Elastic Modulus (lbf/in²)	30 000 ²	10 000 - 60 000
Poisson s Ratio for Soil	0 45	0 45
Steel Reinforcement Ratio (%)	0 115	0 463 – 0 722
Cask Radius (in)	203	44 45 ⁴
Cask Weight (lbf)	62 000 ³	200 0004
Cask Length (in)	160 ³	200 ⁴
Concrete Slab Thickness (in)	22 55	36
Rebar Yield Strength (lbf/in²)	40 000	60 000 ⁴
Resulting Target Hardness	40 000	200 – 400 000

^{50%} higher than the design strength of 3 000 lbf/in²

The analysis considers both vertical (end) drops and side (edge) drops In the case of an end drop the target hardness is given by

$$S_{end} = 2 \ r \ A \ k \ M_u \ \sigma_u \ (W^3(1 - e^{-\beta r} \cos \beta r))$$

In the case of an edge drop the target hardness is

$$S_{edge} = \frac{2 A E_s M_u \sigma_u}{W^3 \beta}$$

² Upper bound for a sand/gravel mix per Bowles (1988) Table 2.7

³ DESH (1999)

⁴Typical value rather than a variable parameter in the study

⁵Rail foundation thickness

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In the case of the end drop the parameters have the following definitions

 $r = cask \ radius$

 $A = cask \ footprint = \pi \ r^2$

$$k = \frac{\pi E_s}{1 - v^2_s}$$

 $E_s = soil\ elastic\ mo\ dulus$

 $v_s = Poisson's ratio of soil$

 $M_u = ultimate concrete moment capacity per unit width$

 $\sigma_u = ultimate strength of the concrete$

W = cask weight

$$\beta = (\frac{E_s}{4 D})^{1/4}$$

$$D_c = \frac{E_c \ h^3}{12 \ (1 - v^2_c)} \quad \text{flexural rigidity of concrete slab}$$

 $E_c = concrete \, elastic \, mo \, dulus$

 $v_c = Poisson \ s \ ratio \ of \ concrete$

h = concrete pad thickness

In the case of the edge drop the parameters β and A have different meanings as follows

$$\beta = \left(\frac{E_s}{4 E_c I_c}\right)^{1/4}$$

$$I_c = \frac{L \ h^3}{12}$$

 $L = cask\ length$

A = cask footprint area = D L

 $D = width \ of \ cask \ footprint \ (D \ is \ avariable \ quantity)$

Given the target hardness and the drop height EPRI (1993) provides data for calculating the average acceleration of the impacting cask. The methodology assumes that the acceleration is constant throughout the impact

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5 2 1 End Drop

Both vertical (end) and horizontal (edge) drops on the transfer bay floor will be considered. The drops are assumed to occur on the rail slab portion of the transfer bay floor. The rail slab has a thickness of 22.5 in and has #5 rebar spaced 12 in on center (GE 1955). Using the methodology described in EPRI (1993), the target hardness of the rail slab for a vertical (end) drop is approximately 40.000 (see Appendix A). According to Figures 22 through 29 of EPRI (1993), the resulting average cask accelerations will be between 20 and 30 g for drop heights greater than approximately 12 in

5 2 2 Side Drop

The target hardness for an edge drop on the rail slab is estimated to be between 16 000 and 40 000 depending on the size of the cask footprint. If the larger value of 40 000 is used the conclusion is the same as for the end drop. That is the average cask accelerations will be between 20 and 30 g for drop heights greater than approximately 12 in

5 3 DROPS ONTO THE WEST CURB WALL

Estimates of the cask acceleration for drops onto the curb wall can be made based on the contact area between the cask and the wall and the ultimate compressive strength of the concrete

531 Vertical Drop

Assuming a centered vertical (end) drop an upper bound estimate of the contact area is given by

$$A_{endmax}$$
=(d_{cask})(w_{wall})=(40 in)(17 75 in)=710 in²

where

 d_{cask} is the MCO cask diameter and w_{wall} is the width of the west curb wall (GE 1955). The maximum force that can be exerted by the wall on the cask can be estimated by multiplying the ultimate compressive strength of the concrete by the contact area. If the ultimate strength of the concrete is assumed to be 4 500 lbf/in² the maximum impact force is given by

$$F_{endmax} = (\sigma_u)(A_{endmax}) = (4 500 lbf/ln^2)(710 ln^2) = 3 2 x 10^6 lbf$$

The corresponding cask acceleration given in terms of g level is

$$a_{cask} = (F_{endmax})/(W_{cask}) = (3.2 \times 10^6 \text{ lbf})(62.000 \text{ lbf}) = 51.6 g$$

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5 3 2 Side Drops

Given the travel path from the IPSS center to the cask transport trailer drops of the cask onto the SLOP wall are possible only during a small portion of the travel path. Therefore, a direct drop onto the SLOP curb is very unlikely. The most likely cask impact onto a SLOP curb wall would be due to a slap down following a vertical drop adjacent to the wall. This is because during a slap down, the long reach of the cask height (160 in.) comes into play. For a slap own onto the curb wall, the impact area would be small since the impact would involve a cylindrical surface impacting one edge of the curb wall. The impact area would increase as the concrete crushes. An upper bound to the impact area is the cask diameter times the wall thickness which is the same area considered for the vertical drop in the previous section and leads to the same bounding acceleration of 52 g

A worse case could be postulated by assuming a horizontal drop onto the west wall with the cask axis parallel to and centered over the curb wall. However, this requires the following combination of unlikely events

- 1) The drop would be initiated at precisely the point in time when the cask reaches the midpoint of the curb wall (centered over the curb wall)
- 2) A single cable failure would result in a full 90° rotation of the cask before it reaches the top of the curb wall
- 3) The cask axis would be precisely oriented in the north/south direction (parallel to the curb wall)
- 4) The cask axis would be precisely horizontal at the time of impact

The probability of this combination of unlikely events is not credible. Therefore the 52 g deceleration is a reasonable upper bound for a side drop involving the curb wall

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6 0 RESOLUTION OF CENTER POST SHIFT CRITICALITY LIMIT

As discussed in Section 3.2 criticality considerations require that the Mark 1A basket center post remain within 2.0 in of the MCO shell centerline. An illustration of the Mark 1A basket geometry is shown in Figure 6-1. Note that the center posts are nearly solid (6.625 in O.D. 1.75 in I.D.). Also note that the 1.25-in thick base plates act as centering devices for the center post. From the relatively stout nature of the basket geometry alone, it is qualitatively concluded based on engineering judgement that a 2.0-in lateral shift of the center post is not possible for drop accidents at the K. Basins

Based upon a combination of judgement and a review of earlier drop calculations the mechanisms identified in Table 6.1 have the potential for producing significant lateral shifts in the center post due to a MCO cask drop accident. A detailed evaluation of each mechanism follows below

Table 6-1 Basket Center Post Lateral Shift Mechanisms

Mechanism Number	Mechanism Title	Mechanism Description
t	Inelastic Center Post Buckling Vertical Drop	Vertical drop plastic bowing/buckling of the bottom basket center post due to a combination of high axial loads and a moment due to eccentric loading (non-uniform fuel loading and/or basket musalignment)
2	Basket Stack Instability Failure Vertical Drop	The Mark 1A stack of five baskets are loosely fit within the MCO cylinder (3/8 in diametral clearance) The MCO cylinder loosely fits within the MCO cask (1.2 in diametral clearance) During a vertical drop an instability failure of the MCO cylinder/basket stack assembly is postulated to occur inside the cask resulting in significant lateral shifting of the center post
3	Horizontal Drop Center Post Beam Bending	Center post lateral deformations due to an inelastic bending response to fuel and center post inertial loading during a horizontal drop or slap down
4	Center Post Thread Failure	Center post/bottom plate separation due to failure of the center post acme threads during a horizontal drop or slap down
5	Bottom Plate Plastic Deformations	Plastic deformations in the basket bottom plates due to high inertia loads acting through the plates during a horizontal drop
6	Center Post Coupling Disengagement	Disengagement of the center post coupling nipple during a sequential vertical slap down drop resulting from a combination of adverse tolerance stack up and internals shortening during the vertical drop
7	Center Post Coupling Shear Failure	Shear failure of the relatively thin walled center post coupling nipple during a horizontal drop or slap down
8	Loose Shield Plug	For the initial cask lift, the MCO shield plug has no vertical constraint. A vertical drop with a loose shield plug could result in basket assembly/shield bounce, which could be followed by a disengagement of the center post coupling nipple.

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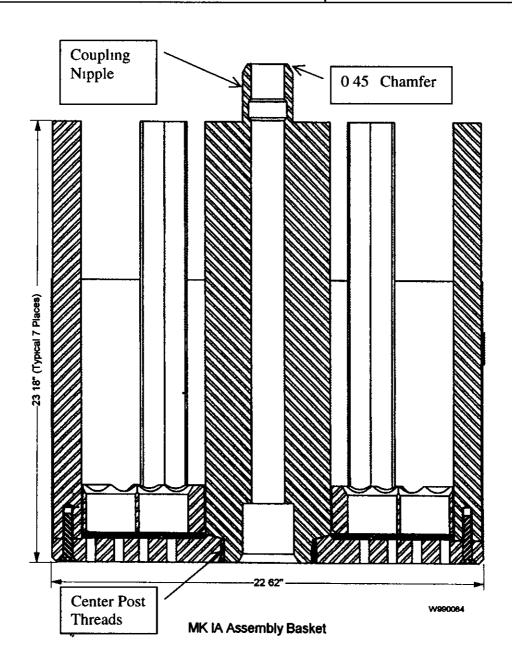


Figure 6 1 Mark 1A Basket Geometry

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6 1 INELASTIC CENTER POST BUCKLING

During a vertical drop the bottom Mark 1A basket experiences the highest inertial loading coming from the five baskets above. Most of the load is carried through the bottom basket center post. Due to both lateral shifting of the baskets and uneven fuel loading eccentric loading on the bottom basket is expected. The combination of high axial loading and bending moments is a potential mechanism for lateral instability of the bottom basket center post.

From Drawing H 2-828060 Rev 1 the maximum lateral offset at one basket interface is 0 075 in. The cumulative offset for five basket interfaces is 5(075) = 0.375 in. or an average basket offset of 0 188 in. The uneven fuel loading is assumed to be limited by the tip angle of the basket during basket insertion. Drawings H-2 828042 Rev 4 and H 2-828060 Rev 1 indicate that if the tip angle is more than approximately 7.3° (tan $^{1}[0.783/6.1]$) the edge of the basket will catch on the canister collar seal shoulder. A tip angle of 7.3° corresponds to a center of gravity offset of approximately 1.5 in. (12tan[7.3°]) Thus a load eccentricity of 1.5 + 0.188 = 1.69 in. is a reasonable bounding value because greater eccentricities would interfere with basket loading

Using the bounding single Mark 1A basket weight of 2 400 lbf the bottom basket 1g loading from the five baskets above is $5(2\,400) = 12\,000$ lbf. From Section 5 1 the bounding vertical drop deceleration is 87 g resulting in a bottom basket load of $87(12\,000) = 1\,044\,000$ lbf. This load is well above the yield strength of the support ribs beneath the bottom basket indicating that the 87 g load is conservative for the baskets. Due to the very low effective slenderness ratio of the center post (kl/r ≈ 10) the instability loading is well above the yield strength. This is demonstrated by performing an plastic instability analysis using the ANSYS computer code

The finite element model of a single center post is shown in Figure 6.2. This scale model illustrates the stout nature of the center post and suggests that a buckling failure is very unlikely. Plastic pipe elements (PIPE20) were used in conjunction with the ANSYS large displacement option (NLGEOM). The bottom end was fully constrained and the top end of the model was conservatively assumed to be pinned (no rotational constraint). A static analysis was performed but the strain rate dependency of material yield strength was included. From Section 8.3.2 of Jones (1997), the strain rate dependency of 304 SS can be expressed as

$$\frac{\sigma_o}{\sigma_o} = 1 + \left(\frac{\partial \varepsilon / \partial t}{100}\right)^{1/10}$$

where σ_0 / σ_0 is the ratio of dynamic-to-static yield stress and $\partial e / \partial t$ is the strain rate (in/in/sec) From Figure 5-2 a ramp time of 0.02 sec is obtained. For a total strain equal to the yield strain over the time duration a strain rate of (0.001/0.02) = 0.05 in/in/sec is obtained. Substituting this strain rate into the equation above gives

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$$\frac{\sigma_o}{\sigma_o} = 1 + \left(\frac{0.05}{100}\right)^{1/10} = 1.47$$

Thus a 47% increase in the 150 °F yield strength was included in the material definition used in the computer model. Note that Paragraph F-1322 3c of the ASME Code allows for yield strength increases due to strain rate effects.

Using a load eccentricity range of 1 to 3 in the conservative loading of 1 044 000 lbf was incrementally applied. With the full load applied, the solutions remained stable. A typical deformation pattern is shown in Figure 6-3. The maximum lateral displacement (bow) of the center post, as a function of load offset is shown in Figure 6-4. Note that the 2 in center post deformation limit is met for load offsets in excess of 3 in. Because the 3 in load eccentricity exceeds the maximum of 1 69 in estimated above, the center post is adequate for the 87 g drop load.

Although the finite element analysis demonstrates that the 2 in limit is met for the maximum g loading it does not address the instability safety factor. Paragraph F 1341 4 of Section III of the ASME Code specifies that the applied load shall not exceed 70% of the plastic instability load. (P₁) which corresponds to a safety factor of 1/0 7 = 1 43. In addition to the center post capacity, the Mark 1A baskets have six support rods positioned on the outer periphery of bottom plate. From p. 25 of Parsons (1999), the combined capacity of the support rods is 393 750 lbf. This capacity is based upon a drop temperature of 270 °F. For the K Basin operating temperature of 150 °F, the material yield strength is 17% higher.

An estimate of the support rod capacity at 150 °F can be found by a simple ratio of the reduced temperature yield strength increase. The result is a support rod capacity of 393 750(1 17) = 460 700 lbf. The combined capacity of the center post and support rods is 1 504 700 lbf. This combined capacity corresponds to a safety factor of 1 44 which exceeds the ASME factor of 1 43. A much larger margin would be obtained by taking advantage of the strain rate dependency of the support rod material, as indicated by the discussion above for the center post analysis.

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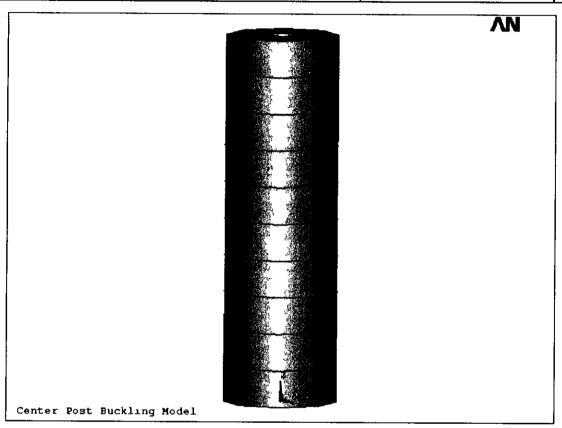


Figure 6 2 Mark 1A Basket Center Post Instability Analysis Model

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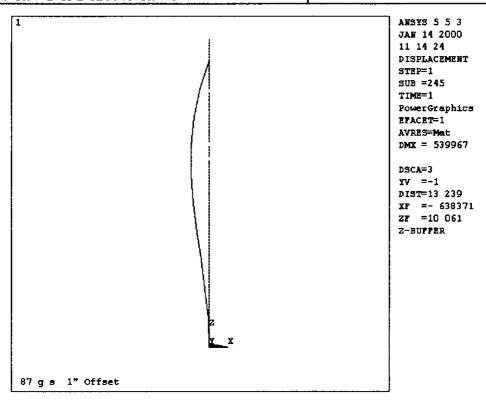


Figure 6 3 Predicted Bottom Basket Center Post Deformations - Vertical Drop

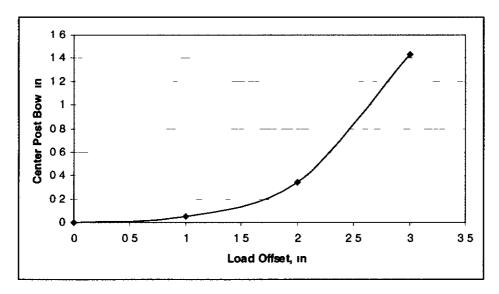


Figure 6 4 Center Post Deflection vs Load Eccentricity

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6 2 BASKET STACK INSTABILITY FAILURE, VERTICAL DROP

Due to clearances at the basket to-basket interfaces there will be some off center shifting of the baskets Fabrication tolerances also allow some rotation of the bottom plates. These initial deviations from vertical will be amplified during a vertical drop and significant bearing stresses can develop at the interfaces between the basket and the MCO shell. As the bearing stresses increase significant MCO shell deformations can occur further amplifying the basket stack deviations from vertical. Thus, an instability type failure can be postulated for the MCO shell and basket assemblies.

If the above instability failure occurred the MCO shell lateral movement would be limited to the inside boundary of the rigid MCO cask (1 2-in diametral clearance). For the most extreme case, the relative displacement between the center of the MCO shell and the basket center post is limited to the 1 2 in diametral clearance. Therefore, a basket stack instability producing a lateral shift of a center post of greater than 2 in is not possible. In reality the maximum shift of a center post relative to the MCO centerline should be very small for the basket stack instability failure mode.

6 3 HORIZONTAL DROP CENTER POST BENDING

During a horizontal impact the inertial loading from the fuel and center post will induce bending stresses in the center post. If the bending stresses exceed the material yield strength, lateral deformations in the center post are possible.

Section 8 1 3 of Parsons (1999) addresses the structural adequacy of the center post for a horizontal drop using ASME Code requirements. The maximum beam bending stress occurs adjacent to the threaded connection. At that location, the bending stress is 29.5% of the ASME allowable bending stress for a 101 g horizontal drop. This results in an allowable acceleration of 101/0 295 = 342 g for the center post bending failure mode, which is well above the bounding accelerations for the K Basin horizontal drops.

6 4 CENTER POST THREAD FAILURE

The center post is threaded into the bottom plate as shown in Figure 6-1 During horizontal impact a significant bending moment will occur at the threaded connection. If the shear stresses in the threads are excessive the connection could fail and center post separation could occur

Section 8 1 3 of Parsons (1999) addresses the structural adequacy of the center post to bottom plate threaded connection for a horizontal drop using ASME Code requirements. The maximum shear stress in the threads due to a 101 g horizontal drop loading is 48% of the ASME allowable. Limiting the horizontal impact loading to the ASME stress limits results in an allowable acceleration of 101/0 48 = 210 g which is well above the bounding accelerations for the K Basin horizontal drops

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6 5 BOTTOM PLATE PLASTIC DEFORMATION

During a horizontal impact significant inertial loading is reacted through the basket bottom plates. If the combination of membrane and bending stresses in the plate exceed the material yield strength, the resulting plate deformations may result in significant lateral movement of the center post.

Horizontal impact plate deformations and potential buckling in the bottom plate are addressed in Section 8 3 4 of Parsons (1999). For a horizontal impact loading of 151 5 g a maximum bottom plate deformation of 0 51 in was predicted. No instability of the bottom plate was predicted for the 151 5 g loading. Thus, the horizontal impact capacity for the basket bottom plate can be conservatively estimated at 151 5 g. This deformation is based upon a maximum operating temperature of 270 °F. For the maximum K Basin temperature of 150 °F (FDH 1999), the material yield strength is 17% higher, which indicates that the 151 5 g capacity prediction is conservative.

The above evaluation is based upon the assumption of a 60° arc of fuel mass is effective in loading the center post. Moore (1998) conservatively assumed that entire fuel mass was reacted through the bottom plates. The predicted deceleration of the cask center of gravity was 479 g which is much higher than the predicted K Basin horizontal impact accelerations. Moore (1998) predicted lateral shift of the center post to be 1.25 in — less than the 2-in limit. Upon comparison to the results predicted by Moore (1998) the capacity predicted here is quite conservative.

6 6 CENTER POST COUPLING DISENGAGEMENT

A center post disengagement requires a sequential drop that is a vertical drop followed by a horizontal slapdown. The vertical drop magnitude must be sufficient to produce significant inelastic shortening of the MCO internals resulting in a corresponding reduction in engagement length of the top basket coupling. If the engagement reduction is sufficient basket decoupling is possible and during the horizontal impact basket rotation may result in a center post shifting in excess of the 2-in limit

As illustrated in Figure 6.1 each Mark 1A basket has a coupling nipple" which inserts into the basket above. The top basket nipple inserts into the filter guard plate as shown in Figure 6.5. From the Mark 1A drawings, the nominal engagement of the nipple into the filter guard plate is 1.65 in. Accounting for dimensional tolerances, a reasonable statistical lower bound engagement is 1.57 in.

For a vertical drop followed by a horizontal slap down there is a potential for an axial shortening of the MCO internals due to axial stress levels that exceed the material yield strength during the vertical impact. If the corresponding reduction in engagement length is sufficient it is possible that the top basket could lose its engagement with the filter guard plate and lateral displacement of the center post could increase

A review of the MCO internal vertical load path indicates that the minimum axial cross section is associated with the six basket support ribs underneath the bottom basket. A sequential drop can only occur outside the SLOP which from Section 5.1 limits the vertical drop acceleration to 52 g. From Section 5.2.

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the maximum acceleration associated with a drop outside the SLOP is 52 g Using the bounding Mark 1A basket weight of 2 400 lbf the 52 g load on the support ribs is $5(2\,400)(52) = 624\,000$ lbf From Drawing H 2 828041 Rev 1 the cross sectional area for the six basket support ribs is $6(9\,8)(0\,5) = 29\,4$ in The corresponding axial stress is $624\,000/29\,4 = 21\,200\,lbf/in^2$

It is noted that the cross sectional area of the center post and six support rods is 48 3 in which is 64% higher than the support ribs cross-sectional area. Also the support ribs carry the inertial loading from all six Mark 1A baskets compared to five baskets for the bottom basket. Thus the maximum axial load is controlled by the support ribs and the significant plastic strains should be limited to the support ribs

The basket support ribs are fabricated from SA-240 304L stainless steel which has a minimum yield strength of 23 200 lbf/in² at the maximum K Basin operating temperature of $150^{\circ}F$ Considering some dynamic amplification of the predicted axial stress of 21 200 lbf/in² some inelastic shortening of the basket support plates is possible. As indicated in Figure 6.1 the coupling nipple has a 0.45 in chamfer at the top end. It is assumed that disengagement will not occur if the chamfer remains inside the guard plate. This results in an axial shortening limit of 1.57 - 0.45 = 1.12 in. The support ribs are only 1.24 in high. Thus the rib plates would have to be almost totally flattened to achieve a 1.12 in height reduction. The corresponding area increase plus material strain hardening would increase the load resistance and prevent a 1.12 in height reduction.

Eccentric loading on the support ribs may result in some twisting action in the ribs which raises the possibility of rib support instability (rolling action). However even if this occurs the ribs are 0.5 in thick and the height reduction is 1.25 - 0.5 = 0.75 in which is less than the 1.12 in limit. Thus, disengagement due to support rib shortening is not physically possible.

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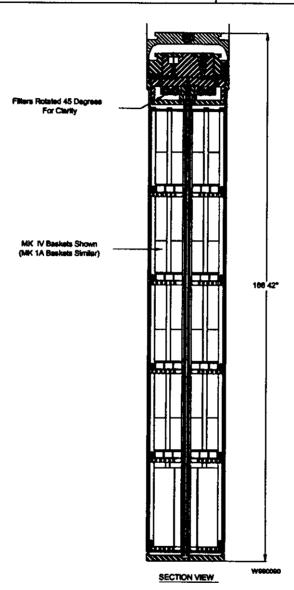


Figure 6 5 MCO and Basket Configuration

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67 CENTER POST COUPLING SHEAR FAILURE

As indicated in Figure 6.1 the minimum cross section of the center post occurs in the coupling nipple just above the top shoulder of the center post. For a horizontal impact significant inertial loading is reacted through this minimum cross section potentially allowing for a shear failure in the coupling. A coupling failure is a possible mechanism for a center post movement above the 2 in design requirement.

From Section 5 3 the bounding horizontal acceleration in the K Basin area is 52 g. Assuming a fuel loading over a 120° arc (corresponding to 16 39 7 lbf fuel elements) results in a 1 g fuel inertial loading of (16)(39 7) = 635 lbf. The corresponding center post inertial 1 g loading is

$$F_{cpost} = \frac{\pi[(6.625)^2 - (1.75)^2]}{4}(21.7)(0.294) = 204 \text{ lbf}$$

The minimum cross sectional area in the coupling is

$$A_{\min} = \frac{\pi[(2.645)^2 - (2.035)^2]}{4} = 2.24 \text{ m}^2$$

From Section 8 1 4 of Parsons (1999) the ASME allowable shear stress for a drop accident is 42% the ultimate tensile strength of the material. At the maximum K Basin operating temperature of 150°F, the minimum ultimate strength of the center post material is 68 100 lbf/in² resulting in a shear allowable of 28 600 lbf/in². Conservatively assuming that half of the inertial loading is carried by the center post connection to the basket bottom plate (bottom end of center tube has moment resistance), the allowable acceleration for this mechanism is

$$g_{allow} = \frac{28,600(2\ 24)}{(635+204)/2} = 153\ g$$

It is noted that the bottom basket interfaces with the rib support plates at the bottom of the MCO which also has a coupling nipple. However, if this nipple fails, the bottom plate of the bottom basket would maintain the center post position.

6 8 LOOSE SHIELD PLUG

For the initial cask lift up to the Immersion Pail pin installation the MCO shield is not secured. If a drop occurred prior to securing the shield plug, the MCO contents could bounce upward following impact. If the relative motion during the bounce is high enough, a center post coupling nipple could become disengaged. If a relative lateral shift at the disengaged joint occurs during the bounce, re-engagement might not occur.

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A qualitative evaluation of the mechanism described above indicates that this mechanism is not a credible issue relative to the acceptability of the criticality design features for the following reasons

- 1) The process tube connected to the bottom of the shield plug passes through all of the baskets and will help keep them lined up
- 2) The coupling nipple is tapered at the end and thus encourages re engagement
- 3) The inertial loading is vertical implying that lateral loading and associated lateral shifting should be minimal
- 4) Even if re engagement does not occur the two criticality limits can not be exceeded unless a basket bounces clear out of the MCO and dumps fuel back into the MCO which is not credible

69 CENTER POST LATERAL SHIFT EVALUATION CONCLUSIONS

From the above evaluations of the potential mechanisms which could result in center post lateral shifts the critical mechanism for a horizontal impact is shear failure of the center post coupling nipple (153 g capacity). The bottom plate deformation failure mode capacity was slightly lower (151 5 g) but as indicated in the discussion this capacity estimate is very conservative. From Section 5 3, the estimated bounding horizontal impact acceleration is 52 g. The resulting capacity/load ratio is 2.9. Although there are significant uncertainties in the above evaluation, the magnitude of the margins supports the conclusion that the 2 in criticality design requirement is met for all drops involving horizontal impacts.

For mechanisms involving vertical drops (mechanisms 1 and 5 Table 6-1) the critical drop is the vertical drop into the SLOP

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7 0 RESOLUTION OF M CO CIRCUMFERENCE INCREASE CRITICALITY LIMIT

As discussed in Section 3.2 criticality considerations require that the MCO shell inside circumference cannot exceed 73.04 in. This circumference limit corresponds to a 0.265 in. diameter increase and applies to both the Mark 1A and Mark IV baskets. Based upon a review of the vertical and horizontal MCO cask drop analyses the critical mechanism for increasing the circumference of the MCO shell is fuel rubble pressure imposed by a failure of the bottom Mark IV basket during a vertical drop. Since the Mark IV basket center post is not designed for drop loading, it is assumed that the bottom basket and fuel can fail during a vertical drop. The inertial loading from the four baskets above is applied to the top of the crushed bottom basket. The inertial loading from the baskets above and the fuel rubble is transmitted to the MCO shell due to the fluid nature of the fuel rubble.

The fuel rubble pressure on the MCO shell is addressed for a 54 g loading in Section 9 4 2 of Parsons (1998) A similar calculation is performed for a Mark 1A scrap basket in Section 8 4 of Parsons (1999) In these calculations the fuel rubble is assumed to have an internal friction angle (soil/gravel type property) of 33° which is the minimum angle for iron ore coal and limestone. The corresponding equivalent fluid pressure coefficient is 0.3 meaning that the horizontal pressure is 30% of the vertical pressure on the bottom of the MCO cylinder. From Section 5.1 the maximum vertical drop acceleration for K Basin is 87 g. If the ratio of the peak fuel pressure from Parsons (1998) (717 lbf/in²) to the peak pressure for the 87 g K Basin drop is calculated the resulting pressure is 717(87/54) = 1155 lbf/in²

It is noted that the 87 g vertical loading is associated with a rigid missile assumption. Failure of the bottom basket would be expected to significantly reduce the g levels for the top four Mark IV baskets. Also it is unlikely that the fuel damage would be sufficient to cause the damaged fuel to flow and induce high fluid pressures at the inside surface of the MCO cylinder. Thus, it is likely that the $1155 \, lbf/in^2$ pressure is very conservative.

A conservative estimate of the stress and deformation associated with a linearly varying pressure on the MCO cylinder can be obtained from Table 28 Case 1d from Young (1989) The maximum hoop stress associated with the fuel pressure is

$$\sigma_2 = \frac{qR}{t} = \frac{1155(22\,985/2)}{0\,5} = 26,548\,\text{lbf/in}^2$$

where q = peak pressure R = shell inside radius and t = the cylinder wall thickness

For the maximum K Basin temperature of 150°F the minimum yield strength of the MCO shell SA 240 304 SS material is 27 500 lbf/in² (Table 3 Parsons [1999]) Because the hoop stress is less than the material yield strength the associated diameter increase is small

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$$\Delta D = 2 \ \Delta R = 2 \frac{qR^2}{Et} = 2 \frac{1155(22.985/2)^2}{28.0 \ 10^6 (0.5)} = 0.022 \text{ in}$$

where q = peak pressure R = shell inside radius E = material elastic modulus and t = wall thickness

Because the diameter increase is less than 0 265 in the criticality design requirement is satisfied. The above static analysis is based upon the assumption that the dynamic load factor is equal to 1 0. The validity of this assumption is addressed below.

The dynamic load factor associated with the drop pressure is a function of the natural period of the structure relative to the duration of the load. The natural period of interest is the breathing mode of the MCO cylinder. From Table 12-1. Case 2 of Blevins (1995), the natural frequency of the cylinder is

$$f_o = \frac{\lambda_o}{2\pi R} \left[\frac{E}{\mu (1 - v^2)} \right]^{1/2} = \frac{1}{2\pi (11.75)} \left[\frac{28.0 \cdot 10^6}{(0.284/386.4)(1 - 0.3^2)} \right]^{1/2} = 2770 \text{ Hz}$$

where $\lambda =$ mode coefficient R = shell mean radius $\mu =$ material density material elastic modulus and $\nu =$ material Poisson's ratio The corresponding natural period T is $1/2770 = 3.61 \times 10^{-4}$ sec

From Figure 5-2 the duration of loading t₁ is 0 044 sec resulting in a t₁/T ratio of 120 From Figure 4 5 3 Thomson (1972) the dynamic load factor is 1 0 Thus the dynamic load factor assumed above is reasonable

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APPENDIX A

TARGET HARDNESS CALCULATIONS

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Calculation of Target Hardness for Vertical Cask Drop onto 22 5 in Thick Rail Slatz

Material and Geometric Parameters

 $\sigma_{\rm u} = 4500$

concrete ultimate strength (1 5 times design strength)

$$E_c = 57000 \sqrt{\sigma_u}$$

$$E_c = 382410^6$$

concrete elastic modulus

$$E_{S} = 30000$$

soil elastic modulus upper bound for a sand/gravel mix per

Bowles (1988) Table 2 7

$$v_c = 0.17$$

Poisson's ratio of concrete

$$v_s = 0.45$$

Poisson's ratio of soil

$$r_{end} = 20$$

cask radius

$$A_{end} = \pi r_{end}^2$$

$$A_{end} = 125710^3$$

cask footprint for end drop

$$W = 62000$$

cask weight

$$h = 225$$

concrete slab thickness

$$k_{end} = \frac{\pi E_s}{\left(1 - v_s^2\right)}$$

soil foundation modulus

$$D_{c} = \frac{E_{c} h^{3}}{12 \left(1 - v_{c}^{2}\right)}$$

concrete slab flexural rigidity

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$$\beta_{\text{end}} = \left(\frac{E_s}{4 D_c}\right)^{\frac{1}{4}}$$

$$\beta_{\text{end}} = 0.03$$

Concrete Moment Capacity

coverdepth = 3.0

rebar cover depth

 $r_{rebar} = 0.3125$

radius of #5 rebar

 $d = h - coverdepth - r_{rebar}$ d = 19 187

distance from rebar to top fiber of slab

A s =0 31 rebar area per unit width of slab

 $f_y = 40000$ rebar yield strength

b = 12

unit width of concrete slab

$$a = \frac{f_y A_s}{0.85 \sigma_u b} \qquad a = 0.27$$

$$M_u = f_y A_s \left(d - \frac{a}{2}\right)$$
 $M_u = 236310^5$

$$M_{\rm u} = 236310^5$$

ultimate moment capacity

$$S_{end} = \frac{2 r_{end} A_{end} k_{end} M_{u} \sigma_{u}}{W^{3} \left(1 - e^{-\beta_{end} r_{end}} \cos \left(\beta_{end} r_{end}\right)\right)}$$

target hardness for end drop

 $S_{end} = 4.03810^4$

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Calculation of Target Hardness for Cask Side Drop onto 22 5 in Thick Rail Slate

 $r_{edge} = 5$ set width of footprint to 10 in which is conservative per EPRI (1993)

$$A_{edge} = 2 r_{edge} L_{cask}$$

$$k_{edge} = E_s$$

$$I_c = \frac{L_{cask} h^3}{12}$$

$$I_c = 151910^5$$

$$\beta_{\text{edge}} = \left(\frac{E_{\text{S}}}{4 E_{\text{C}} I_{\text{C}}}\right)^{\frac{1}{4}}$$

$$\beta_{\text{edge}} = 0.011$$

$$S_{\text{edge}} = \frac{2 A_{\text{edge}} E_{\text{S}} M_{\text{u}} \sigma_{\text{u}}}{W^3 \beta_{\text{edge}}}$$

$$S_{\text{edge}} = 4.017 \cdot 10^4$$

$$S_{\text{edge}} = 401710^4$$

References

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EPRI 1993 Structural Design of Concrete Storage Pads for Spent Fuel Casks EPRI NP-7551 Electric Power Research Institute Palo Alto California

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APPENDIX B

FINITE ELEMENT INPUT FILE LISTINGS

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36-Foot Drop into SLOP

```
/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 4
         rigid link
et 5 39 1 3
               'nonlinear spring(foam)
et 6 21 2
et 7 14 3
               'impacting mass element
               dashpot
real constants
r 1 17 75 300 'West Pit Wall
          n
               'Remaining Pit Walls
r 2 16
r 3 27
          300
                  Basın Walls
r 4 21
                  'Pit Floor
          300
r 5 24
          300
                  'Basın Floor/Pit E Wall (bottom)
r 6 18
          300
                  'Sump Bottom Thickness
                 ∣#5 rebar
r 7 0 31
r 8 0 60
                 #7 rebar
r 9 17
                 'rigid plate floor/wall conn
r 10 1e9
                 'gap element spring
r 11 1e8
           0 0 17965 pit walls friction
r 12 1e8
         11700
                      'basın/channel walls friction
                  'impacting mass (70 000 lbs )
r 13 181 2
r 14 2 5e5 5778 'impact gap element
r 15 0 6545
               'impact dashpot element constant
r 16 10 1000 1000 10 10 1000
                                'rıgıd lınk
r 17 0 0 085 450000 2 5 450000
rmore 3 5 1 4e6 4 4e6 'nonlinear spring (39)
'material prop
|concrete
mp ex 1 4 4e6
mp nuxy 1 0 2
mp dens 1 000225
'rebar elas /plas
mp ex 2 29e8
mp nuxy 2 0 3
Tb Bkin 2 1
Tbdata 1 56e3 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
mp dens 4 000225
Tb Bkin 4 1
Tbdata 1 457 8e5
                 'pseudo yield strength floor eles
n 1 0 0 0
n 3 9 32
f111
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
```

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```
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
f111
n 218 58 48 75
n 222 82 48 75
f111
fill 126 218 3
fill 130 222 3
 n 103 57 93 20 7
'n 107 82 2 20 7
'f111
n 241 57 6 56 2
n 245 83 4 56 2
fill
'generate floor elements
real 4
type 1
mat 1
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
```

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```
ngen 2 700 141 509 46
                          8 15
ngen 2 700 143 511 46
ngen 2 700 157 525 46
                          8 15
                          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
type 2
mat 2
e 49 749
egen 10 2 -1
e 95 795
egen 10 2 -1
e 141 841
egen 9 46 -1
e 143 843
egen 9 46 -1
e 157 857
egen 9 46 -1
e 159 859
egen 9 46 -1
e 555 1255
egen 10 2 -1
e 624 1324
egen 10 2 -1
type 1
mat 1
'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 8 15
k 7 114 15 88 8 15
k 8 128 15 88
k 9 0 147
k 10 14 147 8 15
k 11 37 5 147 8 15
k 12 89 0 147 8 15
k 13 114 147 8 15
k 14 128 147 8 15
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

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```
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 8 15
k 40 89 0 15 88 8 15
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
'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
a 10 6 21 23
a 13 7 22 26
```

a 29 27 59 63

Page No **B10** Professional M&D **B6 CALCULATION SHEET** Services Calculation No 99-024 Client / Location Prepared By / Date Fluor Daniel Hanford B V Winkel 1/18/00 Revision No Checked By / Date Evaluation of Cask Drop Criticality Issues at K Basin F G Abatt 1/18/00 Supporting Document No Ref Drawing(s) Revised By / Date SNF-5557 H 2-828060 Rev 2 H 2 828041 Rev 3

```
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
1sel s loc z 8 15
'lesize all 6 5
alls
esize 13
amesh 16 48
'amesh 16 18
lamesh 22 23
amesh 39 41
aclear 19 21
aclear 24 38
aclear 42 48
'wall/floor connection plates
real 9
mat 3
e 749 751 1345 1344
e 751 753 1343 1345
e 753 755 1365 1343
e 755 757 1364 1365
e 757 759 1363 1364
e 759 761 1362 1363
e 761 763 1361 1362
e 763 765 1392 1361
e 765 767 1391 1392
e 795 749 1344 1344
e 841 795 1344 1434
```

M&D Professional Services	CALCULATION SHEET		Page No of B7 B10 Calculation No
Client / Location Fluor Daniel Hanford		Prepared By / Date B V Winkel 1/18/00	99 024 Revision No
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Ref Drawing(s) H-2-828060 Rev 2 H 2-828041 F	Rev 3	Revised By / Date	Supporting Document No SNF 5557

```
e 887 841 1434 1435
e 933 887 1435 1436
e 979 933 1436 1437
e 1025 979 1437 1438
e 1071 1025 1438 1439
e 1117 1071 1439 1440
e 1163 1117 1440 1441
e 1209 1163 1441 1442
e 1255 1209 1442 1443
e 1255 1443 1433 1324
e 1326 1324 1433 3328
e 1328 1326 3328 3327
e 1330 1328 3327 3341
e 1332 1330 3341 3340
e 1334 1332 3340 3339
e 1336 1334 3339 3338
e 1338 1336 3338 3337
e 1340 1338 3337 3366
e 1342 1340 3366 1499
e 1273 1342 1499 1509
e 1273 1509 1508 1227
e 1227 1508 1507 1181
e 1181 1507 1506 1135
e 1135 1506 1505 1089
e 1089 1505 1504 1043
e 1043 1504 1503 997
e 997 1503 1502 951
e 951 1502 1501 905
e 905 1501 1500 859
e 859 1500 1391 813
e 767 813 1391 1391
e 1344 1345 797 797
e 1345 1343 799 797
e 1343 1365 801 799
e 1365 1364 803 801
e 1364 1363 805 803
e 1363 1362 807 805
e 1362 1361 809 807
e 1361 1392 811 809
e 1392 1391 811 811
e 1344 797 843 1434
e 1434 843 889 1435
e 1435 889 935 1436
e 1436 935 981 1437
e 1437 981 1027 1438
e 1438 1027 1073 1439
e 1439 1073 1119 1440
e 1440 1119 1165 1441
e 1441 1165 1211 1442
e 1442 1211 1257 1443
e 1443 1257 3328 1433
e 1257 1259 3327 3328
e 1259 1261 3341 3327
e 1261 1263 3340 3341
e 1263 1265 3339 3340
e 1265 1267 3338 3339
e 1267 1269 3337 3338
e 1269 1271 3366 3337
e 1271 1509 1499 3366
e 1271 1225 1508 1509
e 1225 1179 1507 1508
```

e 1179 1133 1506 1507

Page No Professional B10 **B8 CALCULATION SHEET** Services Calculation No 99-024 Client / Location Prepared By / Date Fluor Daniel Hanford B V Winkel 1/18/00 Revision No Subject Checked By / Date Evaluation of Cask Drop Criticality Issues at K Basin F G Abatt 1/18/00 Supporting Document No Ref Drawing(s) Revised By / Date SNF 5557 H-2 828060 Rev 2 H 2 828041 Rev 3

```
e 1133 1087 1505 1506
e 1087 1041 1504 1505
e 1041 995 1503 1504
e 995 949 1502 1503
e 949 903 1501 1502
e 903 857 1500 1501
e 857 811 1391 1500
'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
n 4192 38 251 45 012 6
n 4200 89 749 45 012 6
n 4330 38 251 79 998 6
n 4338 89 749 79 998 6
'impacting mass
n 4400 64 62 5 6
n 4401 64 62 5 12
type 6
real 13
e 4400
            mass
type 3
real 14
type 5
real 17
e 4400 4401
              'nonlinear spring (impact limiter)
type 3
real 14
e 192 4192
              'gap elements
e 200 4200
e 330 4330
e 338 4338
type 7
real 15
e 192 4192
             dashpots
e 200 4200
e 330 4330
e 338 4338
type 4
real 16
e 4192 4400 |rigid links
e 4200 4400
e 4330 4400
e 4338 4400
          0 126685636958
                               -0 479200338424E-01 0 990784749451
/VIEW 1
/ANG
       1
          -61 5345416226
eplo
'Water Pressure Loading
esel s real 4
nsle
```

Page No M&D Professional **B9** B10 **CALCULATION SHEET** Calculation No 99-024 Client / Location Prepared By / Date Fluor Daniel Hanford B V Winkel 1/18/00 **Revision No** Subject Checked By / Date Evaluation of Cask Drop Criticality Issues at K Basin F G Abatt 1/18/00 Supporting Document No Ref Drawing(s) Revised By / Date **SNF 5557** H 2 828060 Rev 2 H 2-828041 Rev 3

```
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 75
                        'pit floor water pressure
alls
nsel s loc z 62 9 63 1
           ux uz
d all uy
nsel s node 4000 4500
d all ux
            uу
nall
d 1 ux
           uy
d 23 uy
fini
/solu
antype trans
outres all all
timint off
d 4400 uz - 5778
d 4400 ux
d 4400 uy
time 0 001
                'initial veloc
nsubst 4
solve
ddel 4400 uz
timint on
time 05
'solcon off
autots on
deltim 00005 00001 001
'deltim 00005
solve
fını
/post26
nsol 2 4400 u z uzmass
deriv 3 2 1 vzmass
deriv 4 3 1 azmass
                      00259
plvar 4
```

Center Post Buckling Analysis

```
fını
/clear
/output postbuck out
/prep7
/title Center Post Inelastic Buckling
'element types
et 1 20
           'Plastic Pipe
real constants
r 1 6 625 2 438
                 ¹Center Pipe
r 2 1
           cask thickness
'material prop
mp ex 1 28 3e6
mp nuxy 1 0 3
mp dens 1 0 284 | wt /in^3
Tb Bkin 1 1
Tbdata 1 41 25e3 5e5
```

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```
Nodes
n 1 0 0 0
n 11 21 7
f111
e 1 2
egen 10 1 -1
/VIEW 1 -1
/ANG 1
eplo
fini
/solu
d 1 all
d 11 ux
d 11 ux
d 11 uy
/title 87 g s 3 0 Offset
acel 87 '87 g vertical
f 11 fz -1 044e6
f 11 my 3 12e6 '3 0 load offset
nsubst 100
outres all 1
outres all 1
nlgeom on
solve
fını
/post1
SET LAST
PLNSOL U X 0 1
```