2. To: (Receiving Organization) Technical Operations	3. From: (Originating Organization) CSB Project	4. Related EDT No.: N/A
5. Proj./Prog./Dept./Div.: SNF Project	6. Design Authority/Design Agent/Cog. Engr.: G.D. Bazinet/L.H. Goldmann	7. Purchase Order No.: N/A
8. Originator Remarks: For release		9. Equip./Component No.: MCO
		10. System/Bldg./Facility: CSB
		12. Major Assem. Dwg. No.: N/A
11. Receiver Remarks: <div style="text-align: right;">11A. Design Baseline Document? ☐ Yes ☒ No</div>		13. Permit/Permit Application No.: N/A
		14. Required Response Date: N/A

15. DATA TRANSMITTED					(F)	(G)	(H)	(I)
(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	Approval Designator	Reason for Transmittal	Originator Disposition	Receiver Disposition
1	SNF-5204	all	0	Analysis for Eccentric	S	/	/	/
	(CSB-S-0073)			Multi-Canister Overpack				
				Drops at the Canister				
				Storage Building				

16. KEY		
Approval Designator (F)	Reason for Transmittal (G)	Disposition (H) & (I)
E, S, Q, D OR N/A (See WHC-CM-3-5, Sec. 12.7)	1. Approval 2. Release 3. Information 4. Review 5. Post-Review 6. Dist. (Receipt Acknow. Required)	1. Approved 2. Approved w/comment 3. Disapproved w/comment 4. Reviewed-no/comment 5. Reviewed w/comment 6. Receipt acknowledged

17. SIGNATURE/DISTRIBUTION (See Approval Designator for required signatures)									
(G) Reason	(H) Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN	(G) Reason	(H) Disp.	(J) Name	(K) Signature
/	/	Design Authority	G.D. Bazinet	10/7/99	S8-06	/	/	L.H. Goldmann	R3-86
		Design Agent	N/A						
		Cog. Eng.	N/A						
/	/	Cog. Mgr.	A.S. Daughtridge	10/7/99	R3-86				
		QA	N/A						
/	/	Safety	R. L. Garrett	10/7/99	R3-26				
		Env.							

18. T.B. Bergman Signature of EDT Originator	19. J.A. Swenson Authorized Representative for Receiving Organization	20. A.S. Daughtridge Design Authority/Cognizant Manager	21. DOE APPROVAL (if required) Ctrl No. N/A ☐ Approved ☐ Approved w/comments ☐ Disapproved w/comments
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ANALYSIS FOR ECCENTRIC MULTI-CANISTER OVERPACK DROPS AT THE CANISTER STORAGE BUILDING (CSB-S-0073)

K.C. Tu/R.G. Hollenbeck
Fluor Daniel Northwest
Richland, WA 99352
U.S. Department of Energy Contract DE-AC06-96RL13200

EDT/ECN: 627587 UC: 510
Org Code: 2G200 Charge Code: 105626/B000
B&R Code: EW7040000 Total Pages: 142

Key Words: Drop Analysis, CSB, MCO, SNF

Abstract: Multi-Canister Overpacks (MCOs) containing spent nuclear fuel (SNF) will be routinely handled at the Canister Storage Building (CSB) during fuel movement operations in the SNF Project. This analysis was performed to investigate the potential for damage from an eccentric accidental drop onto the standard storage tube, overpack tube, service station, or sample/weld station. Appendix D was added to the FDNW document to include the peer Review Comment Record & transmittal record.

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Release Approval Date

Approved For Public Release

ENGINEERING REPORT

**ANALYSIS FOR
ECCENTRIC MULTI-CANISTER OVERPACK DROPS
AT THE CANISTER STORAGE BUILDING**

**FLUOR DANIEL HANFORD, INC.
RICHLAND, WA**

SPENT NUCLEAR FUEL PROJECT

CONTRACT 80460210 1800

September 1999

**K. C. Tu
R. G. Hollenbeck
Fluor Daniel Northwest, Inc.**

EXECUTIVE SUMMARY

The Spent Nuclear Fuel (SNF) Canister Storage Building (CSB) is the interim storage facility for the K-Basin SNF at the U.S. Department of Energy (DOE) Hanford Site. The SNF is packaged in multi-canister overpacks (MCOs). The MCOs are placed inside transport casks, then delivered to the service station inside the CSB. At the service station, the MCO handling machine (MHM) moves the MCO from the cask to a storage tube or one of two sample/weld stations. There are 220 standard storage tubes and six overpack storage tubes contained in a below grade reinforced concrete vault. Each storage tube can hold two MCOs.

The purpose of this report is to investigate the potential for damage to the MCO during impact from an eccentric accidental drop onto the standard storage tube, overpack tube, service station or sampling/weld station.

The MCO impacts a 45° inclined surface on the lower flange at both the standard storage tube and the overpack storage tube. The standard storage tubes have a smaller gap between the tube and the embedment than the overpack tubes. This limits the tube lateral displacements to a lower value, which means that during a drop more force would be transferred to the MCO causing more potential for damage. Therefore, the standard storage tube was selected to represent the drop for both locations.

The shielding rings at the service and sampling/weld station are fixed in place and do not move during impact. The inclinations of the impact surfaces of the shielding rings have been reduced from 45° to 15° from vertical to reduce the impact damage to the MCO. The temporary shielding at the sampling/weld station is less massive than the shield hatch ring at the service station and will cause less damage to the MCO from an accidental drop. Therefore, the receiving service station pit has been chosen to represent the drop for both locations.

The maximum equivalent plastic strain is 40 to 45% and occurs on the MCO bottom near the point of impact and is compressive (negative triaxiality factor). Some gouging may occur but since the compressive failure strain for the base metal is above 80%, it is not likely that through the wall cracking will occur, however removal of local surface metal may occur.

The maximum predicted equivalent plastic strain at the MCO lower weld is about 2%, during the drop onto the standard storage tube. This is well below the weld metal failure strain of 10% with a triaxiality factor of greater than 2. The maximum tensile principal strain is in a radial direction, therefore, any failure would be by spalling or flaking rather than through-wall cracking.

The deceleration of the MCO baskets are shown to be about 20 g or less, well within the design allowable of 35 g.

The deformations of the MCO and standard storage tube are less than the tube clearance, therefore, no wedging of the MCO in the tube is expected.

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Expert Panel Report

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- B Stress-Strain Triaxiality Factor Calculations
- C Computer Input Files
 - C-1 ABAQUS Input File Section One, MCO Drop on Standard Storage Tube
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ACRONYM LISTING

CSB	Canister Storage Building
DESH	Duke Engineering & Services Hanford, Inc.
DOE	U. S. Department of Energy
FDNW	Fluor Daniel Northwest
MCO	Multi-canister overpack
MHM	MCO handling machine
QA	Quality Assurance
SNF	Spent Nuclear Fuel

ENGINEERING REPORT

ANALYSIS FOR ECCENTRIC MULTI-CANISTER OVERPACK DROPS AT THE CANISTER STORAGE BUILDING

1.0 INTRODUCTION

The Spent Nuclear Fuel (SNF) Canister Storage Building (CSB) is the interim storage facility for the K-Basin SNF at the U.S. Department of Energy (DOE) Hanford Site. The SNF is packaged in multi-canister overpacks (MCOs). The MCOs are placed inside transport casks, then delivered to the service station inside the CSB. At the service station, the MCO handling machine (MHM) moves the MCO from the cask to a storage tube or one of two sample/weld stations. There are 220 standard storage tubes and six overpack storage tubes in a below grade reinforced concrete vault. Each storage tube can hold two MCOs.

2.0 OBJECTIVE

The purpose of this report is to investigate the potential for damage to the MCO during impact from an eccentric accidental drop onto the standard storage tube, overpack storage tube, service station or sampling/weld station. Damage to the storage tube and sample/weld station is beyond the scope of this report. The results of this analysis are required to show the following;

- If a breach resulting in unacceptable release of contamination could occur in the MCO.
- If the dropped MCO could become stuck in the storage tube after the drop.
- Maximum deceleration of the spent nuclear fuel baskets.

3.0 SUMMARY AND CONCLUSIONS

The maximum equivalent MCO strain is 40 to 45% and occurs on the MCO bottom near the point of impact and is compressive (negative triaxiality factor). Some gouging may occur but since the compressive failure strain is above 80% for the base metal, it is not likely that through the wall cracking will occur but removal of local surface metal may occur.

The maximum predicted equivalent plastic strain at the MCO lower weld is about 2%, during the drop into the standard storage tube. This is well below a 42% failure strain for a negative triaxiality factor. The maximum tensile principal

strain is in a radial direction, therefore, any failure would be by spalling or flaking rather than through-wall cracking.

The maximum deceleration of the MCO baskets is about 20 g or less, well within the design allowable of 35 g.

The deformations of the MCO and target assembly are less than the tube clearance, therefore, wedging of the MCO in the tube is not expected.

The analyses of the standard and overpack storage tube assemblies have been studied in References 1 and 2. However, the strains found in this report are in agreement with previous analyses and no rupture or through wall cracking is anticipated.

4.0 EXPERT PANEL

An expert panel was assembled to oversee this report to verify that appropriate inputs, methods, and assumptions were used and to ensure the findings of this report would be available in a timely manner. The panel was made up of the following members.

• L. D. Blackburn	Metallurgy
• R. D. Crow	Safety Analysis
• L. H. Goldmann	MCO Design Authority
• R. P. Kennedy	Structural Analysis
• L. K. Severud	Engineering Management & Structural Analysis

The expert panel report is included as an attachment to this report.

5.0 DESCRIPTION

Four eccentric MCO drops from the MHM in the CSB are studied in this report. The drops occur at the following locations:

- Standard storage tube assembly
- Overpack storage tube assembly
- Service station
- Sampling/weld station

The MCO is constructed of stainless steel and measures approximately 24 inches in diameter by about 13 feet in length as shown in Figure 5.1 as the shell assembly. The MCOs are maneuvered inside the CSB by the MCO handling machine (MHM). The MCO impacts a 45° inclined surface on the lower flange at both the standard storage tube and the overpack storage tube. The damage to the tube assembly has been studied in References 1 and 2. The standard

storage tubes have a smaller gap (1/2") between the tube and the embedment than the overpack tubes (1"). This limits the tube lateral displacements to a lower value, which means that during a drop more force would be transferred to the MCO causing more potential for damage. Therefore, the standard storage tube was chosen to represent the drop for both locations. The standard storage tube is 28 inches in diameter and approximately 40 feet long and is shown in Figure 5.2. A sketch of the drop onto the standard storage tube is shown in Figure 5.3.

The shielding rings at the service and sampling/weld station are fixed in place and do not move during impact. The inclinations of the impact surfaces of the shielding rings have been reduced from 45° to 15° from vertical to reduce the impact damage to the MCO. The temporary shielding ring at the sampling/weld station is supported on steel posts from the base of the pit. The service station shield hatch ring is more rigidly supported directly on the floor embedment and is more massive than the sampling/weld station shielding ring. A drop on this more rigid and massive ring would cause more damage to the MCO from an accidental drop. Therefore, the service station was chosen to represent the drop for both locations. A sketch of the drop onto the service station is shown on Figure 5.4.

Each MCO has the capacity to contain six Mark 1A baskets (see Figure 5.5) or five Mark IV baskets loaded with fuel pins. The baskets are stacked one on top of the other. At the bottom of the MCO are 6 basket support plates (ribs) in a radial arrangement. These 6 ribs support the entire basket stack. The loaded baskets make up about 70% of the total MCO weight.

5.1 Drop Parameters at Standard Tube Assembly

Loaded MCO weight, without cap	20,000 lbf
Drop height	90 inches
Drop velocity	263.7 in/sec
Kinetic energy at impact	1,800,000 in-lbf
Point of impact	45° inclined surface of lower flange
Impact distance from inside face of standard tube assembly	2.75 inches
MHM off center dimension	1 inch
Drop angle	2°21'

5.2 Drop Parameters at Service Station

Loaded MCO weight, without cap	20,000 lbf
Drop height	90 inches
Drop velocity	263.7 in/sec

Kinetic energy at impact	1,800,000 in-lbf
Point of impact ring	15° inclined surface of shield hatch
Impact distance from top inside face of opening	1.58 inches
MHM off center dimension	3.63 inches
Drop angle	1°40'

5.3 MCO Physical Properties

Wall thickness	0.5 inches
Bottom thickness	2.01 inches
Outside diameter	24.0 inches
Outside diameter at head	25.3 inches

5.4 Standard Storage Tube Physical Properties

Lower flange thickness	3.5 inches
Slope of lower flange sealing surface	45° from vertical
Tube inner diameter	27 inches
Wall thickness	0.5 inches

5.5 Service Station Physical Properties

Shield hatch ring thickness	10 inches
Slope of shield hatch ring	15° from vertical

5.6 Material Properties

The MCO is constructed from 304L stainless steel while the storage tubes are constructed from ASTM A36 steel. The stress-strain curves for these steels are dependent on the applied strain rate. Stress-strain data for a strain rate of 60 inch/inch per second (maximum strain rate observed in an earlier computer run) was calculated (Appendix A) and is plotted on Figures 5.6 and 5.7 along with the normal stress-strain curve for 304L and A36 steel, respectively.

The material properties for the MCO and storage tubes are as follows:

MCO MATERIAL

304L stainless steel

(Ref. Drawing no. H-2-828043)

Elastic modulus

28,000,000 psi

Poisson ratio

0.27

STANDARD TUBE ASSEMBLY
MATERIAL

ASTM A36

Elastic modulus

29,500,000 psi

Poisson ratio

0.27

Figure 5.1. Multi-canister Overpack Shell Assembly

Figure 5.2. Standard Storage Tube.

Figure 5.3. MCO, MHM and Storage Tube at Time of Impact.

Figure 5.4. MCO Drop at Service Station.

Figure 5.5. Mark 1A Fuel Pin Basket.

Figure 5.6. True Stress-Strain Curves for 304SS Steel.

Figure 5.7. True Stress-Strain Curves for SA36 Steel.

6.0 ANALYSIS APPROACH AND ASSUMPTIONS

A finite element computer model is utilized to simulate the MCO impact analysis. The MCO, the standard storage tube assembly and the shielding ring are explicitly modeled so that elastic and plastic strains for both assemblies can be computed to characterize the reactive forces and energy absorption during impact.

The high strain rate material property was used to study the damage at the bottom of the MCO. The strain rate capability of the ABAQUS/Explicit program was not used because it would significantly increase the computer run time.

6.1 Computer Program

Industry-accepted, quality assurance (QA) approved and efficient computer analysis codes are required to perform sophisticated nonlinear dynamic finite-element analyses. The ABAQUS/Explicit computer program was selected for this analysis. ABAQUS/Explicit is a well-documented and proven finite-element program. It is a general-purpose finite-element analysis program, which has been used in the nuclear industry for decades. The program has an extensive element library. Nonlinear geometry (contact surfaces, sliding surfaces and large deflections), nonlinear material properties (plasticity and strain hardening), and explicit time integration are specific options that make the program ideal for evaluation of nonlinear dynamic impact evaluations. Contact surfaces allow free movement of two adjacent nontouching surfaces but preclude penetration of one contact surface into another. Sliding surfaces allow free movement of two adjacent nontouching surfaces but resist movement if the two surfaces are in contact. Friction forces that are determined by normal forces and prescribed friction coefficients model the resistance. The program comes with a well-documented theoretical manual and verification manual. The program has an error reporting system available through the Internet. ABAQUS/Explicit has extensive preprocessing, and graphics capabilities.

ABAQUS/Explicit has previously been used to simulate the puncture-drop tests and drop tests on SNF canisters. Actual test drops were set up and performed to determine how well the simulated drop results and the actual drop results matched. Evaluations of the drop simulations and actual drops are found in References 13 and 14. There was a good match in deformations of the actual dropped canister to those calculated in the model, with the model generally overpredicting the deformations. The model was very good in simulating the actual dropped canister response.

ABAQUS/Explicit has been verified and validated through the FDNW QA program. ABAQUS/Explicit is currently maintained in accordance with these requirements. Use of the program at FDNW is restricted to authorized users administered by the FDNW software administrator. ABAQUS/Explicit version 5.8-10 is used in this analysis

6.2 Computer Simulation

Two computer runs using the comprehensive finite-element model were used to determine the effect of an MCO drop onto a standard storage tube assembly for the material properties (nominal and maximum strain rate stress-strain curves) and geometry parameters listed in Section 5.0. Another computer run was performed for the MCO drop at the service station using the nominal strain rate stress-strain curves (without considering the high strain rate effect).

Coefficients of friction for various materials are given in Reference 3. Sliding coefficients for mild steel on medium steel varied from 0.53 to 0.18 for sliding speeds of 0.0001 in/sec to 100 in/sec. A coefficient of sliding friction of 0.3 is used throughout this analysis.

6.3 Computer Modeling of MCO Drops onto Storage Tube Assembly

The interface surfaces of the MCO and the MHM (MCO handling machine) are modeled with contact surfaces to control the lateral displacement of the falling MCO. The interface surfaces of the standard storage tube assembly lower flange and the concrete deck embedment are modeled with contact surfaces to control the lateral displacement of the deflecting standard tube assembly lower flange resulting from the glancing blow of the MCO onto the inclined surface of the lower flange. The MHM and the concrete deck embedment are modeled with rigid elements.

The interface surfaces of the MCO and the inclined surface of the standard tube assembly lower flange are modeled with contact surfaces to characterize the deformation and sliding at the point of impact. The elements depicting the contact surfaces of the MCO and the standard storage tube assembly are modeled with solid elements having elasto-plastic material properties. Figures 6.1 and 6.2 show the computer model for the drop at the standard storage tube assembly.

Two previous MCO drop analyses were performed to determine the effects of an accidental drop. One analysis (Reference 1) studied the potential damage to the standard storage tubes and the other (Reference 2) studied potential damage to the overpack storage tube. The computer models of these reports are not suitable to study the damage to the MCO.

The improvements in this analysis include better modeling of the MCO internals, accounting for the strain rate effects on the material stress-strain properties, refinement of the finite element model in areas of high strains, and inclusion of appropriate predictions of the failure strain levels. Specifically, the MCO model has been improved in the following ways:

- **Mesh Size**

A finer mesh was used in the high stress/strain area around the impact location. The finer mesh yields lower results, but requires a longer run time.

- **Shell vs. solid elements**

In previous analyses the MCO bottom was made up of solid elements up to the area of the weld between the bottom and the wall. From that point up shell elements were used. The transition from solid to shell elements at the weld could cause undesirable effects on the results. For this analysis the area of solid elements was extended above the high stress area.

- **Four elements vs. seven elements through the wall**

A model with 7 elements across the thickness of the wall has been developed to compare the results with a 4-element model. The maximum equivalent plastic strain of the 7-element model is about 20% less than the results of the 4-element model. Each element in the 7-element model is about 0.07 inches thick. The time required for each iteration of the ABAQUS/Explicit program is controlled by the element size. The 7-element model requires about 60 hours of computer time to run. The final analysis of the drop on the storage tube assembly uses the 7-element model.

- **Basket mass**

The mass of the basket and its contents was accounted for in previous analyses by placing mass elements in the MCO bottom. This method of modeling did not accurately represent the movement of the baskets that occurs during an impact. For this analysis the basket is modeled with solid elements and beam elements in the proper locations. Contact surfaces are modeled between the baskets and the MCO interior surface. The basket is free to bounce inside the MCO during impact, which more accurately simulates the actual condition. The density of the basket material in this model was increased to include the mass of the fuel pins. This process, known as smearing, provides conservative results.

For the MCO drop on the storage tube assembly, the vertical and horizontal gaps between the tube assembly and the concrete deck are included in the pre-impact model configuration to accurately characterize the influence of the impact of the MCO on the inclined surface of the tube assembly lower flange. As the impact occurs the lower flange moves down and away from the point of impact. At the same time the MCO slides down the inclined surface of the lower flange.

6.4 **Computer Modeling of MCO Drops onto Service Station**

The interface surfaces of the MCO and the inclined surface of service station shield hatch ring are modeled with contact surfaces to characterize the deformation and sliding at the point of impact. The elements depicting the contact surfaces of the MCO and shipping cask are modeled with solid elements

having elasto-plastic material properties. Figure 6.3 and 6.4 show the computer model for the drop at the service station.

Basically, the MCO model for the drop onto the service station is similar to the MCO model for the drop onto the storage tube assembly except as follows.

- The number of elements through the wall thickness was reduced from seven to four. The reduction in elements reduces computer run time and gives conservative results.
- A finer vertical mesh was used through the full length of the MCO. A finer horizontal mesh was used near the impact location (as in Standard storage tube assembly drop) and on the opposite side of the impact location.

The finer mesh on the opposite side of the impact location was necessary to yield reasonable results because the basket bounces and impacts the MCO wall at that location.

Figure 6.1. Computer Model of MCO Drop onto Storage Tube.

Figure 6.2. Close-up of Computer Model of MCO Drop onto Standard Storage Tube.

Figure 6.3. Computer Model of MCO Drop onto Service Station Shield Hatch Ring.

Figure 6.4. Close-up Computer Model of MCO Drop onto Service Station Shield Hatch Ring.

7.0 RESULTS

The equivalent plastic strain (peeq) is calculated from three principal plastic strain, and the value is greater than the maximum absolute value of the three direction strains. It is convenient to measure the magnitude of permanent damage/deformation by using ppeq value that is represented by the plastic strain in all directions. The Mises equivalent stress, triaxiality factors, and ppeq's for each component are found in Appendix B. The triaxiality factors and strains at critical location and critical time are summarized in Table 7.1.

Table 7.1. Calculated Failure Strain and Predicted Strain

Location	Node number	Time (second)	Triaxiality factor	Effective failure strain	Equivalent plastic strain
Lower weld	72179	0.021	-0.115	0.428	0.0175
Lower weld	72179	0.02175	0.656	0.018	0.0018
MCO bottom	70019	0.0052501	-2.679	0.80	0.3966

Figure 7.1 shows the deformed shape of the MCO and standard storage tube 0.03 seconds after impact. Figures 7.2 through 7.6 show the deformed shapes and strains of the MCO and storage tube after impact. Deformation strains along with failure strains at the bottom and lower weld on the MCO from the ABAQUS analysis are calculated and documented in Appendix B. These locations represent the areas of highest MCO strain.

The Mises time history plots of the stress near the outer weld surface and the impact location are shown on Figure 7.11 and 7.12, respectively.

The basket velocity during impact with the standard storage tube is plotted in Figure 7.7. The slope of the velocity curve gives the basket deceleration. The steeper the velocity curve, the greater the deceleration. The steepest portion of the curve is between 260 and 230 inches per second. The time interval between the two points is 0.0045 seconds. The change in speed divided by the time interval is $30/0.0045$ or 6667 in/sec/sec. Since the acceleration from gravity is 386.4 inches per second, the g force that the basket experiences is $6667/386.4 = 17$ g (say less than 20 g).

The basket velocity during impact with the service station is plotted in Figure 7.8. Using the method noted above, the basket g force is about 4 g. The basket nodes used for the g force calculations are shown in Figure 7.9.

The computer-generated views on Figures 7.10.a through 7.10.i show a timed sequence of the MCO drop onto the standard storage tube.

The ABAQUS/Explicit computer simulation uses global coordinates to describe the stresses and strains in the model. The ABAQUS direction 1 corresponds to stress/strain in the radial direction at the point of impact and 180° from the point

of impact. At other locations around the MCO circumference, the direction 1 stress/strain represents some combination of radial and hoop stress/strain. The hoop stress and strain at the point of impact is shown on Figures 7.15 and 7.18, respectively. The radial stress and strain at the point of impact is shown on Figures 7.13 and 7.16, respectively. The ABAQUS/Explicit direction 2 corresponds to the stress/strain in the meridian (vertical) direction. The ABAQUS direction 3 corresponds to the hoop stress/strain at the point of impact and 180° from the point of impact. At other locations around the MCO circumference the direction 3 stress represents some combination of hoop and radial stress/strain. The meridian stress and strain at the point of impact is shown on Figures 7.14 and 7.17, respectively.

The deformations near the point of impact for the MCO and standard storage tube are shown in Figures 7.20 and 7.21, respectively. The clearances between the MCO and standard storage tube after the drop are calculated below.

Cold tube O. D.	28.00"
tolerance	- .07"
	<u>27.93"</u>
Tube Wall Thickness	- .588"
" "	- .588"
	<u>26.754"</u>
Cold Tube I. D.	
*MCO top at 220° F	-25.31"
Reduction in tube O. D.	- 1.0"
Net Clearance	<u>.444"</u>

- The top of the MCO is 25.31 inches in diameter while the maximum deformed barrel diameter is about 24.1 inches, the larger of the two values is used.

The maximum kinetic energy during the drop is about 1,800,000 in-lbf. The time history of the kinetic energy for half of the MCO during the drop is plotted in Figure 7.19.

Figure 7.1. Close-up View at 0.03 Seconds After Impact Onto Storage Tube Assembly.

Figure 7.2. Equivalent Plastic Strain at MCO Bottom at 0.03 Second After Impact at Storage Tube Assembly.

Figure 7.3. Equivalent Plastic Strain at MCO Lower Weld at 0.03 Sec After Impact on Storage Tube Assembly.

Figure 7.4. Equivalent Plastic Strain at 0.028 Second at High Strain Rate for MCO Drop Onto Storage Tube Assembly.

Figure 7.5. Equivalent Plastic Strain at MCO Bottom 0.04 Second After Impact
Onto Service Station Shield Hatch Ring.

Figure 7.6. Equivalent Plastic Strain Near Lower Weld At 0.04 Second After Impact Onto Service Station Shield Hatch Ring.

Deceleration of Baskets:

$$\begin{aligned} & (260-230) / (.007-.0025) \\ & = 6667 \text{ in/sec/sec} \\ & = 17 \text{ g} \end{aligned}$$

say less than 20 g

Figure 7.7. Basket Velocity vs Time of MCO Impact onto Storage Tube Assembly.

Deceleration of Baskets:

$$\begin{aligned}
 & (264 - 253.5) / (.019 - .012) \\
 & = 1500 \text{ in/sec/sec} \\
 & = 3.9 \text{ g}
 \end{aligned}$$

say less than 4 g

Figure 7.8. Basket Velocity vs Time of MCO Impact onto Service Station Shield Hatch Ring.

Figure 7.9. Node Locations for Velocity Plot of MCO Drop onto Service Station.

Figure 7.10.a. MCO Drop Animation (Time = 0 second).

Figure 7.10.b. MCO Drop Animation (Time = .00375 second).

Figure 7.10.c. MCO Drop Animation (Time = .0075 second).

Figure 7.10.d. MCO Drop Animation (Time = .01125 second).

Figure 7.10.e. MCO Drop Animation (Time = .015 second).

Figure 7.10.f. MCO Drop Animation (Time = .01875 second).

Figure 7.10.g. MCO Drop Animation (Time = .0225 second).

Figure 7.10.h. MCO Drop Animation (Time = .02625 second).

Figure 7.10.i. MCO Drop Animation (Time = .03 second).

Figure 7.11. Mises Equivalent Stress Time History Plot of Element 70307 near Outside weld.

Figure 7.12. Mises Equivalent Stress Time History Plot of Element 70019 at MCO bottom near Impact location.

Figure 7.13. Stress in Radial Direction (direction 1) at Time 0.03 Second.

Figure 7.14. Stress in Meridian Direction (direction 2) at Time 0.03 Second.

Figure 7.15. Stress in Hoop Direction (direction 3) at Time 0.03 Second.

Figure 7.16. Plastic Strain in Radial in Direction (direction 1) at Time 0.03 Second.

Figure 7.17. Plastic Strain in Meridian Direction (direction 2) at Time 0.03 Second.

Figure 7.18. Plastic Strain in Hoop Direction (direction 3) at Time 0.03 Second.

Figure 7.19. Total Kinetic Energy Time History of the MCO Drops onto the Standard Storage Tube Assembly

Figure 7.20. MCO Deformations.

Figure 7.21. Standard Storage Tube Deformations.

8.0 FAILURE CRITERIA

(Discussion and criteria provided by Larry Blackburn, Metallurgy Consultant to DESH/FDH.)

Failure of the MCO will not occur if the maximum principal strain resulting from the drop is below a value that could initiate local cracking. The multi-axial loading and deformation associated with the drop need to be considered in evaluating limits on maximum principal strain. Manjoine (4) has proposed that the tensile elongation measured in a tension test can be adjusted to predict multi-axial failure strain by the relation.

$$\frac{\bar{\epsilon}}{e_t} = 2^{(1-TF)} \text{ for } TF \geq 0, \text{ and} \quad (1a)$$

$$\frac{\bar{\epsilon}}{e_t} = 2 \text{ for } TF \leq 0 \quad (1b)$$

where $\bar{\epsilon}$ is the effective (Mises) strain at failure,

e_t is the tensile elongation from tension test, and

TF is the stress state triaxiality factor.

The ratio of the Mises strain at failure divided by the uniaxial tensile elongation is a measure of relative ductility between multi-axial and uniaxial stress states. Ductility given by Equation (1) increases as the Triaxiality factor decreases from one and decreases as the triaxiality factor increases from one as shown in Figure 8.1 below.

The effective strain and triaxiality factor is defined by the relations

$$\bar{\epsilon} = \frac{\sqrt{2}}{3} \left[(\epsilon_1 - \epsilon_2)^2 + (\epsilon_2 - \epsilon_3)^2 + (\epsilon_3 - \epsilon_1)^2 \right]^{1/2} \quad (2)$$

where ϵ_1 , ϵ_2 , and ϵ_3 are the principal strains, and

$$TF = \frac{\sqrt{2}(\sigma_1 + \sigma_2 + \sigma_3)}{\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right]^{1/2}} \quad (3)$$

where σ_1 , σ_2 , and σ_3 are the principal stresses.

Figure 8.1 Ductility vs Triaxiality Factor.

Manjoine indicates support for the correlation from several alloys, but does not cite the specific references for the test data. A pressure vessel burst test program sponsored by the Pressure Vessel Research Committee (PVRC) provides support for the Manjoine correlation. Boyer and Rolfe (5) report that ϵ measured after bursting by internal pressure of a smooth pressure vessel made of carbon steel was 0.236, while ϵ_t was 0.33. These results are in good agreement with Equation (1a). A test on a second pressure vessel containing an intentional notch reduced ϵ to 0.125. Goller et al (6) report failure strains in pressurized discs (both smooth and reinforced) of alloy steel that are twice as large as the tensile elongation. These multi-axial failure strains in discs are much higher than would be predicted by the Manjoine correlation. Several researchers (Blejwas [7], Clauss [8], and Horschel [9]) report results for bursting of sub-scale models of nuclear reactor containment structures of carbon steel. In a simple 1/32-scale model, failure strains were about 0.21 for a smooth geometry, and about 0.16 for geometry containing penetrations (Reference 7). The tensile elongation for the steel was not reported, but the multi-axial failure strains are similar to those cited above for the PVRC vessels. Containment models that were 1/8 and 1/6 scale (References 8 & 9) were geometrically more complex and contained various penetrations, hatches, and stiffening rings. Localized failure strains were not measured directly, but indicated strain gage readings for the 1/8 scale test would suggest local failure strain exceeded 0.08.

In these models, failures initiated at a formed stiffener adjacent to the reinforcement at an equipment hatch penetration (1/8 scale model), and at a thickened region around a penetration (1/6 scale model). Both models were loaded beyond general yielding, and the free-field strains (i.e.; away from geometric discontinuities) were in the range 0.013 to 0.031 when ultimate failure occurred.

The MCO being analyzed in the present evaluation exhibits a smooth geometry without any discontinuities or notches that would reduce failure strains below those predicted from the Manjoine correlation.

For assessment of the weld region, the tensile elongation should be based on tests of weld metal. Results from thirteen different welds (References 10 & 11) tested at room temperature were used to determine tensile elongation. These welds were produced using various welding procedures and represent 308, 16-8-2, and 316 stainless steel weld metal compositions. For a total of 27 tension tests on as-deposited welds, the mean value of e_t is 0.37 with a standard deviation of 0.078. Defining the minimum value of e_t as the mean value minus twice the standard deviation, e_t (min.) is 0.214.

For assessment of base metal regions, the specification minimum value for e_t of 304L stainless steel base metal is 40% based on uniaxial tensile test at "low" (nominal) strain rate. The maximum acceptable value of e_t for 304L stainless steel base metal is therefore about twice that for the weld metal.

9.0 DISCUSSION

Results of the inelastic analysis calculations include the following significant findings.

- Failure Criteria.

Conservative failure strain levels were predicted for both welds and parent 304L stainless steel material, accounting for scatter in properties and multi-axial stresses and strains, using the methods in Section 8. For a triaxiality factor of 1.0 (uniaxial tension), the above values are 21% for the weld metal and 40% for the base metal. For a triaxiality factor of 2.0 (maximum value for biaxial tension at surface) the above values are 10% and 20%, respectively. For negative values of triaxiality factor (significant compressive stress) that are characteristic of the major portion of the strain accumulation in the drop, the failure strain values are 42% and 80%, for weld metal and base metal respectively.

- Drop onto Storage Tube.

Improving the model for the MCO internals and impact locations, using the refined finite element model of the wall (7 solid elements through the wall), and maximizing the strain rate effects gives the highest weld region effective strain of less than 0.6%. If the low strain rate effects are used, the value is increased but is still less than 3% with a triaxiality factor less than 2.0. Comparing these to the bounding 10% failure strain predicted above (or 5% when including strain rate effect reduction factor) indicated to the Expert Panel that no cracking would occur. Moreover, the maximum tensile principal strain is in a radial direction, maximum at the outer surface and any failure would be by spalling or flaking rather than crack formation and propagation through the wall.

With the improved models of above, the results indicate the MCO bottom plate area-of-impact sustains a high triaxial compressive stress state (triaxiality factor is negative) with a maximum effective strain of about 45% and 40% for the cases using low (nominal) and high strain rate effects. Since the predicted failure strain is 80%, no cracking is expected to occur. If the strain rate reduction factor is included the failure strain is reduced to 40%, indication a potential failure. However, the maximum tensile principal strain is perpendicular to the base surface and is a Poisson's ratio effect, therefore any failure would be through spalling or flaking.

The above results also show that the areas of MCO not discussed above are structurally acceptable since the strains are much lower (mostly in the elastic range). No structural instabilities are indicated, and the vertical deceleration of the MCO baskets is less than 20 g's, well within a conservative allowable of 35 g's from the MCO design criteria.

The deformation of the support tube where the flange attaches to the tube cylinder is much less than that of the MCO-to-tube clearance, thus, no adverse wedging of the MCO in the tube is expected.

- Drop onto Service Station Guide Ring.

The finite element model gives the highest weld region effective strain of about 1%. Comparing this strain to the bounding 10% failure strain predicted above (or 5% when including strain rate effect reduction factor) indicated to the Expert Panel that no cracking would occur. Moreover, the maximum tensile principal strain is in a radial direction, maximum at the outer surface and any failure would be by spalling or flaking rather than crack formation and propagation through the wall.

The results indicate the MCO bottom plate area-of-impact sustains a triaxial compressive stress state (triaxiality factor is negative) with a maximum effective strain of about 18%, which is less than the storage tube case. Since the predicted failure strain is 80% (or 40% when including strain rate effect reduction factor), no cracking is expected to occur. Moreover, the maximum tensile principal strain is again perpendicular to the base surface and is a Poisson's ratio effect, therefore, any failure would be through spalling or flaking.

The above results also show that the areas of MCO not discussed above are structurally acceptable as the strains are much lower (mostly in the elastic range). No structural instabilities are indicated, and the vertical deceleration of the MCO baskets are about 4 g's, well within a conservative allowable of 35 g's from the MCO design criteria.

10.0 REFERENCES

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ATTACHMENT

EXPERT PANEL REPORT

Conclusions of Expert Panel on Analysis for Eccentric MCO Drops at CSB
September 15, 1999 Richland, WA

Earlier analysis of a postulated eccentric drop at a CSB tube indicated that significant inelastic deformation in the MCO may occur and a breach of the MCO could not be ruled out. In addition, criticality configuration contingency control for the spent nuclear fuel could not be assured. The radiological dose consequences from such a breach had not been shown to meet evaluation guidelines. Accordingly, a plan of action to resolve this issue was undertaken. This plan included the assembly of an expert panel to provide guidance for further work including modeling activities, preliminary calculations, refining the resolution strategy, and implementing the resolution. The drop of the MCO was assessed for the drop on storage tube and for the drop on the service station guide ring. The Expert Panel has met a number of times and the current conclusions reported herein are the results and findings of the new modeling and calculations.

The Expert Panel members were:

LD Blackburn - Metallurgy
 RD Crowe - Safety Analysis
 LH Goldmann - MCO Design Authority
 RP Kennedy - Structural Analysis
 LK Severud - Engineering Management & Structural Analysis

The Expert Panel, after review of the earlier analysis, made recommendations for improving the modeling and reducing the conservatism in the earlier model and calculations. These included better modeling of the MCO internals and impact locations, accounting for the strain rate effects on the material stress-strain properties, refinement of the finite element model in the areas of the high strains, and inclusion of appropriate predictions of the failure strain levels. Results of the inelastic analysis calculations with these changes include the following significant findings:

Failure Criteria. Conservative failure strain levels were predicted for both welds and parent 304L stainless steel material, accounting for scatter in properties and multi-axial stresses and strains, and using the methods in Attachment 1. For a triaxiality factor of 1.0 (uniaxial tension), the above values are 21% for weld metal and 40% base metal. For a triaxiality factor of 2.0 (maximum value for biaxial tension at surface) the above values are 10% and 20%. For negative values of triaxiality factor (significant compressive stress) that are characteristic of the major portion of the strain accumulation in the drop, the values are 42% and 80%, again for weld metal and base metal respectively.

Drop onto Storage Tube.

1. Improving the model for the MCO internals and impact locations, using the refined finite element model of the wall (7 solid elements through the wall), and maximizing the strain rate effects gives the highest weld region effective strain of less than 0.6%. If the minimum strain rate effects are used, the value is increased but is still less than 3% with a triaxiality factor less than 2.0. Comparing these to the bounding 10% failure strain predicted above indicates to the Expert Panel that no cracking will occur. Moreover, the maximum tensile principal strain is in a

radial direction, maximum at the outer surface and any failure would be by spalling or flaking rather than crack formation and propagation through the wall.

2. With the improved models of above, the calculations indicate the MCO bottom plate arc-of-impact sustains a high triaxial compressive stress state (triaxiality factor is negative) with a maximum effective strain of about 45% and 40% for the cases using maximum and minimum strain rate effects. Since the predicted failure strain is 80%, no cracking is expected to occur. Moreover, the maximum tensile principal strain is perpendicular to the base surface and is a Poisson's ratio effect, so that any failure would be through spalling or flaking.
3. The above calculations also show that the areas of MCO not discussed above are structurally acceptable as the strains are much lower, mostly in the elastic range, no structural instabilities are indicated, and the vertical deceleration of the MCO baskets is about 20G's, well within a conservative allowable of 35G's from the MCO design criteria.
4. The deformation of the support tube where the flange attaches to the tube cylinder is much less than that of the MCO-to-tube clearance and so, no adverse sticking of the MCO is expected.

Drop onto Service Station Guide Ring.

1. The finite element model gives the highest shell weld region effective strain, located at the outer surface, of less than 1%. Comparing this strain to the bounding 10% failure strain predicted above indicates to the Expert Panel that no cracking will occur. Moreover, the maximum tensile principal strain is in a radial direction, maximum at the outer surface and any failure would be by spalling or flaking rather than crack formation and propagation through the wall.
2. The calculations indicate the MCO bottom plate arc-of-impact sustains a triaxial compressive stress state (triaxiality factor is negative) with a maximum effective strain of about 18%, which is less than that for the storage tube case. Since the predicted failure strain is 80%, no cracking is expected to occur. Moreover, the maximum tensile principal strain is again perpendicular to the base surface and is a Poisson's ratio effect, so that any failure would be through spalling or flaking.
3. The above calculations also show that the areas of MCO not discussed above are structurally acceptable as the strains are much lower, mostly in the elastic range, no structural instabilities are indicated, and the maximum vertical deceleration of the MCO baskets is about 4G's, well within a conservative allowable of 35G's from the MCO design criteria.

Although the drop analysis report is yet to be drafted, checked and reviewed, the Expert Panel judges that the ongoing work and final report will show that the MCO is not breached in the event of a postulated drops on either the support tube or service station guide ring. The results of the drop on the service station guide ring are also applicable to the drop of the MCO at the sample/weld station.

LD Blackburn - Metallurgy

RD Crowe - Safety Analysis

LH Goldmann - MCO Design Authority

RP Kennedy - Structural Analysis

LK Severud - Engineering Management & Structural Analysis

PREDICTION OF FAILURE STRAIN

Failure of the MCO will not occur if the maximum principal strain resulting from the drop is below a value that could initiate local cracking. The multi-axial loading and deformation associated with the drop need to be considered in evaluating limits on maximum principal strain. Manjoine (1) has proposed that the tensile elongation measured in a tension test can be adjusted to predict multi-axial failure strain by the relation.

$$\frac{\bar{\epsilon}}{e_t} = 2^{(1-TF)} \text{ for } TF \geq 0, \text{ and} \quad (1a)$$

$$\frac{\bar{\epsilon}}{e_t} = 2 \text{ for } TF \leq 0 \quad (1b)$$

where $\bar{\epsilon}$ is the effective (Mises) strain at failure

e_t is the tensile elongation from tension test, and

TF is the triaxiality factor.

The effective strain and triaxiality factor are defined by the relations.

$$\bar{\epsilon} = \frac{\sqrt{2}}{3} \left[(\epsilon_1 - \epsilon_2)^2 + (\epsilon_2 - \epsilon_3)^2 + (\epsilon_3 - \epsilon_1)^2 \right]^{1/2} \quad (2)$$

where ϵ_1 , ϵ_2 , and ϵ_3 are the principal strains, and

$$TF = \frac{\sqrt{2}(\sigma_1 + \sigma_2 + \sigma_3)}{\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right]^{1/2}} \quad (3)$$

where σ_1 , σ_2 , and σ_3 are the principal stresses.

Manjoine indicates support for the correlation from several alloys, but does not cite the specific references for the test data. A pressure vessel burst test program sponsored by the Pressure Vessel Research Committee (PVRC) provides support for the Manjoine correlation. Boyer and Rolfe (2) report that $\bar{\epsilon}$ measured after bursting by internal pressure of a smooth pressure vessel made of carbon steel was 0.236, while e_t was 0.33. These results are in good agreement with equation 1a. A test on a second pressure vessel containing an intentional notch reduced $\bar{\epsilon}$ to 0.125. Goller et al (3) report failure strains in pressurized discs (both smooth and reinforced) of alloy steel that are twice as large as the tensile elongation. These multi-axial failure strains in discs are much higher than would be predicted by the Manjoine correlation. Several

researchers (Blejwas [4], Clauss [5], and Horschel [6]) report results for bursting of sub-scale models of nuclear reactor containment structures of carbon steel. In a simple 1/32 scale model, failure strains were about 0.21 for a smooth geometry, and about 0.16 for a geometry containing penetrations (Ref. 4). The tensile elongation for the steel was not reported, but the multi-axial failure strains are similar to those cited above for the PVRC vessels. Containment models that were 1/8 and 1/6 scale (Ref. 5, 6) were geometrically more complex and contained various penetrations, hatches, and stiffening rings. Localized failure strains were not measured directly, but indicated strain gage readings for the 1/8 scale test would suggest local failure strain exceeded 0.08. In these models, failures initiated at a formed stiffener adjacent to the reinforcement at an equipment hatch penetration (1/8 scale model), and at a thickened region around a penetration (1/6 scale model). Both models were loaded beyond general yielding, and the free-field strains (i.e.; away from geometric discontinuities) were in the range 0.013 to 0.031 when ultimate failure occurred.

The MCO being analyzed in the present evaluation exhibits a smooth geometry without any discontinuities or notches that would reduce failure strains below those predicted from the Manjoine correlation.

For assessment of the weld region, the tensile elongation should be based on tests of weld metal. Results from thirteen different welds (7, 8) tested at room temperature were used to determine tensile elongation. These welds were produced using various welding procedures and represent 308, 16-8-2, and 316 stainless steel weld metal compositions. For a total of 27 tension tests on as-deposited welds, the mean value of e_t is 0.37 with a standard deviation of 0.078. Defining the minimum value of e_t as the mean value minus twice the standard deviation, e_t (min.) is 0.214.

For assessment of base metal regions, the specification minimum value for e_t of 304L stainless steel base metal is 0.40. The maximum acceptable value of e_t for 304L stainless steel is therefore about twice that for weld metal.

REFERENCES

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8. L. D. Blackburn and D. L. Greenslade, Mechanical Properties of Type 316 Stainless Steel Materials After Irradiation at 515°C and 585°C, HEDL-TME 81-4, Hanford Engineering Development Laboratory, Richland, Washington, April 1981.

APPENDIX – A

MATERIAL PROPERTIES

FOR ABAQUS/EXPLICIT INPUT

Originator: M.B. LASOTA ML Date: 9/27/99

Checked by: K.C. Tu KCT Date: 9/27/99

MATERIAL PROPERTIES FOR ABAQUS/EXPLICIT INPUT **Engineering stress-strain curve for 316 SS heat T.**

On the basis of data provided in table A-3 contained in Blackburn 1981, engineering stress-strain curve can be constructed by linear interpolation. Stress values in the table are given in mega Pascals. Further the values are converted to psi.

$i := 0..22$					
$\epsilon_i :=$	$f_{t23,i} :=$				
.002	249	$s_{t23} := f_{t23} \cdot Pa \cdot 1000000$	0.000000	36114	$\cdot psi$
.003	257.9		0.001000	37405	
.004	263.8		0.002000	38261	
.005	268.7		0.003000	38972	
.006	273.1		0.004000	39610	
.007	276.8	$\epsilon_{pl} := \epsilon - 0.002$	0.005000	40146	
.008	280.2	$\epsilon_{pl} =$	0.006000	40640	
.009	283		0.007000	41046	
.01	285.3		0.008000	41379	
.02	306.8		0.018000	44498	
.03	323.7		0.028000	46949	
.04	338.2		0.038000	49052	
.05	351.5		0.048000	50981	
.06	363.4		0.058000	52707	
.07	374.8		0.068000	54360	
.08	385.9		0.078000	55970	
.09	396.2		0.088000	57464	
.1	405.7		0.098000	58842	
.2	471.2		0.198000	68342	
.3	509.3		0.298000	73868	
.4	532.3		0.398000	77204	
.5	548		0.498000	79481	
.6	548		0.598000	79481	

Using the term "Engineering stress-strain" it is implied that cross section of the specimen during uniaxial tension test remains unchanged.

$$v_{\epsilon_{pl}} := \epsilon_{pl} \quad v_{s_{t23}} := s_{t23} \quad v_{s_{t23}(\epsilon)} := \text{linterp } v_{\epsilon_{pl}}, v_{s_{t23}}, \epsilon$$

ENGINEERING STRESS-STRAIN CURVE FOR 316 SS STEEL

INELASTIC RANGE

A-2

MATERIAL PROPERTIES FOR ABAQUS/EXPLICIT INPUT

True stress-strain curve for 316 SS heat T.

Most materials that exhibit ductile behavior ((large inelastic strains) yield at stress levels that are orders of magnitude less than the elastic modulus of material, which implies that the relevant stress and strain measures are "true" stress (Cauchy stress) and logarithmic strain. Material data for all of these models should, therefore, be given in these measures. The engineering (nominal) stress-strain data from uniaxial test for isotropic material can be simply converted to true stress and logarithmic plastic strain by use of the following formulas:

$$\sigma_{\text{true}} = \sigma_{\text{eng}} (1 + \epsilon_{\text{eng}}) \quad \text{and} \quad \epsilon_{\text{pl}} = \ln(1 + \epsilon_{\text{eng}}) - \frac{\sigma_{\text{true}}}{E}$$

Thus for 316 SS heat T steel true stress strain relation can be expressed as follows:

$$E_{\text{ss316}} := 28000000 \cdot \text{psi} \quad \epsilon_{\text{eng}_i} := \frac{s_{t23_i}}{E_{\text{ss316}}} + \epsilon_{\text{pl}_i} \quad s_{\text{tr}_i} := (1 + \epsilon_{\text{eng}_i}) s_{t23_i}$$

$$\epsilon_{\text{tr}_i} := \ln(1 + \epsilon_{\text{eng}_i}) - \frac{s_{\text{tr}_i}}{E_{\text{ss316}}}$$

$$v\epsilon_{\text{tr}} := \overrightarrow{(\epsilon_{\text{tr}})} \quad v s_{\text{tr}} := \overrightarrow{s_{\text{tr}}}$$

$$v s_{\text{tr}}(\epsilon_{\text{tr}}) := \text{linterp}(v\epsilon_{\text{tr}}, v s_{\text{tr}}, \epsilon_{\text{tr}})$$

$\epsilon_{\text{eng}} =$	0.001290		36161		-0.000
	0.002336		37493		0.001
	0.003366		38390		0.002
	0.004392		39143		0.003
	0.005415		39824		0.004
	0.006434		40405	•psi	0.005
	0.007451		40942		0.006
	0.008466		41393		0.007
	0.009478		41771		0.008
	0.019589		45369		0.018
	0.029677		48342		0.028
	0.039752		51002		0.037
	0.049821		53521		0.047
	0.059882		55863		0.056
	0.069941		58162		0.066
	0.079999		60448		0.075
	0.090052		62639		0.084
	0.100101		64732		0.093
	0.200441		82040		0.180
	0.300638		96075		0.259
	0.400757		108143		0.333
	0.500839		119288		0.402
	0.600839		127236		0.466

MATERIAL PROPERTIES FOR ABAQUS/EXPLICIT INPUT

TRUE STRESS-STRAIN CURVE FOR 316 SS STEEL

True stress-strain curve for 304 SS @ specific strain rate.

From ABAQUS output an estimated strain rate can be computed as follows:

Dependent upon how fast the strain is applied to the material, the material exhibits varying value of 2% yield stress. This behavior of Type 304 Stainless Steel is captured in Steicken, 1971. Using actual strain rate from ABAQUS/EXPLICIT run the material properties are adjusted accordingly.

Time interval for which plastic strain can be approximated as straight line is:

$$\Delta t := \frac{11.3}{19} \cdot 5 \cdot 10^{-3} \cdot \text{sec} - \frac{4}{19} \cdot 5 \cdot 10^{-3} \cdot \text{sec} \quad \Delta t = 0.0019 \cdot \text{sec}$$

Corresponding plastic strain increase is:

$$\Delta \epsilon_{pl} := 0.1633 - 0.0475 \quad \Delta \epsilon_{pl} = 0.1158$$

$$\frac{\Delta \epsilon_{pl}}{\Delta t} = 60.28 \cdot \text{sec}^{-1}$$

The effect of the strain rate on the value of "0.2% Yield Stress" (Steicken, 1971, Figure 2.) for 304SS.

$$s_{yss304} := 51820 \cdot \text{psi} \quad \left(\frac{4}{22} \cdot 10 + 50 \right) \cdot 1000 = 51818$$

MATERIAL PROPERTIES FOR ABAQUS/EXPLICIT INPUT

The stress-strain curves for 316 SS steel and 304 SS steel are similar. Due to similarity the final plastic strain curve can be estimated by adjusting the 316SS curve by a difference in the value of the yield stress for 316SS and 304SS @ formerly computed strain rate.

$$\Delta s_y := s_{yss304} - s_{tr_0} \quad \Delta s_y = 15659.02 \cdot \text{psi} \quad s := s_{t23_0} \quad s = 36114.4 \cdot \text{psi}$$

$$s_{trss304} := s_{tr} + \Delta s_y \quad vs_{trss304} := \overrightarrow{s_{trss304}} \quad vs_{trss304}(\epsilon_{tr}) := \text{linterp}(vs_{tr}, vs_{trss304}, \epsilon_{tr} - \frac{s}{E_{ss316}})$$

$$\epsilon_{elss304} := \frac{s}{E_{ss316}}$$

$$\epsilon'_{tr} := 0, 0.0001 \dots 0.5$$

$$vs_{ss304}(\epsilon_{tr}) := \text{if}(\epsilon_{tr} < \epsilon_{elss304}, E_{ss316} \cdot \epsilon_{tr}, vs_{trss304}(\epsilon_{tr}))$$

$$E_{ss316} \cdot \epsilon_{elss304} = 36114.4 \cdot \text{psi}$$

$$vs_{trss304}(.00127) = 51796.88 \cdot \text{psi}$$

$$j := 0 \dots 3$$

$$\epsilon_{in_j} := \quad f_{tin_j} :=$$

0.00001	30032.
0.293	100701.
0.3	101451.
0.307	102201.

$$s_{tin} := f_{tin} \cdot \text{psi}$$

$$\epsilon_{plin} := \epsilon_{in}$$

$$s_{tin} = \begin{bmatrix} 30032 \\ 100701 \\ 101451 \\ 102201 \end{bmatrix} \cdot \text{psi}$$

$$\epsilon_{plin} = \begin{bmatrix} 0.000010 \\ 0.293000 \\ 0.300000 \\ 0.307000 \end{bmatrix}$$

$$vs_{plin} := \overrightarrow{\epsilon_{plin}}$$

$$vs_{tin} := \overrightarrow{s_{tin}}$$

$$s_{tin_0} = 30032 \cdot \text{psi}$$

$$\epsilon'_{elss304} := \frac{s_{tin_0}}{E_{ss316}}$$

$$\epsilon'_{elss304} = 0.001073$$

$$vs_{tin}(\epsilon_{plin}) := \text{linterp}(vs_{plin}, vs_{tin}, \epsilon_{plin})$$

$$vs_{tel}(\epsilon_{plin}) := E_{ss316} \cdot \epsilon_{plin} \quad vs_{tin}(.3) = 101451 \cdot \text{psi}$$

MATERIAL PROPERTIES FOR ABAQUS/EXPLICIT INPUT

$vs\ orig(\epsilon_{plin}) := if(\epsilon_{plin} < \epsilon'_{elss304}, vs\ tel(\epsilon_{plin}), vs\ tin(\epsilon_{plin}))$

$\epsilon_{plin} := 0, 0.0001 .. 0.466$

Figure 2sr-0a. TRUE STRESS-STRAIN CURVES FOR 304SS STEEL

$\epsilon := 0, 0.01 .. 0.05$

ϵ	$vs\ trss304(\epsilon)$ 1000-psi
0	50.10
0.01	57.71
0.02	61.31
0.03	64.33
0.04	67.07
0.05	69.68

$\epsilon_{tr} := 0.05, 0.10 .. 0.5$

ϵ_{tr}	$vs\ trss304\ \epsilon_{tr}$ 1000-psi
0.05	69.68
0.1	81.51
0.15	91.50
0.2	101.04
0.25	109.85
0.3	118.16
0.35	126.33
0.4	134.45
0.45	140.76
0.5	146.95

MATERIAL PROPERTIES FOR ABAQUS/EXPLICIT INPUT

$$\epsilon'_{tr_i} := \ln(1 + \epsilon_{eng_i}) - \frac{s_{tr_i}}{E_{ss316}}$$

$$s'_{tr} := s_{tr} + \Delta s_y$$

$s'_{tr} =$	51820		$\epsilon'_{tr} =$	-0.0000
	53152			0.0010
	54049			0.0020
	54802			0.0030
	55483			0.0040
	56064	psi		0.0050
	56601			0.0060
	57052			0.0070
	57430			0.0079
	61028			0.0178
	64001			0.0275
	66661			0.0372
	69180			0.0467
	71522			0.0562
	73821			0.0655
	76107			0.0748
	78298			0.0840
	80391			0.0931
	97699			0.1798
	111734			0.2594
	123803			0.3332
	134947			0.4018
	142895			0.4660

MATERIAL PROPERTIES FOR ABAQUS/EXPLICIT INPUT

Engineering stress-strain curve for SA36.

j := 0..3

$\epsilon_{csj} :=$ $f_{cst23j} :=$

.00	36044
.02	37786
.095	55085
.161	64728

$s_{cst23} := f_{cst23} \cdot \text{psi}$

$E_{cs36} := 29500000 \cdot \text{psi}$

$\epsilon_{cspl} := \epsilon_{cs}$

$\epsilon_{elcs36} := \frac{s_{cst23_0}}{E_{cs36}}$

$\epsilon_{elcs36} = 0.00122183$

$\epsilon_{cspl} = \begin{bmatrix} 0.000000 \\ 0.020000 \\ 0.095000 \\ 0.161000 \end{bmatrix}$

$s_{cst23} = \begin{bmatrix} 36044 \\ 37786 \\ 55085 \\ 64728 \end{bmatrix} \cdot \text{psi}$

$vs_{cspl} := \overrightarrow{\epsilon_{cspl}} \quad vs_{cst23} := \overrightarrow{s_{cst23}} \quad vs_{cst23}(\epsilon) := \text{interp}(vs_{cspl}, vs_{cst23}, \epsilon, \epsilon := 0, 0.0001 \dots 0.161)$

ENGINEERING STRESS-STRAIN CURVE FOR SA36 CS STEEL

MATERIAL PROPERTIES FOR ABAQUS/EXPLICIT INPUT

True stress-strain curve for SA36 CS.

$$E_{cs36} = 29500000 \cdot \text{psi} \quad \epsilon_{cseng_j} := \frac{s_{csl23_j}}{E_{cs36}} + \epsilon_{pl_j} \quad s_{cstr_j} := (1 + \epsilon_{cseng_j}) s_{csl23_j}$$

$$\epsilon_{cstr_j} := \ln(1 + \epsilon_{cseng_j}) - \frac{s_{cstr_j}}{E_{cs36}} \quad \frac{s_{cstr_0}}{E_{cs36}} \cdot 10^{-3} = 0.000001$$

$$v\epsilon_{cstr} := \overrightarrow{(\epsilon_{cstr})} \quad v s_{cstr} := \overrightarrow{s_{cstr}}$$

$$v s_{cstr}(\epsilon) := \text{linterp}(v\epsilon_{cstr}, v s_{cstr}, \epsilon)$$

$$\epsilon_{cseng} = \begin{bmatrix} 0.001222 \\ 0.002281 \\ 0.003867 \\ 0.005194 \end{bmatrix}$$

$$s_{cstr} = \begin{bmatrix} 36088 \\ 37872 \\ 55298 \\ 65064 \end{bmatrix} \cdot \text{psi}$$

$$\epsilon_{cstr} = \begin{bmatrix} -0.000002 \\ 0.000994 \\ 0.001985 \\ 0.002975 \end{bmatrix}$$

$$\epsilon := 0, 0.0001 \dots 0.161$$

TRUE STRESS-STRAIN CURVE FOR SA36 CS STEEL

MATERIAL PROPERTIES FOR ABAQUS/EXPLICIT INPUT

True stress-strain curve for SA36 @ specific strain rate.

From ABAQUS output an estimated strain rate can be computed as follows:

Time interval for which plastic strain can be approximated as straight line is:

$$\Delta t := \frac{11.3}{19} \cdot 5 \cdot 10^{-3} \cdot \text{sec} - \frac{4}{19} \cdot 5 \cdot 10^{-3} \cdot \text{sec} \quad \Delta t = 0.0019 \cdot \text{sec}$$

Corresponding plastic strain increase is:

$$\Delta \epsilon_{pl} := 0.1633 - 0.0475 \quad \Delta \epsilon_{pl} = 0.1158$$

$$\frac{\Delta \epsilon_{pl}}{\Delta t} = 60.28 \cdot \text{sec}^{-1}$$

The effect of the strain rate on the value of 0.2% Yield Stress (Figure 2. ref.....) for SA36.

$$s_{ysa36} := 57820 \cdot \text{psi} \quad \left(\frac{17.2}{22} \cdot 10 + 50 \right) \cdot 1000 = 57818$$

The stress-strain curves for SA36 steel and 304 SS steel are similar. Due to similarity the final plastic strain curve can be estimated by adjusting the 316SS curve by a difference in the value of the yield stress for 316SS and 304SS @ formerly computed strain rate.

$$\Delta s_y := s_{ysa36} - s_{tr0} \quad \Delta s_y = 21659.02 \cdot \text{psi}$$

$$s_{trsa36} := s_{tr} + \Delta s_y \quad vs_{trsa36} := \overrightarrow{s_{trsa36}} \quad vs_{trsa36} \cdot \epsilon_{tr} := \text{linterp } vs_{tr}, vs_{trsa36}, \epsilon_{tr}$$

$$\Delta s_y = 21659.02 \cdot \text{psi} \quad s := s_{t230} \quad s = 36114.4 \cdot \text{psi}$$

$$s_{trsa36} := s_{tr} + \Delta s_y \quad vs_{trsa36} := \overrightarrow{s_{trsa36}} \quad vs_{trsa36} \cdot \epsilon_{tr} := \text{linterp } vs_{tr}, vs_{trsa36}, \epsilon_{tr} - \frac{s_{trsa36}}{E_{cs36}}$$

$$\epsilon_{elcs36} := \frac{s_{trsa36_0}}{E_{cs36}}$$

$$\epsilon_{tr} := 0, 0.0001 \dots 0.5$$

$$vs_{cs36} \cdot \epsilon_{tr} := \text{if } \epsilon_{tr} < \epsilon_{elcs36}, E_{cs36} \cdot \epsilon_{tr}, vs_{trsa36} \cdot \epsilon_{tr}$$

$$E_{cs36} \cdot \epsilon_{elcs36} = 57820 \cdot \text{psi} \quad \epsilon_{elcs36} = 0.00196$$

$$vs_{cs36}(0.00122183) = 36043.99 \cdot \text{psi}$$

$$vs_{cs36}(0.0016) = 47200 \cdot \text{psi} \quad \epsilon_{elcs36} = 0.00196$$

MATERIAL PROPERTIES FOR ABAQUS/EXPLICIT INPUT

$$\epsilon'_{elcs36} := \frac{s_{t23_0}}{E_{cs36}} \quad \epsilon'_{elcs36} = 0.00122422$$

$$vs'_{t23}(\epsilon) := \text{if}(\epsilon < \epsilon'_{elcs36}, E_{cs36} \cdot \epsilon, vs_{t23}(\epsilon))$$

$$\epsilon_{plin} := 0, 0.00001 .. 0.16$$

Figure 2sr-0b. TRUE STRESS-STRAIN CURVES FOR SA36 STEEL

MATERIAL PROPERTIES FOR ABAQUS/EXPLICIT INPUT $\epsilon := 0, 0.01 \dots 0.16$

ϵ	$\frac{vs \ trsa36(\epsilon)}{1000\text{-psi}}$
0	55.2
0.01	63.5
0.02	67.1
0.03	70.1
0.04	72.9
0.05	75.5
0.06	78.0
0.07	80.4
0.08	82.9
0.09	85.2
0.1	87.4
0.11	89.4
0.12	91.4
0.13	93.4
0.14	95.4
0.15	97.4
0.16	99.4

$$\epsilon'_{tr_j} := \ln(1 + \epsilon_{eng_j}) - \frac{s_{tr_j}}{E_{cs36}}$$

$$s'_{tr} := s_{tr} + \Delta s_y$$

$s'_{tr} =$	57820	$\cdot \text{psi}$	$\epsilon'_{tr} =$	0.0001
	59152			0.0011
	60049			0.0021
	60802			0.0031
	61483			0.0040
	62064			0.0050
	62601			0.0060
	63052			0.0070
	63430			0.0079
	67028			0.0178
	70001			0.0275
	72661			0.0372
	75180			0.0467
	77522			0.0562
	79821			0.0655
	82107			0.0748
	84298			0.0840
	86391			0.0931
	103699			0.1798
	117734			0.2594
	129803			0.3332
	140947			0.4018
	148895			0.4660

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Steicken, J.M., *High Strain Rate Mechanical Properties of Type 304 Stainless Steel and Nickel 200 (RM-14)*. HEDL-TME 71-145, September 1971. Hanford Engineering Development Laboratory, Richland, WA.

A-12

APPENDIX B

STRESS-STRAIN

TRIAXIALITY FACTOR CALCULATION

Originator: KC Tu bo Lu

Date: 9/27/99

Checked by: M.B. LASOTA ALG5

Date: 9/27/99

B.1 CHECK CRITICAL AREA IN WELD REGION**ELEMENT 70301 (element located at welding area near inside surface)**

time (second)	minimum principal stress (psi)	intermed. principal stress (psi)	maximum principal stress (psi)	minimum principal plastic strain	intermed. principal plastic strain	maximum principal plastic strain	triaxiality factor (TF)	Mises stress (psi)	equivalent plastic strain
0.0008	-39924	-5782	-1989	-0.00031	0.00013	0.00019	-1.3180	36188	0.0003
0.0015	-43395	-13645	-2953	-0.00155	0.00052	0.00102	-1.6528	36297	0.0016
0.0023	-42909	-16688	-2967	-0.00668	0.00162	0.00506	-1.7799	35151	0.0070
0.0030	-29056	-15954	-1376	-0.00668	0.00162	0.00506	-1.9341	23983	0.0070
0.0038	-15477	-9839	-1150	-0.00668	0.00162	0.00506	-2.1171	12501	0.0070
0.0045	-14843	-2179	6607	-0.00668	0.00162	0.00506	-0.5576	18677	0.0070
0.0053	-8849	-7531	28411	-0.00613	0.00128	0.00485	0.3285	36619	0.0065
0.0060	-11998	-9144	10543	-0.00582	0.00112	0.00471	-0.4986	21258	0.0062
0.0068	-16102	-13519	-3429	-0.00582	0.00112	0.00471	-2.8493	11599	0.0062
0.0075	-23759	-18898	-5655	-0.00582	0.00112	0.00471	-2.9769	16229	0.0062
0.0083	-17337	-15182	-5220	-0.00582	0.00112	0.00471	-3.3707	11196	0.0062
0.0090	-14405	-7115	1586	-0.00582	0.00112	0.00471	-1.4376	13867	0.0062
0.0098	-15306	-6741	4506	-0.00582	0.00112	0.00471	-1.0192	17210	0.0062
0.0105	-15936	-6283	4399	-0.00582	0.00112	0.00471	-1.0115	17618	0.0062
0.0113	-17049	-6614	737	-0.00582	0.00112	0.00471	-1.4810	15480	0.0062
0.0120	-18016	-6536	-3240	-0.00582	0.00112	0.00471	-2.0687	13435	0.0062
0.0128	-18344	-11635	-6069	-0.00582	0.00112	0.00471	-3.3861	10646	0.0062
0.0135	-22769	-15744	-6533	-0.00582	0.00112	0.00471	-3.1940	14103	0.0062
0.0143	-35357	-13943	-7171	-0.00582	0.00112	0.00471	-2.2159	25484	0.0062
0.0150	-37669	-13260	-7139	-0.00582	0.00112	0.00471	-2.0756	27976	0.0062
0.0158	-13776	-6544	-2704	-0.00582	0.00112	0.00471	-2.3645	9737	0.0062
0.0165	-10715	-6214	-2996	-0.00582	0.00112	0.00471	-2.9670	6716	0.0062
0.0173	-12206	-5991	-1672	-0.00582	0.00112	0.00471	-2.1663	9172	0.0062
0.0180	-17384	-15982	-6819	-0.00582	0.00112	0.00471	-4.0434	9938	0.0062
0.0188	-18902	-11656	-1148	-0.00582	0.00112	0.00471	-2.0506	15462	0.0062
0.0195	-30888	-22322	-5421	-0.00582	0.00112	0.00471	-2.6122	22445	0.0062
0.0203	-23525	-16428	-5741	-0.00582	0.00112	0.00471	-2.9469	15506	0.0062
0.0210	-29179	-5845	-2128	-0.00582	0.00112	0.00471	-1.4628	25397	0.0062
0.0218	-32429	-15516	-4848	-0.00582	0.00112	0.00471	-2.1916	24089	0.0062
0.0225	-34793	-23161	-5170	-0.00582	0.00112	0.00471	-2.4419	25851	0.0062
0.0233	-36657	-24853	-5525	-0.00582	0.00112	0.00471	-2.4625	27222	0.0062
0.0240	-27363	-11578	-5707	-0.00582	0.00112	0.00471	-2.3016	19399	0.0062
0.0248	-27891	-14712	-5179	-0.00582	0.00112	0.00471	-2.4189	19753	0.0062
0.0255	-27132	-13810	-5406	-0.00582	0.00112	0.00471	-2.4425	18975	0.0062
0.0263	-28649	-14014	-5532	-0.00582	0.00112	0.00471	-2.3794	20255	0.0062
0.0270	-28097	-14318	-4522	-0.00582	0.00112	0.00471	-2.2881	20513	0.0062
0.0278	-26474	-12245	-4936	-0.00582	0.00112	0.00471	-2.3012	18971	0.0062
0.0285	-25230	-10376	-4122	-0.00582	0.00112	0.00471	-2.1156	18779	0.0062
0.0293	-29796	-16385	-4335	-0.00582	0.00112	0.00471	-2.2899	22060	0.0062
0.0300	-30207	-14414	-4467	-0.00582	0.00112	0.00471	-2.1834	22482	0.0062
Max.	-8849	-2179	28411	-0.00031	0.00162	0.00506	0.3285	36619	0.0070
Min.	-43395	-24853	-7171	-0.00668	0.00013	0.00019	-4.0434	6716	0.0003

ELEMENT 72307 (element located at welding area near outside surface)

time (second)	minimum principal stress (psi)	intermed. principal stress (psi)	maximum principal stress (psi)	minimum principal plastic strain	intermed. principal plastic strain	maximum principal plastic strain	triaxiality factor (TF)	Mises stress (psi)	equivalent plastic strain
0.0008	-20419	-4986	974	0.00000	0.00000	0.00000	-1.2776	19123	0.0000
0.0015	-26572	-8035	293	0.00000	0.00000	0.00000	-1.4406	23819	0.0000
0.0023	-37094	-3577	-1147	-0.00108	0.00013	0.00095	-1.2018	34796	0.0012
0.0030	-30850	-4588	935	-0.00108	0.00013	0.00095	-1.1730	29415	0.0012
0.0038	-27803	-6760	3780	-0.00108	0.00013	0.00095	-1.1053	27851	0.0012
0.0045	-25385	-9064	5432	-0.00108	0.00013	0.00095	-1.0866	26704	0.0012
0.0053	-38303	-13248	2912	-0.00125	0.00023	0.00102	-1.3522	35969	0.0013
0.0060	-35264	-10251	3037	-0.00135	0.00029	0.00106	-1.2611	33684	0.0014
0.0068	-38785	-12745	634	-0.00135	0.00029	0.00106	-1.4659	34720	0.0014
0.0075	-40398	-14052	424	-0.00143	0.00032	0.00111	-1.5071	35847	0.0015
0.0083	-32723	-13413	503	-0.00143	0.00032	0.00111	-1.5790	28901	0.0015
0.0090	-22442	-10835	904	-0.00143	0.00032	0.00111	-1.6012	20218	0.0015
0.0098	-19816	-9580	798	-0.00143	0.00032	0.00111	-1.6019	17853	0.0015
0.0105	-17671	-8000	737	-0.00143	0.00032	0.00111	-1.5634	15949	0.0015
0.0113	-17162	-8106	566	-0.00143	0.00032	0.00111	-1.6088	15354	0.0015
0.0120	-17912	-7857	549	-0.00143	0.00032	0.00111	-1.5754	16009	0.0015
0.0128	-20536	-8448	414	-0.00143	0.00032	0.00111	-1.5686	18214	0.0015
0.0135	-23707	-8707	-2125	-0.00143	0.00032	0.00111	-1.8028	19159	0.0015
0.0143	-26063	-5176	4304	-0.00143	0.00032	0.00111	-1.0009	26910	0.0015
0.0150	-19025	-1410	12283	-0.00143	0.00032	0.00111	-0.2999	27184	0.0015
0.0158	-3694	-1459	10768	-0.00143	0.00032	0.00111	0.4164	13484	0.0015
0.0165	-671	3024	10793	-0.00143	0.00032	0.00111	1.2970	10135	0.0015
0.0173	-1981	617	11618	-0.00143	0.00032	0.00111	0.8201	12504	0.0015
0.0180	-5302	-4562	8694	-0.00143	0.00032	0.00111	-0.0858	13641	0.0015
0.0188	-18367	-3883	22937	-0.00153	0.00035	0.00118	0.0189	36298	0.0016
0.0195	-13869	-7743	-1457	-0.00155	0.00035	0.00120	-2.1461	10749	0.0016
0.0203	-22390	2710	14387	-0.00155	0.00035	0.00120	-0.1626	32549	0.0016
0.0210	4778	16049	41430	-0.00169	0.00035	0.00134	1.9146	32516	0.0016
0.0218	16347	18717	34009	-0.00169	0.00035	0.00134	4.1599	16604	0.0016
0.0225	6979	16797	36565	-0.00169	0.00035	0.00134	2.3118	26101	0.0018
0.0233	3884	15880	34990	-0.00169	0.00035	0.00134	2.0151	27172	0.0018
0.0240	-4428	13432	32283	-0.00169	0.00035	0.00134	1.2985	31797	0.0018
0.0248	-7804	12392	28695	-0.00169	0.00035	0.00134	1.0510	31669	0.0018
0.0255	-5459	12494	28998	-0.00169	0.00035	0.00134	1.2072	29849	0.0018
0.0263	128	13935	29668	-0.00169	0.00035	0.00134	1.7082	25601	0.0018
0.0270	-3835	10715	28162	-0.00169	0.00035	0.00134	1.2629	27748	0.0018
0.0278	-906	12178	28248	-0.00169	0.00035	0.00134	1.5626	25292	0.0018
0.0285	8929	15297	30875	-0.00169	0.00035	0.00134	2.8176	19556	0.0018
0.0293	15392	18333	33257	-0.00169	0.00035	0.00134	4.0372	16591	0.0018
0.0300	16211	20580	33409	-0.00169	0.00035	0.00134	4.5340	15483	0.0018
Max.	16347	20580	41430	0.00000	0.00035	0.00134	4.5340	36298	0.0018
Min.	-40398	-14052	-2125	-0.00169	0.00000	0.00000	-2.1461	10135	0.0000

Node and Element Plot near Impact Area

CHECK LOWER WELD

The table values are the results at the center of the elements. The strain contour plots ~~presented~~ interpolated at the surface. Following calculations are based on the stress and strain plot at node 72179.

AT TIME = 0.021 SECOND

NOTE: maximum maximum principal stress from table

minimum principal stress	$\sigma_1 := -20000$
intermediate principal stress	$\sigma_2 := 400$
maximum principal stress	$\sigma_3 := 16000$
equivalent plastic strain	$\epsilon_{eq} := 0.0175$

than the mises stress is

$$\text{Mises} := \frac{1}{\sqrt{2}} \cdot \left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right]^{\frac{1}{2}} \quad \text{Mises} = 3.127 \cdot 10^4$$

Triaxiality Factor is

$$\text{TF} := \frac{(\sigma_1 + \sigma_2 + \sigma_3)}{\text{Mises}} \quad \text{TF} = -0.115$$

Total elongation for stainless steel 304L is

$$e_t := 0.214$$

effective failure strain is

$$e_f := \text{if} \left[\text{TF} > 0, \left(e_t \cdot 2^{1-\text{TF}} \right), 2 \cdot e_t \right]$$

$$e_f = 0.428 \quad > \quad \epsilon_{eq} \quad \text{O.K.}$$

Minimum Principal Stress on node 72179 at 0.021 Second

Intermediate Principal Stress on node 72179 at 0.021 Second

Maximum Principal Stress on node 72179 at 0.02175 Second

Equivalent Plastic Strain on node 72179 at 0.02 Second

AT TIME = 0.02175 SECOND NOTE: near maximum triaxial factor

minimum principal stress $\sigma_1 := -9500$

intermediate principal stress $\sigma_2 := 5400$

maximum principal stress $\sigma_3 := 22000$

equivalent plastic strain $\epsilon_{eq} := 0.02$

than the mises stress is

$$\text{Mises} := \frac{1}{\sqrt{2}} \left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right]^{\frac{1}{2}} \quad \text{Mises} = 2.72910^4$$

Triaxiality Factor is

$$\text{TF} := \frac{(\sigma_1 + \sigma_2 + \sigma_3)}{\text{Mises}} \quad \text{TF} = 0.656$$

effective failure strain is

$$\epsilon_f := \text{if} \left[\text{TF} > 0, \left(\epsilon_t \cdot 2^{1-\text{TF}} \right), 2 \cdot \epsilon_t \right]$$

$$\epsilon_f = 0.272 \quad > \quad \epsilon_{eq} \quad \text{O.K.}$$

Minimum Principal Stress on node 72179 at 0.02175 Second

Equivalent Plastic Stress on node 72179 at 0.02175 Second

B.2 CHECK MCO BOTTOM**ELEMENT 70019 (located at MCO bottom maximum strain area)**

time (second)	minimum principal stress (psi)	intermed. principal stress (psi)	maximum principal stress (psi)	minimum principal plastic strain	intermed. principal plastic strain	maximum principal plastic strain	triaxiality factor (TF)	Mises stress (psi)	equivalent plastic strain
0.0008	-179210	-124550	-69634	-0.1448	0.0012	0.1436	-3.9348	94896	0.1665
0.0015	-192760	-129700	-67042	-0.2091	0.0018	0.2073	-3.5775	108875	0.2404
0.0023	-206460	-134520	-62126	-0.2861	0.0014	0.2847	-3.2249	124997	0.3296
0.0030	-211240	-135840	-62855	-0.3142	0.0016	0.3126	-3.1899	128511	0.3619
0.0038	-183340	-121980	-49669	-0.3308	0.0018	0.3290	-3.0631	115892	0.3809
0.0045	-118230	-91761	-26585	-0.3308	0.0018	0.3290	-2.8959	81692	0.3809
0.0053	-97067	-78911	-19176	-0.3308	0.0018	0.3290	-2.7647	70587	0.3809
0.0060	-104790	-85078	-25733	-0.3308	0.0018	0.3290	-3.0249	71276	0.3809
0.0068	-133200	-100830	-37161	-0.3308	0.0018	0.3290	-3.2044	84632	0.3809
0.0075	-162260	-115330	-47240	-0.3308	0.0018	0.3290	-3.2428	100171	0.3809
0.0083	-124870	-97508	-33537	-0.3308	0.0018	0.3290	-3.1522	81187	0.3809
0.0090	-81260	-73948	-15979	-0.3308	0.0018	0.3290	-2.7633	61949	0.3809
0.0098	-65744	-54969	-7096	-0.3308	0.0018	0.3290	-2.3637	54072	0.3809
0.0105	-54531	-33510	-86	-0.3308	0.0018	0.3290	-1.8531	47557	0.3809
0.0113	-49601	-22341	2844	-0.3308	0.0018	0.3290	-1.5210	45431	0.3809
0.0120	-57787	-37133	-2965	-0.3308	0.0018	0.3290	-2.0412	47956	0.3809
0.0128	-64941	-51592	-8088	-0.3308	0.0018	0.3290	-2.4202	51493	0.3809
0.0135	-154570	-113450	-46452	-0.3308	0.0018	0.3290	-3.3269	94523	0.3809
0.0143	-112710	-96877	-43459	-0.3310	0.0018	0.3292	-4.0263	62848	0.3812
0.0150	-62543	-21574	-4666	-0.3310	0.0018	0.3292	-1.7224	51547	0.3812
0.0158	-59030	-11461	8886	-0.3310	0.0018	0.3292	-1.0204	60371	0.3812
0.0165	-49230	-7998	27905	-0.3310	0.0018	0.3292	-0.4386	66854	0.3812
0.0173	-41876	-9322	29111	-0.3310	0.0018	0.3292	-0.3589	61547	0.3812
0.0180	-50712	-10719	24812	-0.3310	0.0018	0.3292	-0.5595	65444	0.3812
0.0188	-79223	-38824	-10472	-0.3310	0.0018	0.3292	-2.1476	59844	0.3812
0.0195	-81066	-30487	-7435	-0.3310	0.0018	0.3292	-1.8240	65235	0.3812
0.0203	-78094	-17704	-2898	-0.3310	0.0018	0.3292	-1.4305	68995	0.3812
0.0210	-69833	-19316	-6858	-0.3310	0.0018	0.3292	-1.6621	57763	0.3812
0.0218	-64766	-21103	-6776	-0.3310	0.0018	0.3292	-1.7708	52319	0.3812
0.0225	-64810	-20060	-5768	-0.3310	0.0018	0.3292	-1.6989	53352	0.3812
0.0233	-83435	-34240	-12015	-0.3310	0.0018	0.3292	-2.0487	63304	0.3812
0.0240	-74936	-16608	-1759	-0.3310	0.0018	0.3292	-1.3926	66998	0.3812
0.0248	-81402	-33337	-9693	-0.3310	0.0018	0.3292	-1.9660	63291	0.3812
0.0255	-77050	-30684	-7337	-0.3310	0.0018	0.3292	-1.8723	61461	0.3812
0.0263	-74068	-30800	-8495	-0.3310	0.0018	0.3292	-1.9631	57747	0.3812
0.0270	-70087	-27219	-7756	-0.3310	0.0018	0.3292	-1.9021	55234	0.3812
0.0278	-69973	-27192	-6981	-0.3310	0.0018	0.3292	-1.8695	55708	0.3812
Max.	-41876	-7998	29111	-0.14480	0.00178	0.32920	-0.3589	128511	0.3812
Min.	-211240	-135840	-69634	-0.33100	0.00120	0.14360	-4.0263	45431	0.1665

CHECK MCO BOTTOM

Following calculations are based on the stress and strain plot at node 70019.

AT TIME = 0.0052501
SECOND

NOTE: near maximum triaxial factor

minimum principal stress	$\sigma_1 := -107900$
intermediate principal stress	$\sigma_2 := -78910$
maximum principal stress	$\sigma_3 := -20300$
equivalent plastic strain	$\epsilon_{eq} := 0.3966$

than the mises stress is

$$\text{Mises} := \frac{1}{\sqrt{2}} \cdot \left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right]^{\frac{1}{2}} \quad \text{Mises} = 7.73 \cdot 10^4$$

Triaxiality Factor is

$$\text{TF} := \frac{(\sigma_1 + \sigma_2 + \sigma_3)}{\text{Mises}} \quad \text{TF} = -2.679$$

Total elongation for stainless steel 304L is

$$e_t := 0.40$$

effective failure strain is

$$e_f := \text{if} \left[\text{TF} > 0, \left(e_t \cdot 2^{1 - \text{TF}} \right), 2 \cdot e_t \right]$$

$$e_f = 0.8 \quad > \quad \epsilon_{eq} \quad \text{O.K.}$$

Minimum Principal Stress on node 70019 at 0.0052501 Second

Intermediate Principal Stress on node 70019 at 0.0052501 Second

Maximum Principal Stress on node 70019 at 0.0052501 Second

APPENDIX - C
COMPUTER INPUT FILES

APPENDIX C

ABAQUS INPUT FILE

SECTION ONE

MCO DROP ON STANDARD STORAGE TUBE

Originator: KCTH KOIu Date: 9/27/99

Checked by: MB LAGIA Legs Date: 9/27/99

APPENDIX C SECTION ONE
INPUT FILE N1010.inp

SNF-5204, Rev. 0/CSB-S-0073

```
** file "n10_10.inp"
*HEADING
MCO DROP ONTO TUBE(MCO shell w/ 7 solid el &
basket support)
*INCLUDE, INPUT=mco7.txt
*INCLUDE, INPUT=bsk1a4.txt
*SYSTEM
**
*INCLUDE, INPUT=stdstd2.txt
*SYSTEM
-1,22.75,
*NODE,NSET=RGD1
95001,-17.5,55,0
95003,-17.5,114.15,0
95005,-13.625,128.91,0
95007,-13.625,160.,0
*NODE,NSET=RGD2
95011,17.5,55,0
95013,17.5,114.15,0
95015,13.625,128.91,0
95017,13.625,160.,0
*SYSTEM
***
*NODE,NSET=RGD3
95031,15.25,-34.5,0
95041,15.25,-3,0
95051,16.00,-2.25,0
95061,23.625,-2.25,0
95071,23.625,6,0
*NCOPY,CHANGE NUMBER=1,OLD SET=RGD3,SHIFT,NEW
SET=RGD3,multiple=6
,0,
0,0,0,0,1,0,3.44
*NCOPY,CHANGE NUMBER=1,OLD SET=RGD2,SHIFT,NEW
SET=RGD2
,0,
0,0,0,0,1,0,3.75
*NCOPY,CHANGE NUMBER=1,OLD SET=RGD1,SHIFT,NEW
SET=RGD1
,0,
0,0,0,0,1,0,-15.
*node
95020,-12.625,100.,
95099,23.625,-10,0
*element,type=R3D4,elset=rgd1
95001, 95001, 95002, 95004, 95003
95002, 95003, 95004, 95006, 95005
95003, 95005, 95006, 95008, 95007
*element,type=R3D4,elset=rgd2
95004, 95011, 95012, 95014, 95013
95005, 95013, 95014, 95016, 95015
95006, 95015, 95016, 95018, 95017
*element,type=R3D4,elset=rgd3
95007, 95031, 95032, 95042, 95041
*elgen,elset=rgd3
95007,4,10,1,5,1,4
**
*ELSET, ELSET=SSTA
FLANG, TUBES, TUBE
*ELSET, ELSET=TTT
MCO, EBSK, SSTA
**
*SOLID SECTION, ELSET=FLANG, MATERIAL=SA36
*SOLID SECTION, ELSET=TUBES, MATERIAL=SA36
*SHELL SECTION, ELSET=TUBE, MATERIAL=SA36
0.5
*rigid body, elset=rgd1,ref node=95020
```

```
1.31
*rigid body, elset=rgd2,ref node=95020
0.001
*rigid body, elset=rgd3,ref node=95099
0.001
*MATERIAL,NAME=SS304
*DENSITY
.000735
*ELASTIC
28.E+06,.27
*PLASTIC
36161,0
38390,0.02
40405,0.05
41771,0.08
45369,0.18
51002,0.37
127236,0.466
*MATERIAL,NAME=SA36
*DENSITY
.0007339
*ELASTIC
29.5E6,0.30
*PLASTIC
36088,0
38590,0.0197
60421,0.0904
75291,0.1486
**
*BOUNDARY
95020,encastre
95099,encastre
*INITIAL CONDITIONS, TYPE=VELOCITY
MCO, 2, -264
BSK, 2, -264
*RESTART, WRITE, NUMBER INTERVAL=40
*STEP
*DYNAMIC, EXPLICIT
,3.E-2
**
*SURFACE DEFINITION, NAME=FTOF
FLGO,S4
FLGB,S1
TUBO,S4
*SURFACE DEFINITION, NAME=DECK
rgd3, SNEG
*CONTACT PAIR, INTERACTION=FO
FTOF,DECK
*SURFACE INTERACTION, NAME=FD
*FRICTION
0.3
**
*SURFACE DEFINITION, NAME=FTIF
FLGI,S6
TUBI,S6
*SURFACE DEFINITION, NAME=MCOBF
MCOBF, S4
MCOBF, S1
*CONTACT PAIR, INTERACTION=FM
MCOBF,FTIF
*SURFACE INTERACTION, NAME=FM
*FRICTION
0.3
**
*SURFACE DEFINITION, NAME=rgd1f
rgd1, SPOS
*SURFACE DEFINITION, NAME=MCOTL
```

APPENDIX C SECTION ONE
INPUT FILE N1010.inp

SNF-5204, Rev. 0/CSB-S-0073

MCOTL, SPOS	76205,76240,1
*CONTACT PAIR, INTERACTION=FMTL	77205,77240,1
rgd1f,MCOTL	78205,78240,1
*SURFACE INTERACTION, NAME=FMTL	79205,79240,1
*FRICTION	80205,80240,1
0.3	81205,81240,1
**	82205,82240,1
*SURFACE DEFINITION, NAME=rgd2f	83205,83240,1
rgd2, SNEG	84205,84240,1
*SURFACE DEFINITION, NAME=MCOTR	85205,85240,1
MCOTR, SPOS	86205,86240,1
*CONTACT PAIR, INTERACTION=FMTR	87205,87240,1
rgd2f,MCOTR	88205,88240,1
*SURFACE INTERACTION, NAME=FMTR	89205,89240,1
*FRICTION	90205,90240,1
0.3	91205,91240,1
**	92205,92240,1
*SURFACE DEFINITION, NAME=bskb1	93205,93240,1
bskb1,S1	*SURFACE DEFINITION, NAME=mcopi
bskc1,s1	mcopi,sneg
bskb1,S4	*CONTACT PAIR, INTERACTION=b1
*SURFACE DEFINITION, NAME=bskb2	BSKB1,mcopi
bskb2,S1	*SURFACE INTERACTION, NAME=b1
bskc2,s1	*FRICTION
bskb2,S4	0.3
*SURFACE DEFINITION, NAME=bskb3	*CONTACT PAIR, INTERACTION=b2
bskb3,S1	BSKB2,mcopi
bskc3,s1	*SURFACE INTERACTION, NAME=b2
bskb3,S4	*FRICTION
*SURFACE DEFINITION, NAME=bskb4	0.3
bskb4,S1	*CONTACT PAIR, INTERACTION=b3
bskc4,s1	BSKB3,mcopi
bskb4,S4	*SURFACE INTERACTION, NAME=b3
*SURFACE DEFINITION, NAME=bskb5	*FRICTION
bskb5,S1	0.3
bskc5,s1	*CONTACT PAIR, INTERACTION=b4
bskb5,S4	BSKB4,mcopi
*SURFACE DEFINITION, NAME=bskb6	*SURFACE INTERACTION, NAME=b4
bskb6,S1	*FRICTION
bskc6,s1	0.3
bskb6,S4	*CONTACT PAIR, INTERACTION=b5
*CONTACT NODE SET, NAME=bspb	BSKB5,mcopi
bspb	*SURFACE INTERACTION, NAME=b5
*SURFACE DEFINITION, NAME=mcosi	*FRICTION
mcobt,S2	0.3
mcosi,s6	*CONTACT PAIR, INTERACTION=b6
*CONTACT PAIR, INTERACTION=BSmco	BSKB6,mcopi
bspb,mcosi	*SURFACE INTERACTION, NAME=b6
*SURFACE INTERACTION, NAME=BSmco	*FRICTION
*FRICTION	0.3
0.3	**
*CONTACT NODE SET, NAME=bspt	*NSET,NSET=NOUT
bspt	70019,70000,70179,82019,94019,82133,94133
*CONTACT PAIR, INTERACTION=BSK01	31231,32231,33231,34231,35231,36231,94577
bspt,BSKB1	*NSET,GENERATE,NSET=TOUT
*SURFACE INTERACTION, NAME=BSK01	260,380,40
*FRICTION	100,220,60
0.3	24100,24220,60
*SURFACE DEFINITION, NAME=mcotb	600,850,50
mcot,S1	24600,24850,50
*elset,elset=mcopi,generate	70300,94300,1000
70205,70240,1	70301,94301,1000
71205,71240,1	70302,94302,1000
72205,72240,1	70303,94303,1000
73205,73240,1	70304,94304,1000
74205,74240,1	70305,94305,1000
75205,75240,1	70306,94306,1000

APPENDIX C SECTION ONE
INPUT FILE N1010.inp

SNF-5204, Rev. 0/CSB-S-0073

```
70307,94307,1000
70308,94308,1000
70309,94309,1000
*OUTPUT,HISTORY,TIME INTERVAL=1.E-4
*NODE OUTPUT, NSET=NOU
U,V,A
*NODE OUTPUT, NSET=TOUT
U
*NODE OUTPUT, NSET=PFLR
RF
*nset,nset=rgdn
95020,95099
*NODE OUTPUT, NSET=rgdn
RF
*ELSET,ELSET=EOUT
70301,70304,70307,70019
*ELEMENT OUTPUT,ELSET=EOUT
S,SP,PE,MISES,PEEQ
*ENERGY output
ALLKE
*elset,elset=st
flang,tubes,tubep
*energy output,elset=st
allie,allpd
*output,field,number interval=40
*element output
S,SP,MISES,PE,PEEQ,E,EP
*node output
U,V,rf
*MONITOR, NODE=70019, DOF=2
*END STEP
** end of file
```

APPENDIX C SECTION ONE
INPUT FILE Mco7.txt

SNF-5204, Rev. 0/CSB-S-0073

```

** "MCO7.TXT"
** 7 elements through thickness
** with basket support plates off symm plane
** MCO model drop on lower right corner
*SYSTEM
4.834, 2.78, 0, 14.8256, 3.19, 0
4.424, 12.7716, 0
** MCO bottom ring
*NODE
70012, 10.3, 0, 0
70132, 11.0125, 2.01, 0
*NGEN, NSET=N3
70012, 70132, 20
*NODE, NSET=N3
70152, 11.366, 2.1564, 0
70172, 11.50, 2.51, 0
*NODE
70019, 11.423, 0, 0
70079, 11.93076, 1.13, 0
*NGEN, NSET=N4
70019, 70079, 20
*NODE
70099, 12, 1.423333, 0
70139, 12, 2.01, 0
70179, 12, 2.51, 0
*NGEN, NSET=N4
70099, 70139, 20
70139, 70179, 20
*NFILL, NSET=N34
N3, N4, 7, 1
*NODE, NSET=N34
70019, 11.394, 0.0502, 0
** shell (solid)
*NODE
70200, 11.5, 2.8, 0
70900, 12.0, 2.8, 0
70240, 11.5, 22.5, 0
70940, 12.0, 22.5, 0
*ngen, NSET=ssb
70200, 70900, 100
*ngen, NSET=sst
70240, 70940, 100
*nfill, nset=n34
ssb, sst, 40, 1
** MCO top ring
*NODE, nset=st
70576, 11.75, 148, 0
*NODE, NSET=N34
70577, 11.75, 160, 0
*nnode, nset=sb
70541, 11.75, 22.5, 0
*NFILL, NSET=N34, BIAS=.91
sb, st, 35, 1
*NCOPY, CHANGE NUMBER=1000, OLD SET=N34, SHIFT, NEW
SET=MCO
,0,
4.834, 2.78, 0, 4.424, 12.7716, 0, 3.75
*NCOPY, CHANGE NUMBER=2000, OLD SET=N34, SHIFT, NEW
SET=MCO
,0,
4.834, 2.78, 0, 4.424, 12.7716, 0, 7.5
*NCOPY, CHANGE NUMBER=3000, OLD SET=N34, SHIFT, NEW
SET=MCO
,0,
4.834, 2.78, 0, 4.424, 12.7716, 0, 11.25

```

```

*NCOPY, CHANGE NUMBER=4000, OLD SET=N34, SHIFT, NEW
SET=MCO
,0,
4.834, 2.78, 0, 4.424, 12.7716, 0, 15.
*NCOPY, CHANGE NUMBER=5000, OLD SET=N34, SHIFT, NEW
SET=MCO
,0,
4.834, 2.78, 0, 4.424, 12.7716, 0, 18.75
*NCOPY, CHANGE NUMBER=6000, OLD SET=N34, SHIFT, NEW
SET=MCO
,0,
4.834, 2.78, 0, 4.424, 12.7716, 0, 22.5
*NCOPY, CHANGE NUMBER=7000, OLD SET=N34, SHIFT, NEW
SET=MCO
,0,
4.834, 2.78, 0, 4.424, 12.7716, 0, 26.25
*NCOPY, CHANGE NUMBER=8000, OLD SET=N34, SHIFT, NEW
SET=MCO
,0,
4.834, 2.78, 0, 4.424, 12.7716, 0, 30.
*NCOPY, CHANGE NUMBER=9000, OLD SET=N34, SHIFT, NEW
SET=MCO
,0,
4.834, 2.78, 0, 4.424, 12.7716, 0, 36.
*NCOPY, CHANGE NUMBER=10000, OLD SET=N34, SHIFT, NEW
SET=MCO
,0,
4.834, 2.78, 0, 4.424, 12.7716, 0, 42.
*NCOPY, CHANGE NUMBER=11000, OLD SET=N34, SHIFT, NEW
SET=MCO
,0,
4.834, 2.78, 0, 4.424, 12.7716, 0, 48.
*NCOPY, CHANGE NUMBER=12000, OLD SET=N34, SHIFT, NEW
SET=MCO
,0,
4.834, 2.78, 0, 4.424, 12.7716, 0, 54.
*NCOPY, CHANGE NUMBER=13000, OLD SET=N34, SHIFT, NEW
SET=MCO
,0,
4.834, 2.78, 0, 4.424, 12.7716, 0, 60.
*NCOPY, CHANGE NUMBER=14000, OLD SET=N34, SHIFT, NEW
SET=MCO
,0,
4.834, 2.78, 0, 4.424, 12.7716, 0, 67.5
*NCOPY, CHANGE NUMBER=15000, OLD SET=N34, SHIFT, NEW
SET=MCO
,0,
4.834, 2.78, 0, 4.424, 12.7716, 0, 75.
*NCOPY, CHANGE NUMBER=16000, OLD SET=N34, SHIFT, NEW
SET=MCO
,0,
4.834, 2.78, 0, 4.424, 12.7716, 0, 82.5
*NCOPY, CHANGE NUMBER=17000, OLD SET=N34, SHIFT, NEW
SET=MCO
,0,
4.834, 2.78, 0, 4.424, 12.7716, 0, 90.
*NCOPY, CHANGE NUMBER=18000, OLD SET=N34, SHIFT, NEW
SET=MCO
,0,
4.834, 2.78, 0, 4.424, 12.7716, 0, 100.
*NCOPY, CHANGE NUMBER=19000, OLD SET=N34, SHIFT, NEW
SET=MCO
,0,
4.834, 2.78, 0, 4.424, 12.7716, 0, 110.
*NCOPY, CHANGE NUMBER=20000, OLD SET=N34, SHIFT, NEW
SET=MCO
,0,

```

APPENDIX C SECTION ONE
INPUT FILE Mco7.txt

SNF-5204, Rev. 0/CSB-S-0073

4.834,2.78,0,4.424,12.7716,0,120.
*NCOPY,CHANGE NUMBER=21000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
4.834,2.78,0,4.424,12.7716,0,135.
*NCOPY,CHANGE NUMBER=22000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
4.834,2.78,0,4.424,12.7716,0,150.
*NCOPY,CHANGE NUMBER=23000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
4.834,2.78,0,4.424,12.7716,0,165.
*NCOPY,CHANGE NUMBER=24000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
4.834,2.78,0,4.424,12.7716,0,180
*NODE
70000,1.25,0,0
70060,1.25,1.13,0
*NGEN,NSET=N1
70000,70060,20
*NODE
70120,2.13,2.01,0
*NGEN,NSET=N1
70060,70120,20
*NCOPY,CHANGE NUMBER=1000,OLD SET=N1,SHIFT,NEW
SET=N1,MULTIPLE=24
,0,
4.834,2.78,0,4.424,12.7716,0,7.5
*NSET,NSET=N2,GENERATE
70012,94012,1000
70032,94032,1000
70052,94052,1000
70072,94072,1000
70092,94092,1000
70112,94112,1000
70132,94132,1000
*NFILL,NSET=N12,BIAS=1.01
N1,N2,12,1
*ELEMENT,TYPE=C3D8R,ELSET=MCOB
70001,70000,70001,71001,71000,70020,70021,71021,7
1020
*ELGEN,ELSET=MCOB
70001,19,1,1,6,20,20,24,1000,1000
70113,2,20,20
70133,7,1,1,2,20,20,24,1000,1000
*ELEMENT,TYPE=C3D8R,ELSET=MCOPS
70301,70172,70173,71173,71172,70200,70300,71300,7
1200
70302,70173,70174,71174,71173,70300,70400,71400,7
1300
70303,70174,70175,71175,71174,70400,70500,71500,7
1400
70304,70175,70176,71176,71175,70500,70600,71600,7
1500
70305,70176,70177,71177,71176,70600,70700,71700,7
1600
70306,70177,70178,71178,71177,70700,70800,71800,7
1700
70307,70178,70179,71179,71178,70800,70900,71900,7
1800
70308,70200,70300,71300,71200,70201,70301,71301,7
1201
*ELGEN,ELSET=MCOPS
70301,24,1000,1000
70302,24,1000,1000

70303,24,1000,1000
70304,24,1000,1000
70305,24,1000,1000
70306,24,1000,1000
70307,24,1000,1000
70308,7,100,1,40,1,7,24,1000,1000
*mpc
beam,70541,70240
beam,71541,71240
beam,72541,72240
beam,73541,73240
beam,74541,74240
beam,75541,75240
beam,76541,76240
beam,77541,77240
beam,78541,78240
beam,79541,79240
beam,80541,80240
beam,81541,81240
beam,82541,82240
beam,83541,83240
beam,84541,84240
beam,85541,85240
beam,86541,86240
beam,87541,87240
beam,88541,88240
beam,89541,89240
beam,90541,90240
beam,91541,91240
beam,92541,92240
beam,93541,93240
beam,94541,94240
beam,70541,70240
beam,71541,71340
beam,72541,72340
beam,73541,73340
beam,74541,74340
beam,75541,75340
beam,76541,76340
beam,77541,77340
beam,78541,78340
beam,79541,79340
beam,80541,80340
beam,81541,81340
beam,82541,82340
beam,83541,83340
beam,84541,84340
beam,85541,85340
beam,86541,86340
beam,87541,87340
beam,88541,88340
beam,89541,89340
beam,90541,90340
beam,91541,91340
beam,92541,92340
beam,93541,93340
beam,94541,94340
beam,70541,70440
beam,71541,71440
beam,72541,72440
beam,73541,73440
beam,74541,74440
beam,75541,75440
beam,76541,76440
beam,77541,77440
beam,78541,78440
beam,79541,79440

APPENDIX C SECTION ONE
INPUT FILE Mco7.txt

SNF-5204, Rev. 0/CSB-S-0073

beam,80541,80440
beam,81541,81440
beam,82541,82440
beam,83541,83440
beam,84541,84440
beam,85541,85440
beam,86541,86440
beam,87541,87440
beam,88541,88440
beam,89541,89440
beam,90541,90440
beam,91541,91440
beam,92541,92440
beam,93541,93440
beam,94541,94440
beam,70541,70540
beam,71541,71540
beam,72541,72540
beam,73541,73540
beam,74541,74540
beam,75541,75540
beam,76541,76540
beam,77541,77540
beam,78541,78540
beam,79541,79540
beam,80541,80540
beam,81541,81540
beam,82541,82540
beam,83541,83540
beam,84541,84540
beam,85541,85540
beam,86541,86540
beam,87541,87540
beam,88541,88540
beam,89541,89540
beam,90541,90540
beam,91541,91540
beam,92541,92540
beam,93541,93540
beam,94541,94540
beam,70541,70640
beam,71541,71640
beam,72541,72640
beam,73541,73640
beam,74541,74640
beam,75541,75640
beam,76541,76640
beam,77541,77640
beam,78541,78640
beam,79541,79640
beam,80541,80640
beam,81541,81640
beam,82541,82640
beam,83541,83640
beam,84541,84640
beam,85541,85640
beam,86541,86640
beam,87541,87640
beam,88541,88640
beam,89541,89640
beam,90541,90640
beam,91541,91640
beam,92541,92640
beam,93541,93640
beam,94541,94640
beam,70541,70740
beam,71541,71740

beam,72541,72740
beam,73541,73740
beam,74541,74740
beam,75541,75740
beam,76541,76740
beam,77541,77740
beam,78541,78740
beam,79541,79740
beam,80541,80740
beam,81541,81740
beam,82541,82740
beam,83541,83740
beam,84541,84740
beam,85541,85740
beam,86541,86740
beam,87541,87740
beam,88541,88740
beam,89541,89740
beam,90541,90740
beam,91541,91740
beam,92541,92740
beam,93541,93740
beam,94541,94740
beam,70541,70840
beam,71541,71840
beam,72541,72840
beam,73541,73840
beam,74541,74840
beam,75541,75840
beam,76541,76840
beam,77541,77840
beam,78541,78840
beam,79541,79840
beam,80541,80840
beam,81541,81840
beam,82541,82840
beam,83541,83840
beam,84541,84840
beam,85541,85840
beam,86541,86840
beam,87541,87840
beam,88541,88840
beam,89541,89840
beam,90541,90840
beam,91541,91840
beam,92541,92840
beam,93541,93840
beam,94541,94840
beam,70541,70940
beam,71541,71940
beam,72541,72940
beam,73541,73940
beam,74541,74940
beam,75541,75940
beam,76541,76940
beam,77541,77940
beam,78541,78940
beam,79541,79940
beam,80541,80940
beam,81541,81940
beam,82541,82940
beam,83541,83940
beam,84541,84940
beam,85541,85940
beam,86541,86940
beam,87541,87940
beam,88541,88940

APPENDIX C SECTION ONE
INPUT FILE Mco7.txt

SNF-5204, Rev. 0/CSB-S-0073

```
beam,89541,89940
beam,90541,90940
beam,91541,91940
beam,92541,92940
beam,93541,93940
beam,94541,94940
*ELEMENT,TYPE=S4RS,ELSET=MCOPL
70205,70540,71540,71541,70541
*ELGEN,ELSET=MCOPL
70205,36,1,1,24,1000,1000
** MCO bottom center
*NODE
60000,-1.08,0,0
66000,-.7637,0,-.7637
*NGEN,NSET=L1
60000,66000,1000
*NODE
60012,1.08,0,0
66012,.7637,0,-.7637
*NGEN,NSET=L2
60012,66012,1000
*NODE
60006,0,0,0
66006,0,0,-1.08
*NGEN,NSET=L3
60006,66006,1000
*NFILL,NSET=L12
L1,L3,6,1
L3,L2,6,1
*NCOPY,CHANGE NUMBER=60,OLD SET=L12,SHIFT,NEW
SET=L13
-0.0262,0.8796,0

*NFILL,NSET=L14
L12,L13,3,20
*ELEMENT,TYPE=C3D8R,ELSET=MCOB
60101,60000,60001,61001,61000,60020,60021,61021,6
1020
*ELGEN,ELSET=MCOB
60101,12,1,1,6,1000,12,3,20,72
*ELEMENT,TYPE=C3D8R,ELSET=EB1
60001,60012,70000,71000,61012,60032,70020,71020,6
1032
*ELGEN,ELSET=EB2
60001,6,1000,1,3,20,6
*ELEMENT,TYPE=C3D8R,ELSET=EB3
60019,66012,76000,77000,66011,66032,76020,77020,6
6031
60020,66011,77000,78000,66010,66031,77020,78020,6
6030
60021,66010,78000,79000,66009,66030,78020,79020,6
6029
60022,66009,79000,80000,66008,66029,79020,80020,6
6028
60023,66008,80000,81000,66007,66028,80020,81020,6
6027
60024,66007,81000,82000,66006,66027,81020,82020,6
6026
60025,66006,82000,83000,66005,66026,82020,83020,6
6025
60026,66005,83000,84000,66004,66025,83020,84020,6
6024
60027,66004,84000,85000,66003,66024,84020,85020,6
6023
60028,66003,85000,86000,66002,66023,85020,86020,6
6022
```

```
60029,66002,86000,87000,66001,66022,86020,87020,6
6021
60030,66001,87000,88000,66000,66021,87020,88020,6
6020
60031,66000,88000,89000,65000,66020,88020,89020,6
5020
60032,65000,89000,90000,64000,65020,89020,90020,6
4020
60033,64000,90000,91000,63000,64020,90020,91020,6
3020
60034,63000,91000,92000,62000,63020,91020,92020,6
2020
60035,62000,92000,93000,61000,62020,92020,93020,6
1020
60036,61000,93000,94000,60000,61020,93020,94020,6
0020
*ELCOPY,ELEMENT SHIFT=18,OLD SET=EB3,SHIFT
NODES=20, NEW SET=EB4
*ELCOPY,ELEMENT SHIFT=18,OLD SET=EB4,SHIFT
NODES=20, NEW SET=EB5
*ELSET,ELSET=MCOB
EB2,EB3,EB4,EB5
** MCO top center
*NODE
50000,-8.,148,0
56000,-1.,148,-8.5
*NGEN,NSET=T1
50000,56000,1000
*NODE
50012,10.8,148,0
56012, 9.1,148,-3.77
*NGEN,NSET=T2
50012,56012,1000
*NODE
50006,5.8,148,0
56006,5.8,148,-7.97
*NGEN,NSET=T3
50006,56006,1000
*NFILL,NSET=T12
T1,T3,6,1
T3,T2,6,1
*NCOPY,CHANGE NUMBER=20,OLD SET=T12,SHIFT,NEW
SET=T13
-0.4920,11.9899,0

*ELEMENT,TYPE=C3D8R,ELSET=MCOT
60601,50000,50001,51001,51000,50020,50021,51021,5
1020
*ELGEN,ELSET=MCOT
60601,12,1,1,6,1000,12
*ELEMENT,TYPE=C3D8R,ELSET=EB11
50001,50012,70576,71576,51012,50032,70577,71577,5
1032
*ELGEN,ELSET=EB11
50001,6,1000,1
*ELEMENT,TYPE=C3D8R,ELSET=EB12
50007,56012,76576,77576,56011,56032,76577,77577,5
6031
50008,56011,77576,78576,56010,56031,77577,78577,5
6030
50009,56010,78576,79576,56009,56030,78577,79577,5
6029
50010,56009,79576,80576,56008,56029,79577,80577,5
6028
50011,56008,80576,81576,56007,56028,80577,81577,5
6027
```

APPENDIX C SECTION ONE
INPUT FILE Mco7.txt

SNF-5204, Rev. 0/CSB-S-0073

50012,56007,81576,82576,56006,56027,81577,82577,5
6026
50013,56006,82576,83576,56005,56026,82577,83577,5
6025
50014,56005,83576,84576,56004,56025,83577,84577,5
6024
50015,56004,84576,85576,56003,56024,84577,85577,5
6023
50016,56003,85576,86576,56002,56023,85577,86577,5
6022
50017,56002,86576,87576,56001,56022,86577,87577,5
6021
50018,56001,87576,88576,56000,56021,87577,88577,5
6020
50019,56000,88576,89576,55000,56020,88577,89577,5
5020
50020,55000,89576,90576,54000,55020,89577,90577,5
4020
50021,54000,90576,91576,53000,54020,90577,91577,5
3020
50022,53000,91576,92576,52000,53020,91577,92577,5
2020
50023,52000,92576,93576,51000,52020,92577,93577,5
1020
50024,51000,93576,94576,50000,51020,93577,94577,5
0020
*ELSET,ELSET=MCOT
EB11,EB12
**
*ELSET,ELSET=MCOBB,GENERATE
70019,82019,1000
70018,82018,1000
70017,82017,1000
70016,82016,1000
70015,82015,1000
70014,82014,1000
*ELSET,ELSET=MCOBF,GENERATE
70019,82019,1000
70039,82039,1000
70059,82059,1000
70079,82079,1000
70099,82099,1000
70119,82119,1000
70139,82139,1000
*ELSET,ELSET=MCOTR
70239
*ELSET,ELSET=MCOTL
93239
*ELSET,ELSET=MCOSF,GENERATE
70202,70215,1
71202,71215,1
72202,72215,1
73202,73215,1
74202,74215,1
75202,75215,1
76202,76215,1
77202,77215,1
78202,78215,1
79202,79215,1
** add basket support plates
*node
40140,1.25,2.01,0
40200,1.25,3.25,0
40154,11.01,2.01,0
40214,11.01,3.25,0
*ngen,nset=bsp1
40140,40200,20

*ngen,nset=bsp2
40154,40214,20
*NCOPY,CHANGE NUMBER=1000,OLD SET=bsp1,SHIFT,NEW
SET=bsp3
,0,
*NCOPY,CHANGE NUMBER=2000,OLD SET=bsp1,SHIFT,NEW
SET=bsp3
,0,
4.834,2.78,0,4.424,12.7716,0,30
*NCOPY,CHANGE NUMBER=3000,OLD SET=bsp1,SHIFT,NEW
SET=bsp3
,0,
4.834,2.78,0,4.424,12.7716,0,60
*NCOPY,CHANGE NUMBER=4000,OLD SET=bsp1,SHIFT,NEW
SET=bsp3
,0,
4.834,2.78,0,4.424,12.7716,0,90
*NCOPY,CHANGE NUMBER=5000,OLD SET=bsp1,SHIFT,NEW
SET=bsp3
,0,
4.834,2.78,0,4.424,12.7716,0,120
*NCOPY,CHANGE NUMBER=6000,OLD SET=bsp1,SHIFT,NEW
SET=bsp3
,0,
4.834,2.78,0,4.424,12.7716,0,150
*NCOPY,CHANGE NUMBER=7000,OLD SET=bsp1,SHIFT,NEW
SET=bsp3
,0,
4.834,2.78,0,4.424,12.7716,0,180
*NCOPY,CHANGE NUMBER=8000,OLD SET=bsp1,SHIFT,NEW
SET=bsp3
,0,
4.834,2.78,0,4.424,12.7716,0,180
*NCOPY,CHANGE NUMBER=9000,OLD SET=bsp1,SHIFT,NEW
SET=bsp3
,0,
4.834,2.78,0,4.424,12.7716,0,180
*NCOPY,CHANGE NUMBER=1000,OLD SET=bsp2,SHIFT,NEW
SET=bsp4
,0,
4.834,2.78,0,4.424,12.7716,0,26.7458
*NCOPY,CHANGE NUMBER=2000,OLD SET=bsp2,SHIFT,NEW
SET=bsp4
,0,
4.834,2.78,0,4.424,12.7716,0,30
*NCOPY,CHANGE NUMBER=3000,OLD SET=bsp2,SHIFT,NEW
SET=bsp4
,0,
4.834,2.78,0,4.424,12.7716,0,33.2542
*NCOPY,CHANGE NUMBER=4000,OLD SET=bsp2,SHIFT,NEW
SET=bsp4
,0,
4.834,2.78,0,4.424,12.7716,0,86.7458
*NCOPY,CHANGE NUMBER=5000,OLD SET=bsp2,SHIFT,NEW
SET=bsp4
,0,
4.834,2.78,0,4.424,12.7716,0,90
*NCOPY,CHANGE NUMBER=6000,OLD SET=bsp2,SHIFT,NEW
SET=bsp4
,0,
4.834,2.78,0,4.424,12.7716,0,93.2542
*NCOPY,CHANGE NUMBER=7000,OLD SET=bsp2,SHIFT,NEW
SET=bsp4
,0,
4.834,2.78,0,4.424,12.7716,0,146.7458

APPENDIX C SECTION ONE
INPUT FILE Mco7.txt

SNF-5204, Rev. 0/CSB-S-0073

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*NCOPY,CHANGE NUMBER=8000,OLD SET=bsp2,SHIFT,NEW
SET=bsp4
,0,
4.834,2.78,0,4.424,12.7716,0,150
*NCOPY,CHANGE NUMBER=9000,OLD SET=bsp2,SHIFT,NEW
SET=bsp4
,0,
4.834,2.78,0,4.424,12.7716,0,153.2542
*nset,nset=bsp3
bsp1
*nset,nset=bsp4
bsp2
*nfill,nset=mco
bsp3,bsp4,14,1
*ELEMENT,TYPE=C3D8R,ELSET=bsp
97001,41140,41141,42141,42140,41160,41161,42161,4
2160
97101,42140,42141,43141,43140,42160,42161,43161,4
3160
*ELGEN,ELSET=bsp
97001,14,1,1,3,20,14,3,3000,200
97101,14,1,1,3,20,14,3,3000,200
*mpc
link,43140,44140
link,43160,44160
link,43180,44180
link,43200,44200
link,46140,47140
link,46160,47160
link,46180,47180
link,46200,47200
*ELSET, ELSET=MCOSL
MCOT, MCOB
*SOLID SECTION, ELSET=MCOSL, MATERIAL=SS304
*SOLID SECTION, ELSET=MCOPS, MATERIAL=SS304
*SHELL SECTION, ELSET=MCOPL, MATERIAL=SS304
0.5
*SOLID SECTION, ELSET=bsp, MATERIAL=SS304
*nset,nset=bspb,generate
40140,40154,1
41140,41154,1
42140,42154,1
43140,43154,1
44140,44154,1
45140,45154,1
46140,46154,1
47140,47154,1
48140,48154,1
49140,49154,1
*nset,nset=bspt,generate
40200,40214,1
41200,41214,1
42200,42214,1
43200,43214,1
44200,44214,1
45200,45214,1
46200,46214,1
47200,47214,1
48200,48214,1
49200,49214,1
*NSET,NSET=MCO
N34,S8,ST,N12,L14,T12,T13
bspt,bspb
*ELSET, ELSET=MCO
MCOPL, MCOSL, mcops, bsp
*elset,elset=mcobt,generate
70101,93101,1000
70102,93102,1000
70103,93103,1000
70104,93104,1000
70105,93105,1000
70106,93106,1000
70107,93107,1000
70108,93108,1000
70109,93109,1000
70110,93110,1000
70111,93111,1000
70112,93112,1000
*elset,elset=mcosi,generate
70133,93133,1000
70153,93153,1000
70301,93301,1000
70308,93308,1000
70315,93315,1000
70322,93322,1000
70329,93329,1000
70336,93336,1000
*NSET,NSET=MCOSY,GENERATE
70000,70999,1
94000,94999,1
50000,50999,1
60000,60999,1
79140,79200,20
*BOUNDARY
MCOSY, ZSYMM
** end of file

```

```

** mark1a4.txt
*SYSTEM
4.7003, 6.0373, 0, 14.6919, 6.4473, 0
4.4240, 12.7716, 0
*node, nset=nbsk0
31000, 11.3125, 0, 0
*NCOPY, CHANGE NUMBER=1, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 3.75
*NCOPY, CHANGE NUMBER=2, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 7.5
*NCOPY, CHANGE NUMBER=3, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 11.25
*NCOPY, CHANGE NUMBER=4, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 15.
*NCOPY, CHANGE NUMBER=5, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 18.75
*NCOPY, CHANGE NUMBER=6, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 22.5
*NCOPY, CHANGE NUMBER=7, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 26.25
*NCOPY, CHANGE NUMBER=8, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 30.
*NCOPY, CHANGE NUMBER=9, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 36.
*NCOPY, CHANGE NUMBER=10, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 42
*NCOPY, CHANGE NUMBER=11, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 48.
*NCOPY, CHANGE NUMBER=12, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 54.
*NCOPY, CHANGE NUMBER=13, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 60
*NCOPY, CHANGE NUMBER=14, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 67.5
*NCOPY, CHANGE NUMBER=15, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 75.

```

```

*NCOPY, CHANGE NUMBER=16, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 82.5
*NCOPY, CHANGE NUMBER=17, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 90.
*NCOPY, CHANGE NUMBER=18, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 100.
*NCOPY, CHANGE NUMBER=19, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 110.
*NCOPY, CHANGE NUMBER=20, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 120.
*NCOPY, CHANGE NUMBER=21, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 135.
*NCOPY, CHANGE NUMBER=22, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 150.
*NCOPY, CHANGE NUMBER=23, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 165.
*NCOPY, CHANGE NUMBER=24, OLD SET=nbsk0, SHIFT, NEW
SET=nbsk1
, 0,
4.7003, 6.0373, 0, 4.4240, 12.7716, 0, 180.
*nset, nset=nbsk1
nbsk0
*node
31037, -8., 0, 0
31115, -1., 0, -8.5
*ngen, nset=bskt1
31037, 31115, 13
*node
31025, 10.6, 0, 0
31103, 9., 0, -3.76
*ngen, nset=bskt2
31025, 31103, 13
*node
31031, 0, 0, 0
31109, 5.7, 0, -7.9
*ngen, nset=bskt3
31031, 31109, 13
*nfill, nset=nbsk1
bskt2, bskt3, 6, 1
bskt3, bskt1, 6, 1
*NCOPY, CHANGE NUMBER=200, OLD
SET=nbsk1, SHIFT, NEW SET=nbsk1
-0.041, 0.9992

*node, nset=bskp0
31410, 11.3125, 8, 0
31411, 11.3125, 16, 0
31412, 11.3125, 23.166, 0
*NCOPY, CHANGE NUMBER=10, OLD SET=bskp0, SHIFT, NEW
SET=nbskp, multiple=3
, 0,

```

APPENDIX C SECTION ONE
INPUT FILE Bsk1a4.txt

SNF-5204, Rev. 0/CSB-S-0073

4.7003,6.0373,0,4.4240,12.7716,0,60.

*node,nset=nbskp

31400,,8,0

31401,,16,0

31402,,23.166,0

*nset,nset=nbsk1

nbskp,bskp0

*NCOPY,CHANGE NUMBER=1000,OLD SET=nbsk1,SHIFT,NEW SET=nbsk

-0.9499,23.1465

*NCOPY,CHANGE NUMBER=2000,OLD SET=nbsk1,SHIFT,NEW SET=nbsk

-1.8998,46.2930

*NCOPY,CHANGE NUMBER=3000,OLD SET=nbsk1,SHIFT,NEW SET=nbsk

-2.8497,69.4396

*NCOPY,CHANGE NUMBER=4000,OLD SET=nbsk1,SHIFT,NEW SET=nbsk

-3.7996,92.5861

*NCOPY,CHANGE NUMBER=5000,OLD SET=nbsk1,SHIFT,NEW SET=nbsk

-4.7495,115.7326

*nset,nset=bsk

nbsk,nbsk1

*ELEMENT,TYPE=C3D8R,ELSET=bsk0

31001,31025,31000,31001,31038,31225,31200,31201,31238

31002,31038,31001,31002,31051,31238,31201,31202,31251

31003,31051,31002,31003,31064,31251,31202,31203,31264

31004,31064,31003,31004,31077,31264,31203,31204,31277

31005,31077,31004,31005,31090,31277,31204,31205,31290

31006,31090,31005,31006,31103,31290,31205,31206,31303

31007,31103,31006,31007,31104,31303,31206,31207,31304

31019,31115,31018,31019,31102,31315,31218,31219,31302

31020,31102,31019,31020,31089,31302,31219,31220,31289

31021,31089,31020,31021,31076,31289,31220,31221,31276

31022,31076,31021,31022,31063,31276,31221,31222,31263

31023,31063,31022,31023,31050,31263,31222,31223,31250

31024,31050,31023,31024,31037,31250,31223,31224,31237

31025,31026,31025,31038,31039,31226,31225,31238,31239

*ELGEN,ELSET=bsk0

31007,12,1,1

31025,12,1,1,6,13,12

*ELcopy,element shift=1000,old set=bsk0,shift nodes=1000,new SET=bsk

*ELcopy,element shift=2000,old set=bsk0,shift nodes=2000,new SET=bsk

*ELcopy,element shift=3000,old set=bsk0,shift nodes=3000,new SET=bsk

*ELcopy,element shift=4000,old set=bsk0,shift nodes=4000,new SET=bsk

*ELcopy,element shift=5000,old set=bsk0,shift nodes=5000,new SET=bsk

*ELEMENT,TYPE=B31,ELSET=postc

31101,31031,31231

31102,31231,31400

31103,31400,31401

*ELEMENT,TYPE=B31,ELSET=posth

31111,31000,31200

31112,31200,31410

31113,31410,31411

*ELEMENT,TYPE=B31,ELSET=postf

31121,31013,31213

31122,31213,31420

31123,31420,31421

31131,31020,31220

31132,31220,31430

31133,31430,31431

*ELEMENT,TYPE=B31,ELSET=posth

31141,31024,31224

31142,31224,31440

31143,31440,31441

*ELGEN,ELSET=postc

31101,6,1000,1000

31102,6,1000,1000

31103,2,1,1,6,1000,1000

*ELGEN,ELSET=posth

31111,6,1000,1000

31112,6,1000,1000

31113,2,1,1,6,1000,1000

31141,6,1000,1000

31142,6,1000,1000

31143,2,1,1,6,1000,1000

*ELGEN,ELSET=postf

31121,6,1000,1000

31122,6,1000,1000

31123,2,1,1,6,1000,1000

31131,6,1000,1000

31132,6,1000,1000

31133,2,1,1,6,1000,1000

*elset,elset=bsk

bsk0

*elset,elset=ebsk

posth,postf,postc,bsk

*SOLID SECTION, ELSET=bsk, MATERIAL=bsk

*BEAM SECTION, ELSET=postc, MATERIAL=bskp, SECTION=arbitrary

4,1.906,0,1.348,1.348,2.4375

0,1.906,2.4375

-1.348,-1.348,2.4375

-1.906,0,2.4375

*BEAM SECTION, ELSET=postf, MATERIAL=bskp, SECTION=trapezoid

3.114,1.45,1.23,0

*BEAM SECTION, ELSET=posth, MATERIAL=bskp, SECTION=trapezoid

1.557,1.45,0.615,0

*MATERIAL,NAME=bsk

*DENSITY

.01556

*ELASTIC

28.E+06,.27

*PLASTIC

30032.,0.0

100701.,0.293

101451.,0.300

APPENDIX C SECTION ONE
INPUT FILE Bsk1a4.txt

SNF-5204, Rev. 0/CSB-S-0073

```

102201.,0.307
*MATERIAL,NAME=bskp
*DENSITY
.000735
*ELASTIC
28.E+06,.27
*PLASTIC
30032.,0.0
100701.,0.293
101451.,0.300
102201.,0.307
*mpc
link,32031,31402
link,32000,31412
link,32013,31422
link,32020,31432
link,32024,31442
link,33031,32402
link,33000,32412
link,33013,32422
link,33020,32432
link,33024,32442
link,34031,33402
link,34000,33412
link,34013,33422
link,34020,33432
link,34024,33442
link,35031,34402
link,35000,34412
link,35013,34422
link,35020,34432
link,35024,34442
link,36031,35402
link,36000,35412
link,36013,35422
link,36020,35432
link,36024,35442
*elset,elset=bskb1,generate
31001,31024,1
*elset,elset=bskb2,generate
32001,32024,1
*elset,elset=bskb3,generate
33001,33024,1
*elset,elset=bskb4,generate
34001,34024,1
*elset,elset=bskb5,generate
35001,35024,1
*elset,elset=bskb6,generate
36001,36024,1
*elset,elset=bskc1,generate
31025,31096,1
*elset,elset=bskc2,generate
32025,32096,1
*elset,elset=bskc3,generate
33025,33096,1
*elset,elset=bskc4,generate
34025,34096,1
*elset,elset=bskc5,generate
35025,35096,1
*elset,elset=bskc6,generate
36025,36096,1
*nset,nset=BSKSY,generate
31000,36000,1000
31024,36024,1000
31025,31037,1
31225,31237,1
32025,32037,1
32225,32237,1
33025,33037,1
33225,33237,1
34025,34037,1
34225,34237,1
35025,35037,1
35225,35237,1
36025,36037,1
36225,36237,1
31400,36400,1000
31401,36401,1000
31402,36402,1000
31410,36410,1000
31411,36411,1000
31412,36412,1000
31440,36440,1000
31441,36441,1000
31442,36442,1000
*BOUNDARY
BSKSY, 2SYMM
** end of file

```

```

**standard storage tube
*NODE
100,13.5,0,0
104,14.0,0,0
106,14.5,0,0
*NGEN,NSET=SSN1
100,104,1
104,106,1
*NODE
140,13.5,0.5,0
144,14.5,0.5,0
146,15.0,0.5,0
*NGEN,NSET=SSN2
140,144,1
144,146,1
*NODE
113,19.0,0,0
*NGEN,NSET=SSN1
106,113,1
*NODE
153,19.5,0.5,0
*NGEN,NSET=SSN2
146,153,1
*NFILL,NSET=flange
SSN1,SSN2,2,20
*NODE
460,16.50,3.5,0
468,18.25,3.5,0
*NGEN,NSET=SSN3
460,468,1
*NODE
473,19.50,3.5,0
*NGEN,NSET=SSN3
468,473,1
*NFILL,NSET=flange
SSN2,SSN3,16,20
*NODE
508,18.25,4.5,0
513,19.50,4.5,0
*NGEN,NSET=SSN4
508,513,1
*nset,NSET=SSN5,generate
468,473,1
*NFILL,NSET=flange
SSN5,SSN4,2,20
*NCOPY,CHANGE NUMBER=1000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,3.75
*NCOPY,CHANGE NUMBER=2000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,7.5
*NCOPY,CHANGE NUMBER=3000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,11.25
*NCOPY,CHANGE NUMBER=4000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,15.
*NCOPY,CHANGE NUMBER=5000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,18.75
*NCOPY,CHANGE NUMBER=6000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,22.5
*NCOPY,CHANGE NUMBER=7000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,26.25
*NCOPY,CHANGE NUMBER=8000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,30.
*NCOPY,CHANGE NUMBER=9000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,36.
*NCOPY,CHANGE NUMBER=10000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,42.
*NCOPY,CHANGE NUMBER=11000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,48.
*NCOPY,CHANGE NUMBER=12000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,54.
*NCOPY,CHANGE NUMBER=13000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,60.
*NCOPY,CHANGE NUMBER=14000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,67.5
*NCOPY,CHANGE NUMBER=15000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,75.
*NCOPY,CHANGE NUMBER=16000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,82.5
*NCOPY,CHANGE NUMBER=17000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,90.
*NCOPY,CHANGE NUMBER=18000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,100.
*NCOPY,CHANGE NUMBER=19000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,110.
*NCOPY,CHANGE NUMBER=20000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,120.
*NCOPY,CHANGE NUMBER=21000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,135.
*NCOPY,CHANGE NUMBER=22000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,150.
*NCOPY,CHANGE NUMBER=23000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,165.
*NCOPY,CHANGE NUMBER=24000,OLDSET=FLANGE,SHIFT

0,-10,0,0,10,0,180.
*ELEMENT,TYPE=C3D8R,ELSET=FLANG
1,100,101,1101,1100,120,121,1121,1120
*ELGEN,ELSET=FLANG
1,18,20,1,13,1,18,24,1000,1000
*ELEMENT,TYPE=C3D8R,ELSET=FLANG
235,468,469,1469,1468,488,489,1489,1488
*ELGEN,ELSET=FLANG
235,2,20,1,5,1,2,24,1000,1000
**
*NODE
600,13.5,-26.25
604,14.0,-26.25
*NGEN,NSET=SSS1
600,604,1
*NODE
660,13.5,-20.25
664,14.0,-20.25

```

```
*NGEN,NSET=SSS2
660,664,1
*NFill,NSET=SS12
SSS1,SSS2,12,5
*NODE
665,13.5,-20.
669,14.0,-20.
*NGEN,NSET=SSS3
665,669,1
*NODE
860,13.5,-0.5
864,14.0,-0.5
*NGEN,NSET=SSS4
860,864,1
*NFill,NSET=SS34
SSS3,SSS4,39,5
*NODE
865,13.50,-0.25
869,14.00,-0.25
870,14.25,-0.25
*NGEN,NSET=SSS5
865,869,1
*NSET,NSET=TUBES
SS12,SS34,SSS5,870
*NCOPY,CHANGE NUMBER=1000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,3.75
*NCOPY,CHANGE NUMBER=2000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,7.5
*NCOPY,CHANGE NUMBER=3000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,11.25
*NCOPY,CHANGE NUMBER=4000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,15.
*NCOPY,CHANGE NUMBER=5000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,18.75
*NCOPY,CHANGE NUMBER=6000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,22.5
*NCOPY,CHANGE NUMBER=7000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,26.25
*NCOPY,CHANGE NUMBER=8000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,30.
*NCOPY,CHANGE NUMBER=9000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,36.
*NCOPY,CHANGE NUMBER=10000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,42.
*NCOPY,CHANGE NUMBER=11000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,48.
*NCOPY,CHANGE NUMBER=12000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,54.
*NCOPY,CHANGE NUMBER=13000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,60.
*NCOPY,CHANGE NUMBER=14000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,67.5
*NCOPY,CHANGE NUMBER=15000,OLDSET=TUBES,SHIFT
```

```
0,-10,0, 0,10,0,75.
*NCOPY,CHANGE NUMBER=16000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,82.5
*NCOPY,CHANGE NUMBER=17000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,90.
*NCOPY,CHANGE NUMBER=18000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,100.
*NCOPY,CHANGE NUMBER=19000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,110.
*NCOPY,CHANGE NUMBER=20000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,120.
*NCOPY,CHANGE NUMBER=21000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,135.
*NCOPY,CHANGE NUMBER=22000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,150.
*NCOPY,CHANGE NUMBER=23000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,165.
*NCOPY,CHANGE NUMBER=24000,OLDSET=TUBES,SHIFT

0,-10,0, 0,10,0,180.
*ELEMENT,TYPE=C3D8R,ELSET=TUBES
301,600,601,1601,1600,605,606,1606,1605
*ELGEN,ELSET=TUBES
301,53,5,1,4,1,53,24,1000,1000
*ELEMENT,TYPE=C3D8R,ELSET=TUBES
550,865,866,1866,1865,100,101,1101,1100
*ELGEN,ELSET=TUBES
550,5,1,1,24,1000,1000
*ELEMENT,TYPE=C3D6,ELSET=TUBES
556,869,870,864,1869,1870,1864
*ELGEN,ELSET=TUBES
556,24,1000,1000
*ELEMENT,TYPE=C3D6,ELSET=TUBES
557,105,106,870,1105,1106,1870
*ELGEN,ELSET=TUBES
557,24,1000,1000
**
*NODE,NSET=SSP1
900,13.75,-475,0
*NODE,NSET=SSP2
997,13.75,-27,0
*NFill,BIAS=1.03,NSET=TUBEP
SSP1,SSP2,97,1
*NCOPY,CHANGE NUMBER=1000,OLDSET=TUBEP,SHIFT

0,-10,0, 0,10,0,3.75
*NCOPY,CHANGE NUMBER=2000,OLDSET=TUBEP,SHIFT

0,-10,0, 0,10,0,7.5
*NCOPY,CHANGE NUMBER=3000,OLDSET=TUBEP,SHIFT

0,-10,0, 0,10,0,11.25
*NCOPY,CHANGE NUMBER=4000,OLDSET=TUBEP,SHIFT

0,-10,0, 0,10,0,15.
*NCOPY,CHANGE NUMBER=5000,OLDSET=TUBEP,SHIFT

0,-10,0, 0,10,0,18.75
```



```

*NCOPY,CHANGE NUMBER=6000,OLDSET=TUBEP,SHIFT
0,-10,0,0,10,0,22.5
*NCOPY,CHANGE NUMBER=7000,OLDSET=TUBEP,SHIFT
0,-10,0,0,10,0,26.25
*NCOPY,CHANGE NUMBER=8000,OLDSET=TUBEP,SHIFT
0,-10,0,0,10,0,30.
*NCOPY,CHANGE NUMBER=9000,OLDSET=TUBEP,SHIFT
0,-10,0,0,10,0,36.
*NCOPY,CHANGE NUMBER=10000,OLDSET=TUBEP,SHIFT
0,-10,0,0,10,0,42.
*NCOPY,CHANGE NUMBER=11000,OLDSET=TUBEP,SHIFT
0,-10,0,0,10,0,48.
*NCOPY,CHANGE NUMBER=12000,OLDSET=TUBEP,SHIFT
0,-10,0,0,10,0,54.
*NCOPY,CHANGE NUMBER=13000,OLDSET=TUBEP,SHIFT
0,-10,0,0,10,0,60.
*NCOPY,CHANGE NUMBER=14000,OLDSET=TUBEP,SHIFT
0,-10,0,0,10,0,67.5
*NCOPY,CHANGE NUMBER=15000,OLDSET=TUBEP,SHIFT
0,-10,0,0,10,0,75.
*NCOPY,CHANGE NUMBER=16000,OLDSET=TUBEP,SHIFT
0,-10,0,0,10,0,82.5
*NCOPY,CHANGE NUMBER=17000,OLDSET=TUBEP,SHIFT
0,-10,0,0,10,0,90.
*NCOPY,CHANGE NUMBER=18000,OLDSET=TUBEP,SHIFT
0,-10,0,0,10,0,100.
*NCOPY,CHANGE NUMBER=19000,OLDSET=TUBEP,SHIFT
0,-10,0,0,10,0,110.
*NCOPY,CHANGE NUMBER=20000,OLDSET=TUBEP,SHIFT
0,-10,0,0,10,0,120.
*NCOPY,CHANGE NUMBER=21000,OLDSET=TUBEP,SHIFT
0,-10,0,0,10,0,135.
*NCOPY,CHANGE NUMBER=22000,OLDSET=TUBEP,SHIFT
0,-10,0,0,10,0,150.
*NCOPY,CHANGE NUMBER=23000,OLDSET=TUBEP,SHIFT
0,-10,0,0,10,0,165.
*NCOPY,CHANGE NUMBER=24000,OLDSET=TUBEP,SHIFT
0,-10,0,0,10,0,180.
*ELEMENT,TYPE=S4RS,ELSET=TUBEP
600,900,1900,1901,901
*ELGEN,ELSET=TUBEP
600,97,1,1,24,1000,1000
*ELEMENT,TYPE=S4RS,ELSET=TUBEP
698,997,1997,1602,602
*ELGEN,ELSET=TUBEP
698,24,1000,1000
*ELEMENT,TYPE=S4RS,ELSET=TUBEP
699,602,1602,1607,607

*ELGEN,ELSET=TUBEP
699,24,1000,1000
*nset,nset=fsym,generate
1,513,1
24001,24513,1
600,870,1
24600,24870,1
901,997,1
24901,24997,1
*nset,nset=PFLR,generate
900,24900,1000
*elset,elset=FLGI,generate
1,18,1
1001,1018,1
2001,2018,1
3001,3018,1
4001,4018,1
5001,5018,1
6001,6018,1
7001,7018,1
8001,8018,1
9001,9018,1
*elset,elset=FLGO,generate
217,234,1
1217,1234,1
243,1243,1000
244,1244,1000
*elset,elset=FLGB,generate
109,217,18
1109,1217,18
*elset,elset=TUBI,generate
301,353,1
1301,1353,1
2301,2353,1
3301,3353,1
4301,4353,1
5301,5353,1
6301,6353,1
7301,7353,1
8301,8353,1
9301,9353,1
550,9550,1000
*elset,elset=TUBO,generate
460,511,1
1460,1511,1
556,1556,1000
557,1557,1000
*BOUNDARY
FSYM, ZSYMM
PFLR, ENCASTRE
**END OF FILE

```

APPENDIX C

ABAQUS INPUT FILE

SECTION TWO

MCO DROP ON SERVICE STATION

Originator: Date: 9/27/99
Checked by: M.B. LASOTA Date: 9/27/99

APPENDIX C SECTION TWO
INPUT FILE S210.inp

SNF-5204, Rev. 0/CSB-S-0073

```
** file "s210.inp"
*HEADING
MCO DROP ONTO SERVICE STATION(MCO shell el &
basket support)
*INCLUDE, INPUT=mcos2.txt
*INCLUDE, INPUT=bsk1as.txt
*SYSTEM
**
*INCLUDE, INPUT=service.txt
*SYSTEM
-1,22.75,
*NODE,NSET=RGD3
95001,-17.5,55,0
95003,-17.5,114.15,0
95005,-13.625,128.91,0
95007,-13.625,160.,0
*NODE,NSET=RGD1
95011,17.5,55,0
95013,17.5,114.15,0
95015,13.625,128.91,0
95017,13.625,160.,0
*SYSTEM
***
*NODE,NSET=RGD1
*NCOPY,CHANGE NUMBER=1,OLD SET=RGD1,SHIFT,NEW
SET=RGD1
,0,
0,0,0,0,1,0,3.75
*NCOPY,CHANGE NUMBER=1,OLD SET=RGD3,SHIFT,NEW
SET=RGD3
,0,
0,0,0,0,1,0,-15.
*node
95020,-12.625,100.
*element,type=R3D4,elset=rgd1
95001, 95001, 95002, 95004, 95003
95002, 95003, 95004, 95006, 95005
95003, 95005, 95006, 95008, 95007
*element,type=R3D4,elset=rgd2
95004, 95011, 95012, 95014, 95013
95005, 95013, 95014, 95016, 95015
95006, 95015, 95016, 95018, 95017
**
**
*SOLID SECTION, ELSET=HATCH, MATERIAL=SA36
*SOLID SECTION, ELSET=GUIDE, MATERIAL=SA36
*SOLID SECTION, ELSET=CASK, MATERIAL=SA36
0.5
*rigid body, elset=rgd1,ref node=95020
1.31
*rigid body, elset=rgd2,ref node=95020
0.001
*MATERIAL,NAME=SS304
*DENSITY
.000735
*ELASTIC
28.E+06,.27
*PLASTIC
36161,0
38390,0.02
40405,0.05
41771,0.08
45369,0.18
51002,0.37
127236,0.466
*MATERIAL,NAME=SA36
*DENSITY
```

```
.0007339
*ELASTIC
29.5E6,0.30
*PLASTIC
36088,0
38590,0.0197
60421,0.0904
75291,0.1486
**
*BOUNDARY
95020,encastre
*INITIAL CONDITIONS, TYPE=VELOCITY
MCO, 2, -264
BSK, 2, -264
*RESTART, WRITE, NUMBER INTERVAL=40
*STEP
*DYNAMIC, EXPLICIT
,4.E-2
*ELSET,ELSET=TTT
GUIDE,HATCH,CASK,MCO,BSK
*DLOAD
TTT,GRAV,386.4,0,-1,0
**
** Surface definitions for Service Station
**
*SURFACE DEFINITION, NAME=SSIF
FLS1,S6
*SURFACE DEFINITION, NAME=MCOBF
MCOBF, S4
MCOBB, S1
*CONTACT PAIR, INTERACTION=FM1
MCOBF,SSIF
*SURFACE INTERACTION, NAME=FM1
*FRICTION
0.3
*SURFACE DEFINITION, NAME=GSIF
GS1,S6
*CONTACT PAIR, INTERACTION=FM2
MCOBF,GSIF
*SURFACE INTERACTION, NAME=FM2
*FRICTION
0.3
*SURFACE DEFINITION, NAME=SSIC
CA11,S6
CA12,S2
CA13,S1
*CONTACT PAIR, INTERACTION=FM3
MCOBF,SSIC
*SURFACE INTERACTION, NAME=FM3
*FRICTION
0.3
**
** Guide, Cask contact surfaces
**
*SURFACE DEFINITION, NAME=GSB
GSB1,S1
GSB2,S6
GSB3,S1
*SURFACE DEFINITION, NAME=CAT
CAT1,S2
CAT2,S4
CAT3,S2
*CONTACT PAIR
GSB,CAT
**
**
**
```

```
*SURFACE DEFINITION, NAME=rgd1f
rgd1, SPOS
*SURFACE DEFINITION, NAME=MCOTL
MCOTL, SPOS
*CONTACT PAIR, INTERACTION=FMTL
rgd1f,MCOTL
*SURFACE INTERACTION, NAME=FMTL
*FRICTION
0.3
**
*SURFACE DEFINITION, NAME=rgd2f
rgd2, SNEG
*SURFACE DEFINITION, NAME=MCOTR
MCOTR, SPOS
*CONTACT PAIR, INTERACTION=FMTR
rgd2f,MCOTR
*SURFACE INTERACTION, NAME=FMTR
*FRICTION
0.3
**
*SURFACE DEFINITION, NAME=bskb1
bskb1,s1
bskc1,s1
bskb1,s4
*SURFACE DEFINITION, NAME=bskb2
bskb2,s1
bskc2,s1
bskb2,s4
*SURFACE DEFINITION, NAME=bskb3
bskb3,s1
bskc3,s1
bskb3,s4
*SURFACE DEFINITION, NAME=bskb4
bskb4,s1
bskc4,s1
bskb4,s4
*SURFACE DEFINITION, NAME=bskb5
bskb5,s1
bskc5,s1
bskb5,s4
*SURFACE DEFINITION, NAME=bskb6
bskb6,s1
bskc6,s1
bskb6,s4
*CONTACT NODE SET, NAME=bspb
bspb
*SURFACE DEFINITION, NAME=mcosi
mcobt,s2
mcosi,s6
*CONTACT PAIR, INTERACTION=BSmco
bspb,mcosi
*SURFACE INTERACTION, NAME=BSmco
*FRICTION
0.3
*CONTACT NODE SET, NAME=bspt
bspt
*CONTACT PAIR, INTERACTION=BSK01
bspt,BSKB1
*SURFACE INTERACTION, NAME=BSK01
*FRICTION
0.3
*SURFACE DEFINITION, NAME=mcotb
mcot,s1
*SURFACE DEFINITION, NAME=mcopi
mcopi,sneg
*CONTACT PAIR, INTERACTION=b1
BSKB1,mcopi
```

```
*SURFACE INTERACTION, NAME=b1
*FRICTION
0.3
*CONTACT PAIR, INTERACTION=b2
BSKB2,mcopi
*SURFACE INTERACTION, NAME=b2
*FRICTION
0.3
*CONTACT PAIR, INTERACTION=b3
BSKB3,mcopi
*SURFACE INTERACTION, NAME=b3
*FRICTION
0.3
*CONTACT PAIR, INTERACTION=b4
BSKB4,mcopi
*SURFACE INTERACTION, NAME=b4
*FRICTION
0.3
*CONTACT PAIR, INTERACTION=b5
BSKB5,mcopi
*SURFACE INTERACTION, NAME=b5
*FRICTION
0.3
*CONTACT PAIR, INTERACTION=b6
BSKB6,mcopi
*SURFACE INTERACTION, NAME=b6
*FRICTION
0.3
**
*NSET,NSET=NOU
70019,70000,70179,82019,94019,82133,94133
31231,32231,33231,34231,35231,36231,94577
*nset,nset=nout,generate
31000,36000,1000
31024,36024,1000
31025,31037,1
32025,32037,1
33025,33037,1
34025,34037,1
35025,35037,1
36025,36037,1
*NSET,GENERATE,NSET=TOUT
**
** nodes for Service Station output
**
100,800,20
**100,220,60
24100,24220,60
600,850,50
24600,24850,50
70300,94300,1000
70301,94301,1000
70302,94302,1000
70303,94303,1000
70304,94304,1000
70305,94305,1000
70306,94306,1000
70307,94307,1000
70308,94308,1000
70309,94309,1000
*ELSET,ELSET=EOUT,generate
70016,70156,20
70017,70157,20
70018,70158,20
70019,70159,20
70160,70175,1
71016,71156,20
```

```

71017,71157,20
71018,71158,20
71019,71159,20
71160,71175,1
72016,72156,20
72017,72157,20
72018,72158,20
72019,72159,20
72160,72175,1
73016,73156,20
73017,73157,20
73018,73158,20
73019,73159,20
73160,73175,1
*OUTPUT,HISTORY,TIME INTERVAL=1.E-4
*NODE OUTPUT, NSET=NOUT
U,V,A
*NODE OUTPUT, NSET=TOUT
U
*NODE OUTPUT, NSET=FLY
RF
*NODE OUTPUT, NSET=FLXYZ
RF
*NODE OUTPUT, NSET=CAXYZ
RF
*nset,nset=rgdn
95020
*NODE OUTPUT, NSET=rgdn
RF
*ENERGY output
ALLKE
*elset,elset=st
hatch,cask,guide
*energy output,elset=st
allie,allpd
*ELEMENT
OUTPUT,ELSET=EQUT,position=nodes,variable=prese
lect
*output,field,number interval=40
*element output
S,SP,MISES,PE,PEEQ,E,EP
*node output
U,v,rf
*MONITOR, NODE=70019, DOF=2
*END STEP
** end of file

```

APPENDIX C SECTION TWO
INPUT FILE Bsk1as.txt

SNF-5204, Rev. 0/CSB-S-0073

```
** mark1a3.txt
*SYSTEM
3.5355,-3.7513, 0, 13.5312,-3.4604,0
3.3392,2.9958, 0
*node,nset=nbsk0
31000,11.3125,0,0
*NCOPY,CHANGE NUMBER=1,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,3.75
*NCOPY,CHANGE NUMBER=2,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,7.5
*NCOPY,CHANGE NUMBER=3,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,11.25
*NCOPY,CHANGE NUMBER=4,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,15.
*NCOPY,CHANGE NUMBER=5,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,20.0
*NCOPY,CHANGE NUMBER=6,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,25.0
*NCOPY,CHANGE NUMBER=7,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,30.0
*NCOPY,CHANGE NUMBER=8,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,37.5
*NCOPY,CHANGE NUMBER=9,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,45.0
*NCOPY,CHANGE NUMBER=10,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,60.0
*NCOPY,CHANGE NUMBER=11,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,75.0
*NCOPY,CHANGE NUMBER=12,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,90.0
*NCOPY,CHANGE NUMBER=13,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,105.0
*NCOPY,CHANGE NUMBER=14,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,120.0
*NCOPY,CHANGE NUMBER=15,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,135.0
```

```
*NCOPY,CHANGE NUMBER=16,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,142.5
*NCOPY,CHANGE NUMBER=17,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,150.0
*NCOPY,CHANGE NUMBER=18,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,155.0
*NCOPY,CHANGE NUMBER=19,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,160.0
*NCOPY,CHANGE NUMBER=20,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,165.0
*NCOPY,CHANGE NUMBER=21,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,168.75
*NCOPY,CHANGE NUMBER=22,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,172.5
*NCOPY,CHANGE NUMBER=23,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,176.25
*NCOPY,CHANGE NUMBER=24,OLD SET=nbsk0,SHIFT,NEW
SET=nbsk1
,0,
3.5355,-3.7513, 0,3.3392,2.9958, 0,180.
*nset,nset=nbsk1
nbsk0
*node
31037,-10.3,0,0
31115,-8.9,0,-5.1
*ngen,nset=bskt1
31037,31115,13
*node
31025,10.3,0,0
31103, 8.9,0,-5.1
*ngen,nset=bskt2
31025,31103,13
*node
31031,0,0,0
31109,0,0,-10.3
*ngen,nset=bskt3
31031,31109,13
*nfill,nset=nbsk1
bskt2,bskt3,6,1
bskt3,bskt1,6,1
*NCOPY,CHANGE NUMBER=200,OLD SET=nbsk1,SHIFT,NEW
SET=nbsk1
-0.0291,0.9996

*node,nset=bskp0
31410,11.3125,7,0
31411,11.3125,13,0
31412,11.3125,19,0
*NCOPY,CHANGE NUMBER=10,OLD SET=bskp0,SHIFT,NEW
SET=bskpk,multiple=3
,0,
```

APPENDIX C SECTION TWO
INPUT FILE Bsk1as.txt

SNF-5204, Rev. 0/CSB-S-0073

3.5355,-3.7513, 0,3.3392,2.9958, 0,60.

*node,nset=nbskp

31400,,7,0

31401,,13,0

31402,,19,0

*nset,nset=nbsk1

nbskp,bskp0

*NCOPY,CHANGE NUMBER=1000,OLD SET=nbsk1,SHIFT,NEW
SET=nbsk

-0.6738,23.1562

*NCOPY,CHANGE NUMBER=2000,OLD SET=nbsk1,SHIFT,NEW
SET=nbsk

-1.3476,46.3124

*NCOPY,CHANGE NUMBER=3000,OLD SET=nbsk1,SHIFT,NEW
SET=nbsk

-2.0213,69.4686

*NCOPY,CHANGE NUMBER=4000,OLD SET=nbsk1,SHIFT,NEW
SET=nbsk

-2.6951,92.6248

*NCOPY,CHANGE NUMBER=5000,OLD SET=nbsk1,SHIFT,NEW
SET=nbsk

-3.3689,115.7810

*nset,nset=bsk

nbsk,nbsk1

*ELEMENT,TYPE=C3D8R,ELSET=bsk0

31001,31025,31000,31001,31038,31225,31200,31201,3
1238

31002,31038,31001,31002,31051,31238,31201,31202,3
1251

31003,31051,31002,31003,31064,31251,31202,31203,3
1264

31004,31064,31003,31004,31077,31264,31203,31204,3
1277

31005,31077,31004,31005,31090,31277,31204,31205,3
1290

31006,31090,31005,31006,31103,31290,31205,31206,3
1303

31007,31103,31006,31007,31104,31303,31206,31207,3
1304

31019,31115,31018,31019,31102,31315,31218,31219,3
1302

31020,31102,31019,31020,31089,31302,31219,31220,3
1289

31021,31089,31020,31021,31076,31289,31220,31221,3
1276

31022,31076,31021,31022,31063,31276,31221,31222,3
1263

31023,31063,31022,31023,31050,31263,31222,31223,3
1250

31024,31050,31023,31024,31037,31250,31223,31224,3
1237

31025,31026,31025,31038,31039,31226,31225,31238,3
1239

*ELGEN,ELSET=bsk0

31007,12,1,1

31025,12,1,1,6,13,12

*ELcopy,element shift=1000,old set=bsk0,shift
nodes=1000,new SET=bsk

*ELcopy,element shift=2000,old set=bsk0,shift
nodes=2000,new SET=bsk

*ELcopy,element shift=3000,old set=bsk0,shift
nodes=3000,new SET=bsk

*ELcopy,element shift=4000,old set=bsk0,shift
nodes=4000,new SET=bsk

*ELcopy,element shift=5000,old set=bsk0,shift
nodes=5000,new SET=bsk

*elset,elset=bsk

bsk0

*ELEMENT,TYPE=B31,ELSET=postc

31101,31031,31231

31102,31231,31400

31103,31400,31401

31105,31402,32031

*ELEMENT,TYPE=B31,ELSET=posth

31111,31000,31200

31112,31200,31410

31113,31410,31411

31115,31412,32000

*ELEMENT,TYPE=B31,ELSET=postf

31121,31010,31210

31122,31210,31420

31123,31420,31421

31125,31422,32010

31131,31014,31214

31132,31214,31430

31133,31430,31431

31135,31432,32014

*ELEMENT,TYPE=B31,ELSET=posth

31141,31024,31224

31142,31224,31440

31143,31440,31441

31145,31442,32024

*ELGEN,ELSET=postc

31101,6,1000,1000

31102,6,1000,1000

31103,2,1,1,6,1000,1000

31105,5,1000,1000

*ELGEN,ELSET=posth

31111,6,1000,1000

31112,6,1000,1000

31113,2,1,1,6,1000,1000

31115,5,1000,1000

31141,6,1000,1000

31142,6,1000,1000

31143,2,1,1,6,1000,1000

31145,5,1000,1000

*ELGEN,ELSET=postf

31121,6,1000,1000

31122,6,1000,1000

31123,2,1,1,6,1000,1000

31125,5,1000,1000

31131,6,1000,1000

31132,6,1000,1000

31133,2,1,1,6,1000,1000

31135,5,1000,1000

*elset,elset=ebsk

posth,postf,postc

*SOLID SECTION, ELSET=bsk, MATERIAL=bsk

*BEAM SECTION, ELSET=postc, MATERIAL=bskp,
SECTION=pipe

3.125,2.4375

*BEAM SECTION, ELSET=postf, MATERIAL=bskp,
SECTION=trapezoid

3.114,1.45,1.23,0

*BEAM SECTION, ELSET=posth, MATERIAL=bskp,
SECTION=trapezoid

1.557,1.45,0.615,0

*MATERIAL,NAME=bsk

*DENSITY

```
.01472
*ELASTIC
28.E+06,-.27
*PLASTIC
30032.,0.0
100701.,0.293
101451.,0.300
102201.,0.307
*MATERIAL,NAME=bskp
*DENSITY
.000735
*ELASTIC
28.E+06,-.27
*PLASTIC
30032.,0.0
100701.,0.293
101451.,0.300
102201.,0.307
*elset,elset=bskb1,generate
31001,31024,1
*elset,elset=bskb2,generate
32001,32024,1
*elset,elset=bskb3,generate
33001,33024,1
*elset,elset=bskb4,generate
34001,34024,1
*elset,elset=bskb5,generate
35001,35024,1
*elset,elset=bskb6,generate
36001,36024,1
*elset,elset=bskc1,generate
31025,31096,1
*elset,elset=bskc2,generate
32025,32096,1
*elset,elset=bskc3,generate
33025,33096,1
*elset,elset=bskc4,generate
34025,34096,1
*elset,elset=bskc5,generate
35025,35096,1
*elset,elset=bskc6,generate
36025,36096,1
*nset,nset=BSKSY,generate
31000,36000,1000
31024,36024,1000
31025,31037,1
31225,31237,1
32025,32037,1
32225,32237,1
33025,33037,1
33225,33237,1
34025,34037,1
34225,34237,1
35025,35037,1
35225,35237,1
36025,36037,1
36225,36237,1
31400,36400,1000
31401,36401,1000
31402,36402,1000
31410,36410,1000
31411,36411,1000
31412,36412,1000
31440,36440,1000
31441,36441,1000
31442,36442,1000
*BOUNDARY
```

BSKSY, ZSYMM
** end of file

APPENDIX C SECTION TWO
INPUT FILE Mcos2.txt

SNF-5204, Rev. 0/CSB-S-0073

```
** "Mcos2.TXT"
** 4 elements through thickness
** with basket support plates off symm plane
** MCO model drop on lower right corner
*SYSTEM
3.630,-7.0, 0, 13.6258,-6.7092,0
3.3392,2.9958,0
** MCO bottom ring
*NODE
70015,10.3,0,0
70135,11.0125,2.01,0
*NGEN,NSET=N3
70015,70135,20
*NODE,NSET=N3
70155,11.366,2.1564,0
70175,11.50,2.51,0
*NODE
70019,11.423,0,0
70079,11.93076,1.13,0
*NGEN,NSET=N4
70019,70079,20
*NODE
70099,12,1.423333,0
70139,12,2.01,0
70179,12,2.51,0
*NGEN,NSET=N4
70099,70139,20
70139,70179,20
*NFill,NSET=N34
N3,N4,4,1
*NODE,NSET=N34
70019,11.394,0.0502,0
*NODE,NSET=N02
70205,11.5,8.51,0
70209,12.0,8.51,0
*NGEN,NSET=N02
70205,70209,1
*NSET,NSET=ND1,GENERATE
70175,70179,1
*NFill,NSET=N34
ND1,ND2,6,5
** shell (shell)
*NODE,nset=sb
70300,11.75,8.51,0
** MCO top ring
*NODE,nset=st
70576,11.75,148,0
*NODE,NSET=N34
70577,11.75,160,0
*NFill,NSET=N34
sb,st,276,1
*NCOPY,CHANGE NUMBER=1000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,3.75
*NCOPY,CHANGE NUMBER=2000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,7.5
*NCOPY,CHANGE NUMBER=3000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,11.25
*NCOPY,CHANGE NUMBER=4000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,15.
```

```
*NCOPY,CHANGE NUMBER=5000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,20.0
*NCOPY,CHANGE NUMBER=6000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,25.0
*NCOPY,CHANGE NUMBER=7000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,30.0
*NCOPY,CHANGE NUMBER=8000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,37.5
*NCOPY,CHANGE NUMBER=9000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,45.0
*NCOPY,CHANGE NUMBER=10000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,60.0
*NCOPY,CHANGE NUMBER=11000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,75.0
*NCOPY,CHANGE NUMBER=12000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,90.0
*NCOPY,CHANGE NUMBER=13000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,105.0
*NCOPY,CHANGE NUMBER=14000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,120.0
*NCOPY,CHANGE NUMBER=15000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,135.0
*NCOPY,CHANGE NUMBER=16000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,142.5
*NCOPY,CHANGE NUMBER=17000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,150.0
*NCOPY,CHANGE NUMBER=18000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,155.0
*NCOPY,CHANGE NUMBER=19000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,160.0
*NCOPY,CHANGE NUMBER=20000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,165.0
*NCOPY,CHANGE NUMBER=21000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
```

APPENDIX C SECTION TWO
INPUT FILE Mcos2.txt

SNF-5204, Rev. 0/CSB-S-0073

```

3.630,-7.00, 0,3.3392,2.9958,0,168.75
*NCOPY,CHANGE NUMBER=22000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,172.5
*NCOPY,CHANGE NUMBER=23000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,176.25
*NCOPY,CHANGE NUMBER=24000,OLD SET=N34,SHIFT,NEW
SET=MCO
,0,
3.630,-7.00, 0,3.3392,2.9958,0,180
*NODE
70000,1.25,0,0
70060,1.25,1.13,0
*NGEN,NSET=N1
70000,70060,20
*NODE
70120,2.13,2.01,0
*NGEN,NSET=N1
70060,70120,20
*NCOPY,CHANGE NUMBER=1000,OLD SET=N1,SHIFT,NEW
SET=N1,MULTIPLE=24
,0,
3.630,-7.00, 0,3.3392,2.9958,0,7.5
*NSET,NSET=N2,GENERATE
70015,94015,1000
70035,94035,1000
70055,94055,1000
70075,94075,1000
70095,94095,1000
70115,94115,1000
70135,94135,1000
*NFILL,NSET=N12,BIAS=1.01
N1,N2,15,1
*ELEMENT,TYPE=C308R,ELSET=MCOB
70001,70000,70001,71001,71000,70020,70021,71021,7
1020
70160,70175,70176,71176,71175,70180,70181,71181,7
1180
*ELGEN,ELSET=MCOB
70001,19,1,1,6,20,20,24,1000,1000
70116,2,20,20
70136,4,1,1,2,20,20,24,1000,1000
70160,4,1,1,6,5,4,24,1000,1000
*mpc
beam,70300,70205
beam,71300,71205
beam,72300,72205
beam,73300,73205
beam,74300,74205
beam,75300,75205
beam,76300,76205
beam,77300,77205
beam,78300,78205
beam,79300,79205
beam,80300,80205
beam,81300,81205
beam,82300,82205
beam,83300,83205
beam,84300,84205
beam,85300,85205
beam,86300,86205
beam,87300,87205
beam,88300,88205
beam,89300,89205
beam,90300,90205
beam,91300,91205
beam,92300,92205
beam,93300,93205
beam,94300,94205
pin,70300,70207
pin,71300,71207
pin,72300,72207
pin,73300,73207
pin,74300,74207
pin,75300,75207
pin,76300,76207
pin,77300,77207
pin,78300,78207
pin,79300,79207
pin,80300,80207
pin,81300,81207
pin,82300,82207
pin,83300,83207
pin,84300,84207
pin,85300,85207
pin,86300,86207
pin,87300,87207
pin,88300,88207
pin,89300,89207
pin,90300,90207
pin,91300,91207
pin,92300,92207
pin,93300,93207
pin,94300,94207
beam,70300,70208
beam,71300,71208
beam,72300,72208
beam,73300,73208
beam,74300,74208
beam,75300,75208
beam,76300,76208
beam,77300,77208
beam,78300,78208
beam,79300,79208
beam,80300,80208
beam,81300,81208

```

APPENDIX C SECTION TWO
INPUT FILE Mcos2.txt

SNF-5204, Rev. 0/CSB-S-0073

```

beam,82300,82208
beam,83300,83208
beam,84300,84208
beam,85300,85208
beam,86300,86208
beam,87300,87208
beam,88300,88208
beam,89300,89208
beam,90300,90208
beam,91300,91208
beam,92300,92208
beam,93300,93208
beam,94300,94208
beam,70300,70209
beam,71300,71209
beam,72300,72209
beam,73300,73209
beam,74300,74209
beam,75300,75209
beam,76300,76209
beam,77300,77209
beam,78300,78209
beam,79300,79209
beam,80300,80209
beam,81300,81209
beam,82300,82209
beam,83300,83209
beam,84300,84209
beam,85300,85209
beam,86300,86209
beam,87300,87209
beam,88300,88209
beam,89300,89209
beam,90300,90209
beam,91300,91209
beam,92300,92209
beam,93300,93209
beam,94300,94209
*ELEMENT,TYPE=S4RS,ELSET=MCOP1
70300,70300,71300,71301,70301
*ELGEN,ELSET=MCOP1
70300,277,1,1,24,1000,1000
** MCO bottom center
*NODE
60000,-1.08,0,0
66000,-.7637,0,-.7637
*NGEN,NSET=L1
60000,66000,1000
*NODE
60012,1.08,0,0
66012,.7637,0,-.7637
*NGEN,NSET=L2
60012,66012,1000
*NODE
60006,0,0,0
66006,0,0,-1.08
*NGEN,NSET=L3
60006,66006,1000
*NFill,NSET=L12
L1,L3,6,1
L3,L2,6,1
*NCOPY,CHANGE NUMBER=60,OLD SET=L12,SHIFT,NEW
SET=L13
-0.0256,0.8796,0

*NFill,NSET=L14
L12,L13,3,20

```

```

*ELEMENT,TYPE=C3D8R,ELSET=MCOB
60101,60000,60001,61001,61000,60020,60021,61021,6
1020
*ELGEN,ELSET=MCOB
60101,12,1,1,6,1000,12,3,20,72
*ELEMENT,TYPE=C3D8R,ELSET=EB1
60001,60012,70000,71000,61012,60032,70020,71020,6
1032
*ELGEN,ELSET=EB2
60001,6,1000,1,3,20,6
*ELEMENT,TYPE=C3D8R,ELSET=EB3
60019,66012,76000,77000,66011,66032,76020,77020,6
6031
60020,66011,77000,78000,66010,66031,77020,78020,6
6030
60021,66010,78000,79000,66009,66030,78020,79020,6
6029
60022,66009,79000,80000,66008,66029,79020,80020,6
6028
60023,66008,80000,81000,66007,66028,80020,81020,6
6027
60024,66007,81000,82000,66006,66027,81020,82020,6
6026
60025,66006,82000,83000,66005,66026,82020,83020,6
6025
60026,66005,83000,84000,66004,66025,83020,84020,6
6024
60027,66004,84000,85000,66003,66024,84020,85020,6
6023
60028,66003,85000,86000,66002,66023,85020,86020,6
6022
60029,66002,86000,87000,66001,66022,86020,87020,6
6021
60030,66001,87000,88000,66000,66021,87020,88020,6
6020
60031,66000,88000,89000,65000,66020,88020,89020,6
5020
60032,65000,89000,90000,64000,65020,89020,90020,6
4020
60033,64000,90000,91000,63000,64020,90020,91020,6
3020
60034,63000,91000,92000,62000,63020,91020,92020,6
2020
60035,62000,92000,93000,61000,62020,92020,93020,6
1020
60036,61000,93000,94000,60000,61020,93020,94020,6
0020
*ELCOPY,ELEMENT SHIFT=18,OLD SET=EB3,SHIFT
NODES=20, NEW SET=EB4
*ELCOPY,ELEMENT SHIFT=18,OLD SET=EB4,SHIFT
NODES=20, NEW SET=EB5
*ELSET,ELSET=MCOB
EB2,EB3,EB4,EB5
** MCO top center
*NODE
50000,-10.8,148,0
56000,-9.3,148,-5.4
*NGEN,NSET=T1
50000,56000,1000
*NODE
50012,10.8,148,0
56012, 9.3,148,-5.4
*NGEN,NSET=T2
50012,56012,1000
*NODE
50006,0,148,0
56006,0,148,-10.8

```

APPENDIX C SECTION TWO
INPUT FILE Mcos2.txt

SNF-5204, Rev. 0/CSB-S-0073

```
*NGEN,NSET=T3
50006,56006,1000
*NFILL,NSET=T12
T1,T3,6,1
T3,T2,6,1
*NCOPY,CHANGE NUMBER=20,OLD SET=T12,SHIFT,NEW
SET=T13
-0.3490,11.9949,0

*ELEMENT,TYPE=C3D8R,ELSET=MCOT
60601,50000,50001,51001,51000,50020,50021,51021,5
1020
*ELGEN,ELSET=MCOT
60601,12,1,1,6,1000,12
*ELEMENT,TYPE=C3D8R,ELSET=EB11
50001,50012,70576,71576,51012,50032,70577,71577,5
1032
*ELGEN,ELSET=EB11
50001,6,1000,1
*ELEMENT,TYPE=C3D8R,ELSET=EB12
50007,56012,76576,77576,56011,56032,76577,77577,5
6031
50008,56011,77576,78576,56010,56031,77577,78577,5
6030
50009,56010,78576,79576,56009,56030,78577,79577,5
6029
50010,56009,79576,80576,56008,56029,79577,80577,5
6028
50011,56008,80576,81576,56007,56028,80577,81577,5
6027
50012,56007,81576,82576,56006,56027,81577,82577,5
6026
50013,56006,82576,83576,56005,56026,82577,83577,5
6025
50014,56005,83576,84576,56004,56025,83577,84577,5
6024
50015,56004,84576,85576,56003,56024,84577,85577,5
6023
50016,56003,85576,86576,56002,56023,85577,86577,5
6022
50017,56002,86576,87576,56001,56022,86577,87577,5
6021
50018,56001,87576,88576,56000,56021,87577,88577,5
6020
50019,56000,88576,89576,55000,56020,88577,89577,5
5020
50020,55000,89576,90576,54000,55020,89577,90577,5
4020
50021,54000,90576,91576,53000,54020,90577,91577,5
3020
50022,53000,91576,92576,52000,53020,91577,92577,5
2020
50023,52000,92576,93576,51000,52020,92577,93577,5
1020
50024,51000,93576,94576,50000,51020,93577,94577,5
0020
*ELSET,ELSET=MCOT
EB11,EB12
**
*ELSET,ELSET=MCobb,GENERATE
70019,82019,1000
70018,82018,1000
70017,82017,1000
70016,82016,1000
70015,82015,1000
70014,82014,1000
*ELSET,ELSET=MCObf,GENERATE
```

```
70019,82019,1000
70039,82039,1000
70059,82059,1000
70079,82079,1000
70099,82099,1000
70119,82119,1000
70139,82139,1000
*ELSET,ELSET=MCOTR
70576
*ELSET,ELSET=MCOTL
93576
***ELSET,ELSET=MCOSF,GENERATE
**70202,70215,1
**71202,71215,1
**72202,72215,1
**73202,73215,1
**74202,74215,1
**75202,75215,1
**76202,76215,1
**77202,77215,1
**78202,78215,1
**79202,79215,1
** add basket support plates
*node
40140,0.5,2.01,0
40200,0.5,3.25,0
40154,11.00,2.01,0
40214,11.00,3.25,0
*ngen,nset=bsp1
40140,40200,20
*ngen,nset=bsp2
40154,40214,20
*NCOPY,CHANGE NUMBER=1000,OLD SET=bsp1,SHIFT,NEW
SET=bsp3
,0,
3.630,-7.00, 0,3.3392,2.9958,0,0
*NCOPY,CHANGE NUMBER=2000,OLD SET=bsp1,SHIFT,NEW
SET=bsp3
,0,
3.630,-7.00, 0,3.3392,2.9958,0,30
*NCOPY,CHANGE NUMBER=3000,OLD SET=bsp1,SHIFT,NEW
SET=bsp3
,0,
3.630,-7.00, 0,3.3392,2.9958,0,60
*NCOPY,CHANGE NUMBER=4000,OLD SET=bsp1,SHIFT,NEW
SET=bsp3
,0,
3.630,-7.00, 0,3.3392,2.9958,0,90
*NCOPY,CHANGE NUMBER=5000,OLD SET=bsp1,SHIFT,NEW
SET=bsp3
,0,
3.630,-7.00, 0,3.3392,2.9958,0,120
*NCOPY,CHANGE NUMBER=6000,OLD SET=bsp1,SHIFT,NEW
SET=bsp3
,0,
3.630,-7.00, 0,3.3392,2.9958,0,150
*NCOPY,CHANGE NUMBER=7000,OLD SET=bsp1,SHIFT,NEW
SET=bsp3
,0,
3.630,-7.00, 0,3.3392,2.9958,0,180
*NCOPY,CHANGE NUMBER=8000,OLD SET=bsp1,SHIFT,NEW
SET=bsp3
,0,
3.630,-7.00, 0,3.3392,2.9958,0,210
*NCOPY,CHANGE NUMBER=9000,OLD SET=bsp1,SHIFT,NEW
SET=bsp3
,0,
```

APPENDIX C SECTION TWO
INPUT FILE Mcos2.txt

SNF-5204, Rev. 0/CSB-S-0073

```

3.630,-7.00, 0,3.3392,2.9958,0,180
*NCOPY,CHANGE NUMBER=1000,OLD SET=bsp2,SHIFT,NEW
SET=bsp4
,0,
3.630,-7.00, 0,3.3392,2.9958,0,28.69805
*NCOPY,CHANGE NUMBER=2000,OLD SET=bsp2,SHIFT,NEW
SET=bsp4
,0,
3.630,-7.00, 0,3.3392,2.9958,0,30
*NCOPY,CHANGE NUMBER=3000,OLD SET=bsp2,SHIFT,NEW
SET=bsp4
,0,
3.630,-7.00, 0,3.3392,2.9958,0,31.30195
*NCOPY,CHANGE NUMBER=4000,OLD SET=bsp2,SHIFT,NEW
SET=bsp4
,0,
3.630,-7.00, 0,3.3392,2.9958,0,88.69805
*NCOPY,CHANGE NUMBER=5000,OLD SET=bsp2,SHIFT,NEW
SET=bsp4
,0,
3.630,-7.00, 0,3.3392,2.9958,0,90
*NCOPY,CHANGE NUMBER=6000,OLD SET=bsp2,SHIFT,NEW
SET=bsp4
,0,
3.630,-7.00, 0,3.3392,2.9958,0,91.30195
*NCOPY,CHANGE NUMBER=7000,OLD SET=bsp2,SHIFT,NEW
SET=bsp4
,0,
3.630,-7.00, 0,3.3392,2.9958,0,148.69805
*NCOPY,CHANGE NUMBER=8000,OLD SET=bsp2,SHIFT,NEW
SET=bsp4
,0,
3.630,-7.00, 0,3.3392,2.9958,0,150
*NCOPY,CHANGE NUMBER=9000,OLD SET=bsp2,SHIFT,NEW
SET=bsp4
,0,
3.630,-7.00, 0,3.3392,2.9958,0,151.30195
*nset,nset=bsp3
bsp1
*nset,nset=bsp4
bsp2
*nfill,nset=mco
bsp3,bsp4,14,1
*ELEMENT,TYPE=C3D8R,ELSET=bsp
97001,41140,41141,42141,42140,41160,41161,42161,4
2160
97101,42140,42141,43141,43140,42160,42161,43161,4
3160
*ELGEN,ELSET=bsp
97001,14,1,1,3,20,14,3,3000,200
97101,14,1,1,3,20,14,3,3000,200
*mpc
link,43140,44140
link,43160,44160
link,43180,44180
link,43200,44200
link,46140,47140
link,46160,47160
link,46180,47180
link,46200,47200
*ELSET, ELSET=MCOSL
MCOT, MCOB
*SOLID SECTION, ELSET=MCOSL, MATERIAL=SS304
*SHELL SECTION, ELSET=MCOPL, MATERIAL=SS304
0.5
*SOLID SECTION, ELSET=bsp, MATERIAL=SS304
*nset,nset=bspb,generate
41140,41154,1
42140,42154,1
43140,43154,1
44140,44154,1
45140,45154,1
46140,46154,1
47140,47154,1
48140,48154,1
49140,49154,1
*nset,nset=bspt,generate
41200,41214,1
42200,42214,1
43200,43214,1
44200,44214,1
45200,45214,1
46200,46214,1
47200,47214,1
48200,48214,1
49200,49214,1
*NSET,NSET=MCO
N34,SB,ST,N12,L14,T12,T13
bspt,bspb
*ELSET, ELSET=MCO
MCOPL, MCOSL, bsp
*elset,elset=mcobt,generate
70101,93101,1000
70102,93102,1000
70103,93103,1000
70104,93104,1000
70105,93105,1000
70106,93106,1000
70107,93107,1000
70108,93108,1000
70109,93109,1000
70110,93110,1000
70111,93111,1000
70112,93112,1000
70113,93113,1000
70114,93114,1000
70115,93115,1000
*elset,elset=mcosi,generate
70136,93136,1000
70156,93156,1000
70160,93160,1000
70164,93164,1000
70168,93168,1000
70172,93172,1000
70176,93176,1000
70180,93180,1000
*NSET,NSET=MCOSY,GENERATE
70000,70999,1
94000,94999,1
50000,50999,1
60000,60999,1
79140,79200,20
*BOUNDARY
MCOSY, ZSYMM
** end of file

```

```

**service station
**
** Shield Hatch Ring definition
**
*system
0,-10.0,0
*NODE,NSET=HATCH
100,14.815,0,0
120,14.815,0.38,0
500,17.25,10.0,0
114,27.875,0,0
340,16.2375,6.0,0
354,29.5,6.0,0
359,33.125,6.0,0
519,34.25,10.0,0
*NGEN,NSET=HATCH
120,500,20
114,354,20
354,359,1
500,519,1
340,354,1
*NSET,NSET=SSN1,GENERATE
100,340,20
*NSET,NSET=SSN2,GENERATE
114,354,20
*NFill,NSET=HATCH
SSN1,SSN2,14,1
*NSET,NSET=SSN3,GENERATE
340,359,1
*NSET,NSET=SSN4,GENERATE
500,519,1
*NFill,NSET=HATCH
SSN3,SSN4,8,20
*NCOPY,CHANGE NUMBER=1000,OLDSET=HATCH,SHIFT

0,-10,0, 0,10,0,3.75
*NCOPY,CHANGE NUMBER=2000,OLDSET=HATCH,SHIFT

0,-10,0, 0,10,0,7.5
*NCOPY,CHANGE NUMBER=3000,OLDSET=HATCH,SHIFT

0,-10,0, 0,10,0,11.25
*NCOPY,CHANGE NUMBER=4000,OLDSET=HATCH,SHIFT

0,-10,0, 0,10,0,15.
*NCOPY,CHANGE NUMBER=5000,OLDSET=HATCH,SHIFT

0,-10,0, 0,10,0,20.0
*NCOPY,CHANGE NUMBER=6000,OLDSET=HATCH,SHIFT

0,-10,0, 0,10,0,25.0
*NCOPY,CHANGE NUMBER=7000,OLDSET=HATCH,SHIFT

0,-10,0, 0,10,0,30.0
*NCOPY,CHANGE NUMBER=8000,OLDSET=HATCH,SHIFT

0,-10,0, 0,10,0,37.5
*NCOPY,CHANGE NUMBER=9000,OLDSET=HATCH,SHIFT

0,-10,0, 0,10,0,45.0
*NCOPY,CHANGE NUMBER=10000,OLDSET=HATCH,SHIFT

0,-10,0, 0,10,0,60.0
*NCOPY,CHANGE NUMBER=11000,OLDSET=HATCH,SHIFT

0,-10,0, 0,10,0,75.0

*NCOPY,CHANGE NUMBER=12000,OLDSET=HATCH,SHIFT
0,-10,0, 0,10,0,90.0
*NCOPY,CHANGE NUMBER=13000,OLDSET=HATCH,SHIFT
0,-10,0, 0,10,0,105.0
*NCOPY,CHANGE NUMBER=14000,OLDSET=HATCH,SHIFT
0,-10,0, 0,10,0,120.0
*NCOPY,CHANGE NUMBER=15000,OLDSET=HATCH,SHIFT
0,-10,0, 0,10,0,135.0
*NCOPY,CHANGE NUMBER=16000,OLDSET=HATCH,SHIFT
0,-10,0, 0,10,0,142.5
*NCOPY,CHANGE NUMBER=17000,OLDSET=HATCH,SHIFT
0,-10,0, 0,10,0,150.0
*NCOPY,CHANGE NUMBER=18000,OLDSET=HATCH,SHIFT
0,-10,0, 0,10,0,155.0
*NCOPY,CHANGE NUMBER=19000,OLDSET=HATCH,SHIFT
0,-10,0, 0,10,0,160.0
*NCOPY,CHANGE NUMBER=20000,OLDSET=HATCH,SHIFT
0,-10,0, 0,10,0,165.0
*NCOPY,CHANGE NUMBER=21000,OLDSET=HATCH,SHIFT
0,-10,0, 0,10,0,168.75
*NCOPY,CHANGE NUMBER=22000,OLDSET=HATCH,SHIFT
0,-10,0, 0,10,0,172.5
*NCOPY,CHANGE NUMBER=23000,OLDSET=HATCH,SHIFT
0,-10,0, 0,10,0,176.25
*NCOPY,CHANGE NUMBER=24000,OLDSET=HATCH,SHIFT
0,-10,0, 0,10,0,180.
*ELEMENT,TYPE=C3DBR,ELSET=HATCH
1,100,101,1101,1100,120,121,1121,1120
*ELGEN,ELSET=HATCH
1,20,20,1,14,1,20,24,1000,1000
*ELEMENT,TYPE=C3DBR,ELSET=HATCH
281,354,355,1355,1354,374,375,1375,1374
*ELGEN,ELSET=HATCH
281,8,20,1,5,1,8,24,1000,1000
**
** Element sets for surfaces
**
*ELSET,ELSET=FLSI,GENERATE
1,20,1
1001,1020,1
2001,2020,1
3001,3020,1
4001,4020,1
5001,5020,1
6001,6020,1
7001,7020,1
8001,8020,1
9001,9020,1
**
** MCO Guide definition
**
*system

```

```

0,-18.81,0
*NODE
520,14.905,0,0
533,20.75,0,0
534,14.905,.5,0
547,20.75,.5,0
548,13.315,1.0,0
549,14.11,1.0,0
550,14.905,1.0,0
563,20.75,1.0,0
564,13.315,1.25,0
579,20.75,1.25,0
772,15.125,8.0,0.0
787,20.75,8.0,0
*NGEN
520,533,1
534,547,1
550,563,1
*NGEN,NSET=SSN5
564,579,1
*NGEN,NSET=SSN6
772,787,1
*NFILL
SSN5,SSN6,13,16
**
** Adjust node coordinates to correct element
angles
**
*NODE
565,14.11,1.25,0
*NGEN
565,579,1
*NSET,NSET=GUIDE,GENERATE
520,787,1
*NCOPY,CHANGE NUMBER=1000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,3.75
*NCOPY,CHANGE NUMBER=2000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,7.5
*NCOPY,CHANGE NUMBER=3000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,11.25
*NCOPY,CHANGE NUMBER=4000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,15.
*NCOPY,CHANGE NUMBER=5000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,20.0
*NCOPY,CHANGE NUMBER=6000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,25.0
*NCOPY,CHANGE NUMBER=7000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,30.0
*NCOPY,CHANGE NUMBER=8000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,37.5
*NCOPY,CHANGE NUMBER=9000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,45.0
*NCOPY,CHANGE NUMBER=10000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,60.0
*NCOPY,CHANGE NUMBER=11000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,75.0

*NCOPY,CHANGE NUMBER=12000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,90.0
*NCOPY,CHANGE NUMBER=13000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,105.0
*NCOPY,CHANGE NUMBER=14000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,120.0
*NCOPY,CHANGE NUMBER=15000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,135.0
*NCOPY,CHANGE NUMBER=16000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,142.5
*NCOPY,CHANGE NUMBER=17000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,150.0
*NCOPY,CHANGE NUMBER=18000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,155.0
*NCOPY,CHANGE NUMBER=19000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,160.0
*NCOPY,CHANGE NUMBER=20000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,165.0
*NCOPY,CHANGE NUMBER=21000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,168.75
*NCOPY,CHANGE NUMBER=22000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,172.5
*NCOPY,CHANGE NUMBER=23000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,176.25
*NCOPY,CHANGE NUMBER=24000,OLDSET=GUIDE,SHIFT

0,-10,0,0,10,0,180.
*ELEMENT,TYPE=C3D8R,ELSET=GUIDE
584,520,521,1521,1520,534,535,1535,1534
*ELGEN,ELSET=GUIDE
584,13,1,1,24,1000,1000
*ELEMENT,TYPE=C3D8R,ELSET=GUIDE
598,534,535,1535,1534,550,551,1551,1550
*ELGEN,ELSET=GUIDE
598,13,1,1,24,1000,1000
*ELEMENT,TYPE=C3D8R,ELSET=GUIDE
612,548,549,1549,1548,564,565,1565,1564
*ELGEN,ELSET=GUIDE
612,15,1,1,14,16,16,24,1000,1000
**
** Element sets for surfaces
**
*ELSET,ELSET=GSI,GENERATE
612,820,16
1612,1820,16
2612,2820,16
3612,3820,16
4612,4820,16
5612,5820,16
6612,6820,16
7612,7820,16
8612,8820,16
9612,9820,16
*ELSET,ELSET=GS81
612,613

```

APPENDIX C SECTION TWO
INPUT FILE Service.txt

SNF-5204, Rev. 0/CSB-S-0073

1612,1613
2612,2613
3612,3613
4612,4613
5612,5613
6612,6613
7612,7613
8612,8613
9612,9613
10612,10613
11612,11613
12612,12613
13612,13613
14612,14613
15612,15613
16612,16613
17612,17613
18612,18613
19612,19613
20612,20613
21612,21613
22612,22613
23612,23613
24612,24613
*ELSET,ELSET=GS82
598,584
1598,1584
2598,2584
3598,3584
4598,4584
5598,5584
6598,6584
7598,7584
8598,8584
9598,9584
10598,10584
11598,11584
12598,12584
13598,13584
14598,14584
15598,15584
16598,16584
17598,17584
18598,18584
19598,19584
20598,20584
21598,21584
22598,22584
23598,23584
24598,24584
*ELSET,ELSET=GSB3,GENERATE
584,597,1
1584,1597,1
2584,2597,1
3584,3597,1
4584,4597,1
5584,5597,1
6584,6597,1
7584,7597,1
8584,8597,1
9584,9597,1
10584,10597,1
11584,11597,1
12584,12597,1
13584,13597,1
14584,14597,1
15584,15597,1

16584,16597,1
17584,17597,1
18584,18597,1
19584,19597,1
20584,20597,1
21584,21597,1
22584,22597,1
23584,23597,1
24584,24597,1
*SYSTEM
0,-17.31,0.
**
** Cask Definition
**
*NODE
820,12.125,-6.87,0
824,12.125,-10.87,0
*NGEN,NSET=CASK
820,824,1
*NODE
825,12.75,-.5,0
831,12.75,-6.4281,0
835,12.595,-11.2023,0
837,12.95,-13.0,0
*NGEN,NSET=CASK
825,831,1
831,835,1
835,837,1
*NODE
840,13.75,-.5,0
852,13.75,-13.0,0
*NGEN,NSET=CASK
840,852,1
*NODE,NSET=CASK
855,14.88,-.5,0
856,14.88,-1.5,0
867,14.88,-13.0,0
*NGEN,NSET=CASK
856,867,1
*NODE
871,15.9,-1.5,0
882,15.9,-13.0,0
*NGEN,NSET=CASK
871,882,1
*NODE
886,16.905,-1.5,0
897,16.905,-13.0,0
*NGEN,NSET=CASK
886,897,1
*NODE
901,17.905,-1.5,0
912,17.905,-13.0,0
*NGEN,NSET=CASK
901,912,1
*NODE
916,18.905,-1.5,0
927,18.905,-13.0,0
*NGEN,NSET=CASK
916,927,1
*NODE
931,19.905,-1.5,0
942,19.905,-13.0,0
*NGEN,NSET=CASK
931,942,1
** Adjust nodes for bevel at top of cask
*NODE,NSET=CASK
825,13.25,-.5,0

APPENDIX C SECTION TWO
INPUT FILE Service.txt

SNF-5204, Rev. 0/CSB-S-0073

826,12.9833,-1.5,0
827,12.75,-2.375,0
*NCOPY,CHANGE NUMBER=1000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,3.75
*NCOPY,CHANGE NUMBER=2000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,7.5
*NCOPY,CHANGE NUMBER=3000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,11.25
*NCOPY,CHANGE NUMBER=4000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,15.
*NCOPY,CHANGE NUMBER=5000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,20.0
*NCOPY,CHANGE NUMBER=6000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,25.0
*NCOPY,CHANGE NUMBER=7000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,30.0
*NCOPY,CHANGE NUMBER=8000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,37.5
*NCOPY,CHANGE NUMBER=9000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,45.0
*NCOPY,CHANGE NUMBER=10000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,60.0
*NCOPY,CHANGE NUMBER=11000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,75.0
*NCOPY,CHANGE NUMBER=12000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,90.0
*NCOPY,CHANGE NUMBER=13000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,105.0
*NCOPY,CHANGE NUMBER=14000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,120.0
*NCOPY,CHANGE NUMBER=15000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,135.0
*NCOPY,CHANGE NUMBER=16000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,142.5
*NCOPY,CHANGE NUMBER=17000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,150.0
*NCOPY,CHANGE NUMBER=18000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,155.0
*NCOPY,CHANGE NUMBER=19000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,160.0
*NCOPY,CHANGE NUMBER=20000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,165.0
*NCOPY,CHANGE NUMBER=21000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,168.75
*NCOPY,CHANGE NUMBER=22000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,172.5
*NCOPY,CHANGE NUMBER=23000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,176.25
*NCOPY,CHANGE NUMBER=24000,OLDSET=CASK,SHIFT

0,-10,0, 0,10,0,180.
**
**
*ELEMENT,TYPE=C3D8R,ELSET=CASK
501,821,832,1832,1821,820,831,1831,1820
*ELGEN,ELSET=CASK
501,4,1,1,24,1000,1000
*ELEMENT,TYPE=C3D8R,ELSET=CASK
505,826,841,1841,1826,825,840,1840,1825
*ELGEN,ELSET=CASK
505,12,1,1,2,15,12,24,1000,1000
*ELEMENT,TYPE=C3D8R,ELSET=CASK
529,857,872,1872,1857,856,871,1871,1856
*ELGEN,ELSET=CASK
529,11,1,1,5,15,11,24,1000,1000
**
** Element set for surface
**
*ELSET,ELSET=CA11,GENERATE
505,510,1
501,504,1
515,516,1
1505,1510,1
1501,1504,1
1515,1516,1
2505,2510,1
2501,2504,1
2515,2516,1
3505,3510,1
3501,3504,1
3515,3516,1
4505,4510,1
4501,4504,1
4515,4516,1
5505,5510,1
5501,5504,1
5515,5516,1
6505,6510,1
6501,6504,1
6515,6516,1
7505,7510,1
7501,7504,1
7515,7516,1
8505,8510,1
8501,8504,1
8515,8516,1
9505,9510,1
9501,9504,1
9515,9516,1
*ELSET,ELSET=CA12
501
1501
2501
3501
4501
5501
6501
7501
8501
9501
*ELSET,ELSET=CA13

APPENDIX C SECTION TWO
INPUT FILE Service.txt

SNF-5204, Rev. 0/CSB-S-0073

504	4529,4573,11
1504	5529,5573,11
2504	6529,6573,11
3504	7529,7573,11
4504	8529,8573,11
5504	9529,9573,11
6504	10529,10573,11
7504	11529,11573,11
8504	12529,12573,11
9504	13529,13573,11
*ELSET,ELSET=CAT1	14529,14573,11
505,517	15529,15573,11
1505,1517	16529,16573,11
2505,2517	17529,17573,11
3505,3517	18529,18573,11
4505,4517	19529,19573,11
5505,5517	20529,20573,11
6505,6517	21529,21573,11
7505,7517	22529,22573,11
8505,8517	23529,23573,11
9505,9517	24529,24573,11
10505,10517	**
11505,11517	** Set boundary conditions
12505,12517	**
13505,13517	*NSET,NSET=FSYM,GENERATE
14505,14517	100,942,1
15505,15517	24100,24942,1
16505,16517	*NSET,NSET=FLY,GENERATE
17505,17517	355,24355,1000
18505,18517	356,24356,1000
19505,19517	357,24357,1000
20505,20517	358,24358,1000
21505,21517	*NSET,NSET=FLXYZ,GENERATE
22505,22517	359,24359,1000
23505,23517	*NSET,NSET=CAXYZ,GENERATE
24505,24517	837,24837,1000
*ELSET,ELSET=CAT2	852,24852,1000
517	867,24867,1000
1517	882,24882,1000
2517	897,24897,1000
3517	912,24912,1000
4517	927,24927,1000
5517	942,24942,1000
6517	*BOUNDARY
7517	FSYM, ZSYMM
8517	FLY,2
9517	FLXYZ,1,3
10517	CAXYZ,1,3
11517	**END OF FILE
12517	
13517	
14517	
15517	
16517	
17517	
18517	
19517	
20517	
21517	
22517	
23517	
24517	
*ELSET,ELSET=CAT3,GENERATE	
529,573,11	
1529,1573,11	
2529,2573,11	
3529,3573,11	

APPENDIX D

**PEER REVIEW COMMENT RECORD
AND FDNW TRANSMITTAL RECORD**

REVIEW COMMENT RECORD (RCR)					1. Date 9/22/99	2. Review No. CSB/MCO-LJJ
5. Document Number(s)/Title(s)			6. Program/Project/Building Number	7. Reviewer	3. Project No. SNF	4. Page 1 of 3
SNF-5204, Rev. 0, Engineering Report, Analysis for Eccentric Multi-Canister Overpack Drops at the Canister Storage Building (DRAFT)			SNF/CSB-MCO	LJ Jolyk	8. Organization/Group LMHC, Equipment Engineering	9. Location/Phone 2750E/376-4608
17. Comment Submittal Approval:			11. CLOSED			
Organization Manager (Optional) Date <u>9/30/99</u> Reviewer/Point of Contract <u>[Signature]</u> Author/Originator <u>[Signature]</u>			Date <u>9/30/99</u> Reviewer/Point of Contract <u>[Signature]</u> Author/Originator <u>[Signature]</u>			
12. Item	13. Comment(s)/Discrepancy(s) (Provide technical justification for the comment and detailed recommendation of the action required to correct/resolve the discrepancy/problem indicated.)	14. Hold Point	15. Disposition (Provide justification if NOT accepted.)	16. Status		
1	Provide evidence of CHECKING.		Accept.	Closed		
2	Executive Summary Include brief discussion on failure strain criterion. Discussion should emphasize that the failure strain criterion is based on Manjome's multi-axial failure strain criterion that accounts for the multi-axial stress state.		Included in text and attachment	Closed		
3	Executive Summary, 5 th par Need to emphasize that the 80% failure strain value is for the 304L base metal of the MCO and is based on a predicted compressive multi-axial stress state at this high plastic-strain location in the base metal. This failure strain value is based on "normal" quasi-static loading, it does not account for any potential loss in ductility associated with high strain rate induced loading. This needs to be addressed.		Accept.	Closed		
4	Executive Summary, 6 th par The 2% maximum predicted equivalent plastic strain value given in the Executive Summary does not appear to agree with the values given in Expert Panel summary (see pg 45, last par). Explain. Need to emphasize that the 13% failure strain value is for the 304L weld metal of the MCO and is based on a predicted tensile multi-axial stress state at this high plastic-strain location in the weld.		Accept. Report changes to "about 2%" and expert panel says < 3% Accept.	Closed		

REVIEW COMMENT RECORD (RCR)

1. Date 9/22/99				2. Review No. CSB/MCO-LJJ	
3. Project No. SNF				4. Page 2 of 3	
12. Item	13. Comment(s)/Discrepancy(s) (Provide technical justification for the comment and detailed recommendation of the action required to correct/resolve the discrepancy/problem indicated.)	14. Hold Point	15. Disposition (Provide justification if NOT accepted.)	16. Status	
	The 13% failure value does not agree with the 43% value listed in Table 7.1 of report or with the 10% value given in Expert Panel summary (see pg 45, last par). Explain.		Accept.		
5	This failure strain value is based on "normal" quasi-static loading, it does not account for any potential loss in ductility associated with high strain rate induced loading. This needs to be addressed.		Accept.		
6	List of Figures needs to have page numbers listed. Add a List of Tables. Pg 1, Section 2.0, 1 st par, 3 rd line Provide REFERENCE for analysis of MCO drop directly into storage tube receptacle.		Accept. Accept. 3 rd line has been deleted.	Closed	
7	Pg 1, Section 3.0 Comments 2, 3 and 4 apply here as well.		Accept.	Closed	
8	Pg 12, Basket mass A better title for this section would be Basket Model. Need to expand on the description of the basket model. Not clear what idealizations were applied for the modeling of the individual baskets—were the individual baskets allowed to separate—allowing for a billiard ball effect in the impact loading. In addition, was there any rebound loading from the baskets onto the upper containment cap of the MCO during the drop? If so, what was the maximum stress or plastic strain in the closure seal weld?		Accept. Accept. The basket does not rebound.	Closed	
9	Pg 13, 3 rd par Provide REFERENCE for analysis of MCO drop through the ring and into the storage tube and shipping cask.		Accept.	Closed	
10	Pg 18, Table 7.1 Provide title for table. Add column for predicted triaxiality factor. Predicted equivalent plastic-strain values listed don't appear to agree with corresponding Figures listed. Explain		Accept. Accept. Accept.	Closed	
11	Pg 19 Provide units for 220° temperature.		Accept.	Closed	

REVIEW COMMENT RECORD (RCR)

1. Date 9/22/99				2. Review No. CSB/MCO-LJ1	
3. Project No. SNF				4. Page 3 of 3	
12. Item	13. Comment(s)/Discrepancy(s) (Provide technical justification for the comment and detailed recommendation of the action required to correct/resolve the discrepancy/problem indicated.)	14. Hold Point	15. Disposition (Provide justification if NOT accepted.)	16. Status	
12	Pg 40, Section 8.0, 1 st par, line 5 The proposed failure criteria is based on the effective (Mises) strain but this sentence talks about maximum <i>principal</i> strain. Explain.		Accept. Revised text.	Closed	
13	Pg 40, Section 8.0 Provide a plot of the ratio of the multi-axial effective failure strain-to-uniaxial tensile failure strain versus the stress state triaxiality factor.		Accept.	Closed	
14	Pg 40, Section 8.0 Explain how potential reduction in ductility with increasing strain rate is addressed.		Accept.	Closed	
15	Pg 42, Section 9.0, Item 1, line 4 Should read as "... were saved only at <i>selected larger intervals</i> ."		Accept.	Closed	
16	Pg 42, Section 9.0, Item 2, line 4 The 1.3% and 5% values don't agree with values listed in Table 7.1. Explain. The 13% failure strain doesn't agree with values listed in Table 7.1 or with 10% value given in Expert Panel summary (see pg 45, last par). Explain.		Accept.	Closed	
17	Pg 42, Section 9.0, Item 3, line 4 Shouldn't "maximum" and "minimum" be reversed to be consistent with Table 7.1?		Accept.	Closed	
18	Pg 42, Section 9.0 The report discusses the results of the analysis using the "nominal" and "maximum" strain rate stress-strain relation. Apparently, the "maximum" strain rate stress-strain relation was applies for all material elements independent of the actual strain rate which varies with location as well as with time after drop. Some strains were reduced while others were apparently increased with application of the "maximum" strain rate stress-strain relation. The more appropriate approach would be to allow the computer program to calculate the correct stress-strain relation during the solution process for each location in space and time. A "RATE DEPENDENT" option in ABAQUS/Explicit is available for use with the "PLASTIC" option.		The ABAQUS/Explicit rate-dependent option was not used because the computer run time would be greatly increased.	Closed	
19	Appendix B, pg B-2, -3, and 4 Add column for predicted failure strain based on multi-axial failure strain criterion. The results in these tables don't appear to agree with results in Table 7.1. Explain.		The column was removed in according with expert panel's recommendation. The crack prediction is not only based on the predicted failure strain, it is based on the direction of the principal strain direction and strain rate. Revised the Appendix B for clarity and updated Table 7.1.	Closed	
20	See provided marked-up review copy for additional suggested typographical changes.		Accept.	Closed	

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TITLE/DESCRIPTION

**ANALYSIS FOR EXCENTRIC MULTI-CANISTER OVERPACK DROPS AT THE CANISTER STORAGE
BUILDING**

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