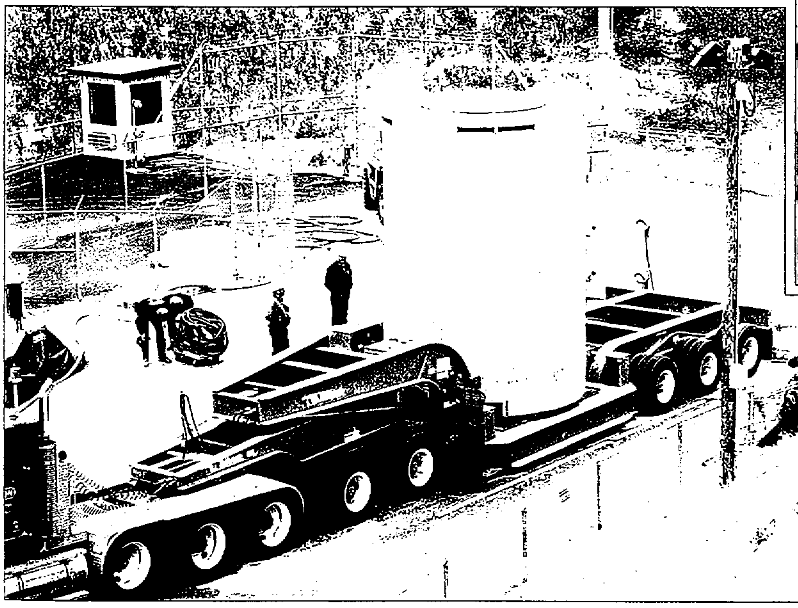
License Amendment Request 00-02 to VSC-24 SAR DFI Changes

BNFL
Fuel Solutions



Volume III

List of Calculations: Volume III

Tab	Calc. No.	Title	Rev.
1	VSC02.6.2.3.10	MTC Lifting Device	0
2	VSC02.6.2.3.11	MTC Thermal Stress Analysis	0
3	VSC02.6.2.3.12	MTC Cover Plate	0
4	VSC02.6.2.3.14	Yoke Analysis	0
5	VSC02.6.2.3.15	VSC-24 Hypothetical Tip-Over 5-Foot Drop Analysis	0
6	VSC02.6.2.3.16	3/16-inch MSB Storage Sleeve	0
7	VSC02.6.2.3.18	VCC Thermal Stress Analysis	0
8	VSC02.6.2.3.19	VSC Flood, Tornado, and Earthquake Analysis	0
9	VSC02.6.2.3.20	Brittle Fracture Evaluation	0
10	VSC02.6.2.3.21	Normal, Off-Normal Handling Analysis	1
11	VSC02.6.2.3.24	MSB Shield Lid Weld Analysis	0
12	VSC02.6.2.3.25	MSB Dead Weight and Vertical Drop Bottom Plate Bending Stress Analysis	1
13	VSC02.6.2.3.31	Calculation for Stress on Structural Lid for a Lifting Bolt Radius of 26.5"	0
14	VSC02.6.2.3.33	Impact on Fuel Sleeve	0
15	VSC02.6.2.5.01	MTC, MSB, and VCC Weights and Centers of Gravity B&W Fuel	0

025621

BNFL Fuel Solutions	**CALCULATION PACKAGE**	Calc. Pkg No. VSC02.6.2.3.10 File No.: VSC02.6.2.3.10 Revision: 0

PROJECT/CUSTOMER:

VSC02/BNFL Fuel Solutions

TITLE:

MTC Lifting Devices.

SCOPE:

Product: ☐ Wesflex™ ☐ TranStor™ ☒ VSC-24 ☐ Other ______

Service: ☒ Storage ☐ Transportation ☐ Other ______

Conditions: ☒ Normal ☐ Off-Normal ☐ Accident ☐ Other ______

Component(s):

MTC trunnions and shell.

Prepared by:

Name: ROBERT KEATING

Signature:

Date: 1/7/2000

Verified by:

Name: Regina Parkerson

Signature: Regina Parkerson

Date: 1/7/2000

Engineering Manager Approval:

Name: Ram Srinivasan

Signature: Srinivasan

Date: 1/15/00

RECORD OF REVISIONS

REV.	AFFECTED PAGES	AFFECTED MEDIA	DESCRIPTION	NAMES (print or type)	
				PREPARER	CHECKER
0	1 – 14 Appendix Pages A1 – A9	None	Replaces Calculation WEP109-002.10, Rev. 2 – Per Ecn No: WEP01-C-018	ROBERT KEATING	Regina Parkerson

Note: This calculation has been prepared in accordance with QAP 3.2, Revision 8, except that because this calculation is a revision of an existing calculation, the format is essentially based on the superceded calculation. The title page, record of revision page, and record of verification page are per QAP 3.2, Revision 8. Other format requirements of QAP 3.2 have been included where this could be readily accomplished. This approach was approved in BFS Memorandum 99-528, dated December 21, 1999.

RECORD OF VERIFICATION

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

COMMENTS:

Verifier: Regina Parkerson Regina Parkerson 1/7/2000
Name/Signature/Date

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LIST OF FIGURES

1. INTRODUCTION

The design of MTC lifting devices must meet the requirements of NUREG 0612, Control of Heavy Loads at Nuclear Power Plants [Reference 3.2.1]. In addition to development of the safe load paths, procedures, etc., the NUREG also requires that special lifting devices and lifting points on heavy loads qualify as "single-failure proof"; otherwise, consequences of the drop must be evaluated. The purpose of this calculation is to determine whether the MTC lifting devices support the single-failure proof design. The scope of the calculation is an analysis of the MTC trunnions and shell.

This calculation was prepared to address technical issues concerning Calculation WEP109-002.10, Revision 2 discussed in CAR 98-50 (date 10/2/98) and the Design Review Record (dated 7/31/98). This calculation supercedes WEP109-002.10, Revision 2. The principal differences between the new and old calculations are:

- The weight of the loaded MTC used as an input has been updated in the new calculation to bound the nominal weight provided in the referenced calculation.
- The MTC load application point in the new calculation has been revised to produce a moment arm of δ=2.25" as compared to the moment arm of δ=3.00" in the old calculation.
- The correct dimensions have been used to calculate the length from the inner shell centerline to the outer shell centerline in the new calculation.

No calculations are known to be affected by this modified calculation.

2. REQUIREMENTS

2.1 Design Inputs

2.1.1 NUREG 0612, "Control of Heavy Loads at Nuclear Power Plants", 1980.
(Specifies the following criteria for single-failure proof devices:)

a) The ANSI N14.6 [Ref. 3.2.2] requirements must be met. For a dual load path design (i.e., a single-failure does not result in uncontrolled movement of the load), the stresses at any point shall not exceed 1/3 of material yield strength or 1/5 of its ultimate strength (safety factors of 3 on yield and 5 on ultimate). As an alternative, the double factors of safety of 6 and 10 must be provided if the lift point system does not have a load path redundancy. This alternative has been applied in this calculation.

b) On top of the ANSI N14.6 criteria above, the design shall include the dynamic load factor (this factor is not specified by NUREG 0612). Based on discussions with the NRC, the increase of 10% was selected to meet this requirement.

2.2 Regulatory Commitments

See Section 2.1.

3. REFERENCES

3.1 BFS Calculation Packages

3.1.1 VSC02.6.2.5.01, Rev. 0, MTC, MSB, and VCC Weights and Centers of Gravity B&W Fuel.
(Weight of wet loaded MTC).

3.2 General References

3.2.1 NUREG 0612, Control of Heavy Loads at Nuclear Power Plants, 1980.

3.2.2 ANSI N14.6, Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds or More , 1986.

3.2.3 Dwg MTC-24-002, Rev. 3, Cask Wall Assembly.

3.2.4 1986 ASME Boiler and Pressure Vessel Code, Section III, Division I, Volume II, Appendices.

3.2.5 1992 ASME Boiler and Pressure Vessel Code, Section II, Part D - Properties.

3.2.6 1986 ASME Boiler and Pressure Vessel Code, Code Cases: Nuclear Components, Volume I, Code Case N-71-14.

4. ASSUMPTIONS

4.1 Design Configuration

Table 4-1: Design Parameters

Item	Material	Value	Reference
Weight of loaded MTC (MSB with water)	N/A	P = 198,000 lbs	Bounds the weight found in Ref. 3.1.1
Inner and Outer Shell Material	A 588, Gr. A or B at 300°F	$S_y = 45.6$ *ksi* $S_u = 70$ *ksi*	3.2.6, Table 3 3.2.6, Table 3
Middle Shell Material	A 36	$S_y = 31.9$ *ksi* $S_u = 58$ *ksi*	3.2.4, Table I-2.1, at 300°F 3.2.5, Table Y-1
Trunnion	A 516, Gr 70 at 200°F	Diameter = 10.75" Thickness = 1.5" $S_y = 34.8$ *ksi* $S_u = 70$ *ksi*	3.2.3 3.2.3 3.2.4, Table I-2.1 3.2.4, Table I-3.1

4.2 Design Criteria

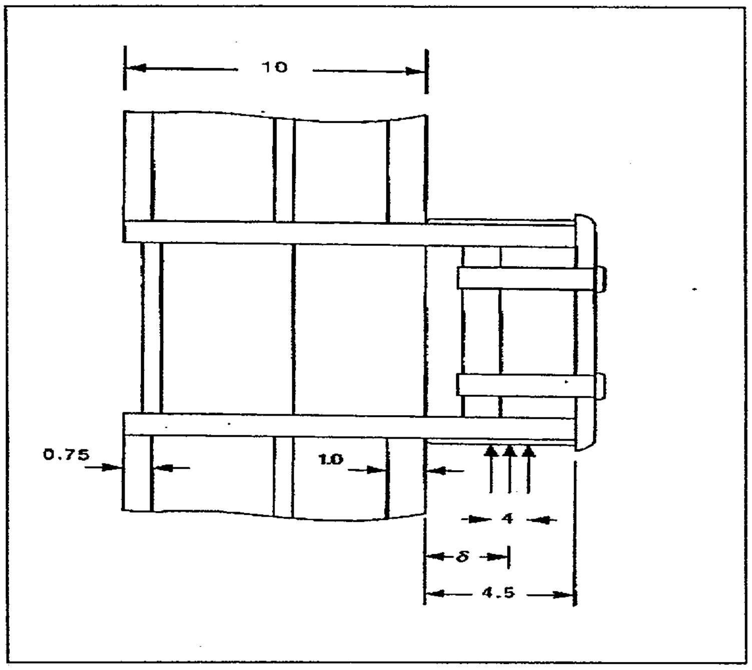
None.

4.3 Calculation Assumptions

4.3.1 The MTC load application point is assumed to be at the center of yoke arm when the arm is in its center position on the trunnion. This produces the moment arm of δ=2.25" used herein. See Figure 4-1.

4.3.2 To obtain section properties, the MTC trunnion is approximated as a pipe with a diameter of 10.75" and a thickness of 1.5".

Figure 4-1: MTC Trunnion



5. CALCULATION METHODOLOGY

To determine whether the MTC trunnion and shell are single-failure proof, as specified by criteria in NUREG 0612, factors of safety are calculated for the trunnion and shell. The calculated factors of safety are then compared to values specified in Section 2.1.

MTC trunnion stresses are calculated by hand by approximating the trunnion as a pipe with an outer diameter of 10.75", and a thickness of 1.5". The outer shell stresses are calculated using ANSYS/PC LINEAR Version 4.3 A-2. These stresses are used along with ultimate strength and yield strength of the trunnion and shell materials to calculate actual factors of safety.

6. CALCULATIONS

6.1 MTC Trunnion

Considering a 10% increase in load, the MTC design load is:

$$P = 1.1 \cdot 198{,}000 = 217{,}800\ lbs$$

Assuming a pipe of dimensions 10.75" × 1.5" thick,

Area of section: S=43.6 in^2

Section modulus: W= 89.0 in^3

Shear stress:

$$\tau = \frac{P}{2S} = \frac{217{,}800}{2 \cdot 43.6} = 2.5\ ksi$$

Bending stress:

$$\sigma_h = \frac{P}{2}\delta\frac{1}{W} = \frac{217{,}800}{2} \cdot 2.25 \cdot \frac{1}{89.0} = 2.75\ ksi$$

Principal stress:

$$S_1 = \frac{\sigma_h}{2} + \sqrt{\left(\frac{\sigma_h}{2}\right)^2 + \tau^2} \quad = 4.2\ ksi$$

$$S_3 = \frac{\sigma_h}{2} - \sqrt{\left(\frac{\sigma_h}{2}\right)^2 + \tau^2} \quad = \text{-}1.5\ ksi$$

$$SI = S_1 \ - S_3 = \ 5.7\ ksi$$

$$K_1 = \frac{34.8}{5.7} = 6.1 > 6.0 \qquad \text{O.K.}$$

$$K_2 = \frac{70}{5.7} = 12.3 > 10.0 \qquad \text{O.K.}$$

6.2 MTC Shell

To evaluate the MTC shell stresses, the trunnion moment was represented by a force couple on the inner and outer shells at the centerlines. The calculated reactions are then applied to the shell model using finite element analysis. Since the force distribution around the trunnion circumference is not known, the loads are applied as weights with the trunnion area supported. This allows the FEA program to achieve the correct distribution automatically. See Figure 6-1.

The reaction on the outer shell is:

$$R = \frac{P}{2}\left(1 + \frac{2.75}{9.125}\right) = 141.7\ kips$$

ANSYS/PC-LINEAR Version 4.3 A-2 code was used for the calculation of the stresses in the outer shell. 2-D STIF42 elements were used. The nodes on the trunnion were simply supported and symmetry conditions provided along x = 0. Refer to Figure 6-2 for a diagram of the finite element model.

Figure 6-1: Trunnion Force Couple on MTC Inner and Outer Shells

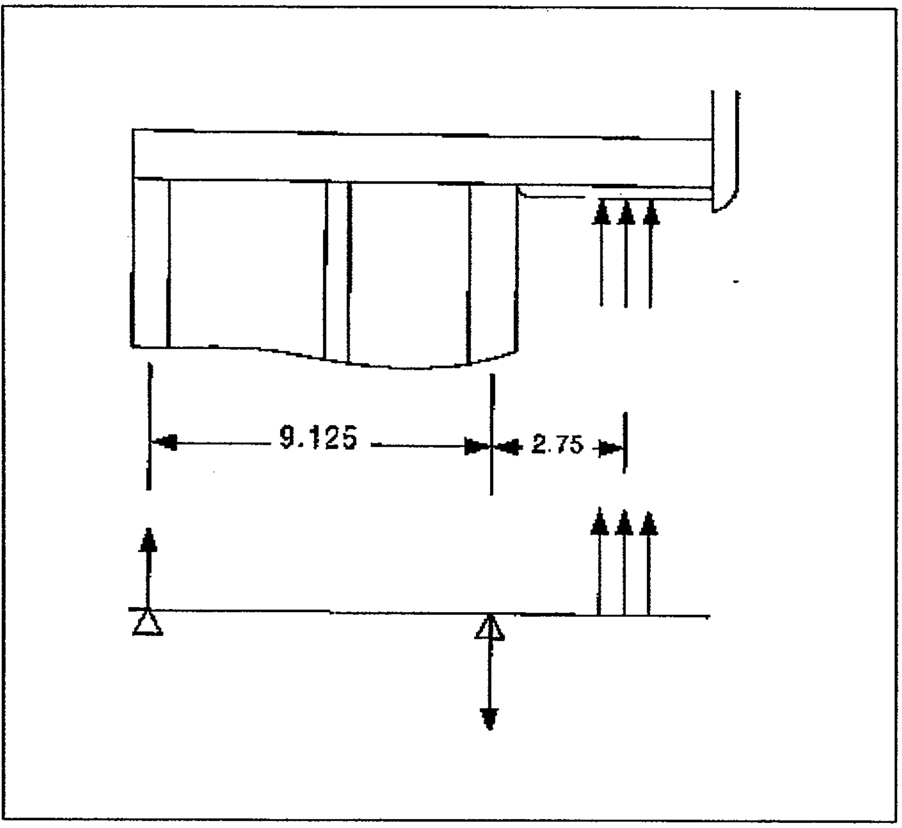
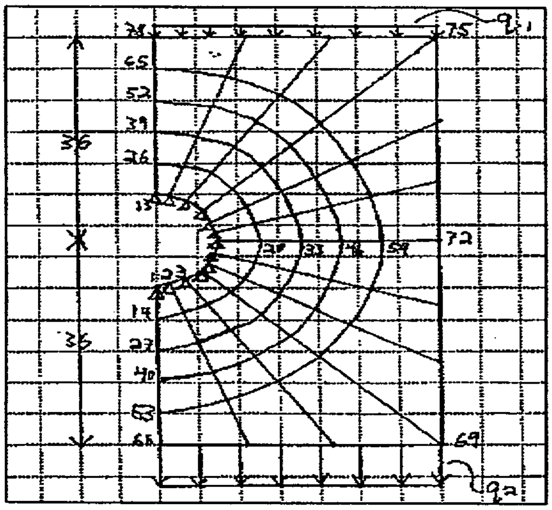


Figure 6-2: MTC Shell Finite Element Model



The plate thickness is 1".

The weight of the modeled 72"-long piece was modeled as density.

The weight is [Ref. 3.1.1]:

$$W = \left(W_{in} + W_{out} + W_{Rx} + W_{lead} + W_{mid}\right) \times \frac{72}{L} = 40.3\ kips$$

Density to adequately represent that in the model:

$$\rho = \frac{W}{4} \cdot \frac{1}{36} \cdot \frac{1}{72}\left(1 + \frac{2.75}{9.125}\right) \cdot 1.1 = 0.0056\ {}^{kips}/_{in^3}$$

The weight of the remaining portion of the loaded MTC is represented by the pressures at the top and bottom of the modeled piece. These pressures are calculated as follows:

q_1 - load due to the weight of the upper ring and cover plate (weights from Ref. 3.1.1)

$$q_1 = \left(1 + \frac{2.75}{9.125}\right)\left(1.30 + 0.40\right) \cdot \frac{1}{4} \cdot \frac{1}{36} \cdot 1.1 = 0.017\ ksi$$

q_2 - load due to the rest of the loaded MTC (not accounted for above)

$$q_2 = \frac{198 - 40.3 - 1.30 - 0.40}{4}\left(1 + \frac{2.75}{9.125}\right)\frac{1}{36} \cdot 1.1 = 1.55\ ksi$$

The ANSYS input/output is attached (Attachment A). The ANSYS analysis was run using a weight W of 40.2 *kips* and a reaction R of 140.1 *kips*. This resulted in a q_1 of 0.018 *ksi* and a q_2 of 1.53 *ksi*. The ANSYS results are scaled up by the ratio of the current q_2 to the q_2 previously evaluated.

From the ANSYS output, the highest stress intensity is at node 2:

$6.84\ ksi \times 1.55 / 1.53 = 6.93\ ksi.$

$$K_1 = \frac{45.6}{6.93} = 6.6 > 6 \qquad \text{O.K.}$$

$$K_2 = \frac{70}{6.93} = 10.1 > 10 \qquad \text{O.K.}$$

7. CONCLUSIONS

The calculation presented in Section 6.0 shows that MTC trunnion and shell are single-failure proof as specified in NUREG 0612. Both the trunnion and shell have safety factors greater than 6 and 10 against yield and ultimate, respectively.

8. ELECTRONIC FILES

8.1 Computer Runs

Copies of computer input and output from ANSYS PC/Linear Version 4.3A-2 for outer shell calculations is provided for convenience in Attachment A. This computer input and output is taken from Reference 3.1.1.

8.2 Other Electronic Files

None.

9. ATTACHMENT A – ANSYS INPUT AND OUTPUT FOR MTC SHELL

```
LIST ALL SELECTED NODE   DSYS=   0

 ODE         X              Y              Z              THXY     THYZ     THXZ
   1   0.20924E-10   -5.3700      0.00000E+00      0.00     0.00     0.00
   2    1.3899       -5.1870      0.00000E+00      0.00     0.00     0.00
   3    2.6850       -4.6506      0.00000E+00      0.00     0.00     0.00
   4    3.7972       -3.7972      0.00000E+00      0.00     0.00     0.00
   5    4.6506       -2.6850      0.00000E+00      0.00     0.00     0.00
   6    5.1870       -1.3899      0.00000E+00      0.00     0.00     0.00
   7    5.3700      0.00000E+00   0.00000E+00      0.00     0.00     0.00
   8    5.1870        1.3899      0.00000E+00      0.00     0.00     0.00
   9    4.6506        2.6850      0.00000E+00      0.00     0.00     0.00
  10    3.7972        3.7972      0.00000E+00      0.00     0.00     0.00
  11    2.6850        4.6506      0.00000E+00      0.00     0.00     0.00
  12    1.3899        5.1870      0.00000E+00      0.00     0.00     0.00
  13   0.20924E-10    5.3700      0.00000E+00      0.00     0.00     0.00
  14   0.28717E-10   -7.3700      0.00000E+00      0.00     0.00     0.00
  15    1.9075       -7.1189      0.00000E+00      0.00     0.00     0.00
  16    3.6850       -6.3826      0.00000E+00      0.00     0.00     0.00
  17    5.2114       -5.2114      0.00000E+00      0.00     0.00     0.00
  18    6.3826       -3.6850      0.00000E+00      0.00     0.00     0.00
  19    7.1189       -1.9075      0.00000E+00      0.00     0.00     0.00
  20    7.3700      0.00000E+00   0.00000E+00      0.00     0.00     0.00

NODE         X              Y              Z              THXY     THYZ     THXZ
  21    7.1189        1.9075      0.00000E+00      0.00     0.00     0.00
  22    6.3826        3.6850      0.00000E+00      0.00     0.00     0.00
  23    5.2114        5.2114      0.00000E+00      0.00     0.00     0.00
  24    3.6850        6.3826      0.00000E+00      0.00     0.00     0.00
  25    1.9075        7.1189      0.00000E+00      0.00     0.00     0.00
  26   0.28717E-10    7.3700      0.00000E+00      0.00     0.00     0.00
  27   0.40407E-10   -10.370      0.00000E+00      0.00     0.00     0.00
  28    2.6840       -10.017      0.00000E+00      0.00     0.00     0.00
  29    5.1850       -8.9807      0.00000E+00      0.00     0.00     0.00
  30    7.3327       -7.3327      0.00000E+00      0.00     0.00     0.00
  31    8.9807       -5.1850      0.00000E+00      0.00     0.00     0.00
  32    10.017       -2.6840      0.00000E+00      0.00     0.00     0.00
  33    10.370      0.00000E+00   0.00000E+00      0.00     0.00     0.00
  34    10.017        2.6840      0.00000E+00      0.00     0.00     0.00
  35    8.9807        5.1850      0.00000E+00      0.00     0.00     0.00
  36    7.3327        7.3327      0.00000E+00      0.00     0.00     0.00
  37    5.1850        8.9807      0.00000E+00      0.00     0.00     0.00
  38    2.6840        10.017      0.00000E+00      0.00     0.00     0.00
  39   0.40407E-10    10.370      0.00000E+00      0.00     0.00     0.00
  40   0.59889E-10   -15.370      0.00000E+00      0.00     0.00     0.00

NODE         X              Y              Z              THXY     THYZ     THXZ
  41    3.9780       -14.846      0.00000E+00      0.00     0.00     0.00
  42    7.6850       -13.311      0.00000E+00      0.00     0.00     0.00
  43    10.868       -10.868      0.00000E+00      0.00     0.00     0.00
  44    13.311       -7.6850      0.00000E+00      0.00     0.00     0.00
  45    14.846       -3.9780      0.00000E+00      0.00     0.00     0.00
  46    15.370      0.00000E+00   0.00000E+00      0.00     0.00     0.00
   7    14.846        3.9780      0.00000E+00      0.00     0.00     0.00
   3    13.311        7.6850      0.00000E+00      0.00     0.00     0.00
   9    10.868        10.868      0.00000E+00      0.00     0.00     0.00
  50    7.6850        13.311      0.00000E+00      0.00     0.00     0.00
  51    3.9780        14.846      0.00000E+00      0.00     0.00     0.00
```

```
   52    0.59889E-10  15.370       0.00000E+00    0.00      0.00      0.00
   53    0.91061E-10 -23.370       0.00000E+00    0.00      0.00      0.00
   54     6.0486     -22.574       0.00000E+00    0.00      0.00      0.00
   55     11.685     -20.239       0.00000E+00    0.00      0.00      0.00
   56     16.525     -16.525       0.00000E+00    0.00      0.00      0.00
   57     20.239     -11.685       0.00000E+00    0.00      0.00      0.00
   58     22.574     -6.0486       0.00000E+00    0.00      0.00      0.00
   59     23.370      0.00000E+00  0.00000E+00    0.00      0.00      0.00
   60     22.574      6.0486       0.00000E+00    0.00      0.00      0.00

 NODE        X            Y            Z          THXY      THYZ      THXZ
   61     20.239      11.685       0.00000E+00    0.00      0.00      0.00
   62     16.525      16.525       0.00000E+00    0.00      0.00      0.00
   63     11.685      20.239       0.00000E+00    0.00      0.00      0.00
   64     6.0486      22.574       0.00000E+00    0.00      0.00      0.00
   65    0.91061E-10  23.370       0.00000E+00    0.00      0.00      0.00
   66    0.00000E+00 -36.000       0.00000E+00    0.00      0.00      0.00
   67     9.6462     -36.000       0.00000E+00    0.00      0.00      0.00
   68     20.785     -36.000       0.00000E+00    0.00      0.00      0.00
   69     36.000     -36.000       0.00000E+00    0.00      0.00      0.00
   70     36.000     -20.785       0.00000E+00    0.00      0.00      0.00
   71     36.000     -9.6462       0.00000E+00    0.00      0.00      0.00
   72     36.000      0.00000E+00  0.00000E+00    0.00      0.00      0.00
   73     36.000      9.6462       0.00000E+00    0.00      0.00      0.00
   74     36.000      20.785       0.00000E+00    0.00      0.00      0.00
   75     36.000      36.000       0.00000E+00    0.00      0.00      0.00
   76     20.785      36.000       0.00000E+00    0.00      0.00      0.00
   77     9.6462      36.000       0.00000E+00    0.00      0.00      0.00
   78    0.00000E+00  36.000       0.00000E+00    0.00      0.00      0.00

L   ALL SELECTED ELEMENTS.   (LIST NODES)

  LEM MAT TYP REL         NODES

    1   1   1   1         1      14      15       2
    2   1   1   1         2      15      16       3
    3   1   1   1         3      16      17       4
    4   1   1   1         4      17      18       5
    5   1   1   1         5      18      19       6
    6   1   1   1         6      19      20       7
    7   1   1   1         7      20      21       8
    8   1   1   1         8      21      22       9
    9   1   1   1         9      22      23      10
   10   1   1   1        10      23      24      11
   11   1   1   1        11      24      25      12
   12   1   1   1        12      25      26      13
   13   1   1   1        14      27      28      15
   14   1   1   1        15      28      29      16
   15   1   1   1        16      29      30      17
   16   1   1   1        17      30      31      18
   17   1   1   1        18      31      32      19
   18   1   1   1        19      32      33      20
   19   1   1   1        20      33      34      21
   20   1   1   1        21      34      35      22

 I  M MAT TYP REL         NODES

    1   1   1   1        22      35      36      23
   22   1   1   1        23      36      37      24
   23   1   1   1        24      37      38      25
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Calc. Pkg. VSC02.6.23.10
Rev.0
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Calc. Pckg. VSC02.6.2.3.10 -
Rev. 0
Pg. A4 of A9

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  24    1    1    1         25     38     39     26
  25    1    1    1         27     40     41     28
  26    1    1    1         28     41     42     29
  27    1    1    1         29     42     43     30
  28    1    1    1         30     43     44     31
  29    1    1    1         31     44     45     32
  30    1    1    1         32     45     46     33
  31    1    1    1         33     46     47     34
  32    1    1    1         34     47     48     35
  33    1    1    1         35     48     49     36
  34    1    1    1         36     49     50     37
  35    1    1    1         37     50     51     38
  36    1    1    1         38     51     52     39
  37    1    1    1         40     53     54     41
  38    1    1    1         41     54     55     42
  39    1    1    1         42     55     56     43
  40    1    1    1         43     56     57     44

 ELEM MAT  TYP  REL             NODES

  41    1    1    1         44     57     58     45
  42    1    1    1         45     58     59     46
  43    1    1    1         46     59     60     47
  44    1    1    1         47     60     61     48
  45    1    1    1         48     61     62     49
  46    1    1    1         49     62     63     50
  47    1    1    1         50     63     64     51
  48    1    1    1         51     64     65     52
  49    1    1    1         53     66     67     54
  50    1    1    1         54     67     68     55
  51    1    1    1         55     68     69     56
  52    1    1    1         56     69     70     57
  53    1    1    1         57     70     71     58
  54    1    1    1         58     71     72     59
  55    1    1    1         59     72     73     60
  56    1    1    1         60     73     74     61
  57    1    1    1         61     74     75     62
  58    1    1    1         62     75     76     63
  59    1    1    1         63     76     77     64
  60    1    1    1         64     77     78     65

IST DISPLACEMENTS FOR ALL SELECTED NODES

NODE   LABEL       DISP               CDISP
   12 UY     0.000000000E+00  0.000000000E+00
   12 UX     0.000000000E+00  0.000000000E+00
    2 UX     0.000000000E+00  0.000000000E+00
    2 UY     0.000000000E+00  0.000000000E+00
    3 UX     0.000000000E+00  0.000000000E+00
    3 UY     0.000000000E+00  0.000000000E+00
    4 UX     0.000000000E+00  0.000000000E+00
    4 UY     0.000000000E+00  0.000000000E+00
    5 UX     0.000000000E+00  0.000000000E+00
    5 UY     0.000000000E+00  0.000000000E+00
    6 UX     0.000000000E+00  0.000000000E+00
      UY     0.000000000E+00  0.000000000E+00
      UX     0.000000000E+00  0.000000000E+00
      UY     0.000000000E+00  0.000000000E+00
    8 UX     0.000000000E+00  0.000000000E+00
    8 UY     0.000000000E+00  0.000000000E+00
```

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```
    9 UX      0.000000000E+00 0.000000000E+00
    9 UY      0.000000000E+00 0.000000000E+00
   10 UX      0.000000000E+00 0.000000000E+00
   10 UY      0.000000000E+00 0.000000000E+00

  ODE  LABEL      DISP            CDISP
   11 UX      0.000000000E+00 0.000000000E+00
   11 UY      0.000000000E+00 0.000000000E+00
    1 UX      0.000000000E+00 0.000000000E+00
   13 UX      0.000000000E+00 0.000000000E+00
   14 UX      0.000000000E+00 0.000000000E+00
   26 UX      0.000000000E+00 0.000000000E+00
   27 UX      0.000000000E+00 0.000000000E+00
   39 UX      0.000000000E+00 0.000000000E+00
   40 UX      0.000000000E+00 0.000000000E+00
   52 UX      0.000000000E+00 0.000000000E+00
   53 UX      0.000000000E+00 0.000000000E+00
   65 UX      0.000000000E+00 0.000000000E+00
   66 UX      0.000000000E+00 0.000000000E+00
   78 UX      0.000000000E+00 0.000000000E+00
   69 UX      0.000000000E+00 0.000000000E+00
   70 UX      0.000000000E+00 0.000000000E+00
   71 UX      0.000000000E+00 0.000000000E+00
   72 UX      0.000000000E+00 0.000000000E+00
   73 UX      0.000000000E+00 0.000000000E+00
   74 UX      0.000000000E+00 0.000000000E+00

 NODE  LABEL      DISP            CDISP
   75 UX      0.000000000E+00 0.000000000E+00

I   r ALL REAL SETS

 REAL CONSTANT SET    1  ITEMS    1 TO    6
   1.0000       0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

LIST ALL MATERIALS  PROPERTY= ALL

PROPERTY TABLE EX     MAT=    1  NUM. POINTS=  2
       TEMPERATURE      DATA          TEMPERATURE      DATA
     0.00000E+00  29000.       2300.0       29000.

PROPERTY TABLE NUXY   MAT=    1  NUM. POINTS=  2
       TEMPERATURE      DATA          TEMPERATURE      DATA
     0.00000E+00 0.30000       2300.0      0.30000

PROPERTY TABLE DENS   MAT=    1  NUM. POINTS=  2
       TEMPERATURE      DATA          TEMPERATURE      DATA
     0.00000E+00 0.56000E-02  2300.0      0.56000E-02

 IST PRESSURES FOR ALL SELECTED NODES

 ELEM   FACE         VALUE(S)                    FACE NODES
    49     2       -1.5300      0.00000E+00        66     67
    50     2       -1.5300      0.00000E+00        67     68
    51     2       -1.5300      0.00000E+00        68     69
    58     2       0.18000E-01  0.00000E+00        75     76
    59     2       0.18000E-01  0.00000E+00        76     77
    60     2       0.18000E-01  0.00000E+00        77     78

 IST ALL ELEMENT TYPES
```

```
NO. STIF            KEYOPT VALUES            INOTPR
 1   42    0  0  3   0  0  0   0  0  0    0  ISOPAR. STRESS SOLID, 2-D
```

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```
PRINT   PRIN   NODAL STRESSES PER NODE

        ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=      1  SECTION=  1
 TIME=   0.00000E+00       LOAD CASE=  1

 NODE        SIG1             SIG2            SIG3            SI              S
    1    3.3473660      0.00000000E+00 -0.64271214       3.9900782       3.710
    2    6.8453732       1.2860227      0.00000000E+00   6.8453732       6.302
    3    5.5715628      0.54872319      0.00000000E+00   5.5715628       5.332
    4    5.1167762      0.84780321E-01 -0.46294371       5.5797199       5.337
    5    4.6108287      0.00000000E+00  -1.3048075       5.9156362       5.408
    6    3.9286908      0.00000000E+00  -2.1152612       6.0439520       5.340
    7    3.1183928      0.00000000E+00  -2.7473579       5.8657507       5.112
    8    2.2423823      0.00000000E+00  -3.1702544       5.4126367       4.739
    9    1.3683977      0.00000000E+00  -3.3926991       4.7610968       4.271
   10   0.54976655      0.00000000E+00  -3.4493303       3.9990968       3.775
   11   0.97719115E-01 -0.25772231      -3.4793174       3.5770365       3.415
   12   0.00000000E+00 -0.68442538      -4.0356456       4.0356456       3.742
   13   0.40275774      0.00000000E+00  -1.9644186       2.3671763       2.193

        ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=      1  SECTION=  1
 TIME=   0.00000E+00       LOAD CASE=  1

 NODE        SIG1             SIG2            SIG3            SI              SI
   14    2.9148414      0.22167840      -1.0177637       3.9326050       3.5821
   15    5.7174623      0.11119332     -0.10688824       5.8243506       5.7213
   16    4.8400640      0.00000000E+00 -0.23306014       5.0731242       4.9636
   17    4.3197731      0.00000000E+00 -0.52143064       4.8412037       4.6144
   18    3.7873358      0.00000000E+00 -0.95038302       4.7377189       4.3610
   19    3.2065456      0.00000000E+00  -1.4067184       4.6132640       4.1181
   20    2.6057631      0.00000000E+00  -1.8448343       4.4505973       3.8941
   21    2.0107673      0.00000000E+00  -2.2206919       4.2314593       3.6859
   22    1.4543242      0.00000000E+00  -2.5131812       3.9675054       3.4935
   23   0.96468081      0.00000000E+00  -2.7243668       3.6890476       3.3256
   24   0.60921995      0.00000000E+00  -2.9032346       3.5124545       3.2554
   25   0.34787796      0.00000000E+00  -3.3069453       3.6548233       3.4975
   26   0.69893260      0.00000000E+00  -1.5872372       2.2861698       2.1330

        ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=      1  SECTION=  1
 TIME=   0.00000E+00       LOAD CASE=  1

 NODE        SIG1             SIG2            SIG3            SI              SI
   27    3.7583257      0.00000000E+00 -0.97257052E-01   3.8555828       3.8086
   28    3.7394854      0.00000000E+00 -0.10446868       3.8439541       3.7933
   29    3.7604706      0.00000000E+00 -0.11331048       3.8737810       3.8189
   30    3.1732198      0.00000000E+00 -0.14167572       3.3148955       3.2468
   31    2.5923582      0.00000000E+00 -0.21642303       2.8087812       2.7104
   32    2.0211890      0.00000000E+00 -0.41054231       2.4317313       2.2629
   33    1.5627681      0.00000000E+00 -0.71057501       2.2733431       2.0267
   34    1.2299526      0.00000000E+00  -1.0981647       2.3281173       2.0271
   35   0.96913710      0.00000000E+00  -1.4964010       2.4655381       2.1583
   36   0.77085502      0.00000000E+00  -1.8142004       2.5850554       2.3032
   37   0.61730963      0.00000000E+00  -2.0958388       2.7131484       2.4683
```

```
  38   0.51204339     0.00000000E+00  -2.0233434        2.5353868       2.3248
  39   0.47553410     0.00000000E+00  -2.0134938        2.4890279       2.2910

       ***** POST1 NODAL STRESS LISTING *****

 AD STEP      1  ITERATION=      1  SECTION=  1
 IME=    0.00000E+00      LOAD CASE=  1

 NODE       SIG1            SIG2            SIG3             SI            SI
   40   3.0468203      0.39178471E-01 -0.71706691E-01   3.1185270       3.0648
   41   2.9640688      0.46446972E-01 -0.57876753E-01   3.0219455       2.9712
   42   2.7287900      0.80002060E-01 -0.22451331E-01   2.7512414       2.7016
   43   2.3886742      0.10356107      0.00000000E+00   2.3886742       2.3387
   44   1.8522461      0.13564379      0.00000000E+00   1.8522461       1.7915
   45   1.3746748      0.12525912     -0.20508359E-01   1.3951831       1.3339
   46   1.0407459      0.34426880E-01 -0.16014997       1.2008958       1.1210
   47  0.83628919      0.00000000E+00 -0.46665531       1.3029445       1.1536
   48  0.72996233      0.00000000E+00 -0.81909363       1.5490560       1.3515
   49  0.62438246      0.00000000E+00  -1.1422495       1.7666320       1.5589
   50  0.51283663      0.00000000E+00  -1.2744969       1.7873336       1.6021
   51  0.46630661      0.00000000E+00  -1.3616556       1.8279622       1.6526
   52  0.44827564      0.00000000E+00  -1.3949995       1.8432751       1.6718

       ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=      1  SECTION=  1
 TIME=    0.00000E+00      LOAD CASE=  1

 NODE       SIG1            SIG2            SIG3             SI            SI
   53   2.4295669      0.11523352      0.00000000E+00   2.4295669       2.3746
    4   2.2910060      0.16067299      0.00000000E+00   2.2910060       2.2159
   55   1.9684818      0.25388314      0.00000000E+00   1.9684818       1.8592
   56   1.6706429      0.42112942      0.00000000E+00   1.6706429       1.5235
   57   1.2988938      0.51716444      0.00000000E+00   1.2988938       1.1512
   58  0.99749249      0.41696246      0.00000000E+00  0.99749249      0.88348
   59  0.80246290      0.14284715      0.00000000E+00  0.80246290      0.74565
   60  0.66301445      0.00000000E+00 -0.17540891      0.83842336      0.76928
   61  0.49031091      0.00000000E+00 -0.37674294      0.86705386      0.76371
   62  0.37777399      0.00000000E+00 -0.51242585      0.89019983      0.80088
   63  0.32567447      0.00000000E+00 -0.56722586      0.89290033      0.79217
   64  0.30693449      0.00000000E+00 -0.75306710       1.0600016      0.95032
   65  0.31898511      0.00000000E+00 -0.84809555       1.1670807       1.0496

       ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=      1  SECTION=  1
 TIME=    0.00000E+00      LOAD CASE=  1

 NODE       SIG1            SIG2            SIG3             SI            SI
   66   2.2205576      0.29449263      0.00000000E+00   2.2205576       2.0889
   67   2.0371177      0.41784524      0.00000000E+00   2.0371177       1.8670
   68   1.6266459      0.65625868      0.00000000E+00   1.6266459       1.4250
   69   1.2369702      0.68679011      0.00000000E+00   1.2369702       1.0736
   70   1.0760286      0.63012472      0.00000000E+00   1.0760286      0.93784
   71  0.85053623      0.52456663      0.00000000E+00  0.85053623      0.74365
       0.74318393      0.20874145      0.00000000E+00  0.74318393      0.66425
       0.66165790      0.00000000E+00 -0.12285001      0.78450791      0.73086
   74  0.50137409      0.00000000E+00 -0.27094964      0.77232374      0.67889
   75  0.29332373      0.00000000E+00 -0.26275665      0.55608037      0.48652
   76  0.42881620E-01 -0.20297801E-01 -0.32851353      0.37139515      0.34421
```

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```
  77   0.71676836E-01 -0.74004593E-02 -0.52055376       0.59223060       0.55941
  78   0.15015510       0.00000000E+00 -0.65766729       0.80782239       0.74419

MAXIMUMS
N DE            2                2              12               2                2
  UE      6.8453732        1.2860227      -4.0356456        6.8453732        6.302
```

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025023

BNFL Fuel Solutions	**CALCULATION PACKAGE**	Calc. Pkg No. VSC02.6.2.3.11 File No.: VSC02.6.2.3.11 Revision: 0

PROJECT/CUSTOMER:

VSC02/BNFL Fuel Solutions

TITLE:

MTC Thermal Stress Analysis

SCOPE:

Product: ☐ Wesflex™ ☐ TranStor™ ☒ VSC-24 ☐ Other ________

Service: ☒ Storage ☐ Transportation ☐ Other ________

Conditions: ☒ Normal ☐ Off-Normal ☐ Accident ☐ Other ________

Component(s):

MTC Outer and Inner Shell

Prepared by:

Name: ROBERT KEATING

Signature:

Date: 1/12/2000

Verified by:

Name: Michelle M. Heinz

Signature: Michelle M. Heinz

Date: 1/12/00

Engineering Manager Approval:

Name: Ram Srinivasan

Signature: R Srinivasan

Date: 1/15/00

RECORD OF REVISIONS

REV.	AFFECTED PAGES	AFFECTED MEDIA	DESCRIPTION	NAMES (print or type)	
				PREPARER	CHECKER
0	1 – 17 & Attachment 1 Pages A1 – A14	None	This calculation supercedes SNC Calculation WEP-109-002.11 (Reference 3.1.2). -	R. Keating Robert Keating	M. Heinz Michelle Heinz
			Per ECN No.: WEP01-C-018		

Note: This calculation has been prepared in accordance with QAP 3.2, Revision 8, except that because this calculation is a revision of an existing calculation, the format is essentially based on the superceded calculation. The title page, record of revision page, and record of verification page are per QAP 3.2, Revision 8. Other format requirements of QAP 3.2 have been included where this could be readily accomplished. This approach was approved in BFS Memorandum 99-528, dated December 21, 1999.

RECORD OF VERIFICATION

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

COMMENTS:

Verifier: Michelle M. Heinz / Michelle M. Heinz / 1/12/00

Name/Signature/Date

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

The purpose/objective of this calculation is to perform a thermal stress analysis of the MTC. The scope of the analysis includes the MTC inner and outer shells.

Since the MTC is exposed to a thermal load, the thermal stress analyses were performed to demonstrate that stresses due to temperature gradients are not excessive. These thermal stresses are secondary, thus, they are not added to stresses due to other service loads.

This Calculation supercedes SNC Calculation WEP-109-002.11, "MTC Thermal Stress Analysis", Revision 1 (Reference 3.1.2). This revision was performed to correct inconsistencies in the temperature properties and allowable stresses. The revision was also performed to update the analysis to new calculation format requirements.

2. REQUIREMENTS

2.1. Design Inputs

2.1.1 1986 ASME Boiler and Pressure Vessel Code, Section III, Division I, Subsection NC. *(Specifies design rules and service limits).*

2.1.2 1986 ASME Boiler and Pressure Vessel Code, Section III, Appendices. *(Specifies design rules and service limits).*

2.2. Regulatory Commitments

None.

3. REFERENCES

3.1. BFS Calculation Packages

3.1.1 SNC Calculation WEP-109.003.07, "VSC Demonstration Project MTC Thermal-Hydraulic Analysis," Revision 3. *(Provides the temperature profile used in the thermal stress analysis).*

3.1.2 SNC Calculation WEP-109.002.11, "MTC Thermal Stress Analysis", Revision 1. *(Provides the ANSYS computer run results).*

3.2. General References

3.2.1 Marks, Standard Handbook for Mechanical Engineers , Fourth Edition. *(Provides material properties for the MTC finite element model).*

3.2.2 BNFL Drawing MTC-24-001, Rev. 3, MSB Transfer Cask (MTC). *(Provides general arrangement for the MTC finite element model).*

3.2.3 BNFL Drawing MTC-24-002, Rev. 3, Cask Wall Assembly. *(Provides dimensions for the MTC finite element model).*

3.2.4 BNFL Drawing MTC-24-003, Rev. 1, Outer Shell. *(Provides dimensions for the MTC finite element model).*

3.2.5 BNFL Drawing MTC-24-005, Rev. 2, Inner Shell. *(Provides dimensions for the MTC finite element model).*

3.2.6 BNFL Drawing MTC-24-004, Rev. 2, Middle Shell. *(Provides dimensions for the MTC finite element model).*

4. ASSUMPTIONS

4.1. Design Configuration

Table 4-1. Summary of Design Parameters

Item	Variable	Value	Reference
MTC Outer Shell			
Outside Diameter	OD_{outer}	83.5 in	3.2.4
Thickness	t_{outer}	1.0 in	3.2.4
Height (Approximate value used)	H	176.75 in	3.2.4
MTC Inner Shell			
Inside Diameter	ID_{inner}	63 in (Assumption 4.3.4)	3.2.5
Thickness (Note 1)	t_{inner}	1 in (Assumption 4.3.4)	3.2.5
MTC Middle Shell			
Outside Diameter	OD_{middle}	73.5 in	3.2.6
Thickness	t_{inner}	0.25 in	3.2.6
Gap at Top of Lead Shielding (Note 1)	Gap	1.0 in	3.2.2
MTC Shell Material		A-588	3.2.3
Elasticity	E_{st}	28.0×10^3 ksi	3.2.1
Thermal Expansion	α_{st}	6.67×10^{-6} in/in-F	3.2.1
Yield Strength	S_y	50 ksi	3.2.1
Tensile Strength	S_u	70 ksi	3.2.1
Gamma Shielding		Lead	3.2.3
Elasticity	E_{lead}	2.0×10^3 ksi	3.2.1
Thermal Expansion	α_{lead}	29×10^{-6} in/in-F	3.2.1
Neutron Shielding		Rx-277	3.2.3
Elasticity	E_{Rx}	3.64×10^3 ksi	3.1.2
Thermal Expansion	α_{Rx}	6.67×10^{-6} in/in-F	3.1.2
Input Temperature Distribution		See Table 4-2	3.1.1

The MTC model is based on the original cask design and does not reflect two important modifications: 1) a 1" thermal expansion gap at the top of lead shielding (the model assumes that lead completely fills the cavity) and 2) the inner shell is modeled as 1" thick while it is 0.75" thick in the final design. Effect of these modifications on the stresses is addressed in Section 4.3.

The input temperature distribution is based on the MTC thermal calculation [Reference 3.1.1] The axial profile is generated using the MSB axial profile: it is assumed that all heat is transferred radially so that the gradient through the MTC wall is proportional to the gradient through the MSB at the same elevation. The temperature profile is shown in Table 4-2.

Table 4-2. MTC Temperature Profile

Node Number	Position (inches from Bottom)	Inside Surface Temperature
1	1	230
6	2	230
15	4.75	230
23	20.75	231
31	36.75	302
39	52.75	324
47	68.75	322
55	84.75	318
63	100.75	309
71	116.75	296
79	132.75	268
87	148.75	212
95	164.75	211
103	174.75	210

4.2. Design Criteria

The ASME Code is used for service level definitions (per Reference 2.1.1) and allowable stresses. The limit for primary membrane plus secondary stress is (Reference 2.1.2, Section XIII-1140)

$$P_m + Q \leq 3\ S_m$$

4.3. Calculation Assumptions

4.3.1 The allowable stresses are based on a bounding temperature of the MTC Shell of 350°F.

4.3.2 Temperature distribution is axisymmetric and an axisymmetric model was used for the MTC .

4.3.3 It was assumed that the MTC bottom has a uniform temperature and a thermal stress analysis for the bottom was not performed.

4.3.4 The MTC model is based on the original cask design and does not reflect two important modifications:

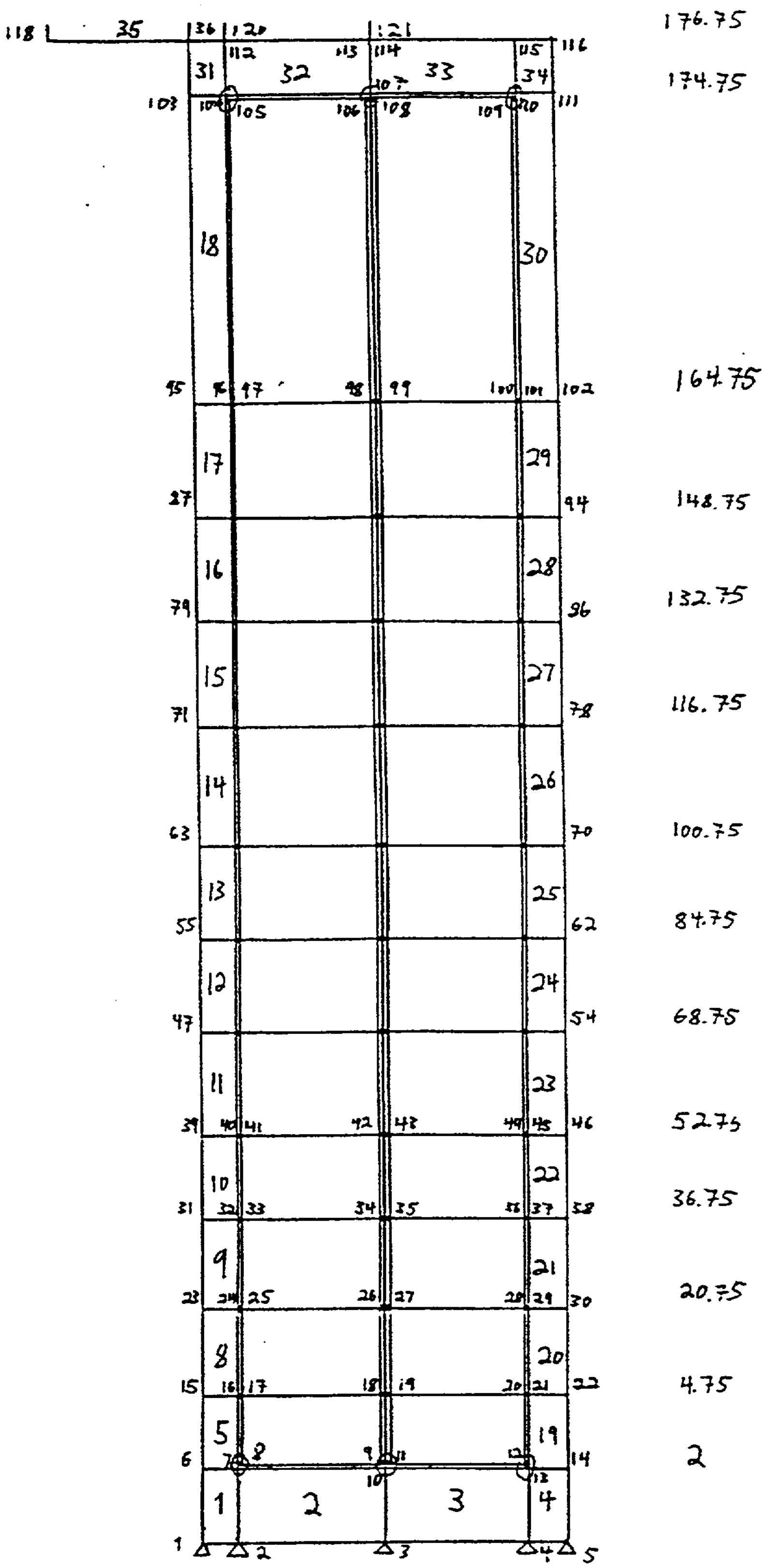
- There is a 1-inch thermal expansion gap at the top of the lead shielding while the model assumes that lead completely fills the cavity. This is conservative since the gap will tend to reduce the expansion stresses due to the growth of the lead.
- The inner shell is modeled as 1" thick while it is 0.75" thick in the final design. This is also conservative. The stress in the inner shell results primarily from displacement of the lead which grows more than the inner shell. Therefore, stresses in the inner shell are displacement limited. If the actual shell is thinner, less stress will result from the compatibility of the displacements.

5. CALCULATION METHODOLOGY

ANSYS/PC Version 4.3A-2 finite element code was used for this analysis. The axisymmetric model used is shown in Fig. 5-1. Gap elements are to model the interaction between steel and lead, lead and RX-277, and RX-277 and steel in the radial direction. There is no interaction between them in the axial direction, except in the bottom nodes for lead and RX, and the top nodes for lead only. All bottom nodes are supported in the axial direction.

ANSYS output is presented in Attachment 1. The computer run was made as part of the original calculation (Reference 3.1.2). The adequacy of the inner and outer shell is determined by first calculating stresses resulting from the temperature profile. Thermal stresses are calculated using ANSYS Version 4.3A-2.

The stresses resulting from the above load conditions are combined according to the ASME Code for Service Level A. The combined loads are compared to ASME allowables.



(Reference 3.1.2)

Figure 5-1. Finite Element Model

6. CALCULATIONS

The resulting stresses from ANSYS output are summarized below.

Bottom: Nodes 3, 10

$$\sigma_x = \frac{1.26+1.14}{2} = 1.2\ ksi$$

$$\sigma_y = -12.9\ ksi \qquad \tau = 0$$

$$\sigma_z = -\frac{2.66+2.76}{2} = -2.7$$

$$S.I = 1.2-(-12.9) = 14.1\ ksi$$

Outer shell:

Near bottom nodes 29, 30

$$\sigma_x = -\frac{0.99+0.14}{2} = -0.57$$

$$\sigma_y = \frac{30.36+30.09}{2} = 30.2 \qquad \tau = -0.74$$

$$\sigma_z = \frac{35.2+34.4}{2} = 34.8$$

$$\sigma_{1,2} = \frac{30.2-0.57}{2} \pm \sqrt{\left(\frac{30.2+0.57}{2}\right)^2 + 0.74^2}$$

$$\sigma_1 = 30.2; \quad \sigma_2 = -0.6; \quad \sigma_3 = \sigma_z = 34.8\ ksi$$

$$S.I = 34.8-(-0.6) = 35.4\ \text{ksi}$$

Middle: nodes 45, 46

$$\sigma_x = -\frac{1.16+0.02}{2} = -0.59 ksi$$

$$\sigma_y = \frac{29.73+30.71}{2} = 30.2 ksi\, \tau_{xy} = -0.28$$

$$\sigma_z = \frac{47.44+46.8}{2} = 47.1$$

$$S.I = 47.1-(-0.6) = 47.7 ksi$$

nodes 69, 70

$$\sigma_x = -\frac{1.06 - 0.03}{2} = -0.52$$

$$\sigma_y = \frac{30.3 + 30.1}{2} = 30.2ksi\, \tau_{xy} = 0.36$$

$$\sigma_z = \frac{45 + 44}{2} = 44.5ksi$$

$$S.I = 44.5 - (-0.52) = 44.0ksi$$

Near top: nodes 101, 102

$$\sigma_x = \frac{-4.8 - 4.5}{2} = -4.6\ ksi$$

$$\sigma_y = \frac{42.5 + 18.1}{2} = 30.3\ ksi \qquad \tau_{xy} = -0.27$$

$$\sigma_z = \frac{6.5 - 1}{2} = 2.75\ ksi$$

$$S.I = 30.3 - (-4.6) = 34.9\ ksi$$

Inner Shell:

Near bottom nodes 23, 24

$$\sigma_x = 0; \quad \sigma_y = \frac{14 + 13.7}{2} = 13.9; \quad \sigma_z = 3.8$$

$$\tau_{xy} = -0.26; \qquad S.I = 13.9 - 0 = 13.9\ ksi$$

Middle nodes 47, 48

$$\sigma_x = 0; \quad \sigma_y = \frac{13.4 + 14.3}{2} = 13.9; \quad \sigma_z = \frac{0.3 + .0.9}{2} = 0.6\ ksi$$

$$\tau_{xy} = 0.34; \qquad S.I = 13.9 - 0 = 13.9\ ksi$$

Near top nodes 95,96

$$\sigma_x = \frac{0.7 + 0.42}{2} = 0.55\ ksi$$

$$\sigma_y = \frac{20.5 + 7.3}{2} = 13.9\ ksi \qquad \tau_{xy} = 1.6\ ksi$$

$$\sigma_z = \frac{-17.5 - 21}{2} = -19.3\ ksi$$

$$\sigma_{1,2} = \frac{13.9 + 0.5}{2} \pm \sqrt{\left(\frac{13.9 - 0.5}{2}\right)^2 + 1.6^2}$$

$$\sigma_1 = 14.1; \quad \sigma_2 = 0.3; \quad \sigma_3 = \sigma_z = -19.3\ ksi$$

$$S.I = 14.1 - (-19.3) = 33.4\ ksi$$

Top Plate: nodes 107, 114

$$\sigma_x = \frac{-33 + 37}{2} = 2\ ksi$$

$$\sigma_y = \frac{-9.7 - 4.6}{2} = -7.2\ ksi \qquad \tau_{xy} = \frac{-5.9 - 6.7}{2} = -6.3$$

$$\sigma_z = \frac{31.4 - 16}{2} = 7.7\ ksi$$

$$\sigma_{1,2} = \frac{2 - 7.2}{2} \pm \sqrt{\left(\frac{2 + 7.2}{2}\right)^2 + 6.3^2}$$

$$\sigma_1 = -10.4; \quad \sigma_2 = 5.2; \quad \sigma_3 = \sigma_z = 7.7\ ksi$$

$$S.I = 7.7 - (-10.4) = 18.1\ ksi$$

Cover Plate: nodes 113, 120

$$\sigma_x = \frac{17.7 + 30.3}{2} = 24$$

$$\sigma_y = \frac{-12.9 - 9.9}{2} = -11.4\ ksi \qquad \tau_{xy} = \frac{5.9 + 4.8}{2} = 5.4$$

$$\sigma_z = \frac{22.3 + 39.5}{2} = 30.9$$

$$\sigma_{1,2} = \frac{24 - 11.4}{2} \pm \sqrt{\left(\frac{24 + 11.4}{2}\right)^2 + 5.4^2}$$

$$\sigma_1 = 24.8; \quad \sigma_2 = -12.2; \quad \sigma_3 = 30.9$$

$$S.I = 30.9 - (-12.2) = 43.1\ ksi$$

The highest stresses in the steel components of the MTC are shown in Table 6-1. The stresses in the lead and Rx-277 are of no concern because these materials are for shielding only and have no structural function.

Table 6-1. Thermal Stress Intensities for MTC

	I/Shell near bottom	I/Shell middle	I/Shell top	O/Shell near bottom	O/Shell middle	O/Shell top	Bottom Plate	Top Plate	Cover Plate
S.I	13.9	13.9	33.4	35.4	47.7	34.9	14.1	18.1	43.1

The allowable stress for thermal loading is based on the ASME Code allowable for secondary stresses. For A-588 Steel, the allowable stress intensity is the lesser of (Reference 2.1.2, Section III-3210):

$S_m = S_u/3 = 70ksi/3 = 23.3$ ksi

$S_m = 2\ S_y/3 = 2 * 50ksi/3 = 33.3$ ksi

The allowable secondary stress limit is (Reference 2.1.2, Section XIII-1140):

$P + Q = 3\ S_m = 3 * 23.3$ ksi $=69.9$ ksi

7. CONCLUSIONS

It can be seen that all stresses are below the allowable secondary stress for the A-588 steel. Since these stresses are secondary (self-limiting), they were not considered in load combination.

8. ELECTRONIC FILES

8.1. Computer Runs

For convenience, copies of the computer run results are provided in Attachment 1. The computer results are from the original analysis provided in Reference 3.1.2.

8.2. Other Electronic Files

None.

9. ATTACHMENT A—ANSYS Output

MTC Thermal stresses

[illegible]

Nodes

```
 LIST ALL SELECTED NODE  DSYS=   0

✗ NODE              X              Y              Z              THXY      THYZ      THXZ
     1          31.500  1"     1.0000     0.00000E+00       0.00      0.00      0.00
     2   10'    32.500         1.0000     0.00000E+00       0.00      0.00      0.00
     3          36.625         1.0000     0.00000E+00       0.00      0.00      0.00
     4          40.750  1"     1.0000     0.00000E+00       0.00      0.00      0.00
     5          41.750         1.0000     0.00000E+00       0.00      0.00      0.00
     6          31.500         2.0000     0.00000E+00       0.00      0.00      0.00
     7          32.500         2.0000     0.00000E+00       0.00      0.00      0.00
     8          32.600         2.0000     0.00000E+00       0.00      0.00      0.00
     9          36.500         2.0000     0.00000E+00       0.00      0.00      0.00
    10          36.625         2.0000     0.00000E+00       0.00      0.00      0.00
    11          36.750         2.0000     0.00000E+00       0.00      0.00      0.00
    12          40.700         2.0000     0.00000E+00       0.00      0.00      0.00
    13          40.750         2.0000     0.00000E+00       0.00      0.00      0.00
    14          41.750         2.0000     0.00000E+00       0.00      0.00      0.00
    15          31.500         4.7500     0.00000E+00       0.00      0.00      0.00
    16          32.500         4.7500     0.00000E+00       0.00      0.00      0.00
    17          32.600         4.7500     0.00000E+00       0.00      0.00      0.00
    18          36.500         4.7500     0.00000E+00       0.00      0.00      0.00
    19          36.750         4.7500     0.00000E+00       0.00      0.00      0.00
    20          40.700         4.7500     0.00000E+00       0.00      0.00      0.00
MORE (YES,NO OR CONTINUOUS)=

MORE (YES,NO OR CONTINUOUS)=y

 NODE               X              Y              Z              THXY      THYZ      THXZ
    21          40.750         4.7500     0.00000E+00       0.00      0.00      0.00
    22          41.750         4.7500     0.00000E+00       0.00      0.00      0.00
    23          31.500         20.750     0.00000E+00       0.00      0.00      0.00
    24          32.500         20.750     0.00000E+00       0.00      0.00      0.00
    25          32.600         20.750     0.00000E+00       0.00      0.00      0.00
    26          36.500         20.750     0.00000E+00       0.00      0.00      0.00
    27          36.750         20.750     0.00000E+00       0.00      0.00      0.00
    28          40.700         20.750     0.00000E+00       0.00      0.00      0.00
    29          40.750         20.750     0.00000E+00       0.00      0.00      0.00
    30          41.750         20.750     0.00000E+00       0.00      0.00      0.00
    31          31.500         36.750     0.00000E+00       0.00      0.00      0.00
    32          32.500         36.750     0.00000E+00       0.00      0.00      0.00
    33          32.600         36.750     0.00000E+00       0.00      0.00      0.00
    34          36.500         36.750     0.00000E+00       0.00      0.00      0.00
```

```
 NODE        X           Y            Z          THXY      THYZ    THXZ
   81       00        132.75     0.00000E+00     0.00      0.00    0.00
   82       00        132.75     0.00000E+00     0.00      0.00    0.00
   83     36.750      132.75     0.00000E+00     0.00      0.00    0.00
   84     40.700      132.75     0.00000E+00     0.00      0.00    0.00
   85     40.750      132.75     0.00000E+00     0.00      0.00    0.00
   86     41.750      132.75     0.00000E+00     0.00      0.00    0.00
   87     31.500      148.75     0.00000E+00     0.00      0.00    0.00
   88     32.500      148.75     0.00000E+00     0.00      0.00    0.00
   89     32.600      148.75     0.00000E+00     0.00      0.00    0.00
   90     36.500      148.75     0.00000E+00     0.00      0.00    0.00
   91     36.750      148.75     0.00000E+00     0.00      0.00    0.00
   92     40.700      148.75     0.00000E+00     0.00      0.00    0.00
   93     40.750      148.75     0.00000E+00     0.00      0.00    0.00
   94     41.750      148.75     0.00000E+00     0.00      0.00    0.00
   95     31.500      164.75     0.00000E+00     0.00      0.00    0.00
   96     32.500      164.75     0.00000E+00     0.00      0.00    0.00
   97     32.600      164.75     0.00000E+00     0.00      0.00    0.00
   98     36.500      164.75     0.00000E+00     0.00      0.00    0.00
   99     36.750      164.75     0.00000E+00     0.00      0.00    0.00
  100     40.700      164.75     0.00000E+00     0.00      0.00    0.00
MORE (YES.NO OR CONTINUOUS)=

MORE (YES.NO OR CONTINUOUS)=v

 NODE        X           Y            Z          THXY      THYZ    THXZ
  101     40.750      164.75     0.00000E+00     0.00      0.00    0.00
  102     41.750      164.75     0.00000E+00     0.00      0.00    0.00
  103     31.500      174.75     0.00000E+00     0.00      0.00    0.00
  104     32.500      174.75     0.00000E+00     0.00      0.00    0.00
  105     32.600      174.75     0.00000E+00     0.00      0.00    0.00
  106     36.500      174.75     0.00000E+00     0.00      0.00    0.00
  107     36.625      174.75     0.00000E+00     0.00      0.00    0.00
  108     36.750      174.75     0.00000E+00     0.00      0.00    0.00
  109     40.700      174.75     0.00000E+00     0.00      0.00    0.00
  110     40.750      174.75     0.00000E+00     0.00      0.00    0.00
  111     41.750      174.75     0.00000E+00     0.00      0.00    0.00
  112     31.500      176.75     0.00000E+00     0.00      0.00    0.00
  113     32.500      176.75     0.00000E+00     0.00      0.00    0.00
  114     36.625      176.75     0.00000E+00     0.00      0.00    0.00
  115     40.750      176.75     0.00000E+00     0.00      0.00    0.00
  116     41.750      176.75     0.00000E+00     0.00      0.00    0.00
  117     20.000      176.75     0.00000E+00     0.00      0.00    0.00
  118     20.000      177.75     0.00000E+00     0.00      0.00    0.00
  119     31.500      177.75     0.00000E+00     0.00      0.00    0.00
  120     32.500      177.75     0.00000E+00     0.00      0.00    0.00
MORE (YES.NO OR CONTINUOUS)=

  120     32.500      177.75     0.00000E+00     0.00      0.00    0.00
MORE (YES.NO OR CONTINUOUS)=v

 NODE        X           Y            Z          THXY      THYZ    THXZ
  121     36.625      177.75     0.00000E+00     0.00      0.00    0.00
PREP7 -INP=elist.1.13

LIST SELECTED ELEMENTS IN RANGE      1 TO     13 BY      1

  ELEM MAT TYP REL         NODES

     1    1    1    1       1      2      7      6
```

```
      13    1    1    1      47    48    56    55
 PREP7 -INP=

 LIST SELECTED ELEMENTS IN RANGE     14 TO    100 BY      1

   ELEM MAT TYP REL.         NODES

     14    1    1    1      55    56    64    63
     15    1    1    1      63    64    72    71
     16    1    1    1      71    72    80    79
     17    1    1    1      79    80    88    87
     18    1    1    1      87    88    96    95
     19    1    1    1      95    96   104   103
     20    1    1    1      21    22    30    29
     21    1    1    1      29    30    38    37
     22    1    1    1      37    38    46    45
     23    1    1    1      45    46    54    53
     24    1    1    1      53    54    62    61
     25    1    1    1      61    62    70    69
     26    1    1    1      69    70    78    77
     27    1    1    1      77    78    86    85
     28    1    1    1      85    86    94    93
     29    1    1    1      93    94   102   101
     30    1    1    1     101   102   111   110
     31    1    1    1     103   104   113   112
     32    1    1    1     104   107   114   113
     33    1    1    1     107   110   115   114
 MORE (YES,NO OR CONTINUOUS)=


   ELEM MAT TYP REL.         NODES

     34    1    1    1     110   111   116   115
     35    1    1    1     117   112   119   118
     36    1    1    1     112   113   120   119
     37    1    1    1     113   114   121   120
     38    2    1    1       8     9    18    17
     39    2    1    1      17    18    26    25
     40    2    1    1      25    26    34    33
     41    2    1    1      33    34    42    41
     42    2    1    1      41    42    50    49
     43    2    1    1      49    50    58    57
     44    2    1    1      57    58    66    65
     45    2    1    1      65    66    74    73
     46    2    1    1      73    74    82    81
     47    2    1    1      81    82    90    89
     48    2    1    1      89    90    98    97
     49    2    1    1      97    98   106   105
     50    3    1    1      11    12    20    19
     51    3    1    1      19    20    28    27
     52    3    1    1      27    28    36    35
     53    3    1    1      35    36    44    43
 MORE (YES,NO OR CONTINUOUS)=


   ELEM MAT TYP REL.         NODES

     54    3    1    1      43    44    52    51
     55    3    1    1      51    52    60    59
     56    3    1    1      59    60    68    67
     57    3    1    1      67    68    76    75
     58    3    1    1      75    76    84    83
     59    3    1    1      83    84    92    91
```

```
     60   3   1   1       91    92   100    99
     61   3   1   1       99   100   109   100
     75   1   2   2        9    11
     76   1   2   2       18    19
     77   1   2   2       26    27
     78   1   2   2       34    35
     79   1   2   2       42    43
     80   1   2   2       50    51
     81   1   2   2       58    59
     82   1   2   2       66    67
     83   1   2   2       74    75
     84   1   2   2       82    83
     85   1   2   2       90    91
     86   1   2   2       98    99
 MORE (YES,NO OR CONTINUOUS)=

     82   1   2   2       66    67
     83   1   2   2       74    75
     84   1   2   2       82    83
     85   1   2   2       90    91
     86   1   2   2       98    99
 MORE (YES,NO OR CONTINUOUS)=v

   ELEM MAT TYP REL         NODES

     87   1   2   2      106   108
     88   1   2   2       12    13
     89   1   2   2       20    21
     90   1   2   2       28    29
     91   1   2   2       36    37
     92   1   2   2       44    45
     93   1   2   2       52    53
     94   1   2   2       60    61
     95   1   2   2       68    69
     96   1   2   2       76    77
     97   1   2   2       84    85
     98   1   2   2       92    93
     99   1   2   2      100   101
    100   1   2   2      109   110
 PREP7 -INP=
```

Temperatures

```
 LIST TEMPERATURES FOR ALL SELECTED NODES

  NODE    TEMPERATURE    FLUENCE
     1      230.00      0.00000E+00
     2      229.00      0.00000E+00
     3      224.00      0.00000E+00
     4      112.00      0.00000E+00
  -  5      111.00      0.00000E+00
     6      230.00      0.00000E+00
     7      229.00      0.00000E+00
     8      229.00      0.00000E+00
     9      224.00      0.00000E+00
    10      224.00      0.00000E+00
    11      224.00      0.00000E+00
    12      112.00      0.00000E+00
```

```
  17      229.00      0.00000E+00
  18      224.00      0.00000E+00
  19      224.00      0.00000E+00
  20      112.00      0.00000E+00
MORE (YES.NO OR CONTINUOUS)=

MORE (YES.NO OR CONTINUOUS)=v

 NODE   TEMPERATURE    FLUENCE
  21      112.00      0.00000E+00
  22      111.00      0.00000E+00
  23      231.00      0.00000E+00
  24      230.00      0.00000E+00
  25      230.00      0.00000E+00
  26      225.00      0.00000E+00
  27      225.00      0.00000E+00
  28      113.00      0.00000E+00
  29      113.00      0.00000E+00
  30      112.00      0.00000E+00
  31      302.00      0.00000E+00
  32      300.00      0.00000E+00
  33      300.00      0.00000E+00
  34      294.00      0.00000E+00
  35      294.00      0.00000E+00
  36      121.00      0.00000E+00
  37      121.00      0.00000E+00
  38      120.00      0.00000E+00
  39      324.00      0.00000E+00
  40      322.00      0.00000E+00
MORE (YES.NO OR CONTINUOUS)=

MORE (YES.NO OR CONTINUOUS)=v

 NODE   TEMPERATURE    FLUENCE
  41      322.00      0.00000E+00
  42      315.00      0.00000E+00
  43      315.00      0.00000E+00
  44      123.00      0.00000E+00
  45      123.00      0.00000E+00
  46      122.00      0.00000E+00
  47      322.00      0.00000E+00
  48      320.00      0.00000E+00
  49      320.00      0.00000E+00
  50      313.00      0.00000E+00
  51      313.00      0.00000E+00
  52      123.00      0.00000E+00
  53      123.00      0.00000E+00
  54      122.00      0.00000E+00
  55      318.00      0.00000E+00
  56      316.00      0.00000E+00
  57      316.00      0.00000E+00
  58      310.00      0.00000E+00
  59      310.00      0.00000E+00
  60      122.00      0.00000E+00
MORE (YES.NO OR CONTINUOUS)=

MORE (YES.NO OR CONTINUOUS)=v

 NODE   TEMPERATURE    FLUENCE
  61      122.00      0.00000E+00
  62      121.00      0.00000E+00
  63      309.00      0.00000E+00
```

```
  63    309.00      0.00000E+00
  64    307.00      0.00000E+00
  65    307.00      0.00000E+00
  66    301.00      0.00000E+00
  67    301.00      0.00000E+00
  68    121.00      0.00000E+00
  69    121.00      0.00000E+00
  70    120.00      0.00000E+00
  71    296.00      0.00000E+00
  72    294.00      0.00000E+00
  73    294.00      0.00000E+00
  74    288.00      0.00000E+00
  75    288.00      0.00000E+00
  76    120.00      0.00000E+00
  77    120.00      0.00000E+00
  78    119.00      0.00000E+00
  79    268.00      0.00000E+00
  80    267.00      0.00000E+00
MORE (YES.NO OR CONTINUOUS)=

MORE (YES.NO OR CONTINUOUS)=v

 NODE   TEMPERATURE   FLUENCE
  81    267.00      0.00000E+00
  82    261.00      0.00000E+00
  83    261.00      0.00000E+00
  84    117.00      0.00000E+00
  85    117.00      0.00000E+00
  86    116.00      0.00000E+00
  87    212.00      0.00000E+00
  88    211.00      0.00000E+00
  89    211.00      0.00000E+00
  90    208.00      0.00000E+00
  91    208.00      0.00000E+00
  92    112.00      0.00000E+00
  93    112.00      0.00000E+00
  94    111.00      0.00000E+00
  95    211.00      0.00000E+00
  96    210.00      0.00000E+00
  97    210.00      0.00000E+00
  98    207.00      0.00000E+00
  99    207.00      0.00000E+00
 100    111.00      0.00000E+00
MORE (YES,NO OR CONTINUOUS)=

MORE (YES.NO OR CONTINUOUS)=v

 NODE   TEMPERATURE   FLUENCE
 101    111.00      0.00000E+00
 102    110.00      0.00000E+00
 103    210.00      0.00000E+00
 104    209.00      0.00000E+00
 105    209.00      0.00000E+00
 106    206.00      0.00000E+00
 107    206.00      0.00000E+00
 108    206.00      0.00000E+00
 109    110.00      0.00000E+00
 110    110.00      0.00000E+00
 111    109.00      0.00000E+00
 112    210.00      0.00000E+00
 113    209.00      0.00000E+00
 114    206.00      0.00000E+00
```

```
   118    210.00      0.00000E+00
   119    210.00      0.00000E+00
   120    209.00      0.00000E+00
 MORE (YES,NO OR CONTINUOUS)=


 LIST SELECTED NODES IN THE RANGE   121 TO   121 BY     1  DSYS=  0

   NODE        X            Y            Z            THXY     THYZ     THXZ
    121     36.625       177.75     0.00000E+00      0.00     0.00     0.0
 PREP7 -INP=dlist.all


 LIST DISPLACEMENTS FOR ALL SELECTED NODES

  NODE  LABEL      DISP              CDISP
     1 UY     0.000000000E+00 0.000000000E+00
     2 UY     0.000000000E+00 0.000000000E+00
     3 UY     0.000000000E+00 0.000000000E+00
     4 UY     0.000000000E+00 0.000000000E+00
     5 UY     0.000000000E+00 0.000000000E+00
 PREP7 -INP=rlist.all


 LIST ALL REAL SETS

  REAL CONSTANT SET    2  ITEMS    1 TO    6
   0.50000E+08  0.00000E+00   3.0000       0.00000E+00  0.00000E+00  0.00000E+00
 PREP7 -INP=


 PROPERTY TABLE EX     MAT=    1  NUM. POINTS=  2
        TEMPERATURE      DATA            TEMPERATURE      DATA
     0.00000E+00  28000.        2300.0      28000.

 PROPERTY TABLE ALPX  MAT=    1  NUM. POINTS=  2
        TEMPERATURE      DATA            TEMPERATURE      DATA
     0.00000E+00 0.66700E-05  2300.0     0.66700E-05

 PROPERTY TABLE ALPX  MAT=    2  NUM. POINTS=  2
        TEMPERATURE      DATA            TEMPERATURE      DATA
     0.00000E+00 0.29300E-04  2300.0     0.29300E-04

 PROPERTY TABLE EX     MAT=    2  NUM. POINTS=  2
        TEMPERATURE      DATA            TEMPERATURE      DATA
     0.00000E+00  2000.0       2300.0      2000.0

 PROPERTY TABLE EX     MAT=    3  NUM. POINTS=  2
        TEMPERATURE      DATA            TEMPERATURE      DATA
     0.00000E+00  3640.0       2300.0      3640.0

 PROPERTY TABLE ALPX  MAT=    3  NUM. POINTS=  2
        TEMPERATURE      DATA            TEMPERATURE      DATA
     0.00000E+00 0.65000E-05  2300.0     0.65000E-05
 PREP7 -INP=




        *****                                    *****
```

```
*****                                    *****
```

Stresses

```
POST1 -INP=prnstr.comn

PRINT  COMP  NODAL STRESSES PER NODE

         ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=     10  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1

 THE FOLLOWING X,Y,Z STRESSES ARE IN GLOBAL COORDINATES

 NODE       SX          SY          SZ          SXY          SYZ         SXZ
    1    2.700       12.77       3.533      -0.8155      0.0000E+00 0.0000E+00
    2    2.504      -3.552      -1.198      -0.4226      0.0000E+00 0.0000E+00
    3    1.264      -12.89      -2.650      -0.2226E-01  0.0000E+00 0.0000E+00
    4    2.253       14.83       25.52       0.4146      0.0000E+00 0.0000E+00
    5    3.402       23.14       27.61       0.8164      0.0000E+00 0.0000E+00
    6 -0.9369        11.35       2.318      -1.296       0.0000E+00 0.0000E+00
    7 -0.1807        3.533       0.2776     -0.8766      0.0000E+00 0.0000E+00
    8    1.024      -8.532      -11.17       0.2765E-01  0.0000E+00 0.0000E+00
    9 -0.2645       -16.40      -11.95       0.7439E-01  0.0000E+00 0.0000E+00
   10    1.145      -12.89      -2.672       0.9909E-01  0.0000E+00 0.0000E+00
   11  0.3336       -1.207     -0.3135E-01-0.2113E-01  0.0000E+00 0.0000E+00
MORE (YES,NO OR CONTINUOUS)=

   10    1.145      -12.89      -2.672       0.9909E-01  0.0000E+00 0.0000E+00
   11  0.3336       -1.207     -0.3135E-01-0.2113E-01  0.0000E+00 0.0000E+00
MORE (YES,NO OR CONTINUOUS)=v

         ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=     10  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1

 THE FOLLOWING X,Y,Z STRESSES ARE IN GLOBAL COORDINATES

 NODE       SX          SY          SZ          SXY          SYZ         SXZ
   12  0.5098        1.166       3.154      -0.2369E-01  0.0000E+00 0.0000E+00
                                               1.561       0.0000E+00 0.0000E+00
```

Bottom

```
 17 -0.1997      -11.00      -11.71      0.6131      0.0          0.0000E+00
 18  -1.400      -13.95      -11.07      0.6545      0.0          0.0000E+00
 19  -1.330      -1.373     -0.5023    -0.5444E-01 0.00         0.0000E+00
 20  -1.113       1.327      2.653     -0.6207E-01 0.0000E+00 0.0000E+00
 21 -0.2522       30.15      27.30       0.1660    0.0000E+00 0.0000E+00
 22  0.4504       30.30      26.03       0.1065    0.0000E+00 0.0000E+00
MORE (YES,NO OR CONTINUOUS)=

 21 -0.2522       30.15      27.30       0.1660    0.0000E+00 0.0000E+00
 22  0.4504       30.30      26.03       0.1065    0.0000E+00 0.0000E+00
MORE (YES,NO OR CONTINUOUS)=v


      ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    10  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1

 THE FOLLOWING X,Y,Z STRESSES ARE IN GLOBAL COORDINATES

 NODE      SX          SY          SZ         SXY         SYZ         SXZ
   23 -0.5949E-02  13.99       3.771     -0.2563      0.0000E+00 0.0000E+00
   24  0.6150E-01  13.69       3.847     -0.2605      0.0000E+00 0.0000E+00
   25 -0.4583E-01 -12.96      -11.37      0.7804E-01  0.0000E+00 0.0000E+00
   26  -1.271     -12.13      -9.595      0.9260E-01  0.0000E+00 0.0000E+00
   27  -1.223     -2.074      0.1078     -0.1143E-01  0.0000E+00 0.0000E+00
   28 -0.9056      2.020       4.110     -0.1893E-01  0.0000E+00 0.0000E+00
   29 -0.9962      30.36       35.19     -0.7329      0.0000E+00 0.0000E+00
   30 -0.1382      30.09       34.44     -0.7436      0.0000E+00 0.0000E+00
   31 -0.9390E-03  13.58      -2.784     -0.9858      0.0000E+00 0.0000E+00
   32 -0.1782E-01  14.09      -2.288      -1.002      0.0000E+00 0.0000E+00
   33 -0.4767E-02 -12.78      -15.01      0.1856      0.0000E+00 0.0000E+00
MORE (YES,NO OR CONTINUOUS)=

   32 -0.1782E-01  14.09      -2.288      -1.002      0.0000E+00 0.0000E+00
   33 -0.4767E-02 -12.78      -15.01      0.1856      0.0000E+00 0.0000E+00
MORE (YES,NO OR CONTINUOUS)=v


      ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    10  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1

 THE FOLLOWING X,Y,Z STRESSES ARE IN GLOBAL COORDINATES

 NODE      SX          SY          SZ         SXY         SYZ         SXZ
```

inner shell near bottom

outer shell near bottom

MIC thermal stresses

Stresses (cont'd)

```
   32 -0.1782E-01  14.09      -2.200      -1.002      0.0000E+00 0.0000E+00
   33 -0.4767E-02 -12.78      -15.01      0.1856      0.0000E+00 0.0000E+00
MORE (YES,NO OR CONTINUOUS)=v

        ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=    10  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1

 THE FOLLOWING X,Y,Z STRESSES ARE IN GLOBAL COORDINATES

 NODE       SX          SY          SZ          SXY         SYZ         SXZ
   34  -1.433      -12.31      -13.09      0.1896      0.0000E+00 0.0000E+00
   35  -1.447      -3.052     -0.6556E-01  0.1314E-01  0.0000E+00 0.0000E+00
   36  -1.060       2.940       5.189      0.8452E-02  0.0000E+00 0.0000E+00
   37  -1.051       29.58       43.70     -0.2065      0.0000E+00 0.0000E+00
   38 -0.1053E-01   30.87       43.24     -0.2078      0.0000E+00 0.0000E+00
   39  0.1448E-01   13.29      -1.254      0.4444E-01  0.0000E+00 0.0000E+00
   40 -0.1430E-01   14.38      -0.5254     0.4515E-01  0.0000E+00 0.0000E+00
   41 -0.1476      -12.98      -16.08      0.2031E-01  0.0000E+00 0.0000E+00
   42  -1.710      -12.11      -13.86      0.2542E-01  0.0000E+00 0.0000E+00
   43  -1.679      -3.353     -0.1910     -0.1341E-01  0.0000E+00 0.0000E+00
   44  -1.256       3.236       5.781     -0.1260E-01  0.0000E+00 0.0000E+00
MORE (YES,NO OR CONTINUOUS)=

   43  -1.679      -3.353     -0.1910     -0.1341E-01  0.0000E+00 0.0000E+00
   44  -1.256       3.236       5.781     -0.1260E-01  0.0000E+00 0.0000E+00
MORE (YES,NO OR CONTINUOUS)=v

        ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=    10  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1

 THE FOLLOWING X,Y,Z STRESSES ARE IN GLOBAL COORDINATES

 NODE       SX          SY          SZ          SXY         SYZ         SXZ
   45  -1.161       29.73       47.44      -0.2766      0.0000E+00 0.0000E+00
   46 -0.2849E-01   30.71       46.70      -0.2810      0.0000E+00 0.0000E+00
   47 -0.3730E-02   13.40       0.3032      0.3437      0.0000E+00 0.0000E+00
   48  0.6597E-03   14.27       0.9350      0.3492      0.0000E+00 0.0000E+00
   49 -0.1164E-01  -12.81      -15.92     -0.7250E-02  0.0000E+00 0.0000E+00
   50  -1.592      -12.77      -13.78     -0.9256E-02  0.0000E+00 0.0000E+00
```

outer shell (middle), max

inner shell (middle)

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```
      -1.100      30.00       47.29       0.1966      0.00
   54  0.3907E-01  30.37       46.41       0.2003      0.00      00 0.0000E+00
   55 -0.7905E-02  13.51     -0.7304E-01 0.7524E-01  0.00            0.0000E+00
 MORE (YES,NO OR CONTINUOUS)=                                        0.0000E+00

   54  0.3907E-01  30.37       46.41       0.2003      0.0000E+00 0.0000E+00
   55 -0.7905E-02  13.51     -0.7304E-01 0.7524E-01  0.0000E+00 0.0000E+00
 MORE (YES,NO OR CONTINUOUS)=v


          ***** POST1 NODAL STRESS LISTING *****

  LOAD STEP      1  ITERATION=     10  SECTION=  1
  TIME=   0.00000E+00      LOAD CASE=  1

  THE FOLLOWING X,Y,Z STRESSES ARE IN GLOBAL COORDINATES

  NODE      SX          SY          SZ          SXY         SYZ         SXZ
    56  0.6641E-03  14.16       0.4063      0.7645E-01  0.0000E+00  0.0000E+00
    57 -0.8105E-01 -12.85      -15.74      -0.2438E-01  0.0000E+00  0.0000E+00
    58  -1.639     -12.24      -13.64      -0.2467E-01  0.0000E+00  0.0000E+00
    59  -1.501     -3.160      -0.1252     -0.1164E-01  0.0000E+00  0.0000E+00
    60  -1.079      3.053       5.729      -0.7872E-02  0.0000E+00  0.0000E+00
    61  -1.148      29.86       47.07      -0.1439      0.0000E+00  0.0000E+00
    62 -0.1175E-01  30.58       46.34      -0.1471      0.0000E+00  0.0000E+00
    63  0.6119E-02  13.51      -0.2201     -0.7332E-01  0.0000E+00  0.0000E+00
    64  0.7806E-02  14.16       0.3458     -0.7450E-01  0.0000E+00  0.0000E+00
    65 -0.3369E-01 -12.79      -15.31      -0.3769E-01  0.0000E+00  0.0000E+00
    66  -1.549     -12.30      -13.29      -0.4018E-01  0.0000E+00  0.0000E+00
 MORE (YES,NO OR CONTINUOUS)=

    65 -0.3369E-01 -12.79      -15.31      -0.3769E-01  0.0000E+00  0.0000E+00
    66  -1.549     -12.30      -13.29      -0.4018E-01  0.0000E+00  0.0000E+00
 MORE (YES,NO OR CONTINUOUS)=v


          ***** POST1 NODAL STRESS LISTING *****

  LOAD STEP      1  ITERATION=     10  SECTION=  1
  TIME=   0.00000E+00      LOAD CASE=  1

  THE FOLLOWING X,Y,Z STRESSES ARE IN GLOBAL COORDINATES

  NODE      SX          SY          SZ          SXY         SYZ         SXZ
    67  -1.744     -3.231      -0.2357      0.2254E-01  0.0000E+00  0.0000E+00
    68  -1.331      3.123       5.493       0.1842E-01  0.0000E+00  0.0000E+00
    69  -1.064      30.30       44.99       0.3611      0.0000E+00  0.0000E+00
    70  0.3269E-01  30.15       44.04       0.3673      0.0000E+00  0.0000E+00
    71 -0.3554E-01  13.49      -0.4043     -0.1292      0.0000E+00  0.0000E+00
    72 -0.3113E-01  14.18       0.1251     -0.1312      0.0000E+00  0.0000E+00
    73 -0.1025     -12.89      -14.65      -0.6547E-01  0.0000E+00  0.0000E+00
    74  -1.541     -12.20      -12.65      -0.7046E-01  0.0000E+00  0.0000E+00
    75  -1.229     -2.766       0.7849E-01-0.3245E-01  0.0000E+00  0.0000E+00
    76 -0.8441      2.671       5.229      -0.2293E-01  0.0000E+00  0.0000E+00
    77  -1.083      29.45       44.14      -0.1359      0.0000E+00  0.0000E+00
 MORE (YES,NO OR CONTINUOUS)=

    76 -0.8441      2.671       5.229      -0.2293E-01  0.0000E+00  0.0000E+00
    77  -1.083      29.45       44.14      -0.1359      0.0000E+00  0.0000E+00
 MORE (YES,NO OR CONTINUOUS)=v


          ***** POST1 NODAL STRESS LISTING *****

  LOAD STEP      1  ITERATION=     10  SECTION=  1
  TIME=   0.00000E+00      LOAD CASE=  1
```

outer shell near middle.

```
          ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=     10  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1

 THE FOLLOWING X,Y,Z STRESSES ARE IN GLOBAL COORDINATES

 NODE       SX           SY          SZ          SXY          SYZ         SXZ
    78 -0.3176E-01  30.99       43.74      -0.1401       0.0000E+00 0.0000E+00
    79  0.9809E-01  13.35       0.5921     -0.6522       0.0000E+00 0.0000E+00
    80  0.1345      14.33       1.083      -0.6626       0.0000E+00 0.0000E+00
    81  0.2607E-01 -12.68      -13.34      -0.1661       0.0000E+00 0.0000E+00
    82  -1.255     -12.41      -11.67      -0.1716       0.0000E+00 0.0000E+00
    83  -1.678      -2.692    -0.8492E-01  0.3852E-01  0.0000E+00 0.0000E+00
    84  -1.315       2.596      4.403      0.3027E-01  0.0000E+00 0.0000E+00
    85 -0.9510      30.61      38.05       0.7466      0.0000E+00 0.0000E+00
    86 -0.1349E-01  29.84      37.07       0.7591      0.0000E+00 0.0000E+00
    87 -0.4001      12.96       2.487     -0.8764      0.0000E+00 0.0000E+00
    88 -0.4777      14.71       3.275     -0.8905      0.0000E+00 0.0000E+00
MORE (YES,NO OR CONTINUOUS)=

    87 -0.4001      12.96       2.487     -0.8764      0.0000E+00 0.0000E+00
    88 -0.4777      14.71       3.275     -0.8905      0.0000E+00 0.0000E+00
MORE (YES,NO OR CONTINUOUS)=y


          ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=     10  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1

 THE FOLLOWING X,Y,Z STRESSES ARE IN GLOBAL COORDINATES

 NODE       SX           SY          SZ          SXY         SYZ         SXZ
    89 -0.1896     -13.53      -10.26       0.2472E-01 0.0000E+00 0.0000E+00
    90  -1.332     -11.58       -8.312      0.1003E-01 0.0000E+00 0.0000E+00
    91 -0.7660      -2.500      0.7158      0.7051E-01 0.0000E+00 0.0000E+00
    92 -0.5251       2.430      4.509      0.8678E-01 0.0000E+00 0.0000E+00
    93 -0.2411E-01  27.32      37.15        0.2453     0.0000E+00 0.0000E+00
    94  0.7367      33.10      38.31        0.2425     0.0000E+00 0.0000E+00
    95  0.7010      20.47     -17.53        1.567      0.0000E+00 0.0000E+00
    96  0.4200       7.276    -21.02        1.634      0.0000E+00 0.0000E+00
    97  0.3998      -8.893    -12.03      -0.7668     0.0000E+00 0.0000E+00
    98 -0.8266     -16.05     -12.78      -0.7113     0.0000E+00 0.0000E+00
    99 -0.9923       1.433     -2.787     -0.2734E-01 0.0000E+00 0.0000E+00
MORE (YES,NO OR CONTINUOUS)=

    98 -0.8266     -16.05     -12.78      -0.7113     0.0000E+00 0.0000E+00
    99 -0.9923       1.433     -2.787     -0.2734E-01 0.0000E+00 0.0000E+00
MORE (YES,NO OR CONTINUOUS)=y


          ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=     10  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1

 THE FOLLOWING X,Y,Z STRESSES ARE IN GLOBAL COORDINATES

 NODE       SX           SY          SZ          SXY         SYZ         SXZ
   100 -0.9200      -1.300     -1.476     -0.1190E-01 0.0000E+00 0.0000E+00
   101  -4.014      42.49       6.497     -0.3071     0.0000E+00 0.0000E+00
   102  -4.462      10.06     -0.9907     -0.2309     0.0000E+00 0.0000E+00
   103   1.970      55.94      13.93       1.616      0.0000E+00 0.0000E+00
   104   10.57     -10.64     -11.40       2.609      0.0000E+00 0.0000E+00
   105  0.2094       3.070     10.23       3.144      0.0000E+00 0.0000E+00
```

inner shell near top (beside nodes 95–97)

outer shell near top (beside nodes 101–103)

```
 110  -1.150                  0.4026      0.4026      0.0000E+00 0.0000E+00
MORE (YES,NO OR CONTINUOUS)=  37.60       10.03       -2.303      0.0000E+00 0.0000E+00

       ***** POST1 NODAL STRESS LISTING *****

LOAD STEP     1  ITERATION=    10  SECTION=  1
TIME=    0.00000E+00      LOAD CASE=  1

THE FOLLOWING X,Y,Z STRESSES ARE IN GLOBAL COORDINATES

NODE      SX          SY          SZ          SXY         SYZ         SXZ
 111   1.726      -34.96      -5.173       4.249      0.0000E+00 0.0000E+00
 112  -2.332       30.46       20.05       8.356      0.0000E+00 0.0000E+00
 113   17.67      -12.07       22.35       5.936      0.0000E+00 0.0000E+00
 114   37.28      -4.568       31.43      -5.853      0.0000E+00 0.0000E+00
 115   5.949       26.84       47.56       1.921      0.0000E+00 0.0000E+00
 116  -9.716      -65.29       13.94       18.08      0.0000E+00 0.0000E+00
 117 -0.4267      -1.747       34.27     -0.7230      0.0000E+00 0.0000E+00
 118   4.012      -1.585       51.73      0.7230      0.0000E+00 0.0000E+00
 119   35.15       3.943       45.97       8.130      0.0000E+00 0.0000E+00
 120   30.30      -9.941       39.48       4.831      0.0000E+00 0.0000E+00
 121   7.673       5.801       36.27      -4.745      0.0000E+00 0.0000E+00

MAXIMUMS
NODE      114         116         118         116          0          0
VALUE    37.28      -65.29       51.73       18.08      0.0000E+00 0.0000E+00
POST1 -INP=
```

top plate

web plate

ATTACHMENT I
VSCO2.6.3.11, REV. 0

025025

BNFL Fuel Solutions	**CALCULATION PACKAGE**	Calc. Pkg No. VSC02.6.2.3.12 File No.: VSC02.6.2.3.12 Revision: 0

PROJECT/CUSTOMER:

VSC02/BNFL Fuel Solutions

TITLE:

MTC Cover Plate.

SCOPE:

Product:	☐ Wesflex™	☐ TranStor™	☒ VSC-24	☐ Other ____
Service:	☒ Storage	☐ Transportation		☐ Other ____
Conditions:	☐ Normal	☐ Off-Normal	☒ Accident	☐ Other ____

Component(s):

MTC cover plate and cover plate bolts.

Prepared by:	Verified by:
Name: ROBERT KEATING	*Name:* Michelle M. Heinz
Signature: Robert Keating	*Signature:* Michelle M. Heinz
Date: 1/12/2000	*Date:* 1/12/00

Engineering Manager Approval:

Name: RAM SRINIVASAN

Signature: R Srinivasan

Date: 1/21/00

RECORD OF REVISIONS

				NAMES (print or type)	
REV.	AFFECTED PAGES	AFFECTED MEDIA	DESCRIPTION	PREPARER	CHECKER
0	1 – 12	None	Replaces Calculation WEP109-002.12, Rev. 3 –	Robert Keating	Michelle Heinz
			Per Ecn No.: WeP01-C-018		

Note: This calculation has been prepared in accordance with QAP 3.2, Revision 8, except that because this calculation is a revision of an existing calculation, the format is essentially based on the superceded calculation. The title page, record of revision page, and record of verification page are per QAP 3.2, Revision 8. Other format requirements of QAP 3.2 have been included where this could be readily accomplished. This approach was approved in BFS Memorandum 99-528, dated December 21, 1999.

RECORD OF VERIFICATION

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

COMMENTS:

Verifier: Michelle M. Heinz / Michelle M. Heinz / 1/12/00

Name/Signature/Date

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1. INTRODUCTION

The cover plate of the MTC is designed to prevent inadvertent lifting of the MSB while the loaded MTC is on the concrete cask. It is desirable to ensure against undue radiation exposure to nearby workers. The lifting could be caused by crane malfunction or by mistake of a crane operator. The entire weight of the empty MTC would be taken by the cover plate, thus the adequate strength of the cover plate and the bolts must be provided.

The purpose/objective of this calculation is to compare MTC cover plate and MTC cover plate bolt stresses and loads to AISC code allowable values. This comparison ensures the entire weight of the empty MTC can be safey supported during an inadvertent lifting event. Because this is a very unlikely accident condition, NUREG 01612 safety factors do not have to be met.

This calculation was prepared to address technical issues concerning Calculation WEP109-002.12, Revision 3 discussed in CAR 98-50 (date 10/2/98) and the Design Review Record (dated 7/31/98). This calculation supercedes WEP109-002.12, Revision 3. The principal differences between the new and old calculations are:

- The weight of the empty MTC used as an input has been updated in the new calculation to bound the nominal weight provided in the referenced calculation.
- MTC component dimensions used as inputs in the new calculation have been correctly taken from the referenced drawings.
- Material properties have been assessed at a temperature of 210°F in the new calculation as compared to 100°F in the old calculation.

No calculations are known to be affected by this modified calculation.

2. REQUIREMENTS

2.1 Design Inputs

2.1.1 1986 ASME Boiler and Pressure Vessel Code, Section III, Division I, Volume II, Appendices. *(Material Properties)*

2.1.2 AISC Manual, Edition 9 *(Material Properties)*

2.2 Regulatory Commitments

None.

3. REFERENCES

3.1 BFS Calculation Packages

3.1.1 VSC02.6.2.5.01, Rev. 0, MTC, MSB, and VCC Weights and Centers of Gravity B&W Fuel.
(Bounding weight of empty MTC).

3.2 General References

3.2.1 1986 ASME Boiler and Pressure Vessel Code, Section III, Division I, Volume II, Appendices.

3.2.2 AISC Manual, Edition 9.

3.2.3 Drawing MTC-24-001, Rev. 3, MSB Transfer Cask.

3.2.4 Drawing MTC-24-006, Rev. 2, MTC Lid and Shim Rings.

3.2.5 MSB-24-001, Rev. 5, MSB Assembly.

3.2.6 Roark, Formulas for Stress and Strain , Edition 4.

4. ASSUMPTIONS

4.1 Design Configuration

TABLE 4.1-1: DESIGN PARAMETERS

Item	Material	Value	Reference
Weight of empty MTC	N/A	P = 120 kips	Bounds value from Ref. 3.1.1
MTC Cover Plate	A-516, Grade 70	D_{outer} = 74" Thickness = 1" D_{inner} = 60.5"	3.2.4
		S_y = 34.5 ksi	3.2.1, Table I-2.1
MTC Cover Plate Bolts	1"-8UNC A-325	Number of bolts = 16 $Radius_{bolt\ circle}$ = 35.5"	3.2.3, 3.2.4
		S_{allow} = 44.0 ksi	3.2.2
MSB		Diameter = 62.5"	3.2.5

The cover plate loading is shown in Figure 4.1-1. The cover plate model is shown in Figure 4.1-2.

FIGURE 4.1-1: MTC COVER PLATE LOADING

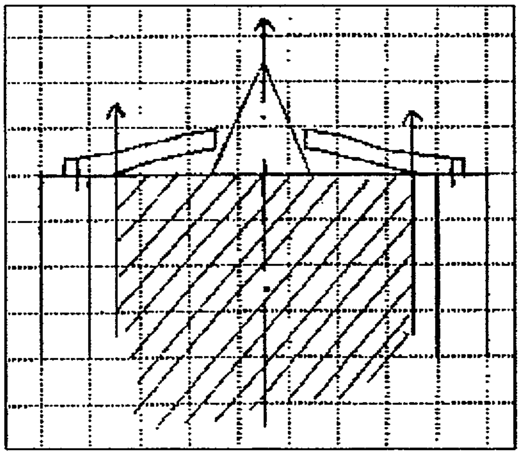
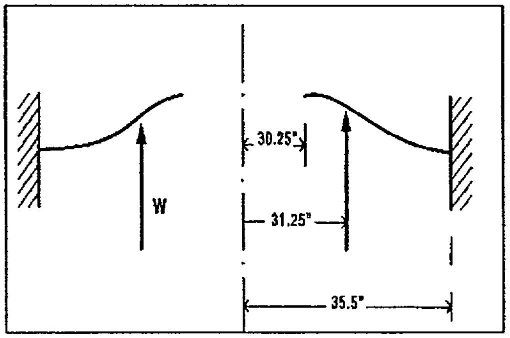


FIGURE 4.1-2: COVER PLATE MODEL



4.2 Design Criteria

None.

4.3 Calculation Assumptions

4.3.1 Because most of the heat is transferred out of the MTC radially, the cover plate and bolt temperatures are expected to be only slightly above the ambient. However, a temperature of 210°F is conservatively assumed for this analysis.

5. CALCULATION METHODOLOGY

To determine whether the MTC cover plate and cover plate bolts can adequately support the weight of the empty MTC during an inadvertent lifting event, cover plate stresses are compared to allowable values, and the bolt tension load is compared to the allowable value specified in the AISC Code.

6. CALCULATIONS

6.1 Cover Plate Stresses

From Roark [Reference 3.2.6] p. 232, #60, the stresses on the inner edge are:

$$S_i = S_t = -\frac{3W}{4\pi m t^2}\left[(m+1)\left(2\ln\frac{a}{r_0}+\frac{r_0^2}{a^2}-1\right)\right]-\frac{6M}{t^2}\left[\frac{a^2(m-1)-b^2(m+1)}{a^2(m-1)+b^2(m+1)}\right]$$

and the stresses on the outer edge are:

$$S_o = S_r = \frac{3W}{2\pi t^2}\left[1-\frac{r_o^2}{a^2}\right]+\frac{6mM}{t^2}\left[\frac{2b^2}{a^2(m-1)+b^2(m+1)}\right]$$

Where $M = \frac{W}{8\,\pi\, m}\left((m+1)\left(2\ln\frac{a}{r_o}+\frac{r_o^2}{a^2}-1\right)\right)$

For our case: $r_0 = 31.25"$; $a = 35.5"$; $b = 30.25"$; $W = 120 kips$; $m = \frac{1}{\nu} = 3.33$

$$M = \frac{120}{8\pi 3.33}\cdot(3.33+1)\cdot\left(2\ln\frac{35.5}{31.25}+\frac{31.25^2}{35.5^2}-1\right) = 0.186\ kips$$

Inside edge:

$$S_i = -\frac{3\cdot 120}{4\pi(3.33)\cdot 1^2}\left[(3.33+1)(2\ln\frac{35.5}{31.25}+\frac{31.25^2}{35.5^2}-1)\right]-$$
$$\frac{6\cdot 0.186}{1^2}\left[\frac{35.5^2(3.33-1)-30.25^2(3.33+1)}{35.5^2\cdot(3.33-1)+30.25^2\cdot(3.33+1)}\right] = -0.95 ksi$$

Outside edge:

$$S_o = \frac{3 \cdot 120}{2\ \pi\ 1^2}\left[1 - \frac{31.25^2}{35.5^2}\right] + \frac{6 \cdot 3.33 \cdot 0.186}{1^2}\left[\frac{2 \cdot 30.25^2}{35.5^2 \cdot 2.33 + 30.25^2 \cdot 4.33}\right] = 13.9ksi$$

$$S \leq 0.75 S_y = 0.75(34.5ksi) = 25.9ksi$$

Shear stress on the outer edge:

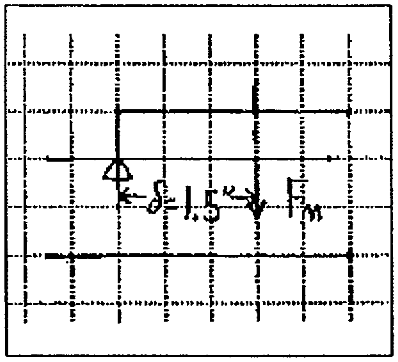
$$\tau = \frac{W}{2\pi a t} = \frac{120}{2\pi \cdot 35.5 \cdot 1} = 0.5ksi \leq 0.4S_y = 0.4(34.5ksi) = 13.8ksi$$

6.2 MTC Cover Plate Bolts

Load on one bolt due to the reaction force:

$$F_F = \frac{W}{h} = \frac{120}{16} = 7.5kips$$

FIGURE 6.2-1: MTC COVER PLATE BOLT PRYING LOAD



Prying load on the bolt due to bending of the plate:

$$F_m = \frac{M_r 2\pi a}{16 \cdot \delta} = \frac{t^2 S_r \cdot 2\pi a}{6 \cdot 16 \cdot 1.5} = \frac{1^2 13.9 \cdot 2\pi \cdot 35.5}{6 \cdot 16 \cdot 1.5} = 21.5kips$$

Total load on the bolt:

$$F = F_F + F_M = 7.5 + 21.5 = 29.0 \ \ kips$$

The allowable tension for A-325 bolt per AISC Code:

$$F_{all} = \frac{\pi d^2 S_{allow}}{4} = \frac{\pi (1inch)^2 \cdot 44.0}{4} = 34.6kips > F = 29.0kips \quad \text{OK}$$

7. CONCLUSIONS

Because the calculated stresses for the MTC cover plate and the calculated tension load for the MTC cover plate bolts are less than specified allowable values, the MTC cover plate and cover plate bolts are adequate to support the MTC load. Should the inadvertent attempt to lift the MSB out of the MTC occur, the MTC will be lifted with the MSB so that workers will not be subjected to increased radiation doses.

8. ELECTRONIC FILES

8.1 Computer Runs

None.

8.2 Other Electronic Files

None.

024981

BNFL Fuel Solutions

CALCULATION PACKAGE

Calc. Pkg No. VSC02.6.2.3.14
File No.: VSC02.6.2.3.14
Revision: 0

PROJECT/CUSTOMER:

VSC02/BNFL Fuel Solutions

TITLE:

Yoke Analysis.

SCOPE:

Product: ☐ Wesflex™ ☐ TranStor™ ☒ VSC-24 ☐ Other ____________
Service: ☒ Storage ☐ Transportation ☐ Other ____________
Conditions: ☒ Normal ☐ Off-Normal ☐ Accident ☐ Other ____________

Component(s):

MTC lifting yoke lifting pin, beam, link, hook, and lifting arm.

Prepared by:
Name: ROBERT KEATING
Signature:
Date: 1/12/2000

Verified by:
Name: Michelle M. Heinz
Signature: Michelle M. Heinz
Date: 1/12/00

Engineering Manager Approval:
Name: Ram Srinivasan
Signature: R Srinivasan
Date: 1/17/00

RECORD OF REVISIONS

REV.	AFFECTED PAGES	AFFECTED MEDIA	DESCRIPTION	NAMES (print or type)	
				PREPARER	CHECKER
0	1 – 19	None	Replaces Calculation WEP109-002.14, Rev. 1 —	ROBERT KEATING	Michelle Heinz
			Per Ecn No.: WEP01-C-018		

Note: This calculation has been prepared in accordance with QAP 3.2, Revision 8, except that because this calculation is a revision of an existing calculation, the format is essentially based on the superceded calculation. The title page, record of revision page, and record of verification page are per QAP 3.2, Revision 8. Other format requirements of QAP 3.2 have been included where this could be readily accomplished. This approach was approved in BFS Memorandum 99-528, dated December 21, 1999.

RECORD OF VERIFICATION

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

COMMENTS:

Verifier: Michelle M. Heinz / Michelle M. Heinz / 1/12/00

Name/Signature/Date

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1. INTRODUCTION

This calculation package presents the stress analysis of the Lifting Yoke for the MSB Transfer Cask. The analyzed design is typical and subject to site-specific modifications. The purpose/objective of this calculation is to show that the yoke meets requirements of NUREG 0612 [Reference 3.2.1] for single-failure proof devices. The scope of the calculation includes the lifting yoke lifting pin, beams, link, hook, and lifting arm.

This calculation was prepared to address technical issues concerning Calculation WEP109-002.14, Revision 1 discussed in CAR 98-50 (date 10/2/98), CAR 98-19 (dated 4/24/99), and the Design Review Record (dated 7/31/98). This calculation supercedes WEP109-002.14, Revision 1. The principle differences between the new and old calculations are:

- The lifting pin material has been correctly reported as A-514 steel in the new calculation.
- The material ultimate strength for the lifting yoke is assumed to be greater than the minimum specified for this material. This is true for existing yokes based on a BNFL review of Certified Material Test Reports. The drawing for the hook should be revised to specify the minimum strength required to be consistent with this calculation.
- The weight of the wet loaded MTC used as an input has been updated in the new calculation to bound the nominal weight provided in the referenced calculation.
- The section modulus used to calculate the stresses in the center of the beams takes into account the hole in the beam in the new calculation.
- The shear stress at the edge of the beam hole has been correctly calculated in the new calculation.
- Bending stress in the hook is calculated as it would be for a truss structure, i.e., a correction factor for a curved beam is not considered to be applicable.
- Stress at the hook section with a cut-out is calculated with a assuming a moment couple in the two parallel arms of the hook.

No BFS calculations are affected by this modified calculation.

2. REQUIREMENTS

2.1 Design Inputs

2.1.1 NUREG 0612, "Control of Heavy Loads at Nuclear Power Plants", 1980.
(Specifies the following criteria for single-failure proof devices:)

a) The ANSI N14.6 [Ref. 3.2.2] requirements must be met. For a dual load path design (i.e., a single-failure does not result in uncontrolled movement of the load), the stresses at any point shall not exceed 1/3 of material yield strength or 1/5 of its ultimate strength (safety factors of 3 on yield and 5 on ultimate). As an alternative, the double factors of safety of 6 and 10 must be provided if the lift point system does not have a load path redundancy. This alternative has been applied in this calculation.

b) On top of the ANSI N14.6 criteria above, the design shall include the dynamic load factor (but this factor is not specified by NUREG 0612). Based on discussions with the NRC, the increase of 10% was selected to meet this requirement.

2.2 Regulatory Commitments

See Section 2.1.

3. REFERENCES

3.1 BFS Calculation Packages

3.1.1 VSC02.6.2.5.01, Rev. 0, MTC, MSB, and VCC Weights and Centers of Gravity B&W Fuel.
(Bounding weight of wet loaded MTC).

3.2 General References

3.2.1 NUREG 0612, Control of Heavy Loads at Nuclear Power Plants, 1980.

3.2.2 ANSI N14.6, Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds or More , 1986.

3.2.3 Drawing LY-001, Cask Lifting Yoke Arm Type, Rev. B.

3.2.4 Roark, Formulas for Stress and Strain, Edition 4.

3.2.5 ASTM A 514, 1989.

3.2.6 Drawing LY-002, Cask Lifting Yoke Hook Type, Rev. B.

4. ASSUMPTIONS

4.1 Design Configuration

Table 4-1: Design Parameters

Item	Material	Value	Reference
Weight of wet loaded MTC	N/A	P = 198.5 kips	Bounds value from Ref. 3.1.1
Lifting Pin, Link, Lifting Arm, and Hook	A-514 Steel [References 3.2.3 and 3.2.6]	S_y = 90 ksi S_u = 100 ksi	3.2.5, Table 2 (Thickness over 2.5")
Beams	A-514 Steel [Reference 3.2.3]	S_y = 100 ksi S_u = 110 ksi	3.2.5, Table 2 (Thickness bet. 0.75" and 2.5")

Figure 4-1 provides the MTC lifting yoke hook design from Reference 3.2.6. Designs for other yoke components from References 3.2.3 and 3.2.6 are provided in Section 6.0. The thickness of the lifting yoke is 4 inches (Reference 3.2.6).

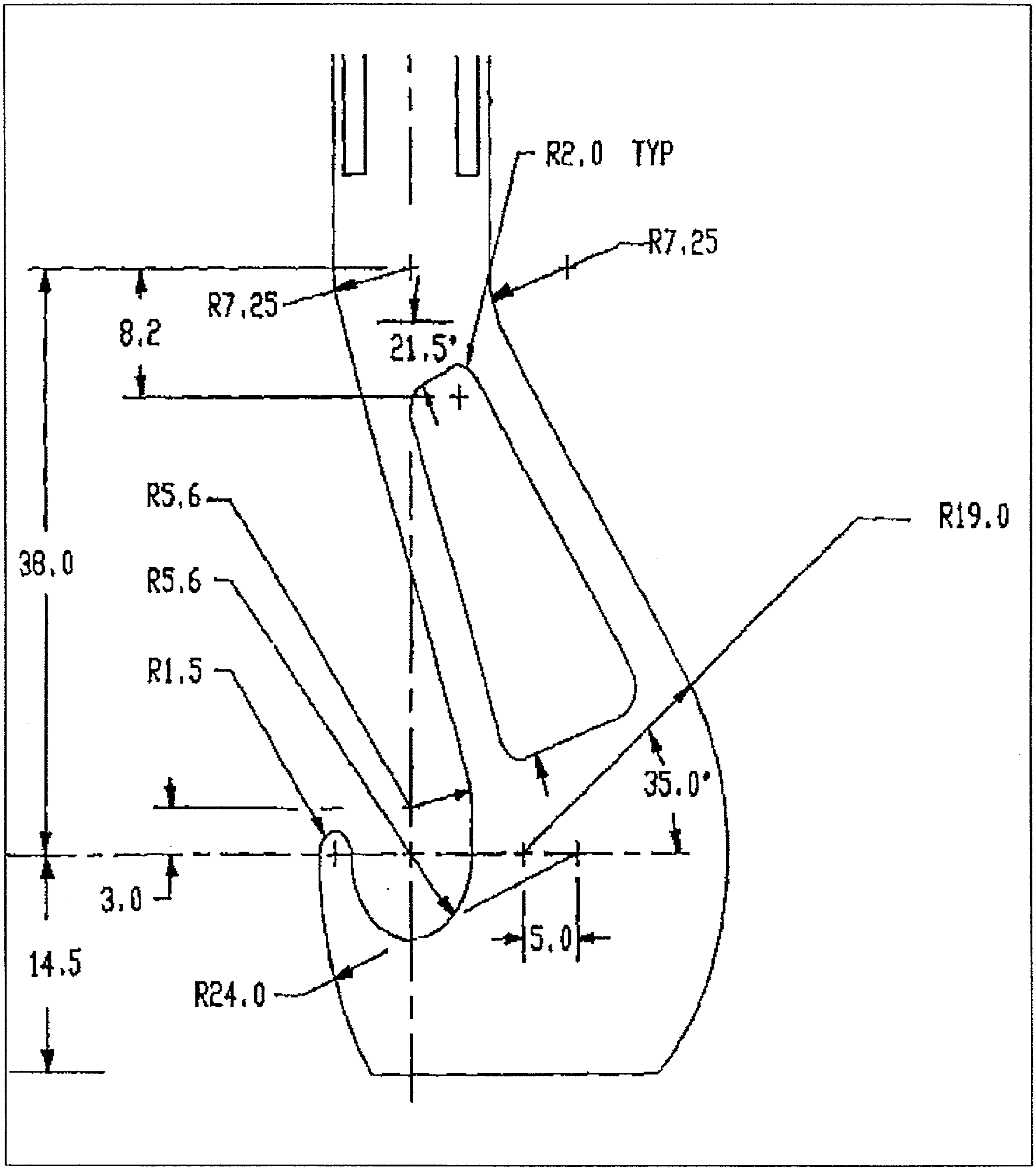
4.2 Design Criteria

None.

4.3 Calculation Assumptions

4.3.1 It is assumed that the hook minimum material ultimate strength is 110 ksi. This is greater than the minimum specified ultimate strength of 100 ksi for this material when the thickness is greater than 2.5 inches (lifting hook thickness is 4 inches). Existing hooks meet this assumption based on a BNFL review of Certified Material Test Reports.

Figure 4-1: MTC Lifting Yoke Design



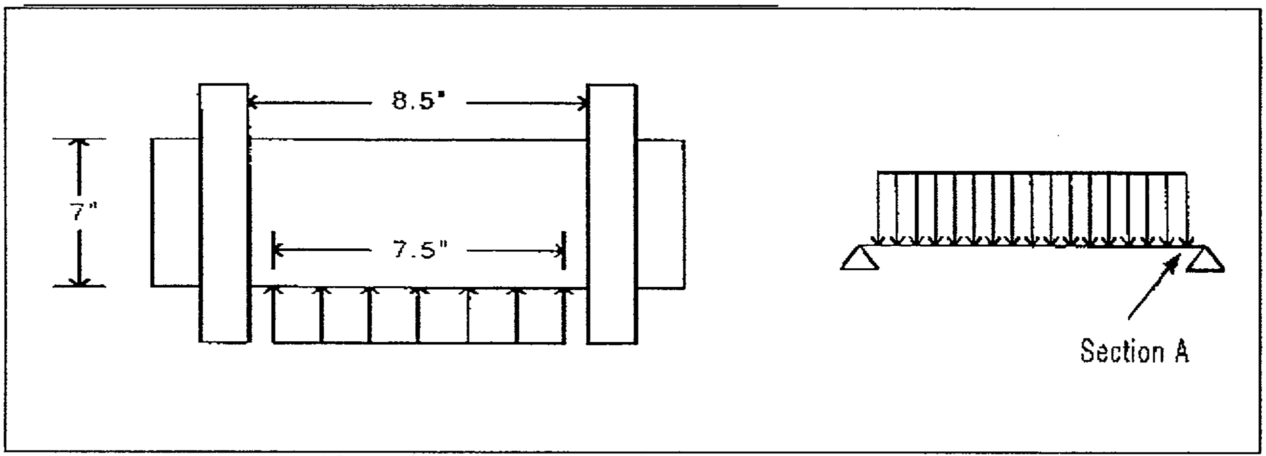
5. CALCULATION METHODOLOGY

To determine whether the MTC lifting yoke meets the requirements of NUREG 0612 for single-failure proof devices, safety factors against yield and ultimate are calculated for the lifting yoke lifting pin, beams, link, hook, and lifting arm. These safety factors are compared to those values specified in Section 2.0 for yield and ultimate.

6. CALCULATIONS

6.1 Lifting Pin

Figure 6-1: MTC Lifting Pin



Note: Dimensions are per Reference 3.2.3.

Load with dynamic increase factor: $P = 198.5 \cdot 1.1 = 218.4 kips$

Max shear:

$$V = P/_2 = 109.2; A = 7^2 \frac{\pi}{4} = 38.5 in^2; \tau = \frac{4V}{3A} = 3.8 ksi$$

Bending: (Roark, Table III, #14 [Reference 3.2.4])

$$M = P\frac{1}{2}\left(\frac{8.5-7.5}{2} + \frac{7.5 \cdot \frac{8.5}{2}}{2 \cdot 8.5}\right) = 259.4 kips - in$$

$$W = \frac{1}{4}\pi R^3 = 33.6 in^3 \rightarrow \sigma_b = 7.7 ksi$$

In the Middle:

$$\tau = 0,\ SI = \sigma_b$$

$$\frac{S_y}{SI} = \frac{90}{7.7} = 11.7 > 6\,\text{O.K.}$$

$$\frac{S_u}{SI} = \frac{100}{7.7} = 13.0 > 10\ \text{O.K.}$$

At Location of Section A (Assumed worst case with hook against one side)

$$M = \frac{P}{2} \cdot (8.5 - 7.5) = 109.2 kips - in$$

$$\sigma_b = 3.3 ksi; S = \frac{\sigma}{2} \pm \sqrt{\left(\frac{\sigma}{2}\right)^2 + \tau^2} = +5.8 ksi; -2.5 ksi$$

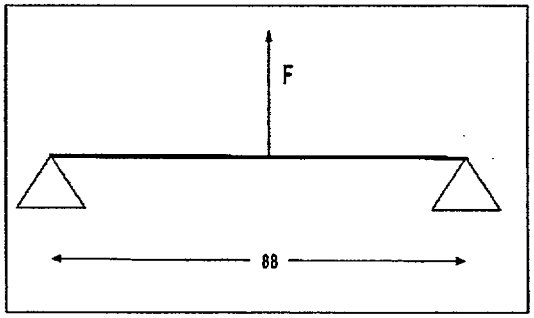
Stress Intensity = 5.8 – (-2.5) = 8.3 ksi

$$\frac{S_y}{SI} = \frac{90}{8.3} = 10.8 > 6\,\text{O.K.}$$

$$\frac{S_u}{SI} = \frac{100}{8.3} = 12.0 > 10\ \text{O.K.}$$

6.2 Beams

Figure 6-2: MTC Lifting Yoke Beams



Note: Dimensions are per Reference 3.2.3.

Stresses at the center of the hole, assuming the hole is centered in the plate:

$$F = \frac{P}{2} = 109.2 kips$$

$$M = \frac{F\ell}{4} = 2{,}402 kip - in$$

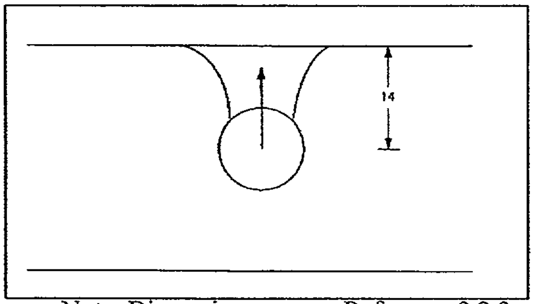
$$\sigma = \frac{Mc}{I} \cdot \frac{2{,}402 \cdot 13}{2 \cdot \left[\frac{2 \cdot (13-3.5)^3}{12} + 2 \cdot 9.5 \cdot 8.25^2 \right]} = 10.87 ksi$$

$\tau = 0,\ SI = \sigma_b$

$$\frac{S_y}{SI} = \frac{100}{10.87} = 9.2 > 6 \text{O.K.}$$
$$\frac{S_u}{SI} = \frac{110}{10.87} = 10.1 > 10 \text{ O.K.}$$

Stresses at the edge of the hole:

Figure 6-3: Hole in Lifting Yoke Beams



Note: Dimensions are per Reference 3.2.3.

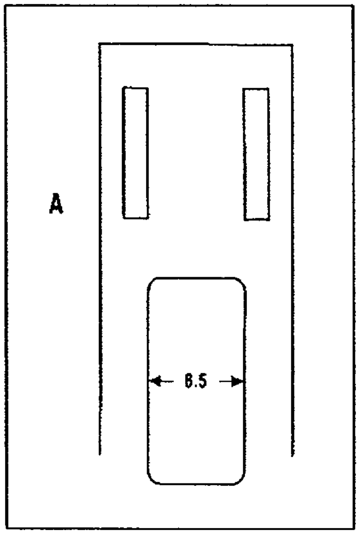
$$\sigma = \frac{M}{W} = \frac{2{,}402 - 109.2 \cdot \frac{3.5}{2}}{2 \cdot \left[\frac{26^2}{6} \right]} = 9.8 ksi$$

$$\tau = \frac{F}{2} \cdot \frac{1}{2(14-3.5)} = \frac{109.2}{2 \cdot} \frac{1}{2(14-3.5)} = 2.6 ksi$$

$$\mathrm{S} = \frac{\sigma}{2} \pm \sqrt{\left(\frac{\sigma}{2}\right)^2 + \tau^2} = +10.4 ksi; -0.6 ksi$$
$$SI = +10.4 - (-0.6) = 11.0$$
$$\frac{S_y}{S} = \frac{100}{11.0} = 9.1 > 6 \text{O.K.}$$
$$\frac{S_u}{S} = \frac{110}{11.0} = 10.0 \geq 10 \text{O.K.}$$

6.3 Link

Figure 6-4: Lifting Yoke Link



Note: Dimensions are per Reference 3.2.3.

Moment = 0; $\sigma = \frac{F}{A}$ tension only

Section A:

$$S = \sigma = \frac{109.2}{4 \cdot (14.5 - 4)} = 2.6ksi$$

$$\frac{S_y}{S} = \frac{90}{2.6} = 34.6 > 6 \text{O.K.}$$

$$\frac{S_u}{S} = \frac{100}{2.6} = 38.5 > 10 \text{O.K.}$$

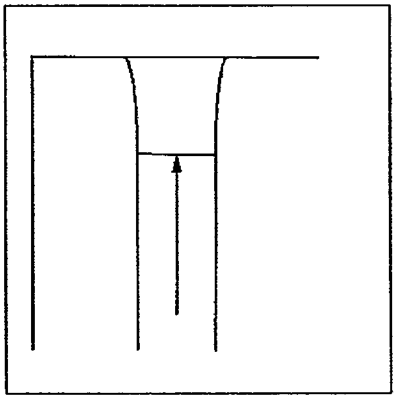
Section B:

$$\text{S} = \sigma = \frac{109.2}{4 \cdot (14.5 - 8.5)} = 4.6ksi$$

$$\frac{S_y}{S} = \frac{90}{4.6} = 19.6 > 6 \text{O.K.}$$

$$\frac{S_u}{S} = \frac{100}{4.6} = 21.7 > 10 \text{O.K.}$$

Figure 6-5: Lifting Yoke Link Top



Link top (above the beam holes):

$$\tau = \frac{109.2}{2} \cdot \frac{1}{4" \cdot 3"} = 4.6ksi$$

Pure shear :

$$\frac{0.57 \cdot S_y}{S} = \frac{0.57 \cdot 90}{4.6} = 11.2 > 6 \text{O.K.}$$

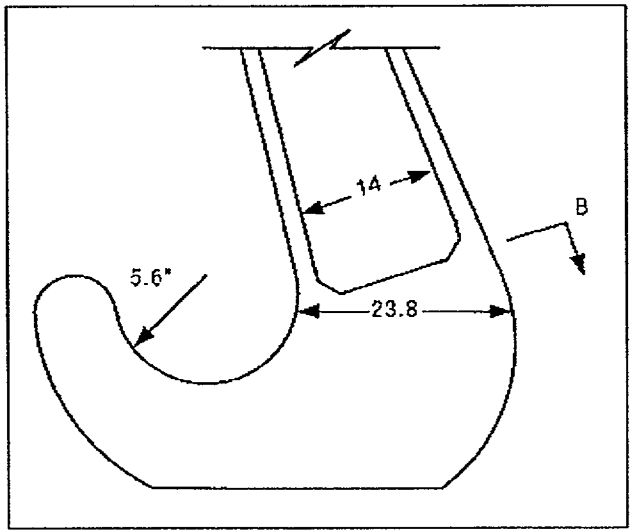
$$\frac{0.57 \cdot S_u}{S} = \frac{0.57 \cdot 100}{4.6} = 12.4 > 10 \text{O.K.}$$

6.4 Hook

The maximum bending moment arm is

$$R = 5.6 + \frac{23.8}{2} = 17.5in$$

Figure 6-6: Lifting Yoke Hook



Note: Dimensions are per Reference 3.2.6.

The bending stress is

$$\sigma_b = \frac{M}{W} = \frac{17.5 \cdot 109.2}{4 \cdot \frac{23.8^2}{6}} = 5.05 ksi$$

$$\sigma_t = \frac{F}{A} = \frac{109.2}{4 \cdot 23.8} = 1.15$$

$$\sigma = \sigma_b + \sigma_t = 6.2 ksi$$

Shear stresses are negligible. Therefore, SI = σ

$$\frac{S_y}{S} = \frac{90}{6.2} = 14.5 > 6 \text{O.K.}$$

$$\frac{\mathrm{S_u}}{S} = \frac{110}{6.2} = 17.8 > 10 \text{O.K.}$$

Section B:

$$M = 109.2\left[\frac{(19\cos 35° + 10.4 - 5.6)}{2} + 5.6\right] = 1{,}724 kips - in$$

The moment is reacted by a force couple in the two parallel arms of the hook. The force acts at the middle of the arm section. The force is

$$F = \frac{1{,}724 kips - in}{(\frac{21.3in + 13.7in}{2})} = 98.3 kips$$

$$\sigma = \frac{V}{2 \cdot A} + \frac{F}{A} = \frac{\frac{109.2}{2} + 98.3}{\left(\frac{21.3 - 13.7}{2}\right) \cdot 4} = 10.05 ksi$$

$$\frac{S_u}{\sigma} = \frac{110}{10.05} = 10.9 > 10 O.K.$$

$$\frac{S_y}{\sigma} = \frac{90}{10.05} = 9.0 > 6 O.K.$$

6.5 Lifting Arm (Optional)

Tension (Section A)

$$\sigma_t = \frac{109.2}{4 \cdot (19 - 14)} = 5.5 ksi\, S = \sigma_t$$

$$\frac{S_y}{S} = \frac{90}{5.5} = 16.4 > 6 O.K.$$

$$\frac{S_u}{S} = \frac{100}{5.5} = 18.2 > 10 O.K.$$

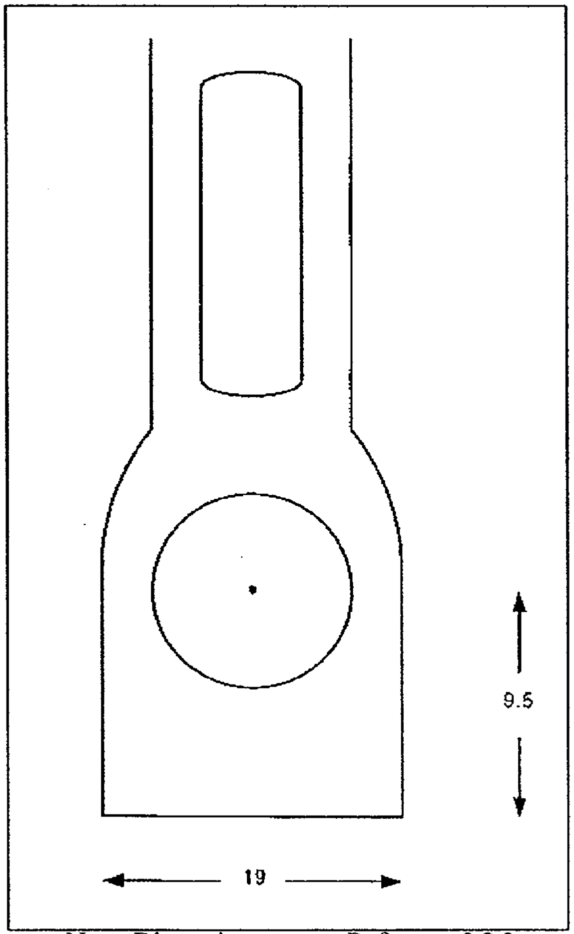
Shear(SectionB)

$$\tau = \frac{109.2}{2 \cdot (9.5 - 5.6) \cdot 4} = 3.5 ksi \; S = \tau$$

$$\frac{0.57 \cdot S_y}{\tau} = \frac{0.57 \cdot 90}{3.5} = 14.7 > 6 \text{O.K.}$$

$$\frac{0.57 \cdot S_u}{\tau} = \frac{0.57 \cdot 100}{3.5} = 16.3 > 10 \text{O.K.}$$

Figure 6-7: Lifting Yoke Lifting Arm



Note: Dimensions are per Reference 3.2.3.

7. CONCLUSIONS

The MTC lifting yoke lifting pin, beams, link, hook, and lifting arm meet the requirements of NUREG 0612 for single-failure proof devices. The calculated safety factors are greater than the required minimums specified in Section 2.0.

8. ELECTRONIC FILES

8.1 Computer Runs

None.

8.2 Other Electronic Files

None.

024972

BNFL Fuel Solutions	**CALCULATION PACKAGE**	Calc. Pkg No. VSC02.6.2.3.15 File No.: VSC02.6.2.3.15 Revision: 0

PROJECT/CUSTOMER:

VSC02/BNFL Fuel Solutions

TITLE:

VSC-24 Hypothetical Tip-Over and 5-foot Drop Analyses

SCOPE:

Product: ☐ Wesflex™ ☐ TranStor™ ☒ VSC-24 ☐ Other ________

Service: ☒ Storage ☐ Transportation ☐ Other ________

Conditions: ☒ Normal ☒ Off-Normal ☒ Accident ☐ Other ________

Component(s):

VSC-24 concrete cask.

Prepared by:

Name: J L Hibbard

Signature: JL Hibbard

Date: 1-12-00

Verified by:

Name: Michelle M. Heinz

Signature: Michelle M Heinz

Date: 1/12/00

Engineering Manager Approval:

Name: RAM SRINIVASAN

Signature: R Srinivasan

Date: 1/17/00

RECORD OF REVISIONS

REV.	AFFECTED PAGES	AFFECTED MEDIA	DESCRIPTION	NAMES (print or type)	
				PREPARER	CHECKER
0	1 – 22 Attachment A p. A1-A9 Attachment A.1 p. A.1.1-A.1.26		Replaces Calculation WEP109-002.15, Rev. 3 – Per ECN No.: WEP01-C-018		Michelle Heinz

Note: This calculation has been prepared in accordance with QAP 3.2, Revision 8, except that because this calculation is a revision of an existing calculation, the format is essentially based on the superceded calculation. The title page, record of revision page, and record of verification page are per QAP 3.2, Revision 8. Other format requirements of QAP 3.2 have been included where this could be readily accomplished. This approach was approved in BFS Memorandum 99-528, dated December 21, 1999.

RECORD OF VERIFICATION

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

COMMENTS:

Verifier: Michelle M. Heinz / Michelle M. Heinz / 1/12/00
Name/Signature/Date

1.0 INTRODUCTION

Although it has been shown that no credible event could tip over the VCC, the tipover accident is postulated and analyzed per the NRC request. In addition, a hypothetical 5-foot drop of the VCC is also considered despite the fact that the cask is never lifted that high.

This calculation replaces Calculation WEP109-002.15, Rev. 3. There are no deficiencies identified in CAR 98-50 for this calculation. The principal differences between this calculation and the previous calculation are:

- Updated dimensions and masses used as inputs.
- Corrected the VCC shear and moment calculations. The hand calculation approach was replaced with an ANSYS analysis.
- Corrected the VCC natural frequency calculation.
- Corrected the footprint radius for the vertical drop evaluation.
- Used the shear strength of the liner to calculate the shear capacity of the VCC.

2.0 DESIGN INPUT AND ASSUMPTIONS

The cask geometry is obtained from the MSB and VCC drawings.

$D_{VCC} := 132 \cdot in$	VCC OD, Reference 1
$h_{VSC} := 214 \cdot in$	Bounding value for height of VCC, Reference 1
$od_{liner} := 74 \cdot in$	VCC liner OD, Reference 8
$t_{liner} := 1.75 \cdot in$	VCC liner wall thickness, Reference 8
$od_{MSB} := 62.5 \cdot in$	MSB OD, Reference 14

The following mass and cg data bound the values in Reference 2:

$P_{VSC} := 278000 \cdot lb$	Weight of loaded VCC
$h_{cg} := 112 \cdot in$	Loaded VCC center of gravity
$P_{MSB} := 70000 \cdot lb$	Weight of loaded MSB
$P_{VCC} := 205500 \cdot lb$	Weight of empty VCC
$P_{cover} := 2500 \cdot lb$	Weight of VCC cover

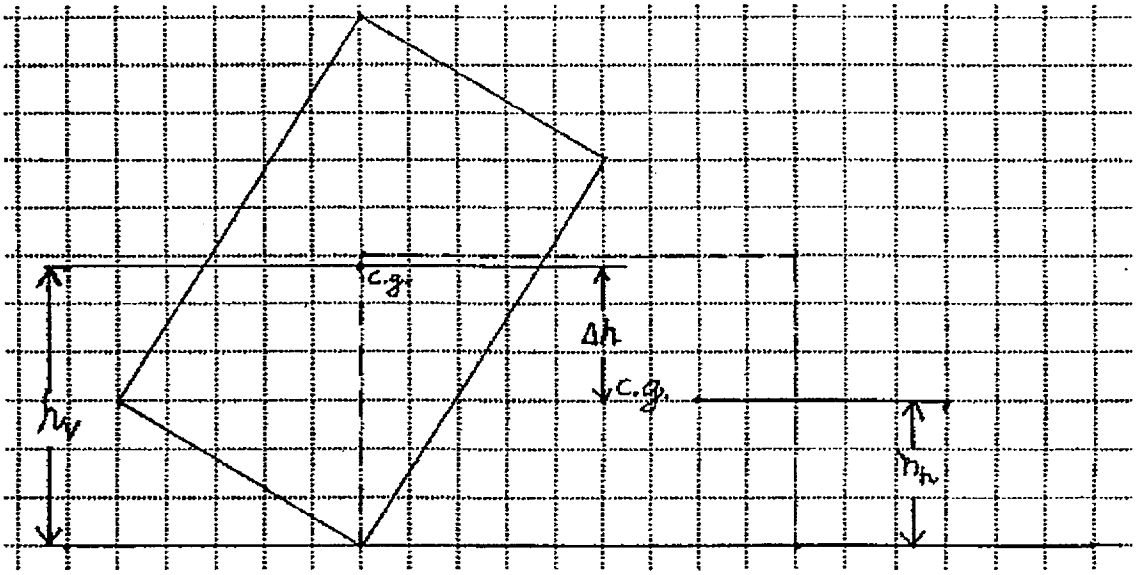
Other assumptions are stated in Section 3.0.

3.0 CALCULATIONS

3.1 Tip-Over Analysis

Two parameters are important as tip-over consequences: VSC concrete crush depth, and MSB deceleration level.

The geometry of the VSC tip-over is shown below.



The height of the cask cg above ground when the cask is balanced on its corner is calculated below. The calculation assumes that the MSB is at the cask centerline. The mass of the MSB is small compared to the mass of the VCC, so a shift in the MSB centerline is assumed to have a negligible effect on this calculation.

$$h_v := \sqrt{h_{cg}^2 + \left(\frac{D_{VCC}}{2}\right)^2}$$

$$h_v = 130.00 \cdot in$$

The thickness of the concrete cask wall is

$$t_{VCC} := \frac{D_{VCC} - od_{liner}}{2}$$

$$t_{VCC} = 29.00 \cdot in$$

The height of the cask cg above ground when the cask is horizontal is calculated below. It is assumed that the MSB has slid inside the VCC such that the MSB OD is contacting the liner ID.

$$h_h := \frac{P_{MSB} \cdot \left(\frac{od_{MSB}}{2} + t_{VCC} + t_{liner} \right) + \left(P_{VCC} + P_{cover} \right) \cdot \frac{D_{VCC}}{2}}{P_{VSC}}$$

$$h_h = 64.99 \cdot in$$

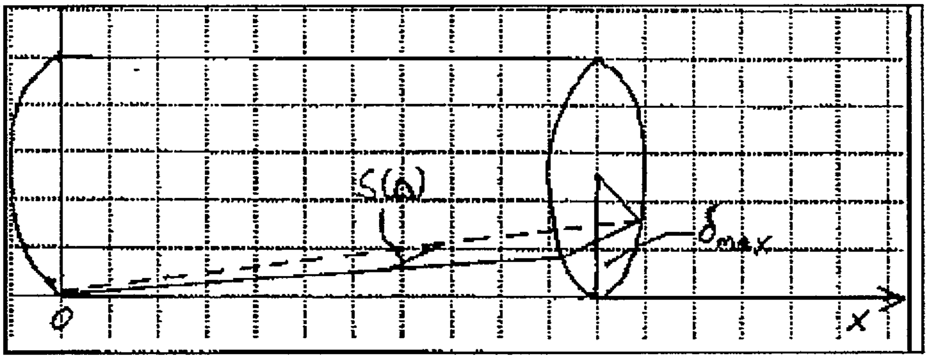
Then, the potential energy is

$$\Delta E := P_{VSC} \cdot \left(h_v - h_h \right) \cdot 1 \cdot g$$

$$\Delta E = 1.81 \cdot 10^7 \cdot in \cdot lbf$$

VSC Concrete Crush Depth

It was conservatively assumed for this calculation that the VSC hits a rigid surface so that all impact energy is absorbed by the cask. Since the motion is rotational and the rotational velocity at impact is linearly distributed along the VSC length, a linear distribution was assumed for the crush depth. The governing equation and geometry are shown below.



Parameters for the calculation are as follows:

$L := h_{VSC}$	
$L = 214.00 \cdot in$	Length of cask
$r_{VSC} := \frac{D_{VCC}}{2}$	
$r_{VSC} = 66.00 \cdot in$	Radius of cask
$\sigma_u := 4000 \cdot psi$	Compressive strength of the VCC concrete, Ref. 13
Δ	Distance from ground into cask wall
$S(\Delta)$	Width of contact area as a function of the depth Δ
δ_{max}	Maximum crush depth
ΔE	Potential energy loss due to cask tip-over

The energy of the impact is set equal to the energy absorbed by the crushed concrete.

$$\Delta E = \int_0^L \int_0^{\frac{x}{L} \cdot \delta_{max}} \sigma_u \cdot S(\Delta)\, d\Delta\, dx$$

The width of the contact area as a function of the depth is:

$$S(\Delta) = 2 \cdot \sqrt{r_{VSC}^2 - (r_{VSC} - \Delta)^2} = 2 \cdot \sqrt{2 \cdot r_{VSC} \cdot \Delta - \Delta^2}$$

Substituting gives

$$\Delta E = \sigma_u \cdot \int_0^L \int_0^{\frac{x}{L}\cdot\delta_{max}} 2\cdot\sqrt{2\cdot r_{VSC}\cdot\Delta}\, d\Delta\, dx$$

Integrating gives

$$\Delta E = \sigma_u \cdot \int_0^L 2\cdot\sqrt{2\cdot r_{VSC}}\cdot\frac{2}{3}\cdot\left(\frac{x}{L}\cdot\delta_{max}\right)^{\frac{3}{2}} dx$$

$$\Delta E = \frac{4}{3}\cdot\sqrt{2\cdot r_{VSC}}\cdot\sigma_u\cdot\frac{1}{L^{\frac{3}{2}}}\cdot\delta_{max}^{\frac{3}{2}}\cdot\frac{2}{5}\cdot L^{\frac{5}{2}}$$

Simplifying

$$\Delta E = \frac{8}{15}\cdot L\cdot\sqrt{2\cdot r_{VSC}}\cdot\sigma_u\cdot\delta_{max}^{\frac{3}{2}}$$

Solving for δ_{max} gives

$$\delta_{max} := \left(\frac{\Delta E}{\sigma_u\cdot L\cdot\sqrt{2\cdot r_{VSC}}}\cdot\frac{15}{8}\right)^{\frac{2}{3}}$$

$$\delta_{max} = 2.28\cdot in$$

This depth of crushed concrete was obtained using the very conservative assumption that the target surface is rigid and all the energy is absorbed by crushing the VCC concrete. In reality, the crushing strength of the storage pad or road asphalt is lower than the crushing strength of the cask concrete, and therefore, the impacted surface would be crushed instead of the VSC concrete.

Deceleration Resulting from the Postulated Tip-over

For this calculation the crushing assumption is reversed: the cask is assumed to be rigid and the target absorbs the energy. As calculated above, the potential energy of impact is:

$$\Delta E = 1.81 \cdot 10^{7} \cdot in \cdot lbf$$

This energy is assumed to be absorbed by the target.

Find the equivalent height of the horizontal drop.

$$\Delta E = P_{VSC} \cdot g \cdot h_{eq}$$

$$h_{eq} := \frac{\Delta E}{P_{VSC} \cdot g}$$

$$h_{eq} = 65.0 \cdot in$$

The methodology presented in EPRI report NP-4830, "The Effects of Target Hardness on the Structural Design of Concrete Storage Pads for Spent-Fuel Casks" [Ref. 3] was used for these calculations.

The following conservative assumptions were made about a typical ISFSI storage pad:

Slab Thickness: $d := 36 \cdot in$

#11 @ 12 top and bottom
two-way, under 2 inch cover

Reinforcement

$E_{steel} := 28 \cdot 10^{6}$

$S_{y} := 60000 \cdot psi$

Concrete Pad

$f_{c} := 3000 \cdot psi$

$v_{c} := .17$

$$E_{c} := 57000 \cdot psi \cdot \sqrt{\frac{f_{c}}{psi}}$$ ACI 349, Reference 4, Paragraph 8.5.1

$$E_{c} = 3.12 \cdot 10^{6} \cdot psi$$

Soil	$E_s := 60000 \cdot psi$ $\nu_s := .45$

These assumptions are conservative. (It is noted that a typical pad is only 2' thick and has #6@ 18" reinforcement; thus, the typical pad is not as rigid as assumed above and would produce lower acceleration values.)

Find the slab moment capacity (Reference 9, Eq. 12.3.5):

$A_{11} := 1.56 \cdot in^2$ No. 11 rebar cross section area, Ref. 9, Table 12.3.1

$$a := \frac{A_{11} \cdot S_y}{0.85 \cdot L \cdot f_c}$$

$a = 0.1715 \cdot in$

$\phi := 0.9$ Strength reduction factor for bending from Ref. 9, p. 12-49

$$M_u := \phi \cdot A_{11} \cdot S_y \cdot \left(d - \frac{a}{2}\right)$$

$M_u = 3.03 \cdot 10^6 \cdot in \cdot lbf$

The slab moment of inertia is

$$I_c := \frac{L \cdot d^3}{12}$$

$I_c = 832032 \cdot in^4$

The parameter β is (Ref. 3):

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

$\beta = 0.00872 \cdot \frac{1}{in}$

The recommended value for D from Reference 3 is

$D := 10 \cdot in$

The area is

$$A := D \cdot L$$

$$A = 2140 \cdot in^2$$

Now the target hardness number can be calculated (Ref. 3):

$$S := \frac{2 \cdot A \cdot E_s \cdot M_u \cdot f_c}{\left(P_{VSC} \cdot g\right)^3 \cdot \beta}$$

$$S = 12445$$

Conservatively using the curve for 70" drop from Ref. 3, p. 2-40, the deceleration is

$$a := 20 \cdot g$$

3.2 FIVE-FOOT DROP ANALYSIS

The assumptions and notations used for this analysis are the same as for the tip-over calculations. The potential energy from a 5 foot drop impact is

$$h := 60\ in$$

$$\Delta E := P_{VSC} \cdot g \cdot h$$

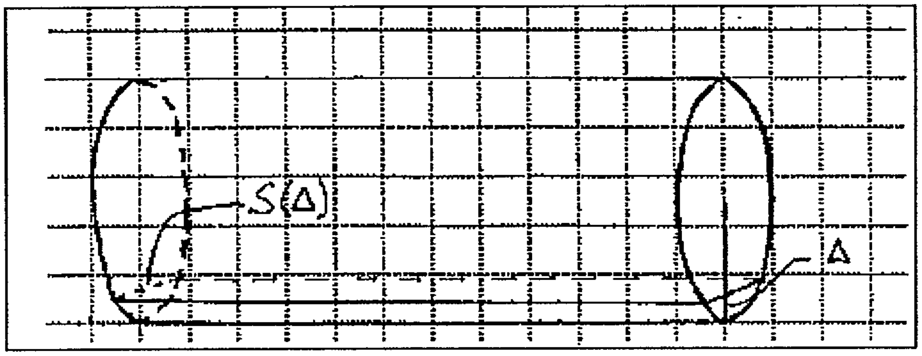
$$\Delta E = 1.67 \cdot 10^7 \cdot in \cdot lbf$$

3.2.1 Horizontal Drop

VSC Concrete Crush Depth

Again, it is conservatively assumed that all energy is absorbed by crushing of the cask concrete.

$$\Delta E = \int_0^L \int_0^{\frac{x}{L}\cdot\delta_{max2}} S(\Delta)\, d\Delta\, dx$$



$$S(\Delta) = 2\cdot\sqrt{r_{VSC}^2 - \left(r_{VSC} - \Delta\right)^2} = 2\cdot\sqrt{2\cdot r_{VSC}\cdot\Delta - \Delta^2}$$

which is approximately equal to

$$S(\Delta) = 2\cdot\sqrt{2\cdot r_{VSC}\cdot\Delta}$$

For the horizontal drop, all points have the same velocity, so the crush depth is assumed to be constant along the cask length. Therefore, D is not a function of x.

Thus,

$$\Delta E = L\cdot\sigma_u\cdot 2\cdot\int_0^{\delta_{max2}} \sqrt{2\cdot r_{VSC}\cdot\Delta}\, d\Delta$$

$$\Delta E = 2\cdot L\cdot\sigma_u\cdot\sqrt{2\cdot r_{VSC}}\cdot\frac{2}{3}\,\delta_{max2}^{\frac{3}{2}}$$

Solving for δ_{max} gives

$$\delta_{max2} := \left(\frac{3}{4} \cdot \frac{\Delta E}{\sqrt{2 \cdot r_{VSC} \cdot L \cdot \sigma_u}} \right)^{\frac{2}{3}}$$

$$\delta_{max2} = 1.17 \cdot in$$

This depth of crushed concrete was obtained using the very conservative assumption that the target surface is rigid and all the energy is absorbed by crushing the VCC concrete. In reality, the crushing strength of the storage pad or road asphalt is lower than the crushing strength of the cask concrete, and therefore, the impacted surface would be crushed instead of the VSC concrete.

Deceleration

The target hardness number was calculated above for the tipover case. Using a hardness number of

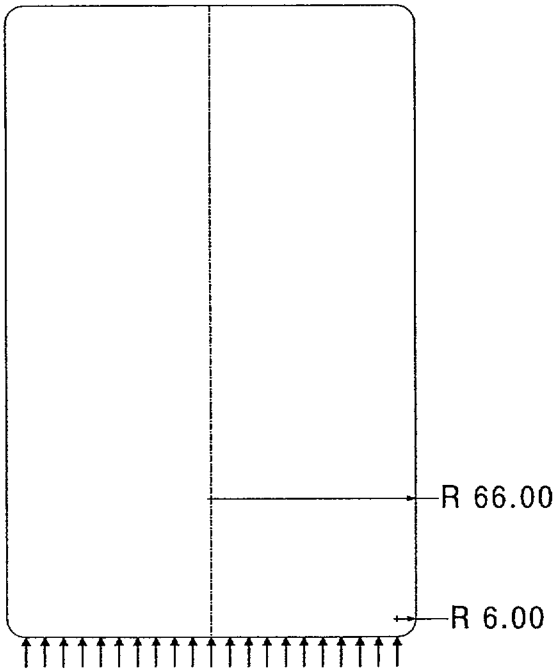
$$S = 12445$$

and using the curve for a 60" drop height from Ref. 3 gives a deceleration of

$$a_h := 20 \cdot g$$

3.2.2 Vertical Drop

VSC Concrete Crush Depth



Again,

$$\Delta E = \sigma_u \cdot Area \cdot \delta_{max3} = \sigma_u \cdot \pi \cdot \left(r_{VSC} - r_{corner}\right)^2 \cdot \delta_{max3}$$

where $r_{corner} := 6 \cdot in$ cask corner radius, Ref. 1

Solving for δ_{max3} gives

$$\delta_{max3} := \frac{\Delta E}{\sigma_u \cdot \pi \cdot \left(r_{VSC} - r_{corner}\right)^2}$$

$$\delta_{max3} = 0.369 \cdot in$$

Using the EPRI methodology (Ref. 3)

$$S = \frac{2 \cdot r \cdot A \cdot k \cdot M_u \cdot f_c}{\left(P_{VSC} \cdot g\right)^3 \cdot \left(1 - e^{-\beta \cdot r} \cdot cos(\beta \cdot r)\right)}$$

where

$r := r_{VSC} - r_{corner}$ Radius of the footprint accounting for the corner radius at the bottom of the cask, Ref. 1

$r = 60.00 \cdot in$

$A := \pi \cdot r^2$ Cask footprint area

$A = 11310 \cdot in^2$

$M_u = 3.03 \cdot 10^6 \cdot in \cdot lbf$ Target moment capacity calculated above

$$k := \frac{\pi \cdot E_s}{1 - {v_s}^2}$$

Foundation modulus, Ref. 3

$k = 236358 \cdot psi$

$$D_c := \frac{E_c \cdot d^3}{12 \cdot \left(1 - {v_c}^2\right)}$$

Slab rigidity, Ref. 3

$D_c = 1.25 \cdot 10^{10} \cdot in \cdot lbf$

$$\beta := \left(\frac{E_s}{4 \cdot in \cdot D_c}\right)^{\frac{1}{4}}$$

$$\beta = 0.0331 \cdot \frac{1}{in}$$

$f_c = 3000 \cdot psi$ Assumption about storage pad concrete strength

Then,

$$S := \frac{2 \cdot r \cdot A \cdot k \cdot M_u \cdot f_c}{\left(P_{VSC} \cdot g\right)^3 \cdot \left(1 - e^{-\beta \cdot r} \cdot cos(\beta \cdot r)\right)}$$

$S = 128405$

Using the curve for a 60" drop from Ref. 3 gives

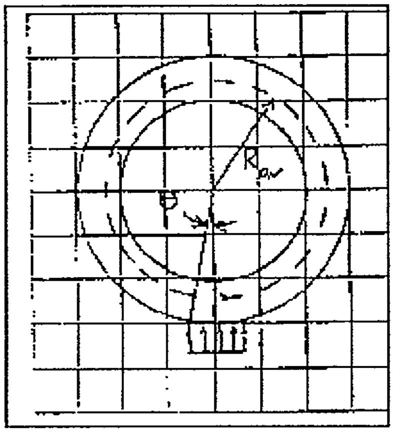
$a_v := 54 \cdot g$

3.3 Concrete Cask Evaluation

Shear and moment in the cask section for the horizontal drop are calculated below. It is assumed that the horizontal drop is the drop orientation that has the most potential to damage the cask.

The methodology is based on allowable ductility ratios (ACI-349 [Ref. 4], Appendix C), dynamic response curves from Biggs' "Structural Dynamics" [Ref. 6] and formulas from Timoshenko [Ref. 7].

The model is presented below. Since the concept is based on crushing of concrete, the maximum force will occur at the maximum crush depth.



The cask is treated as a shell. The average radius is (Ref. 1 and 8)

$$R_{av} := \frac{66 + 37}{2} \cdot in$$

$$R_{av} = 51.50 \cdot in$$

Angle θ can be calculated using results from above.

$$\delta_{max2} = 1.174 \cdot in$$

$$\theta = \frac{S(\theta)}{2 \cdot r_{VSC}}$$

$$\theta := \frac{\sqrt{2 \cdot r_{VSC} \cdot \delta_{max2}}}{r_{VSC}}$$

$$\theta = 0.189$$

The deceleration was calculated earlier to be $a_h = 20 \cdot g$. Impact time can be found using conservation of momentum.

$$mass \cdot velocity = force \cdot time$$

$$P_{VCC} \cdot \sqrt{2 \cdot g \cdot h} = a_h \cdot P_{VCC} \cdot t_i$$

Solving for the time gives

$$t_i := \frac{1}{a_h} \cdot \sqrt{2 \cdot g \cdot h}$$

$$t_i = 0.0279 \cdot sec$$

The natural frequency of the shell is calculated using a formula from Timoshenko & Young "Vibration Problems in Engineering," Equation 202 (Ref. 7).

$$f = \frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{E_{VSC} \cdot I \cdot i^2 \cdot \left(1 - i^2\right)^2}{\rho_{VSC} \cdot A \cdot R_{av}^{\ 4} \cdot \left(1 + i^2\right)}}$$

where

$i := 2$ Fundamental mode of flexural vibration

I is the section moment of inertia (calculation is based on a one foot length of the cask). Use of the gross section moment of inertia is conservative because it produces a higher natural frequency.

$b := 1 \cdot ft$ Cask basis length of one foot

$h := (66 - 37) \cdot in$ Cask concrete wall thickness, Ref. 1 and 8

$h = 29.00 \cdot in$

$$I := \frac{b \cdot h^3}{12}$$

$I = 24389 \cdot in^4$

The section area is

$$A := h \cdot b$$

$$A = 348.00 \cdot in^2$$

The density of the VCC concrete from Reference 13 is

$$\rho_{VSC} := 144 \cdot \frac{lb}{ft^3}$$

The modulus of elasticity for the VSC concrete is calculated from Reference 4, Paragraph 8.5.1.

$$E_{VSC} := 33 \cdot psi \cdot \left[\frac{\rho_{VSC}}{\frac{lb}{ft^3}} \right]^{1.5} \cdot \sqrt{\frac{\sigma_u}{psi}}$$

$$E_{VSC} = 3.61 \cdot 10^6 \cdot psi$$

The natural frequency and period are

$$f := \frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{E_{VSC} \cdot I \cdot i^2 \cdot \left(1 - i^2\right)^2}{\rho_{VSC} \cdot A \cdot R_{av}{}^4 \cdot \left(1 + i^2\right)}}$$

$$f = 174 \cdot Hz$$

$$T := \frac{1}{f}$$

$$T = 0.00574 \text{ sec}$$

The ratio of the impulse time to the natural period is

$$\frac{t_i}{T} = 4.86$$

Assume that the impulse load is a triangular load impulse. Using the dynamic response curve from Reference 6, Figure 2.8, the dynamic load factor is about 1.0, i.e., no dynamic amplification of the load is required.

Shear and moment in the cask wall due to the drop are calculated in Appendix A. The maximum shear and moment are:

$V_{max} := 74.1 \cdot \frac{kip}{ft}$ shear and moment are per foot of cask length

$M_{max} := 1157 \cdot \frac{in \cdot kip}{ft}$

The shear and moment capacities are calculated below. The shear capacity is based on the strength of the liner and the moment capacity is based on the strength of the reinforced concrete.

Shear Capacity of Liner:

$s_y := 32.3 \cdot ksi$ Liner yield strength at bounding temperature of 250°F (Reference 11); liner material is A-36 steel from Reference 8; yield strength from Reference 10

$t := 1.75 \cdot in$ Liner thickness from Reference 8

$$F := \frac{s_y}{2} \cdot t$$

$F = 339 \cdot \frac{kip}{ft}$ per foot of cask length

The shear capacity $F = 339 \cdot \frac{kip}{ft}$ is greater than the applied shear $V_{max} := 74.1 \cdot \frac{kip}{ft}$.

Bending Capacity of Liner:

The strength of the concrete and reinforcing steel are increased with a Dynamic Increase Factor (DIF) from Appendix C.2 of Reference 4. The reinforcing steel yield strength is $s_y = 60 \cdot ksi$ from Reference 12.

$$DIF_{steel} := 1.1$$

$$DIF_{conc\_bend} := 1.25$$

$A_s := 2 \cdot \left(.44 \cdot in^2\right)$ Area of reinforcing steel; Two No. 6 bars in one foot per Ref. 12; rebar area from Ref. 9, Table 12.3.1

$$a := \frac{A_s \cdot DIF_{steel} \cdot S_y}{.85 \cdot DIF_{conc\_bend} \cdot \sigma_u \cdot b}$$

$$a = 1.139 \cdot in$$

The moment capacity of the VSC reinforced concrete is

$$M_u := \left[\phi \cdot A_s \cdot DIF_{steel} \cdot S_y \cdot \left(h - \frac{a}{2} \right) \right] \cdot \frac{1}{ft}$$

$M_u = 1486 \cdot \frac{in \cdot kip}{ft}$ per foot of cask length

The moment capacity $M_u = 1486 \cdot \frac{in \cdot kip}{ft}$ is greater than the applied moment $M_{max} = 1157 \cdot \frac{in \cdot kip}{ft}$.

4.0 CONCLUSION

The postulated tip-over and 5 foot drop will not cause significant damage to the VCC concrete.

The results of this calculation are used for the structural design of the MSB components. The calculated decelerations for the horizontal drop and vertical drop are conservatively increased by the maximum dynamic amplification factor of 2 (see the dynamic load factors for different shaped impulse loadings in Ref. 6, Figures 2.6-2.9) and applied statically as follows:

$$a_{h\_dif} := 2 \cdot a_h$$

$$a_{h\_dif} = 40 \cdot g$$

$$a_{v\_dif} := 2 \cdot a_v$$

$$a_{v\_dif} = 108 \cdot g$$

5.0 REFERENCES

1. BNFL Drawing No. VCC-24-001, Sh. 1/2, Rev. 3, "VCC Assembly."
2. BNFL Calculation No. VSC02.6.2.5.01, "MTC, MSB, and VCC Weights and Centers of Gravity (B&W Fuel)," Revision 0.
3. EPRI Report NP-4830, The Effect of Target Hardness on Structural Design of Storage Pads for Spent Fuel Casks, 1986.
4. ACI 349, Code Requirements for Nuclear Safety-related Concrete Structures, 1985.
5. Roark, "Formulas for Stress and Strain," McGraw-Hill Book Company, 4th Edition.
6. Biggs, "Introduction to Structural Dynamics," McGraw-Hill Book Company, 1964.
7. Timoshenko, "Vibration Problems in Engineering," Van Nostrand Company, 2nd Edition.
8. BNFL Drawing No. VCC-24-002, "Cask Liner and Lid Assembly," Revision 3.
9. Marks' Handbook for Mechanical Engineers, McGraw-Hill Inc., 9th Edition.
10. 1986 ASME Code, Section III, Division I, Appendices, Table I-2.1.
11. BNFL Calculation No. WEP-109-003.4, "VSC-24 Thermal Hydraulic Analysis," Revision 2.
12. BNFL Drawing No. VCC-24-006, "VCC Reinforcement," Revision 3.
13. BNFL Document No. A2VCC-99-001, "Specification for the Construction of a VSC-24 Ventilated Concrete Cask," Revision 1.
14. BNFL Drawing No. MSB-24-001, Sh 1/2, "MSB Assembly," Revision 5.

APPENDIX A

FINITE ELEMENT CALCULATION OF SHEAR LOAD AND MOMENT IN CASK WALL

A.1.0 PURPOSE

The purpose of this attachment is to document a finite element analysis of the Vented Concrete Cask (VCC). The analysis provides the bending moment and shear load in the wall of the cask due to loads applied to the cask when it is dropped on its side from a 5 foot elevation.

A.2.0 SUMMARY OF RESULTS

The maximum moment and shear loads in the concrete wall of the cask are provided below in Table A.2-1. Note that the results are provided on a per inch of cask length basis.

Table A.2-1
Calculated Loads

Result	Maximum Value
Bending	96,435 in-lbs/in
Shear Load	6,177 lbs/in

A.3.0 FINITE ELEMENT MODEL

A.3.1 Geometry

The cask is modeled using a three dimensional finite element model. The model is a half model cut along a plane of symmetry parallel to the axis of the cask. The model includes the concrete cask and the carbon steel liner. Figure A.3-1 shows a dimensioned drawing of the cask and Figure A.3-2 shows the finite element model. The model is meshed with ANSYS SOLID45 elements (8-node bricks with 3 degrees of freedom per node).

The steel liner and concrete cask are modeled as though they were glued together (tensile loads are allowed to be carried across the interface). In reality, a small gap may exist between the concrete and the liner. This assumption will not have a significant effect on the results.

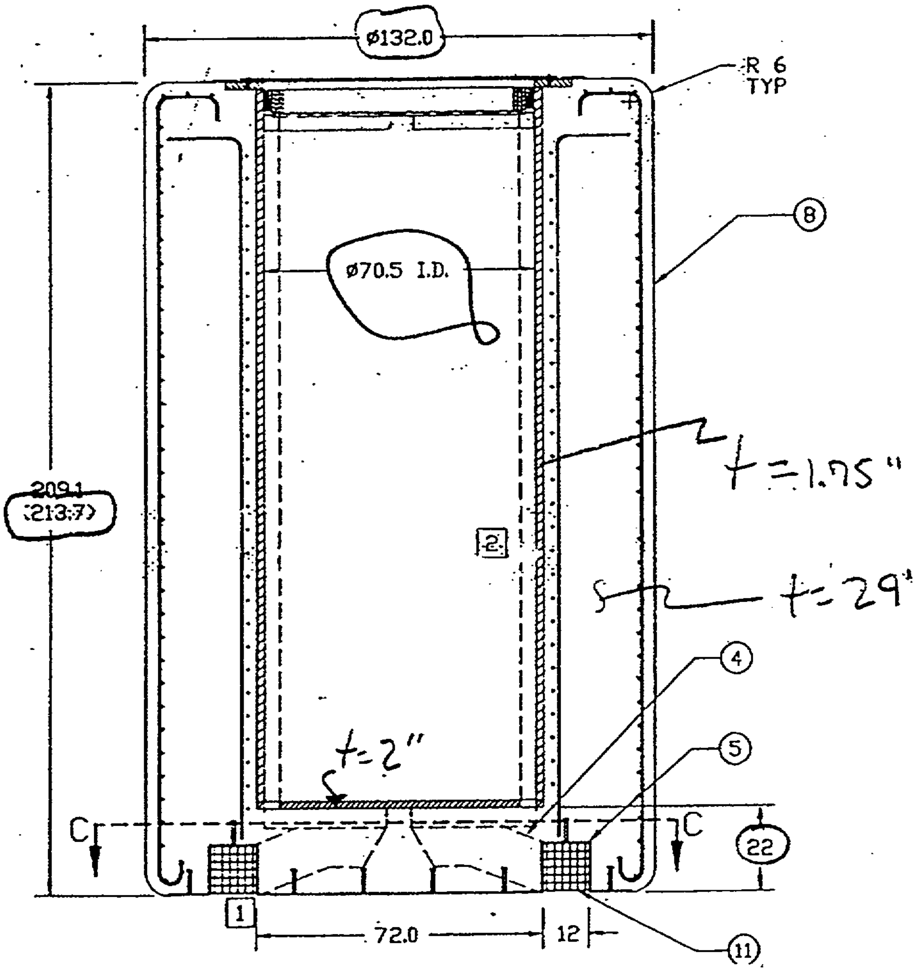


Figure A.3-1. Cask Dimensions
(References A.1 and A.2)

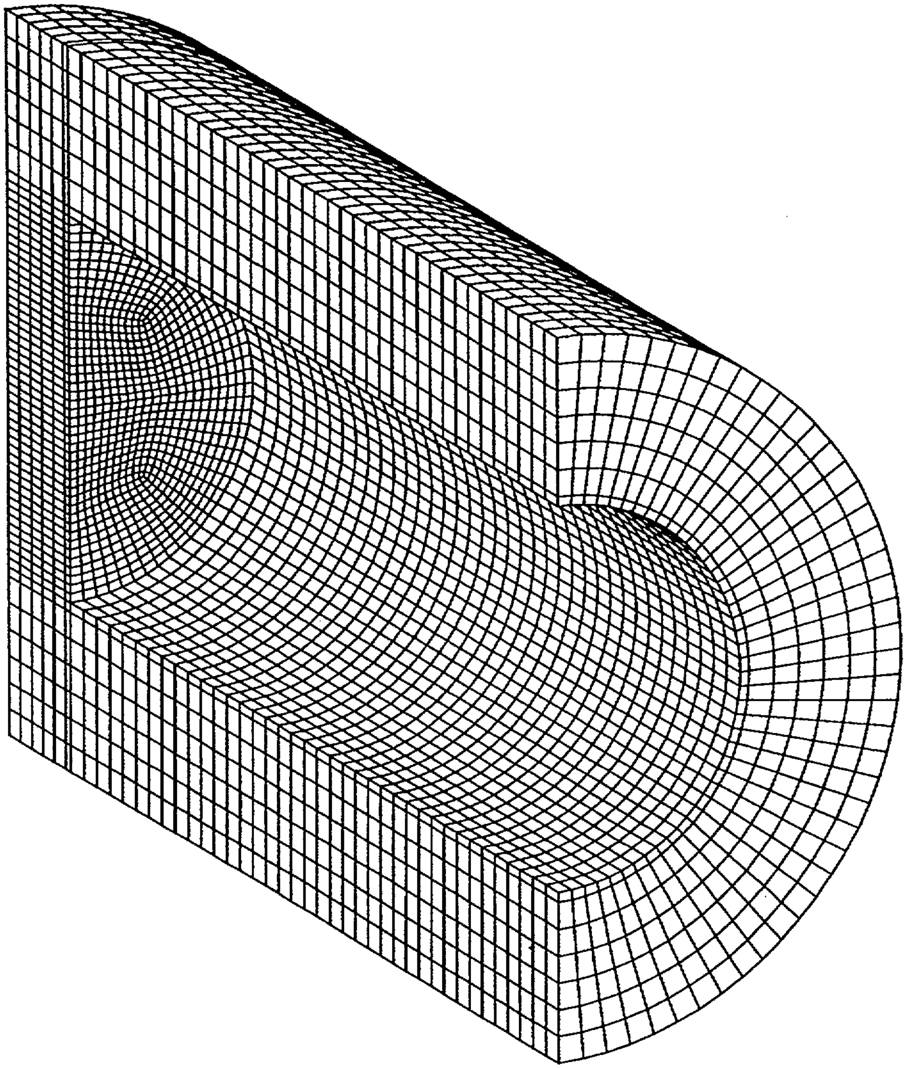


Figure A.3-2. Finite Element Model

A.3.2 Material Properties

Table A.3-1 shows the material properties used in the model. The cask is made of concrete (Reference A.1) and the liner is A36 carbon steel (Reference A.2).

Table A.3-1
Material Properties

Material	Elastic Modulus (psi)	Density (lb/in^3)	Poisson's Ratio
A36 Carbon Steel	28.6×10^6 (Reference A.3 at 250°F)	0.29 (assumed)	0.3 (assumed)
Concrete	3.61×10^6 (see main calculation)	0.0833 (see main calculation)	0.17 (see main calculation)

A.3.3 Boundary and Loading Conditions

The model is loaded with a 20g acceleration (see main calculation). The motion of the cask is restrained along the edge of the cask where it would contact the ground. The region of restraint extends the full length of the cask. The width of the modeled region is calculated based on the ½ angle over which the contact occurs (as calculated in the main calculation):

Width = θ R = (0.189)(66) = 12.5 in (assuming angle is small)

Where R = cask outside radius = 66 in (Reference A.1)
θ = ½ angle = 0.189 rad (See main calculation)

Nodes on the plane of symmetry are restrained in the direction normal to the plane of symmetry and a single node on the plane of symmetry is restrained in the cask's axial direction for solution purposes. Figure A.3-3 shows the loading and boundary conditions.

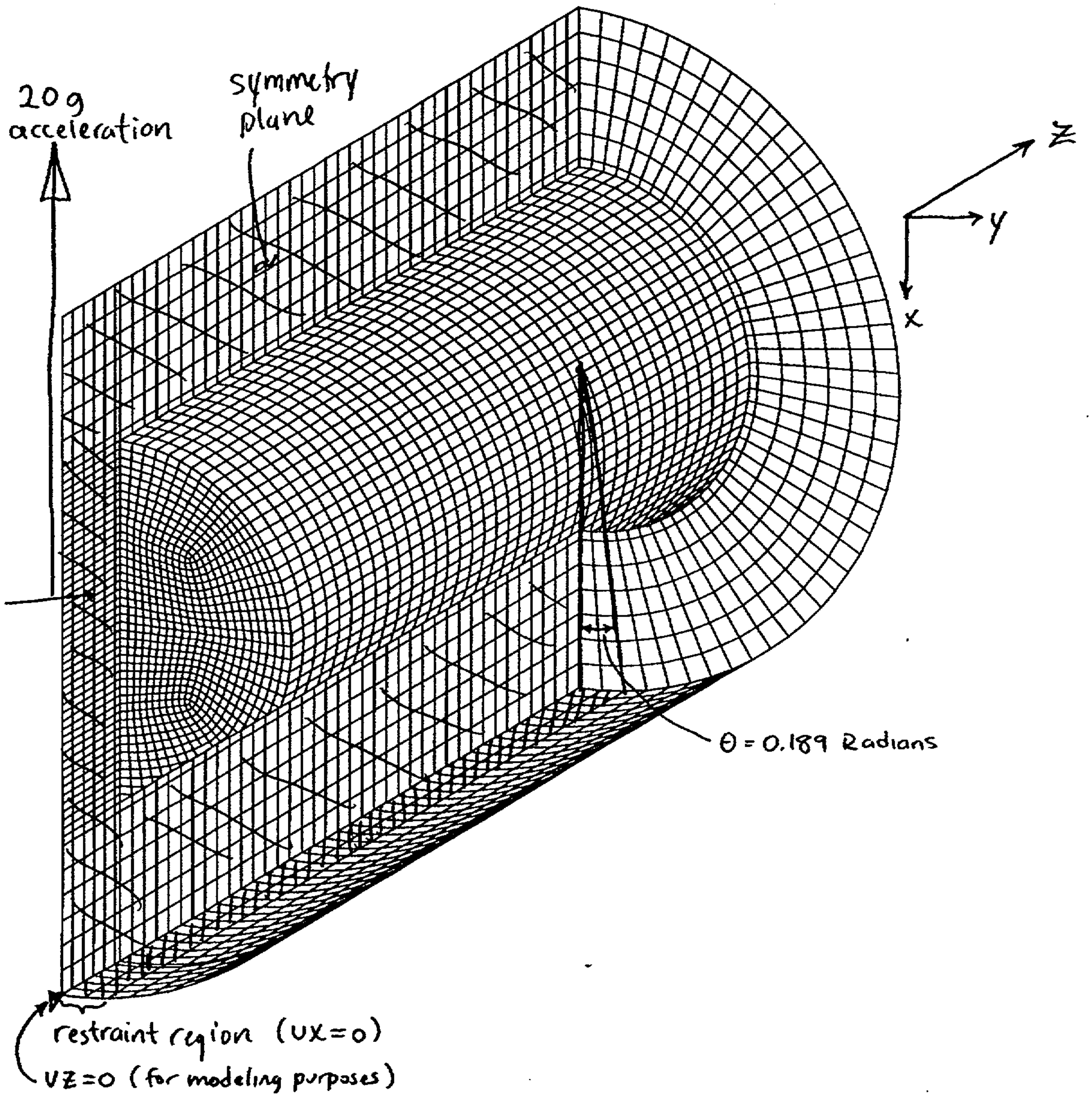


Figure A.3-3. Loading and Boundary Conditions

A.4.0 ANALYSIS RESULTS

The finite element model was analyzed using the ANSYS Computer Program version 5.5. This program is on the BFNL Fuel Solutions Computer Software List (see Reference A.5).

Filename	File Date	Computer Code	Category	Version	Platform	Machine
DROPL.OUT	1/5/00, 12:22	ANSYS	2	5.5	NT	ANSYS #4

The analysis output file is documented in Reference A.4 and portions of the output are provided as Attachment A.1 to this appendix. Bending moment and shear load are calculated using the linearized membrane plus bending stress and the shear stress in the concrete wall. Linearized stress is calculated using the ANSYS PRSECT command, which provides an analysis of the stresses along a defined path through the component thickness. Results are obtained at paths located along the edge of the region of restraint near the open end of the cask. Maximum stresses occur near the open end. Figure A.4-1 provides the displaced shape of the cask with path locations shown on the figure. From Attachment A.1, the maximum stresses are:

Membrane plus Bending = 707 psi
Shear = 213 psi

Bending moment and shear forces are calculated based on the stresses calculated using the finite element model. The moment and load are calculated on a per inch of cask length basis. For bending in the wall of the cask:

$$\sigma = \frac{6M}{t^2}, \text{ thus, } \quad M = \frac{1}{6}\sigma \cdot t^2 = \frac{1}{6}(707)(29)^2 = 99{,}098 \text{ in-lbs/in}$$

Where: M = moment per unit length of cask,
t = wall thickness = 29 in (Reference A.1, A.2)
σ = membrane plus bending stress = 707 psi

The shear load in the wall is:

$$\tau = \frac{V}{t}, \text{ thus, } \quad V = \tau \cdot P = (29)(213) = 6{,}177 \text{ lbs / in}$$

Where: V = shear load per unit length of cask
τ = shear stress = 213 psi

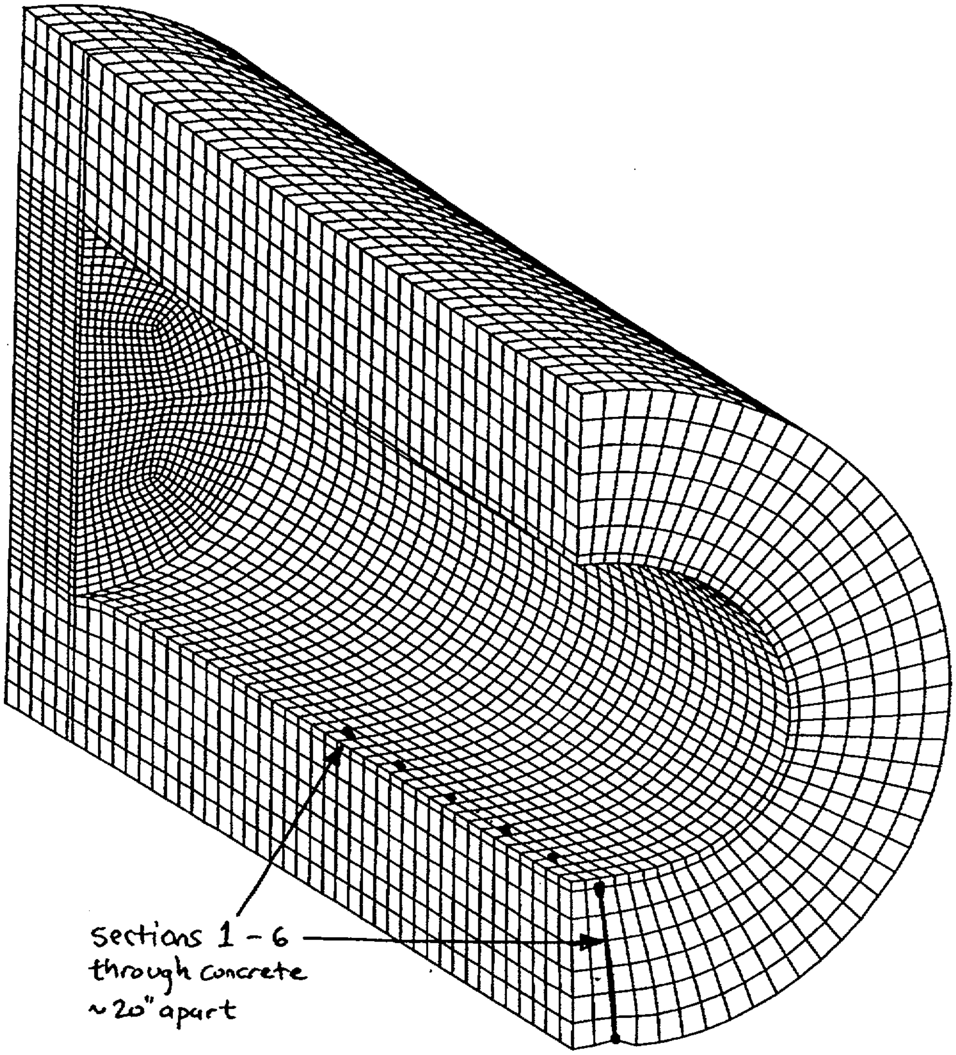


Figure A.4-1. Displaced Shape Plot

A.5.0 REFERENCES

A.1 BNFL Drawing No. VCC-24-001, "Ventilated Concrete Cask (VCC) Assembly," Sh. 1, Revision 3.

A.2 BNFL Drawing No. VCC-24-002, "Cask Liner and Lid Assembly," Revision 3.

A.3 ASME Boiler and Pressure Vessel Code, Section III, Division 1, Appendices, 1986 Edition.

A.4 ANSYS Output File, "DROPL.OUT", 1/5/00, 12:22.

A.5 BNFL Fuel Solutions Computer Software Listing—ANSYS Mechanical Version 5.5 (PC), File Number: Soft.001.001, Revision 0.

ATTACHMENT A.1

Selected Analysis Output

```
*-------------------------------------------------------------*
|                                                             |
|   W E L C O M E   T O   T H E   A N S Y S   P R O G R A M   |
|                                                             |
*-------------------------------------------------------------*



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                    Completing ANSYS Load Process.


ANSYS/Mechanical U


        *****  ANSYS COMMAND LINE ARGUMENTS  *****
 INITIAL JOBNAME              = dropl
 MEMORY REQUESTED (MB)        = 200
 BATCH MODE REQUESTED         = LIST
 START-UP FILE MODE           = READ
 STOP FILE MODE               = READ
 LANGUAGE                     = Default
 DATABASE SIZE REQUESTED (MB) = 64

*** NOTE ***                            CP=       0.030   TIME= 11:25:5
6
There are no parameters defined.


00107763          VERSION=INTEL NT         RELEASE= 5.5.3   UP19990405
CURRENT JOBNAME=dropl  11:25:57  JAN 05, 2000 CP=       0.030

     1  /batch,list
     2  /filnam,dropl
     3  /prep7
     4
     5  liner=1
     6
     7  r1=70.5/2
     8  r2=r1+1.75
     9  r3=132/2
    10
    11  z1=22
    12  z2=z1+2
    13  z3=213.7
    14
    15  cylind,0,r3,0,z1,0,180
    16  *if,liner,eq,1,then
    17    cylind,0,r3,z1,z2,0,180
    18    nummrg,kp
```

```
  vsel,none
  asel,none
  lsel,none
  ksel,none
*endif
cylind,r2,r3,0,z3,0,180
*if,liner,eq,1,then
  cylind,r1,r2,0,z3,0,180
  nummrg,kp
*endif
allsel
vovlap,all

wprota,,,90
vsbw,all

et,1,solid45
type,1
eshape,2
!csys,1
!lsel,s,loc,y,1,89
!lsel,a,loc,y,91,179
!lsel,a,loc,x,0,r1-1
!lesize,all,,,10
!lsel,s,loc,x,r2+1,r3-1
!lesize,all,,,6
esize,5
csys,1
lsel,s,loc,x,r3
lsel,a,loc,z,0
csys,0
asll,s,1
vsla
cm,concrete,volu
vatt,1
*if,liner,eq,1,then
  vsel,inve
  cm,steel,volu
  vatt,2
*endif
save,solid,db
allsel
vmesh,all

mp,ex,1,3.61e6
mp,nuxy,1,.17
mp,dens,1,144/1728
mp,ex,2,28.6e6
mp,nuxy,2,.3
mp,dens,2,.29

csys,1
```

```
nsel,s,loc,x,r3
nsel,r,loc,y,-1,90
csys,0
nsel,r,loc,y,-1,.189*r3
d,all,ux,0
d,node(r3,0,0),uz,0
nsel,s,loc,y,0
d,all,uy,0
allsel

acel,-20,0,0

fini
/solu
solve
save

fini

/post1
file,,rst
set,1
csys,1
dsys,1
rsys,1
cmsel,s,concrete
eslv
nsle
*do,ii,z3-100,z3,20
  lpath,node(r2,10,ii),node(r3,10,ii)
  prsect
*enddo
```

```
 RUN SETUP PROCEDURE FROM FILE= C:\ansys55\docu\start55.ans


 /INPUT FILE= C:\ansys55\docu\start55.ans  LINE=       0

 CURRENT JOBNAME REDEFINED AS dropl
1

 ***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.3   *****
 ANSYS/Mechanical U
 00107763          VERSION=INTEL NT      11:25:57  JAN 05, 2000 CP=
  0.080




          ***** ANSYS ANALYSIS DEFINITION (PREP7) *****
```

```
PARAMETER LINER     =     1.000000

PARAMETER R1        =     35.25000

PARAMETER R2        =     37.00000

PARAMETER R3        =     66.00000

PARAMETER Z1        =     22.00000

PARAMETER Z2        =     24.00000

PARAMETER Z3        =     213.7000

CREATE A CYLINDRICAL VOLUME WITH
INNER RADIUS           =     0.000000000
OUTER RADIUS           =     66.00000000
STARTING THETA ANGLE =     0.000000000
ENDING   THETA ANGLE =     180.0000000
END Z-DISTANCES FROM         0.000000000     TO      22.00000000

     OUTPUT VOLUME =      1

*IF  liner                                  ( =    1.00000      )  EQ
     1                                      ( =    1.00000      )  THEN

CREATE A CYLINDRICAL VOLUME WITH
INNER RADIUS           =     0.000000000
OUTER RADIUS           =     66.00000000
STARTING THETA ANGLE =     0.000000000
ENDING   THETA ANGLE =     180.0000000
END Z-DISTANCES FROM         22.00000000     TO      24.00000000

     OUTPUT VOLUME =      2

MERGE COINCIDENT KEYPOINTS WITHIN TOLERANCE OF  0.10000E-03
KEYPOINT       4 USED FOR KEYPOINT(S)        8
KEYPOINT       5 USED FOR KEYPOINT(S)        9
KEYPOINT       6 USED FOR KEYPOINT(S)        7
LINE       4 USED FOR LINE(S)      12
LINE       5 USED FOR LINE(S)      11
LINE       6 USED FOR LINE(S)      10
AREA       2 USED FOR AREA(S)       6

NONE SELECT   FOR ITEM=VOLU COMPONENT=
 IN RANGE        1 TO         2 STEP        1

     0 VOLUMES (OF      2  DEFINED) SELECTED BY VSEL  COMMAND.

NONE SELECT   FOR ITEM=AREA COMPONENT=
 IN RANGE        1 TO        10 STEP        1
```

```
     0 AREAS (OF      9  DEFINED) SELECTED BY ASEL  COMMAND.

NONE SELECT  FOR ITEM=LINE COMPONENT=
 IN RANGE       1 TO       18 STEP       1

     0 LINES (OF     15  DEFINED) SELECTED BY LSEL  COMMAND.

NONE SELECT  FOR ITEM=KP   COMPONENT=
 IN RANGE       1 TO       12 STEP       1

     0 KEYPOINTS (OF      9  DEFINED) SELECTED BY KSEL  COMMAND.

*ENDIF

CREATE A CYLINDRICAL VOLUME WITH
INNER RADIUS        =     37.00000000
OUTER RADIUS        =     66.00000000
STARTING THETA ANGLE =    0.000000000
ENDING   THETA ANGLE =    180.0000000
END Z-DISTANCES FROM      0.000000000     TO      213.7000000

     OUTPUT VOLUME =     3

*IF  liner                               ( =   1.00000      )  EQ
     1                                   ( =   1.00000      )  THEN

CREATE A CYLINDRICAL VOLUME WITH
INNER RADIUS        =     35.25000000
OUTER RADIUS        =     37.00000000
STARTING THETA ANGLE =    0.000000000
ENDING   THETA ANGLE =    180.0000000
END Z-DISTANCES FROM      0.000000000     TO      213.7000000

     OUTPUT VOLUME =     4

MERGE COINCIDENT KEYPOINTS WITHIN TOLERANCE OF  0.10000E-03
KEYPOINT       9 USED FOR KEYPOINT(S)      21
KEYPOINT       8 USED FOR KEYPOINT(S)      18
KEYPOINT      16 USED FOR KEYPOINT(S)      23
KEYPOINT      17 USED FOR KEYPOINT(S)      22
LINE      11 USED FOR LINE(S)      31
LINE      22 USED FOR LINE(S)      32
LINE      27 USED FOR LINE(S)      37
LINE      26 USED FOR LINE(S)      36
AREA      13 USED FOR AREA(S)      18

*ENDIF

SELECT ALL ENTITIES OF TYPE= ALL  AND BELOW

ALL SELECT   FOR ITEM=VOLU COMPONENT=
 IN RANGE       1 TO        4 STEP       1
```

```
      4   VOLUMES (OF      4  DEFINED) SELECTED BY  VSEL  COMMAND.

 ALL SELECT   FOR ITEM=AREA COMPONENT=
  IN RANGE         1 TO        21 STEP         1

    20  AREAS (OF    20  DEFINED) SELECTED BY ASEL COMMAND.

 ALL SELECT   FOR ITEM=LINE COMPONENT=
  IN RANGE         1 TO        39 STEP         1

    35  LINES (OF    35  DEFINED) SELECTED BY LSEL COMMAND.

 ALL SELECT   FOR ITEM=KP   COMPONENT=
  IN RANGE         1 TO        25 STEP         1

     21  KEYPOINTS (OF     21  DEFINED) SELECTED BY  KSEL  COMMAND.

 ALL SELECT   FOR ITEM=ELEM COMPONENT=
  IN RANGE         0 TO         0 STEP         1

        0  ELEMENTS (OF        0  DEFINED) SELECTED BY  ESEL  COMMAND.

 ALL SELECT   FOR ITEM=NODE COMPONENT=
  IN RANGE         0 TO         0 STEP         1

        0  NODES (OF        0  DEFINED) SELECTED BY NSEL  COMMAND.

 OVERLAP VOLUMES
      INPUT VOLUMES =      1    2    3    4
      INPUT VOLUMES WILL BE DELETED
      OUTPUT VOLUMES =      5    6    7    8    9   10   11   12

 ROTATE WORKING PLANE
      0.0000      DEGREES ABOUT WORKING PLANE'S Z AXIS (X TOWARDS Y)
      0.0000      DEGREES ABOUT WORKING PLANE'S X AXIS (Y TOWARDS Z)
      90.000      DEGREES ABOUT WORKING PLANE'S Y AXIS (Z TOWARDS X)

 SUBTRACT WORKING PLANES FROM A VOLUME
      VOLUME NUMBERS TO BE OPERATED ON =      5      6      7      8
    9
      VOLUME NUMBERS TO BE OPERATED ON =     10     11     12
      VOLUMES OPERATED ON WILL BE DELETED
      OUTPUT VOLUMES =      1    2    3    4   13   14   15   16   17
18
      OUTPUT VOLUMES =     19   20   21   22   23   24

 ELEMENT TYPE      1 IS SOLID45      3-D STRUCTURAL SOLID
  KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0

 CURRENT NODAL DOF SET IS  UX    UY    UZ
  THREE-DIMENSIONAL MODEL
```

```
 ELEMENT TYPE SET TO         1

 FOR ELEMENT TYPE(S) ALLOWING MULTIPLE SHAPES:
      PRODUCE ALL QUADRILATERAL OR BRICK ELEMENTS. (MAPPED)

 DEFAULT ELEMENT DIVISIONS PER LINE BASED ON ELEMENT SIZE =   5.00

 ACTIVE COORDINATE SYSTEM SET TO      1  (CYLINDRICAL)

 SELECT        FOR ITEM=LOC  COMPONENT=X     BETWEEN  66.000     AND  6
6.000
   KABS=  0.  TOLERANCE= 0.330000

    17  LINES (OF    86  DEFINED) SELECTED BY LSEL  COMMAND.

 ALSO SELECT   FOR ITEM=LOC  COMPONENT=Z     BETWEEN  0.0000     AND  0
.0000
   KABS=  0.  TOLERANCE= 0.100000E-05

    30  LINES (OF    86  DEFINED) SELECTED BY LSEL COMMAND.

 ACTIVE COORDINATE SYSTEM SET TO      0  (CARTESIAN)

 SELECT       ONLY AREAS COMPLETELY CONTAINED WITHIN LINE SET

     12  AREAS (OF     64  DEFINED) SELECTED FROM
     30 SELECTED LINES BY  ASLL  COMMAND.

 SELECT       ALL VOLUMES HAVING ANY AREA IN AREA SET.

     10  VOLUMES (OF     16  DEFINED) SELECTED FROM
     12 SELECTED AREAS BY  VSLA  COMMAND.

 DEFINITION OF COMPONENT = CONCRETE  ENTITY=VOLU

  SET ATTRIBUTES FOR ALL SELECTED VOLUMES
 MAT =    1   REAL =       0   TYPE =    0   ESYS =   0
 ATTRIBUTES SET FOR     10 VOLUMES (OUT OF     10 SELECTED)

 *IF  liner                          ( =   1.00000     )  EQ
      1                              ( =   1.00000     )  THEN

 INVERT        FOR ITEM=VOLU COMPONENT=
  IN RANGE        1 TO        24 STEP        1

     6  VOLUMES (OF    16  DEFINED) SELECTED BY VSEL  COMMAND.

 DEFINITION OF COMPONENT = STEEL     ENTITY=VOLU

  SET ATTRIBUTES FOR ALL SELECTED VOLUMES
 MAT =    2   REAL =       0   TYPE =    0   ESYS =   0
```

```
ATTRIBUTES SET FOR       6 VOLUMES (OUT OF      6 SELECTED)

*ENDIF

ALL CURRENT ANSYS DATA WRITTEN TO FILE NAME= solid.db
 FOR POSSIBLE RESUME FROM THIS POINT

SELECT ALL ENTITIES OF TYPE= ALL  AND BELOW

ALL SELECT   FOR ITEM=VOLU COMPONENT=
 IN RANGE        1 TO        24 STEP        1

    16  VOLUMES (OF     16  DEFINED) SELECTED BY  VSEL  COMMAND.

ALL SELECT   FOR ITEM=AREA COMPONENT=
 IN RANGE        1 TO        84 STEP        1

   64  AREAS (OF    64  DEFINED) SELECTED BY ASEL COMMAND.

ALL SELECT   FOR ITEM=LINE COMPONENT=
 IN RANGE        1 TO        98 STEP        1

   86  LINES (OF    86  DEFINED) SELECTED BY LSEL COMMAND.

ALL SELECT   FOR ITEM=KP   COMPONENT=
 IN RANGE        1 TO        39 STEP        1

    39  KEYPOINTS (OF     39  DEFINED) SELECTED BY  KSEL  COMMAND.

ALL SELECT   FOR ITEM=ELEM COMPONENT=
 IN RANGE        0 TO         0 STEP        1

       0  ELEMENTS (OF        0  DEFINED) SELECTED BY  ESEL  COMMAND.

ALL SELECT   FOR ITEM=NODE COMPONENT=
 IN RANGE        0 TO         0 STEP        1

       0  NODES (OF        0  DEFINED) SELECTED BY NSEL  COMMAND.

GENERATE NODES AND ELEMENTS   IN  ALL  SELECTED VOLUMES

NUMBER OF VOLUMES MESHED   =       16
MAXIMUM NODE NUMBER        =    21282
MAXIMUM ELEMENT NUMBER     =    17908

MATERIAL         1     EX   =   3610000.


MATERIAL         1     NUXY =  0.1700000


MATERIAL         1     DENS =  0.8333333E-01
```

```
 MATERIAL          2      EX   =  0.2860000E+08


 MATERIAL          2      NUXY =  0.3000000


 MATERIAL          2      DENS =  0.2900000


 ACTIVE COORDINATE SYSTEM SET TO      1  (CYLINDRICAL)

 SELECT       FOR ITEM=LOC  COMPONENT=X     BETWEEN  66.000     AND   6
6.000
   KABS=  0.  TOLERANCE= 0.330000

      2025  NODES (OF    21282  DEFINED) SELECTED BY  NSEL  COMMAND.

 RESELECT     FOR ITEM=LOC  COMPONENT=Y     BETWEEN -1.0000     AND   9
0.000
   KABS=  0.  TOLERANCE= 0.910000E-06

      1035  NODES (OF    21282  DEFINED) SELECTED BY  NSEL  COMMAND.

 ACTIVE COORDINATE SYSTEM SET TO      0  (CARTESIAN)

 RESELECT     FOR ITEM=LOC  COMPONENT=Y     BETWEEN -1.0000     AND   1
2.474
   KABS=  0.  TOLERANCE= 0.134740E-06

       135  NODES (OF    21282  DEFINED) SELECTED BY  NSEL  COMMAND.

 SPECIFIED CONSTRAINT UX    FOR SELECTED NODES         1 TO    21282 BY
     1
 REAL=  0.00000000       IMAG=  0.00000000

 SPECIFIED CONSTRAINT UZ    FOR SELECTED NODES      6518 TO     6518 BY
     1
 REAL=  0.00000000       IMAG=  0.00000000

 SELECT       FOR ITEM=LOC  COMPONENT=Y     BETWEEN  0.0000     AND   0
.0000
   KABS=  0.  TOLERANCE= 0.100000E-05

      1021  NODES (OF    21282  DEFINED) SELECTED BY  NSEL  COMMAND.

 SPECIFIED CONSTRAINT UY    FOR SELECTED NODES         1 TO    21282 BY
     1
 REAL=  0.00000000       IMAG=  0.00000000

 SELECT ALL ENTITIES OF TYPE= ALL  AND BELOW
```

```
 ALL SELECT    FOR ITEM=VOLU COMPONENT=
  IN RANGE         1 TO       24 STEP        1

     16  VOLUMES (OF     16  DEFINED) SELECTED BY  VSEL  COMMAND.

 ALL SELECT    FOR ITEM=AREA COMPONENT=
  IN RANGE         1 TO       84 STEP        1

    64  AREAS (OF    64  DEFINED) SELECTED BY ASEL COMMAND.

 ALL SELECT    FOR ITEM=LINE COMPONENT=
  IN RANGE         1 TO       98 STEP        1

    86  LINES (OF    86  DEFINED) SELECTED BY LSEL COMMAND.

 ALL SELECT    FOR ITEM=KP   COMPONENT=
  IN RANGE         1 TO       39 STEP        1

     39  KEYPOINTS (OF     39  DEFINED) SELECTED BY  KSEL  COMMAND.

 ALL SELECT    FOR ITEM=ELEM COMPONENT=
  IN RANGE         1 TO    17908 STEP        1

    17908  ELEMENTS (OF    17908  DEFINED) SELECTED BY  ESEL  COMMAND.

 ALL SELECT    FOR ITEM=NODE COMPONENT=
  IN RANGE         1 TO    21282 STEP        1

    21282  NODES (OF    21282  DEFINED) SELECTED BY NSEL  COMMAND.

 ACEL=   -20.000      0.0000      0.0000


 ***** ROUTINE COMPLETED *****  CP =        50.553



 *****  ANSYS SOLUTION ROUTINE  *****

 *****  ANSYS SOLVE    COMMAND  *****

 *** NOTE ***                            CP=     50.993   TIME= 11:26:5
7
 There is no title defined for this analysis.

1

 ***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.3   *****
 ANSYS/Mechanical U
 00107763         VERSION=INTEL NT      11:27:00  JAN 05, 2000 CP=
 53.497
```

```
                    S O L U T I O N   O P T I O N S

   PROBLEM DIMENSIONALITY. . . . . . . . . . . . .3-D
   DEGREES OF FREEDOM. . . . . . UX   UY   UZ
   ANALYSIS TYPE . . . . . . . . . . . . . . . . .STATIC (STEADY-STATE)

 *** NOTE ***                            CP=     54.048   TIME= 11:27:0
0
 Present time 0 is less than or equal to the previous time.

  Time will default to 1.

                    L O A D   S T E P   O P T I O N S

   LOAD STEP NUMBER. . . . . . . . . . . . . . . .     1
   TIME AT END OF THE LOAD STEP. . . . . . . . . .  1.0000
   NUMBER OF SUBSTEPS. . . . . . . . . . . . . . .     1
   STEP CHANGE BOUNDARY CONDITIONS . . . . . . . .    NO
   INERTIA LOADS                         X            Y            Z
      ACEL . . . . . . . . . . . . . -20.000      0.0000       0.0000
   PRINT OUTPUT CONTROLS . . . . . . . . . . . . .NO PRINTOUT
   DATABASE OUTPUT CONTROLS. . . . . . . . . . . .ALL DATA WRITTEN
                                                   FOR THE LAST SUBSTEP


 NONLINEAR MONITORING INFO IS WRITTEN TO FILE= dropl.mntr




          ***** CENTROID, MASS, AND MASS MOMENTS OF INERTIA *****

  CALCULATIONS ASSUME ELEMENT MASS AT ELEMENT CENTROID

  TOTAL MASS =   99587.

                         MOM. OF INERTIA        MOM. OF INERTIA
     CENTROID             ABOUT ORIGIN          ABOUT CENTROID

  XC =   0.11684E-08     IXX =   0.1587E+10     IXX =   0.4248E+09
  YC =    31.516         IYY =   0.1587E+10     IYY =   0.5237E+09
  ZC =    103.32         IZZ =   0.2560E+09     IZZ =   0.1570E+09
                         IXY =  -0.3442E-02     IXY =   0.2251E-03
                         IYZ =  -0.3308E+09     IYZ =  -0.6510E+07
```

```
                             IZX =   -0.1474E-01      IZX =   -0.2717E-02

  *** MASS SUMMARY BY ELEMENT TYPE ***

  TYPE      MASS
     1   99587.2

 Range of element maximum matrix coefficients in global coordinates
 Maximum= 40162757.8 at element 17582.

 Minimum= 2613078.73 at element 2652.


   *** ELEMENT MATRIX FORMULATION TIMES
  TYPE  NUMBER   ENAME      TOTAL CP  AVE CP

     1   17908   SOLID45      42.782    0.002
 Time at end of element matrix formulation CP= 101.726275.


 Estimated number of active DOF= 62689.

 Maximum wavefront= 2126.


 Time at end of matrix triangularization CP= 2136.17166.

 Equation solver maximum pivot= 112636347 at node 20647 UY.

 Equation solver minimum pivot= 1460212.73 at node 5573 UZ.


   *** ELEMENT RESULT CALCULATION TIMES
  TYPE  NUMBER   ENAME      TOTAL CP  AVE CP

     1   17908   SOLID45      22.613    0.001

   *** NODAL LOAD CALCULATION TIMES
  TYPE  NUMBER   ENAME      TOTAL CP  AVE CP

     1   17908   SOLID45       1.642    0.000
 *** LOAD STEP     1   SUBSTEP     1  COMPLETED.    CUM ITER =      1
 *** TIME =   1.00000         TIME INC =   1.00000      NEW TRIANG MATR
IX

 *** NOTE ***                            CP=    2187.465   TIME= 12:18:1
7
 Page file used.
```

```
  *** PROBLEM STATISTICS
 ACTUAL NO. OF ACTIVE DEGREES OF FREEDOM =  62689
 R.M.S. WAVEFRONT SIZE =  1732.7


*** ANSYS BINARY FILE STATISTICS
 BUFFER SIZE USED=  4096
      92.594 MB WRITTEN ON ELEMENT MATRIX FILE: dropl.emat
      60.938 MB WRITTEN ON ELEMENT SAVED DATA FILE: dropl.esav
     799.953 MB WRITTEN ON TRIANGULARIZED MATRIX FILE: dropl.tri
      35.609 MB WRITTEN ON RESULTS FILE: dropl.rst

ALL CURRENT ANSYS DATA WRITTEN TO FILE NAME= dropl.db
 FOR POSSIBLE RESUME FROM THIS POINT

FINISH SOLUTION PROCESSING


***** ROUTINE COMPLETED *****  CP =      2191.932


1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.3   *****
ANSYS/Mechanical U
00107763          VERSION=INTEL NT      12:20:21  JAN 05, 2000 CP=   2
191.932




         ***** ANSYS RESULTS INTERPRETATION (POST1) *****

*** NOTE ***                            CP=   2191.932   TIME= 12:20:2
1
Reading results into the database (SET command) will update the curren
t
 displacement and force boundary conditions in the database with the

 values from the results file for that load set.  Note that any

 subsequent solutions will use these values unless action is taken to

 either SAVE the current values or not overwrite them (/EXIT,NOSAVE).

DATA FILE CHANGED TO FILE= dropl.rst


USE LOAD STEP     1  SUBSTEP     0  FOR LOAD CASE 0
```

```
 SET COMMAND GOT LOAD STEP=     1  SUBSTEP=     1  CUMULATIVE ITERATION
=     1
   TIME/FREQUENCY=  1.0000
 TITLE=


 ACTIVE COORDINATE SYSTEM SET TO      1  (CYLINDRICAL)

 DISPLAY COORDINATE SYSTEM SET TO      1  (CYLINDRICAL)

 RSYS KEY SET TO   1

 USE COORDINATE SYSTEM   1 FOR SOLUTION RESULTS

 SELECT      COMPONENT CONCRETE

 SELECT      ELEMENTS CREATED FROM SELECTED VOLUMES.

    15466  ELEMENTS (OF    17908  DEFINED) SELECTED FROM
       10 SELECTED VOLUMES BY  ESLV  COMMAND.

 SELECT      ALL NODES HAVING ANY ELEMENT IN ELEMENT SET.

    18801 NODES (OF    21282  DEFINED) SELECTED FROM
    15466 SELECTED ELEMENTS BY NSLE COMMAND.

 *DO LOOP ON PARAMETER= II       FROM  113.70     TO  213.70     BY  20
.000

 DEFINE A PATH FOR SUBSEQUENT CALCULATIONS THROUGH NODES:
      15528 14502

 PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY LPATH COMMAND.  D
SYS=  1
1

 ***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.3   *****
 ANSYS/Mechanical U
 00107763          VERSION=INTEL NT      12:21:41  JAN 05, 2000 CP=   2
210.038




          ***** POST1 LINEARIZED STRESS LISTING *****
         INSIDE NODE =  15528     OUTSIDE NODE =  14502

  LOAD STEP     1  SUBSTEP=     1
  TIME=    1.0000         LOAD CASE=  0
```

```
THE FOLLOWING X,Y,Z STRESSES ARE IN COORDINATE SYSTEM    1

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
 -393.8      -203.7      -74.09       185.6      -3.080      -6.960

     S1          S2          S3          SINT        SEQV
 -71.90      -92.35      -507.3       435.4       425.5

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   526.2       435.3       163.1       14.13       4.779      -3.707

C   0.000       0.000       0.000       0.000       0.000       0.000

O  -526.2      -435.3      -163.1      -14.13      -4.779       3.707

     S1          S2          S3          SINT        SEQV
I   528.4       433.3       163.0       365.4       328.4
C   0.000       0.000       0.000       0.000       0.000
O  -163.0      -433.3      -528.4       365.4       328.4

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   132.4       231.6       89.02       199.7       1.699      -10.67

C  -393.8      -203.7      -74.09       185.6      -3.080      -6.960

O  -920.0      -639.0      -237.2       171.5      -7.859      -3.253

     S1          S2          S3          SINT        SEQV
I   387.9       89.71      -24.54       412.5       368.9
C  -71.90      -92.35      -507.3       435.4       425.5
O  -237.0      -558.1      -1001.       764.2       664.6

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -141.6      -71.85      -36.40      -11.38     -0.5865       1.373

C   93.53       47.55       24.08       11.06      0.5263     -0.7521

O  -151.6      -312.7      -79.11      -14.68      -1.568      0.1078

     S1          S2          S3          SINT        SEQV
I  -36.36      -70.06      -143.5       107.1       94.84
C   96.06       45.06       24.05       72.00       64.14
O  -79.10      -150.2      -314.1       235.0       208.7

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -9.191       159.8       52.62       188.3       1.112      -9.294
```

```
 C  -300.3      -156.1      -50.01      196.6      -2.554      -7.712

 O  -1072.      -951.7      -316.3      156.8      -9.428      -3.145

       S1          S2          S3         SINT        SEQV        TEMP
 I   281.8       52.93      -131.5      413.3       358.6       0.000

 C  -17.45      -51.25      -437.7      420.2       404.4
 O  -316.1      -844.0      -1180.      863.4       753.9       0.000


 *ENDDO  INDEX= II
1

 ***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.3   *****
 ANSYS/Mechanical U
 00107763         VERSION=INTEL NT      12:21:42  JAN 05, 2000 CP=   2
211.049




          ***** POST1 LINEARIZED STRESS LISTING *****
         INSIDE NODE =  15524     OUTSIDE NODE =  14498

  LOAD STEP     1  SUBSTEP=     1
  TIME=    1.0000          LOAD CASE=  0

 THE FOLLOWING X,Y,Z STRESSES ARE IN COORDINATE SYSTEM   1

            ** MEMBRANE **
      SX          SY          SZ         SXY         SYZ         SXZ
  -402.6      -210.4      -70.92      190.1      -2.592      -5.804

      S1          S2          S3         SINT        SEQV
  -69.73      -94.64      -519.5      449.8       437.9

            ** BENDING **   I=INSIDE C=CENTER O=OUTSIDE
       SX          SY          SZ         SXY         SYZ         SXZ
 I   540.5       450.3       166.1      14.68       4.067      -2.861

 C   0.000       0.000       0.000      0.000       0.000       0.000

 O  -540.5      -450.3      -166.1     -14.68      -4.067       2.861

       S1          S2          S3         SINT        SEQV
 I   542.8       448.1       166.0      376.8       339.5
 C   0.000       0.000       0.000      0.000       0.000
 O  -166.0      -448.1      -542.8      376.8       339.5

            ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
```

```
          SX          SY          SZ          SXY         SYZ         SXZ
  I     137.9       239.9       95.16       204.8       1.475      -8.665

  C    -402.6      -210.4      -70.92       190.1      -2.592      -5.804

  O    -943.0      -660.7      -237.0       175.4      -6.659      -2.943

          S1          S2          S3          SINT        SEQV
  I     400.0       95.61      -22.66       422.7       377.7
  C    -69.73      -94.64      -519.5       449.8       437.9
  O    -236.8      -576.9      -1027.       790.2       686.5

                   ** PEAK **   I=INSIDE  C=CENTER  O=OUTSIDE
          SX          SY          SZ          SXY         SYZ         SXZ
  I    -145.5      -72.87      -37.47      -11.65     -0.6700       1.096

  C     96.07       48.39       24.83       11.29      0.5599     -0.6174

  O    -155.6      -320.2      -81.51      -14.91      -1.699      0.3550E
 -01
          S1          S2          S3          SINT        SEQV
  I    -37.44      -71.07      -147.4       109.9       97.55
  C     98.61       45.87       24.80       73.81       65.85
  O    -81.50      -154.2      -321.6       240.1       213.2

                   ** TOTAL **   I=INSIDE  C=CENTER  O=OUTSIDE
          SX          SY          SZ          SXY         SYZ         SXZ
  I    -7.629       167.0       57.69       193.1      0.8047      -7.570

  C    -306.5      -162.0      -46.09       201.4      -2.032      -6.421

  O    -1099.      -980.9      -318.5       160.5      -8.359      -2.907

          S1          S2          S3          SINT        SEQV        TEMP
  I     291.7       57.89      -132.5       424.2       368.0       0.000

  C    -19.23      -47.12      -448.3       429.0       415.8
  O    -318.4      -868.9      -1211.       892.4       779.8       0.000

 1

  ***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.3    *****
  ANSYS/Mechanical U
  00107763          VERSION=INTEL NT      12:21:43  JAN 05, 2000 CP=    2
 212.071



           ***** POST1 LINEARIZED STRESS LISTING *****
           INSIDE NODE =   15520     OUTSIDE NODE =   14494
```

```
 LOAD STEP     1  SUBSTEP=     1
 TIME=    1.0000         LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN COORDINATE SYSTEM   1

                 ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
 -411.9      -216.9      -67.58       194.2      -2.610      -3.474

     S1          S2          S3          SINT        SEQV
 -67.03      -97.62      -531.7       464.7       450.2

                 ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   554.3       463.2       167.2       14.72       3.939      -1.480

C   0.000       0.000       0.000       0.000       0.000       0.000

O  -554.3      -463.2      -167.2      -14.72      -3.939       1.480

     S1          S2          S3          SINT        SEQV
I   556.6       461.0       167.1       389.5       351.6
C   0.000       0.000       0.000       0.000       0.000
O  -167.1      -461.0      -556.6       389.5       351.6

                 ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   142.4       246.4       99.60       208.9       1.329      -4.954

C  -411.9      -216.9      -67.58       194.2      -2.610      -3.474

O  -966.2      -680.1      -234.8       179.5      -6.549      -1.994

     S1          S2          S3          SINT        SEQV
I   409.7       99.77      -21.12       430.8       384.9
C  -67.03      -97.62      -531.7       464.7       450.2
O  -234.6      -593.8      -1053.       818.0       710.2

                 ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -149.3      -74.13      -38.73      -11.82     -0.5279      0.4441

C   98.55       49.29       25.75       11.49      0.4500     -0.2159

O  -159.5      -327.6      -84.30      -15.20      -1.507     -0.2889

     S1          S2          S3          SINT        SEQV
I  -38.72      -72.33      -151.2       112.4       99.96
C   101.1       46.75       25.74       75.36       67.36
O  -84.29      -158.1      -329.0       244.7       217.4
```

```
                ** TOTAL **   I=INSIDE C=CENTER O=OUTSIDE
         SX           SY           SZ           SXY          SYZ          SXZ
 I   -6.953        172.2        60.87        197.1        0.8007       -4.510

 C   -313.4       -167.6       -41.83        205.7       -2.160        -3.690

 O   -1126.       -1008.       -319.1        164.3       -8.057        -2.283

         S1           S2           S3           SINT         SEQV         TEMP
 I    299.2        60.94       -134.0        433.1        375.7        0.000

 C   -21.49       -42.57       -458.7        437.2        427.1
 O   -318.9       -892.3       -1241.        922.3        806.6        0.000

1

 ***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.3   *****
 ANSYS/Mechanical U
 00107763          VERSION=INTEL NT      12:21:44  JAN 05, 2000 CP=   2
213.072



           ***** POST1 LINEARIZED STRESS LISTING *****
          INSIDE NODE =  15516     OUTSIDE NODE =   14490

  LOAD STEP     1  SUBSTEP=     1
  TIME=    1.0000          LOAD CASE=  0

 THE FOLLOWING X,Y,Z STRESSES ARE IN COORDINATE SYSTEM   1

                ** MEMBRANE **
        SX           SY           SZ           SXY          SYZ          SXZ
  -420.6       -220.9       -61.74        197.1       -3.739        2.844

        S1           S2           S3           SINT         SEQV
  -61.62       -99.91       -541.8        480.2        462.2

                ** BENDING **   I=INSIDE C=CENTER O=OUTSIDE
        SX           SY           SZ           SXY          SYZ          SXZ
 I    568.4        476.0        158.7        13.78        5.593        1.860

 C    0.000        0.000        0.000        0.000        0.000        0.000

 O   -568.4       -476.0       -158.7       -13.78       -5.593       -1.860

        S1           S2           S3           SINT         SEQV
 I    570.4        474.1        158.6        411.8        373.1
 C    0.000        0.000        0.000        0.000        0.000
 O   -158.6       -474.1       -570.4        411.8        373.1
```

```
             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I   147.7       255.1       96.95       210.9       1.855       4.704

 C  -420.6      -220.9      -61.74       197.1      -3.739       2.844

 O  -989.0      -696.9      -220.4       183.3      -9.332      0.9841

      S1          S2          S3          SINT        SEQV
 I   419.1       96.95      -16.26       435.3       391.2
 C  -61.62      -99.91      -541.8       480.2       462.2
 O  -220.2      -608.8      -1077.       857.2       743.4

             ** PEAK **   I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I  -153.3      -74.79      -40.89      -11.70       0.2676     -1.433

 C   101.0       49.85       27.43       11.55     -0.7728E-01   1.044

 O  -163.1      -334.2      -89.07      -15.45     -0.4237     -1.444

      S1          S2          S3          SINT        SEQV
 I  -40.87      -73.10      -155.0       114.1       101.9
 C   103.5       47.36       27.41       76.07       68.32
 O  -89.05      -161.8      -335.6       246.5       219.4

             ** TOTAL **   I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I  -5.524       180.3       56.06       199.2       2.122       3.272

 C  -319.7      -171.1      -34.31       208.7      -3.816       3.888

 O  -1152.      -1031.      -309.5       167.9      -9.756     -0.4599

      S1          S2          S3          SINT        SEQV        TEMP
 I   307.2       56.02      -132.4       439.7       382.0       0.000

 C  -23.82      -34.32      -466.9       443.1       438.0
 O  -309.4      -913.3      -1270.       960.8       841.2       0.000

1

 ***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.3    *****
 ANSYS/Mechanical U
 00107763         VERSION=INTEL NT      12:21:45  JAN 05, 2000 CP=    2
214.094
```

```
            ***** POST1 LINEARIZED STRESS LISTING *****
           INSIDE NODE =  15512     OUTSIDE NODE =  14486

  LOAD STEP      1  SUBSTEP=     1
  TIME=    1.0000         LOAD CASE=  0

 THE FOLLOWING X,Y,Z STRESSES ARE IN COORDINATE SYSTEM   1

                 ** MEMBRANE **
      SX          SY          SZ          SXY         SYZ         SXZ
  -423.3      -218.5      -47.60       196.3      -8.215       19.17

      S1          S2          S3          SINT        SEQV
  -46.58      -99.72      -543.2       496.6       472.3

                 ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I   578.1       488.1       116.9       12.18       13.31       9.228

 C   0.000       0.000       0.000       0.000       0.000       0.000

 O  -578.1      -488.1      -116.9      -12.18      -13.31      -9.228

      S1          S2          S3          SINT        SEQV
 I   579.9       486.8       116.3       463.7       424.8
 C   0.000       0.000       0.000       0.000       0.000
 O  -116.3      -486.8      -579.9       463.7       424.8

                 ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I   154.7       269.5       69.33       208.4       5.093       28.40

 C  -423.3      -218.5      -47.60       196.3      -8.215       19.17

 O  -1001.      -706.6      -164.5       184.1      -21.52       9.943

      S1          S2          S3          SINT        SEQV
 I   429.6       73.00      -8.979       438.6       403.9
 C  -46.58      -99.72      -543.2       496.6       472.3
 O  -163.7      -618.7      -1090.       926.5       802.4

                 ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I  -156.1      -72.66      -45.53      -11.02       3.291      -5.751

 C   102.6       49.25       30.95       11.01      -1.998       4.077

 O  -165.3      -336.4      -99.11      -14.83       5.122      -3.988

      S1          S2          S3          SINT        SEQV
 I  -44.68      -71.84      -157.8       113.1       102.3
 C   105.0       47.52       30.32       74.64       67.70
```

```
 O  -98.72      -164.3      -337.8      239.1       214.0

                ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I  -1.356       196.9       23.80       197.4       8.385       22.65

 C  -320.7      -169.3      -16.65       207.3      -10.21       23.25

 O  -1167.      -1043.      -263.6       169.3      -16.40       5.955

      S1          S2          S3          SINT        SEQV        TEMP
 I   319.9       24.08      -124.7       444.6       392.0       0.000

 C  -13.10      -26.51      -467.0       454.0       447.4
 O  -263.3      -924.8      -1285.       1022.       897.8       0.000

1

 ***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.3   *****
 ANSYS/Mechanical U
 00107763         VERSION=INTEL NT      12:21:46  JAN 05, 2000 CP=   2
215.105



          ***** POST1 LINEARIZED STRESS LISTING *****
         INSIDE NODE =  14786     OUTSIDE NODE =  13723

  LOAD STEP     1  SUBSTEP=     1
  TIME=    1.0000         LOAD CASE=  0

 THE FOLLOWING X,Y,Z STRESSES ARE IN COORDINATE SYSTEM    1

                ** MEMBRANE **
      SX          SY          SZ          SXY         SYZ         SXZ
  -361.1      -189.8      -10.39      213.1       -6.583      20.67

      S1          S2          S3          SINT        SEQV
  -8.518      -46.78      -505.9      497.4       479.4

                ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I   475.5       401.1       14.09       45.06       11.72      -10.45

 C   0.000       0.000       0.000       0.000       0.000       0.000

 O  -475.5      -401.1      -14.09      -45.06      -11.72       10.45

      S1          S2          S3          SINT        SEQV
 I   496.7       380.5       13.43       483.3       436.9
```

```
C    0.000        0.000        0.000        0.000        0.000
O   -13.43       -380.5       -496.7        483.3        436.9

          ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ           SXY          SYZ          SXZ
I    114.4        211.3        3.697        258.1        5.133        10.22

C   -361.1       -189.8       -10.39        213.1       -6.583        20.67

O   -836.5       -590.9       -24.49        168.0       -18.30        31.12

     S1           S2           S3           SINT         SEQV
I    425.8        3.640       -99.98        525.7        482.4
C   -8.518       -46.78       -505.9        497.4        479.4
O   -23.03       -505.6       -923.3        900.2        780.3

          ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ           SXY          SYZ          SXZ
I   -122.7       -79.96       -26.88       -20.02       0.2724       7.872

C    78.77        49.52        9.892        17.47       0.6566      -6.233

O   -124.6       -317.0       -27.61       -25.52        2.453        12.56

     S1           S2           S3           SINT         SEQV
I   -26.20       -72.20       -131.1        104.9        91.11
C    87.30        41.68        9.197        78.10        67.96
O   -26.01       -122.8       -320.4        294.4        259.9

          ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ           SXY          SYZ          SXZ
I   -8.304        131.4       -23.18        238.1        5.406        18.09

C   -282.3       -140.2      -0.5019        230.5       -5.927        14.43

O   -961.1       -907.8       -52.10        142.5       -15.85        43.68

     S1           S2           S3           SINT         SEQV         TEMP
I    310.4       -23.10       -187.4        497.7        439.3        0.000

C    30.44      -0.4711       -453.0        483.5        468.8
O   -49.91       -789.8       -1081.        1031.        920.9        0.000


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BNFL
Fuel Solutions

CALCULATION PACKAGE

Calc. Pkg No. VSC02.6.2.3.16
File No.: VSC02.6.2.3.16
Revision: 0

PROJECT/CUSTOMER:

VSC02/BNFL Fuel Solutions

TITLE:

3/16-inch MSB Storage Sleeve

SCOPE:

Product: ☐ Wesflex™ ☐ TranStor™ ☒ VSC-24 ☐ Other ______
Service: ☒ Storage ☐ Transportation ☐ Other ______
Conditions: ☐ Normal ☐ Off-Normal ☒ Accident ☐ Other ______

Component(s):

MSB storage sleeve

Prepared by:

Name: J L Hibbard
Signature: JL Hibbard
Date: 1-12-00

Verified by:

Name: Michelle M. Heinz
Signature: Michelle M. Heinz
Date: 1/12/00

Engineering Manager Approval:

Name: RAM SRINIVASAN
Signature: R Srinivasan
Date: 1/17/00

RECORD OF REVISIONS

REV.	AFFECTED PAGES	AFFECTED MEDIA	DESCRIPTION	NAMES (print or type)	
				PREPARER	CHECKER
0	1 – 11	None	Replaces Calculation WEP109-002.16, Rev. 3 —		Michelle Heinz
			Per Ecn No.: WEP01-C-018		

Note: This calculation has been prepared in accordance with QAP 3.2, Revision 8, except that because this calculation is a revision of an existing calculation, the format is essentially based on the superceded calculation. The title page, record of revision page, and record of verification page are per QAP 3.2, Revision 8. Other format requirements of QAP 3.2 have been included where this could be readily accomplished. This approach was approved in BFS Memorandum 99-528, dated December 21, 1999.

RECORD OF VERIFICATION

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

COMMENTS:

Verifier: Michelle M. Heinz / Michelle M. Heinz / 1/12/00

Name/Signature/Date

1.0 PURPOSE AND RESULTS

Purpose

This calculation determines the minimum allowable thickness of the MSB sleeve wall based on the two sleeve design criteria: (1) deflection less than 0.5 inch so that fuel can be removed after an accident drop, and (2) stress less than ultimate strength.

This calculation supersedes WEP109.002.16, Revision 3. This calculation incorporates comments from CAR 98-50.

The principal differences between the new and old calculations are:

- Calculated the sleeve assembly collapse load for the vertical drop with the approach in the AISC Code, which is conservative. (The old calculation used the Euler collapse load, which is not conservative for the sleeve slenderness ratio of about 45; a slenderness ratio of at least 120 is required to apply the Euler collapse formula).

- Corrected the temperature used for the sleeve assembly yield and ultimate strength.

- Corrected the moment of inertia calculation for the sleeve assembly.

- Updated the sleeve mass used for the calculations. Updated the 5-foot drop deceleration.

Results

The sleeve stress is the controlling parameter. The calculated minimum allowable wall thickness is 0.181 inches for a maximum stress of ultimate strength. The deflection of the sleeve with a 0.181-inch wall thickness is 0.23 inches, which is less than the allowable of 0.5 inches. It is concluded that the stress and the deflection of the sleeve are acceptable for a sleeve thickness of 0.181 inches.

Buckling was also considered for the horizontal and vertical drops in Attachment 1. For the vertical drop case, the P_u' = 169 kips (critical load) is much greater than the actual load of 37.4 kips. For the horizontal drop case, P_u' = 3.28 kips/in (critical load) is greater than the actual load of 2.83 kips/in. It is concluded that the sleeve will not buckle due to the vertical or horizontal drops.

Attachment 2 evaluates the acceptable size of pockmarks in the sleeve material. The maximum allowable size pockmark is 1/4 inch x 1/4 inch, with at least a 3 inch centerline to centerline spacing between adjacent pockmarks, and a minimum allowable wall thickness in the pockmark of 1/8 inch.

2.0 DESIGN INPUT AND ASSUMPTIONS

The licensing basis sleeve stresses and sleeve geometry are:

Calculated maximum stress	57 ksi	Reference 2
Calculated maximum elastic deflection	0.12 inch	Reference 2
Used wall thickness	0.20 inch	Reference 6
A 516 Gr. 70 S_y	28.1 ksi at 600°F	Reference 5
A 516 Gr. 70 S_u	70 ksi at 600°F	Reference 5

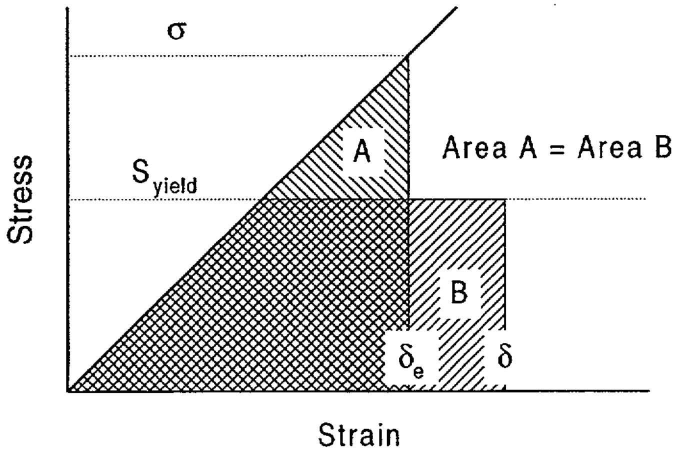
The 600°F design temperature for the sleeve bounds the temperature in Reference 7.

3.0 METHODOLOGY

It is noted that only the horizontal drop affects the required sleeve wall thickness. During the vertical drop, the sleeve is loaded only in compression by its self-weight; the load, therefore, is reduced together with the section area, i.e., there is no change in stresses or deflections from a reduction in the sleeve wall thickness.

For the horizontal drop, the sleeve assembly criterion is that plastic deformation of the sleeves shall not prevent removal of the fuel assembles (Reference 2). This means that the maximum stress intensity resulting from the drop should not exceed the sleeve ultimate stress (no structural failure) and the maximum deflection should be smaller than the gap between sleeve wall and fuel assembly (no interference between the sleeve and the fuel).

The original ANSYS run (presented in Reference 2) was an elastic analysis, and calculated the maximum equivalent stress of 57 ksi. This is well within the minimum ultimate strength of 70 ksi for A 516, Gr. 70 steel, but the stress is over the minimum yield strength of 28.1 ksi. Accordingly, the calculated elastic deflection of 0.12 inch was adjusted to account for plastic deformation. The absorbed energy from the elastic stress/strain curve (Area A) was balanced with the absorbed energy based on an ideal elasto-plastic material (Area B). This approach is illustrated below. The resulting formula for total deflection is derived in Reference 2.



The total plastic deformation is

$$\delta = \delta_y + \delta_{pl} = \delta_{an} \cdot \left(\frac{S_y}{\sigma_{an}} \right) + \frac{1}{2} \cdot (\delta_{an} \cdot \frac{\sigma_{an}}{S_y} - \delta_{an} \cdot \frac{S_y}{\sigma_{an}})$$

When the sleeve wall thickness is changed, it affects both the stress and deflection. The values are scaled as follows:

Stress

The stress consists of two components – membrane stress and bending stress. Membrane stress is inversely proportional to thickness, bending stress is inversely proportional to thickness squared (section modulus = $bt^2/6$). Therefore, it is conservative to scale the stress using the ratio of wall thicknesses squared.

Deflection

The total deflection also consists of two components – membrane and bending. Membrane deflection is inversely proportional to thickness, but bending deflection is inversely proportional to thickness cubed (moment of inertia = $bt^3/12$). Therefore, it is conservative to scale the elastic deflection using the cubed ratio of wall thicknesses.

4.0 CALCULATIONS

Calculate the minimum wall thickness based on a stress equal to the minimum ultimate strength:

thickness = $(57 / 70)^{1/2}$ x 0.20 = 0.181 inch

Calculated the maximum elastic deflection of a sleeve assembly with this wall thickness:

elastic deflection = 0.12 x $(.20/.181)^3$ = .162 inch

Using the formula from above, calculate the plastic deformation:

elasto-plastic deflection = .162 x (28.1/70) + 1/2 x .162 [70/28.1 – 28.1/70]

= 0.23 inch < 0.5 inch OK

5.0 REFERENCES

1. BNFL Calculation No. VSC02.6.2.3.15, "VSC-24 Hypothetical Tip-over and 5-foot Drop Analyses," Revision 0.
2. BNFL Calculation No. VSC02.6.2.3.08, "MSB-24 Drop Analysis," Revision 0.
3. AISC Manual of Steel Construction, 6th Edition.
4. Marks' Standard Handbook for Mechanical Engineers, McGraw-Hill Inc., 9th Edition.
5. 1986 ASME Boiler and Pressure Vessel Code, Section III, Division I, Volume II, Appendices.
6. BNFL Drawing No. MSB-24-004, Revision 4, Sheet 1/3, "Storage Sleeve Assembly."
7. BNFL Calculations WEP-109-003.4, "VSC-24 Thermal Hydraulic Analysis," Revision 2, and WEP-109-003.5, "MSB-24 Thermal Hydraulic Analysis," Revision 5.
8. BNFL Calculation No. VSC02.6.2.5.01, "MTC, MSB, and VCC Weights and Centers of Gravity B&W Fuel," Revision 0.

ATTACHMENT 1

Vertical Drop

The force from deceleration of the sleeve in the vertical drop is the sleeve mass (350 lb bounds the value from Reference 8) times the acceleration (Reference 1).

Sleeve Load: W = 350 lb x 108 g = 37,428 lbf = 37.4 kip

Calculate moment of inertia for the tube (dimensions from Reference 6):

$$I = \left[\frac{9^4}{12}\right] - \left[\frac{(9-2\times.181)^4}{12}\right]$$

$$I = 82.8\ \text{in}^4$$

Calculate the collapse load from Reference 3, Page 5-16, Paragraph 1.5.1.3, Formula 1. The tube cross sectional area and radius of gyration are (radius of gyration from Reference 4, Table 5.2.6)

$$w_{\text{inside}} = 9 \cdot in - 2 \cdot .181 \cdot in = 8.64 \cdot in$$

$$\text{Area} = (9 \cdot in)^2 - (9 \cdot in - 2 \cdot .181 \cdot in)^2 = 6.38 \cdot in^2$$

$$r = \sqrt{\frac{(9^2 + 8.64^2)}{12}} = 3.60 in$$

The slenderness ratio is (sleeve length from Reference 6)

$$l/r = \frac{164 \cdot in}{3.60 \cdot in} = 45.5$$

The constant C_c is (the modulus of elasticity is from Reference 5 for SA 516 Gr. 70 steel at 600°F; Reference 6 for material and Reference 7 for temperature)

$$C_c = \sqrt{\frac{2 \cdot \pi^2 \cdot E}{S_y}} = \sqrt{\frac{2 \cdot \pi^2 \cdot 26.7 \cdot 10^6}{28{,}100}} = 137.0$$

Assuming pinned-pinned end conditions (K=1, Reference 3, Table C 1.8.1, Page 5-117) and a factor of safety equal to 1 (FS=1) gives the following collapse load:

$$P_u^1 = Area \cdot (1 - \frac{1}{2} \cdot (\frac{K \cdot L}{r \cdot C_c})^2) \cdot \frac{S_y}{FS} = 6.38 \cdot (1 - \frac{1}{2} \cdot (\frac{1 \cdot 164}{3.60 \cdot 137})^2) \cdot \frac{28{,}100}{1.0} = 169 kip$$

$P_U^1 >> W = 37.4$ kip

This approach is very conservative because the tubes are actually welded together and the moment of inertia is much higher.

Horizontal Drop

The design basis fuel assembly weight is 1,600 lb (Reference 8). The horizontal deceleration is 40g (Reference 1).

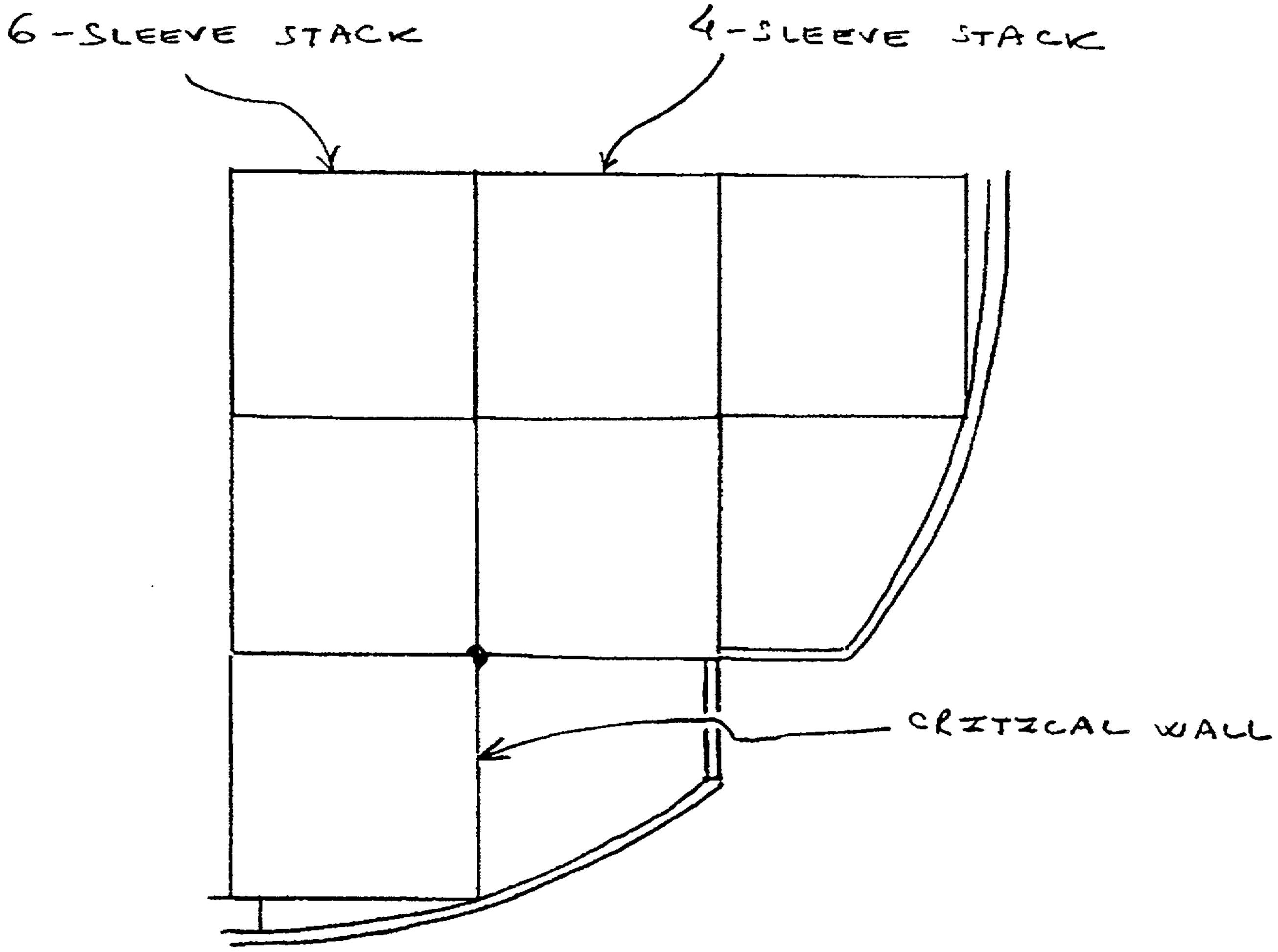


Figure A-1. Critical Wall for Buckling Evaluation

Load for the critical wall:

$$W = 40g\ x\left(\frac{5}{2}+\frac{4}{2}\right)\left(1{,}600+350\right) = 351\,kip$$

Assume the column is fixed at the top (sleeves are welded together) and simply supported at the bottom (in reality some moment resistance is provided by the horizontal wall). Use the Euler formula to calculate the collapse load. The radius of gyration is (Reference 4, Table 5.2.6):

$$r = \frac{0.181 \cdot in}{\sqrt{12}} = 0.0523\ inch$$

The length of the column is 9". Then, the l/r ratio is 172, which is large enough to use the Euler collapse formula for slender columns (Reference 4, p. 5-42).

Euler force per inch of length (use Roark 4th Edition, Table XV, Case 3)

$$P_u^1 = \frac{\pi^2\ EI}{(.7L)^2} \qquad I = \frac{1(0.181)^3}{12} = 4.9 \cdot 10^{-4}\ \text{in} \qquad L = 9"$$

$$P_u^1 = \frac{\pi^2\ (26.7\ \text{x}\ 10^3)\,(4.9 \cdot 10^{-4})}{(.7\ \text{x}\ 9)^2} = 3.28\ \text{k/in}$$

The top support for the wall is provided across the entire length. However, the bottom support is only provided along 28 x 3 = 84 inches.

Use the average length of (164 + 84) /2 = 124. Then the load per inch is:

$P = 351 / 124 = 2.83$ k/in

$P < P_u{}^1 = 3.28$ k/in

ATTACHMENT 2

Evaluate the acceptance size of a potential pockmark in the sleeve material.

From the review of calculation VSC02.6.2.3.8, the highest stress occurs during horizontal drop in Node 225. From review of the ANSYS output, the highest stress in the neighbor node is 47.5 ksi in Node 226. The sleeve wall thickness for this calculation was 0.20 inch.

Assuming the sleeve wall thickness is 0.181 inch, the stresses can be scaled as follows. Stress is scaled as explained on Page 6 of this calculation. A scale factor is also included for the change in deceleration from 44 g to 40 g (References 1 and 2).

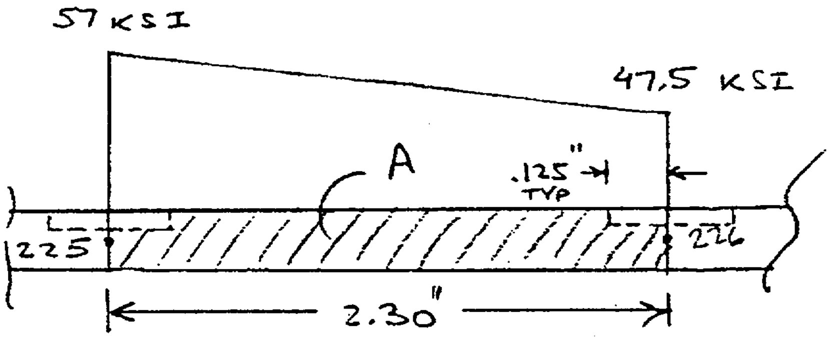
Node 225: $57 \times (.20 / .18)^2 \times 40/44 = 63.3$ ksi

Node 226: $47.5 \times (.20 / .18)^2 \times 40/44 = 52.7$ ksi

From the ANSYS model, the distance between Nodes 225 and 226 is 2.3 inch. The average force on the metal between these nodes is $[(63.3 + 52.7) / 2] \times 2.3 \times .181 = 24.2$ kips.

It is postulated that there are pockmarks at each of these nodes. The pockmark diameter is assumed to be 0.25 inch and the remaining wall thickness is assumed to be 0.125 inch. Then, the cross section area between Nodes 225 and 226 is:

$$A = (.125 + .125)(.125) + (2.30 - 2 \times 1.25)(.181) = .402 \text{ in}^2$$



The average stress at the section with the postulated pockmark is 24.2 kips/.402 = 60.2 ksi < 70 ksi

Based on this calculation, use the following limitation: the maximum pockmark size is 1/4 x 1/4 inch at a minimum spacing of 3 inches with a minimum remaining wall thickness of 0.125 inches.

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CALCULATION PACKAGE

Calc. Pkg No. VSC02.6.2.3.18
File No.: VSC02.6.2.3.18
Revision: 0

PROJECT/CUSTOMER:

VSC02/BNFL Fuel Solutions

TITLE:

VCC Thermal Stress Analysis

SCOPE:

Product: ☐ Wesflex™ ☐ TranStor™ ☒ VSC-24 ☐ Other ____________
Service: ☒ Storage ☐ Transportation ☐ Other ____________
Conditions: ☒ Normal ☐ Off-Normal ☐ Accident ☐ Other ____________

Component(s):

VCC concrete, rebar, liner, bottom plate, and cover plate

Prepared by:
Name: ROBERT KEATING
Signature:
Date: 1/12/2000

Verified by:
Name: Michelle M. Heinz
Signature: Michelle M. Heinz
Date: 1/12/00

Engineering Manager Approval:

Name: RAM SRINIVASAN
Signature: RSrinivasan
Date: 1/21/00

RECORD OF REVISIONS

REV.	AFFECTED PAGES	AFFECTED MEDIA	DESCRIPTION	NAMES (print or type)	
				PREPARER	CHECKER
0	1 – 16 Appendix Pages A1 – A79	None	Replaces SNC Calculation WEP109-002.18, Rev. 2 – Per ECn No: WEP01-C-018	Robert Keating	Michelle Heinz

Note: This calculation has been prepared in accordance with QAP 3.2, Revision 8, except that because this calculation is a revision of an existing calculation, the format is essentially based on the superceded calculation. The title page, record of revision page, and record of verification page are per QAP 3.2, Revision 8. Other format requirements of QAP 3.2 have been included where this could be readily accomplished. This approach was approved in BFS Memorandum 99-528, dated December 21, 1999.

RECORD OF VERIFICATION

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

COMMENTS:

Verifier: Michelle M. Heinz / Michelle M. Heinz / 1/12/00

Name/Signature/Date

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LIST OF FIGURES

1. INTRODUCTION

Because the VCC is exposed to a thermal load, thermal stresses must be evaluated. The purpose/objective of this calculation is to perform an analysis to determine the thermal stresses of VCC components, and ensure these stresses are less than allowable values. These stresses are input to the VCC Load Combination Evaluation calculation to determine total loads and stresses. The scope of this calculation includes the VCC concrete, rebar, liner, bottom plate, and cover plate. This thermal analysis is performed for the case with the highest temperature gradient through the concrete wall, which bounds all other cases.

This calculation was prepared to address technical issues concerning SNC Calculation WEP109-002.18, Revision 2 discussed in CAR 98-50 (date 10/2/98) and the Design Review Record (dated 7/31/98). This calculation supercedes SNC WEP109-002.18, Revision 2. The principal differences between the new and old calculations are:

- The liner thermal stress is adjusted to account for differences in the liner thickness between the old and new calculation.
- The correct yield strength for A-36 steel at 250°F is applied in this calculation.
- Notes are added to this calculation addressing the correct concrete modulus of elasticity, the linking of the liner and concrete in the ANSYS model, and the correct ID of the liner.

Changes to this calculation affect stresses used as inputs to the VCC Load Combination Evaluation Calculation.

2. REQUIREMENTS

2.1 Design Inputs

2.1.1 ACI 349, "Code Requirements for Nuclear Safety Related Concrete Structures", 1985. *(Material Properties)*

2.1.2 1986 ASME Boiler and Pressure Vessel Code, Section III, Division I, Volume II, Appendices. *(Material Properties)*

2.2 Regulatory Commitments

2.2.1 "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High Level Radioactive Waste", Code of Federal Regulations Title 10, Part 72.

3. REFERENCES

3.1 BFS Calculation Packages

3.1.1 SNC Calculation WEP-109.003.04, "VCC Thermal-Hydraulic Analysis", Revision 1. *(Provides temperature gradient through the VCC wall).*

3.1.2 SNC Calculation WEP-109.003.04, "VCC Thermal-Hydraulic Analysis", Revision 0. *(Provides temperature distribution of the VCC).*

3.1.3 SNC Calculation WEP-109.002.18, "VCC Thermal Stress Analysis", Revision 2. *(Source of ANSYS input and output included in Attachment A).*

3.2 General References

3.2.1 BNFL Drawing VCC-24-002, "Cask Liner and Lid Assembly", Revision 2.

3.2.2 BNFL Drawing VCC-24-006, "VCC Reinforcement", Revision 3.

3.2.3 ACI 349, "Code Requirements for Nuclear Safety Related Concrete Structures", 1985.

3.2.4 1986 ASME Boiler and Pressure Vessel Code, Section III, Division I, Volume II, Appendices.

3.2.5 BNFL Document No. A2VCC-99-001, "Specification for the Construction of a VSC-24 Ventilated Concrete Cask", Revision 1, October, 1999.

3.2.6 Spiegel, Leonard, and George F. Limbrunner, "Reinforced Concrete Design", Prentice-Hall, Inc., 1980.

4. ASSUMPTIONS

4.1 Design Configuration

Table 4-1 summarizes the design parameters used in this thermal analysis.

Table 4-1: Design Parameters

Item	Material	Value	Reference
Concrete		$f_c' = 4{,}000$ psi $w_c' = 144$ lb/ft^3 $\alpha = 5.5 \times 10^{-6}/°F$	3.2.5 (minimum strength and density) 3.2.3
Rebar	A-615 Grade 60	$S_y = 60.0$ ksi	3.2.2
VCC liner	A-36 [Ref. 3.2.1]	$S_y = 32.4$ ksi $t_{liner} = 1.75$ in. $ID_{liner} = 70.5$ in.	3.2.4, Table I-2.1, at 250°F 3.2.1 3.2.1
VCC bottom plate and cover plate	A-36 [Ref. 3.2.1]	$S_y = 32.4$ ksi	3.2.4, Table I-2.1 at 250°F

4.2 Design Criteria

None.

4.3 Calculation Assumptions

4.3.1 The discrepancy between References 3.1.3 and 3.2.1 concerning the inside diameter of the VCC liner (65.75" vs. 70.5") is expected to have a minimal effect on the liner thermal stresses obtained from ANSYS runs. Because the thermal stresses obtained for the liner from Reference 3.1.3 are much less than the allowable (1.8 ksi vs. 32.4 ksi), no safety impact is expected if ANSYS is run with the correct VCC liner inside diameter.

4.3.2 The concrete modulus of elasticity used as input in the ANSYS model (3.28×10^6 psi) differs from the actual value (3.61×10^6 psi – Section 8.5, Reference 3.2.3). This difference will only impact the results by 10%. Because the stresses are small, the effect is not included in this calculation.

4.3.3 The stiffness of the gap elements in the ANSYS model is assumed to be 0.2×10^7 kips/in, approximately twice the maximum stiffness of concrete elements.

5. CALCULATION METHODOLOGY

5.1 Temperature Gradient

ANSYS/PC – LINEAR 4.3A-2 is used to determine the thermal stresses for the VCC components. The maximum temperature gradient through the VCC wall used in the analysis was obtained from Reference 3.1.1. The temperature results from this reference are provided in Table 5-1.

Table 5-1: VCC Temperature Gradients

Case	75°F normal	-40°F	100°F	125°F	75°F ½ inlets	75°F no inlets
Inside Surface	186	45	220	255	194	201
Outside Surface	85	-32	135	187	86	87
ΔT	101	77	85	68	108	114

The maximum gradient through the wall exists in the case of complete inlet blockage. This temperature gradient case should be used for the VCC thermal stress analysis. The ΔT of 114°F, however, is less than the ΔT = 125°F case used in the analysis in Reference 3.1.2. The old temperature distribution (ΔT=125°F) case is therefore conservative and is applied in this thermal analysis.

5.2 Temperature Distribution

The ANSYS thermal stress analysis provided in Attachment A is based on the temperature distribution obtained from Reference 3.1.2. Figure 5-1 presents the temperature distribution used in this analysis.

5.3 Finite Element Model

ANSYS/PC – LINEAR 4.3A-2 was used to determine the thermal stresses for the VCC components. The finite element model is provided in Figure 5-2. Although the cask and its temperature distribution are axisymmetric, an 11.25° slice is used for the finite element model to include cracking of the concrete in the circumferential direction. The model includes 433 elements and 615 nodes. Air inlets and outlets were judged not to have a noticeable effect on the cask behavior and are not modeled in this analysis.

The outside rebars (both vertical and hoops) are #6 @ 6" [Reference 3.2.2]. They are bundled together at node locations and modeled using the equivalent areas: total rebar area within an element was split between two spars running along the element edges. This methodology is illustrated in Figure 5-3. The resulting areas are summarized in Figure 5-3. Each number corresponds to the appropriate real constant in ANSYS input.

Figure 5-1: VCC Temperature Distribution

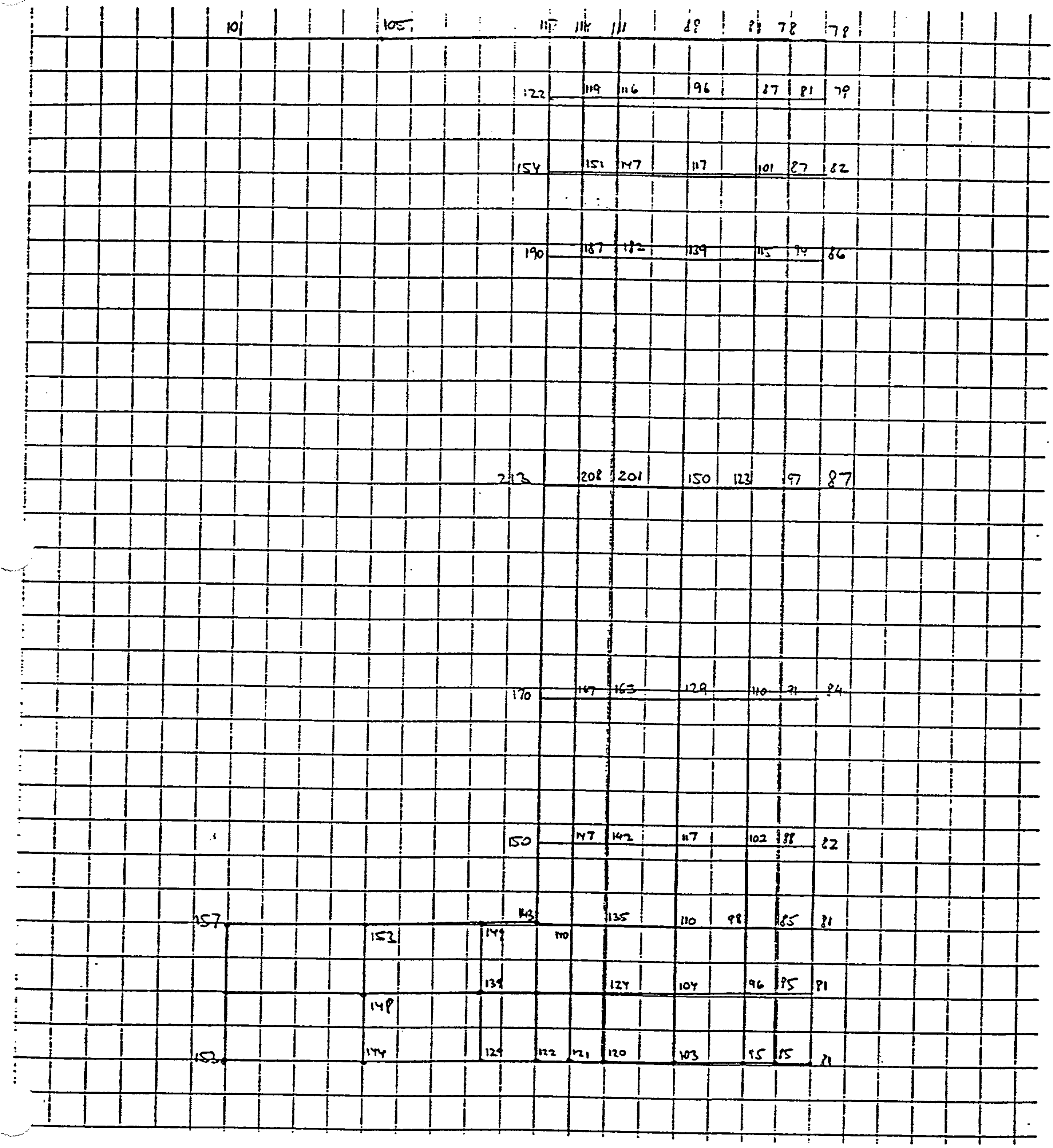


Figure 5-2: Finite Element Model

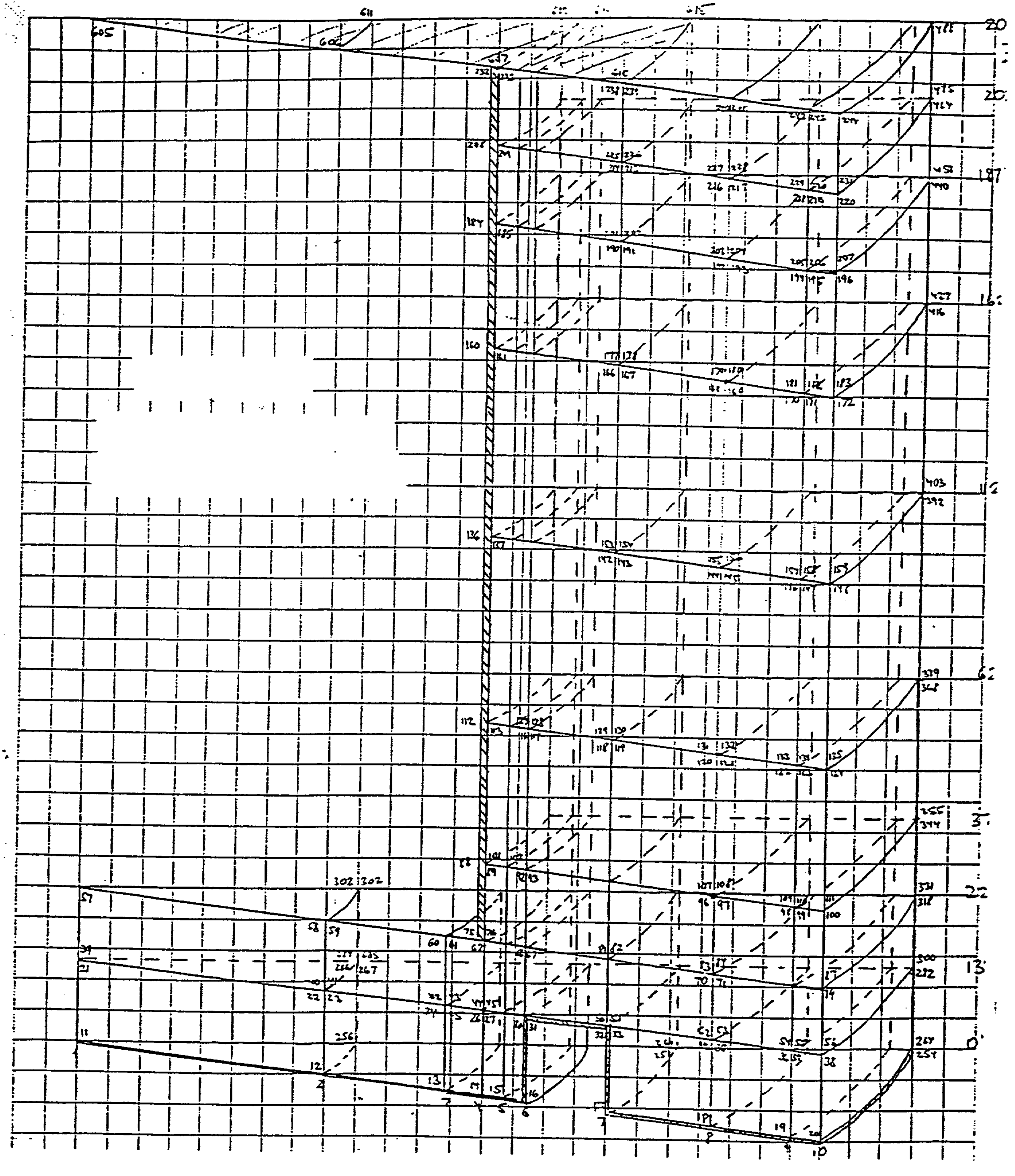
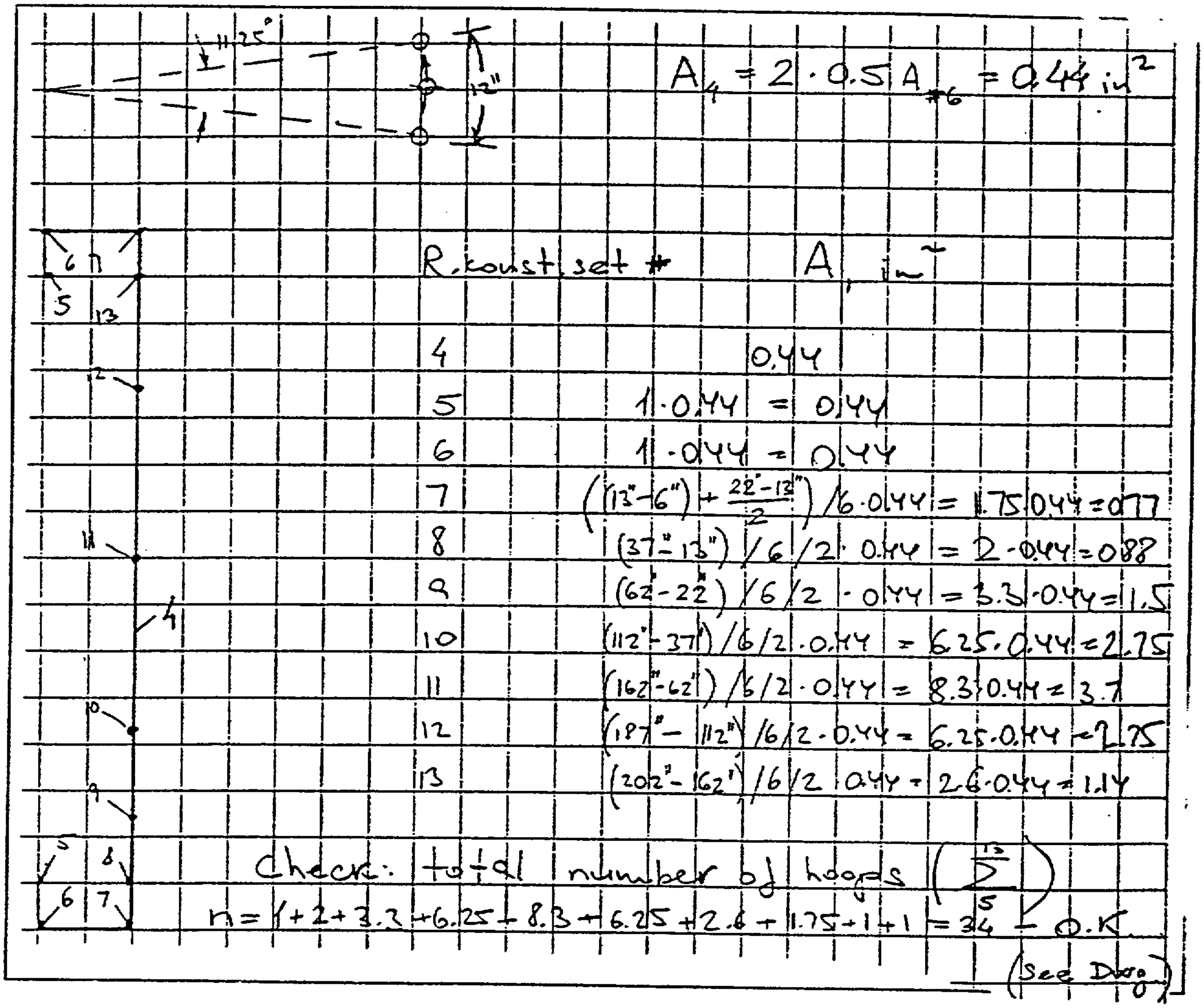


Figure 5-3: Rebar Area



$A_4 = 2 \cdot 0.5 A_{\#6} = 0.44 \text{ in}^2$

R. konst set #	A, in²
4	0.44
5	$1 \cdot 0.44 = 0.44$
6	$1 \cdot 0.44 = 0.44$
7	$\left((13''-6'') + \frac{22''-13''}{2}\right)/6 \cdot 0.44 = 1.75 \cdot 0.44 = 0.77$
8	$(37''-13'')/6/2 \cdot 0.44 = 2 \cdot 0.44 = 0.88$
9	$(62''-22'')/6/2 \cdot 0.44 = 3.3 \cdot 0.44 = 1.5$
10	$(112''-37'')/6/2 \cdot 0.44 = 6.25 \cdot 0.44 = 2.75$
11	$(162''-62'')/6/2 \cdot 0.44 = 8.3 \cdot 0.44 = 3.7$
12	$(187''-112'')/6/2 \cdot 0.44 = 6.25 \cdot 0.44 = 2.75$
13	$(202''-162'')/6/2 \cdot 0.44 = 2.6 \cdot 0.44 = 1.14$

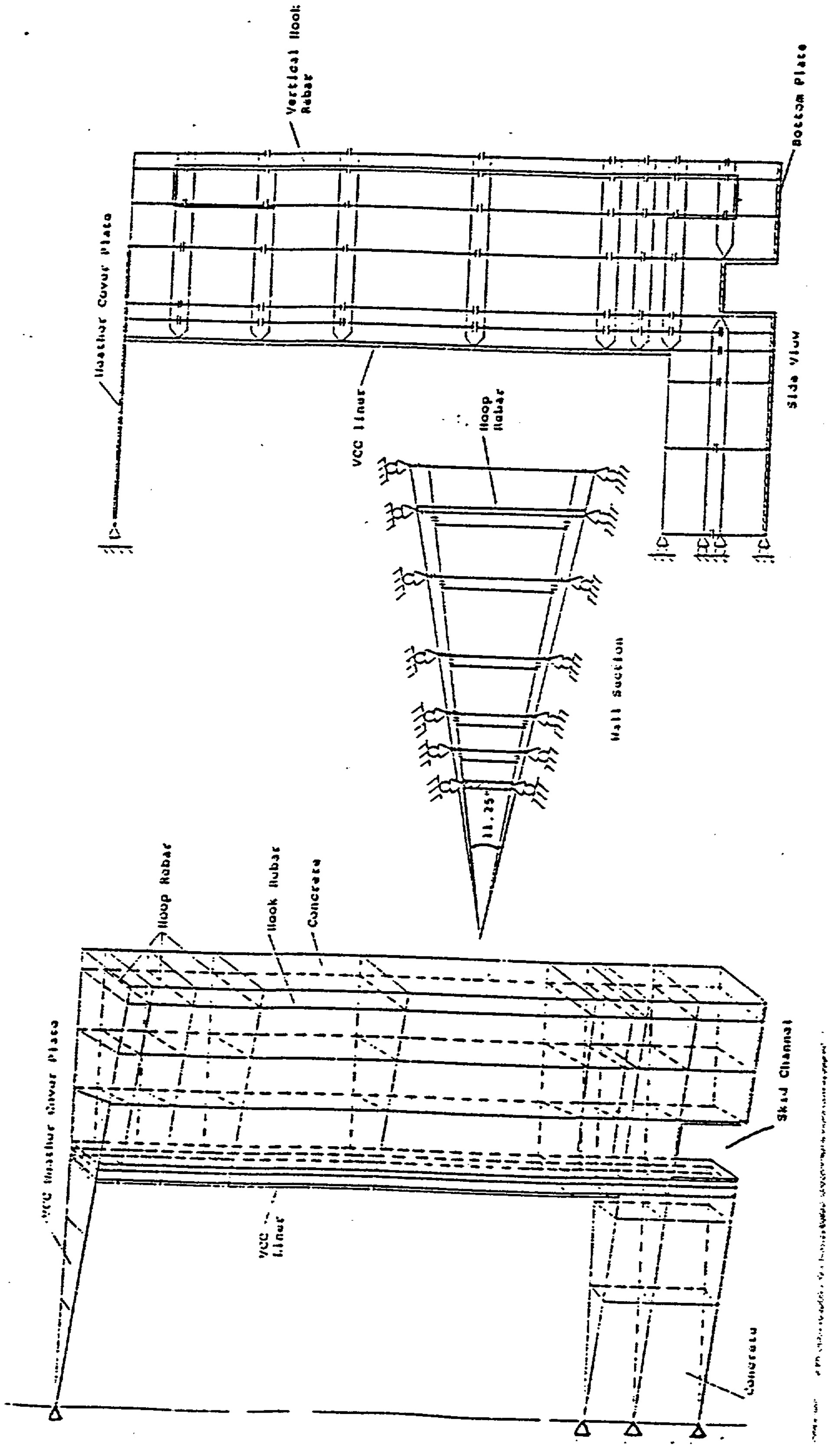
Check: total number of hoops $\left(\sum_{5}^{13}\right)$

$n = 1+2+3.3+6.25+8.3+6.25+2.6+1.75+1+1 = 34 \le$ O.K.

(See Dwg.)

Gap elements are used to model concrete ineffectiveness in tension. The elements are located in the areas where tensile stresses are expected so that cracks transfer all load to the rebars. The gap elements are not shown in Figure 5-2 due to the lack of room, but the idea is presented in Figure 5-4, and all elements are listed in ANSYS output provided in Attachment A. The gap elements' stiffness is assumed to be 0.2 x 10^7 kips/in (approximately twice the maximum stiffness of concrete elements). The element nodes are coupled in the radial direction to account for shear transfer between adjacent concrete elements.

Figure 5-4: Finite Element Model



5.4 VCC Liner Stresses

Stress results from ANSYS runs are provided in Attachment A. These runs were originally made and included in Reference 3.1.3. The thickness of the VCC liner used as an input to this analysis was 2.0". According to Reference 3.2.1, the actual thickness of the VCC liner is 1.75". As a result of the liner thickness discrepancy, thermal stresses in the liner will increase. To account for this increase, the thermal stress in the liner obtained from the ANSYS output in Attachment A is multiplied by the ratio of the old VCC liner thickness and new VCC liner thickness in Section 6.0.

6. CALCULATIONS

6.1 Concrete

The following stresses for the VCC concrete are obtained from the ANSYS output provided in Attachment A:

Maximum compressive stress (allowable from sections 9.3 and 10.2.7 of Ref. 3.2.3):

$$-0.4\ ksi < 0.7\ (0.85 f_c') = 0.7\ (0.85)\ (4\ ksi) = 2.38\ ksi \quad \text{OK}$$

Maximum shear stress (allowable from equation 11-3 and section 9.3 of Ref. 3.2.3):

$$0.08 ksi < 0.85 \cdot (2 \cdot \sqrt{f_c'}) = 0.11 ksi \quad \text{OK}$$

Maximum tensile stress (allowable from section 9.3 of Ref. 3.2.3 and Page 5 of Reference 3.2.7):

$$0.26 ksi < 0.9 \cdot 6.7 \sqrt{f_c'} = 0.38 ksi \quad \text{OK}$$

6.2 Rebar

The following stresses for the rebar are obtained from ANSYS output provided in Attachment A:

Vertical stress:

$$\sigma = 28.8\ ksi < F_y = 60\ ksi \quad \text{OK}$$

Hoop stress:

$$\sigma = 14.6\ ksi < F_y = 60\ ksi \quad \text{OK}$$

6.3 Liner

The following stress intensity for the VCC liner is obtained from the ANSYS output provided in Attachment A:

Maximum Stress Intensity, multiplied by ratio of old and new liner thickness values:

$1.8\ (2.0/1.75)=2.1 ksi < F_y = 32.4\ ksi$ OK

6.4 Bottom Plate

The following stress intensity for the VCC bottom plate is obtained from the ANSYS output provided in Attachment A:

Maximum Stress Intensity:

$6.2\ ksi < F_y = 32.4\ ksi$ OK

6.5 Cover Plate

The following stress intensity for the VCC cover plate is obtained from the ANSYS output provided in Attachment A:

Maximum Stress Intensity:

$5.3\ ksi < F_y = 32.4\ ksi$ OK

7. CONCLUSIONS

The calculation presented in Section 6.0 shows that VCC component thermal stresses are less than allowable values. These stresses will be used as input to the MSB-24 Load Combination Evaluation.

Summary of conservatisms:

- The VCC liner and concrete are linked in the ANSYS model, adding conservatism to the calculated stresses.
- This analysis is performed for the case of a temperature gradient of ΔT = 125°F. This is conservative as compared to the actual temperature gradient of ΔT = 114°F from Reference 3.1.1 (see Table 5-1).

8. ELECTRONIC FILES

8.1 Computer Runs

Copies of computer input and output from ANSYS PC/Linear Version 4.3A-2 for the thermal stress analysis is provided for convenience in Attachment A. This computer input and output is taken from Reference 3.1.3.

8.2 Other Electronic Files

None.

9. ATTACHMENT A – ANSYS INPUT AND OUTPUT FOR THERMAL ANALYSIS

ATTACHMENT

```
LIST ALL SELECTED NODE   DSYS=   0

 NODE        X             Y             Z              THXY     THYZ     THXZ
    1   0.00000E+00  0.00000E+00  0.00000E+00         0.00     0.00     0.00
    2    20.000      0.00000E+00  0.00000E+00         0.00     0.00     0.00
    3    30.000      0.00000E+00  0.00000E+00         0.00     0.00     0.00
    4    34.000      0.00000E+00  0.00000E+00         0.00     0.00     0.00
    5    36.000      0.00000E+00  0.00000E+00         0.00     0.00     0.00
    6    38.000      0.00000E+00  0.00000E+00         0.00     0.00     0.00
    7    48.000      0.00000E+00  0.00000E+00         0.00     0.00     0.00
    8    55.000      0.00000E+00  0.00000E+00         0.00     0.00     0.00
    9    63.000      0.00000E+00  0.00000E+00         0.00     0.00     0.00
   10    66.000      0.00000E+00  0.00000E+00         0.00     0.00     0.00
   11   0.00000E+00  0.00000E+00  0.12500             0.00     0.00     0.00
   12    20.000      0.00000E+00  0.12500             0.00     0.00     0.00
   13    30.000      0.00000E+00  0.12500             0.00     0.00     0.00
   14    34.000      0.00000E+00  0.12500             0.00     0.00     0.00
   15    36.000      0.00000E+00  0.12500             0.00     0.00     0.00
   16    37.875      0.00000E+00  0.12500             0.00     0.00     0.00
   17    48.125      0.00000E+00  0.12500             0.00     0.00     0.00
   18    55.000      0.00000E+00  0.12500             0.00     0.00     0.00
   19    63.000      0.00000E+00  0.12500             0.00     0.00     0.00
   20    66.000      0.00000E+00  0.12500             0.00     0.00     0.00

 NODE        X             Y             Z              THXY     THYZ     THXZ
   21   0.00000E+00  0.00000E+00   13.000             0.00     0.00     0.00
   22    19.875      0.00000E+00   13.000             0.00     0.00     0.00
   23    20.000      0.00000E+00   13.000             0.00     0.00     0.00
   24    29.875      0.00000E+00   13.000             0.00     0.00     0.00
   25    30.000      0.00000E+00   13.000             0.00     0.00     0.00
   26    33.875      0.00000E+00   13.000             0.00     0.00     0.00
   27    34.000      0.00000E+00   13.000             0.00     0.00     0.00
   28    35.875      0.00000E+00   13.000             0.00     0.00     0.00
   29    36.000      0.00000E+00   13.000             0.00     0.00     0.00
   30    37.875      0.00000E+00   13.000             0.00     0.00     0.00
   31    38.000      0.00000E+00   13.000             0.00     0.00     0.00
   32    48.000      0.00000E+00   13.000             0.00     0.00     0.00
   33    48.125      0.00000E+00   13.000             0.00     0.00     0.00
   34    54.875      0.00000E+00   13.000             0.00     0.00     0.00
   35    55.000      0.00000E+00   13.000             0.00     0.00     0.00
   36    62.875      0.00000E+00   13.000             0.00     0.00     0.00
   37    63.000      0.00000E+00   13.000             0.00     0.00     0.00
   38    66.000      0.00000E+00   13.000             0.00     0.00     0.00
   39   0.00000E+00  0.00000E+00   13.125             0.00     0.00     0.00
   40    19.875      0.00000E+00   13.125             0.00     0.00     0.00

 NODE        X             Y             Z              THXY     THYZ     THXZ
   41    20.000      0.00000E+00   13.125             0.00     0.00     0.00
   42    29.875      0.00000E+00   13.125             0.00     0.00     0.00
   43    30.000      0.00000E+00   13.125             0.00     0.00     0.00
   44    33.875      0.00000E+00   13.125             0.00     0.00     0.00
   45    34.000      0.00000E+00   13.125             0.00     0.00     0.00
   46    35.875      0.00000E+00   13.125             0.00     0.00     0.00
   47    36.000      0.00000E+00   13.125             0.00     0.00     0.00
   48    37.875      0.00000E+00   13.125             0.00     0.00     0.00
   49    38.000      0.00000E+00   13.125             0.00     0.00     0.00
   50    48.000      0.00000E+00   13.125             0.00     0.00     0.00
   51    48.125      0.00000E+00   13.125             0.00     0.00     0.00
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   52     54.875      0.00000E+00  13.125        0.00     0.00     0.00
   53     55.000      0.00000E+00  13.125        0.00     0.00     0.00
   54     62.875      0.00000E+00  13.125        0.00     0.00     0.00
   55     63.000      0.00000E+00  13.125        0.00     0.00     0.00
   56     66.000      0.00000E+00  13.125        0.00     0.00     0.00
   57   0.00000E+00   0.00000E+00  22.000        0.00     0.00     0.00
   58     19.875      0.00000E+00  22.000        0.00     0.00     0.00
   59     20.000      0.00000E+00  22.000        0.00     0.00     0.00
   60     29.875      0.00000E+00  22.000        0.00     0.00     0.00

 NODE       X             Y           Z          THXY     THYZ     THXZ
   61     30.000      0.00000E+00  22.000        0.00     0.00     0.00
   62     33.875      0.00000E+00  22.000        0.00     0.00     0.00
   63     34.000      0.00000E+00  22.000        0.00     0.00     0.00
   64     35.875      0.00000E+00  22.000        0.00     0.00     0.00
   65     36.000      0.00000E+00  22.000        0.00     0.00     0.00
   66     37.875      0.00000E+00  22.000        0.00     0.00     0.00
   67     38.000      0.00000E+00  22.000        0.00     0.00     0.00
   68     48.000      0.00000E+00  22.000        0.00     0.00     0.00
   69     48.125      0.00000E+00  22.000        0.00     0.00     0.00
   70     54.875      0.00000E+00  22.000        0.00     0.00     0.00
   71     55.000      0.00000E+00  22.000        0.00     0.00     0.00
   72     62.875      0.00000E+00  22.000        0.00     0.00     0.00
   73     63.000      0.00000E+00  22.000        0.00     0.00     0.00
   74     66.000      0.00000E+00  22.000        0.00     0.00     0.00
   75     33.875      0.00000E+00  22.125        0.00     0.00     0.00
   76     34.000      0.00000E+00  22.125        0.00     0.00     0.00
   77     35.875      0.00000E+00  22.125        0.00     0.00     0.00
   78     36.000      0.00000E+00  22.125        0.00     0.00     0.00
   79     37.875      0.00000E+00  22.125        0.00     0.00     0.00
   80     38.000      0.00000E+00  22.125        0.00     0.00     0.00

 NODE       X             Y           Z          THXY     THYZ     THXZ
   81     48.000      0.00000E+00  22.125        0.00     0.00     0.00
   82     48.125      0.00000E+00  22.125        0.00     0.00     0.00
   83     54.875      0.00000E+00  22.125        0.00     0.00     0.00
   84     55.000      0.00000E+00  22.125        0.00     0.00     0.00
   85     62.875      0.00000E+00  22.125        0.00     0.00     0.00
   86     63.000      0.00000E+00  22.125        0.00     0.00     0.00
   87     66.000      0.00000E+00  22.125        0.00     0.00     0.00
   88     33.875      0.00000E+00  37.125        0.00     0.00     0.00
   89     34.000      0.00000E+00  37.125        0.00     0.00     0.00
   90     35.875      0.00000E+00  37.125        0.00     0.00     0.00
   91     36.000      0.00000E+00  37.125        0.00     0.00     0.00
   92     37.875      0.00000E+00  37.125        0.00     0.00     0.00
   93     38.000      0.00000E+00  37.125        0.00     0.00     0.00
   94     48.000      0.00000E+00  37.125        0.00     0.00     0.00
   95     48.125      0.00000E+00  37.125        0.00     0.00     0.00
   96     54.875      0.00000E+00  37.125        0.00     0.00     0.00
   97     55.000      0.00000E+00  37.125        0.00     0.00     0.00
   98     62.875      0.00000E+00  37.125        0.00     0.00     0.00
   99     63.000      0.00000E+00  37.125        0.00     0.00     0.00
  100     66.000      0.00000E+00  37.125        0.00     0.00     0.00

  ODE       X             Y           Z          THXY     THYZ     THXZ
  101     35.875      0.00000E+00  37.250        0.00     0.00     0.00
  102     36.000      0.00000E+00  37.250        0.00     0.00     0.00
  103     37.875      0.00000E+00  37.250        0.00     0.00     0.00
  104     38.000      0.00000E+00  37.250        0.00     0.00     0.00
  105     48.000      0.00000E+00  37.250        0.00     0.00     0.00
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  106     48.125     0.00000E+00  37.250       0.00     0.00     0.00
  107     54.875     0.00000E+00  37.250       0.00     0.00     0.00
  108     55.000     0.00000E+00  37.250       0.00     0.00     0.00
   09     62.875     0.00000E+00  37.250       0.00     0.00     0.00
  110     63.000     0.00000E+00  37.250       0.00     0.00     0.00
  111     66.000     0.00000E+00  37.250       0.00     0.00     0.00
  112     33.875     0.00000E+00  62.125       0.00     0.00     0.00
  113     34.000     0.00000E+00  62.125       0.00     0.00     0.00
  114     35.875     0.00000E+00  62.125       0.00     0.00     0.00
  115     36.000     0.00000E+00  62.125       0.00     0.00     0.00
  116     37.875     0.00000E+00  62.125       0.00     0.00     0.00
  117     38.000     0.00000E+00  62.125       0.00     0.00     0.00
  118     48.000     0.00000E+00  62.125       0.00     0.00     0.00
  119     48.125     0.00000E+00  62.125       0.00     0.00     0.00
  120     54.875     0.00000E+00  62.125       0.00     0.00     0.00

 NODE        X            Y           Z        THXY     THYZ     THXZ
  121     55.000     0.00000E+00  62.125       0.00     0.00     0.00
  122     62.875     0.00000E+00  62.125       0.00     0.00     0.00
  123     63.000     0.00000E+00  62.125       0.00     0.00     0.00
  124     66.000     0.00000E+00  62.125       0.00     0.00     0.00
  125     35.875     0.00000E+00  62.250       0.00     0.00     0.00
  126     36.000     0.00000E+00  62.250       0.00     0.00     0.00
  127     37.875     0.00000E+00  62.250       0.00     0.00     0.00
  128     38.000     0.00000E+00  62.250       0.00     0.00     0.00
  129     48.000     0.00000E+00  62.250       0.00     0.00     0.00
  130     48.125     0.00000E+00  62.250       0.00     0.00     0.00
  131     54.875     0.00000E+00  62.250       0.00     0.00     0.00
   32     55.000     0.00000E+00  62.250       0.00     0.00     0.00
  133     62.875     0.00000E+00  62.250       0.00     0.00     0.00
  134     63.000     0.00000E+00  62.250       0.00     0.00     0.00
  135     66.000     0.00000E+00  62.250       0.00     0.00     0.00
  136     33.875     0.00000E+00  112.12       0.00     0.00     0.00
  137     34.000     0.00000E+00  112.12       0.00     0.00     0.00
  138     35.875     0.00000E+00  112.12       0.00     0.00     0.00
  139     36.000     0.00000E+00  112.12       0.00     0.00     0.00
  140     37.875     0.00000E+00  112.12       0.00     0.00     0.00

 NODE        X            Y           Z        THXY     THYZ     THXZ
  141     38.000     0.00000E+00  112.12       0.00     0.00     0.00
  142     48.000     0.00000E+00  112.12       0.00     0.00     0.00
  143     48.125     0.00000E+00  112.12       0.00     0.00     0.00
  144     54.875     0.00000E+00  112.12       0.00     0.00     0.00
  145     55.000     0.00000E+00  112.12       0.00     0.00     0.00
  146     62.875     0.00000E+00  112.12       0.00     0.00     0.00
  147     63.000     0.00000E+00  112.12       0.00     0.00     0.00
  148     66.000     0.00000E+00  112.12       0.00     0.00     0.00
  149     35.875     0.00000E+00  112.25       0.00     0.00     0.00
  150     36.000     0.00000E+00  112.25       0.00     0.00     0.00
  151     37.875     0.00000E+00  112.25       0.00     0.00     0.00
  152     38.000     0.00000E+00  112.25       0.00     0.00     0.00
  153     48.000     0.00000E+00  112.25       0.00     0.00     0.00
  154     48.125     0.00000E+00  112.25       0.00     0.00     0.00
  155     54.875     0.00000E+00  112.25       0.00     0.00     0.00
   56     55.000     0.00000E+00  112.25       0.00     0.00     0.00
  157     62.875     0.00000E+00  112.25       0.00     0.00     0.00
  158     63.000     0.00000E+00  112.25       0.00     0.00     0.00
  159     66.000     0.00000E+00  112.25       0.00     0.00     0.00
  160     33.875     0.00000E+00  162.12       0.00     0.00     0.00
```

NODE	X	Y	Z	THXY	THYZ	THXZ
161	34.000	0.00000E+00	162.12	0.00	0.00	0.00
162	35.875	0.00000E+00	162.12	0.00	0.00	0.00
163	36.000	0.00000E+00	162.12	0.00	0.00	0.00
164	37.875	0.00000E+00	162.12	0.00	0.00	0.00
165	38.000	0.00000E+00	162.12	0.00	0.00	0.00
166	48.000	0.00000E+00	162.12	0.00	0.00	0.00
167	48.125	0.00000E+00	162.12	0.00	0.00	0.00
168	54.875	0.00000E+00	162.12	0.00	0.00	0.00
169	55.000	0.00000E+00	162.12	0.00	0.00	0.00
170	62.875	0.00000E+00	162.12	0.00	0.00	0.00
171	63.000	0.00000E+00	162.12	0.00	0.00	0.00
172	66.000	0.00000E+00	162.12	0.00	0.00	0.00
173	35.875	0.00000E+00	162.25	0.00	0.00	0.00
174	36.000	0.00000E+00	162.25	0.00	0.00	0.00
175	37.875	0.00000E+00	162.25	0.00	0.00	0.00
176	38.000	0.00000E+00	162.25	0.00	0.00	0.00
177	48.000	0.00000E+00	162.25	0.00	0.00	0.00
178	48.125	0.00000E+00	162.25	0.00	0.00	0.00
179	54.875	0.00000E+00	162.25	0.00	0.00	0.00
180	55.000	0.00000E+00	162.25	0.00	0.00	0.00
181	62.875	0.00000E+00	162.25	0.00	0.00	0.00
182	63.000	0.00000E+00	162.25	0.00	0.00	0.00
183	66.000	0.00000E+00	162.25	0.00	0.00	0.00
184	33.875	0.00000E+00	187.12	0.00	0.00	0.00
185	34.000	0.00000E+00	187.12	0.00	0.00	0.00
186	35.875	0.00000E+00	187.12	0.00	0.00	0.00
187	36.000	0.00000E+00	187.12	0.00	0.00	0.00
188	37.875	0.00000E+00	187.12	0.00	0.00	0.00
189	38.000	0.00000E+00	187.12	0.00	0.00	0.00
190	48.000	0.00000E+00	187.12	0.00	0.00	0.00
191	48.125	0.00000E+00	187.12	0.00	0.00	0.00
192	54.875	0.00000E+00	187.12	0.00	0.00	0.00
193	55.000	0.00000E+00	187.12	0.00	0.00	0.00
194	62.875	0.00000E+00	187.12	0.00	0.00	0.00
195	63.000	0.00000E+00	187.12	0.00	0.00	0.00
196	66.000	0.00000E+00	187.12	0.00	0.00	0.00
197	35.875	0.00000E+00	187.25	0.00	0.00	0.00
198	36.000	0.00000E+00	187.25	0.00	0.00	0.00
199	37.875	0.00000E+00	187.25	0.00	0.00	0.00
200	38.000	0.00000E+00	187.25	0.00	0.00	0.00
201	48.000	0.00000E+00	187.25	0.00	0.00	0.00
202	48.125	0.00000E+00	187.25	0.00	0.00	0.00
203	54.875	0.00000E+00	187.25	0.00	0.00	0.00
204	55.000	0.00000E+00	187.25	0.00	0.00	0.00
205	62.875	0.00000E+00	187.25	0.00	0.00	0.00
206	63.000	0.00000E+00	187.25	0.00	0.00	0.00
207	66.000	0.00000E+00	187.25	0.00	0.00	0.00
208	33.875	0.00000E+00	202.12	0.00	0.00	0.00
209	34.000	0.00000E+00	202.12	0.00	0.00	0.00
210	35.875	0.00000E+00	202.12	0.00	0.00	0.00
211	36.000	0.00000E+00	202.12	0.00	0.00	0.00
212	37.875	0.00000E+00	202.12	0.00	0.00	0.00
213	38.000	0.00000E+00	202.12	0.00	0.00	0.00
214	48.000	0.00000E+00	202.12	0.00	0.00	0.00
215	48.125	0.00000E+00	202.12	0.00	0.00	0.00

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  216      54.875      0.00000E+00  202.12        0.00      0.00      0.00
  217      55.000      0.00000E+00  202.12        0.00      0.00      0.00
  218      62.875      0.00000E+00  202.12        0.00      0.00      0.00
   19      63.000      0.00000E+00  202.12        0.00      0.00      0.00
  220      66.000      0.00000E+00  202.12        0.00      0.00      0.00

 NODE        X             Y            Z         THXY      THYZ      THXZ
  221      35.875      0.00000E+00  202.25        0.00      0.00      0.00
  222      36.000      0.00000E+00  202.25        0.00      0.00      0.00
  223      37.875      0.00000E+00  202.25        0.00      0.00      0.00
  224      38.000      0.00000E+00  202.25        0.00      0.00      0.00
  225      48.000      0.00000E+00  202.25        0.00      0.00      0.00
  226      48.125      0.00000E+00  202.25        0.00      0.00      0.00
  227      54.875      0.00000E+00  202.25        0.00      0.00      0.00
  228      55.000      0.00000E+00  202.25        0.00      0.00      0.00
  229      62.875      0.00000E+00  202.25        0.00      0.00      0.00
  230      63.000      0.00000E+00  202.25        0.00      0.00      0.00
  231      66.000      0.00000E+00  202.25        0.00      0.00      0.00
  232      33.875      0.00000E+00  208.12        0.00      0.00      0.00
  233      34.000      0.00000E+00  208.12        0.00      0.00      0.00
  234      35.875      0.00000E+00  208.12        0.00      0.00      0.00
  235      36.000      0.00000E+00  208.12        0.00      0.00      0.00
  236      37.875      0.00000E+00  208.12        0.00      0.00      0.00
  237      38.000      0.00000E+00  208.12        0.00      0.00      0.00
  238      48.000      0.00000E+00  208.12        0.00      0.00      0.00
  239      48.125      0.00000E+00  208.12        0.00      0.00      0.00
  240      54.875      0.00000E+00  208.12        0.00      0.00      0.00

   DE        X             Y            Z         THXY      THYZ      THXZ
   41      55.000      0.00000E+00  208.12        0.00      0.00      0.00
  242      62.875      0.00000E+00  208.12        0.00      0.00      0.00
  243      63.000      0.00000E+00  208.12        0.00      0.00      0.00
  244      66.000      0.00000E+00  208.12        0.00      0.00      0.00
  246      19.616        3.9018      0.00000E+00   11.25      0.00      0.00
  247      29.424        5.8527      0.00000E+00   11.25      0.00      0.00
  248      33.347        6.6331      0.00000E+00   11.25      0.00      0.00
  249      35.308        7.0233      0.00000E+00   11.25      0.00      0.00
  250      37.270        7.4134      0.00000E+00   11.25      0.00      0.00
  251      47.078        9.3643      0.00000E+00   11.25      0.00      0.00
  252      53.943        10.730      0.00000E+00   11.25      0.00      0.00
  253      61.789        12.291      0.00000E+00   11.25      0.00      0.00
  254      64.732        12.876      0.00000E+00   11.25      0.00      0.00
  256      19.616        3.9018      0.12500       11.25      0.00      0.00
  257      29.424        5.8527      0.12500       11.25      0.00      0.00
  258      33.347        6.6331      0.12500       11.25      0.00      0.00
  259      35.308        7.0233      0.12500       11.25      0.00      0.00
  260      37.147        7.3890      0.12500       11.25      0.00      0.00
  261      47.200        9.3887      0.12500       11.25      0.00      0.00
  262      53.943        10.730      0.12500       11.25      0.00      0.00

 NODE        X             Y            Z         THXY      THYZ      THXZ
  263      61.789        12.291      0.12500       11.25      0.00      0.00
  264      64.732        12.876      0.12500       11.25      0.00      0.00
   66      19.493        3.8774       13.000       11.25      0.00      0.00
   67      19.616        3.9018       13.000       11.25      0.00      0.00
  268      29.301        5.8283       13.000       11.25      0.00      0.00
  269      29.424        5.8527       13.000       11.25      0.00      0.00
  270      33.224        6.6087       13.000       11.25      0.00      0.00
  271      33.347        6.6331       13.000       11.25      0.00      0.00
  272      35.186        6.9989       13.000       11.25      0.00      0.00
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NODE	X	Y	Z	THXY	THYZ	THXZ
273	35.308	7.0233	13.000	11.25	0.00	0.00
274	37.147	7.3890	13.000	11.25	0.00	0.00
275	37.270	7.4134	13.000	11.25	0.00	0.00
76	47.078	9.3643	13.000	11.25	0.00	0.00
277	47.200	9.3887	13.000	11.25	0.00	0.00
278	53.821	10.706	13.000	11.25	0.00	0.00
279	53.943	10.730	13.000	11.25	0.00	0.00
280	61.667	12.266	13.000	11.25	0.00	0.00
281	61.789	12.291	13.000	11.25	0.00	0.00
282	64.732	12.876	13.000	11.25	0.00	0.00
284	19.493	3.8774	13.125	11.25	0.00	0.00
NODE	X	Y	Z	THXY	THYZ	THXZ
285	19.616	3.9018	13.125	11.25	0.00	0.00
286	29.301	5.8283	13.125	11.25	0.00	0.00
287	29.424	5.8527	13.125	11.25	0.00	0.00
288	33.224	6.6087	13.125	11.25	0.00	0.00
289	33.347	6.6331	13.125	11.25	0.00	0.00
290	35.186	6.9989	13.125	11.25	0.00	0.00
291	35.308	7.0233	13.125	11.25	0.00	0.00
292	37.147	7.3890	13.125	11.25	0.00	0.00
293	37.270	7.4134	13.125	11.25	0.00	0.00
294	47.078	9.3643	13.125	11.25	0.00	0.00
295	47.200	9.3887	13.125	11.25	0.00	0.00
296	53.821	10.706	13.125	11.25	0.00	0.00
297	53.943	10.730	13.125	11.25	0.00	0.00
298	61.667	12.266	13.125	11.25	0.00	0.00
299	61.789	12.291	13.125	11.25	0.00	0.00
300	64.732	12.876	13.125	11.25	0.00	0.00
302	19.493	3.8774	22.000	11.25	0.00	0.00
303	19.616	3.9018	22.000	11.25	0.00	0.00
304	29.301	5.8283	22.000	11.25	0.00	0.00
305	29.424	5.8527	22.000	11.25	0.00	0.00
NODE	X	Y	Z	THXY	THYZ	THXZ
306	33.224	6.6087	22.000	11.25	0.00	0.00
307	33.347	6.6331	22.000	11.25	0.00	0.00
308	35.186	6.9989	22.000	11.25	0.00	0.00
309	35.308	7.0233	22.000	11.25	0.00	0.00
310	37.147	7.3890	22.000	11.25	0.00	0.00
311	37.270	7.4134	22.000	11.25	0.00	0.00
312	47.078	9.3643	22.000	11.25	0.00	0.00
313	47.200	9.3887	22.000	11.25	0.00	0.00
314	53.821	10.706	22.000	11.25	0.00	0.00
315	53.943	10.730	22.000	11.25	0.00	0.00
316	61.667	12.266	22.000	11.25	0.00	0.00
317	61.789	12.291	22.000	11.25	0.00	0.00
318	64.732	12.876	22.000	11.25	0.00	0.00
319	33.224	6.6087	22.125	11.25	0.00	0.00
320	33.347	6.6331	22.125	11.25	0.00	0.00
321	35.186	6.9989	22.125	11.25	0.00	0.00
322	35.308	7.0233	22.125	11.25	0.00	0.00
323	37.147	7.3890	22.125	11.25	0.00	0.00
324	37.270	7.4134	22.125	11.25	0.00	0.00
325	47.078	9.3643	22.125	11.25	0.00	0.00
NODE	X	Y	Z	THXY	THYZ	THXZ
326	47.200	9.3887	22.125	11.25	0.00	0.00
327	53.821	10.706	22.125	11.25	0.00	0.00
328	53.943	10.730	22.125	11.25	0.00	0.00

NODE	X	Y	Z	THXY	THYZ	THXZ
329	61.667	12.266	22.125	11.25	0.00	0.00
330	61.789	12.291	22.125	11.25	0.00	0.00
331	64.732	12.876	22.125	11.25	0.00	0.00
32	33.224	6.6087	37.125	11.25	0.00	0.00
333	33.347	6.6331	37.125	11.25	0.00	0.00
334	35.186	6.9989	37.125	11.25	0.00	0.00
335	35.308	7.0233	37.125	11.25	0.00	0.00
336	37.147	7.3890	37.125	11.25	0.00	0.00
337	37.270	7.4134	37.125	11.25	0.00	0.00
338	47.078	9.3643	37.125	11.25	0.00	0.00
339	47.200	9.3887	37.125	11.25	0.00	0.00
340	53.821	10.706	37.125	11.25	0.00	0.00
341	53.943	10.730	37.125	11.25	0.00	0.00
342	61.667	12.266	37.125	11.25	0.00	0.00
343	61.789	12.291	37.125	11.25	0.00	0.00
344	64.732	12.876	37.125	11.25	0.00	0.00
345	35.186	6.9989	37.250	11.25	0.00	0.00
346	35.308	7.0233	37.250	11.25	0.00	0.00
347	37.147	7.3890	37.250	11.25	0.00	0.00
348	37.270	7.4134	37.250	11.25	0.00	0.00
349	47.078	9.3643	37.250	11.25	0.00	0.00
350	47.200	9.3887	37.250	11.25	0.00	0.00
351	53.821	10.706	37.250	11.25	0.00	0.00
352	53.943	10.730	37.250	11.25	0.00	0.00
353	61.667	12.266	37.250	11.25	0.00	0.00
354	61.789	12.291	37.250	11.25	0.00	0.00
55	64.732	12.876	37.250	11.25	0.00	0.00
356	33.224	6.6087	62.125	11.25	0.00	0.00
357	33.347	6.6331	62.125	11.25	0.00	0.00
358	35.186	6.9989	62.125	11.25	0.00	0.00
359	35.308	7.0233	62.125	11.25	0.00	0.00
360	37.147	7.3890	62.125	11.25	0.00	0.00
361	37.270	7.4134	62.125	11.25	0.00	0.00
362	47.078	9.3643	62.125	11.25	0.00	0.00
363	47.200	9.3887	62.125	11.25	0.00	0.00
364	53.821	10.706	62.125	11.25	0.00	0.00
365	53.943	10.730	62.125	11.25	0.00	0.00
366	61.667	12.266	62.125	11.25	0.00	0.00
367	61.789	12.291	62.125	11.25	0.00	0.00
368	64.732	12.876	62.125	11.25	0.00	0.00
369	35.186	6.9989	62.250	11.25	0.00	0.00
370	35.308	7.0233	62.250	11.25	0.00	0.00
371	37.147	7.3890	62.250	11.25	0.00	0.00
372	37.270	7.4134	62.250	11.25	0.00	0.00
373	47.078	9.3643	62.250	11.25	0.00	0.00
374	47.200	9.3887	62.250	11.25	0.00	0.00
375	53.821	10.706	62.250	11.25	0.00	0.00
376	53.943	10.730	62.250	11.25	0.00	0.00
377	61.667	12.266	62.250	11.25	0.00	0.00
78	61.789	12.291	62.250	11.25	0.00	0.00
79	64.732	12.876	62.250	11.25	0.00	0.00
380	33.224	6.6087	112.12	11.25	0.00	0.00
381	33.347	6.6331	112.12	11.25	0.00	0.00
382	35.186	6.9989	112.12	11.25	0.00	0.00
383	35.308	7.0233	112.12	11.25	0.00	0.00
384	37.147	7.3890	112.12	11.25	0.00	0.00

385	37.270	7.4134	112.12	11.25	0.00	0.00

NODE	X	Y	Z	THXY	THYZ	THXZ
386	47.078	9.3643	112.12	11.25	0.00	0.00
387	47.200	9.3887	112.12	11.25	0.00	0.00
388	53.821	10.706	112.12	11.25	0.00	0.00
389	53.943	10.730	112.12	11.25	0.00	0.00
390	61.667	12.266	112.12	11.25	0.00	0.00
391	61.789	12.291	112.12	11.25	0.00	0.00
392	64.732	12.876	112.12	11.25	0.00	0.00
393	35.186	6.9989	112.25	11.25	0.00	0.00
394	35.308	7.0233	112.25	11.25	0.00	0.00
395	37.147	7.3890	112.25	11.25	0.00	0.00
396	37.270	7.4134	112.25	11.25	0.00	0.00
397	47.078	9.3643	112.25	11.25	0.00	0.00
398	47.200	9.3887	112.25	11.25	0.00	0.00
399	53.821	10.706	112.25	11.25	0.00	0.00
400	53.943	10.730	112.25	11.25	0.00	0.00
401	61.667	12.266	112.25	11.25	0.00	0.00
402	61.789	12.291	112.25	11.25	0.00	0.00
403	64.732	12.876	112.25	11.25	0.00	0.00
404	33.224	6.6087	162.12	11.25	0.00	0.00
405	33.347	6.6331	162.12	11.25	0.00	0.00

NODE	X	Y	Z	THXY	THYZ	THXZ
406	35.186	6.9989	162.12	11.25	0.00	0.00
407	35.308	7.0233	162.12	11.25	0.00	0.00
408	37.147	7.3890	162.12	11.25	0.00	0.00
09	37.270	7.4134	162.12	11.25	0.00	0.00
410	47.078	9.3643	162.12	11.25	0.00	0.00
411	47.200	9.3887	162.12	11.25	0.00	0.00
412	53.821	10.706	162.12	11.25	0.00	0.00
413	53.943	10.730	162.12	11.25	0.00	0.00
414	61.667	12.266	162.12	11.25	0.00	0.00
415	61.789	12.291	162.12	11.25	0.00	0.00
416	64.732	12.876	162.12	11.25	0.00	0.00
417	35.186	6.9989	162.25	11.25	0.00	0.00
418	35.308	7.0233	162.25	11.25	0.00	0.00
419	37.147	7.3890	162.25	11.25	0.00	0.00
420	37.270	7.4134	162.25	11.25	0.00	0.00
421	47.078	9.3643	162.25	11.25	0.00	0.00
422	47.200	9.3887	162.25	11.25	0.00	0.00
423	53.821	10.706	162.25	11.25	0.00	0.00
424	53.943	10.730	162.25	11.25	0.00	0.00
425	61.667	12.266	162.25	11.25	0.00	0.00

NODE	X	Y	Z	THXY	THYZ	THXZ
426	61.789	12.291	162.25	11.25	0.00	0.00
427	64.732	12.876	162.25	11.25	0.00	0.00
428	33.224	6.6087	187.12	11.25	0.00	0.00
429	33.347	6.6331	187.12	11.25	0.00	0.00
430	35.186	6.9989	187.12	11.25	0.00	0.00
431	35.308	7.0233	187.12	11.25	0.00	0.00
32	37.147	7.3890	187.12	11.25	0.00	0.00
433	37.270	7.4134	187.12	11.25	0.00	0.00
434	47.078	9.3643	187.12	11.25	0.00	0.00
435	47.200	9.3887	187.12	11.25	0.00	0.00
436	53.821	10.706	187.12	11.25	0.00	0.00
437	53.943	10.730	187.12	11.25	0.00	0.00
438	61.667	12.266	187.12	11.25	0.00	0.00

439	61.789	12.291	187.12	11.25	0.00	0.00
440	64.732	12.876	187.12	11.25	0.00	0.00
441	35.186	6.9989	187.25	11.25	0.00	0.00
442	35.308	7.0233	187.25	11.25	0.00	0.00
443	37.147	7.3890	187.25	11.25	0.00	0.00
444	37.270	7.4134	187.25	11.25	0.00	0.00
445	47.078	9.3643	187.25	11.25	0.00	0.00
NODE	X	Y	Z	THXY	THYZ	THXZ
446	47.200	9.3887	187.25	11.25	0.00	0.00
447	53.821	10.706	187.25	11.25	0.00	0.00
448	53.943	10.730	187.25	11.25	0.00	0.00
449	61.667	12.266	187.25	11.25	0.00	0.00
450	61.789	12.291	187.25	11.25	0.00	0.00
451	64.732	12.876	187.25	11.25	0.00	0.00
452	33.224	6.6087	202.12	11.25	0.00	0.00
453	33.347	6.6331	202.12	11.25	0.00	0.00
454	35.186	6.9989	202.12	11.25	0.00	0.00
455	35.308	7.0233	202.12	11.25	0.00	0.00
456	37.147	7.3890	202.12	11.25	0.00	0.00
457	37.270	7.4134	202.12	11.25	0.00	0.00
458	47.078	9.3643	202.12	11.25	0.00	0.00
459	47.200	9.3887	202.12	11.25	0.00	0.00
460	53.821	10.706	202.12	11.25	0.00	0.00
461	53.943	10.730	202.12	11.25	0.00	0.00
462	61.667	12.266	202.12	11.25	0.00	0.00
463	61.789	12.291	202.12	11.25	0.00	0.00
464	64.732	12.876	202.12	11.25	0.00	0.00
65	35.186	6.9989	202.25	11.25	0.00	0.00
NODE	X	Y	Z	THXY	THYZ	THXZ
466	35.308	7.0233	202.25	11.25	0.00	0.00
467	37.147	7.3890	202.25	11.25	0.00	0.00
468	37.270	7.4134	202.25	11.25	0.00	0.00
469	47.078	9.3643	202.25	11.25	0.00	0.00
470	47.200	9.3887	202.25	11.25	0.00	0.00
471	53.821	10.706	202.25	11.25	0.00	0.00
472	53.943	10.730	202.25	11.25	0.00	0.00
473	61.667	12.266	202.25	11.25	0.00	0.00
474	61.789	12.291	202.25	11.25	0.00	0.00
475	64.732	12.876	202.25	11.25	0.00	0.00
476	33.224	6.6087	208.12	11.25	0.00	0.00
477	33.347	6.6331	208.12	11.25	0.00	0.00
478	35.186	6.9989	208.12	11.25	0.00	0.00
479	35.308	7.0233	208.12	11.25	0.00	0.00
480	37.147	7.3890	208.12	11.25	0.00	0.00
481	37.270	7.4134	208.12	11.25	0.00	0.00
482	47.078	9.3643	208.12	11.25	0.00	0.00
483	47.200	9.3887	208.12	11.25	0.00	0.00
484	53.821	10.706	208.12	11.25	0.00	0.00
485	53.943	10.730	208.12	11.25	0.00	0.00
NODE	X	Y	Z	THXY	THYZ	THXZ
86	61.667	12.266	208.12	11.25	0.00	0.00
87	61.789	12.291	208.12	11.25	0.00	0.00
488	64.732	12.876	208.12	11.25	0.00	0.00
489	19.999	-0.17453	13.000	-0.50	0.00	0.00
490	29.999	-0.26180	13.000	-0.50	0.00	0.00
491	33.999	-0.29670	13.000	-0.50	0.00	0.00
492	35.999	-0.31416	13.000	-0.50	0.00	0.00

```
  493     54.998    -0.47996      13.000      -0.50    0.00    0.00
  494     62.998    -0.54977      13.000      -0.50    0.00    0.00
  495     65.997    -0.57595      13.000      -0.50    0.00    0.00
  496     19.999    -0.17453      22.000      -0.50    0.00    0.00
  497     29.999    -0.26180      22.000      -0.50    0.00    0.00
  498     33.999    -0.29670      22.000      -0.50    0.00    0.00
  499     35.999    -0.31416      22.000      -0.50    0.00    0.00
  500     37.999    -0.33161      22.000      -0.50    0.00    0.00
  501     47.998    -0.41887      22.000      -0.50    0.00    0.00
  502     54.998    -0.47996      22.000      -0.50    0.00    0.00
  503     62.998    -0.54977      22.000      -0.50    0.00    0.00
  504     65.997    -0.57595      22.000      -0.50    0.00    0.00
  505     35.999    -0.31416      37.125      -0.50    0.00    0.00

 NODE       X           Y            Z         THXY    THYZ    THXZ
  506     37.999    -0.33161      37.125      -0.50    0.00    0.00
  507     47.998    -0.41887      37.125      -0.50    0.00    0.00
  508     54.998    -0.47996      37.125      -0.50    0.00    0.00
  509     62.998    -0.54977      37.125      -0.50    0.00    0.00
  510     65.997    -0.57595      37.125      -0.50    0.00    0.00
  511     35.999    -0.31416      62.125      -0.50    0.00    0.00
  512     37.999    -0.33161      62.125      -0.50    0.00    0.00
  513     47.998    -0.41887      62.125      -0.50    0.00    0.00
  514     54.998    -0.47996      62.125      -0.50    0.00    0.00
  515     62.998    -0.54977      62.125      -0.50    0.00    0.00
  516     65.997    -0.57595      62.125      -0.50    0.00    0.00
  517     35.999    -0.31416      112.12      -0.50    0.00    0.00
  518     37.999    -0.33161      112.12      -0.50    0.00    0.00
  519     47.998    -0.41887      112.12      -0.50    0.00    0.00
  520     54.998    -0.47996      112.12      -0.50    0.00    0.00
  521     62.998    -0.54977      112.12      -0.50    0.00    0.00
  522     65.997    -0.57595      112.12      -0.50    0.00    0.00
  523     35.999    -0.31416      162.12      -0.50    0.00    0.00
  524     37.999    -0.33161      162.12      -0.50    0.00    0.00
  525     47.998    -0.41887      162.12      -0.50    0.00    0.00

 NODE       X           Y            Z         THXY    THYZ    THXZ
  526     54.998    -0.47996      162.12      -0.50    0.00    0.00
  527     62.998    -0.54977      162.12      -0.50    0.00    0.00
  528     65.997    -0.57595      162.12      -0.50    0.00    0.00
  529     35.999    -0.31416      187.12      -0.50    0.00    0.00
  530     37.999    -0.33161      187.12      -0.50    0.00    0.00
  531     47.998    -0.41887      187.12      -0.50    0.00    0.00
  532     54.998    -0.47996      187.12      -0.50    0.00    0.00
  533     62.998    -0.54977      187.12      -0.50    0.00    0.00
  534     65.997    -0.57595      187.12      -0.50    0.00    0.00
  535     35.999    -0.31416      202.12      -0.50    0.00    0.00
  536     37.999    -0.33161      202.12      -0.50    0.00    0.00
  537     47.998    -0.41887      202.12      -0.50    0.00    0.00
  538     54.998    -0.47996      202.12      -0.50    0.00    0.00
  539     62.998    -0.54977      202.12      -0.50    0.00    0.00
  540     65.997    -0.57595      202.12      -0.50    0.00    0.00
  541     35.999    -0.31416      208.12      -0.50    0.00    0.00
  542     37.999    -0.33161      208.12      -0.50    0.00    0.00
   43     47.998    -0.41887      208.12      -0.50    0.00    0.00
  544     54.998    -0.47996      208.12      -0.50    0.00    0.00
  545     62.998    -0.54977      208.12      -0.50    0.00    0.00

 NODE       X           Y            Z         THXY    THYZ    THXZ
  546     65.997    -0.57595      208.12      -0.50    0.00    0.00
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547	19.581	4.0728	13.000	11.75	0.00	0.00
548	29.371	6.1093	13.000	11.75	0.00	0.00
549	33.288	6.9238	13.000	11.75	0.00	0.00
50	35.246	7.3311	13.000	11.75	0.00	0.00
551	53.848	11.200	13.000	11.75	0.00	0.00
552	61.680	12.829	13.000	11.75	0.00	0.00
553	64.617	13.440	13.000	11.75	0.00	0.00
554	19.581	4.0728	22.000	11.75	0.00	0.00
555	29.371	6.1093	22.000	11.75	0.00	0.00
556	33.288	6.9238	22.000	11.75	0.00	0.00
557	35.246	7.3311	22.000	11.75	0.00	0.00
558	37.204	7.7384	22.000	11.75	0.00	0.00
559	46.994	9.7748	22.000	11.75	0.00	0.00
560	53.848	11.200	22.000	11.75	0.00	0.00
561	61.680	12.829	22.000	11.75	0.00	0.00
562	64.617	13.440	22.000	11.75	0.00	0.00
563	35.246	7.3311	37.125	11.75	0.00	0.00
564	37.204	7.7384	37.125	11.75	0.00	0.00
565	46.994	9.7748	37.125	11.75	0.00	0.00

NODE	X	Y	Z	THXY	THYZ	THXZ
566	53.848	11.200	37.125	11.75	0.00	0.00
567	61.680	12.829	37.125	11.75	0.00	0.00
568	64.617	13.440	37.125	11.75	0.00	0.00
569	35.246	7.3311	62.125	11.75	0.00	0.00
570	37.204	7.7384	62.125	11.75	0.00	0.00
571	46.994	9.7748	62.125	11.75	0.00	0.00
572	53.848	11.200	62.125	11.75	0.00	0.00
73	61.680	12.829	62.125	11.75	0.00	0.00
74	64.617	13.440	62.125	11.75	0.00	0.00
575	35.246	7.3311	112.12	11.75	0.00	0.00
576	37.204	7.7384	112.12	11.75	0.00	0.00
577	46.994	9.7748	112.12	11.75	0.00	0.00
578	53.848	11.200	112.12	11.75	0.00	0.00
579	61.680	12.829	112.12	11.75	0.00	0.00
580	64.617	13.440	112.12	11.75	0.00	0.00
581	35.246	7.3311	162.12	11.75	0.00	0.00
582	37.204	7.7384	162.12	11.75	0.00	0.00
583	46.994	9.7748	162.12	11.75	0.00	0.00
584	53.848	11.200	162.12	11.75	0.00	0.00
585	61.680	12.829	162.12	11.75	0.00	0.00

NODE	X	Y	Z	THXY	THYZ	THXZ
586	64.617	13.440	162.12	11.75	0.00	0.00
587	35.246	7.3311	187.12	11.75	0.00	0.00
588	37.204	7.7384	187.12	11.75	0.00	0.00
589	46.994	9.7748	187.12	11.75	0.00	0.00
590	53.848	11.200	187.12	11.75	0.00	0.00
591	61.680	12.829	187.12	11.75	0.00	0.00
592	64.617	13.440	187.12	11.75	0.00	0.00
593	35.246	7.3311	202.12	11.75	0.00	0.00
594	37.204	7.7384	202.12	11.75	0.00	0.00
595	46.994	9.7748	202.12	11.75	0.00	0.00
596	53.848	11.200	202.12	11.75	0.00	0.00
97	61.680	12.829	202.12	11.75	0.00	0.00
598	64.617	13.440	202.12	11.75	0.00	0.00
599	35.246	7.3311	208.12	11.75	0.00	0.00
600	37.204	7.7384	208.12	11.75	0.00	0.00
601	46.994	9.7748	208.12	11.75	0.00	0.00
602	53.848	11.200	208.12	11.75	0.00	0.00

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 603   61.680       12.829       208.12       11.75    0.00    0.00
 604   64.617       13.440       208.12       11.75    0.00    0.00
 605 0.00000E+00  0.00000E+00    208.13        0.00    0.00    0.00

NODE      X             Y           Z          THXY    THYZ    THXZ
 606   6.0000     0.00000E+00    208.13        0.00    0.00    0.00
 607   18.000     0.00000E+00    208.13        0.00    0.00    0.00
 608   36.000     0.00000E+00    208.13        0.00    0.00    0.00
 609   38.000     0.00000E+00    208.13        0.00    0.00    0.00
 610   48.125     0.00000E+00    208.13        0.00    0.00    0.00
 611   5.8847       1.1705       208.13       11.25    0.00    0.00
 612   17.654       3.5116       208.13       11.25    0.00    0.00
 613   35.308       7.0233       208.13       11.25    0.00    0.00
 614   37.270       7.4134       208.13       11.25    0.00    0.00
 615   47.200       9.3887       208.13       11.25    0.00    0.00

LIST ALL ELEMENT TYPES

NO. STIF          KEYOPT VALUES          INOTPR
 1   45    0  0  0   0  0  0   0  0  0     0  ISOPAR. STRESS SOLID, 3-D
 2   63    0  0  0   0  0  0   0  0  0     0  QUAD. FLAT SHELL
 3    8    0  0  0   0  0  0   0  0  0     0  SPAR, 3-D
 4   52    0  0  1   0  0  0   0  0  0     0  INTERFACE ELEM. 3-D

LIST ALL SELECTED ELEMENTS.   (LIST NODES)

  ELEM MAT TYP REL           NODES

     1   2   2   2       2   246     1     1
     2   2   2   2       3   247   246     2
     3   2   2   2       4   248   247     3
     4   2   2   2       5   249   248     4
     5   2   2   2       6   250   249     5
     6   2   2   2      31   275   250     6
     7   2   2   2      32   276   275    31
     8   2   2   2       7   251   276    32
     9   2   2   2       8   252   251     7
    10   2   2   2       9   253   252     8
    11   2   2   2      10   254   253     9
    12   1   1   1      12   256    11    11    22   266    21    21
    13   1   1   1      13   257   256    12    24   268   267    23
    14   1   1   1      14   258   257    13    26   270   269    25
    15   1   1   1      15   259   258    14    28   272   271    27
    16   1   1   1      16   260   259    15    30   274   273    29
    17   1   1   1      18   262   261    17    34   278   277    33
    18   1   1   1      19   263   262    18    36   280   279    35
    19   1   1   1      20   264   263    19    38   282   281    37
    20   1   1   1      40   284    39    39    58   302    57    57

  ELEM MAT TYP REL           NODES

    21   1   1   1      42   286   285    41    60   304   303    59
    22   1   1   1      44   288   287    43    62   306   305    61
    23   1   1   1      46   290   289    45    64   308   307    63
    24   1   1   1      48   292   291    47    66   310   309    65
    25   1   1   1      50   294   293    49    68   312   311    67
    26   1   1   1      52   296   295    51    70   314   313    69
    27   1   1   1      54   298   297    53    72   316   315    71
    28   1   1   1      56   300   299    55    74   318   317    73
    29   2   2   3      38   332   319    75
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   30    2    2    3      112   356   332    88
   31    2    2    3      136   380   356   112
   32    2    2    3      160   404   380   136
   33    2    2    3      184   428   404   160
   34    2    2    3      208   452   428   184
   35    2    2    3      232   476   452   208
   36    1    1    1       77   321   320    76    90   334   333    89
   37    1    1    1       79   323   322    78    92   336   335    91
   38    1    1    1       81   325   324    80    94   338   337    93
   39    1    1    1       83   327   326    82    96   340   339    95
   40    1    1    1       85   329   328    84    98   342   341    97

 ELEM  MAT  TYP  REL            NODES

   41    1    1    1       87   331   330    86   100   344   343    99
   42    1    1    1      101   345   333    89   114   358   357   113
   43    1    1    1      103   347   346   102   116   360   359   115
   44    1    1    1      105   349   348   104   118   362   361   117
   45    1    1    1      107   351   350   106   120   364   363   119
   46    1    1    1      109   353   352   108   122   366   365   121
   47    1    1    1      111   355   354   110   124   368   367   123
   48    1    1    1      125   369   357   113   138   382   381   137
   49    1    1    1      127   371   370   126   140   384   383   139
   50    1    1    1      129   373   372   128   142   386   385   141
   51    1    1    1      131   375   374   130   144   388   387   143
   52    1    1    1      133   377   376   132   146   390   389   145
   53    1    1    1      135   379   378   134   148   392   391   147
   54    1    1    1      149   393   381   137   162   406   405   161
   55    1    1    1      151   395   394   150   164   408   407   163
   56    1    1    1      153   397   396   152   166   410   409   165
   57    1    1    1      155   399   398   154   168   412   411   167
   58    1    1    1      157   401   400   156   170   414   413   169
   59    1    1    1      159   403   402   158   172   416   415   171
   60    1    1    1      173   417   405   161   186   430   429   185

 ELEM  MAT  TYP  REL            NODES

   61    1    1    1      175   419   418   174   188   432   431   187
   62    1    1    1      177   421   420   176   190   434   433   189
   63    1    1    1      179   423   422   178   192   436   435   191
   64    1    1    1      181   425   424   180   194   438   437   193
   65    1    1    1      183   427   426   182   196   440   439   195
   66    1    1    1      197   441   429   185   210   454   453   209
   67    1    1    1      199   443   442   198   212   456   455   211
   68    1    1    1      201   445   444   200   214   458   457   213
   69    1    1    1      203   447   446   202   216   460   459   215
   70    1    1    1      205   449   448   204   218   462   461   217
   71    1    1    1      207   451   450   206   220   464   463   219
   72    1    1    1      221   465   453   209   234   478   477   233
   73    1    1    1      223   467   466   222   236   480   479   235
   74    1    1    1      225   469   468   224   238   482   481   237
   75    1    1    1      227   471   470   226   240   484   483   239
   76    1    1    1      229   473   472   228   242   486   485   241
   77    1    1    1      231   475   474   230   244   488   487   243
   78    2    3    4       34    83
   79    2    3    4      278   327
   80    2    3    4       34    37

 ELEM  MAT  TYP  REL            NODES
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   81    2    3    4       37     73
   82    2    3    4       73     99
   83    2    3    4       99    123
   84    2    3    4      123    147
   85    2    3    4      147    171
   86    2    3    4      171    195
   87    2    3    4      195    230
   88    2    3    4      230    227
   89    2    3    4      227    192
   90    2    3    4      278    281
   91    2    3    4      281    317
   92    2    3    4      317    343
   93    2    3    4      343    367
   94    2    3    4      367    391
   95    2    3    4      391    415
   96    2    3    4      415    439
   97    2    3    4      439    474
   98    2    3    4      474    471
   99    2    3    4      471    436
  100    2    3    5      502    560

 ELEM MAT  TYP  REL            NODES

  101    2    3    5      532    590
  102    2    3    6      493    551
  103    2    3    6      538    596
  104    2    3    7      494    552
  105    2    3    7      539    597
  106    2    3    8      503    561
  107    2    3    9      509    567
  108    2    3   10      515    573
  109    2    3   11      521    579
  110    2    3   12      527    585
  111    2    3   13      533    591
  112    3    4   14       22     23
  113    3    4   14       24     25
  114    3    4   14       26     27
  115    3    4   14       28     29
  116    3    4   14       34     35
  117    3    4   14       36     37
  118    3    4   14       58     59
  119    3    4   14       60     61
  120    3    4   14       62     63

 ELEM MAT  TYP  REL            NODES

  121    3    4   14       64     65
  122    3    4   14       66     67
  123    3    4   14       68     69
  124    3    4   14       70     71
  125    3    4   14       72     73
  126    3    4   14       90     91
  127    3    4   14       92     93
  128    3    4   14       94     95
  129    3    4   14       96     97
  130    3    4   14       98     99
  131    3    4   14      114    115
  132    3    4   14      116    117
  133    3    4   14      118    119
  134    3    4   14      120    121
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  135    3    4   14      122    123
  136    3    4   14      138    139
  137    3    4   14      140    141
  138    3    4   14      142    143
  139    3    4   14      144    145
  140    3    4   14      146    147

 ELEM MAT  TYP  REL            NODES

  141    3    4   14      162    163
  142    3    4   14      164    165
  143    3    4   14      166    167
  144    3    4   14      168    169
  145    3    4   14      170    171
  146    3    4   14      186    187
  147    3    4   14      188    189
  148    3    4   14      190    191
  149    3    4   14      192    193
  150    3    4   14      194    195
  151    3    4   14      210    211
  152    3    4   14      212    213
  153    3    4   14      214    215
  154    3    4   14      216    217
  155    3    4   14      218    219
  156    3    4   14      234    235
  157    3    4   14      236    237
  158    3    4   14      238    239
  159    3    4   14      240    241
  160    3    4   14      242    243

 ELEM MAT  TYP  REL            NODES

  161    3    4   14      266    267
  162    3    4   14      268    269
  163    3    4   14      270    271
  164    3    4   14      272    273
  165    3    4   14      278    279
  166    3    4   14      280    281
  167    3    4   14      302    303
  168    3    4   14      304    305
  169    3    4   14      306    307
  170    3    4   14      308    309
  171    3    4   14      310    311
  172    3    4   14      312    313
  173    3    4   14      314    315
  174    3    4   14      316    317
  175    3    4   14      334    335
  176    3    4   14      336    337
  177    3    4   14      338    339
  178    3    4   14      340    341
  179    3    4   14      342    343
  180    3    4   14      358    359

 ELEM MAT  TYP  REL            NODES

  181    3    4   14      360    361
  182    3    4   14      362    363
  183    3    4   14      364    365
  184    3    4   14      366    367
  135    3    4   14      382    383
```

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  186     3    4   14        384    385
  187     3    4   14        386    387
  188     3    4   14        388    389
  189     3    4   14        390    391
  190     3    4   14        406    407
  191     3    4   14        408    409
  192     3    4   14        410    411
  193     3    4   14        412    413
  194     3    4   14        414    415
  195     3    4   14        430    431
  196     3    4   14        432    433
  197     3    4   14        434    435
  198     3    4   14        436    437
  199     3    4   14        438    439
  200     3    4   14        454    455

 ELEM MAT TYP REL              NODES

  201     3    4   14        456    457
  202     3    4   14        458    459
  203     3    4   14        460    461
  204     3    4   14        462    463
  205     3    4   14        478    479
  206     3    4   14        480    481
  207     3    4   14        482    483
  208     3    4   14        484    485
  209     3    4   14        486    487
  210     3    4   14        489     23
  211     3    4   14        490     25
  212     3    4   14        491     27
  213     3    4   14        492     29
  214     3    4   14        493     35
  215     3    4   14        494     37
  216     3    4   14        495     38
  217     3    4   14        496     59
  218     3    4   14        497     61
  219     3    4   14        498     63
  220     3    4   14        499     65

 ELEM MAT TYP REL              NODES

  221     3    4   14        500     67
  222     3    4   14        501     68
  223     3    4   14        502     71
  224     3    4   14        503     73
  225     3    4   14        504     74
  226     3    4   14        505     91
  227     3    4   14        506     93
  228     3    4   14        507     94
  229     3    4   14        508     97
  230     3    4   14        509     99
  231     3    4   14        510    100
  232     3    4   14        511    115
  233     3    4   14        512    117
  234     3    4   14        513    118
  235     3    4   14        514    121
  236     3    4   14        515    123
  237     3    4   14        516    124
  238     3    4   14        517    139
  239     3    4   14        518    141
```

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  240    3    4   14        519    142

 ELEM  MAT  TYP  REL              NODES

  241    3    4   14        520    145
  242    3    4   14        521    147
  243    3    4   14        522    148
  244    3    4   14        523    163
  245    3    4   14        524    165
  246    3    4   14        525    166
  247    3    4   14        526    169
  248    3    4   14        527    171
  249    3    4   14        528    172
  250    3    4   14        529    187
  251    3    4   14        530    189
  252    3    4   14        531    190
  253    3    4   14        532    193
  254    3    4   14        533    195
  255    3    4   14        534    196
  256    3    4   14        535    211
  257    3    4   14        536    213
  258    3    4   14        537    214
  259    3    4   14        538    217
  260    3    4   14        539    219

 ELEM  MAT  TYP  REL              NODES

  261    3    4   14        540    220
  262    3    4   14        541    235
  263    3    4   14        542    237
  264    3    4   14        543    238
  265    3    4   14        544    241
  266    3    4   14        545    243
  267    3    4   14        546    244
  268    3    4   14        267    547
  269    3    4   14        269    548
  270    3    4   14        271    549
  271    3    4   14        273    550
  272    3    4   14        279    551
  273    3    4   14        281    552
  274    3    4   14        282    553
  275    3    4   14        303    554
  276    3    4   14        305    555
  277    3    4   14        307    556
  278    3    4   14        309    557
  279    3    4   14        311    558
  280    3    4   14        312    559

 ELEM  MAT  TYP  REL              NODES

  281    3    4   14        315    560
  282    3    4   14        317    561
  283    3    4   14        318    562
  284    3    4   14        335    563
  285    3    4   14        337    564
  286    3    4   14        338    565
  287    3    4   14        341    566
  288    3    4   14        343    567
  289    3    4   14        344    568
  290    3    4   14        359    569
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```
  291    3    4   14      361    570
  292    3    4   14      362    571
  293    3    4   14      365    572
  294    3    4   14      367    573
  295    3    4   14      368    574
  296    3    4   14      383    575
  297    3    4   14      385    576
  298    3    4   14      386    577
  299    3    4   14      389    578
  300    3    4   14      391    579

 ELEM MAT TYP REL             NODES

  301    3    4   14      392    580
  302    3    4   14      407    581
  303    3    4   14      409    582
  304    3    4   14      410    583
  305    3    4   14      413    584
  306    3    4   14      415    585
  307    3    4   14      416    586
  308    3    4   14      431    587
  309    3    4   14      433    588
  310    3    4   14      434    589
  311    3    4   14      437    590
  312    3    4   14      439    591
  313    3    4   14      440    592
  314    3    4   14      455    593
  315    3    4   14      457    594
  316    3    4   14      458    595
  317    3    4   14      461    596
  318    3    4   14      463    597
  319    3    4   14      464    598
  320    3    4   14      479    599

 ELEM MAT TYP REL             NODES

  321    3    4   14      481    600
  322    3    4   14      482    601
  323    3    4   14      485    602
  324    3    4   14      487    603
  325    3    4   14      488    604
  326    3    4   14       21     39
  327    3    4   14       23     41
  328    3    4   14       25     43
  329    3    4   14       27     45
  330    3    4   14       29     47
  331    3    4   14       35     53
  332    3    4   14       37     55
  333    3    4   14       38     56
  334    3    4   14       63     76
  335    3    4   14       65     78
  336    3    4   14       67     80
  337    3    4   14       69     82
  338    3    4   14       71     84
  339    3    4   14       73     86
  340    3    4   14       74     87

 ELEM MAT TYP REL             NODES

  341    3    4   14       91    102
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```
  342    3    4   14       93    104
  343    3    4   14       95    106
  344    3    4   14       97    108
  345    3    4   14       99    110
  346    3    4   14      100    111
  347    3    4   14      115    126
  348    3    4   14      117    128
  349    3    4   14      119    130
  350    3    4   14      121    132
  351    3    4   14      123    134
  352    3    4   14      124    135
  353    3    4   14      139    150
  354    3    4   14      141    152
  355    3    4   14      143    154
  356    3    4   14      145    156
  357    3    4   14      147    158
  358    3    4   14      148    159
  359    3    4   14      163    174
  360    3    4   14      165    176

 ELEM MAT TYP REL           NODES

  361    3    4   14      167    178
  362    3    4   14      169    180
  363    3    4   14      171    182
  364    3    4   14      172    183
  365    3    4   14      187    198
  366    3    4   14      189    200
  367    3    4   14      191    202
  368    3    4   14      193    204
  369    3    4   14      195    206
  370    3    4   14      196    207
  371    3    4   14      211    222
  372    3    4   14      213    224
  373    3    4   14      215    226
  374    3    4   14      217    228
  375    3    4   14      219    230
  376    3    4   14      220    231
  378    3    4   14      267    285
  379    3    4   14      269    287
  380    3    4   14      271    289
  381    3    4   14      273    291

 ELEM MAT TYP REL           NODES

  382    3    4   14      279    297
  383    3    4   14      281    299
  384    3    4   14      282    300
  385    3    4   14      307    320
  386    3    4   14      309    322
  387    3    4   14      311    324
  388    3    4   14      313    326
  389    3    4   14      315    328
  390    3    4   14      317    330
  391    3    4   14      318    331
  392    3    4   14      335    346
  393    3    4   14      337    348
  394    3    4   14      339    350
  395    3    4   14      341    352
  396    3    4   14      343    354
```

```
    397    3    4   14      344    355
    398    3    4   14      359    370
    399    3    4   14      361    372
    400    3    4   14      363    374
    401    3    4   14      365    376

  ELEM MAT  TYP  REL            NODES

    402    3    4   14      367    378
    403    3    4   14      368    379
    404    3    4   14      383    394
    405    3    4   14      385    396
    406    3    4   14      387    398
    407    3    4   14      389    400
    408    3    4   14      391    402
    409    3    4   14      392    403
    410    3    4   14      407    418
    411    3    4   14      409    420
    412    3    4   14      411    422
    413    3    4   14      413    424
    414    3    4   14      415    426
    415    3    4   14      416    427
    416    3    4   14      431    442
    417    3    4   14      433    444
    418    3    4   14      435    446
    419    3    4   14      437    448
    420    3    4   14      439    450
    421    3    4   14      440    451

  ELEM MAT  TYP  REL            NODES

    422    3    4   14      455    466
    423    3    4   14      457    468
    424    3    4   14      459    470
    425    3    4   14      461    472
    426    3    4   14      463    474
    427    3    4   14      464    475
    428    2    2   15      606    611    605    605
    429    2    2   15      607    612    611    606
    430    2    2   15      232    476    612    607
    431    2    2   15      608    613    476    232
    432    2    2   15      609    614    613    608
    433    2    2   15      610    615    614    609

 LIST ALL REAL SETS

  REAL CONSTANT  SET    2   ITEMS    1 TO    6
   0.25000       0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

  REAL CONSTANT  SET    3   ITEMS    1 TO    6
    2.0000       0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

  REAL CONSTANT  SET    4   ITEMS    1 TO    6
    .44000       0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

  REAL CONSTANT  SET    5   ITEMS    1 TO    6
   0.44000       0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

  REAL CONSTANT  SET    6   ITEMS    1 TO    6
   0.44000       0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
```

```
 REAL CONSTANT SET    7  ITEMS    1 TO    6
  0.77000      0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00

 REAL CONSTANT SET    8  ITEMS    1 TO    6
  0.88000      0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00

 REAL CONSTANT SET    9  ITEMS    1 TO    6
   1.5000      0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00

 REAL CONSTANT SET   10  ITEMS    1 TO    6
   2.7500      0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00

 REAL CONSTANT SET   11  ITEMS    1 TO    6
   3.7000      0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00

 REAL CONSTANT SET   12  ITEMS    1 TO    6
   2.7500      0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00

 REAL CONSTANT SET   13  ITEMS    1 TO    6
   1.1400      0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00

 REAL CONSTANT SET   14  ITEMS    1 TO    6
  0.20000E+07  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00

 REAL CONSTANT SET   15  ITEMS    1 TO    6
  0.75000      0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00

   T ALL MATERIALS  PROPERTY= ALL

PROPERTY TABLE EX     MAT=    1  NUM. POINTS=  3
       TEMPERATURE      DATA          TEMPERATURE      DATA
      70.000        3640.0       100.00        3640.0
      200.00        3280.0

PROPERTY TABLE ALPX  MAT=    1  NUM. POINTS=  3
       TEMPERATURE      DATA          TEMPERATURE      DATA
      70.000       0.55000E-05  100.00       0.55000E-05
      200.00       0.55000E-05

PROPERTY TABLE EX     MAT=    2  NUM. POINTS=  3
       TEMPERATURE      DATA          TEMPERATURE      DATA
      70.000        29500.       100.00        29500.
      200.00        28800.

PROPERTY TABLE ALPX  MAT=    2  NUM. POINTS=  3
       TEMPERATURE      DATA          TEMPERATURE      DATA
      70.000       0.55300E-05  100.00       0.55300E-05
      200.00       0.58900E-05

LIST DISPLACEMENTS FOR ALL SELECTED NODES

 NODE  LABEL     DISP            CDISP
    1 UZ     0.000000000E+00 0.000000000E+00
    2 UZ     0.000000000E+00 0.000000000E+00
    3 UZ     0.000000000E+00 0.000000000E+00
    4 UZ     0.000000000E+00 0.000000000E+00
    5 UZ     0.000000000E+00 0.000000000E+00
    6 UZ     0.000000000E+00 0.000000000E+00
    7 UZ     0.000000000E+00 0.000000000E+00
```

```
    8 UZ     0.000000000E+00 0.000000000E+00
    9 UZ     0.000000000E+00 0.000000000E+00
   10 UZ     0.000000000E+00 0.000000000E+00
  246 UZ     0.000000000E+00 0.000000000E+00
  247 UZ     0.000000000E+00 0.000000000E+00
  248 UZ     0.000000000E+00 0.000000000E+00
  249 UZ     0.000000000E+00 0.000000000E+00
  250 UZ     0.000000000E+00 0.000000000E+00
  251 UZ     0.000000000E+00 0.000000000E+00
  252 UZ     0.000000000E+00 0.000000000E+00
  253 UZ     0.000000000E+00 0.000000000E+00
  254 UZ     0.000000000E+00 0.000000000E+00
  489 UY     0.000000000E+00 0.000000000E+00

 NODE  LABEL      DISP          CDISP
  490 UY     0.000000000E+00 0.000000000E+00
  491 UY     0.000000000E+00 0.000000000E+00
  492 UY     0.000000000E+00 0.000000000E+00
  493 UY     0.000000000E+00 0.000000000E+00
  494 UY     0.000000000E+00 0.000000000E+00
  495 UY     0.000000000E+00 0.000000000E+00
  496 UY     0.000000000E+00 0.000000000E+00
  497 UY     0.000000000E+00 0.000000000E+00
  498 UY     0.000000000E+00 0.000000000E+00
  499 UY     0.000000000E+00 0.000000000E+00
  500 UY     0.000000000E+00 0.000000000E+00
  501 UY     0.000000000E+00 0.000000000E+00
  502 UY     0.000000000E+00 0.000000000E+00
  503 UY     0.000000000E+00 0.000000000E+00
  504 UY     0.000000000E+00 0.000000000E+00
  505 UY     0.000000000E+00 0.000000000E+00
  506 UY     0.000000000E+00 0.000000000E+00
  507 UY     0.000000000E+00 0.000000000E+00
  508 UY     0.000000000E+00 0.000000000E+00
  509 UY     0.000000000E+00 0.000000000E+00

 NODE  LABEL      DISP          CDISP
  510 UY     0.000000000E+00 0.000000000E+00
  511 UY     0.000000000E+00 0.000000000E+00
  512 UY     0.000000000E+00 0.000000000E+00
  513 UY     0.000000000E+00 0.000000000E+00
  514 UY     0.000000000E+00 0.000000000E+00
  515 UY     0.000000000E+00 0.000000000E+00
  516 UY     0.000000000E+00 0.000000000E+00
  517 UY     0.000000000E+00 0.000000000E+00
  518 UY     0.000000000E+00 0.000000000E+00
  519 UY     0.000000000E+00 0.000000000E+00
  520 UY     0.000000000E+00 0.000000000E+00
  521 UY     0.000000000E+00 0.000000000E+00
  522 UY     0.000000000E+00 0.000000000E+00
  523 UY     0.000000000E+00 0.000000000E+00
  524 UY     0.000000000E+00 0.000000000E+00
  525 UY     0.000000000E+00 0.000000000E+00
  526 UY     0.000000000E+00 0.000000000E+00
  527 UY     0.000000000E+00 0.000000000E+00
  528 UY     0.000000000E+00 0.000000000E+00
  529 UY     0.000000000E+00 0.000000000E+00

 NODE  LABEL      DISP          CDISP
  530 UY     0.000000000E+00 0.000000000E+00
```

```
  531 UY     0.000000000E+00 0.000000000E+00
  532 UY     0.000000000E+00 0.000000000E+00
  533 UY     0.000000000E+00 0.000000000E+00
  534 UY     0.000000000E+00 0.000000000E+00
  535 UY     0.000000000E+00 0.000000000E+00
  536 UY     0.000000000E+00 0.000000000E+00
  537 UY     0.000000000E+00 0.000000000E+00
  538 UY     0.000000000E+00 0.000000000E+00
  539 UY     0.000000000E+00 0.000000000E+00
  540 UY     0.000000000E+00 0.000000000E+00
  541 UY     0.000000000E+00 0.000000000E+00
  542 UY     0.000000000E+00 0.000000000E+00
  543 UY     0.000000000E+00 0.000000000E+00
  544 UY     0.000000000E+00 0.000000000E+00
  545 UY     0.000000000E+00 0.000000000E+00
  546 UY     0.000000000E+00 0.000000000E+00
  547 UY     0.000000000E+00 0.000000000E+00
  548 UY     0.000000000E+00 0.000000000E+00
  549 UY     0.000000000E+00 0.000000000E+00

 NODE  LABEL      DISP           CDISP
  550 UY     0.000000000E+00 0.000000000E+00
  551 UY     0.000000000E+00 0.000000000E+00
  552 UY     0.000000000E+00 0.000000000E+00
  553 UY     0.000000000E+00 0.000000000E+00
  554 UY     0.000000000E+00 0.000000000E+00
  555 UY     0.000000000E+00 0.000000000E+00
  556 UY     0.000000000E+00 0.000000000E+00
  557 UY     0.000000000E+00 0.000000000E+00
  558 UY     0.000000000E+00 0.000000000E+00
  559 UY     0.000000000E+00 0.000000000E+00
  560 UY     0.000000000E+00 0.000000000E+00
  561 UY     0.000000000E+00 0.000000000E+00
  562 UY     0.000000000E+00 0.000000000E+00
  563 UY     0.000000000E+00 0.000000000E+00
  564 UY     0.000000000E+00 0.000000000E+00
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  566 UY     0.000000000E+00 0.000000000E+00
  567 UY     0.000000000E+00 0.000000000E+00
  568 UY     0.000000000E+00 0.000000000E+00
  569 UY     0.000000000E+00 0.000000000E+00

 NODE  LABEL      DISP           CDISP
  570 UY     0.000000000E+00 0.000000000E+00
  571 UY     0.000000000E+00 0.000000000E+00
  572 UY     0.000000000E+00 0.000000000E+00
  573 UY     0.000000000E+00 0.000000000E+00
  574 UY     0.000000000E+00 0.000000000E+00
  575 UY     0.000000000E+00 0.000000000E+00
  576 UY     0.000000000E+00 0.000000000E+00
  577 UY     0.000000000E+00 0.000000000E+00
  578 UY     0.000000000E+00 0.000000000E+00
  579 UY     0.000000000E+00 0.000000000E+00
  580 UY     0.000000000E+00 0.000000000E+00
  581 UY     0.000000000E+00 0.000000000E+00
  582 UY     0.000000000E+00 0.000000000E+00
  583 UY     0.000000000E+00 0.000000000E+00
  584 UY     0.000000000E+00 0.000000000E+00
  585 UY     0.000000000E+00 0.000000000E+00
  586 UY     0.000000000E+00 0.000000000E÷00
```

```
  587 UY     0.000000000E+00 0.000000000E+00
  588 UY     0.000000000E+00 0.000000000E+00
  589 UY     0.000000000E+00 0.000000000E+00

 NODE  LABEL      DISP             CDISP
  590 UY     0.000000000E+00 0.000000000E+00
  591 UY     0.000000000E+00 0.000000000E+00
  592 UY     0.000000000E+00 0.000000000E+00
  593 UY     0.000000000E+00 0.000000000E+00
  594 UY     0.000000000E+00 0.000000000E+00
  595 UY     0.000000000E+00 0.000000000E+00
  596 UY     0.000000000E+00 0.000000000E+00
  597 UY     0.000000000E+00 0.000000000E+00
  598 UY     0.000000000E+00 0.000000000E+00
  599 UY     0.000000000E+00 0.000000000E+00
  600 UY     0.000000000E+00 0.000000000E+00
  601 UY     0.000000000E+00 0.000000000E+00
  602 UY     0.000000000E+00 0.000000000E+00
  603 UY     0.000000000E+00 0.000000000E+00
  604 UY     0.000000000E+00 0.000000000E+00
   75 UY     0.000000000E+00 0.000000000E+00
   76 UY     0.000000000E+00 0.000000000E+00
   88 UY     0.000000000E+00 0.000000000E+00
   89 UY     0.000000000E+00 0.000000000E+00
  112 UY     0.000000000E+00 0.000000000E+00

 NODE  LABEL      DISP             CDISP
  113 UY     0.000000000E+00 0.000000000E+00
  .36 UY     0.000000000E+00 0.000000000E+00
  137 UY     0.000000000E+00 0.000000000E+00
  160 UY     0.000000000E+00 0.000000000E+00
  161 UY     0.000000000E+00 0.000000000E+00
  184 UY     0.000000000E+00 0.000000000E+00
  185 UY     0.000000000E+00 0.000000000E+00
  208 UY     0.000000000E+00 0.000000000E+00
  209 UY     0.000000000E+00 0.000000000E+00
  232 UY     0.000000000E+00 0.000000000E+00
  233 UY     0.000000000E+00 0.000000000E+00
  319 UY     0.000000000E+00 0.000000000E+00
  320 UY     0.000000000E+00 0.000000000E+00
  332 UY     0.000000000E+00 0.000000000E+00
  333 UY     0.000000000E+00 0.000000000E+00
  356 UY     0.000000000E+00 0.000000000E+00
  357 UY     0.000000000E+00 0.000000000E+00
  380 UY     0.000000000E+00 0.000000000E+00
  381 UY     0.000000000E+00 0.000000000E+00
  404 UY     0.000000000E+00 0.000000000E+00

 NODE  LABEL      DISP             CDISP
  405 UY     0.000000000E+00 0.000000000E+00
  428 UY     0.000000000E+00 0.000000000E+00
  429 UY     0.000000000E+00 0.000000000E+00
  452 UY     0.000000000E+00 0.000000000E+00
   53 UY     0.000000000E+00 0.000000000E+00
  .76 UY     0.000000000E+00 0.000000000E+00
  477 UY     0.000000000E+00 0.000000000E+00
    1 UX     0.000000000E+00 0.000000000E+00
   11 UX     0.000000000E+00 0.000000000E+00
   21 UX     0.000000000E+00 0.000000000E+00
   39 UX     0.000000000E+00 0.000000000E+00
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   57 UX     0.000000000E+00 0.000000000E+00
   57 UY     0.000000000E+00 0.000000000E+00
   39 UY     0.000000000E+00 0.000000000E+00
   21 UY     0.000000000E+00 0.000000000E+00
    1 UY     0.000000000E+00 0.000000000E+00
    2 UY     0.000000000E+00 0.000000000E+00
    3 UY     0.000000000E+00 0.000000000E+00
    4 UY     0.000000000E+00 0.000000000E+00
    5 UY     0.000000000E+00 0.000000000E+00

 NODE  LABEL      DISP            CDISP
    6 UY     0.000000000E+00 0.000000000E+00
    7 UY     0.000000000E+00 0.000000000E+00
    8 UY     0.000000000E+00 0.000000000E+00
    9 UY     0.000000000E+00 0.000000000E+00
   10 UY     0.000000000E+00 0.000000000E+00
   11 UY     0.000000000E+00 0.000000000E+00
  605 UX     0.000000000E+00 0.000000000E+00
  615 UY     0.000000000E+00 0.000000000E+00
  614 UY     0.000000000E+00 0.000000000E+00
  613 UY     0.000000000E+00 0.000000000E+00
  612 UY     0.000000000E+00 0.000000000E+00
  611 UY     0.000000000E+00 0.000000000E+00
  610 UY     0.000000000E+00 0.000000000E+00
  609 UY     0.000000000E+00 0.000000000E+00
  608 UY     0.000000000E+00 0.000000000E+00
  246 UY     0.000000000E+00 0.000000000E+00
  247 UY     0.000000000E+00 0.000000000E+00
   48 UY     0.000000000E+00 0.000000000E+00
  249 UY     0.000000000E+00 0.000000000E+00
  250 UY     0.000000000E+00 0.000000000E+00

 NODE  LABEL      DISP            CDISP
  251 UY     0.000000000E+00 0.000000000E+00
  252 UY     0.000000000E+00 0.000000000E+00
  253 UY     0.000000000E+00 0.000000000E+00
  254 UY     0.000000000E+00 0.000000000E+00
  607 UY     0.000000000E+00 0.000000000E+00
  606 UY     0.000000000E+00 0.000000000E+00
  605 UY     0.000000000E+00 0.000000000E+00
  264 UZ     0.000000000E+00 0.000000000E+00
  263 UZ     0.000000000E+00 0.000000000E+00
  262 UZ     0.000000000E+00 0.000000000E+00
  261 UZ     0.000000000E+00 0.000000000E+00
  260 UZ     0.000000000E+00 0.000000000E+00
  259 UZ     0.000000000E+00 0.000000000E+00
   31 UY     0.000000000E+00 0.000000000E+00
   32 UY     0.000000000E+00 0.000000000E+00
  276 UY     0.000000000E+00 0.000000000E+00
  275 UY     0.000000000E+00 0.000000000E+00
   11 UZ     0.000000000E+00 0.000000000E+00
   12 UZ     0.000000000E+00 0.000000000E+00
   13 UZ     0.000000000E+00 0.000000000E+00

   DE  LABEL      DISP            CDISP
   14 UZ     0.000000000E+00 0.000000000E+00
   15 UZ     0.000000000E+00 0.000000000E+00
   16 UZ     0.000000000E+00 0.000000000E+00
   17 UZ     0.000000000E+00 0.000000000E+00
   18 UZ     0.000000000E+00 0.000000000E+00
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    19 UZ     0.000000000E+00 0.000000000E+00
    20 UZ     0.000000000E+00 0.000000000E+00
   256 UZ     0.000000000E+00 0.000000000E+00
   257 UZ     0.000000000E+00 0.000000000E+00
   258 UZ     0.000000000E+00 0.000000000E+00

 LIST ALL COUPLED SETS

 COUPLED SET=       1  DIRECTION= UX     TOTAL NODES=       2
 NODES=      22      40

 COUPLED SET=       2  DIRECTION= UX     TOTAL NODES=       2
 NODES=      24      42

 COUPLED SET=       3  DIRECTION= UX     TOTAL NODES=       2
 NODES=      26      44

 COUPLED SET=       4  DIRECTION= UX     TOTAL NODES=       2
 NODES=      28      46

 COUPLED SET=       5  DIRECTION= UX     TOTAL NODES=       4
 NODES=      30      31      48      49

 COUPLED SET=       6  DIRECTION= UX     TOTAL NODES=       4
 NODES=      32      33      50      51

 COUPLED SET=       7  DIRECTION= UX     TOTAL NODES=       2
 NODES=      34      52

    JPLED SET=       8  DIRECTION= UX     TOTAL NODES=       2
 NODES=      36      54

 COUPLED SET=       9  DIRECTION= UX     TOTAL NODES=       3
 NODES=      38      56     495

 COUPLED SET=      10  DIRECTION= UX     TOTAL NODES=       2
 NODES=      23      41

 COUPLED SET=      11  DIRECTION= UX     TOTAL NODES=       2
 NODES=      25      43

 COUPLED SET=      12  DIRECTION= UX     TOTAL NODES=       2
 NODES=      27      45

 COUPLED SET=      13  DIRECTION= UX     TOTAL NODES=       2
 NODES=      29      47

 COUPLED SET=      14  DIRECTION= UX     TOTAL NODES=       3
 NODES=      35      53     493

 COUPLED SET=      15  DIRECTION= UX     TOTAL NODES=       3
 NODES=      37      55     494

 COUPLED SET=      16  DIRECTION= UX     TOTAL NODES=       3
    ES=      63      75      76

 COUPLED SET=      17  DIRECTION= UX     TOTAL NODES=       2
 NODES=      64      77

 COUPLED SET=      18  DIRECTION= UX     TOTAL NODES=       2
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 NODES=      66      79

 COUPLED  SET=       19   DIRECTION= UX      TOTAL NODES=        2
   DES=      68      81

 COUPLED  SET=       20   DIRECTION= UX      TOTAL NODES=        2
 NODES=      70      83

 COUPLED  SET=       21   DIRECTION= UX      TOTAL NODES=        2
 NODES=      72      85

 COUPLED  SET=       22   DIRECTION= UX      TOTAL NODES=        3
 NODES=      74      87     504

 COUPLED  SET=       23   DIRECTION= UX      TOTAL NODES=        2
 NODES=      65      78

 COUPLED  SET=       24   DIRECTION= UX      TOTAL NODES=        2
 NODES=      67      80

 COUPLED  SET=       25   DIRECTION= UX      TOTAL NODES=        2
 NODES=      69      82

 COUPLED  SET=       26   DIRECTION= UX      TOTAL NODES=        3
 NODES=      71      84     502

 COUPLED  SET=       27   DIRECTION= UX      TOTAL NODES=        3
 NODES=      73      86     503

    UPLED  SET=      28   DIRECTION= UX      TOTAL NODES=        2
 NODES=      90     101

 COUPLED  SET=       29   DIRECTION= UX      TOTAL NODES=        2
 NODES=      92     103

 COUPLED  SET=       30   DIRECTION= UX      TOTAL NODES=        2
 NODES=      94     105

 COUPLED  SET=       31   DIRECTION= UX      TOTAL NODES=        2
 NODES=      96     107

 COUPLED  SET=       32   DIRECTION= UX      TOTAL NODES=        2
 NODES=      98     109

 COUPLED  SET=       33   DIRECTION= UX      TOTAL NODES=        2
 NODES=     100     111

 COUPLED  SET=       34   DIRECTION= UX      TOTAL NODES=        2
 NODES=      91     102

 COUPLED  SET=       35   DIRECTION= UX      TOTAL NODES=        2
 NODES=      93     104

    UPLED  SET=      36   DIRECTION= UX      TOTAL NODES=        2
   DES=      95     106

 COUPLED  SET=       37   DIRECTION= UX      TOTAL NODES=        2
 NODES=      97     108

 COUPLED  SET=       38   DIRECTION= UX      TOTAL NODES=        3
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NODES=     99     110     509

COUPLED SET=     39   DIRECTION= UX     TOTAL NODES=        2
NODES=    114     125

COUPLED SET=     40   DIRECTION= UX     TOTAL NODES=        2
NODES=    138     149

COUPLED SET=     41   DIRECTION= UX     TOTAL NODES=        2
NODES=    162     173

COUPLED SET=     42   DIRECTION= UX     TOTAL NODES=        2
NODES=    186     197

COUPLED SET=     43   DIRECTION= UX     TOTAL NODES=        2
NODES=    210     221

COUPLED SET=     44   DIRECTION= UX     TOTAL NODES=        2
NODES=    116     127

COUPLED SET=     45   DIRECTION= UX     TOTAL NODES=        2
NODES=    140     151

COUPLED SET=     46   DIRECTION= UX     TOTAL NODES=        2
NODES=    164     175

COUPLED SET=     47   DIRECTION= UX     TOTAL NODES=        2
NODES=    188     199

COUPLED SET=     48   DIRECTION= UX     TOTAL NODES=        2
NODES=    212     223

COUPLED SET=     49   DIRECTION= UX     TOTAL NODES=        2
NODES=    118     129

COUPLED SET=     50   DIRECTION= UX     TOTAL NODES=        2
NODES=    142     153

COUPLED SET=     51   DIRECTION= UX     TOTAL NODES=        2
NODES=    166     177

COUPLED SET=     52   DIRECTION= UX     TOTAL NODES=        2
NODES=    190     201

COUPLED SET=     53   DIRECTION= UX     TOTAL NODES=        2
NODES=    214     225

COUPLED SET=     54   DIRECTION= UX     TOTAL NODES=        2
NODES=    120     131

COUPLED SET=     55   DIRECTION= UX     TOTAL NODES=        2
NODES=    144     155

COUPLED SET=     56   DIRECTION= UX     TOTAL NODES=        2
NODES=    168     179

COUPLED SET=     57   DIRECTION= UX     TOTAL NODES=        2
NODES=    192     203

COUPLED SET=     58   DIRECTION= UX     TOTAL NODES=        2
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NODES=    216    227

  UPLED SET=     59  DIRECTION= UX     TOTAL NODES=      2
   DES=   122    133

COUPLED SET=     60  DIRECTION= UX     TOTAL NODES=      2
NODES=    146    157

COUPLED SET=     61  DIRECTION= UX     TOTAL NODES=      2
NODES=    170    181

COUPLED SET=     62  DIRECTION= UX     TOTAL NODES=      2
NODES=    194    205

COUPLED SET=     63  DIRECTION= UX     TOTAL NODES=      2
NODES=    218    229

COUPLED SET=     64  DIRECTION= UX     TOTAL NODES=      2
NODES=    124    135

COUPLED SET=     65  DIRECTION= UX     TOTAL NODES=      2
NODES=    148    159

COUPLED SET=     66  DIRECTION= UX     TOTAL NODES=      2
NODES=    172    183

COUPLED SET=     67  DIRECTION= UX     TOTAL NODES=      3
NODES=    196    207    553

  UPLED SET=     68  DIRECTION= UX     TOTAL NODES=      2
NODES=    220    231

COUPLED SET=     69  DIRECTION= UX     TOTAL NODES=      2
NODES=    115    126

COUPLED SET=     70  DIRECTION= UX     TOTAL NODES=      2
NODES=    139    150

COUPLED SET=     71  DIRECTION= UX     TOTAL NODES=      2
NODES=    163    174

COUPLED SET=     72  DIRECTION= UX     TOTAL NODES=      2
NODES=    187    198

COUPLED SET=     73  DIRECTION= UX     TOTAL NODES=      2
NODES=    211    222

COUPLED SET=     74  DIRECTION= UX     TOTAL NODES=      2
NODES=    117    128

COUPLED SET=     75  DIRECTION= UX     TOTAL NODES=      2
NODES=    141    152

   PLED SET=     76  DIRECTION= UX     TOTAL NODES=      2
   ES=    165    176

COUPLED SET=     77  DIRECTION= UX     TOTAL NODES=      2
NODES=    189    200

COUPLED SET=     78  DIRECTION= UX     TOTAL NODES=      2
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NODES=   213   224

COUPLED SET=    79  DIRECTION= UX    TOTAL NODES=      2
   DES=  119   130

COUPLED SET=    80  DIRECTION= UX    TOTAL NODES=      2
NODES=   143   154

COUPLED SET=    81  DIRECTION= UX    TOTAL NODES=      2
NODES=   167   178

COUPLED SET=    82  DIRECTION= UX    TOTAL NODES=      2
NODES=   191   202

COUPLED SET=    83  DIRECTION= UX    TOTAL NODES=      2
NODES=   215   226

COUPLED SET=    84  DIRECTION= UX    TOTAL NODES=      2
NODES=   121   132

COUPLED SET=    85  DIRECTION= UX    TOTAL NODES=      2
NODES=   145   156

COUPLED SET=    86  DIRECTION= UX    TOTAL NODES=      2
NODES=   169   180

COUPLED SET=    87  DIRECTION= UX    TOTAL NODES=      3
NODES=   193   204   532

   PLED SET=    88  DIRECTION= UX    TOTAL NODES=      3
NODES=   217   228   538

COUPLED SET=    89  DIRECTION= UX    TOTAL NODES=      3
NODES=   123   134   515

COUPLED SET=    90  DIRECTION= UX    TOTAL NODES=      3
NODES=   147   158   521

COUPLED SET=    91  DIRECTION= UX    TOTAL NODES=      3
NODES=   171   182   527

COUPLED SET=    92  DIRECTION= UX    TOTAL NODES=      3
NODES=   195   206   533

COUPLED SET=    93  DIRECTION= UX    TOTAL NODES=      3
NODES=   219   230   539

COUPLED SET=    94  DIRECTION= UX    TOTAL NODES=      2
NODES=   266   284

COUPLED SET=    95  DIRECTION= UX    TOTAL NODES=      2
NODES=   268   286

COUPLED SET=    96  DIRECTION= UX    TOTAL NODES=      2
    ES=  270   288

COUPLED SET=    97  DIRECTION= UX    TOTAL NODES=      2
NODES=   272   290

COUPLED SET=    98  DIRECTION= UX    TOTAL NODES=      4
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NODES=    274     275     292     293

COUPLED SET=      99    DIRECTION= UX     TOTAL NODES=        4
NODES=    276     277     294     295

COUPLED SET=     100    DIRECTION= UX     TOTAL NODES=        2
NODES=    278     296

COUPLED SET=     101    DIRECTION= UX     TOTAL NODES=        2
NODES=    280     298

COUPLED SET=     102    DIRECTION= UX     TOTAL NODES=        2
NODES=    282     300

COUPLED SET=     103    DIRECTION= UX     TOTAL NODES=        2
NODES=    267     285

COUPLED SET=     104    DIRECTION= UX     TOTAL NODES=        2
NODES=    269     287

COUPLED SET=     105    DIRECTION= UX     TOTAL NODES=        2
NODES=    271     289

COUPLED SET=     106    DIRECTION= UX     TOTAL NODES=        2
NODES=    273     291

COUPLED SET=     107    DIRECTION= UX     TOTAL NODES=        3
NODES=    279     297     551

COUPLED SET=     108    DIRECTION= UX     TOTAL NODES=        3
NODES=    281     299     552

COUPLED SET=     109    DIRECTION= UX     TOTAL NODES=        3
NODES=    307     319     320

COUPLED SET=     110    DIRECTION= UX     TOTAL NODES=        2
NODES=    308     321

COUPLED SET=     111    DIRECTION= UX     TOTAL NODES=        2
NODES=    310     323

COUPLED SET=     112    DIRECTION= UX     TOTAL NODES=        2
NODES=    312     325

COUPLED SET=     113    DIRECTION= UX     TOTAL NODES=        2
NODES=    314     327

COUPLED SET=     114    DIRECTION= UX     TOTAL NODES=        2
NODES=    316     329

COUPLED SET=     115    DIRECTION= UX     TOTAL NODES=        3
NODES=    318     331     562

COUPLED SET=     116    DIRECTION= UX     TOTAL NODES=        2
NODES=    309     322

COUPLED SET=     117    DIRECTION= UX     TOTAL NODES=        2
NODES=    311     324

COUPLED SET=     118    DIRECTION= UX     TOTAL NODES=        2
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NODES=    313     326

COUPLED SET=     119   DIRECTION= UX     TOTAL NODES=        3
NODES=    315     328    560

COUPLED SET=     120   DIRECTION= UX     TOTAL NODES=        3
NODES=    317     330    561

COUPLED SET=     121   DIRECTION= UX     TOTAL NODES=        2
NODES=    334     345

COUPLED SET=     122   DIRECTION= UX     TOTAL NODES=        2
NODES=    336     347

COUPLED SET=     123   DIRECTION= UX     TOTAL NODES=        2
NODES=    338     349

COUPLED SET=     124   DIRECTION= UX     TOTAL NODES=        2
NODES=    340     351

COUPLED SET=     125   DIRECTION= UX     TOTAL NODES=        2
NODES=    342     353

COUPLED SET=     126   DIRECTION= UX     TOTAL NODES=        2
NODES=    344     355

COUPLED SET=     127   DIRECTION= UX     TOTAL NODES=        2
NODES=    335     346

C[illegible]LED SET=     128   DIRECTION= UX     TOTAL NODES=        2
N[illegible]ES=    337     348

COUPLED SET=     129   DIRECTION= UX     TOTAL NODES=        2
NODES=    339     350

COUPLED SET=     130   DIRECTION= UX     TOTAL NODES=        2
NODES=    341     352

COUPLED SET=     131   DIRECTION= UX     TOTAL NODES=        3
NODES=    343     354    567

COUPLED SET=     132   DIRECTION= UX     TOTAL NODES=        2
NODES=    358     369

COUPLED SET=     133   DIRECTION= UX     TOTAL NODES=        2
NODES=    382     393

COUPLED SET=     134   DIRECTION= UX     TOTAL NODES=        2
NODES=    406     417

COUPLED SET=     135   DIRECTION= UX     TOTAL NODES=        2
NODES=    430     441

COUPLED SET=     136   DIRECTION= UX     TOTAL NODES=        2
N[illegible]S=    454     465

COUPLED SET=     137   DIRECTION= UX     TOTAL NODES=        2
NODES=    360     371

COUPLED SET=     138   DIRECTION= UX     TOTAL NODES=        2
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NODES=    384     395

COUPLED SET=     139   DIRECTION= UX      TOTAL NODES=       2
   DES=    408     419

COUPLED SET=     140   DIRECTION= UX      TOTAL NODES=       2
NODES=    432     443

COUPLED SET=     141   DIRECTION= UX      TOTAL NODES=       2
NODES=    456     467

COUPLED SET=     142   DIRECTION= UX      TOTAL NODES=       2
NODES=    362     373

COUPLED SET=     143   DIRECTION= UX      TOTAL NODES=       2
NODES=    386     397

COUPLED SET=     144   DIRECTION= UX      TOTAL NODES=       2
NODES=    410     421

COUPLED SET=     145   DIRECTION= UX      TOTAL NODES=       2
NODES=    434     445

COUPLED SET=     146   DIRECTION= UX      TOTAL NODES=       2
NODES=    458     469

COUPLED SET=     147   DIRECTION= UX      TOTAL NODES=       2
NODES=    364     375

   UPLED SET=     148   DIRECTION= UX      TOTAL NODES=       2
NODES=    388     399

COUPLED SET=     149   DIRECTION= UX      TOTAL NODES=       2
NODES=    412     423

COUPLED SET=     150   DIRECTION= UX      TOTAL NODES=       2
NODES=    436     447

COUPLED SET=     151   DIRECTION= UX      TOTAL NODES=       2
NODES=    460     471

COUPLED SET=     152   DIRECTION= UX      TOTAL NODES=       2
NODES=    366     377

COUPLED SET=     153   DIRECTION= UX      TOTAL NODES=       2
NODES=    390     401

COUPLED SET=     154   DIRECTION= UX      TOTAL NODES=       2
NODES=    414     425

COUPLED SET=     155   DIRECTION= UX      TOTAL NODES=       2
NODES=    438     449

COUPLED SET=     156   DIRECTION= UX      TOTAL NODES=       2
    ES=    462     473

COUPLED SET=     157   DIRECTION= UX      TOTAL NODES=       2
NODES=    368     379

COUPLED SET=     158   DIRECTION= UX      TOTAL NODES=       2
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NODES=    392    403

COUPLED SET=    159   DIRECTION= UX     TOTAL NODES=       2
     ES=    416    427

COUPLED SET=    160   DIRECTION= UX     TOTAL NODES=       2
NODES=    440    451

COUPLED SET=    161   DIRECTION= UX     TOTAL NODES=       2
NODES=    464    475

COUPLED SET=    162   DIRECTION= UX     TOTAL NODES=       2
NODES=    359    370

COUPLED SET=    163   DIRECTION= UX     TOTAL NODES=       2
NODES=    383    394

COUPLED SET=    164   DIRECTION= UX     TOTAL NODES=       2
NODES=    407    418

COUPLED SET=    165   DIRECTION= UX     TOTAL NODES=       2
NODES=    431    442

COUPLED SET=    166   DIRECTION= UX     TOTAL NODES=       2
NODES=    455    466

COUPLED SET=    167   DIRECTION= UX     TOTAL NODES=       2
NODES=    361    372

    PLED SET=    168   DIRECTION= UX     TOTAL NODES=       2
NODES=    385    396

COUPLED SET=    169   DIRECTION= UX     TOTAL NODES=       2
NODES=    409    420

COUPLED SET=    170   DIRECTION= UX     TOTAL NODES=       2
NODES=    433    444

COUPLED SET=    171   DIRECTION= UX     TOTAL NODES=       2
NODES=    457    468

COUPLED SET=    172   DIRECTION= UX     TOTAL NODES=       2
NODES=    363    374

COUPLED SET=    173   DIRECTION= UX     TOTAL NODES=       2
NODES=    387    398

COUPLED SET=    174   DIRECTION= UX     TOTAL NODES=       2
NODES=    411    422

COUPLED SET=    175   DIRECTION= UX     TOTAL NODES=       2
NODES=    435    446

COUPLED SET=    176   DIRECTION= UX     TOTAL NODES=       2
     ES=    459    470

COUPLED SET=    177   DIRECTION= UX     TOTAL NODES=       2
NODES=    365    376

COUPLED SET=    178   DIRECTION= UX     TOTAL NODES=       2
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NODES=    389    400

COUPLED SET=    179   DIRECTION= UX    TOTAL NODES=      2
   DES=   413    424

COUPLED SET=    180   DIRECTION= UX    TOTAL NODES=      3
NODES=    437    448    590

COUPLED SET=    181   DIRECTION= UX    TOTAL NODES=      3
NODES=    461    472    596

COUPLED SET=    182   DIRECTION= UX    TOTAL NODES=      3
NODES=    367    378    573

COUPLED SET=    183   DIRECTION= UX    TOTAL NODES=      3
NODES=    391    402    579

COUPLED SET=    184   DIRECTION= UX    TOTAL NODES=      3
NODES=    415    426    585

COUPLED SET=    185   DIRECTION= UX    TOTAL NODES=      3
NODES=    439    450    591

COUPLED SET=    186   DIRECTION= UX    TOTAL NODES=      3
NODES=    463    474    597

COUPLED SET=    187   DIRECTION= UY    TOTAL NODES=      4
NODES=     22     23     40     41

   PLED SET=    188   DIRECTION= UY    TOTAL NODES=      4
N DES=     24     25     42     43

COUPLED SET=    189   DIRECTION= UY    TOTAL NODES=      4
NODES=     26     27     44     45

COUPLED SET=    190   DIRECTION= UY    TOTAL NODES=      4
NODES=     28     29     46     47

COUPLED SET=    191   DIRECTION= UY    TOTAL NODES=      3
NODES=     30     48     49

COUPLED SET=    192   DIRECTION= UY    TOTAL NODES=      3
NODES=     50     51     33

COUPLED SET=    193   DIRECTION= UY    TOTAL NODES=      4
NODES=     34     35     52     53

COUPLED SET=    194   DIRECTION= UY    TOTAL NODES=      4
NODES=     36     37     54     55

COUPLED SET=    195   DIRECTION= UY    TOTAL NODES=      2
NODES=     38     56

COUPLED SET=    196   DIRECTION= UY    TOTAL NODES=      2
N   ES=    58     59

COUPLED SET=    197   DIRECTION= UY    TOTAL NODES=      2
NODES=     60     61

COUPLED SET=    198   DIRECTION= UY    TOTAL NODES=      2
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NODES=      62      63

COUPLED SET=     199   DIRECTION= UY     TOTAL NODES=       2
    DES=    75      76

COUPLED SET=     200   DIRECTION= UY     TOTAL NODES=       4
NODES=      64      65      77      78

COUPLED SET=     201   DIRECTION= UY     TOTAL NODES=       4
NODES=      66      67      79      80

COUPLED SET=     202   DIRECTION= UY     TOTAL NODES=       4
NODES=      68      69      81      82

COUPLED SET=     203   DIRECTION= UY     TOTAL NODES=       4
NODES=      70      71      83      84

COUPLED SET=     204   DIRECTION= UY     TOTAL NODES=       4
NODES=      72      73      85      86

COUPLED SET=     205   DIRECTION= UY     TOTAL NODES=       2
NODES=      74      87

COUPLED SET=     206   DIRECTION= UY     TOTAL NODES=       2
NODES=      88      89

COUPLED SET=     207   DIRECTION= UY     TOTAL NODES=       4
NODES=      90      91     101     102

    PLED SET=    208   DIRECTION= UY     TOTAL NODES=       4
NODES=      92      93     103     104

COUPLED SET=     209   DIRECTION= UY     TOTAL NODES=       4
NODES=      94      95     105     106

COUPLED SET=     210   DIRECTION= UY     TOTAL NODES=       4
NODES=      96      97     107     108

COUPLED SET=     211   DIRECTION= UY     TOTAL NODES=       4
NODES=      98      99     109     110

COUPLED SET=     212   DIRECTION= UY     TOTAL NODES=       2
NODES=     100     111

COUPLED SET=     213   DIRECTION= UY     TOTAL NODES=       2
NODES=     112     113

COUPLED SET=     214   DIRECTION= UY     TOTAL NODES=       2
NODES=     136     137

COUPLED SET=     215   DIRECTION= UY     TOTAL NODES=       2
NODES=     160     161

COUPLED SET=     216   DIRECTION= UY     TOTAL NODES=       2
    ES=    184     185

COUPLED SET=     217   DIRECTION= UY     TOTAL NODES=       2
NODES=     208     209

COUPLED SET=     218   DIRECTION= UY     TOTAL NODES=       4
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NODES=    114     115     125     126

COUPLED SET=    219   DIRECTION= UY     TOTAL NODES=       4
    ES=   138     139     149     150

COUPLED SET=    220   DIRECTION= UY     TOTAL NODES=       4
NODES=    162     163     173     174

COUPLED SET=    221   DIRECTION= UY     TOTAL NODES=       4
NODES=    186     187     197     198

COUPLED SET=    222   DIRECTION= UY     TOTAL NODES=       4
NODES=    210     211     221     222

COUPLED SET=    223   DIRECTION= UY     TOTAL NODES=       4
NODES=    116     117     127     128

COUPLED SET=    224   DIRECTION= UY     TOTAL NODES=       4
NODES=    140     141     151     152

COUPLED SET=    225   DIRECTION= UY     TOTAL NODES=       4
NODES=    164     165     175     176

COUPLED SET=    226   DIRECTION= UY     TOTAL NODES=       4
NODES=    188     189     199     200

COUPLED SET=    227   DIRECTION= UY     TOTAL NODES=       4
NODES=    212     213     223     224

    PLED SET=   228   DIRECTION= UY     TOTAL NODES=       4
NODES=    118     119     129     130

COUPLED SET=    229   DIRECTION= UY     TOTAL NODES=       4
NODES=    142     143     153     154

COUPLED SET=    230   DIRECTION= UY     TOTAL NODES=       4
NODES=    166     167     177     178

COUPLED SET=    231   DIRECTION= UY     TOTAL NODES=       4
NODES=    190     191     201     202

COUPLED SET=    232   DIRECTION= UY     TOTAL NODES=       4
NODES=    214     215     225     226

COUPLED SET=    233   DIRECTION= UY     TOTAL NODES=       4
NODES=    120     121     131     132

COUPLED SET=    234   DIRECTION= UY     TOTAL NODES=       4
NODES=    144     145     155     156

COUPLED SET=    235   DIRECTION= UY     TOTAL NODES=       4
NODES=    168     169     179     180

COUPLED SET=    236   DIRECTION= UY     TOTAL NODES=       4
N    S=   192     193     203     204

COUPLED SET=    237   DIRECTION= UY     TOTAL NODES=       4
NODES=    216     217     227     228

COUPLED SET=    238   DIRECTION= UY     TOTAL NODES=       4
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NODES=    122    123    133    134

COUPLED SET=    239   DIRECTION= UY    TOTAL NODES=      4
  DES=    146    147    157    158

COUPLED SET=    240   DIRECTION= UY    TOTAL NODES=      4
NODES=    170    171    181    182

COUPLED SET=    241   DIRECTION= UY    TOTAL NODES=      4
NODES=    194    195    205    206

COUPLED SET=    242   DIRECTION= UY    TOTAL NODES=      4
NODES=    218    219    229    230

COUPLED SET=    243   DIRECTION= UY    TOTAL NODES=      2
NODES=    124    135

COUPLED SET=    244   DIRECTION= UY    TOTAL NODES=      2
NODES=    148    159

COUPLED SET=    245   DIRECTION= UY    TOTAL NODES=      2
NODES=    172    183

COUPLED SET=    246   DIRECTION= UY    TOTAL NODES=      2
NODES=    196    207

COUPLED SET=    247   DIRECTION= UY    TOTAL NODES=      2
NODES=    220    231

   PLED SET=    248   DIRECTION= UY    TOTAL NODES=      2
  DES=    232    233

COUPLED SET=    249   DIRECTION= UY    TOTAL NODES=      2
NODES=    234    235

COUPLED SET=    250   DIRECTION= UY    TOTAL NODES=      2
NODES=    236    237

COUPLED SET=    251   DIRECTION= UY    TOTAL NODES=      2
NODES=    238    239

COUPLED SET=    252   DIRECTION= UY    TOTAL NODES=      2
NODES=    240    241

COUPLED SET=    253   DIRECTION= UY    TOTAL NODES=      2
NODES=    242    243

COUPLED SET=    254   DIRECTION= UY    TOTAL NODES=      4
NODES=    266    267    284    285

COUPLED SET=    255   DIRECTION= UY    TOTAL NODES=      4
NODES=    268    269    286    287

COUPLED SET=    256   DIRECTION= UY    TOTAL NODES=      4
N  ES=    270    271    288    289

COUPLED SET=    257   DIRECTION= UY    TOTAL NODES=      4
NODES=    272    273    290    291

COUPLED SET=    258   DIRECTION= UY    TOTAL NODES=      3
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NODES=    274     292     293

COUPLED SET=     259   DIRECTION= UY     TOTAL NODES=        3
NODES=    277     294     295

COUPLED SET=     260   DIRECTION= UY     TOTAL NODES=        4
NODES=    278     279     296     297

COUPLED SET=     261   DIRECTION= UY     TOTAL NODES=        4
NODES=    280     281     298     299

COUPLED SET=     262   DIRECTION= UY     TOTAL NODES=        2
NODES=    282     300

COUPLED SET=     263   DIRECTION= UY     TOTAL NODES=        2
NODES=    302     303

COUPLED SET=     264   DIRECTION= UY     TOTAL NODES=        2
NODES=    304     305

COUPLED SET=     265   DIRECTION= UY     TOTAL NODES=        2
NODES=    306     307

COUPLED SET=     266   DIRECTION= UY     TOTAL NODES=        2
NODES=    319     320

COUPLED SET=     267   DIRECTION= UY     TOTAL NODES=        4
NODES=    308     309     321     322

COUPLED SET=     268   DIRECTION= UY     TOTAL NODES=        4
NODES=    310     311     323     324

COUPLED SET=     269   DIRECTION= UY     TOTAL NODES=        4
NODES=    312     313     325     326

COUPLED SET=     270   DIRECTION= UY     TOTAL NODES=        4
NODES=    314     315     327     328

COUPLED SET=     271   DIRECTION= UY     TOTAL NODES=        4
NODES=    316     317     329     330

COUPLED SET=     272   DIRECTION= UY     TOTAL NODES=        2
NODES=    318     331

COUPLED SET=     273   DIRECTION= UY     TOTAL NODES=        2
NODES=    332     333

COUPLED SET=     274   DIRECTION= UY     TOTAL NODES=        4
NODES=    334     335     345     346

COUPLED SET=     275   DIRECTION= UY     TOTAL NODES=        4
NODES=    336     337     347     348

COUPLED SET=     276   DIRECTION= UY     TOTAL NODES=        4
NODES=    338     339     349     350

COUPLED SET=     277   DIRECTION= UY     TOTAL NODES=        4
NODES=    340     341     351     352

COUPLED SET=     278   DIRECTION= UY     TOTAL NODES=        4
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NODES=    342    343    353    354

COUPLED SET=    279   DIRECTION= UY     TOTAL NODES=       2
NODES=    344    355

COUPLED SET=    280   DIRECTION= UY     TOTAL NODES=       2
NODES=    356    357

COUPLED SET=    281   DIRECTION= UY     TOTAL NODES=       2
NODES=    380    381

COUPLED SET=    282   DIRECTION= UY     TOTAL NODES=       2
NODES=    404    405

COUPLED SET=    283   DIRECTION= UY     TOTAL NODES=       2
NODES=    428    429

COUPLED SET=    284   DIRECTION= UY     TOTAL NODES=       2
NODES=    452    453

COUPLED SET=    285   DIRECTION= UY     TOTAL NODES=       4
NODES=    358    359    369    370

COUPLED SET=    286   DIRECTION= UY     TOTAL NODES=       4
NODES=    382    383    393    394

COUPLED SET=    287   DIRECTION= UY     TOTAL NODES=       4
NODES=    406    407    417    418

COUPLED SET=    288   DIRECTION= UY     TOTAL NODES=       4
NODES=    430    431    441    442

COUPLED SET=    289   DIRECTION= UY     TOTAL NODES=       4
NODES=    454    455    465    466

COUPLED SET=    290   DIRECTION= UY     TOTAL NODES=       4
NODES=    360    361    371    372

COUPLED SET=    291   DIRECTION= UY     TOTAL NODES=       4
NODES=    384    385    395    396

COUPLED SET=    292   DIRECTION= UY     TOTAL NODES=       4
NODES=    408    409    419    420

COUPLED SET=    293   DIRECTION= UY     TOTAL NODES=       4
NODES=    432    433    443    444

COUPLED SET=    294   DIRECTION= UY     TOTAL NODES=       4
NODES=    456    457    467    468

COUPLED SET=    295   DIRECTION= UY     TOTAL NODES=       4
NODES=    362    363    373    374

COUPLED SET=    296   DIRECTION= UY     TOTAL NODES=       4
NODES=    386    387    397    398

COUPLED SET=    297   DIRECTION= UY     TOTAL NODES=       4
NODES=    410    411    421    422

COUPLED SET=    298   DIRECTION= UY     TOTAL NODES=       4
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NODES=    434    435    445    446

COUPLED SET=    299    DIRECTION= UY    TOTAL NODES=      4
NODES=    458    459    469    470

COUPLED SET=    300    DIRECTION= UY    TOTAL NODES=      4
NODES=    364    365    375    376

COUPLED SET=    301    DIRECTION= UY    TOTAL NODES=      4
NODES=    388    389    399    400

COUPLED SET=    302    DIRECTION= UY    TOTAL NODES=      4
NODES=    412    413    423    424

COUPLED SET=    303    DIRECTION= UY    TOTAL NODES=      4
NODES=    436    437    447    448

COUPLED SET=    304    DIRECTION= UY    TOTAL NODES=      4
NODES=    460    461    471    472

COUPLED SET=    305    DIRECTION= UY    TOTAL NODES=      4
NODES=    366    367    377    378

COUPLED SET=    306    DIRECTION= UY    TOTAL NODES=      4
NODES=    390    391    401    402

COUPLED SET=    307    DIRECTION= UY    TOTAL NODES=      4
NODES=    414    415    425    426

COUPLED SET=    308    DIRECTION= UY    TOTAL NODES=      4
NODES=    438    439    449    450

COUPLED SET=    309    DIRECTION= UY    TOTAL NODES=      4
NODES=    462    463    473    474

COUPLED SET=    310    DIRECTION= UY    TOTAL NODES=      2
NODES=    368    379

COUPLED SET=    311    DIRECTION= UY    TOTAL NODES=      2
NODES=    392    403

COUPLED SET=    312    DIRECTION= UY    TOTAL NODES=      2
NODES=    416    427

COUPLED SET=    313    DIRECTION= UY    TOTAL NODES=      2
NODES=    440    451

COUPLED SET=    314    DIRECTION= UY    TOTAL NODES=      2
NODES=    464    475

COUPLED SET=    315    DIRECTION= UY    TOTAL NODES=      2
NODES=    476    477

COUPLED SET=    316    DIRECTION= UY    TOTAL NODES=      2
NODES=    478    479

COUPLED SET=    317    DIRECTION= UY    TOTAL NODES=      2
NODES=    480    481

COUPLED SET=    318    DIRECTION= UY    TOTAL NODES=      2
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NODES=     482     483

COUPLED SET=     319   DIRECTION= UY     TOTAL NODES=       2
   DES=    484     485

COUPLED SET=     320   DIRECTION= UY     TOTAL NODES=       2
NODES=     486     487

COUPLED SET=     321   DIRECTION= UX     TOTAL NODES=       2
NODES=       2      12

COUPLED SET=     322   DIRECTION= UX     TOTAL NODES=       2
NODES=       3      13

COUPLED SET=     323   DIRECTION= UX     TOTAL NODES=       2
NODES=       4      14

COUPLED SET=     324   DIRECTION= UX     TOTAL NODES=       2
NODES=       5      15

COUPLED SET=     325   DIRECTION= UX     TOTAL NODES=       2
NODES=       6      16

COUPLED SET=     326   DIRECTION= UX     TOTAL NODES=       2
NODES=       7      17

COUPLED SET=     327   DIRECTION= UX     TOTAL NODES=       2
NODES=       8      18

   JPLED SET=     328   DIRECTION= UX     TOTAL NODES=       2
   DES=      9      19

COUPLED SET=     329   DIRECTION= UX     TOTAL NODES=       2
NODES=      10      20

COUPLED SET=     330   DIRECTION= UX     TOTAL NODES=       2
NODES=     246     256

COUPLED SET=     331   DIRECTION= UX     TOTAL NODES=       2
NODES=     247     257

COUPLED SET=     332   DIRECTION= UX     TOTAL NODES=       2
NODES=     248     258

COUPLED SET=     333   DIRECTION= UX     TOTAL NODES=       2
NODES=     249     259

COUPLED SET=     334   DIRECTION= UX     TOTAL NODES=       2
NODES=     250     260

COUPLED SET=     335   DIRECTION= UX     TOTAL NODES=       2
NODES=     251     261

COUPLED SET=     336   DIRECTION= UX     TOTAL NODES=       2
    ES=    252     262

COUPLED SET=     337   DIRECTION= UX     TOTAL NODES=       2
NODES=     253     263

COUPLED SET=     338   DIRECTION= UX     TOTAL NODES=       2
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NODES=    254    264

COUPLED SET=     339  DIRECTION= UX     TOTAL NODES=      2
  DES=     88     89

COUPLED SET=     340  DIRECTION= UX     TOTAL NODES=      2
NODES=    112    113

COUPLED SET=     341  DIRECTION= UX     TOTAL NODES=      2
NODES=    136    137

COUPLED SET=     342  DIRECTION= UX     TOTAL NODES=      2
NODES=    160    161

COUPLED SET=     343  DIRECTION= UX     TOTAL NODES=      2
NODES=    184    185

COUPLED SET=     344  DIRECTION= UX     TOTAL NODES=      2
NODES=    208    209

COUPLED SET=     345  DIRECTION= UX     TOTAL NODES=      2
NODES=    232    233

COUPLED SET=     346  DIRECTION= UX     TOTAL NODES=      2
NODES=    332    333

COUPLED SET=     347  DIRECTION= UX     TOTAL NODES=      2
NODES=    356    357

   UPLED SET=     348  DIRECTION= UX     TOTAL NODES=      2
  DES=    380    381

COUPLED SET=     349  DIRECTION= UX     TOTAL NODES=      2
NODES=    404    405

COUPLED SET=     350  DIRECTION= UX     TOTAL NODES=      2
NODES=    428    429

COUPLED SET=     351  DIRECTION= UX     TOTAL NODES=      2
NODES=    452    453

COUPLED SET=     352  DIRECTION= UX     TOTAL NODES=      2
NODES=    476    477

COUPLED SET=     353  DIRECTION= UZ     TOTAL NODES=      2
NODES=     22     23

COUPLED SET=     354  DIRECTION= UZ     TOTAL NODES=      2
NODES=     24     25

COUPLED SET=     355  DIRECTION= UZ     TOTAL NODES=      2
NODES=     26     27

COUPLED SET=     356  DIRECTION= UZ     TOTAL NODES=      2
   ES=     28     29

COUPLED SET=     357  DIRECTION= UZ     TOTAL NODES=      4
NODES=     30     31     48     49

COUPLED SET=     358  DIRECTION= UZ     TOTAL NODES=      4
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```
NODES=     32      33      50      51

COUPLED SET=     359   DIRECTION= UZ      TOTAL NODES=       2
    DES=     34      35

COUPLED SET=     360   DIRECTION= UZ      TOTAL NODES=       2
NODES=     36      37

COUPLED SET=     361   DIRECTION= UZ      TOTAL NODES=       2
NODES=     40      41

COUPLED SET=     362   DIRECTION= UZ      TOTAL NODES=       2
NODES=     42      43

COUPLED SET=     363   DIRECTION= UZ      TOTAL NODES=       2
NODES=     44      45

COUPLED SET=     364   DIRECTION= UZ      TOTAL NODES=       2
NODES=     46      47

COUPLED SET=     365   DIRECTION= UZ      TOTAL NODES=       2
NODES=     52      53

COUPLED SET=     366   DIRECTION= UZ      TOTAL NODES=       2
NODES=     54      55

COUPLED SET=     367   DIRECTION= UZ      TOTAL NODES=       2
NODES=     58      59

    UPLED SET=     368   DIRECTION= UZ      TOTAL NODES=       2
NODES=     60      61

COUPLED SET=     369   DIRECTION= UZ      TOTAL NODES=       2
NODES=     62      63

COUPLED SET=     370   DIRECTION= UZ      TOTAL NODES=       2
NODES=     64      65

COUPLED SET=     371   DIRECTION= UZ      TOTAL NODES=       2
NODES=     66      67

COUPLED SET=     372   DIRECTION= UZ      TOTAL NODES=       2
NODES=     68      69

COUPLED SET=     373   DIRECTION= UZ      TOTAL NODES=       2
NODES=     70      71

COUPLED SET=     374   DIRECTION= UZ      TOTAL NODES=       2
NODES=     72      73

COUPLED SET=     375   DIRECTION= UZ      TOTAL NODES=       2
NODES=     75      76

COUPLED SET=     376   DIRECTION= UZ      TOTAL NODES=       2
     ES=     77      78

COUPLED SET=     377   DIRECTION= UZ      TOTAL NODES=       2
NODES=     79      80

COUPLED SET=     378   DIRECTION= UZ      TOTAL NODES=       2
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```
NODES=      81      82

COUPLED SET=     379   DIRECTION= UZ     TOTAL NODES=       2
NODES=      83      84

COUPLED SET=     380   DIRECTION= UZ     TOTAL NODES=       2
NODES=      85      86

COUPLED SET=     381   DIRECTION= UZ     TOTAL NODES=       2
NODES=      88      89

COUPLED SET=     382   DIRECTION= UZ     TOTAL NODES=       2
NODES=      90      91

COUPLED SET=     383   DIRECTION= UZ     TOTAL NODES=       2
NODES=      92      93

COUPLED SET=     384   DIRECTION= UZ     TOTAL NODES=       2
NODES=      94      95

COUPLED SET=     385   DIRECTION= UZ     TOTAL NODES=       2
NODES=      96      97

COUPLED SET=     386   DIRECTION= UZ     TOTAL NODES=       2
NODES=      98      99

COUPLED SET=     387   DIRECTION= UZ     TOTAL NODES=       2
NODES=     101     102

    PLED SET=     388   DIRECTION= UZ     TOTAL NODES=       2
NODES=     103     104

COUPLED SET=     389   DIRECTION= UZ     TOTAL NODES=       2
NODES=     105     106

COUPLED SET=     390   DIRECTION= UZ     TOTAL NODES=       2
NODES=     107     108

COUPLED SET=     391   DIRECTION= UZ     TOTAL NODES=       2
NODES=     109     110

COUPLED SET=     392   DIRECTION= UZ     TOTAL NODES=       2
NODES=     112     113

COUPLED SET=     393   DIRECTION= UZ     TOTAL NODES=       2
NODES=     136     137

COUPLED SET=     394   DIRECTION= UZ     TOTAL NODES=       2
NODES=     160     161

COUPLED SET=     395   DIRECTION= UZ     TOTAL NODES=       2
NODES=     184     185

COUPLED SET=     396   DIRECTION= UZ     TOTAL NODES=       2
NODES=     114     115

COUPLED SET=     397   DIRECTION= UZ     TOTAL NODES=       2
NODES=     138     139

COUPLED SET=     398   DIRECTION= UZ     TOTAL NODES=       2
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```
NODES=    162    163

COUPLED SET=    399   DIRECTION= UZ     TOTAL NODES=       2
   DES=   186    187

COUPLED SET=    400   DIRECTION= UZ     TOTAL NODES=       2
NODES=    116    117

COUPLED SET=    401   DIRECTION= UZ     TOTAL NODES=       2
NODES=    140    141

COUPLED SET=    402   DIRECTION= UZ     TOTAL NODES=       2
NODES=    164    165

COUPLED SET=    403   DIRECTION= UZ     TOTAL NODES=       2
NODES=    188    189

COUPLED SET=    404   DIRECTION= UZ     TOTAL NODES=       2
NODES=    118    119

COUPLED SET=    405   DIRECTION= UZ     TOTAL NODES=       2
NODES=    142    143

COUPLED SET=    406   DIRECTION= UZ     TOTAL NODES=       2
NODES=    166    167

COUPLED SET=    407   DIRECTION= UZ     TOTAL NODES=       2
NODES=    190    191

   UPLED SET=    408   DIRECTION= UZ     TOTAL NODES=       2
   DES=   120    121

COUPLED SET=    409   DIRECTION= UZ     TOTAL NODES=       2
NODES=    144    145

COUPLED SET=    410   DIRECTION= UZ     TOTAL NODES=       2
NODES=    168    169

COUPLED SET=    411   DIRECTION= UZ     TOTAL NODES=       2
NODES=    192    193

COUPLED SET=    412   DIRECTION= UZ     TOTAL NODES=       2
NODES=    122    123

COUPLED SET=    413   DIRECTION= UZ     TOTAL NODES=       2
NODES=    146    147

COUPLED SET=    414   DIRECTION= UZ     TOTAL NODES=       2
NODES=    170    171

COUPLED SET=    415   DIRECTION= UZ     TOTAL NODES=       2
NODES=    194    195

COUPLED SET=    416   DIRECTION= UZ     TOTAL NODES=       2
   DES=   125    126

COUPLED SET=    417   DIRECTION= UZ     TOTAL NODES=       2
NODES=    149    150

COUPLED SET=    418   DIRECTION= UZ     TOTAL NODES=       2
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```
NODES=    173    174

COUPLED SET=     419   DIRECTION= UZ      TOTAL NODES=        2
   DES=   197    198

COUPLED SET=     420   DIRECTION= UZ      TOTAL NODES=        2
NODES=    127    128

COUPLED SET=     421   DIRECTION= UZ      TOTAL NODES=        2
NODES=    151    152

COUPLED SET=     422   DIRECTION= UZ      TOTAL NODES=        2
NODES=    175    176

COUPLED SET=     423   DIRECTION= UZ      TOTAL NODES=        2
NODES=    199    200

COUPLED SET=     424   DIRECTION= UZ      TOTAL NODES=        2
NODES=    129    130

COUPLED SET=     425   DIRECTION= UZ      TOTAL NODES=        2
NODES=    153    154

COUPLED SET=     426   DIRECTION= UZ      TOTAL NODES=        2
NODES=    177    178

COUPLED SET=     427   DIRECTION= UZ      TOTAL NODES=        2
NODES=    201    202

    JPLED SET=     428   DIRECTION= UZ      TOTAL NODES=        2
NODES=    131    132

COUPLED SET=     429   DIRECTION= UZ      TOTAL NODES=        2
NODES=    155    156

COUPLED SET=     430   DIRECTION= UZ      TOTAL NODES=        2
NODES=    179    180

COUPLED SET=     431   DIRECTION= UZ      TOTAL NODES=        2
NODES=    203    204

COUPLED SET=     432   DIRECTION= UZ      TOTAL NODES=        2
NODES=    133    134

COUPLED SET=     433   DIRECTION= UZ      TOTAL NODES=        2
NODES=    157    158

COUPLED SET=     434   DIRECTION= UZ      TOTAL NODES=        2
NODES=    181    182

COUPLED SET=     435   DIRECTION= UZ      TOTAL NODES=        2
NODES=    205    206

COUPLED SET=     436   DIRECTION= UZ      TOTAL NODES=        2
    ES=   208    209

COUPLED SET=     437   DIRECTION= UZ      TOTAL NODES=        2
NODES=    210    211

COUPLED SET=     438   DIRECTION= UZ      TOTAL NODES=        2
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```
NODES=    212    213

COUPLED SET=     439   DIRECTION= UZ     TOTAL NODES=       2
NODES=    214    215

COUPLED SET=     440   DIRECTION= UZ     TOTAL NODES=       2
NODES=    216    217

COUPLED SET=     441   DIRECTION= UZ     TOTAL NODES=       2
NODES=    218    219

COUPLED SET=     442   DIRECTION= UZ     TOTAL NODES=       2
NODES=    221    222

COUPLED SET=     443   DIRECTION= UZ     TOTAL NODES=       2
NODES=    223    224

COUPLED SET=     444   DIRECTION= UZ     TOTAL NODES=       2
NODES=    225    226

COUPLED SET=     445   DIRECTION= UZ     TOTAL NODES=       2
NODES=    227    228

COUPLED SET=     446   DIRECTION= UZ     TOTAL NODES=       2
NODES=    229    230

COUPLED SET=     447   DIRECTION= UZ     TOTAL NODES=       2
NODES=    266    267

   PLED SET=     448   DIRECTION= UZ     TOTAL NODES=       2
  DES=    268    269

COUPLED SET=     449   DIRECTION= UZ     TOTAL NODES=       2
NODES=    270    271

COUPLED SET=     450   DIRECTION= UZ     TOTAL NODES=       2
NODES=    272    273

COUPLED SET=     451   DIRECTION= UZ     TOTAL NODES=       4
NODES=    274    275    292    293

COUPLED SET=     452   DIRECTION= UZ     TOTAL NODES=       4
NODES=    276    277    294    295

COUPLED SET=     453   DIRECTION= UZ     TOTAL NODES=       2
NODES=    278    279

COUPLED SET=     454   DIRECTION= UZ     TOTAL NODES=       2
NODES=    280    281

COUPLED SET=     455   DIRECTION= UZ     TOTAL NODES=       2
NODES=    284    285

COUPLED SET=     456   DIRECTION= UZ     TOTAL NODES=       2
N  ES=    286    287

COUPLED SET=     457   DIRECTION= UZ     TOTAL NODES=       2
NODES=    288    289

COUPLED SET=     458   DIRECTION= UZ     TOTAL NODES=       2
```

```
NODES=    290    291

  UPLED SET=    459   DIRECTION= UZ     TOTAL NODES=       2
   DES=   296    297

COUPLED SET=    460   DIRECTION= UZ     TOTAL NODES=       2
NODES=    298    299

COUPLED SET=    461   DIRECTION= UZ     TOTAL NODES=       2
NODES=    302    303

COUPLED SET=    462   DIRECTION= UZ     TOTAL NODES=       2
NODES=    304    305

COUPLED SET=    463   DIRECTION= UZ     TOTAL NODES=       2
NODES=    306    307

COUPLED SET=    464   DIRECTION= UZ     TOTAL NODES=       2
NODES=    308    309

COUPLED SET=    465   DIRECTION= UZ     TOTAL NODES=       2
NODES=    310    311

COUPLED SET=    466   DIRECTION= UZ     TOTAL NODES=       2
NODES=    312    313

COUPLED SET=    467   DIRECTION= UZ     TOTAL NODES=       2
NODES=    314    315

  UPLED SET=    468   DIRECTION= UZ     TOTAL NODES=       2
NODES=    316    317

COUPLED SET=    469   DIRECTION= UZ     TOTAL NODES=       2
NODES=    319    320

COUPLED SET=    470   DIRECTION= UZ     TOTAL NODES=       2
NODES=    321    322

COUPLED SET=    471   DIRECTION= UZ     TOTAL NODES=       2
NODES=    323    324

COUPLED SET=    472   DIRECTION= UZ     TOTAL NODES=       2
NODES=    325    326

COUPLED SET=    473   DIRECTION= UZ     TOTAL NODES=       2
NODES=    327    328

COUPLED SET=    474   DIRECTION= UZ     TOTAL NODES=       2
NODES=    329    330

COUPLED SET=    475   DIRECTION= UZ     TOTAL NODES=       2
NODES=    332    333

   PLED SET=    476   DIRECTION= UZ     TOTAL NODES=       2
   DES=   334    335

COUPLED SET=    477   DIRECTION= UZ     TOTAL NODES=       2
NODES=    336    337

COUPLED SET=    478   DIRECTION= UZ     TOTAL NODES=       2
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```
NODES=    338    339

COUPLED SET=     479   DIRECTION= UZ     TOTAL NODES=        2
     )ES=    340    341

COUPLED SET=     480   DIRECTION= UZ     TOTAL NODES=        2
NODES=    342    343

COUPLED SET=     481   DIRECTION= UZ     TOTAL NODES=        2
NODES=    345    346

COUPLED SET=     482   DIRECTION= UZ     TOTAL NODES=        2
NODES=    347    348

COUPLED SET=     483   DIRECTION= UZ     TOTAL NODES=        2
NODES=    349    350

COUPLED SET=     484   DIRECTION= UZ     TOTAL NODES=        2
NODES=    351    352

COUPLED SET=     485   DIRECTION= UZ     TOTAL NODES=        2
NODES=    353    354

COUPLED SET=     486   DIRECTION= UZ     TOTAL NODES=        2
NODES=    356    357

COUPLED SET=     487   DIRECTION= UZ     TOTAL NODES=        2
NODES=    380    381

   JPLED SET=     488   DIRECTION= UZ     TOTAL NODES=        2
NODES=    404    405

COUPLED SET=     489   DIRECTION= UZ     TOTAL NODES=        2
NODES=    428    429

COUPLED SET=     490   DIRECTION= UZ     TOTAL NODES=        2
NODES=    358    359

COUPLED SET=     491   DIRECTION= UZ     TOTAL NODES=        2
NODES=    382    383

COUPLED SET=     492   DIRECTION= UZ     TOTAL NODES=        2
NODES=    406    407

COUPLED SET=     493   DIRECTION= UZ     TOTAL NODES=        2
NODES=    430    431

COUPLED SET=     494   DIRECTION= UZ     TOTAL NODES=        2
NODES=    360    361

COUPLED SET=     495   DIRECTION= UZ     TOTAL NODES=        2
NODES=    384    385

COUPLED SET=     496   DIRECTION= UZ     TOTAL NODES=        2
     ES=    408    409

COUPLED SET=     497   DIRECTION= UZ     TOTAL NODES=        2
NODES=    432    433

COUPLED SET=     498   DIRECTION= UZ     TOTAL NODES=        2
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```
NODES=   362    363

COUPLED SET=    499  DIRECTION= UZ    TOTAL NODES=      2
     ES=   386    387

COUPLED SET=    500  DIRECTION= UZ    TOTAL NODES=      2
NODES=   410    411

COUPLED SET=    501  DIRECTION= UZ    TOTAL NODES=      2
NODES=   434    435

COUPLED SET=    502  DIRECTION= UZ    TOTAL NODES=      2
NODES=   364    365

COUPLED SET=    503  DIRECTION= UZ    TOTAL NODES=      2
NODES=   388    389

COUPLED SET=    504  DIRECTION= UZ    TOTAL NODES=      2
NODES=   412    413

COUPLED SET=    505  DIRECTION= UZ    TOTAL NODES=      2
NODES=   436    437

COUPLED SET=    506  DIRECTION= UZ    TOTAL NODES=      2
NODES=   366    367

COUPLED SET=    507  DIRECTION= UZ    TOTAL NODES=      2
NODES=   390    391

   PLED SET=    508  DIRECTION= UZ    TOTAL NODES=      2
NODES=   414    415

COUPLED SET=    509  DIRECTION= UZ    TOTAL NODES=      2
NODES=   438    439

COUPLED SET=    510  DIRECTION= UZ    TOTAL NODES=      2
NODES=   369    370

COUPLED SET=    511  DIRECTION= UZ    TOTAL NODES=      2
NODES=   393    394

COUPLED SET=    512  DIRECTION= UZ    TOTAL NODES=      2
NODES=   417    418

COUPLED SET=    513  DIRECTION= UZ    TOTAL NODES=      2
NODES=   441    442

COUPLED SET=    514  DIRECTION= UZ    TOTAL NODES=      2
NODES=   371    372

COUPLED SET=    515  DIRECTION= UZ    TOTAL NODES=      2
NODES=   395    396

COUPLED SET=    516  DIRECTION= UZ    TOTAL NODES=      2
     ES=   419    420

COUPLED SET=    517  DIRECTION= UZ    TOTAL NODES=      2
NODES=   443    444

COUPLED SET=    518  DIRECTION= UZ    TOTAL NODES=      2
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NODES=    373    374

COUPLED SET=    519   DIRECTION= UZ     TOTAL NODES=        2
NODES=    397    398

COUPLED SET=    520   DIRECTION= UZ     TOTAL NODES=        2
NODES=    421    422

COUPLED SET=    521   DIRECTION= UZ     TOTAL NODES=        2
NODES=    445    446

COUPLED SET=    522   DIRECTION= UZ     TOTAL NODES=        2
NODES=    375    376

COUPLED SET=    523   DIRECTION= UZ     TOTAL NODES=        2
NODES=    399    400

COUPLED SET=    524   DIRECTION= UZ     TOTAL NODES=        2
NODES=    423    424

COUPLED SET=    525   DIRECTION= UZ     TOTAL NODES=        2
NODES=    447    448

COUPLED SET=    526   DIRECTION= UZ     TOTAL NODES=        2
NODES=    377    378

COUPLED SET=    527   DIRECTION= UZ     TOTAL NODES=        2
NODES=    401    402

COUPLED SET=    528   DIRECTION= UZ     TOTAL NODES=        2
NODES=    425    426

COUPLED SET=    529   DIRECTION= UZ     TOTAL NODES=        2
NODES=    449    450

COUPLED SET=    530   DIRECTION= UZ     TOTAL NODES=        2
NODES=    452    453

COUPLED SET=    531   DIRECTION= UZ     TOTAL NODES=        2
NODES=    454    455

COUPLED SET=    532   DIRECTION= UZ     TOTAL NODES=        2
NODES=    456    457

COUPLED SET=    533   DIRECTION= UZ     TOTAL NODES=        2
NODES=    458    459

COUPLED SET=    534   DIRECTION= UZ     TOTAL NODES=        2
NODES=    460    461

COUPLED SET=    535   DIRECTION= UZ     TOTAL NODES=        2
NODES=    462    463

COUPLED SET=    536   DIRECTION= UZ     TOTAL NODES=        2
NODES=    465    466

COUPLED SET=    537   DIRECTION= UZ     TOTAL NODES=        2
NODES=    467    468

COUPLED SET=    538   DIRECTION= UZ     TOTAL NODES=        2
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```
NODES=    469    470

COUPLED SET=    539  DIRECTION= UZ     TOTAL NODES=      2
   DES=   471    472

COUPLED SET=    540  DIRECTION= UZ     TOTAL NODES=      2
NODES=    473    474

COUPLED SET=    541  DIRECTION= UZ     TOTAL NODES=      2
NODES=    232    233

COUPLED SET=    542  DIRECTION= UZ     TOTAL NODES=      3
NODES=    234    235    608

COUPLED SET=    543  DIRECTION= UZ     TOTAL NODES=      3
NODES=    236    237    609

COUPLED SET=    544  DIRECTION= UZ     TOTAL NODES=      3
NODES=    238    239    610

COUPLED SET=    545  DIRECTION= UZ     TOTAL NODES=      2
NODES=    240    241

COUPLED SET=    546  DIRECTION= UZ     TOTAL NODES=      2
NODES=    242    243

COUPLED SET=    547  DIRECTION= UZ     TOTAL NODES=      2
NODES=    476    477

   UPLED SET=   548  DIRECTION= UZ     TOTAL NODES=      3
NODES=    478    479    613

COUPLED SET=    549  DIRECTION= UZ     TOTAL NODES=      3
NODES=    480    481    614

COUPLED SET=    550  DIRECTION= UZ     TOTAL NODES=      3
NODES=    482    483    615

COUPLED SET=    551  DIRECTION= UZ     TOTAL NODES=      2
NODES=    484    485

COUPLED SET=    552  DIRECTION= UZ     TOTAL NODES=      2
NODES=    486    487

COUPLED SET=    553  DIRECTION= UX     TOTAL NODES=      2
NODES=    608    235

COUPLED SET=    554  DIRECTION= UX     TOTAL NODES=      2
NODES=    609    237

COUPLED SET=    555  DIRECTION= UX     TOTAL NODES=      2
NODES=    610    239

COUPLED SET=    556  DIRECTION= UX     TOTAL NODES=      2
   DES=   613    479

COUPLED SET=    557  DIRECTION= UX     TOTAL NODES=      2
NODES=    614    481

COUPLED SET=    558  DIRECTION= UX     TOTAL NODES=      2
```

```
NODES=   615   483

  IMUM COUPLED SET NUMBER= 558

LIST TEMPERATURES FOR ALL SELECTED NODES

 NODE    TEMPERATURE    FLUENCE
    1      153.00      0.00000E+00
    2      144.00      0.00000E+00
    3      129.00      0.00000E+00
    4      122.00      0.00000E+00
    5      121.00      0.00000E+00
    6      120.00      0.00000E+00
    7      103.00      0.00000E+00
    8      95.000      0.00000E+00
    9      85.000      0.00000E+00
   10      81.000      0.00000E+00
   11      153.00      0.00000E+00
   12      144.00      0.00000E+00
   13      129.00      0.00000E+00
   14      122.00      0.00000E+00
   15      121.00      0.00000E+00
   16      120.00      0.00000E+00
   17      103.00      0.00000E+00
   18      95.000      0.00000E+00
   19      85.000      0.00000E+00
   20      81.000      0.00000E+00

   DE    TEMPERATURE    FLUENCE
   21      155.00      0.00000E+00
   22      148.00      0.00000E+00
   23      148.00      0.00000E+00
   24      139.00      0.00000E+00
   25      139.00      0.00000E+00
   26      131.00      0.00000E+00
   27      131.00      0.00000E+00
   28      129.00      0.00000E+00
   29      129.00      0.00000E+00
   30      124.00      0.00000E+00
   31      124.00      0.00000E+00
   32      104.00      0.00000E+00
   33      104.00      0.00000E+00
   34      96.000      0.00000E+00
   35      96.000      0.00000E+00
   36      85.000      0.00000E+00
   37      85.000      0.00000E+00
   38      81.000      0.00000E+00
   39      155.00      0.00000E+00
   40      148.00      0.00000E+00

 NODE    TEMPERATURE    FLUENCE
   41      148.00      0.00000E+00
   42      139.00      0.00000E+00
   43      139.00      0.00000E+00
   44      131.00      0.00000E+00
   45      131.00      0.00000E+00
   46      129.00      0.00000E+00
   47      129.00      0.00000E+00
   48      124.00      0.00000E+00
   49      124.00      0.00000E+00
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```
   50     104.00      0.00000E+00
   51     104.00      0.00000E+00
   52     96.000      0.00000E+00
   53     96.000      0.00000E+00
   54     85.000      0.00000E+00
   55     85.000      0.00000E+00
   56     81.000      0.00000E+00
   57     157.00      0.00000E+00
   58     153.00      0.00000E+00
   59     153.00      0.00000E+00
   60     149.00      0.00000E+00

 NODE   TEMPERATURE    FLUENCE
   61     149.00      0.00000E+00
   62     143.50      0.00000E+00
   63     143.50      0.00000E+00
   64     140.00      0.00000E+00
   65     140.00      0.00000E+00
   66     135.00      0.00000E+00
   67     135.00      0.00000E+00
   68     110.00      0.00000E+00
   69     110.00      0.00000E+00
   70     98.000      0.00000E+00
   71     98.000      0.00000E+00
   72     85.400      0.00000E+00
   73     85.400      0.00000E+00
   74     81.000      0.00000E+00
   75     143.50      0.00000E+00
   76     143.50      0.00000E+00
   77     140.00      0.00000E+00
   78     140.00      0.00000E+00
   79     135.00      0.00000E+00
   80     135.00      0.00000E+00

 NODE   TEMPERATURE    FLUENCE
   81     110.00      0.00000E+00
   82     110.00      0.00000E+00
   83     98.000      0.00000E+00
   84     98.000      0.00000E+00
   85     85.400      0.00000E+00
   86     85.400      0.00000E+00
   87     81.000      0.00000E+00
   88     150.00      0.00000E+00
   89     150.00      0.00000E+00
   90     147.00      0.00000E+00
   91     147.00      0.00000E+00
   92     142.00      0.00000E+00
   93     142.00      0.00000E+00
   94     117.00      0.00000E+00
   95     117.00      0.00000E+00
   96     103.00      0.00000E+00
   97     103.00      0.00000E+00
   98     88.000      0.00000E+00
   99     88.000      0.00000E+00
  100     82.000      0.00000E+00

 NODE   TEMPERATURE    FLUENCE
  101     147.00      0.00000E+00
  102     147.00      0.00000E+00
  103     142.00      0.00000E+00
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  104     142.00      0.00000E+00
  105     117.00      0.00000E+00
  106     117.00      0.00000E+00
  107     103.00      0.00000E+00
  108     103.00      0.00000E+00
  109     88.000      0.00000E+00
  110     88.000      0.00000E+00
  111     82.000      0.00000E+00
  112     170.00      0.00000E+00
  113     170.00      0.00000E+00
  114     167.00      0.00000E+00
  115     167.00      0.00000E+00
  116     163.00      0.00000E+00
  117     163.00      0.00000E+00
  118     128.50      0.00000E+00
  119     128.50      0.00000E+00
  120     110.00      0.00000E+00

 NODE   TEMPERATURE    FLUENCE
  121     110.00      0.00000E+00
  122     91.000      0.00000E+00
  123     91.000      0.00000E+00
  124     84.000      0.00000E+00
  125     167.00      0.00000E+00
  126     167.00      0.00000E+00
  127     163.00      0.00000E+00
  128     163.00      0.00000E+00
  129     128.50      0.00000E+00
  130     128.50      0.00000E+00
  131     110.00      0.00000E+00
  132     110.00      0.00000E+00
  133     91.000      0.00000E+00
  134     91.000      0.00000E+00
  135     84.000      0.00000E+00
  136     213.00      0.00000E+00
  137     213.00      0.00000E+00
  138     208.00      0.00000E+00
  139     208.00      0.00000E+00
  140     201.00      0.00000E+00

 NODE   TEMPERATURE    FLUENCE
  141     201.00      0.00000E+00
  142     150.00      0.00000E+00
  143     150.00      0.00000E+00
  144     123.00      0.00000E+00
  145     123.00      0.00000E+00
  146     97.000      0.00000E+00
  147     97.000      0.00000E+00
  148     87.500      0.00000E+00
  149     208.00      0.00000E+00
  150     208.00      0.00000E+00
  151     201.00      0.00000E+00
  152     201.00      0.00000E+00
  153     150.00      0.00000E+00
  154     150.00      0.00000E+00
  155     123.00      0.00000E+00
  156     123.00      0.00000E+00
  157     97.000      0.00000E+00
  158     97.000      0.00000E+00
  159     87.500      0.00000E+00
```

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  160      190.00      0.00000E+00

 NODE   TEMPERATURE    FLUENCE
  161      190.00      0.00000E+00
  162      187.00      0.00000E+00
  163      187.00      0.00000E+00
  164      182.00      0.00000E+00
  165      182.00      0.00000E+00
  166      139.00      0.00000E+00
  167      139.00      0.00000E+00
  168      115.00      0.00000E+00
  169      115.00      0.00000E+00
  170      94.000      0.00000E+00
  171      94.000      0.00000E+00
  172      86.000      0.00000E+00
  173      187.00      0.00000E+00
  174      187.00      0.00000E+00
  175      182.00      0.00000E+00
  176      182.00      0.00000E+00
  177      139.00      0.00000E+00
  178      139.00      0.00000E+00
  179      115.00      0.00000E+00
  180      115.00      0.00000E+00

 NODE   TEMPERATURE    FLUENCE
  181      94.000      0.00000E+00
  182      94.000      0.00000E+00
  183      86.000      0.00000E+00
   84      154.00      0.00000E+00
  185      154.00      0.00000E+00
  186      151.00      0.00000E+00
  187      151.00      0.00000E+00
  188      147.00      0.00000E+00
  189      147.00      0.00000E+00
  190      117.00      0.00000E+00
  191      117.00      0.00000E+00
  192      101.00      0.00000E+00
  193      101.00      0.00000E+00
  194      87.000      0.00000E+00
  195      87.000      0.00000E+00
  196      82.000      0.00000E+00
  197      151.00      0.00000E+00
  198      151.00      0.00000E+00
  199      147.00      0.00000E+00
  200      147.00      0.00000E+00

 NODE   TEMPERATURE    FLUENCE
  201      117.00      0.00000E+00
  202      117.00      0.00000E+00
  203      101.00      0.00000E+00
  204      101.00      0.00000E+00
  205      87.000      0.00000E+00
  206      87.000      0.00000E+00
  207      82.000      0.00000E+00
   08      122.00      0.00000E+00
  209      122.00      0.00000E+00
  210      119.00      0.00000E+00
  211      119.00      0.00000E+00
  212      116.00      0.00000E+00
  213      116.00      0.00000E+00
```

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  214     96.000      0.00000E+00
  215     96.000      0.00000E+00
  216     87.000      0.00000E+00
  217     87.000      0.00000E+00
  218     81.000      0.00000E+00
  219     81.000      0.00000E+00
  220     79.000      0.00000E+00

 NODE   TEMPERATURE    FLUENCE
  221     119.00      0.00000E+00
  222     119.00      0.00000E+00
  223     116.00      0.00000E+00
  224     116.00      0.00000E+00
  225     96.000      0.00000E+00
  226     96.000      0.00000E+00
  227     87.000      0.00000E+00
  228     87.000      0.00000E+00
  229     81.000      0.00000E+00
  230     81.000      0.00000E+00
  231     79.000      0.00000E+00
  232     117.00      0.00000E+00
  233     117.00      0.00000E+00
  234     114.00      0.00000E+00
  235     114.00      0.00000E+00
  236     111.00      0.00000E+00
  237     111.00      0.00000E+00
  238     88.000      0.00000E+00
  239     88.000      0.00000E+00
   40     81.000      0.00000E+00

 NODE   TEMPERATURE    FLUENCE
  241     81.000      0.00000E+00
  242     78.500      0.00000E+00
  243     78.500      0.00000E+00
  244     78.000      0.00000E+00
  246     144.00      0.00000E+00
  247     129.00      0.00000E+00
  248     122.00      0.00000E+00
  249     121.00      0.00000E+00
  250     120.00      0.00000E+00
  251     103.00      0.00000E+00
  252     95.000      0.00000E+00
  253     85.000      0.00000E+00
  254     81.000      0.00000E+00
  256     144.00      0.00000E+00
  257     129.00      0.00000E+00
  258     122.00      0.00000E+00
  259     121.00      0.00000E+00
  260     120.00      0.00000E+00
  261     103.00      0.00000E+00
  262     95.000      0.00000E+00

 NODE   TEMPERATURE    FLUENCE
   63     85.000      0.00000E+00
   64     81.000      0.00000E+00
  266     148.00      0.00000E+00
  267     148.00      0.00000E+00
  268     139.00      0.00000E+00
  269     139.00      0.00000E+00
  270     131.00      0.00000E+00
```

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  271     131.00      0.00000E+00
  272     129.00      0.00000E+00
  273     129.00      0.00000E+00
   74     124.00      0.00000E+00
   75     124.00      0.00000E+00
  276     104.00      0.00000E+00
  277     104.00      0.00000E+00
  278     96.000      0.00000E+00
  279     96.000      0.00000E+00
  280     85.000      0.00000E+00
  281     85.000      0.00000E+00
  282     81.000      0.00000E+00
  284     148.00      0.00000E+00

 NODE   TEMPERATURE    FLUENCE
  285     148.00      0.00000E+00
  286     139.00      0.00000E+00
  287     139.00      0.00000E+00
  288     131.00      0.00000E+00
  289     131.00      0.00000E+00
  290     129.00      0.00000E+00
  291     129.00      0.00000E+00
  292     124.00      0.00000E+00
  293     124.00      0.00000E+00
  294     104.00      0.00000E+00
  295     104.00      0.00000E+00
  296     96.000      0.00000E+00
  297     96.000      0.00000E+00
   98     85.000      0.00000E+00
   99     85.000      0.00000E+00
  300     81.000      0.00000E+00
  302     153.00      0.00000E+00
  303     153.00      0.00000E+00
  304     149.00      0.00000E+00
  305     149.00      0.00000E+00

 NODE   TEMPERATURE    FLUENCE
  306     143.50      0.00000E+00
  307     143.50      0.00000E+00
  308     140.00      0.00000E+00
  309     140.00      0.00000E+00
  310     135.00      0.00000E+00
  311     135.00      0.00000E+00
  312     110.00      0.00000E+00
  313     110.00      0.00000E+00
  314     98.000      0.00000E+00
  315     98.000      0.00000E+00
  316     85.400      0.00000E+00
  317     85.400      0.00000E+00
  318     81.000      0.00000E+00
  319     143.50      0.00000E+00
  320     143.50      0.00000E+00
  321     140.00      0.00000E+00
  322     140.00      0.00000E+00
   23     135.00      0.00000E+00
  324     135.00      0.00000E+00
  325     110.00      0.00000E+00

 NODE   TEMPERATURE    FLUENCE
  326     110.00      0.00000E+00
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  327      98.000      0.00000E+00
  328      98.000      0.00000E+00
  329      85.400      0.00000E+00
  330      85.400      0.00000E+00
  331      81.000      0.00000E+00
  332      150.00      0.00000E+00
  333      150.00      0.00000E+00
  334      147.00      0.00000E+00
  335      147.00      0.00000E+00
  336      142.00      0.00000E+00
  337      142.00      0.00000E+00
  338      117.00      0.00000E+00
  339      117.00      0.00000E+00
  340      103.00      0.00000E+00
  341      103.00      0.00000E+00
  342      88.000      0.00000E+00
  343      88.000      0.00000E+00
  344      82.000      0.00000E+00
  345      147.00      0.00000E+00

 NODE    TEMPERATURE   FLUENCE
  346      147.00      0.00000E+00
  347      142.00      0.00000E+00
  348      142.00      0.00000E+00
  349      117.00      0.00000E+00
  350      117.00      0.00000E+00
  351      103.00      0.00000E+00
  352      103.00      0.00000E+00
  353      88.000      0.00000E+00
  354      88.000      0.00000E+00
  355      82.000      0.00000E+00
  356      170.00      0.00000E+00
  357      170.00      0.00000E+00
  358      167.00      0.00000E+00
  359      167.00      0.00000E+00
  360      163.00      0.00000E+00
  361      163.00      0.00000E+00
  362      128.50      0.00000E+00
  363      128.50      0.00000E+00
  364      110.00      0.00000E+00
  365      110.00      0.00000E+00

 NODE    TEMPERATURE   FLUENCE
  366      91.000      0.00000E+00
  367      91.000      0.00000E+00
  368      84.000      0.00000E+00
  369      167.00      0.00000E+00
  370      167.00      0.00000E+00
  371      163.00      0.00000E+00
  372      163.00      0.00000E+00
  373      128.50      0.00000E+00
  374      128.50      0.00000E+00
  375      110.00      0.00000E+00
  376      110.00      0.00000E+00
   77      91.000      0.00000E+00
  378      91.000      0.00000E+00
  379      84.000      0.00000E+00
  380      213.00      0.00000E+00
  381      213.00      0.00000E+00
  382      208.00      0.00000E+00
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  383     208.00      0.00000E+00
  384     201.00      0.00000E+00
  385     201.00      0.00000E+00

 NODE   TEMPERATURE    FLUENCE
  386     150.00      0.00000E+00
  387     150.00      0.00000E+00
  388     123.00      0.00000E+00
  389     123.00      0.00000E+00
  390     97.000      0.00000E+00
  391     97.000      0.00000E+00
  392     87.500      0.00000E+00
  393     208.00      0.00000E+00
  394     208.00      0.00000E+00
  395     201.00      0.00000E+00
  396     201.00      0.00000E+00
  397     150.00      0.00000E+00
  398     150.00      0.00000E+00
  399     123.00      0.00000E+00
  400     123.00      0.00000E+00
  401     97.000      0.00000E+00
  402     97.000      0.00000E+00
  403     87.500      0.00000E+00
  404     190.00      0.00000E+00
  405     190.00      0.00000E+00

 NODE   TEMPERATURE    FLUENCE
  406     187.00      0.00000E+00
  407     187.00      0.00000E+00
  408     182.00      0.00000E+00
  409     182.00      0.00000E+00
  410     139.00      0.00000E+00
  411     139.00      0.00000E+00
  412     115.00      0.00000E+00
  413     115.00      0.00000E+00
  414     94.000      0.00000E+00
  415     94.000      0.00000E+00
  416     86.000      0.00000E+00
  417     187.00      0.00000E+00
  418     187.00      0.00000E+00
  419     182.00      0.00000E+00
  420     182.00      0.00000E+00
  421     139.00      0.00000E+00
  422     139.00      0.00000E+00
  423     115.00      0.00000E+00
  424     115.00      0.00000E+00
  425     94.000      0.00000E+00

 NODE   TEMPERATURE    FLUENCE
  426     94.000      0.00000E+00
  427     86.000      0.00000E+00
  428     154.00      0.00000E+00
  429     154.00      0.00000E+00
  430     151.00      0.00000E+00
  431     151.00      0.00000E+00
  432     147.00      0.00000E+00
  433     147.00      0.00000E+00
  434     117.00      0.00000E+00
  435     117.00      0.00000E+00
  436     101.00      0.00000E+00
```

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 437     101.00     0.00000E+00
 438     87.000     0.00000E+00
 439     87.000     0.00000E+00
  40     82.000     0.00000E+00
 441     151.00     0.00000E+00
 442     151.00     0.00000E+00
 443     147.00     0.00000E+00
 444     147.00     0.00000E+00
 445     117.00     0.00000E+00

NODE   TEMPERATURE   FLUENCE
 446     117.00     0.00000E+00
 447     101.00     0.00000E+00
 448     101.00     0.00000E+00
 449     87.000     0.00000E+00
 450     87.000     0.00000E+00
 451     82.000     0.00000E+00
 452     122.00     0.00000E+00
 453     122.00     0.00000E+00
 454     119.00     0.00000E+00
 455     119.00     0.00000E+00
 456     116.00     0.00000E+00
 457     116.00     0.00000E+00
 458     96.000     0.00000E+00
 459     96.000     0.00000E+00
 460     87.000     0.00000E+00
 461     87.000     0.00000E+00
 462     81.000     0.00000E+00
  63     81.000     0.00000E+00
  64     79.000     0.00000E+00
 465     119.00     0.00000E+00

NODE   TEMPERATURE   FLUENCE
 466     119.00     0.00000E+00
 467     116.00     0.00000E+00
 468     116.00     0.00000E+00
 469     96.000     0.00000E+00
 470     96.000     0.00000E+00
 471     87.000     0.00000E+00
 472     87.000     0.00000E+00
 473     81.000     0.00000E+00
 474     81.000     0.00000E+00
 475     79.000     0.00000E+00
 476     117.00     0.00000E+00
 477     117.00     0.00000E+00
 478     114.00     0.00000E+00
 479     114.00     0.00000E+00
 480     111.00     0.00000E+00
 481     111.00     0.00000E+00
 482     88.000     0.00000E+00
 483     88.000     0.00000E+00
 484     81.000     0.00000E+00
 485     81.000     0.00000E+00

  DE   TEMPERATURE   FLUENCE
 486     78.500     0.00000E+00
 487     78.500     0.00000E+00
 488     78.000     0.00000E+00
 493     96.000     0.00000E+00
 494     85.000     0.00000E+00
```

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  502     98.000       0.00000E+00
  503     85.400       0.00000E+00
  509     88.000       0.00000E+00
   15     91.000       0.00000E+00
  521     97.000       0.00000E+00
  527     94.000       0.00000E+00
  532     101.00       0.00000E+00
  533     87.000       0.00000E+00
  538     87.000       0.00000E+00
  539     81.000       0.00000E+00
  551     96.000       0.00000E+00
  552     85.000       0.00000E+00
  560     98.000       0.00000E+00
  561     85.400       0.00000E+00
  567     88.000       0.00000E+00

 NODE   TEMPERATURE    FLUENCE
  573     91.000       0.00000E+00
  579     97.000       0.00000E+00
  585     94.000       0.00000E+00
  590     101.00       0.00000E+00
  591     87.000       0.00000E+00
  596     87.000       0.00000E+00
  597     81.000       0.00000E+00
  605     101.00       0.00000E+00
  606     105.00       0.00000E+00
  607     114.00       0.00000E+00
  608     114.00       0.00000E+00
   09     111.00       0.00000E+00
   10     88.000       0.00000E+00
  611     105.00       0.00000E+00
  612     114.00       0.00000E+00
  613     114.00       0.00000E+00
  614     111.00       0.00000E+00
  615     88.000       0.00000E+00
```

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PRINT  PRIN  NODAL STRESSES PER NODE

           ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE       SIG1            SIG2            SIG3             SI              SI
   11  -0.49969945E-01 -0.13814871     -0.31858959      0.26861964      0.23716
   12   0.66613128E-01 -0.19376230E-01 -0.94825473E-01  0.16143860      0.14239
   13  -0.11947303E-01 -0.37265571E-01 -0.10727279      0.95325491E-01  0.86787
   14  -0.53031508E-02 -0.97653133E-02 -0.57796446E-01  0.52493295E-01  0.50430
   15  -0.10790701E-01 -0.19867322E-01 -0.67685445E-01  0.56894744E-01  0.53124
   16   0.49013964E-04 -0.15465408E-01 -0.44592701E-01  0.44641715E-01  0.39255
   17   0.79430031E-01 -0.79697430E-02 -0.46667070E-01  0.12609710      0.11188
   18   0.64535384E-01 -0.41324532E-02 -0.58328765E-01  0.12286415      0.10701
   19  -0.36474643E-02 -0.12483041E-01 -0.78135768E-01  0.74488303E-01  0.70644
   20  -0.25282781E-01 -0.64453641E-01 -0.94942964E-01  0.69660183E-01  0.60483
   21  -0.50651531E-01 -0.20986708     -0.36796355      0.31731202      0.27480
   22   0.10967035E-01 -0.41951640E-01 -0.14649001      0.15745705      0.13878
   23   0.17237465E-01 -0.17769520E-01 -0.13722075      0.15445821      0.14027

           ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1
S  LL STRESSES ARE AT MIDDLE

 NODE       SIG1            SIG2            SIG3             SI              SI
   24  -0.40070429E-01 -0.65223028E-01 -0.15607547      0.11600504      0.10569
   25   0.31457235E-01 -0.11879897E-01 -0.80004326E-01  0.11146156      0.97320
   26   0.35978292E-01 -0.52622014E-02 -0.28758844E-01  0.64737136E-01  0.56761
   27   0.35952740E-01  0.12645857E-01 -0.39327643E-01  0.75280383E-01  0.66751
   28   0.19261884E-01  0.73932221E-03 -0.68556822E-01  0.87818706E-01  0.80178
   29   0.85386734E-02 -0.53024690E-01 -0.57111398E-01  0.65650072E-01  0.63705
   30   0.67876448E-02 -0.44373130E-01 -0.53664744E-01  0.60452389E-01  0.56383
   33   0.86526928E-01  0.13397594E-01 -0.10769973E-01  0.97296902E-01  0.87745
   34   0.80135762E-01  0.17463633E-01 -0.12896257E-01  0.93032019E-01  0.82172
   35   0.64662160E-01  0.17129491E-02 -0.30720494E-02  0.67734209E-01  0.65472
   36   0.27618274E-01  0.22647205E-02 -0.37436300E-01  0.65054575E-01  0.56793
   37   0.14805323E-01  0.30764270E-02 -0.27305331E-01  0.42110654E-01  0.37642
   38   0.11088755E-01 -0.18785157E-01 -0.85966129E-01  0.97054884E-01  0.86096

           ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE       SIG1            SIG2            SIG3             SI              SI
   39   0.83122416E-02 -0.15850198     -0.33492294      0.34323518      0.29728
   40  -0.19544488E-02 -0.15841428E-01 -0.16390007      0.16194562      0.15546
   41   0.17269048E-02  0.28493896E-03 -0.11388169      0.11560860      0.11489
   42   0.19140163E-01 -0.51253706E-02 -0.11520877      0.13434893      0.12400
   43   0.54665204E-01  0.36587991E-02 -0.15159298      0.20625819      0.18607
   44  -0.15710219E-01 -0.25415890E-01 -0.30745124      0.29174102      0.28701
   45  -0.28979668E-01 -0.61177020E-01 -0.24678768      0.21780802      0.20362
   46  -0.27896057E-01 -0.50866616E-01 -0.10689232      0.73996267E-01  0.70380
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   47  -0.11389460E-01 -0.49779608E-01 -0.92076246E-01  0.80686786E-01  0.69904
   48   0.26922098E-01 -0.82632409E-02 -0.55194413E-01  0.82116511E-01  0.71357
   49  -0.95642187E-02 -0.15132980E-01 -0.85363769E-01  0.75799550E-01  0.73174
   50   0.37694522E-01 -0.23717571E-01 -0.85184636E-01  0.12287916      0.10641
   51   0.86820780E-01  0.15902609E-01 -0.30921566E-01  0.11774235      0.10267

        ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=     15  SECTION=  1
 TIME=    0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE       SIG1            SIG2            SIG3            SI              SI
   52   0.24739921E-01 -0.25383828E-01 -0.72247674E-01  0.96987595E-01  0.84009
   53   0.30088766E-01 -0.96823442E-02 -0.49105357E-01  0.79194123E-01  0.68584
   54   0.68547432E-01  0.10061291E-01 -0.97364017E-02  0.78283833E-01  0.70501
   55   0.59868786E-01  0.37852865E-01  0.31750003E-01  0.28118783E-01  0.25618
   56   0.37848381E-01  0.10687460E-01 -0.29188237E-01  0.67036618E-01  0.58402
   57   0.13291929E-01 -0.12365803     -0.27702784      0.29031977      0.25155
   58   0.27904143E-01 -0.96057464E-02 -0.10227562      0.13017976      0.11606
   59  -0.55302173E-02 -0.21284849E-01 -0.17469724      0.16916703      0.16186
   60  -0.26171577E-02 -0.12971208E-01 -0.17524808      0.17263092      0.16769
   61   0.74642218E-03 -0.19272537E-01 -0.30459512      0.30534154      0.29584
   62  -0.48343456E-01 -0.16235320     -0.36773295      0.31938949      0.28034
   63  -0.62576267E-02 -0.14123116     -0.24924098      0.24298335      0.21086
   64  -0.51740335E-02 -0.84284418E-01 -0.15598193      0.15080790      0.13065

        ***** POST1 NODAL STRESS LISTING *****

  AD STEP      1  ITERATION=     15  SECTION=  1
 TIME=    0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE       SIG1            SIG2            SIG3            SI              SI
   65  -0.19551967E-01 -0.86658529E-01 -0.13351775      0.11396578      0.99215
   66   0.18759591E-01 -0.98763603E-02 -0.13190172      0.15066131      0.13858
   67   0.95092123E-02 -0.15137694E-01 -0.86137455E-01  0.95646667E-01  0.86013
   68   0.37692947E-01 -0.46440000E-02 -0.85961600E-01  0.12365455      0.10884
   69   0.80177242E-01  0.23282054E-01 -0.71583438E-01  0.15176068      0.13279
   70  -0.52143233E-03 -0.18005245E-01 -0.94290869E-01  0.93769436E-01  0.86365
   71   0.60826986E-02 -0.18970002E-01 -0.62402268E-01  0.68484967E-01  0.60017
   72   0.61632649E-01  0.77370150E-03 -0.40124666E-01  0.10175732      0.88687
   73   0.59868502E-01  0.78216935E-02 -0.66645048E-02  0.66533007E-01  0.60602
   74  -0.66688738E-02 -0.13240860E-01 -0.29188624E-01  0.22519750E-01  0.20058
   76  -0.68779254E-02 -0.12430433E-01 -0.13282831      0.12595039      0.12326
   77  -0.39501260E-01 -0.53341363E-01 -0.13285821      0.93356947E-01  0.87263
   78  -0.11923994E-01 -0.55005767E-01 -0.11850140      0.10657741      0.92861

        ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=     15  SECTION=  1
 TIME=    0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

   DE       SIG1            SIG2            SIG3            SI              SI
   79   0.34944792E-01  0.12407973E-01 -0.11816741      0.15311220      0.14318
   80   0.89231797E-02  0.29605297E-02 -0.90114882E-01  0.99038062E-01  0.96195
   81  -0.85565585E-02 -0.11696620E-01 -0.90201475E-01  0.81644917E-01  0.80121
   82   0.47265849E-02 -0.34296769E-02 -0.54595503E-01  0.59322088E-01  0.55693
   83   0.30460120E-01  0.16454219E-02 -0.54428074E-01  0.84888194E-01  0.74768
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   84    0.45257235E-01  0.75571528E-02 -0.23669392E-01  0.68926627E-01  0.59779
   85    0.38508626E-01 -0.46935009E-02 -0.24583885E-01  0.63092511E-01  0.55869
   86    0.35036475E-01 -0.38843883E-03 -0.88293604E-02  0.43865835E-01  0.40313
   87   -0.88263918E-02 -0.98017250E-02 -0.15659234E-01  0.68328425E-02  0.64011
   89    0.71575925E-01  0.35557533E-01 -0.34758840E-02  0.75051809E-01  0.66596
   90    0.30060206E-01  0.10123554E-01 -0.53506000E-01  0.83566206E-01  0.75595
   91    0.13466782E-01 -0.29187929E-01 -0.56242802E-01  0.69709584E-01  0.60872
   92    0.18880056E-01  0.17680715E-01  0.60918031E-02  0.12788253E-01  0.12232

          ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE        SIG1            SIG2            SIG3            SI              SI
   93    0.12786367E-01  0.36521221E-02  0.13636767E-02  0.11422690E-01  0.10467
   94    0.71098119E-02 -0.78755507E-02 -0.13655577E-01  0.20765389E-01  0.18563
   95    0.87910572E-02 -0.26773046E-04 -0.94965974E-02  0.18287655E-01  0.15840
   96    0.30797108E-01  0.57098944E-02 -0.62632514E-02  0.37060359E-01  0.32758
   97    0.46646786E-01  0.10588273E-01 -0.13950997E-01  0.60597784E-01  0.52794
   98    0.40229448E-01 -0.16623828E-02 -0.15196758E-01  0.55426206E-01  0.50050
   99    0.35036592E-01  0.10654368E-01  0.31083177E-02  0.31928275E-01  0.28903
  100    0.31100509E-02  0.12411308E-02 -0.15657930E-01  0.18767981E-01  0.17906
  101    0.27438996E-01 -0.14705577E-01 -0.28729220E-01  0.56168216E-01  0.50634
  102    0.28882356E-01 -0.14056757E-01 -0.26812152E-01  0.55694508E-01  0.50538
  103    0.34316664E-01  0.32357534E-01 -0.18441923E-02  0.36160857E-01  0.35222
  104    0.16926529E-01 -0.54311410E-02 -0.12835657E-01  0.29762186E-01  0.26837
  105    0.19843707E-01  0.39417232E-02 -0.74043000E-02  0.27248007E-01  0.23707

          ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE        SIG1            SIG2            SIG3            SI              SI
  106    0.99488308E-02  0.46519893E-02 -0.17281327E-01  0.27230158E-01  0.25006
  107    0.13515007E-02 -0.28796794E-02 -0.21141931E-01  0.22493432E-01  0.20704
  108   -0.16755882E-02 -0.33473970E-02 -0.22585063E-01  0.20909475E-01  0.20125
  109    0.38071595E-01 -0.76883557E-02 -0.15369283E-01  0.53440878E-01  0.50044
  110    0.44615370E-01  0.94133014E-02  0.48817587E-02  0.39733612E-01  0.37672
  111    0.59128333E-02  0.48835033E-02 -0.17386765E-01  0.23299598E-01  0.22802
  113    0.11480121      0.51581138E-01 -0.12735071E-01  0.12753628      0.11077
  114    0.75685513E-02 -0.24973829E-01 -0.28947211E-01  0.36515762E-01  0.34700
  115    0.56799678E-02 -0.26272659E-01 -0.40193411E-01  0.45873379E-01  0.40737
  116    0.20935417E-01  0.16640967E-01 -0.21545927E-01  0.42481344E-01  0.40505
  117    0.52194381E-02 -0.10273284E-01 -0.23263826E-01  0.28483264E-01  0.24698
  118    0.11258618E-01 -0.90045938E-03 -0.20954432E-01  0.32213050E-01  0.28175
  119    0.13542376E-01  0.10619596E-01 -0.15047696E-01  0.28590072E-01  0.27246

          ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE        SIG1            SIG2            SIG3            SI              SI
  120    0.60106867E-02  0.26885883E-02 -0.19574602E-01  0.25585289E-01  0.24096
  121   -0.57165731E-02 -0.86109093E-02 -0.26250937E-01  0.20534364E-01  0.19961
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 122   0.37889911E-01 -0.14620179E-01 -0.21226146E-01  0.59116056E-01  0.56105
 123   0.44615207E-01 -0.61362980E-02 -0.81614754E-02  0.52776682E-01  0.51793
 124  -0.81582245E-02 -0.96367679E-02 -0.17388433E-01  0.92302086E-02  0.85869
  25   0.31221734E-01 -0.29982383E-01 -0.41456245E-01  0.72677979E-01  0.67674
  26   0.19890724E-01 -0.36006256E-01 -0.51980486E-01  0.71871210E-01  0.65364
 127   0.31035716E-01  0.19829149E-01 -0.36046046E-01  0.67081762E-01  0.62239
 128   0.12067023E-01 -0.42764245E-03 -0.35265249E-01  0.47332272E-01  0.42485
 129   0.28611691E-01 -0.76956539E-02 -0.23199059E-01  0.51810749E-01  0.46059
 130   0.30294834E-01  0.12370492E-01 -0.19655462E-01  0.49950295E-01  0.43829
 131   0.14348527E-02 -0.57255387E-03 -0.49377780E-01  0.50812632E-01  0.49839
 132   0.34252192E-02  0.44491664E-03 -0.47325552E-01  0.50750771E-01  0.49328

       ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=    0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE       SIG1            SIG2            SIG3            SI              SI
 133   0.13499415      0.68032672E-02 -0.51258825E-02  0.14012003      0.13455
 134   0.14259168      0.19233725E-01  0.38754584E-02  0.13871622      0.13171
 135   0.38758334E-02 -0.10847207E-01 -0.58903219E-01  0.62779052E-01  0.56865
 137   0.12608629      0.47192401E-01 -0.40985277E-01  0.16707157      0.14699
 138   0.51039120E-02 -0.32083552E-01 -0.81778798E-01  0.86882710E-01  0.75502
 139   0.14303940E-01 -0.25548388E-01 -0.47538479E-01  0.61842418E-01  0.54296
 140   0.57467813E-01  0.14229379E-01 -0.47565281E-01  0.10503309      0.91433
 141   0.20568435E-02 -0.31261344E-03 -0.47326858E-01  0.49383702E-01  0.48242
 142   0.23863791E-01 -0.75800429E-02 -0.40523531E-01  0.64387322E-01  0.55766
  43   0.28418114E-01  0.92037705E-02 -0.29832476E-01  0.58250590E-01  0.51410
  44  -0.17319143E-02 -0.96748395E-02 -0.52329182E-01  0.50597268E-01  0.47130
 145  -0.89331471E-02 -0.13543433E-01 -0.51348592E-01  0.42415445E-01  0.40308
 146   0.13472315     -0.25750702E-02 -0.25846298E-01  0.16056944      0.15029

       ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=    0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE       SIG1            SIG2            SIG3            SI              SI
 147   0.14259167      0.15685855E-01 -0.19092006E-02  0.14450087      0.13655
 148  -0.19088010E-02 -0.14395077E-01 -0.58903249E-01  0.56994448E-01  0.51890
 149   0.38465856E-01  0.34977782E-01 -0.25654388E-02  0.41031295E-01  0.39403
 150   0.18604355E-01 -0.16525936E-01 -0.33153410E-01  0.51757764E-01  0.45768
 151   0.53528307E-01  0.25499438E-02 -0.35809859E-01  0.89338167E-01  0.77625
 152   0.19071253E-02 -0.67041455E-02 -0.37028145E-01  0.38935270E-01  0.35423
 153   0.13951546E-01 -0.10231226E-01 -0.33320776E-01  0.47272322E-01  0.40942
 154   0.23665317E-01  0.17469880E-01 -0.21991964E-01  0.45657281E-01  0.42896
 155  -0.46345020E-02 -0.11528573E-01 -0.35338629E-01  0.30704127E-01  0.27903
 156  -0.15911535E-01 -0.17392751E-01 -0.37727150E-01  0.21815615E-01  0.21114
 157   0.78910402E-01 -0.94489480E-02 -0.32542883E-01  0.11145329      0.10188
 158   0.91677559E-01  0.92528803E-02 -0.70903814E-02  0.98767941E-01  0.91695
 159  -0.70896454E-02 -0.18541688E-01 -0.32869779E-01  0.25780134E-01  0.22372

       ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=    0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE
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```
 NODE        SIG1            SIG2            SIG3              SI              SI
  161  -0.17914887E-02 -0.32724488E-01 -0.13189430      0.13010281      0.12077
  162   0.17456541E-01 -0.69016619E-01 -0.13683144      0.15428798      0.13394
   63   0.15691305E-01 -0.31330897E-01 -0.96235701E-01  0.11192701      0.97343
  164   0.38723346E-01 -0.25887576E-02 -0.96666499E-01  0.13538985      0.12018
  165   0.22390019E-02 -0.11294568E-01 -0.69732628E-01  0.71971630E-01  0.66249
  166   0.12126154E-01 -0.98993443E-02 -0.68790293E-01  0.80916447E-01  0.72459
  167   0.22343689E-01  0.80353343E-02 -0.58333340E-01  0.80677030E-01  0.74559
  168  -0.14069061E-01 -0.23997770E-01 -0.60532422E-01  0.46463361E-01  0.42380
  169   0.56769553E-02 -0.47729538E-02 -0.27506088E-01  0.33183044E-01  0.29386
  170   0.79114324E-01  0.13618533E-01 -0.11384938E-01  0.90499262E-01  0.80947
  171   0.91677582E-01  0.33128026E-01  0.13707162E-01  0.77970421E-01  0.70301
  172   0.13707774E-01  0.53334562E-02 -0.32869631E-01  0.46577406E-01  0.43006
  173   0.26242564E-01  0.16610356E-01 -0.95559231E-01  0.12180180      0.11728

         ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE        SIG1            SIG2            SIG3              SI              SI
  174   0.18445110E-01 -0.15548682E-01 -0.11746618      0.13591129      0.12250
  175   0.36735646E-01  0.25719562E-01 -0.11446699      0.15120264      0.14600
  176   0.34012251E-01 -0.21636680E-02 -0.93631074E-01  0.12764333      0.11394
  177  -0.13441345E-01 -0.17074159E-01 -0.10585852      0.92417178E-01  0.90655
  178   0.20827113E-01  0.85980069E-02 -0.63004477E-01  0.83831590E-01  0.78435
  179   0.14691001      0.25924195E-01 -0.38574017E-01  0.18548403      0.16309
   80   0.15546267      0.65966340E-02 -0.62789964E-01  0.21825264      0.19314
   81  -0.33981444E-01 -0.57669437E-01 -0.25812625      0.22414481      0.21328
  182  -0.22957566E-01 -0.50930414E-01 -0.23629060      0.21333303      0.20081
  183   0.12174295      0.15426926E-01 -0.22961376E-01  0.14470433      0.12983
  185   0.18951375E-01 -0.88649936E-01 -0.16574261      0.18469398      0.16103
  186   0.16127677E-01 -0.34536640E-01 -0.14569373      0.16182141      0.14336
  187   0.24013591E-01 -0.80443502E-02 -0.94167165E-01  0.11818076      0.10585

         ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE        SIG1            SIG2            SIG3              SI              SI
  188   0.41004708E-01  0.33223896E-01 -0.89868565E-01  0.13087327      0.12716
  189   0.41077258E-01  0.46349860E-02 -0.60187397E-01  0.10126466      0.88838
  190   0.34320510E-02 -0.10275510E-01 -0.82223232E-01  0.85655283E-01  0.79690
  191   0.20856208E-01  0.92726958E-02 -0.51780249E-01  0.72636456E-01  0.67593
  192   0.14793012      0.14369846E-01 -0.16111766E-01  0.16404189      0.15112
  193   0.15957010      0.31594136E-01 -0.18148129E-01  0.17771823      0.15880
  194   0.12209280E-01 -0.32671907E-01 -0.25556774      0.26777702      0.24839
  195   0.50227081E-02 -0.18076779E-01 -0.23629055      0.24131325      0.23063
  196   0.12174311      0.48280564E-01  0.50187897E-02  0.11672432      0.10220
  197   0.87873169E-01 -0.53039473E-01 -0.16280053      0.25067370      0.21764
  198   0.67065534E-01 -0.61201991E-02 -0.17663802      0.24370355      0.21659
   99   0.83637216E-01  0.11337580E-01 -0.16681082      0.25044804      0.22325
  200   0.71761933E-01 -0.36432273E-02 -0.11983739      0.19159932      0.16717

         ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
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```
 TIME=    0.00000E+00     LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

  )DE        SIG1            SIG2            SIG3             SI             SI
  201    0.61209706E-01 -0.63060945E-02 -0.12762354      0.18883325      0.16573
  202    0.41433124E-01  0.21477532E-01 -0.91496240E-01  0.13292936      0.12416
  203    0.53958950E-01 -0.52278742E-01 -0.84078598E-01  0.13803755      0.12520
  204    0.70250168E-01  0.10375233E-01 -0.34719324E-01  0.10496949      0.91206
  205    0.34967952E-01  0.98575320E-02 -0.10138724      0.13635520      0.12569
  206    0.26161623E-01  0.36843287E-02 -0.74168821E-01  0.10033044      0.91193
  207    0.42762696E-02 -0.15612325E-02 -0.56960421E-01  0.61236690E-01  0.58536
  209    0.13600617      0.87153901E-01 -0.92028700E-01  0.22803487      0.20808
  210    0.11128295      0.45158380E-01 -0.13748698      0.24876993      0.22317
  211    0.11594574      0.96026590E-02 -0.12740453      0.24335027      0.21130
  212    0.12723214      0.27060439E-01 -0.11229205      0.23952419      0.20835
  213    0.97383170E-01  0.59585840E-03 -0.91183041E-01  0.18856621      0.16332
  214    0.89448454E-01 -0.20669751E-02 -0.10158673      0.19103519      0.16548

         ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=    0.00000E+00     LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE        SIG1            SIG2            SIG3             SI             SI
  215    0.64097142E-01  0.41824489E-01 -0.68220110E-01  0.13231725      0.12270
  216    0.73214663E-01 -0.31931789E-01 -0.57394160E-01  0.13060882      0.11992
  217    0.59142477E-01  0.95406975E-03 -0.53858820E-01  0.11300130      0.97876
  218    0.11199762E-01  0.43636591E-03 -0.10786624      0.11906600      0.11406
  219    0.12309986E-01 -0.24341033E-02 -0.73962047E-01  0.86272033E-01  0.79926
  220    0.12776924E-01 -0.30156824E-01 -0.56628778E-01  0.69405701E-01  0.60668
  221    0.12106383     -0.90678096E-02 -0.57487711E-01  0.17855154      0.15993
  222    0.10626410      0.10438147E-01 -0.80413274E-01  0.18667737      0.16168
  223    0.11364530      0.46410454E-01 -0.70983432E-01  0.18462873      0.16184
  224    0.10408537      0.14968326E-01 -0.94448090E-01  0.19853346      0.17223
  225    0.79613402E-01 -0.26071212E-01 -0.12731402      0.20692742      0.17921
  226    0.12421136      0.49653578E-01 -0.10882436      0.23303572      0.20613
  227    0.15499279     -0.16002987E-01 -0.79544516E-01  0.23453730      0.21010

         ***** POST1 NODAL STRESS LISTING *****
```

```
 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=    0.00000E+00     LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE        SIG1            SIG2            SIG3             SI             SI
  228    0.44247578E-01  0.41701871E-01  0.26188363E-02  0.41628742E-01  0.40416
  229    0.43687108E-01  0.14978744E-01  0.25458540E-02  0.41141254E-01  0.36546
  230    0.64088269E-01  0.10862298E-01 -0.89813961E-03  0.64986409E-01  0.59977
  231    0.29136115E-01 -0.19532454E-01 -0.11794450      0.14708061      0.12978
  233    0.11254257      0.96020117E-01 -0.70760582E-01  0.18330315      0.17562
  234    0.82650394E-01 -0.61739564E-01 -0.83667886E-01  0.16631828      0.15651
  235    0.10693622     -0.39318404E-01 -0.79935460E-01  0.18687168      0.17023
  236    0.11426617     -0.33461227E-02 -0.70454345E-01  0.18472052      0.16195
  237    0.11907674     -0.18915954E-01 -0.81556133E-01  0.20063287      0.17779
  238    0.98320935E-01 -0.59952336E-01 -0.11814139      0.21646232      0.19402
  239    0.24840616      0.13145998E-01 -0.57510786E-01  0.30591695      0.27742
  240    0.26075538     -0.97985617E-02 -0.52510743E-01  0.31326612      0.29424
  241    0.41910583E-01  0.16223981E-01 -0.30502005E-01  0.72412588E-01  0.63587
```

```
          ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE       SIG1            SIG2            SIG3              SI             SI
  242   0.41308134E-01 -0.10509818E-01 -0.30522336E-01  0.71830470E-01  0.64207
  243   0.52079203E-01  0.93644177E-03 -0.46110897E-01  0.98190099E-01  0.85059
  244  -0.23884478E-01 -0.29458207E-01 -0.12214583      0.98261351E-01  0.95596
  256   0.66612679E-01 -0.19374487E-01 -0.94822502E-01  0.16143518      0.14239
  257  -0.11947183E-01 -0.37252834E-01 -0.10726734      0.95320160E-01  0.86785
  258  -0.53039603E-02 -0.97666486E-02 -0.57773620E-01  0.52469660E-01  0.50407
  259  -0.10783402E-01 -0.19864721E-01 -0.67676766E-01  0.56893364E-01  0.53121
  260   0.64161397E-04 -0.15465397E-01 -0.44591869E-01  0.44656031E-01  0.39266
  261   0.79469938E-01 -0.79697585E-02 -0.46610673E-01  0.12608061      0.11188
  262   0.64589873E-01 -0.41324899E-02 -0.58259490E-01  0.12284936      0.10700
  263  -0.36466888E-02 -0.12405399E-01 -0.78047844E-01  0.74401155E-01  0.70591
  264  -0.25283036E-01 -0.64273326E-01 -0.94939388E-01  0.69656353E-01  0.60467
  266   0.10966174E-01 -0.41953394E-01 -0.14649112      0.15745730      0.13878
```

```
          ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE       SIG1            SIG2            SIG3              SI             SI
  267   0.17237326E-01 -0.17767324E-01 -0.13721053      0.15444785      0.14026
  268  -0.40070602E-01 -0.65214936E-01 -0.15606505      0.11599444      0.10568
  269   0.31457246E-01 -0.11864264E-01 -0.80001774E-01  0.11145902      0.97320
  270   0.35978300E-01 -0.52564341E-02 -0.28744073E-01  0.64722373E-01  0.56749
  271   0.35952731E-01  0.12649316E-01 -0.39310353E-01  0.75263084E-01  0.66736
  272   0.19261878E-01  0.75100120E-03 -0.68546611E-01  0.87808488E-01  0.80172
  273   0.85386806E-02 -0.53021735E-01 -0.57099161E-01  0.65637842E-01  0.63697
  274   0.67876545E-02 -0.44377980E-01 -0.53643913E-01  0.60431567E-01  0.56372
  277   0.86578001E-01  0.13397603E-01 -0.10724766E-01  0.97302768E-01  0.87764
  278   0.80197407E-01  0.17463643E-01 -0.12848118E-01  0.93045525E-01  0.82194
  279   0.64763383E-01  0.17139878E-02 -0.30369023E-02  0.67800285E-01  0.65554
  280   0.27789254E-01  0.22650956E-02 -0.37450571E-01  0.65239825E-01  0.56943
  281   0.14999444E-01  0.30761630E-02 -0.27323900E-01  0.42323344E-01  0.37799
```

```
          ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE       SIG1            SIG2            SIG3              SI             SI
  282   0.11287086E-01 -0.18785405E-01 -0.85980575E-01  0.97267661E-01  0.86257
  284  -0.19529482E-02 -0.15838265E-01 -0.16389836      0.16194541      0.15546
  285   0.17296291E-02  0.28972884E-03 -0.11387014      0.11559977      0.11488
  286   0.19139662E-01 -0.51130253E-02 -0.11519214      0.13433180      0.12399
  287   0.54718505E-01  0.36588788E-02 -0.15150925      0.20622775      0.18602
  288  -0.15613787E-01 -0.25416037E-01 -0.30739270      0.29177891      0.28700
  289  -0.28979700E-01 -0.61097145E-01 -0.24676547      0.21778577      0.20363
  290  -0.27896112E-01 -0.50773991E-01 -0.10687721      0.78981095E-01  0.70388
  291  -0.11389516E-01 -0.49714590E-01 -0.92069285E-01  0.80679769E-01  0.69899
  292   0.26922035E-01 -0.82447840E-02 -0.55137137E-01  0.82059172E-01  0.71306
  293  -0.95642575E-02 -0.15122095E-01 -0.85272674E-01  0.75708416E-01  0.73088
```

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  294   0.37706548E-01 -0.23717634E-01 -0.85067831E-01  0.12277438      0.10632
  295   0.86838959E-01  0.15902619E-01 -0.30828263E-01  0.11766722      0.10261

         ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00     LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE       SIG1            SIG2            SIG3            SI             SI
  296   0.24813568E-01 -0.25383689E-01 -0.72194333E-01  0.97007901E-01  0.84028
  297   0.30139843E-01 -0.96818485E-02 -0.49020752E-01  0.79160595E-01  0.68555
  298   0.68543479E-01  0.10061930E-01 -0.95774111E-02  0.78120890E-01  0.70387
  299   0.59897197E-01  0.38060816E-01  0.31749915E-01  0.28147282E-01  0.25582
  300   0.38065889E-01  0.10687314E-01 -0.29158072E-01  0.67223960E-01  0.58550
  302   0.27905187E-01 -0.96022219E-02 -0.10227381      0.13017900      0.11606
  303  -0.55252310E-02 -0.21284547E-01 -0.17468347      0.16915824      0.16185
  304  -0.26182457E-02 -0.12961968E-01 -0.17522775      0.17260951      0.16767
  305   0.78010535E-03 -0.19271783E-01 -0.30449244      0.30527254      0.29575
  306  -0.48343354E-01 -0.16228926     -0.36764217      0.31929881      0.28027
  307  -0.62576574E-02 -0.14114732     -0.24922273      0.24296507      0.21084
  308  -0.51740758E-02 -0.84226864E-01 -0.15593176      0.15075768      0.13061
  309  -0.19552022E-01 -0.86640975E-01 -0.13346332      0.11391130      0.99169

         ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00     LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE       SIG1            SIG2            SIG3            SI             SI
  310   0.18759530E-01 -0.98639991E-02 -0.13183835      0.15059788      0.13852
  311   0.95091621E-02 -0.15126837E-01 -0.86046321E-01  0.95555483E-01  0.85928
  312   0.37704957E-01 -0.46440623E-02 -0.85844781E-01  0.12354974      0.10874
  313   0.80187977E-01  0.23281929E-01 -0.71482558E-01  0.15167054      0.13270
  314  -0.47654025E-03 -0.18005554E-01 -0.94208325E-01  0.93731785E-01  0.86312
  315   0.61016745E-02 -0.18970077E-01 -0.62284992E-01  0.68386666E-01  0.59922
  316   0.61624792E-01  0.77371680E-03 -0.39961147E-01  0.10158594      0.88549
  317   0.59897077E-01  0.78216057E-02 -0.64567178E-02  0.66353795E-01  0.60491
  318  -0.64515379E-02 -0.13241095E-01 -0.29158198E-01  0.22706660E-01  0.20187
  320  -0.68779128E-02 -0.12408466E-01 -0.13278503      0.12590711      0.12323
  321  -0.39501212E-01 -0.53317613E-01 -0.13281314      0.93311930E-01  0.87228
  322  -0.11924036E-01 -0.54995801E-01 -0.11844754      0.10652350      0.92813
  323   0.34944748E-01  0.12421920E-01 -0.11811419      0.15305894      0.14313

         ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00     LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE       SIG1            SIG2            SIG3            SI             SI
  324   0.89258806E-02  0.29605334E-02 -0.90070927E-01  0.98996807E-01  0.96153
  325  -0.85571614E-02 -0.11693088E-01 -0.90145466E-01  0.81588305E-01  0.80066
   26   0.47266416E-02 -0.34220295E-02 -0.54552980E-01  0.59279621E-01  0.55654
  327   0.30468142E-01  0.16454901E-02 -0.54378891E-01  0.84847033E-01  0.74727
  328   0.45251426E-01  0.75571054E-02 -0.23644669E-01  0.68896095E-01  0.59754
  329   0.38501401E-01 -0.46935502E-02 -0.24555043E-01  0.63056444E-01  0.55840
  330   0.35026844E-01 -0.38842569E-03 -0.88541292E-02  0.43880974E-01  0.40320
  331  -0.88525788E-02 -0.98017851E-02 -0.15669010E-01  0.68164310E-02  0.63948
```

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 333    0.71575931E-01  0.35585197E-01 -0.34729459E-02  0.75048877E-01  0.66599
 334    0.30108668E-01  0.10123578E-01 -0.53485624E-01  0.83594293E-01  0.75609
 335    0.13507580E-01 -0.29187971E-01 -0.56219767E-01  0.69727347E-01  0.60891
  36    0.18878603E-01  0.17680754E-01  0.61603304E-02  0.12718272E-01  0.12163
  37    0.12789472E-01  0.36522097E-02  0.14071442E-02  0.11382328E-01  0.10442

         ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE        SIG1            SIG2            SIG3            SI              SI
  338   0.71491559E-02 -0.78758024E-02 -0.13635730E-01  0.20784886E-01  0.18586
  339   0.87911143E-02  0.32057150E-06 -0.94735205E-02  0.18264635E-01  0.15821
  340   0.30806601E-01  0.57099627E-02 -0.62155401E-02  0.37022141E-01  0.32731
  341   0.46640252E-01  0.10588249E-01 -0.13925572E-01  0.60565824E-01  0.52767
  342   0.40221448E-01 -0.16623993E-02 -0.15167175E-01  0.55388623E-01  0.50022
  343   0.35026949E-01  0.10654383E-01  0.30835611E-02  0.31943388E-01  0.28911
  344   0.30839883E-02  0.12411224E-02 -0.15667882E-01  0.18751870E-01  0.17901
  345   0.27445684E-01 -0.14716532E-01 -0.28729223E-01  0.56174906E-01  0.50643
  346   0.28892311E-01 -0.14064715E-01 -0.26812152E-01  0.55704464E-01  0.50550
  347   0.34316701E-01  0.32369394E-01 -0.18539886E-02  0.36170689E-01  0.35237
  348   0.16941497E-01 -0.54311481E-02 -0.12839755E-01  0.29781251E-01  0.26854
  349   0.19861907E-01  0.39417193E-02 -0.74087753E-02  0.27270682E-01  0.23727
  350   0.99565581E-02  0.46519923E-02 -0.17278209E-01  0.27234767E-01  0.25008

         ***** POST1 NODAL STRESS LISTING *****

   AD STEP     1  ITERATION=    15  SECTION=  1
 IME=   0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE        SIG1            SIG2            SIG3            SI              SI
  351   0.13638805E-02 -0.28796717E-02 -0.21141948E-01  0.22505829E-01  0.20712
  352  -0.16756406E-02 -0.33420536E-02 -0.22586613E-01  0.20910973E-01  0.20129
  353   0.38072491E-01 -0.76883499E-02 -0.15365907E-01  0.53438398E-01  0.50043
  354   0.44614697E-01  0.94133012E-02  0.48857658E-02  0.39728931E-01  0.37669
  355   0.59128334E-02  0.48877292E-02 -0.17387498E-01  0.23300331E-01  0.22805
  357   0.11480121      0.51586087E-01 -0.12741549E-01  0.12754276      0.11078
  358   0.75771677E-02 -0.24986717E-01 -0.28947210E-01  0.36524378E-01  0.34713
  359   0.56907547E-02 -0.26281446E-01 -0.40193414E-01  0.45884169E-01  0.40749
  360   0.20935416E-01  0.16649759E-01 -0.21552617E-01  0.42488033E-01  0.40515
  361   0.52311883E-02 -0.10273292E-01 -0.23264706E-01  0.28495894E-01  0.24710
  362   0.11271004E-01 -0.90047138E-03 -0.20953085E-01  0.32224088E-01  0.28183
  363   0.13542385E-01  0.10627997E-01 -0.15045258E-01  0.28587642E-01  0.27247
  364   0.60106928E-02  0.27017433E-02 -0.19575393E-01  0.25586086E-01  0.24102

         ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

   E         SIG1            SIG2            SIG3            SI              SI
  65   -0.57122207E-02 -0.86109453E-02 -0.26251512E-01  0.20539292E-01  0.19254
  366   0.37890629E-01 -0.14620186E-01 -0.21222580E-01  0.59113210E-01  0.56104
  367   0.44614531E-01 -0.61362981E-02 -0.81574658E-02  0.52771997E-01  0.51791
  368  -0.81539745E-02 -0.96367673E-02 -0.17389191E-01  0.92352161E-02  0.85903
  369   0.31223856E-01 -0.29988464E-01 -0.41456245E-01  0.72685101E-01  0.67683
```

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  370    0.19897187E-01 -0.36012106E-01 -0.51980487E-01  0.71877674E-01  0.65372
  371    0.31035716E-01  0.19835951E-01 -0.36052203E-01  0.67087919E-01  0.62248
  372    0.12073905E-01 -0.42764279E-03 -0.35271760E-01  0.47345665E-01  0.42497
  373    0.28619598E-01 -0.76956560E-02 -0.23206497E-01  0.51826095E-01  0.46072
  374    0.30301605E-01  0.12370492E-01 -0.19661871E-01  0.49963477E-01  0.43840
  375    0.14348498E-02 -0.56437881E-03 -0.49385540E-01  0.50820390E-01  0.49850
  376    0.34316100E-02  0.44490504E-03 -0.47330610E-01  0.50762220E-01  0.49336
  377    0.13499649      0.68032634E-02 -0.51267072E-02  0.14012320      0.13455

         ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00     LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE        SIG1            SIG2            SIG3             SI              SI
  378    0.14259202      0.19233724E-01  0.38777354E-02  0.13871428      0.13170
  379    0.38782406E-02 -0.10847206E-01 -0.58902881E-01  0.62781122E-01  0.56866
  381    0.12608629      0.47196643E-01 -0.40988256E-01  0.16707454      0.14699
  382    0.51086509E-02 -0.32083552E-01 -0.81782496E-01  0.86891147E-01  0.75509
  383    0.14309804E-01 -0.25548388E-01 -0.47543730E-01  0.61853533E-01  0.54306
  384    0.57467813E-01  0.14235553E-01 -0.47570809E-01  0.10503862      0.91438
  385    0.20633788E-02 -0.31257951E-03 -0.47333058E-01  0.49396437E-01  0.48252
  386    0.23870164E-01 -0.75800408E-02 -0.40529438E-01  0.64399602E-01  0.55776
  387    0.28423906E-01  0.92037722E-02 -0.29837907E-01  0.58261813E-01  0.51420
  388   -0.17319205E-02 -0.96655748E-02 -0.52338029E-01  0.50606108E-01  0.47142
  389   -0.89331709E-02 -0.13535377E-01 -0.51355303E-01  0.42422132E-01  0.40318
  390    0.13472520     -0.25750715E-02 -0.25846840E-01  0.16057204      0.15029
  391    0.14259201      0.15685855E-01 -0.19069233E-02  0.14449893      0.13655

         ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00     LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE        SIG1            SIG2            SIG3             SI              SI
  392   -0.19063923E-02 -0.14395075E-01 -0.58902913E-01  0.56996521E-01  0.51891
  393    0.38465864E-01  0.34983521E-01 -0.25695629E-02  0.41035427E-01  0.39409
  394    0.18607692E-01 -0.16525936E-01 -0.33154007E-01  0.51761699E-01  0.45771
  395    0.53528307E-01  0.25548077E-02 -0.35811841E-01  0.89340148E-01  0.77627
  396    0.19071285E-02 -0.66964669E-02 -0.37029876E-01  0.38937005E-01  0.35427
  397    0.13957680E-01 -0.10231237E-01 -0.33319382E-01  0.47277061E-01  0.40946
  398    0.23670104E-01  0.17469885E-01 -0.21994446E-01  0.45664550E-01  0.42901
  399   -0.46345076E-02 -0.11515975E-01 -0.35348588E-01  0.30714080E-01  0.27916
  400   -0.15906735E-01 -0.17392896E-01 -0.37739492E-01  0.21832757E-01  0.21128
  401    0.78908778E-01 -0.94489527E-02 -0.32550043E-01  0.11145882      0.10189
  402    0.91671501E-01  0.92528800E-02 -0.71037983E-02  0.98775300E-01  0.91697
  403   -0.71037374E-02 -0.18541682E-01 -0.32876094E-01  0.25772357E-01  0.22366
  405   -0.17737702E-02 -0.32724491E-01 -0.13190540      0.13013163      0.12079

         ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00     LOAD CASE=  1
 ELL STRESSES ARE AT MIDDLE

 NODE        SIG1            SIG2            SIG3             SI              SI
  406    0.17457480E-01 -0.69016620E-01 -0.13683075      0.15428823      0.13394
  407    0.15692860E-01 -0.31330898E-01 -0.96234517E-01  0.11192738      0.97043
```

```
  408   0.38723345E-01 -0.25868267E-02 -0.96665548E-01  0.13538889      0.12018
  409   0.22390001E-02 -0.11290569E-01 -0.69730675E-01  0.71969675E-01  0.66249
   10   0.12130006E-01 -0.98993533E-02 -0.68786620E-01  0.80916626E-01  0.72458
   11   0.22346234E-01  0.80353342E-02 -0.58333574E-01  0.80679809E-01  0.74561
  412  -0.14069064E-01 -0.23990783E-01 -0.60536772E-01  0.46467709E-01  0.42386
  413   0.56769312E-02 -0.47693955E-02 -0.27517311E-01  0.33194242E-01  0.29397
  414   0.79113110E-01  0.13618537E-01 -0.11392517E-01  0.90505626E-01  0.80951
  415   0.91671523E-01  0.33128025E-01  0.13693747E-01  0.77977776E-01  0.70304
  416   0.13693695E-01  0.53334589E-02 -0.32875955E-01  0.46569650E-01  0.43003
  417   0.26273452E-01  0.16610351E-01 -0.95577777E-01  0.12185123      0.11731
  418   0.18474726E-01 -0.15548700E-01 -0.11746860      0.13594333      0.12252

        ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=    0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE         SIG1            SIG2            SIG3            SI              SI
  419   0.36763433E-01  0.25719545E-01 -0.11446618      0.15122961      0.14602
  420   0.34032047E-01 -0.21638090E-02 -0.93601762E-01  0.12763381      0.11393
  421  -0.13399594E-01 -0.17074347E-01 -0.10583823      0.92438639E-01  0.90657
```

```
 NODE        SIG1           SIG2           SIG3            SI              SI
  446   0.41500113E-01  0.21477568E-01 -0.91481233E-01  0.13298135      0.12418
  447   0.54029137E-01 -0.52278703E-01 -0.84055288E-01  0.13808442      0.12525
  448   0.70308325E-01  0.10375134E-01 -0.34689024E-01  0.10499735      0.91233
  449   0.35060378E-01  0.98574204E-02 -0.10137855      0.13643893      0.12574
  450   0.26161549E-01  0.37904728E-02 -0.74173372E-01  0.10033492      0.91230
  451   0.43874751E-02 -0.15611467E-02 -0.56965358E-01  0.61352833E-01  0.58605
  453   0.13602876      0.87192570E-01 -0.92060187E-01  0.22808894      0.20814
  454   0.11133094      0.45158414E-01 -0.13752555      0.24885650      0.22325
  455   0.11597858      0.96026522E-02 -0.12742030      0.24339888      0.21134
  456   0.12726658      0.27060431E-01 -0.11230853      0.23957511      0.20840
  457   0.97447637E-01  0.59572108E-03 -0.91204485E-01  0.18865212      0.16339
  458   0.89531310E-01 -0.20671512E-02 -0.10161524      0.19114655      0.16558
  459   0.64175015E-01  0.41824519E-01 -0.68215981E-01  0.13239100      0.12275

         ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=     15  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE        SIG1           SIG2           SIG3            SI              SI
  460   0.73298611E-01 -0.31931753E-01 -0.57384607E-01  0.13068322      0.11999
  461   0.59190362E-01  0.95400102E-03 -0.53818277E-01  0.11300864      0.97883
  462   0.11288176E-01  0.43629294E-03 -0.10785357      0.11914175      0.11410
  463   0.12415984E-01 -0.24341830E-02 -0.73966446E-01  0.86382430E-01  0.79997
  464   0.12888213E-01 -0.30156752E-01 -0.56633785E-01  0.69521998E-01  0.60775
  465   0.12114538     -0.90677879E-02 -0.57515913E-01  0.17866130      0.16003
  466   0.10638494      0.10438159E-01 -0.80479864E-01  0.18686481      0.16184
  467   0.11377167      0.46410469E-01 -0.71052731E-01  0.18482440      0.16201
  468   0.10417090      0.14968154E-01 -0.94498213E-01  0.19866911      0.17235
  469   0.79724895E-01 -0.26071361E-01 -0.12738086      0.20710576      0.17937
  470   0.12436637      0.49653780E-01 -0.10885010      0.23321647      0.20627
  471   0.15515671     -0.16002756E-01 -0.79561045E-01  0.23471776      0.21027
  472   0.44251854E-01  0.41698411E-01  0.25905081E-02  0.41661346E-01  0.40445

         ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=     15  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE        SIG1           SIG2           SIG3            SI              SI
  473   0.43687943E-01  0.14978636E-01  0.25136754E-02  0.41174268E-01  0.36571
  474   0.64089237E-01  0.10862317E-01 -0.94434721E-03  0.65033584E-01  0.60007
  475   0.29116296E-01 -0.19532563E-01 -0.11797194      0.14708824      0.12979
  477   0.11254225      0.96092246E-01 -0.70781812E-01  0.18332406      0.17567
  478   0.82729558E-01 -0.61739321E-01 -0.83693923E-01  0.16642348      0.15660
  479   0.10705710     -0.39318459E-01 -0.80002016E-01  0.18705911      0.17039
  480   0.11439264     -0.33461509E-02 -0.70523694E-01  0.18491633      0.16212
  481   0.11916399     -0.18915083E-01 -0.81609026E-01  0.20077302      0.17791
  482   0.98431390E-01 -0.59951135E-01 -0.11820854      0.21663993      0.19418
  483   0.24856363      0.13146118E-01 -0.57538901E-01  0.30610253      0.27759
  484   0.26093818     -0.98339721E-02 -0.52510507E-01  0.31344869      0.29443
   85   0.41913521E-01  0.16223713E-01 -0.30532187E-01  0.72445708E-01  0.63617
  486   0.41311110E-01 -0.10509777E-01 -0.30556806E-01  0.71867916E-01  0.64235

         ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=     15  SECTION=  1
```

```
 TIME=   0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

  ODE         SIG1            SIG2            SIG3             SI            SI
  487   0.52076058E-01  0.93630008E-03 -0.46152831E-01  0.98228889E-01  0.85092
  488  -0.23898306E-01 -0.29458432E-01 -0.12217915      0.98280841E-01  0.95622

MAXIMUMS
NODE          484              21              21              39             39
VALUE     0.26093818      -0.20986708     -0.36796355      0.34323518      0.2972
                    max tension          max stress
ESEL   FOR LABEL= TYPE   FROM      2 TO      2 BY     1

    24  ELEMENTS (OF    432  DEFINED) SELECTED BY  ESEL  COMMAND.

    50  NODES (OF    610  DEFINED) SELECTED FROM    24  SELECTED ELEMENTS BY  N

PRINT  PRIN  NODAL STRESSES PER NODE

        ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE         SIG1            SIG2            SIG3             SI            SI
    1   0.00000000E+00 -3.8789619      -3.8789715       3.8789715       3.8789
    2   0.00000000E+00 -1.2312101      -1.5541415       1.5541415       1.4628
    3   0.97080359      0.00000000E+00 -0.40830314      1.3791067       1.2531
    4    2.0514487      0.10949885     -0.47181199E-01  2.0986299       2.0255
    5    2.1119983      0.13134757      0.00000000E+00  2.1119983       2.0509
    6    2.1084328      0.55161145E-01  0.00000000E+00  2.1084328       2.0814
    7    4.3224602       1.3099720      0.00000000E+00  4.3224602       3.8677
    8    4.8348788      0.86811748      0.00000000E+00  4.8348788       4.4652
    9    5.7646625       1.0705878      0.00000000E+00  5.7646625       5.3118
   10    6.1674020       1.1835111      0.00000000E+00  6.1674020       5.6690
   31    1.8982293      0.33312611E-01 -0.28563054E-02  1.9010857  )    1.8834
   32    4.5459302      0.92069634     -0.29051317E-02  4.5488353  )    4.2421
   75   0.00000000E+00 -0.53679007     -0.54295715      0.54295715 )    0.53990

        ***** POST1 NODAL STRESS LISTING *****          bottom plate

 LOAD STEP     1  ITERATION=    15  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE
                                                                    liner
 NODE         SIG1            SIG2            SIG3             SI            SI
   88   0.30559899E-01 -0.45936070E-01 -0.60563774      0.63619764 (    0.60168
  112   0.39733066E-01 -0.19868935     -0.92022432      0.95995738 (    0.87209
  136   0.00000000E+00 -0.56818787      -1.4538588      1.4538588  (     1.2695
  160   0.00000000E+00  -1.5763491      -1.6827548      1.6827548  (     1.6327
  184   0.00000000E+00  -1.1451513      -1.6097803      1.6097803  (     1.4517
  208   0.70040191      0.00000000E+00 -0.44335733      1.1437592  (     1.0251
  232    1.7423364       1.0781777     -0.51210608E-01  1.7935470        1.6258
  246   0.00000000E+00  -1.2311875      -1.5541415      1.5541415        1.4628
  247   0.97080359      0.00000000E+00 -0.40828155      1.3790851        1.2531
  248    2.0514487      0.10945444     -0.47195156E-01  2.0986439        2.0256
  249    2.1119983      0.13126032      0.00000000E+00  2.1119983        2.0509
  250    2.1084328      0.55104367E-01  0.00000000E+00  2.1084328        2.0814
  251    4.3224602       1.3098163      0.00000000E+00  4.3224602        3.8677
```

```
        ***** POST1 NODAL STRESS LISTING *****

 )AD STEP      1  ITERATION=    15  SECTION=  1
 IME=    0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 NODE        SIG1           SIG2           SIG3          SI           SI
  252     4.8348788      0.86779566    0.00000000E+00   4.8348788      4.4654
  253     5.7646625      1.0698432     0.00000000E+00   5.7646625      5.3120
  254     6.1674020      1.1823712     0.00000000E+00   6.1674020      5.6694
  275     1.8982293      0.33298298E-01 -0.24849872E-02 1.9007143      1.8832
  276     4.5459302      0.92066873    -0.24360981E-02  4.5483662      4.2419
  319   0.00000000E+00 -0.53674904     -0.54295715     0.54295715     0.53987
  332   0.30559899E-01 -0.45936070E-01 -0.60562260     0.63618249     0.60167
  356   0.39733066E-01 -0.19868935     -0.92022803     0.95996110     0.87210
  380   0.00000000E+00 -0.56818787      -1.4538584      1.4538584      1.2695
  404   0.00000000E+00  -1.5763504      -1.6827548      1.6827548      1.6327
  428   0.00000000E+00  -1.1451491      -1.6097803      1.6097803      1.4517
  452    0.70040191    0.00000000E+00 -0.44336787       1.1437698      1.0251
  476     1.7424303      1.0781777     -0.51219084E-01  1.7936494      1.6258

        ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP      1  ITERATION=    15  SECTION=  1
 TIME=    0.00000E+00      LOAD CASE=  1
SHELL STRESSES ARE AT MIDDLE

 ODE         SIG1           SIG2           SIG3          SI           SI
  ,05     3.4436507      3.4434940     0.00000000E+00   3.4436507      3.4435
  606     2.6127054      2.5659266     0.00000000E+00   2.6127054      2.5899
  607     2.4196213      1.7610405     0.00000000E+00   2.4196213      2.1678
  608     2.0872626      1.9983592     0.00000000E+00   2.0872626      2.0450
  609     2.4402242      1.6192528     0.00000000E+00   2.4402242      2.1625
  610     5.3338550      1.3426721     0.00000000E+00   5.3338550      4.8053
  611     2.6127054      2.5659124     0.00000000E+00   2.6127054      2.5899
  612     2.4196278      1.7610405     0.00000000E+00   2.4196278      2.1678
  613     2.0873145      1.9983496     0.00000000E+00   2.0873145      2.0450
  614     2.4402242      1.6194794     0.00000000E+00   2.4402242      2.1625
  615     5.3338550      1.3432715     0.00000000E+00   5.3338550      4.8051
```

cover plate

```
MAXIMUMS
NODE         10               1               1               10           254
VALUE     6.1674020      -3.8789619      -3.8789715       6.1674020       5.669

ESEL   FOR LABEL= TYPE   FROM      3 TO      3 BY     1

    34  ELEMENTS (OF    432  DEFINED) SELECTED BY  ESEL  COMMAND.

PRINT ELEMENT STRESS ITEMS PER ELEMENT

        ***** POST1 ELEMENT STRESS LISTING *****

 LOAD STEP      1  ITERATION=    15  SECTION=  1
   ME=    0.00000E+00      LOAD CASE=  1

 ELEM       SIG
   78     5.0192426
   79     5.0197294
   30    -0.20863126
```

```
  81    0.34575605
  82     4.1717945
  83     8.3283509
  84     11.357610
  85     22.260990
  86     28.770849
  87     11.147482
  88     3.8774260
  89     7.7453509
  90   -0.20670294
  91    0.34562934

       ***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP     1  ITERATION=    15  SECTION=  1
TIME=    0.00000E+00     LOAD CASE=  1

ELEM          SIG
  92     4.1720909
  93     8.3283769
  94     11.357609
  95     22.260989
  96     28.770446      — max. vertical rebars
  97     11.147090
  98     3.8792454
  99     7.7452418
 100     5.4677720
 101     6.1714419
 102     4.9486159
 103     6.1672162
 104     5.9807687
 105     6.2699157

       ***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP     1  ITERATION=    15  SECTION=  1
TIME=    0.00000E+00     LOAD CASE=  1

ELEM          SIG
 106     6.6394128
 107     7.7989740
 108     10.026639
 109     14.558004     - max. hoops
 110     11.366707
 111     7.5203293
```

024978

BNFL Fuel Solutions	**CALCULATION PACKAGE**	Calc. Pkg No. VSC02.6.2.3.19 File No.: VSC02.6.2.3.19 Revision: 0

PROJECT/CUSTOMER:

VSC02/BNFL Fuel Solutions

TITLE:

VSC Flood, Tornado, and Earthquake Analysis.

SCOPE:

Product: ☐ Wesflex™ ☐ TranStor™ ☒ VSC-24 ☐ Other ______

Service: ☒ Storage ☐ Transportation ☐ Other ______

Conditions: ☒ Normal ☒ Off-Normal ☒ Accident ☐ Other ______

Component(s):

VSC-24 Concrete cask.

Prepared by:

Name: J L Hibbard

Signature: JLHibbard

Date: 1-12-00

Verified by:

Name: Michelle McHenry

Signature: Michelle McHenry

Date: 1/12/00

Engineering Manager Approval:

Name: RAM SRINIVASAN

Signature: RSrinivasan

Date: 1/17/00

RECORD OF REVISIONS

REV.	AFFECTED PAGES	AFFECTED MEDIA	DESCRIPTION	NAMES (print or type) PREPARER	NAMES (print or type) CHECKER
0	1 – 29	None	Replaces Calculation WEP109-002.19, Rev. 2–	JLHubbard	Michelle Heinz
			Per Ecn No.: WEP01-C-018		

Note: This calculation has been prepared in accordance with QAP 3.2, Revision 8, except that because this calculation is a revision of an existing calculation, the format is essentially based on the superceded calculation. The title page, record of revision page, and record of verification page are per QAP 3.2, Revision 8. Other format requirements of QAP 3.2 have been included where this could be readily accomplished. This approach was approved in BFS Memorandum 99-528, dated December 21, 1999.

RECORD OF VERIFICATION

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

COMMENTS:

Verifier: Michelle M. Heinz /Michelle M. Heinz/1/12/00

Name/Signature/Date

1.0 INTRODUCTION

In accordance with 10CFR72, Subpart E (Ref. 3.2.1) and ANSI 57.9 (Ref. 3.2.2), the VSC-24 cask is designed to withstand loads associated with the most severe environmental events postulated to occur at an ISFSI site. The purpose/objective of this calculation is to demonstrate that the cask can successfully withstand the loads from tornado, flood, and earthquake events.

This calculation supercedes WEP-109-002.19, Rev. 2. The prinicipal differences between the calculations are:

- Revised weights and centers of gravity are used.
- The rotational moment of inertia calculation calculation was corrected.
- The calculation of tornado wind loads was updated to the latest revision of ANSI 7-93.

2.0 REQUIREMENTS

2.1 Design Inputs

2.1.1 10CFR72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High Level Waste", 1987
(Specifies that the VSC-24 Cask must be designed to withstand loads associated with the most severe environmental events postulated to occur at an ISFSI site).

2.1.2 ANSI 57.9, "Design Criteria for an Independent Spent Fuel Storage Installation," 1984.
(Specifies that the VSC-24 Cask must be designed to withstand loads associated with the most severe environmental events postulated to occur at an ISFSI site).

2.1.3 NUREG-0800, "Standard Review Plan for Nuclear Power Plants," 1981.
(Provides methods to convert tornado and wind loadings into forces and provides a basis for loads due to tornado generated missiles).

2.1.4 Reg Guide 1.76, "Design Basis Tornado for Nuclear Power Plants," 1974.
(Specifies design basis tornado characteristics).

2.2 Regulatory Requirements

See Section 2.1.

3.0 REFERENCES

3.1 BFS Calculation Packages

3.1.1 Calculation VSC02.6.2.5.01, "Weight and Center of Gravity," Revision 0.
(Mass and c.g. of VCC)

3.1.2 Calculation VSC02.6.2.3.04, "MSB-24 Pressure Stress Analysis," Revision 0.
(Allowable external pressure)

3.1.3 Calculation VSC02.6.2.3.05, "Normal, Off-Normal, and Maximum Accident Pressure in the MSB," Revision 0.
(Bounding MSB internal accident pressure)

3.2 General References

3.2.1 10CFR72, 1987.

3.2.2 ANSI 57.9, "Design Criteria for an Independent Spent Fuel Storage Installation," 1984.

3.2.3 BNFL Drawing VCC-24-001, "Ventilated Concrete Cask (VCC) Assembly," Sheet 1/2, Revision 3.

3.2.4 BNFL Drawing VCC-24-002, "Cask Lid and Liner Assembly," Sheet 1/3, Revision 3.

3.2.5 BNFL Document No. A2VCC-99-001, "Specification for the Construction of a VSC-24 Ventilated Concrete Case," Revision 1.

3.2.6 BNFL Drawing VCC-24-006, "VCC Reinforcement," Sheet 1/2, Revision 3.

3.2.7 Reg Guide 1.76, "Design Basis Tornado for Nuclear Power Plants," 1974.

3.2.8 NUREG-0800, "Standard Review Plan for Nuclear Power Plants," 1981.

3.2.9 ANSI/ASCE 7-93, "Minimum Design Loads for Buildings and Other Structures."

3.2.10 EPRI Report NP-440, "Full Scale Tornado Missile Impact Tests," 1977.

3.2.11 EPRI Report NP-1217, "Local Response of Reinforced Concrete to Missile Impact," 1982.

3.2.12 Bechtel Report, "Design of Structures for Missile Impact," 1974.

3.2.13 ACI-349, "Code Requirements for Nuclear Safety Related Structures", 1980.

3.2.14 Deleted.

3.2.15 Roark and Young, "Formulas for Stress and Strain", 5th Edition.

3.2.16 Regulatory Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants," 1973 Edition.

3.2.17 1992 ASME Code, Section II, Materials, Part D, Properties, Table Y-1.

3.2.18 "Marks' Standard Handbook for Mechanical Engineers," McGraw-Hill Inc., 9th Edition.

3.2.19 Perry & Chilton, "Chemical Engineers' Handbook," McGraw-Hill Inc., 5th edition.

4.0 ASSUMPTIONS

4.1 Design Configuration

4.1.1 VCC Parameters

VCC and MSB Loaded mass	$P_{VCC} := 260000\ \mathrm{lb}$	(Lower Bound Ref. 3.1.1)
VCC and MSB c.g.	$cg_{VCC} := 109\ \mathrm{in}$	(Lower Bound Ref. 3.1.1)
Cask Outside Diameter	$OD_{VCC} := 132\ \mathrm{in}$	(Reference 3.2.3)
Cask Height	$h_{VCC} := 213.7\ \mathrm{in}$	(Reference 3.2.3)
VCC Liner Outside Diameter	$OD_{liner} := 74\ \mathrm{in}$	(Reference 3.2.4)
VCC Liner Inside Diameter	$ID_{liner} := 70.5\ \mathrm{in}$	(Reference 3.2.4)
Height of the Liner	$h_{liner} := 191.7\ \mathrm{in}$	(Reference 3.2.4)
VCC Lid Thickness	$t_{VCC\_lid} := 0.75\ \mathrm{in}$	(Reference 3.2.4)
Concrete Strength	$f_c := 4000\ \mathrm{psi}$	(Reference 3.2.5)
Number of Bars in Air Outlet Cross Section	$N_{bars} := 32$	(Ref. 3.2.6, Part 3)
Diameter of Bars in Air Outlet Cross Section	$d_{bars} := 0.75\ \mathrm{in}$	(Ref. 3.2.6, Part 3)
Bar Yield Strength	$f_y := 60000\ \mathrm{psi}$	(Ref. 3.2.6, Part 3)

4.1.2 Wind and Tornado Loads

Tornado design parameters used to evaluate the suitability of the cask include tornado winds, wind generated pressure differentials and tornado generated missiles. The design basis tornado characteristics have been selected to be consistent with Regulatory Guide 1.76 (Reference 3.2.7).

The methods used to convert the tornado and wind loadings into forces on the cask are based on NUREG-0800 (Reference 3.2.8), Section 3.3.1, "Wind Loadings" and Section 3.3.2, "Tornado Loadings". Loads due to tornado generated missiles are based on NUREG-0800, Section 3.5.3, "Barrier Design Procedures". All missiles are assumed to impact in a manner that produces the maximum damage to the cask. The tornado properties are as follows.

Maximum Wind Speed	$Wind_{max} := 360\ mph$
Missile Velocity	$V_{missile} := 126\ mph$
Automobile Missile	$M_{auto} := 3960\ lb$
Armor Piercing Shell	$M_{shell} := 275\ lb$
	$d_{shell} := 8\ in$
Steel Sphere (1 in dia)	$M_{sphere} := 0.22\ lb$

Local damage of the cask body has been estimated using the National Defense Research Committee methodology presented in References 3.2.10 and 3.2.11. For the overall damage assessment, cask stability and stresses were evaluated. The tornado missile analysis is conservative in that the direction of the impact is assumed to be in-line with the cask axis.

4.1.3 Seismic Acceleration

The seismic acceleration was selected to bound the applicable accelerations at all sites East of the Rocky Mountains. All accelerations are assumed to act simultaneously with the worst possible sign combination. The assumed accelerations are as follows:

Horizontal Acceleration	$a_h := 0.25\ g$
Vertical Acceleration	$a_v := 0.17\ g$

4.2 Design Criteria

4.3 Calculation Assumptions

4.3.1 The friction coefficient for steel on concrete is assumed to be a typical value of $\mu := 0.2$.

4.3.2 The effective velocity pressure for the wind loads in the Tornado Accident Analysis is assumed constant with the height of the cask, and is assumed uniform over the projected area of the cask.

5.0 CALCULATIONS

5.1 Tornado Accident Analysis

5.1.1 Wind Loads

The tornado wind velocity is transformed into an effective pressure applied to the cask using procedures outlined in Reference 3.2.9. The maximum velocity pressure is determined from the maximum wind speed as follows:

$C_p := 0.00256 \frac{\text{lbf}}{\text{ft}^2 \cdot \text{mph}^2}$ Reference 3.2.9, Eq. 3

$K_z := 1.2$ Reference 3.2.9, Table 6, Exposure D, assume 0 to 15 feet above ground

$\text{Pressure} := C_p \cdot K_z \cdot \text{Wind}_{max}^2$ Reference 3.2.9, Eq. 3

$\text{Pressure} = 398 \cdot \text{psf}$

The above effective velocity pressure is assumed constant with height and, since the cask is small in relation to the radius of the tornado, is assumed to be uniform over the projected area of the cask. Gust factors are taken as unity in evaluating effects of velocity pressures on cask surfaces.

The total tornado wind loading on the projected area of the cask is computed as follows:

$A_{proj} := OD_{VCC} \cdot h_{VCC}$ $A_{proj} = 196 \cdot \text{ft}^2$

$\frac{OD_{VCC}}{\text{ft}} \cdot \sqrt{\frac{\text{Pressure}}{\text{psf}}} = 219$

$\frac{h_{VCC}}{OD_{VCC}} = 1.6$

Parameters required for Table 12 in Reference 3.2.9.

$C_v := \text{linterp}\left[\begin{bmatrix} 1 \\ 7 \end{bmatrix}, \begin{bmatrix} .5 \\ .6 \end{bmatrix}, \frac{h_{VCC}}{OD_{VCC}}\right]$ Pressure coefficient, Ref. 3.2.9, Table 12, round and moderately smooth.

$C_v = 0.51$

$P_{tornado} := Pressure \cdot C_v \cdot A_{proj}$

$P_{tornado} = 39800 \cdot lbf$

The sliding of the cask is resisted by friction between the steel bottom and the concrete pad. The resisting force is:

$P_{friction} := \mu \cdot P_{VCC} \cdot g$ $\qquad$ $P_{friction} = 52000 \cdot lbf$

Criterion1 = "FRICTION FORCE EXCEEDS TORNADO FORCE—ACCEPTABLE"

The overturning moment applied by the tornado wind load is the c.g. times the applied load. The potential for the cask to tip over is resisted by the mass of the cask times the moment arm from the c.g. to the cask corner.

$M_{overturn} := P_{tornado} \cdot cg_{VCC}$ $\qquad$ $M_{overturn} = 4.34 \cdot 10^6 \cdot in \cdot lbf$

$M_{resist} := P_{VCC} \cdot g \cdot \left(\frac{OD_{VCC}}{2}\right)$ $\qquad$ $M_{resist} = 1.72 \cdot 10^7 \cdot in \cdot lbf$

Criterion1a = "CASK DOES NOT TIP OVER DUE TO TORNADO FORCE -- ACCEPTABLE"

The shear force in the concrete between the cylindrical portion of the VCC and the VCC bottom is:

$$f_v := \frac{P_{tornado}}{\frac{\pi}{4} \cdot \left(OD_{VCC}^2 - OD_{liner}^2\right)}$$

$f_v = 4.2 \cdot psi$

This shear stress is negligible.

5.1.2 Tornado Missiles

Local Damage Prediction -- VCC Body

The armor piercing shell is considered to be the most critical for the local damage of the cask components. Local damage of the cask body has been assessed using the National Defense Research Committee (NDRC) formula. This formula has been selected as the basis for predicting depth of penetration and minimum thickness of concrete to prevent spalling and scabbing. Penetration depths computed by this method have been shown to provide reasonable correlation with test results. (Reference: EPRI Reports NP-440 and NP-1217; References 3.2.10 and 3.2.11). The depth of penetration (X) as predicted using this approach is computed as follows.

$d_{shell} = 8 \cdot in$	Diameter of the missile
$M_{shell} = 275 \cdot lb$	Mass of the missile
$V_{missile} = 126 \cdot mph$	Velocity of the missile
$K_c := \frac{180 \cdot psi^{.5}}{f_c^{.5}}$	Factor depending on concrete strength
$K_c = 2.85$	
$N_{missile} := 1.14$	Missile Shape Factor 1.14 for Sharp nosed missiles (EPRI NP-1217 (Ref 3.2.11))

The depth of penetration is calculated as:

$$X_{missile} := \left[4 \cdot K_c \cdot N_{missile} \cdot \frac{M_{shell}}{lb} \cdot \left(\frac{d_{shell}}{in} \right)^{-0.8} \cdot \left(\frac{V_{missile}}{1000 \frac{ft}{sec}} \right)^{1.8} \right]^{.5} \cdot in$$

$$X_{missile} = 5.69 \cdot in$$

The minimum depth to prevent spalling is selected as three times the value calculated above or:

$X_{spall} := 3 \cdot X_{missile}$ $\qquad X_{spall} = 17.1 \cdot in$

The minimum thickness of the concrete body of the VCC is:

$$t_{VCC} := \frac{OD_{VCC} - OD_{liner}}{2}$$

$t_{VCC} = 29.0 \cdot in$

Criterion2 = "ACTUAL THICKNESS EXCEEDS REQUIRED THICKNESS -- ACCEPTABLE"

Local Damage Prediction - Cask Closure Plate

The VCC is closed with a steel cover plate which is bolted in place. The perforation thickness in a steel plate is given in Reference 3.2.12.

$$T_{perf} := \frac{\left[0.5 \cdot \left(\frac{M_{shell}}{slug}\right) \cdot \left(\frac{V_{missile}}{\frac{ft}{sec}}\right)^2\right]^{\frac{2}{3}} \cdot in^2}{672 \cdot d_{shell}}$$

$T_{perf} = 0.52 \cdot in$

The VCC lid thickness is

$t_{VCC\_lid} = 0.75 \cdot in$

Criterion3 = "ACTUAL THICKNESS EXCEEDS REQUIRED THICKNESS -- ACCEPTABLE"

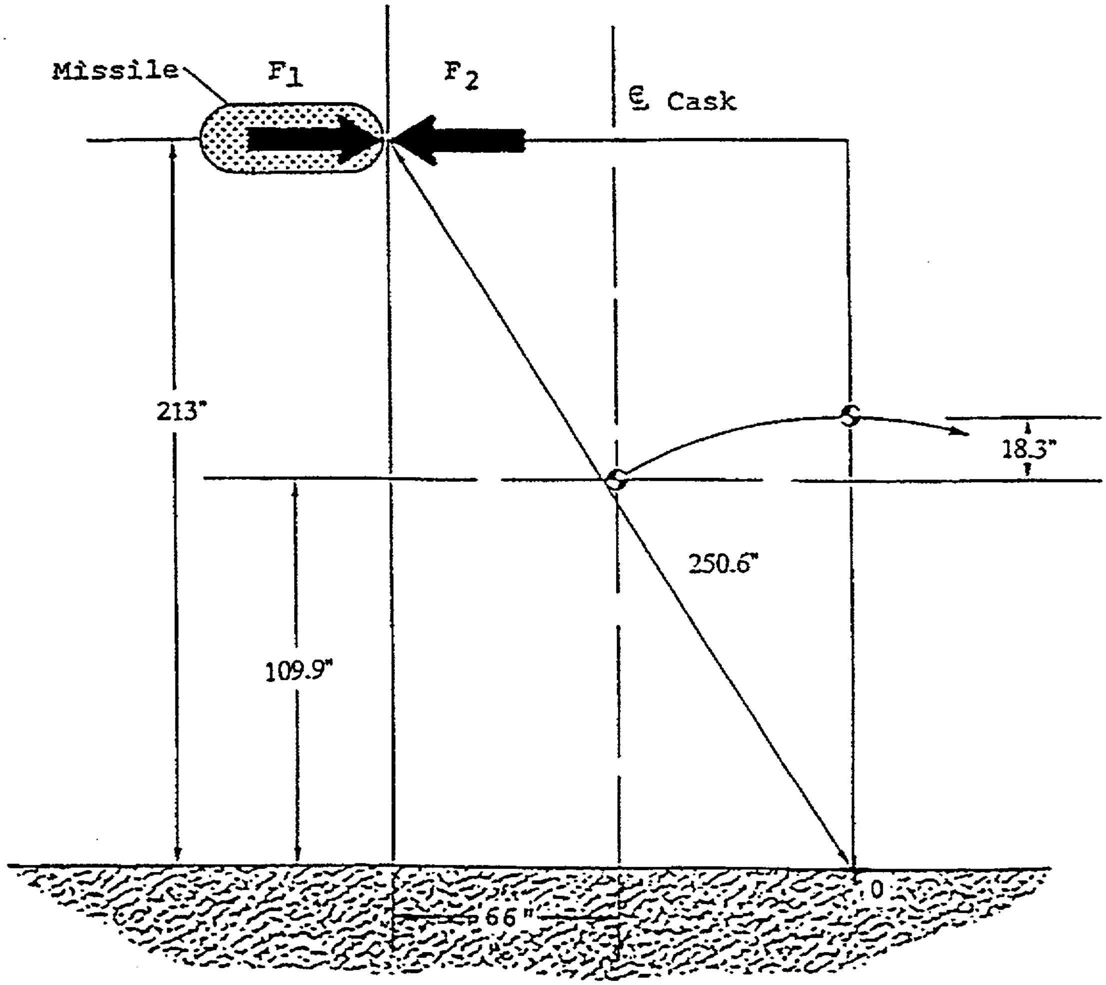

Figure 1

Sketch of Missile Cask Impact Geometry

Overall Damage Prediction

For the overall damage evaluation, the most critical missile is an automobile because it has the greatest mass. Since the cask is a freestanding structure, the tip-over analysis has been conducted using the principle of conservation of momentum during the impact event.

From the principle of conservation of momentum, the impulse force from the missile impact on the cask must equal the change in angular momentum of the cask. The impulse force due to the impact of the missile must equal the change in linear momentum of the missile. See Figure 1 for the cask geometry.

During the initial impact phase, the momentum of the missile is:

$$\text{Momentum}_{\text{initial}} := M_{\text{auto}} \cdot V_{\text{missile}}$$

$$\text{Momentum}_{\text{initial}} = 731808 \cdot \text{ft} \cdot \frac{\text{lb}}{\text{sec}}$$

The moment of inertia of the cask about it's center of gravity is (Reference 3.2.18, p. 3-10):

$$\text{Io} := P_{\text{VCC}} \cdot \left(\frac{OD_{\text{VCC}}^{2}}{16} + \frac{h_{\text{VCC}}^{2}}{12} \right)$$

$$\text{Io} = 1.27 \cdot 10^{9} \cdot \text{lb} \cdot \text{in}^{2}$$

The distance from the corner of the cask to the center of gravity, R, is:

$$R := \sqrt{cg_{\text{VCC}}^{2} + \left(\frac{OD_{\text{VCC}}}{2} \right)^{2}} \qquad R = 127 \cdot \text{in}$$

The moment of inertia of the cask about the corner is (Reference 3.2.18, p. 3-10):

$$I_{\text{cask}} := \text{Io} + P_{\text{VCC}} \cdot R^{2}$$

$$I_{\text{cask}} = 5.49 \cdot 10^{9} \cdot \text{lb} \cdot \text{in}^{2}$$

It is assumed that the velocity of the missile after impact is zero and that there is a perfectly elastic collision between the missile and the cask, i.e., there is no energy loss due to deformation of the missile or spalling of the concrete. The angular momentum of the cask is:

$$\mathrm{Momentum}_{\mathrm{angular}} := \mathrm{Momentum}_{\mathrm{initial}} \cdot h_{\mathrm{VCC}}$$

$$\mathrm{Momentum}_{\mathrm{angular}} = 1.3032 \cdot 10^{7} \cdot \mathrm{ft}^{2} \cdot \frac{\mathrm{lb}}{\mathrm{sec}}$$

Therefore the angular velocity is:

$$\omega := \frac{\mathrm{Momentum}_{\mathrm{angular}}}{I_{\mathrm{cask}}}$$

$$\omega = 0.342 \cdot \frac{\mathrm{rad}}{\mathrm{sec}}$$

The kinematic energy of the cask is:

$$E_{\mathrm{cask}} := I_{\mathrm{cask}} \cdot \frac{\omega^{2}}{2}$$

$$E_{\mathrm{cask}} = 69177 \cdot \mathrm{ft} \cdot \mathrm{lbf}$$

The energy required to overturn the cask is equal to the potential energy when the cask is balanced on it's edge minus the potential energy of the cask sitting flat on its bottom. This energy is given as:

$$R = 127 \cdot \mathrm{in}$$

$$E_{\mathrm{tip\_over}} := P_{\mathrm{VCC}} \cdot g \cdot \left(R - cg_{\mathrm{VCC}}\right)$$

$$E_{\mathrm{tip\_over}} = 399197 \cdot \mathrm{ft} \cdot \mathrm{lbf}$$

Criterion4 = "ENERGY OF IMPACT LESS THAN ENERGY TO TIP OVER -- ACCEPTABLE"

Stress in the VCC During Impact

The overall VCC stresses are evaluated at the corresponding critical sections of the concrete cask. The most critical missile for this evaluation is the automobile because it has the most mass.

The force developed by the missile has been calculated using the methodology presented in Bechtel Report "Design of Structures for Missile Impact" (Ref 3.2.12). The maximum force is:

$$F_{impact} := 0.625 \cdot \frac{V_{missile}}{\left(\frac{ft}{sec}\right)} \cdot \frac{M_{auto}}{lb} \cdot lbf$$

$$F_{impact} = 457380 \cdot lbf$$

For shear, the critical cask section is the one in the plane of the air outlets. The section capacity is calculated using the shear-friction formula per ACI-349, Section 11.7 (Ref 3.2.13).

$\phi_s := 0.85$	Shear Strength Reduction Factor (Ref. 3.2.13, Paragraph 9.3.2)
$A_v := N_{bars} \cdot \frac{\pi}{4} \cdot d_{bars}^{2}$	$A_v = 14.14 \cdot in^2$
$\mu_c := 1.4$	Monolithic Concrete (Ref. 3.2.13, Paragraph 11.7.5)
$U_{shear} := \phi_s \cdot A_v \cdot \left(1.1 \cdot f_y\right) \cdot \mu_c$	Ultimate shear capacity of the section (Note: use 1.1 f_y per Ref. 3.2.13, Appendix C.2)
$U_{shear} = 1.11 \cdot 10^6 \cdot lbf$	

Criterion5 = "SHEAR CAPACITY EXCEEDS FORCE OF IMPACT -- ACCEPTABLE"

The maximum moment due to the impact of the cask exists in the cask section adjacent to the bottom of the cask. The maximum moment is given as:

$$M_{impact} := F_{impact} \cdot h_{liner}$$

$$M_{impact} = 8.768 \cdot 10^{7} \cdot in \cdot lbf$$

The moment of inertia of the cask liner at this section is:

$$I_{bottom} := \frac{\pi}{64} \cdot \left(OD_{liner}{}^{4} - ID_{liner}{}^{4} \right)$$

$$I_{bottom} = 259338 \cdot in^{4}$$

The strength of the liner is calculated conservatively ignoring the strength of the concrete. The yield strength of the SA-36 carbon steel liner is (Reference 3.2.4 for material; Reference 3.2.17 for yield strength at 300°F):

$$\sigma_{y} := 31900 \cdot psi$$

$$U_{bending} := \left[\sigma_{y} \cdot \frac{I_{bottom}}{\left(\frac{OD_{liner}}{2} \right)} \right]$$

Bending capacity of the liner, assuming that the outer fiber of the liner is at yield strength.

$$U_{bending} = 2.236 \cdot 10^{8} \cdot in \cdot lbf$$

Criterion6 = "BENDING CAPACITY EXCEEDS MOMENT DUE TO IMPACT -- ACCEPTABLE"

Combined Tornado Wind and Missile

The effects of tornado winds and missiles have been considered both separately and combined in accordance with NUREG-0800, Section 3.3.2.II.3.d (Reference 3.2.8). Calculate the maximum possible rotation of the cask for the case of tornado wind plus impact. The increase in the cask c.g. due to rotation is

$$\delta_{cask} := \frac{E_{cask}}{P_{VCC} \cdot g} \qquad \delta_{cask} = 3.19 \cdot in$$

The rotation of the cask (α_{cask}) is

$$R = 127 \cdot in$$

$$\theta_1 := asin\left(\frac{cg_{VCC}}{R}\right) \qquad \theta_1 = 58.8 \cdot deg$$

$$\alpha_{cask} := asin\left(\frac{\delta_{cask} + cg_{VCC}}{R}\right) - \theta_1 \qquad \alpha_{cask} = 2.89 \cdot deg$$

Applying the total tornado wind load to the cask in this configuration results in a net restoring moment of:

$$M_{restoring} := P_{VCC} \cdot g \cdot \left(R \cdot cos\left(\alpha_{cask} + \theta_1\right)\right) - P_{tornado} \cdot \left(cg_{VCC} + \delta_{cask}\right)$$

$$M_{restoring} = 1.12 \cdot 10^7 \cdot in \cdot lbf$$

Criterion7 = "NO OVERTURING—NET RESTORING MOMENT POSITIVE—ACCEPTABLE"

MSB Under Tornado Missiles

Since the postulated tornado loading is not capable of overturning the cask, the tornado events have no effect on the MSB.

5.2 Flood

5.2.1 Flood Analysis

Immersing Flood Analysis

The buoyancy force on the cask, assuming full immersion of the cask is computed from the weight of the displaced water.

$\rho_w := 62.4 \frac{lb}{ft^3}$ Density of water

$V_{cask} := \frac{\pi}{4} \cdot (OD_{VCC})^2 \cdot h_{VCC}$

$V_{cask} = 1692 \cdot ft^3$

$F_b := (V_{cask} \cdot \rho_w) \cdot 1 \cdot g$

$F_b = 105605 \cdot lbf$ Buoyancy force for the loaded VCC

The drag force required to topple the cask is calculated by equating the overturning moment created by the drag force and the restoring moment:

$$F_{tip\_over} := \frac{(P_{VCC} \cdot g - F_b) \cdot \left(\frac{OD_{VCC}}{2}\right)}{cg_{VCC}}$$

$F_{tip\_over} = 93487 \cdot lbf$

Assuming the cask is fully immersed in a steady state flow condition, the stream velocity required to overturn the cask is:

$C_d := 1.2$ Drag coefficient for an infinite cylinder, which depends on the Reynolds Number. The value of 1.2 is bounding for Re>10^3 (Reference 3.2.19, Figure 5-78).

$\mu_w := 20.92 \cdot 10^{-6} \cdot \frac{lbf \cdot sec}{ft^2}$ Viscosity of water at 68°F, Ref. 3.2.18, Table 3.3.3

$OD_{VCC} = 132 \cdot in$ Outside Diameter of the VCC

$A_{proj} = 196 \cdot ft^2$ Projected Area of the Cask

$V_{stream} := \sqrt{\frac{F_{tip\_over} \cdot 2}{C_d \cdot \rho_w \cdot A_{proj}}}$ Velocity required to tip over the cask based on rearrangement of the drag equation.

$V_{stream} = 20.25 \cdot \frac{ft}{sec}$

Check the Reynolds Number.

$$Re := \frac{\rho_w \cdot V_{stream} \cdot OD_{VCC}}{\mu_w}$$

$Re = 2.1 \cdot 10^7$

The Reynolds Number is greater than 1,000 and the drag coefficient of 1.2 is bounding.

The calculated stream velocity is considered to bound the site flood velocity, and therefore, the VCC is acceptable for flood conditions

MSB Flood Analysis

The bounding MSB accident internal pressure from Reference 3.1.3 is 60 psig. From Reference 3.1.2, the ASME Code allowable external pressure is 210 psig. The flood height required to achieve the 60 psig limiting pressure is:

$P_{limiting} := 60\ psi$ MSB Shell Limiting Pressure

$d_{flood} := \frac{P_{limiting}}{\rho_w \cdot g}$ Flood Depth to Reach Limiting Pressure

$d_{flood} = 138 \cdot ft$

This flood depth is considered bounding and the MSB is acceptable for flood conditions.

5.3 Earthquake Events

5.3.1 Earthquake Event

The VSC is a very stiff structure. Although free-standing, it has been analyzed as a cantilever fixed at the base. (Ref 3.2.15, Table 36, Case 3b).

The fundamental natural frequency of vibration of the cask is:

$K_n := 3.52$ First Modal Frequency

$E_c := 57000\ \text{psi} \cdot \sqrt{\frac{f_c}{\text{psi}}}$ Elasticity of the concrete; Ref. 3.2.13, Paragraph 8.5.1

$E_c = 3.605 \cdot 10^6 \cdot \text{psi}$

$I_{VSC} := \frac{\pi}{64} \cdot \left(OD_{VCC}{}^4 - OD_{liner}{}^4\right)$

$I_{VSC} = 1.34 \cdot 10^7 \cdot \text{in}^4$ Moment of inertia of the cask

$w_{dist} := \frac{P_{VCC}}{h_{VCC}}$ Distributed weight of the cask

$w_{dist} = 1217 \cdot \frac{\text{lb}}{\text{in}}$

$$f_{natural} := \frac{K_n}{2 \cdot \pi} \cdot \sqrt{\frac{E_c \cdot I_{VSC}}{w_{dist} \cdot h_{VCC}{}^4}}$$

$f_{natural} = 48.1 \cdot \text{Hz}$

As shown in Reg. Guide 1.60 (Reference 3.2.16), the dynamic amplification is 1.0.

The VSC is evaluated for overturning by conservatively applying equivalent static loads to the cask in each of two orthogonal horizontal directions simultaneous with an upward vertical lift component.

$$P_{horizontal} := P_{VCC} \cdot \sqrt{a_h^2 + a_h^2}$$

$$P_{horizontal} = 91924 \cdot lbf$$

$$P_{vertical} := P_{VCC} \cdot a_v$$

$$P_{vertical} = 44200 \cdot lbf$$

The margin of safety against overturning is:

$$Margin_{tip\_over} := \frac{\left(P_{VCC} \cdot g - P_{vertical}\right) \cdot \left(\frac{OD_{VCC}}{2}\right)}{P_{horizontal} \cdot cg_{VCC}}$$

$$Margin_{tip\_over} = 1.421$$

Criterion8 = "NO OVERTURING BECAUSE MARGIN IS GREATER THAN 1.0 -- ACCEPTABLE"

The maximum kinematic energy that can possibly be imparted to the cask from seismic motion is computed to compare with the energy required to tip over the cask.

The maximum relative horizontal and vertical velocities are obtained from Figures 1 and 2 of Reg. Guide 1.60 respectively, based on 0.5% damping (Reference 3.2.16). Since the figures are based on a 1 g acceleration, the velocites are scaled to $a_h = 0.25 \cdot g$ and $a_v = 0.17 \cdot g$.

$$V_{hor\_rel} := \left(180 \frac{in}{sec}\right) \cdot \frac{a_h}{1\ g}$$

$$V_{hor\_rel} = 45 \cdot \frac{in}{sec}$$

$$V_{vert\_rel} := \left(125 \frac{in}{sec}\right) \cdot \frac{a_v}{1\ g}$$

$$V_{vert\_rel} = 21 \cdot \frac{in}{sec}$$

Since the maximum ground velocities are bounded by any amplified velocity spectrum, the maximum vertical ground velocities are taken from Figures 1 and 2, respectively, based on 10% damping (Reference 3.2.16).

$$V_{hor\_abs} := \left(90 \frac{in}{sec}\right) \cdot \frac{a_h}{1\ g}$$

$$V_{hor\_abs} = 23 \cdot \frac{in}{sec}$$

$$V_{vert\_abs} := \left(65 \frac{in}{sec}\right) \cdot \frac{a_v}{1\ g}$$

$$V_{vert\_abs} = 11 \cdot \frac{in}{sec}$$

The maximum horizontal velocity (in two directions) is:

$$V_{hor} := \sqrt{V_{hor\_rel}^2 + V_{hor\_abs}^2} \qquad V_{hor} = 50.3 \cdot \frac{in}{sec}$$

$$V_{hor\_max} := \sqrt{V_{hor}^2 + V_{hor}^2} \qquad V_{hor\_max} = 71.2 \cdot \frac{in}{sec}$$

The maximum angular velocity is:

$$V_{angular} := \frac{V_{hor\_max}}{cg_{VCC}} \qquad V_{angular} = 0.653 \cdot \frac{rad}{sec}$$

The maximum rotational energy is:

$$E_{rot\_max} := \frac{I_{cask} \cdot V_{angular}^{2}}{2} \qquad E_{rot\_max} = 3.03 \cdot 10^{6} \cdot in \cdot lbf$$

The maximum vertical velocity is:

$$V_{vert\_max} := \sqrt{V_{vert\_rel}^{2} + V_{vert\_abs}^{2}} \qquad V_{vert\_max} = 24 \cdot \frac{in}{sec}$$

The maximum translational energy is:

$$E_{tran\_max} := \frac{P_{VCC}}{2} \cdot V_{vert\_max}^{2} \qquad E_{tran\_max} = 193159 \cdot in \cdot lbf$$

The maximum total kinematic energy is:

$$E_{max} := E_{tran\_max} + E_{rot\_max} \qquad E_{max} = 3.225 \cdot 10^{6} \cdot in \cdot lbf$$

The energy required to tip over the cask is

$$E_{tip\_over} = 399197 \cdot ft \cdot lbf$$

Criterion9 = "ENERGY OF IMPACT LESS THAN ENERGY TO TIP OVER -- ACCEPTABLE"

Therefore, the worst possible combination of natural frequency, vibration mode, damping ratio, and loading combination will not impart sufficient kinematic energy to topple the cask. The cask is concluded to be stable under seismic loads. The MSB stresses, therefore, are negligible and bounded by the vertical and horizontal drop analyses.

VCC Seismic Stresses

The internal stresses due to the seismic loading are calculated below:

$$\tau_{seismic} := \frac{P_{horizontal}}{\frac{\pi}{4}\cdot\left(OD_{VCC}^{2} - OD_{liner}^{2}\right)} \qquad \tau_{seismic} = 9.8\cdot psi$$

Shear Stress

$$\sigma_{seismic} := \frac{P_{horizontal}\cdot\left[cg_{VCC} - \left(h_{VCC} - h_{liner}\right)\right]\cdot\left(\frac{OD_{VCC}}{2}\right)}{I_{VSC}}$$

Bending Stress

$$\sigma_{seismic} = 39.3\cdot psi$$

Theses stresses are negligible and the VCC is acceptable for seismic loads.

Relative Ground Motion

Figure 2 shows the vertical ground displacement required to topple the cask:

$$\theta_{ground} := atan\left[\frac{cg_{VCC}}{\left(\frac{OD_{VCC}}{2}\right)}\right] \qquad \theta_{ground} = 58.8\cdot deg$$

$$\alpha_{ground} := OD_{VCC}\cdot\sin\left(90\ deg - \theta_{ground}\right)$$

$$\alpha_{ground} = 5.7\cdot ft$$

The type of ground motion and the required vertical ground displacement to tip over the cask are considered unrealistic. It is concluded that the cask will not topple due to permanent failure and vertical movement of the foundation.

$$\Theta = \text{arc sin} \frac{109.9}{109.9 - 18} = 59^\circ$$

$$\alpha = 90 - \Theta = 31^\circ$$

$$\lambda = 132 \ (\sin\alpha) = 68'' \quad (5.6')$$

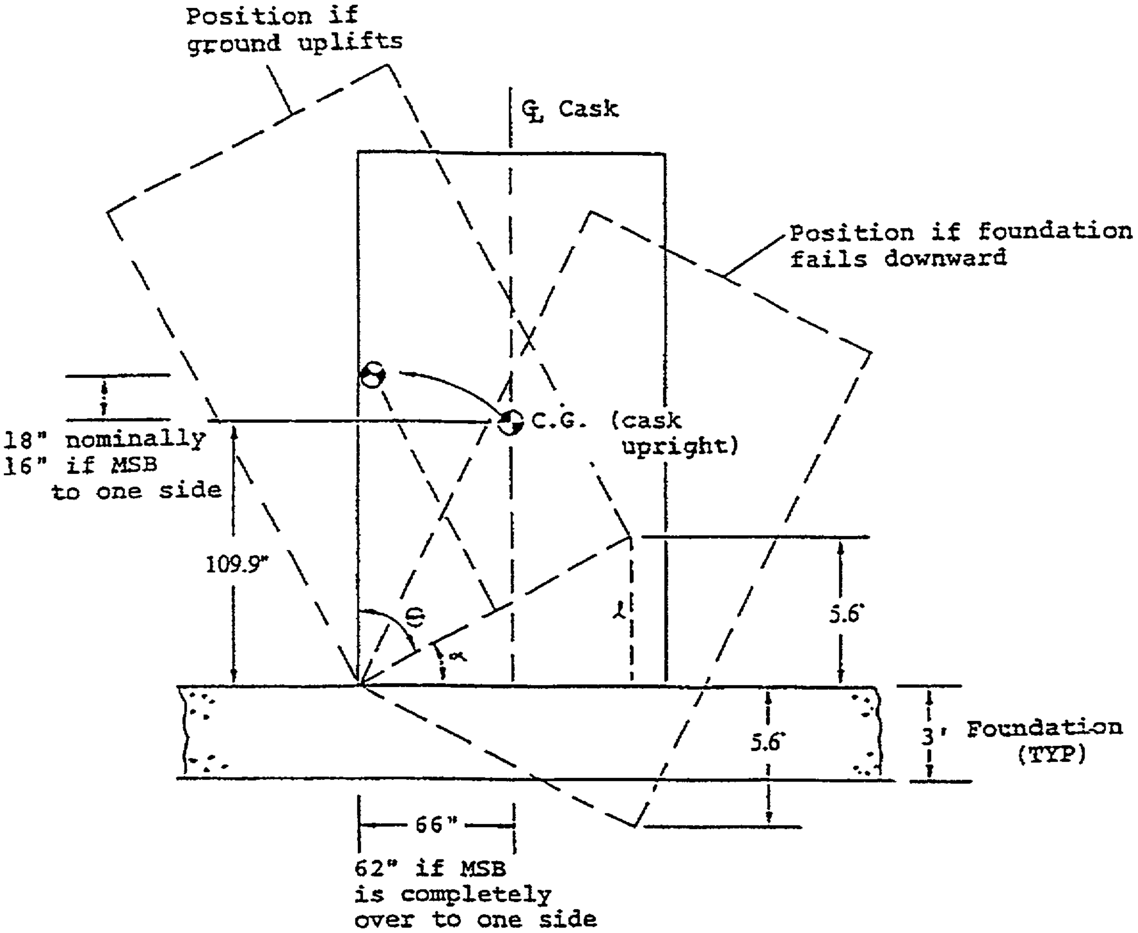

Figure 2

Cask Tip-Over Requirements

7.0 CONCLUSIONS

The analyses indicate that the cask will remain upright following all postulated natural phenomena. In addition, the loads associated with these events do not compromise the overall structural integrity of the cask (minor local damage to the concrete surface may occur but could be easily repaired). The VSC-24 cask can successfully withstand tornado, flood, and earthquakes that may occur at the ISFSI site.

8.0 ELECTRONIC FILES

8.1 Computer Runs

None.

8.2 Other Electronic Files

None.

BNFL Fuel Solutions	**CALCULATION PACKAGE**	Calc. Pkg No. File No.: Revision:	VSC02.6.2.3.20 VSC02.6.2.3.20 0

PROJECT/CUSTOMER:

VSC02/BNFL Fuel Solutions

TITLE:

Brittle Fracture Evaluation

SCOPE:

Product:	☐ Wesflex™	☐ TranStor™	☒ VSC-24	☐ Other ______
Service:	☒ Storage	☐ Transportation		☐ Other ______
Conditions:	☐ Normal	☐ Off-Normal	☒ Accident	☐ Other ______

Component(s):

MSB shell, bottom, and structural lid.

Prepared by:

Name: James L. Hibbard

Signature: JLHibbard

Date: 2-22-00

Verified by:

Name: Michelle M. Heinz

Signature: Michelle M. Heinz

Date: 2-25-00

Engineering Manager Approval:

Name: RAM SRINIVASAN

Signature: RSrinivasan

Date: 2/29/00

RECORD OF REVISIONS

REV.	AFFECTED PAGES	AFFECTED MEDIA	DESCRIPTION	NAMES (print or type)	
				PREPARER	CHECKER
0	1 - 7 Attachment A1-A11		Replaces Calculation WEP-109-002.20, Rev. 1	J.L. Hibbard	Michelle Heinz

Note: This calculation has been prepared in accordance with QAP 3.2, Revision 8, except that because this calculation is a revision of an existing calculation, the format is essentially based on the superceded calculation. The title page, record of revision page, and record of verification page are per QAP 3.2, Revision 8. Other format requirements of QAP 3.2 have been included where this could be readily accomplished. This approach was approved in BFS Memorandum 99-528, dated December 21, 1999.

RECORD OF VERIFICATION

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

COMMENTS:

Verifier: Michelle M. Heinz Michelle M. Heinz 2-25-00
Name/Signature/Date

1.0 INTRODUCTION

This calculation package has been generated to resolve the NRC staff concern regarding a possibility of MSB brittle fracture. In general, since the MSB is loaded with a fuel, its temperature is such that brittle fracture cannot occur. However, the worst combination of conditions is investigated herein (combination of lowest ambient temperature, coolest fuel, and the highest stress due to the drop accident).

2.0 ASSUMPTIONS AND INPUT

The ANSYS Finite Element Analysis program was used in Reference 5 to calculate the MSB shell lowest temperature. The computer input – output from Reference 5 is provided for convenience in Attachment 1. Figure 1 shows the finite element model node and element numbers. No new finite element analysis was performed as part of the present calculation.

The lowest ambient temperature at which the drop has to be considered is -20°F (Reference 2). The drop accident is assumed to happen at the end of cask life, after 20 years of storage. The thermal finite element analysis in Reference 5 was performed with a heat load at 20 years of:

$$Q = 9.6\ KWt$$

The methodology of NUREG 1815 [Ref. 3] is used to determine the ductility requirements for the MSB pressure boundary material.

3.0 RESULTS

From Reference 5, the lowest temperature of the MSB pressure boundary is 2.5°F (the structural lid-to-shell junction).

The maximum stress for the MSB shell is for the horizontal drop (Reference 4). A stress of 50 ksi bounds the highest stress in Reference 4 for the MSB shell. The maximum stress for the MSB bottom plate and structural lid is the critical pressure cases (Reference 4), where a stress of 72 ksi bounds the highest stress for the MSB bottom plate and structural lid. The thickness of the MSB shell is 1.0 inch, the thickness of the MSB bottom plate is 0.75 inch, and the thickness of the MSB structural lid is 3.0 inch (Reference 1). Using the methodology of NUREG 1815:

MSB Shell: $$\frac{\sigma}{\sigma_{yd}} = \frac{50}{(38+30)} = 0.74$$

MSB Bottom Plate: $$\frac{\sigma}{\sigma_{yd}} = \frac{72}{(38+30)} = 1.06$$

Using Figure 3 from NUREG 1815 (see Figure 2), the minimum value for A is:

$A = 35°F$

Therefore, the NDT of 2.5 − 35 = -32.5°F is required. To achieve this NDT, we will specify the Charpy V-Notch test at -30°F; these temperatures are above the required NDT. Per NUREG 1815, Section 4.2 and Figure 2 (see Figure 3), the Charpy value needed is:

$$C_V = \frac{K_{ID}^{\ 2}}{5 \cdot E} = \frac{42{,}000^2}{5 \cdot 28 \text{ x } 10^6} = 12.6 \text{ ft} - \text{lb}$$

This requirement should be included in the MSB Fabrication Specification.

4.0 CONCLUSIONS

To prevent brittle fracture of the MSB pressure boundary, the shell, bottom plate, and structural lid materials must have a minimum Charpy V-Notch energy absorption of 12.6 ft-lbs at -30°F.

The NRC staff, during their review, imposed a stricter requirement of 15 ft-lbs at -50°F. This requirement was incorporated into the MSB fabrication Specification.

5.0 REFERENCES

1. BNFL Drawing No. MSB-24-002, "MSB Shell and Structural Plates," Sheet 1, Revision 4.
2. "Packaging and Transportation of Radioactive Material," Code of Federal Regulations, Title 10, Part 71, 1999 Edition.
3. NUREG 1815, "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers up to Four Inches Thick," 1981.
4. BNFL Calculation No. VSC02.6.2.3.02, Revision 0, "MSB-24 Load Combination Evaluation."
5. BNFL Calculation No. WEP-109-002.20, Revision 1, "Brittle Fracture Evaluation."
   BNFL Calculation No. WEP-109-003.04, Revision 1, "VCC-24 Thermal Analysis."

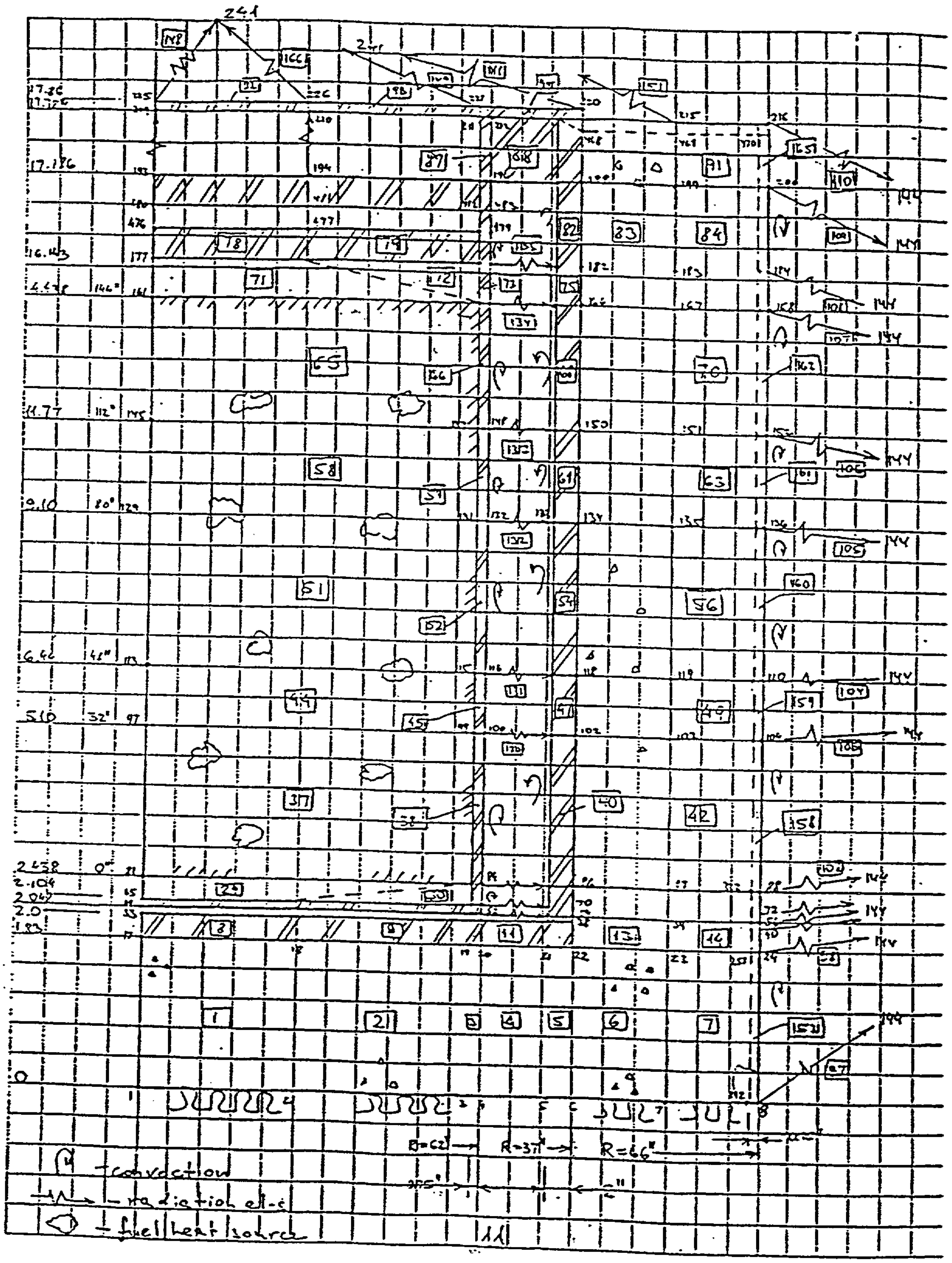

Figure 1. Finite Element Model

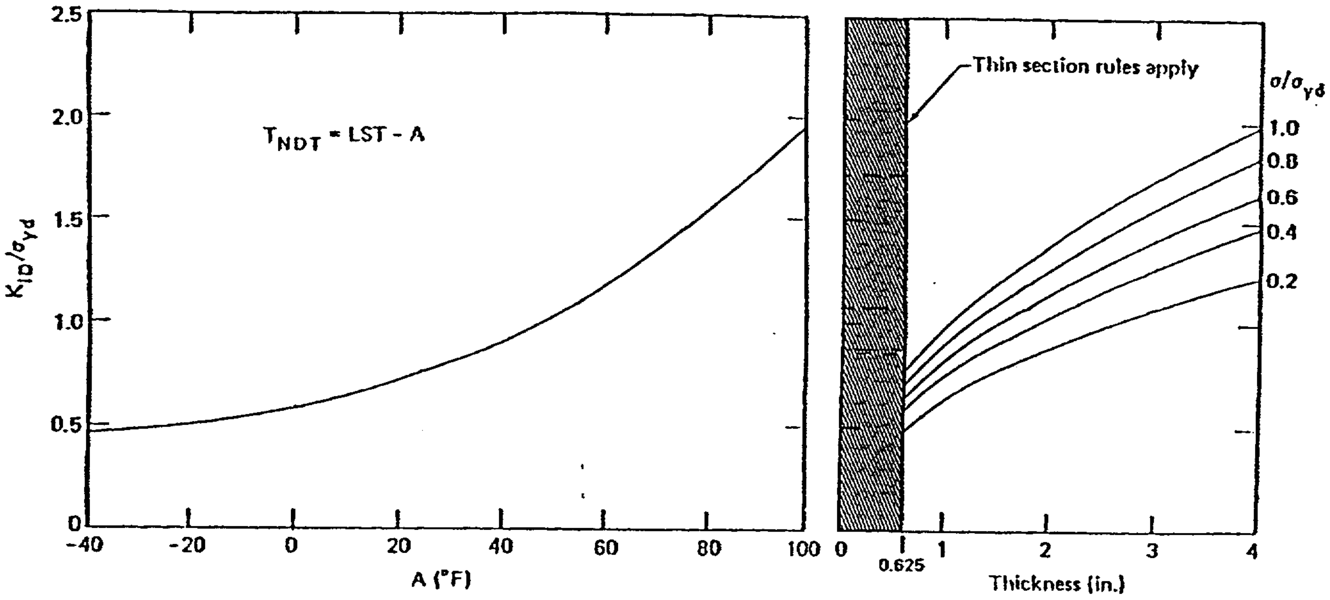

Figure 2. Design Chart for Category I Fracture Critical Components (Reference 3

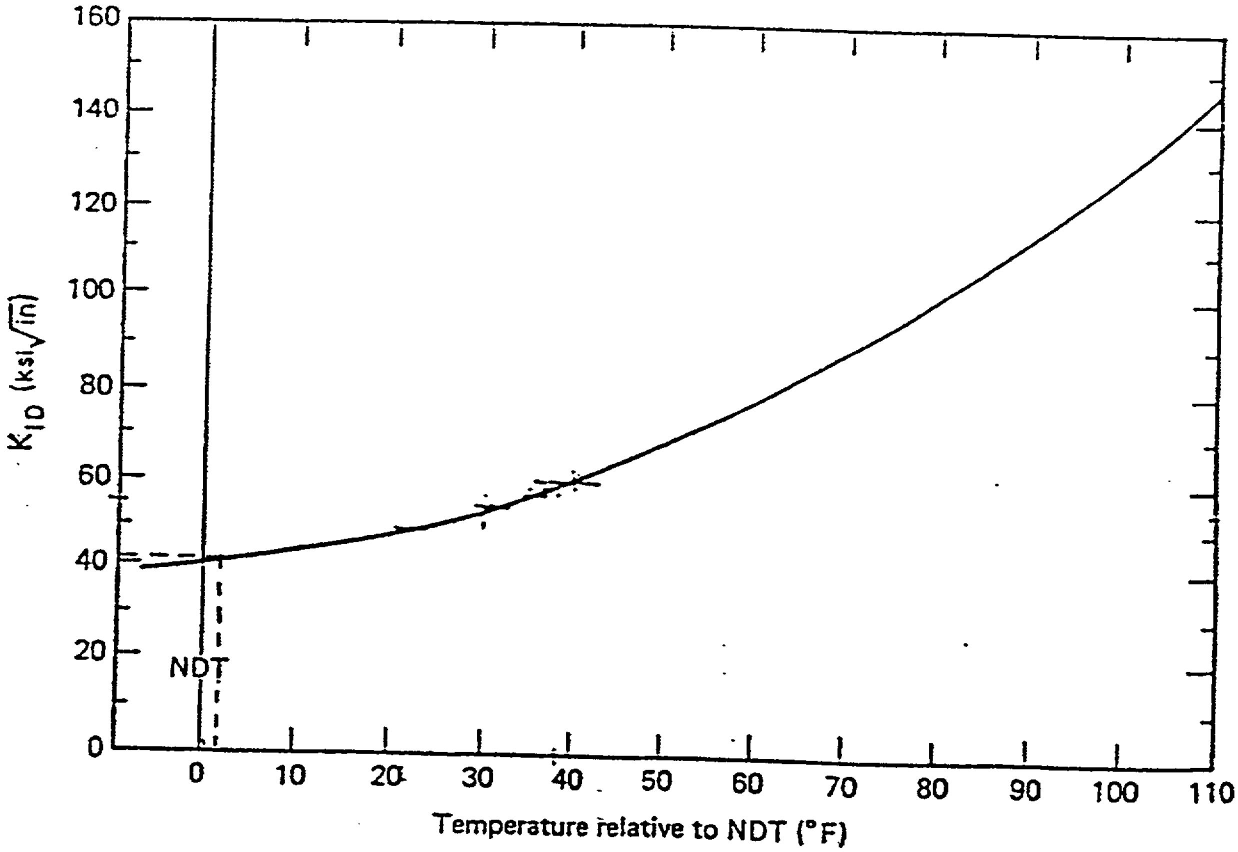

Figure 3. Design-reference Curve Relating K_{ID} and the Temperature Relative to NDT (Reference 3)

Attachment A

Finite Element Analysis Output

WEP 109.002.20

ATTACHMENT I

NORMAL FLOW PATH	D(H)	A	L	F	K	A**2	K/A**2	VEL	Re
INLET SNOW SKIRT with screens	-	11.87000	-	-	0.77000	140.90	0.00546	0.97	-
INLET SECTION DOWN OUTSIDE	0.66700	11.87000	3.00000	0.04000	0.17991	140.90	0.00128	0.97	4.48E+03
BEND & ENTER. SKID CHANNELS	-	4.68000	-	-	1.38000	21.90	0.06301	2.46	-
SKID CHANNELS	1.08000	4.68000	5.11833	0.03000	0.14218	21.90	0.00649	2.46	1.84E+04
BEND INTO 12 IN SQ TUBE	-	4.00000	-	-	2.16000	16.00	0.13500	2.88	-
BENDS AT CHANNEL AND INLET ASSY	-	4.00000	-	-	0.38700	16.00	0.02419	2.88	-
STRAIGHT SECTION	1.00000	4.00000	1.33333	0.02600	0.03467	16.00	0.00217	2.88	1.99E+04
INLET ASSEMBLY AND BEND INTO ANN.	-	4.47200	-	-	1.38400	20.00	0.06920	2.57	-
SUDDEN EXPANSION INTO ANNULUS	-	5.76000	-	-	0.05000	33.18	0.00151	2.00	-
FLOW UP ANNULUS	0.66600	5.76000	14.16667	0.03300	0.70195	33.18	0.02116	2.00	9.21E+03
BEND&CNTRCT INTO 3" by 52" SLIT	-	4.33333	-	-	1.20000	18.78	0.06391	2.65	-
Z - BEND	-	4.33333	-	-	2.78000	18.78	0.14805	2.65	-
OUTLET STRAIGHT SECTION	1.89000	4.33333	2.66667	0.02600	0.03668	18.78	0.00195	2.65	3.48E+04
RGE with screens	-	4.33333	-	-	1.14000	18.78	0.06071	2.65	-

K/A**2	0.60408
T TEMP	-20.00000
ET TEMP	17.90000
TEMP	-1.05000
T HEIGHT	15.00000
S DT=	37.90000
=	32755.20
	0.24100
EAT BAL)	0.99614
DENSITY	0.08662
LOW=	0.10746
TACK=	0.10729
ALC	37.90000
) FLOW)	0.99614
/IN	227.46667

X POSITION	f REL POWER	Q(x) POWER/IN	QX	AIR TEMP	DT TEMP
0	-	-	-	-20.00	-
0-16	0.69000000	156.95200	2511.23	-17.08	2.92
16-32	1.08000000	245.66400	3930.62	-12.52	4.57
32-48	1.20000000	272.96000	4367.36	-7.44	5.07
48-64	1.19000000	270.68533	4330.97	-2.41	5.03
64-80	1.17000000	266.13600	4258.18	2.54	4.95
80-96	1.12000000	254.76267	4076.20	7.27	4.74
96-112	1.05000000	238.84000	3821.44	11.71	4.44
112-128	0.90000000	204.72000	3275.52	15.52	3.81
128-144	0.60000000	136.48000	2183.68	18.06	2.54

```
LIST ELEMENT CONVECTIONS FOR ALL SELECTED ELEMENTS

 ELEM   FACE        VALUE(S)                             FACE NODES
   17     3      2.00000000      -20.0000000          43      36      52      59
   24     3      2.00000000      -20.0000000          59      52      68      75
   31     3      2.00000000      -20.0000000          75      68      84      91
   38     3      2.00000000      -15.0000000          91      84     100     107
   45     3      2.00000000      -7.00000000         107     100     116     123
   52     3      2.00000000      0.000000000E+00     123     116     132     139
   59     3      2.00000000       9.00000000         139     132     148     155
   66     3      2.00000000       16.5000000         155     148     164     171
   73     3      2.00000000       18.0000000         171     164     180     187
   80     3      2.00000000       18.0000000         187     180     479     486
   19     5      2.00000000      -20.0000000          37      44      60      53
   26     5      2.00000000      -20.0000000          53      60      76      69
   33     5      2.00000000      -20.0000000          69      76      92      85
   40     5      2.00000000      -15.0000000          85      92     108     101
   47     5      2.00000000      -7.00000000         101     108     124     117
   54     5      2.00000000      0.000000000E+00     117     124     140     133
   61     5      2.00000000       9.00000000         133     140     156     149
   68     5      2.00000000       16.5000000         149     156     172     165
   75     5      2.00000000       18.0000000         165     172     188     181
   82     5      2.00000000       18.0000000         181     188     204     197

 ELEM   FACE        VALUE(S)                             FACE NODES
  171     6      2.00000000      -20.0000000         215     214     221     222
  172     6      2.00000000      -20.0000000         450     215     222     451
  164     3      2.00000000      -20.0000000         191     184     200     207
   96     6      2.00000000      -20.0000000         230     229     236     237
   95     6      2.00000000      -20.0000000         229     228     235     236
   94     6      2.00000000      -20.0000000         228     227     234     235
    3     6      2.00000000      -20.0000000         227     226     233     234
   32     6      2.00000000      -20.0000000         226     225     233     233
  153     3      2.00000000      -20.0000000          15       8      24      31
  154     3      2.00000000      -20.0000000          31      24      40      47
  155     3      2.00000000      -20.0000000          47      40      56      63
  156     3      2.00000000      -20.0000000          63      56      72      79
  157     3      2.00000000      -20.0000000          79      72      88      95
  158     3      2.00000000      -20.0000000          95      88     104     111
  159     3      2.00000000      -20.0000000         111     104     120     127
  160     3      2.00000000      -20.0000000         127     120     136     143
  161     3      2.00000000      -20.0000000         143     136     152     159
  162     3      2.00000000      -20.0000000         159     152     168     175
  163     3      2.00000000      -20.0000000         175     168     184     191
  165     3      2.00000000      -20.0000000         207     200     216     223

  LEM   FACE        VALUE(S)                             FACE NODES
  173     3      2.00000000      -20.0000000         475     471     216     223
  173     6      2.00000000      -20.0000000         216     450     451     223
  179     3      2.00000000       18.0000000         489     483     196     203
  176     3      2.00000000       18.0000000         486     479     483     489

   ST TEMPERATURES FOR ALL SELECTED NODES

   DE  LABEL      TEMPR
      TEMP  -20.0000000      0.000000000E+00
       EMP  -20.0000000      0.000000000E+00

   T ELEM HEAT GENERATIONS FOR ALL SELECTED ELEMENTS
```

```
 37        130.500000
 44        161.400000
 51        157.400000
 58        148.000000
 65        103.600000
```

```
RINT NODAL TEMPERATURES

        ***** POST1 NODAL TEMPERATURE LISTING *****

I AD STEP      1  ITERATION=     12  SECTION=  1
    '=   0.00000E+00      LOAD CASE=  1

  NODE       TEMP
    1     10.528862
    2     8.0809758
    3     1.1418336
    4    0.91076857
    5   -0.67504239
    6    -2.0284315
    7    -9.3777614
    8    -17.849450
    9     8.0809794
   10     1.1417585
   11    0.91069905
   12   -0.67505895
   13    -2.0284210
   14    -9.3777639

        ***** POST1 NODAL TEMPERATURE LISTING *****

OAD STEP      1  ITERATION=     12  SECTION=  1
IME=   0.00000E+00      LOAD CASE=  1

  NODE       TEMP
    5    -17.849450
          18.201884
    8     15.934369
   19     11.415625
   20     10.628605
   21     6.5473116
   22     5.3964418
   23    -9.1953469
   24    -17.816159
   25     15.934362
   26     11.415780
   27     10.628749
   28     6.5473465
   29     5.3964202

        ***** POST1 NODAL TEMPERATURE LISTING *****

AD STEP      1  ITERATION=     12  SECTION=  1
ME=   0.00000E+00      LOAD CASE=  1

  NODE       TEMP
   30    -9.1953419
   31    -17.816159
   33     18.456847
   34     15.883332
          11.807938
          11.429526
          5.8019143
   38     4.9572026
   39    -9.1589570
```

```
   40   -17.790365
   41    15.883283
   42    11.808403
   43    11.430089
   44    5.8018472

        ***** POST1 NODAL TEMPERATURE LISTING *****

LOAD STEP      1  ITERATION=     12  SECTION=  1
TIME=    0.00000E+00      LOAD CASE=  1

  NODE       TEMP
   45    4.9571346
   46   -9.1589424
   47   -17.790365
   49    20.651208
   50    16.768760
   51    13.474562
   52    12.530077
   53    5.0478368
   54    4.7604405
   55   -9.1436192
   56   -17.787874
   57    16.769147
   58    13.477594
   59    12.530521

        ***** POST1 NODAL TEMPERATURE LISTING *****

LOAD STEP      1  ITERATION=     12  SECTION=  1
TIME=    0.00000E+00      LOAD CASE=  1

  NODE       TEMP
   60    5.0477899
   61    4.7603212
   62   -9.1435927
   63   -17.787876
   65    20.875863
   66    16.700852
   67    13.787143
   68    14.159950
   69    4.2228388
   70    4.2749708
   71   -9.0824172
   72   -17.782689
   73    16.701022
   74    13.792190

        ***** POST1 NODAL TEMPERATURE LISTING *****

OAD STEP      1  ITERATION=     12  SECTION=  1
IME=    0.00000E+00      LOAD CASE=  1

  NODE       TEMP
   75    14.148697
   76    4.2228830
         4.2746976
        -9.0823535
   79   -17.782695
   81    156.01884
```

```
    83     30.666108
    84     30.354084
    85      1.5062096
    86      1.5835151
    87     -8.8290696
    88    -17.740354
    90     30.288404
    91     30.017918

        ***** POST1 NODAL TEMPERATURE LISTING *****

 LOAD STEP      1  ITERATION=    12  SECTION=  1
 TIME=    0.00000E+00      LOAD CASE=  1

   NODE       TEMP
    92      1.5036572
    93      1.5821389
    94     -8.8287409
    95    -17.740388
    97    197.23205
    99     56.223279
   100     55.762471
   101      2.7361548
   102      2.6870989
   103     -8.1387875
   104    -17.575323
   106     55.750676
   107     55.338339
   108      2.7306738

        ***** POST1 NODAL TEMPERATURE LISTING *****

 LOAD STEP      1  ITERATION=    12  SECTION=  1
 TIME=    0.00000E+00      LOAD CASE=  1

   NODE       TEMP
   109      2.6839771
   110     -8.1380451
   111    -17.575377
   113    216.16313
   115     67.426759
   116     66.931016
   117      8.0064575
   118      7.9209098
   119     -6.3720040
   120    -17.174813
   122     66.893302
   123     66.454968
   124      8.0003327
   125      7.9174537

        ***** POST1 NODAL TEMPERATURE LISTING *****

 LOAD STEP      1  ITERATION=    12  SECTION=  1
 TIME=    0.00000E+00      LOAD CASE=  1

      E       TEMP
      6    -6.3711816
   127    -17.174877
   129    222.75685
```

```
    131    73.248163
    132    72.901349
    133    14.799039
    134    14.713771
    135   -3.0223393
    136   -16.659352
     38    72.762469
     39    72.462912
    140    14.793674
    141    14.710729
    142   -3.0216153

      ***** POST1 NODAL TEMPERATURE LISTING *****

 LOAD STEP     1  ITERATION=    12  SECTION=  1
 TIME=    0.00000E+00      LOAD CASE=  1

   NODE       TEMP
   143   -16.659412
   144   -20.000000
   145    188.26758
   147    70.361933
   148    69.531398
   149    18.691338
   150    18.574070
   151   -1.4339053
   152   -16.398790
   154    69.854315
   155    69.088245
   156    18.685185
   157    18.570591
         -1.4330777

      ***** POST1 NODAL TEMPERATURE LISTING *****

 OAD STEP     1  ITERATION=    12  SECTION=  1
 IME=    0.00000E+00      LOAD CASE=  1

 NODE       TEMP
 159   -16.398851
 161    156.68978
 163    45.817749
 164    45.002709
 165    15.363814
 166    15.264143
 167   -3.1856065
 168   -16.709285
 170    45.465394
 171    44.703787
 172    15.360532
 173    15.262304
 174   -3.1851687
 175   -16.709320

      ***** POST1 NODAL TEMPERATURE LISTING *****

     EP     1  ITERATION=    12  SECTION=  1
 IE    0.00000E+00      LOAD CASE=  1

 ODE        TEMP
```

```
 177     9.9938229
 178     9.7747063
 179     11.396873
 180     11.817315
 181     8.5027849
 182     8.3624418
   3    -7.2436905
   4    -17.549803
 185     9.7694540
 186     11.442326
 187     11.847753
 188     8.5042530
 189     8.3632204
 190    -7.2438757

      ***** POST1 NODAL TEMPERATURE LISTING *****

OAD STEP      1  ITERATION=    12  SECTION=  1
IME=    0.00000E+00      LOAD CASE=  1

 NODE       TEMP
 191    -17.549796
 193     3.3689431
 194     3.9923754
 195     3.1684856
 196     2.6271948
 197     1.5838838
 198     1.6503074
 199    -12.398635
 200    -18.604150
         3.9923719
         3.1684683
         2.6273861
 204     1.5835925
 205     1.6501971

      ***** POST1 NODAL TEMPERATURE LISTING *****

AD STEP       1  ITERATION=    12  SECTION=  1
ME=     0.00000E+00      LOAD CASE=  1

 NODE       TEMP
 206    -12.398609
 207    -18.604150
 209    -12.625305
 210    -10.185625
 211    -1.7947644
 212    -1.3215028
 213   -0.96864665
 214    -1.7587605
 215    -17.576772
 216    -19.142915
 217    -10.185627
 218    -1.7947541
 219    -1.3215723
 2     -0.96856954

      ***** POST1 NODAL TEMPERATURE LISTING *****

AD STEP       1  ITERATION=    12  SECTION=  1
```

```
TIME=    0.00000E+00       LOAD CASE=  1

  NODE        TEMP
  221    -1.7587585
  222    -17.576772
  223    -19.142916
    5    -12.692814
   26    -10.191472
  227    -1.9412206
  228    -1.4703840
  229    -1.1203322
  230    -1.7434968
  233    -10.191472
  234    -1.9412174
  235    -1.4704210
  236    -1.1202809
  237    -1.7434767

       ***** POST1 NODAL TEMPERATURE LISTING *****

LOAD STEP      1  ITERATION=     12  SECTION=  1
TIME=    0.00000E+00       LOAD CASE=  1

  NODE        TEMP
  241    -20.000000
  242    -17.078291
  243    -17.078291
  258    -17.014775
  259    -17.014773
  274    -16.980666
    5    -16.980659
         -16.972530
    1    -16.972524
  306    -16.974876
  307    -16.974879
  322    -16.950658
  323    -16.950724
  338    -16.681453

       ***** POST1 NODAL TEMPERATURE LISTING *****

OAD STEP      1  ITERATION=     12  SECTION=  1
IME=    0.00000E+00       LOAD CASE=  1

  NODE        TEMP
  339    -16.681581
  354    -16.196217
  355    -16.196363
  370    -15.420412
  371    -15.420541
  386    -15.046945
  387    -15.047089
  402    -15.498147
  403    -15.498226
  418    -16.663369
         -16.663335
         -18.189751
  4      -18.189758
  450    -18.832282
```

```
      ***** POST1 NODAL TEMPERATURE LISTING *****

 LOAD STEP     1  ITERATION=    12  SECTION=  1
 TIME=    0.00000E+00      LOAD CASE=  1

   NODE       TEMP
      1    -18.832281
     68    -1.5325281
    469    -17.352319
    470    -18.789446
    471    -19.161712
    472    -1.5325296
    473    -17.352319
    474    -18.789445
    475    -19.161713
    476     9.3625431
    477     10.236637
    478     9.5283540
    479     9.2010530
    480     4.0916090

      ***** POST1 NODAL TEMPERATURE LISTING *****

 LOAD STEP     1  ITERATION=    12  SECTION=  1
 TIME=    0.00000E+00      LOAD CASE=  1

   NODE       TEMP
    481    3.5355492
    482    4.9548205
    483    5.4696433
           10.238468
           9.5153883
    486    9.1947453
    487    3.5356008
    488    4.9544814
    489    5.4680363

XIMUMS
DE           129
LUE      222.75685
```

BNFL Fuel Solutions	CALCULATION PACKAGE	Calc. Pkg No. VSC02.6.2.3.21 File No.: VSC02.6.2.3.21 Revision: 1

PROJECT/CUSTOMER:

VSC02/BNFL Fuel Solutions

TITLE:

Normal and Off-normal Handling Analysis

SCOPE:

Product: ☐ Wesflex™ ☐ TranStor™ ☒ VSC-24 ☐ Other ______

Service: ☒ Storage ☐ Transportation ☐ Other ______

Conditions: ☒ Normal ☒ Off-Normal ☐ Accident ☐ Other ______

Component(s):

MSB Components.

Prepared by:

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Signature: Warren Price

Date: 04-14-00

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Signature:

Date: 4-17-00

Engineering Manager Approval:

Name: RAM SRINIVASAN

Signature: RSrinivasan

Date: 4/17/00

RECORD OF REVISIONS

REV.	AFFECTED PAGES	AFFECTED MEDIA	DESCRIPTION	NAMES (print or type)	
				PREPARER	CHECKER
0	1 - 13	None	Replaces Calculation WEP109-002.21, Rev. 1. Per ECN No. WEP01-C-018	J Hibbard	M Heinz
1	All	None	Incorporated changes due to alternative support of MSB by ceramic tiles, as per ECN No. VSC02-ECN-003 Editorial re-write	W. Price	G. Mukhim

Note: This calculation has been prepared in accordance with QAP 3.2, Revision 8, except that because this calculation is a revision of an existing calculation, the format is essentially based on the superceded calculation. The title page, record of revision page, and record of verification page are per QAP 3.2, Revision 8. Other format requirements of QAP 3.2 have been included where this could be readily accomplished. This approach was approved in BFS Memorandum 99-528, dated December 21, 1999.

RECORD OF VERIFICATION

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

COMMENTS: None

Verifier: GOLE S. MUKHIM / 4-17-00

Name/Signature/Date

1. INTRODUCTION

This purpose/objective of this calculation is to determine stresses in the MSB 24 for normal and off-normal handling loads while the MSB is being stored. A separate calculation combines stresses for different loading conditions and compares stresses to ASME Code allowable stresses. This revision incorporates the analysis results of alternative ceramic tile support configuration performed in Ref 3.1.1 and 3.1.3.

This calculation supersedes WEP109-002.21, Revision 1. This calculation addresses comments in CAR 98-50. The principal differences between this calculation and WEP109-002.21 are:

- Updated the calculation for revised inputs from the references.
- Revised the calculation of the deceleration for the off-normal handling impact.
- Applied a dynamic load factor to stresses calculated for the off-normal handling impact.
- Considered off normal handling for case of MSB in transfer cask, and MSB being lowered into storage cask.

2. REQUIREMENTS

2.1. Design Inputs

None.

2.2. Regulatory Commitments

2.2.1. "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High Level Radioactive Waste", Code of Federal Regulations Title 10, Part 72.

3. REFERENCES

3.1. BFS Calculation Packages

3.1.1. BFS Calculation VSC02.6.2.3.08, "MSB-24 Drop Analysis," Revision 1. (Stress results).

3.1.2. BFS Calculation VSC02.6.2.3.15, "VSC-24 Hypothetical Tip-Over and 5-foot Drop Analyses," Revision 0. (Five-foot drop deceleration, target hardness number).

3.1.3. BFS Calculation VSC02.6.2.3.25, "MSB Dead Weight and Vertical Drop Bottom Plate Bending Stress Analysis," Revision 1 (Stress Results)

3.2. General References

3.2.1. R. J. Roark, "Formulas for Stress and Strain," McGraw Hill, Fourth Edition.

3.2.2. John N. Biggs, "Introduction to Structural Dynamics," McGraw Hill, 1964.

3.2.3. EPRI Report NP-4830, "The Effect of Target Hardness on Structural Design of Storage Pads for Spent Fuel Casks," 1986.

4. ASSUMPTIONS

4.1. Design Configuration

No assumptions are made with regard to the design configuration.

4.2. Design Criteria

No assumptions are made regarding the design criteria.

4.3. Calculations

4.3.1. The normal operation acceleration is assumed to be 0.5 g, acting in the vertical, and the two horizontal directions simultaneously (per the NRC staff suggestion).

4.3.2. The off-normal acceleration for MSB transported inside the transfer cask results from an assumed impact of 2 ft/sec crane speed. The off-normal acceleration for the MSB being lowered into the storage cask is assumed to result from an impact at a lowering speed of 0.75 ft/sec.

4.3.3. Stresses due to simultaneous vertical and horizontal deceleration are conservatively assumed to add. (A less conservative but still accurate approach is to SRSS the stress components.)

4.3.4. Assume that the target hardness for the off-normal impact is 128,405. This is the maximum target hardness calculated for the horizontal and vertical cask drops in Reference 3.1.2.

4.3.5. Assume that the dynamic load factor (DLF) for normal and off-normal handling is 2.0. This is conservative, since 2.0 bounds DLFs for typical impulse loads as shown in Figures 2.6 through 2.9 of Reference 3.2.2.

5. CALCULATION METHODOLOGY

The MSB stresses due to handling loads are calculated by scaling the results from the drop analysis in Reference 3.1.1 as follows:

$$SI_{handling} = SI_{drop} \frac{a_{handling}}{a_{drop}} .DLF$$

Where,

$SI_{handling}$ = Stress Intensity for acceleration due to handling

SI_{drop} = Stress Intensity for acceleration load due to drop

$a_{handling}$ = Acceleration due to handling

a_{drop} = Acceleration due to drop

DLF = Dynamic Load Factor

6. CALCULATIONS

6.1. Normal Handling

The acceleration for normal handling is assumed to be 0.5 g acting simultaneously in the vertical and two horizontal directions.

$a_{handling\_vert} = 0.5g$

$a_{handling\_horiz} = 0.5g\sqrt{2}$

$a_{handling\_horiz} = 0.71g$

The accelerations for the vertical and horizontal drops in Reference 3.1.2 are as follows:

$a_{deadweight} = 1g$

$a_{drop\_horiz} = 40g$

The stresses from the vertical and horizontal accelerations are assumed to add. A function for calculating the handling stress is as follows:

$$HandlingStress = \left[\left(\frac{a_{handling\_vert}}{a_{deadweight}}\right)SI_{vert} + \left(\frac{a_{handling\_horiz}}{a_{drop\_horiz}}\right)SI_{horiz}\right]DLF$$

Where,

SI_{vert} = Stress Intensity due to 1g dead weight analysis. (Ref 3.1.1 and Ref 3.1.3)

SI_{horiz} = Stress Intensity due to 40g horizontal drop analysis. (Ref 3.1.1)

DLF = 2. Dynamic Load Factor, (Assumption 4.3.5)

Using the above calculation to combine vertical and horizontal normal handling, the final normal handling stresses are summarized in Table 6-1.

Horizontal stress intensity above is derived from the horizontal side drop analysis of Ref 3.1.1.

Since a dead weight analysis has been completed for two support configurations (MSB uniformly supported in the transfer cask, and MSB supported on ceramic tiles), the stresses of Table 6-1 are the bounding values of the two analyses. Dead weight stresses taken from Ref 3.1.3 are already unit g stresses and are used directly in this calculation, while stresses taken from Ref 3.1.1 are scaled by a factor of 1/108 since this is a vertical drop analysis, with a drop acceleration of 108g.

Table 6-1 Summary of Normal handling Stresses

LOCATION	STRESS CATEGORY	Stress (ksi)				
		Dead Weight	Horiz Drop	Vert Handling	Horiz Handling	Total Handling
MSB Shell	P_m	0.50	18.3	0.50	0.65	1.15
	$P_L + P_b$	1.50	42.6	1.50	1.51	3.01
Bottom Plate	P_m	0.35	27.8	0.35	0.99	1.34
	$P_L + P_b$	12.20	37.2	12.20	1.32	13.52
Structural Lid	P_m	0.01	18.8	0.01	0.67	0.68
	$P_L + P_b$	0.04	40.4	0.04	1.43	1.47
Sleeve Assembly	P_m	0.06	55.2	0.06	1.96	2.02
	$P_L + P_b$	0.06	57.3	0.06	2.03	2.10
Support Ring Weld	P_m	0.14	0	0.14	0.00	0.14
	$P_L + P_b$	0.14	0	0.14	0.00	0.14
Structural Lid Weld	P_m	0.03	8.8	0.03	0.31	0.35
	$P_L + P_b$	0.08	40.4	0.08	1.43	1.51
Bottom Plate Weld	P_m	0.50	24.5	0.50	0.87	1.37
	$P_L + P_b$	12.20	37.2	12.20	1.32	13.52
Shield Lid	P_m	0.03	18.2	0.03	0.65	0.67
	$P_L + P_b$	0.30	32.4	0.30	1.15	1.45
Shield Lid Weld	P_m	0.27	8.7	0.27	0.31	0.58
	$P_L + P_b$	0.27	19.4	0.27	0.69	0.96

Note:
The sleeve assembly membrane and membrane plus bending stresses are from Reference 3.1.1, Attachment I. The sleeve assembly membrane stress is the average of the Node 225 shell top and shell bottom stress intensities with a correction factor to reduce the stress to a 40g acceleration from the 44g used in Attachment I ($\frac{58.38 \cdot ksi + 63.00 \cdot ksi}{2} \cdot \frac{40 \cdot g}{44 \cdot g} = 55.2\,ksi$). This estimate of the membrane stress has significant margin since it includes the bending stress. The membrane plus bending stress is the maximum stress intensity, which is occurs at Node 225, shell bottom ($63 \cdot ksi \cdot \frac{40 \cdot g}{44 \cdot g} = 57.3\,ksi$).

6.2. Off-Normal Handling

Off normal handling is considered for two scenarios.

1. The MSB is being moved via the transfer cask at an off normal crane velocity of 2 ft/sec.
2. The MSB is being lowered into the storage cask at an off normal lowering velocity of 0.75 ft/sec

Consider the off-normal load as impacts at handling velocities of 2 ft/sec, and 0.75 ft/sec. This is equivalent to a vertical drop from:

$$h = \frac{v^2}{2g}$$

For v = 2 ft/sec

$$h = 0.75 \quad in.$$

and for v = 0.75 ft/sec

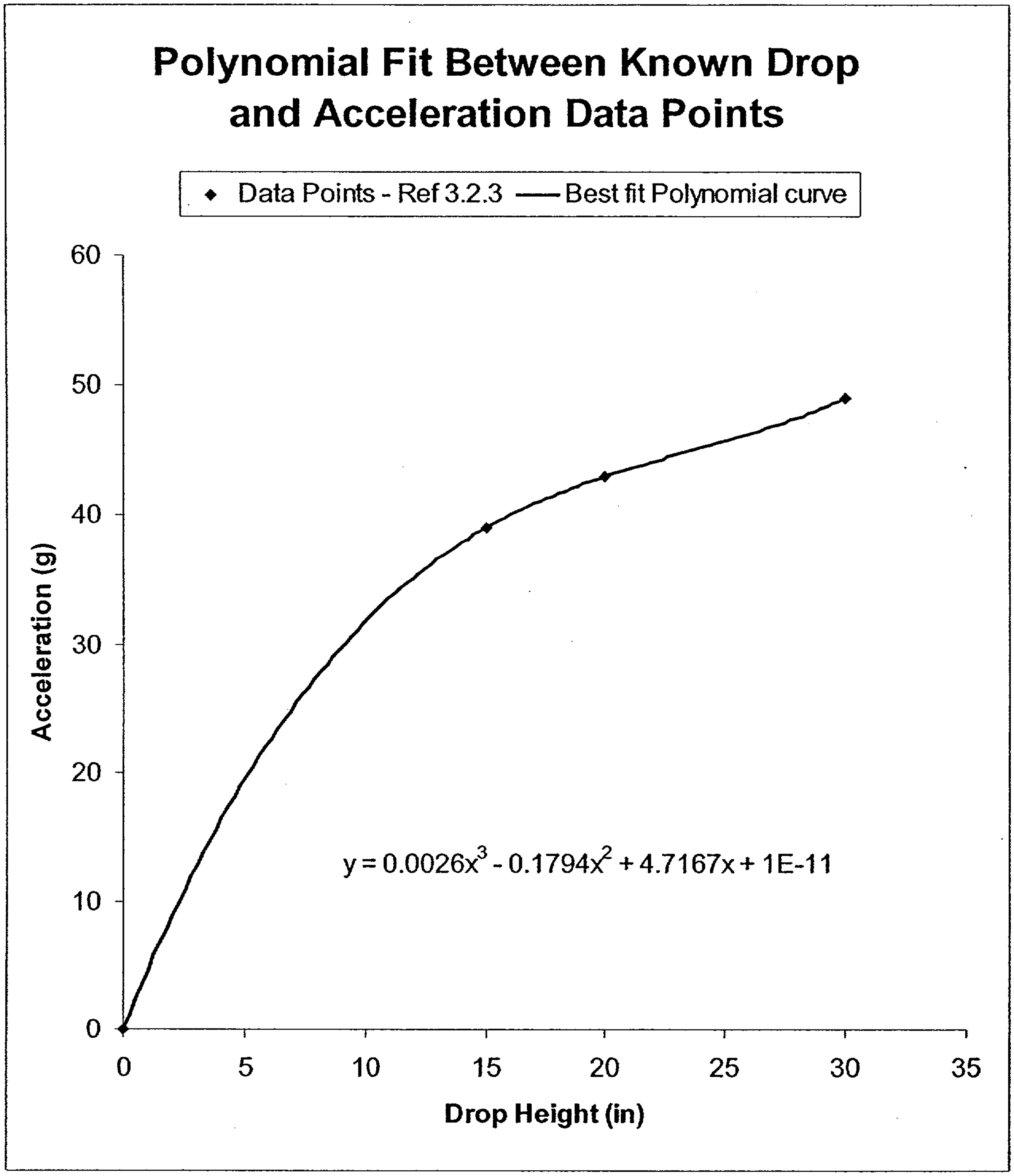
$$h = 0.1 \quad in.$$

Calculate the deceleration from the above impact velocities using the approach and the results in Reference 3.1.2, where the deceleration was calculated for vertical and horizontal drops from five feet. The maximum target hardness calculated in Reference 3.1.2 was 128,405, for a vertical drop onto a 36" thick concrete storage pad. Assume that the target hardness for the off-normal impact is also 128,405. Reference 3.2.3, Figure 19 gives the deceleration for drop heights from 15 inches to 80 inches. Use the data to determine the deceleration for the drop heights of *h = 0.75 in, and h = 0.1 in.* Data from Reference 3.2.3, Figure 19 is as follows:

$$x = \begin{bmatrix} 0 \\ 15 \\ 20 \\ 30 \\ 40 \\ 50 \end{bmatrix} \qquad a = \begin{bmatrix} 0 \\ 39 \\ 43 \\ 49 \\ 52 \\ 53 \end{bmatrix}$$

A fourth order polynomial curve fit was applied to the above data points using an Excel spreadsheet. Clearly, the drop heights of 0.75 and 0.1 inches are very small. For this reason the curve fit was restricted to the first 30 inches of drop height data. The equation of the polynomial was determined and the appropriate value of drop height (*x*) substituted into the equation (shown below), to yield the equivalent drop acceleration.

$$a = 0.0026x^3 - 0.1794x^2 + 4.7167x + 1e-11$$



It is noted that the curve fit is an approximation. For small drop heights such as those being dealt with in this analysis, it is very accurate up to a drop height of 20 inches, which easily bounds the drop heights considered of 0.1 and 0.75 inches. A higher order polynomial or different curve fitting technique would be needed if interpolation at higher drop heights was being performed.

Using the polynomial equation for the curve, and substituting the value of the off-normal impact drop from h = 0.75 in, the drop accleleration is;

$a_{0.75}$ = 3.438g conservatively use 3.5g

and for a drop height of 0.1 in

$a_{0.1}$ = 0.470g conservatively use 0.5g

Assume that the DLF for calculation of stress due off-normal handling loads is 2.0. The off-normal decelerations including the DLF are 7.0g and 1.0g for MSB off-normal handling in the transfer cask and storage cask respectively.

Stress for the off-normal impact is calculated by scaling either the horizontal drop stress or the dead weight stress. The stress to use for scaling is based on comparing the unit acceleration stress, i.e., the horizontal drop stress is divided by the horizontal drop acceleration, and compared with the dead weight stress - which already represents unit vertical acceleration. The maximum of the unit acceleration stresses provides the stress intensity to be scaled to give the off-normal handling stress. The calculations are performed separately for transfer cask and storage cask conditions due to different off-normal handling accelerations.

Hence, for the condition of MSB in the transfer cask;

$$\text{Stress Intensity} = (\text{Max unit g Stress})_{\text{transfer cask}} \times 3.5\text{g} \times \text{DLF}$$

$$\text{With DLF} = 2, \text{Stress Intensity} = (\text{Max unit g Stress})_{\text{transfer cask}} \times 7.0$$

And for the condition of MSB lowered onto the ceramic tiles;

$$\text{Stress Intensity} = (\text{Max unit g Stress})_{\text{tiles}} \times 0.5\text{g} \times \text{DLF}$$

$$\text{With DLF} = 2, \text{Stress Intensity} = (\text{Max unit g Stress})_{\text{tiles}}$$

A noted previously, two separate calculations for the off-normal handling stress are completed i.e. the MSB being moved via the transfer cask at a crane velocity of 2 ft/sec, and the MSB is being lowered into the storage cask at a lowering velocity of 0.75 ft/sec.

For the calculation with the MSB in the transfer cask the unit g vertical stress is based on factoring the vertical drop stresses of Refs 3.1.1 and 3.1.3 by 1/108. The off-normal handling stresses for the MSB inside the transfer cask are summarized in Table 6-2.

For the calculation with the MSB lowered into the storage cask the unit g vertical stress is taken from Ref 3.1.3 for the MSB shell, MSB base, and MSB base weld. Since these components are analyzed for a dead weight analysis, no scaling is applied. The remaining components are taken from Refs 3.1.1 and 3.1.3, with a scaling factor of 1/108 applied. The off-normal handling stresses for the MSB inside the storage cask are summarized in Table 6-3.

The unit g acceleration stress for the horizontal orientation applies to both off-normal conditions, and is calculated based on the horizontal side drop analysis of Ref 3.1.1 and scaled by 1/40.

Table 6-2 Summary of Off Normal Handling Stresses – MSB Inside Transfer Cask, Impact at 2 ft/sec

LOCATION	STRESS CATEGORY	STRESS (ksi)					
		DEAD WT (Vert)	HORIZ DROP	Unit g Stress Vertical	Unit g Stress Horizontal	Max Unit g Stress	Off normal handling stress
MSB Shell	P_m	0.10	18.30	0.10	0.46	0.46	3.20
	$P_L + P_b$	0.11	42.60	0.11	1.07	1.07	7.46
Bottom Plate	P_m	0.04	27.80	0.04	0.70	0.70	4.87
	$P_L + P_b$	0.24	37.20	0.24	0.93	0.93	6.51
Structural Lid	P_m	0.01	18.80	0.01	0.47	0.47	3.29
	$P_L + P_b$	0.04	40.40	0.04	1.01	1.01	7.07
Sleeve Assembly	P_m	0.06	55.20	0.06	1.38	1.38	9.66
	$P_L + P_b$	0.06	57.30	0.06	1.43	1.43	10.03
Support Ring Weld	P_m	0.14	0.00	0.14	0.00	0.14	0.98
	$P_L + P_b$	0.14	0.00	0.14	0.00	0.14	0.98
Structural Lid Weld	P_m	0.03	8.80	0.03	0.22	0.22	1.54
	$P_L + P_b$	0.08	40.40	0.08	1.01	1.01	7.07
Bottom Plate Weld	P_m	0.10	24.50	0.10	0.61	0.61	4.29
	$P_L + P_b$	0.24	37.20	0.24	0.93	0.93	6.51
Shield Lid	P_m	0.03	18.20	0.03	0.46	0.46	3.19
	$P_L + P_b$	0.30	32.40	0.30	0.81	0.81	5.67
Shield Lid Weld	P_m	0.27	8.70	0.27	0.22	0.27	1.89
	$P_L + P_b$	0.27	19.40	0.27	0.49	0.49	3.40

Note:

The sleeve assembly membrane and membrane plus bending stresses are from Reference 3.1.1, Attachment I. The sleeve assembly membrane stress is the average of the Node 225 shell top and shell bottom stress intensities with a correction factor to reduce the stress to a 40g acceleration from the 44g used in Attachment I ($\frac{58.38\cdot ksi + 63.00\cdot ksi}{2}\cdot\frac{40\cdot g}{44\cdot g} = 55.2\,ksi$). This estimate of the membrane stress has significant margin since it includes the bending stress. The membrane plus bending stress is the maximum stress intensity, which is occurs at Node 225, shell bottom ($63\cdot ksi\cdot\frac{40\cdot g}{44\cdot g} = 57.3\,ksi$).

Table 6-3 Summary of Off Normal Handling Stresses – MSB Lowered onto Ceramic Tiles, Impact at 0.75 ft/sec

LOCATION	STRESS CATEGORY	STRESS (ksi)					
		DEAD WT (Vert)	HORIZ DROP	Unit g Stress Vertical	Unit g Stress Horiz-ontal	Max Unit g Stress	Off normal handling stress
MSB Shell	P_m	0.50	18.30	0.50	0.46	0.50	0.50
	$P_L + P_b$	1.50	42.60	1.50	1.07	1.50	1.50
Bottom Plate	P_m	0.35	27.80	0.35	0.70	0.70	0.70
	$P_L + P_b$	12.20	37.20	12.20	0.93	12.20	12.20
Structural Lid	P_m	0.01	18.80	0.01	0.47	0.47	0.47
	$P_L + P_b$	0.04	40.40	0.04	1.01	1.01	1.01
Sleeve Assembly	P_m	0.06	55.20	0.06	1.38	1.38	1.38
	$P_L + P_b$	0.06	57.30	0.06	1.43	1.43	1.43
Support Ring Weld	P_m	0.14	0.00	0.14	0.00	0.14	0.14
	$P_L + P_b$	0.14	0.00	0.14	0.00	0.14	0.14
Structural Lid Weld	P_m	0.03	8.80	0.03	0.22	0.22	0.22
	$P_L + P_b$	0.08	40.40	0.08	1.01	1.01	1.01
Bottom Plate Weld	P_m	0.50	24.50	0.50	0.61	0.61	0.61
	$P_L + P_b$	12.2	37.20	12.20	0.93	12.20	12.20
Shield Lid	P_m	0.03	18.20	0.03	0.46	0.46	0.46
	$P_L + P_b$	0.30	32.40	0.30	0.81	0.81	0.81
Shield Lid Weld	P_m	0.27	8.70	0.27	0.22	0.27	0.27
	$P_L + P_b$	0.27	19.40	0.27	0.49	0.49	0.49

Note:

The sleeve assembly membrane and membrane plus bending stresses are from Reference 3.1.1, Attachment I. The sleeve assembly membrane stress is the average of the Node 225 shell top and shell bottom stress intensities with a correction factor to reduce the stress to a 40g acceleration from the 44g used in Attachment I ($\frac{58.38\cdot ksi + 63.00\cdot ksi}{2}\cdot\frac{40\cdot g}{44\cdot g} = 55.2\,ksi$). This estimate of the membrane stress has significant margin since it includes the bending stress. The membrane plus bending stress is the maximum stress intensity, which is occurs at Node 225, shell bottom ($63\cdot ksi\cdot\frac{40\cdot g}{44\cdot g} = 57.3\,ksi$).

7. CONCLUSIONS

The calculated stresses are combined with stresses due to other loads in a separate calculation.

8. ELECTRONIC FILES

8.1. Computer Runs

None.

025030

BNFL Fuel Solutions

CALCULATION PACKAGE

Calc. Pkg No. VSC02.6.2.3.24
File No.: VSC02.6.2.3.24
Revision: 0

PROJECT/CUSTOMER:

VSC02/BNFL Fuel Solutions

TITLE:

MSB Shield Lid Weld Analysis

SCOPE:

Product:	☐ Wesflex™	☐ TranStor™	☒ VSC-24	☐ Other ________
Service:	☒ Storage	☐ Transportation		☐ Other ________
Conditions:	☒ Normal	☒ Off-Normal	☒ Accident	☐ Other ________

Component(s):

MSB shield lid weld

Prepared by:

Name: JL Hibbard
Signature: JLHibbard
Date: 1-12-00

Verified by:

Name: Michelle M. Heinz
Signature: Michelle M Heinz
Date: 1/12/00

Engineering Manager Approval:

Name: RAM SRINIVASAN
Signature: Srinivasan
Date: 1/17/00

RECORD OF REVISIONS

REV.	AFFECTED PAGES	AFFECTED MEDIA	DESCRIPTION	NAMES (print or type)	
				PREPARER	CHECKER
0	Pages 1-9 Appendix Pages A1-A7 and B1-B8	None	Replaces Calculation WEP109-002.24, Rev. 3 Per Ecn No.: WEP01-C-08	JC Hubbard	Michelle Heinz

Note: This calculation has been prepared in accordance with QAP 3.2, Revision 8, except that because this calculation is a revision of an existing calculation, the format is essentially based on the superceded calculation. The title page, record of revision page, and record of verification page are per QAP 3.2, Revision 8. Other format requirements of QAP 3.2 have been included where this could be readily accomplished. This approach was approved in BFS Memorandum 99-528, dated December 21, 1999.

RECORD OF VERIFICATION

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

COMMENTS:

Verifier: Michelle M. Heinz / Michelle M. Heinz / 1/12/00

Name/Signature/Date

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LIST OF FIGURES

1. INTRODUCTION

The purpose/objective of this calculation is to provide a stress analysis of the 1/4-inch partial penetration weld between the MSB shield lid and shell. The scope is an evaluation of the shield lid weld for normal, off normal, and accident conditions while the MSB is being stored. The calculated shield lid weld stresses are used as inputs in other calculations.

This calculation supercedes WEP109-002.24, Revision 3. This calculation addresses comments in CAR 98-50. The principal differences between this calculation and WEP109-002.24 are:

- Removed stress calculations for the following load conditions: deadweight, vertical drop, horizontal drop, normal handling, off normal handling, and off normal pressure. These calculations were duplications of calculations provided in other references.

- Removed the comparison of weld stresses to ASME Code allowable stresses. This comparison was a duplication of a comparison made in the load combination calculation.

2. REQUIREMENTS

2.1. Design Inputs

None.

2.2. Regulatory Commitments

None.

3. REFERENCES

3.1. BFS Calculation Packages

3.1.1 BNFL Calculation No. WEP-109-003.24, Revision 3 "MSB Shield Lid Weld Analysis." *(ANSYS results included as attachments to this calculation).*

3.1.2 BNFL Calculations WEP-109-003.4, "VSC-24 Thermal Hydraulic Analysis," Revision 2 *(Referred to in this calculation).*

3.2. General References

3.2.1 BNFL Drawing No. MSB-24-001, "MSB Assembly," Shts. 1 & 2, Revision 5.

3.2.2 BNFL Drawing No. MSB-24-002, "MSB Shell & Structural Plates," Sh. 1, Revision 4.

3.2.3 BNFL Drawing No. MSB-24-003, "Shield Lid Assembly," Sh. 1, Revision 4.

4. ASSUMPTIONS

4.1. Design Configuration

None.

4.2. Design Criteria

None.

4.3. Calculation Assumptions

4.3.1 The ANSYS analysis in Reference 3.1.1 used dimensions for the MSB that have since been revised. The dimensions that changed are as follows:

Parameter	Value Used in Reference 3.1.1	Correct Value (References 3.2.1, 3.2.2, & 3.2.3)
MSB wall thickness	0.75 inches	1.0 inch
MSB ID	31 inches	30.25 inches

This calculation assumes that the design changes have a minor effect on the weld stress calculations, and that the stresses calculated in Reference 3.1.1 are still valid.

5. CALCULATION METHODOLOGY

Stress in the shield lid weld is calculated for the following load conditions:

- Thermal
- Accident pressure

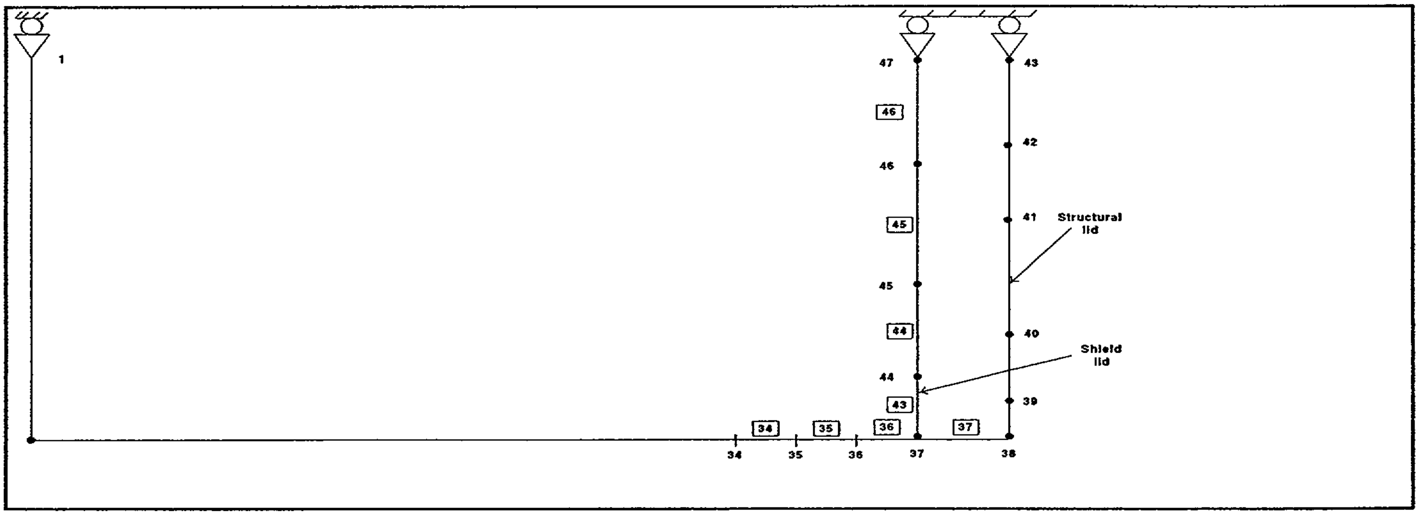
Thermal and accident pressure stresses are calculated using ANSYS Version 4.3A-2.

6. CALCULATIONS

6.1. Thermal Stress

Thermal stresses were calculated in Reference 3.1.1. This calculation used the ANSYS Version 4.3A-2 model, shown in Figure 6-1. The temperatures used for the calculation in Reference 3.1.1 were from the VCC thermal analysis (Reference 3.1.2). The most conservative case with an ambient temperature of -40° F was used. Input / output from Reference 3.1.1 are attached to this calculation for convenience (Attachment A). The ANSYS calculated thermal stress is 1.3 ksi.

Figure 6-1 – Finite Element Model



6.2. Accident Pressure Stress

The ANSYS model from Section 6.1 is used with somewhat different element sizes to evaluate bending more accurately. The analysis used a pressure of 28.5 psig. The actual accident pressure is higher, but this is accounted for in other calculations by scaling the stresses calculated below to the correct accident pressure. The ANSYS input/output is attached (Attachment B).

The calculated shear force of 13.7 kips / rad results in a stress of:

$$\tau = \frac{13.7}{30.25 \cdot 0.25} = 1.8ksi$$

The moment is 4.2 *kips - in / rad*

$$\sigma = \frac{4.2}{30.25 \cdot 0.25^2} \cdot 6 = 13.3ksi$$

Note that the bending stress is secondary, since it is not needed to restrict stresses in the middle of the shield lid (ASME, Appendix XIII). However, to be conservative it is included as $P_L + P_b$.

$$P_M = 2\tau = 3.6ksi$$

$$P_L + P_b = \sqrt{\sigma^2 + 4\tau^2} = 13.8ksi$$

7. CONCLUSIONS

Stress in the shield lid weld has been calculated for the thermal and pressure conditions. The stresses are combined with stresses due to other loads and compared to ASME Code allowable stresses in a separate calculation.

Summary of Conservatisms

- The accident pressure bending stress is secondary, but is conservatively included in the calculation of $P_L + P_b$ for accident pressure.

8. ELECTRONIC FILES

8.1. Computer Runs

No new computer calculations were prepared in this calculation. Computer calculations from WEP109-002.24, Revision 3 are used as an input to this calculation. For convenience, the computer printouts from WEP109-002.24, Revision 3 are provided in Attachments A and B.

8.2. Other Electronic Files

None.

9. ATTACHMENT A – ANSYS INPUT AND OUTPUT FOR THERMAL LOAD CASE

```
LIST ALL SELECTED NODE   DSYS=   0

 NODE        X            Y            Z            THXY     THYZ     THXZ
     1  0.00000E+00  0.00000E+00  0.00000E+00     0.00     0.00     0.00
     2   8.0000      0.00000E+00  0.00000E+00     0.00     0.00     0.00
     3   16.000      0.00000E+00  0.00000E+00     0.00     0.00     0.00
     4   24.000      0.00000E+00  0.00000E+00     0.00     0.00     0.00
     5   28.000      0.00000E+00  0.00000E+00     0.00     0.00     0.00
     6   30.000      0.00000E+00  0.00000E+00     0.00     0.00     0.00
     7   31.000      0.00000E+00  0.00000E+00     0.00     0.00     0.00
     8   31.000       3.0000      0.00000E+00     0.00     0.00     0.00
     9   31.000       9.0000      0.00000E+00     0.00     0.00     0.00
    10   31.000       15.000      0.00000E+00     0.00     0.00     0.00
    11   31.000       21.000      0.00000E+00     0.00     0.00     0.00
    12   31.000       27.000      0.00000E+00     0.00     0.00     0.00
    13   31.000       33.000      0.00000E+00     0.00     0.00     0.00
    14   31.000       39.000      0.00000E+00     0.00     0.00     0.00
    15   31.000       45.000      0.00000E+00     0.00     0.00     0.00
    16   31.000       51.000      0.00000E+00     0.00     0.00     0.00
    17   31.000       57.000      0.00000E+00     0.00     0.00     0.00
    18   31.000       63.000      0.00000E+00     0.00     0.00     0.00
    19   31.000       69.000      0.00000E+00     0.00     0.00     0.00
    20   31.000       75.000      0.00000E+00     0.00     0.00     0.00

 NODE        X            Y            Z            THXY     THYZ     THXZ
    21   31.000       81.000      0.00000E+00     0.00     0.00     0.00
    22   31.000       87.000      0.00000E+00     0.00     0.00     0.00
    23   31.000       93.000      0.00000E+00     0.00     0.00     0.00
    :4   31.000       99.000      0.00000E+00     0.00     0.00     0.00
     5   31.000       105.00      0.00000E+00     0.00     0.00     0.00
    26   31.000       111.00      0.00000E+00     0.00     0.00     0.00
    27   31.000       117.00      0.00000E+00     0.00     0.00     0.00
    28   31.000       123.00      0.00000E+00     0.00     0.00     0.00
    29   31.000       129.00      0.00000E+00     0.00     0.00     0.00
    30   31.000       135.00      0.00000E+00     0.00     0.00     0.00
    31   31.000       141.00      0.00000E+00     0.00     0.00     0.00
    32   31.000       147.00      0.00000E+00     0.00     0.00     0.00
    33   31.000       153.00      0.00000E+00     0.00     0.00     0.00
    34   31.000       159.00      0.00000E+00     0.00     0.00     0.00
    35   31.000       165.00      0.00000E+00     0.00     0.00     0.00
    36   31.000       171.00      0.00000E+00     0.00     0.00     0.00
    37   31.000       176.00      0.00000E+00     0.00     0.00     0.00
    38   31.000       181.00      0.00000E+00     0.00     0.00     0.00
    39   29.000       181.00      0.00000E+00     0.00     0.00     0.00
    40   25.000       181.00      0.00000E+00     0.00     0.00     0.00

 NODE        X            Y            Z            THXY     THYZ     THXZ
    41   17.000       181.00      0.00000E+00     0.00     0.00     0.00
    42   9.0000       181.00      0.00000E+00     0.00     0.00     0.00
    43  0.00000E+00   181.00      0.00000E+00     0.00     0.00     0.00
    44   28.000       176.00      0.00000E+00     0.00     0.00     0.00
    45   22.000       176.00      0.00000E+00     0.00     0.00     0.00
    46   12.000       176.00      0.00000E+00     0.00     0.00     0.00
     '  0.00000E+00   176.00      0.00000E+00     0.00     0.00     0.00

IST ALL ELEMENT TYPES

O. STIF          KEYOPT VALUES          INOTPR
```

```
 1   51   0   0   0   0  1  0   0   0   0    0  PLASTIC AXISYM. CONIC SHELL
LIST ALL SELECTED ELEMENTS.   (LIST NODES)
  ELEM MAT TYP REL            NODES

     1    1    1    1          1       2
     2    1    1    1          2       3
     3    1    1    1          3       4
     4    1    1    1          4       5
     5    1    1    1          5       6
     6    1    1    1          6       7
     7    1    1    1          7       8
     8    1    1    1          8       9
     9    1    1    1          9      10
    10    1    1    1         10      11
    11    1    1    1         11      12
    12    1    1    1         12      13
    13    1    1    1         13      14
    14    1    1    1         14      15
    15    1    1    1         15      16
    16    1    1    1         16      17
    17    1    1    1         17      18
    18    1    1    1         18      19
    19    1    1    1         19      20
    20    1    1    1         20      21
  ELEM MAT TYP REL            NODES

    21    1    1    1         21      22
    22    1    1    1         22      23
    23    1    1    1         23      24
    24    1    1    1         24      25
    25    1    1    1         25      26
    26    1    1    1         26      27
    27    1    1    1         27      28
    28    1    1    1         28      29
    29    1    1    1         29      30
    30    1    1    1         30      31
    31    1    1    1         31      32
    32    1    1    1         32      33
    33    1    1    1         33      34
    34    1    1    1         34      35
    35    1    1    1         35      36
    36    1    1    1         36      37
    37    1    1    1         37      38
    38    1    1    3         38      39
    39    1    1    2         39      40
    40    1    1    2         40      41
 ELEM MAT TYP REL            NODES

    41    1    1    2         41      42
    42    1    1    2         42      43
    43    1    1    5         37      44
          1    1    4         44      45
          1    1    4         45      46
    46    1    1    4         46      47
ST ALL REAL SETS
```

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```
REAL CONSTANT SET    1  ITEMS    1 TO    6
 0.75000        0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

REAL CONSTANT SET    2  ITEMS    1 TO    6
  .0000         0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

REAL CONSTANT SET    3  ITEMS    1 TO    6
 0.75000         3.0000      0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

REAL CONSTANT SET    4  ITEMS    1 TO    6
  7.0000        0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

REAL CONSTANT SET    5  ITEMS    1 TO    6
 0.25000         7.0000      0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

IST ALL MATERIALS   PROPERTY= ALL

ROPERTY TABLE EX     MAT=    1  NUM. POINTS=  3
      TEMPERATURE         DATA          TEMPERATURE       DATA
     70.000        29200.        100.00         29200.
     200.00        29200.

ROPERTY TABLE ALPX  MAT=    1  NUM. POINTS=  3
      TEMPERATURE         DATA          TEMPERATURE       DATA
     70.000      0.55300E-05  100.00       0.55300E-05
     200.00      0.58900E-05

IST DISPLACEMENTS FOR ALL SELECTED NODES

IC      LABEL       DISP               CDISP
  1 UX      0.000000000E+00 0.000000000E+00
 43 UX      0.000000000E+00 0.000000000E+00
  1 UY      0.000000000E+00 0.000000000E+00
 47 UX      0.000000000E+00 0.000000000E+00

ST TEMPERATURES FOR ALL SELECTED NODES

ODE    TEMPERATURE    FLUENCE
  1      58.500      0.00000E+00
  2      53.500      0.00000E+00
  3      48.500      0.00000E+00
  4      44.000      0.00000E+00
  5      41.700      0.00000E+00
  6      40.600      0.00000E+00
  7      40.000      0.00000E+00
  8      70.000      0.00000E+00
  9      88.600      0.00000E+00
 10      98.900      0.00000E+00
 11      109.20      0.00000E+00
 12      119.50      0.00000E+00
 13      129.80      0.00000E+00
 14      139.10      0.00000E+00
 15      147.40      0.00000E+00
 1       155.60      0.00000E+00
         158.40      0.00000E+00
 1       160.00      0.00000E+00
 19      161.80      0.00000E+00
 20      163.50      0.00000E+00
```

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```
NODE     TEMPERATURE    FLUENCE
  21       165.10      0.00000E+00
  22       165.00      0.00000E+00
  23       163.00      0.00000E+00
  24       161.00      0.00000E+00
  25       159.00      0.00000E+00
  26       157.00      0.00000E+00
  27       155.00      0.00000E+00
  28       144.30      0.00000E+00
  29       133.40      0.00000E+00
  30       122.50      0.00000E+00
  31       111.70      0.00000E+00
  32       100.80      0.00000E+00
  33       80.000      0.00000E+00
  34       57.000      0.00000E+00
  35       34.200      0.00000E+00
  36       18.500      0.00000E+00
  37       8.0000      0.00000E+00
  38       4.6000      0.00000E+00
  39       5.0000      0.00000E+00
  40       5.5000      0.00000E+00

NODE     TEMPERATURE    FLUENCE
  41       6.4000      0.00000E+00
  42       5.8000      0.00000E+00
  43       5.2000      0.00000E+00
  44       7.5000      0.00000E+00
  45       6.5000      0.00000E+00
  46       6.0000      0.00000E+00
   7       6.0000      0.00000E+00
```

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```
PRINT ELEMENT STRESS ITEMS PER ELEMENT

         ***** POST1 ELEMENT STRESS LISTING *****

    D STEP      1  ITERATION=      1  SECTION=  1
 TIME=    0.00000E+00      LOAD CASE=  1

 ELEM         Q
    1     0.33122102
    2     0.40369000
    3     0.84324196
    4      1.2034220
    5      1.3845015
    6      1.4753769
    7     0.18735827
    8      1.0315863
    9     0.33608688
   10     0.48117278E-01
   11     0.22033741E-01
   12     0.25122956E-01
   13     0.48638334E-01
   14     0.47312766E-01

         ***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP      1  ITERATION=      1  SECTION=  1
TIME=    0.00000E+00      LOAD CASE=  1

E'   1          Q
          0.17076335
   16     0.20570861
   17     0.45994719E-01
   18     0.10926665E-01
   19     0.72778753E-02
   20     0.60121295E-01
   21     0.11485653
   22     0.62677556E-01
   23     0.58742439E-02
   24     0.13821336E-01
   25     0.38503086E-01
   26     0.27295698
   27     0.27393824
   28     0.35364006E-01

         ***** POST1 ELEMENT STRESS LISTING *****

OAD STEP      1  ITERATION=      1  SECTION=  1
IME=    0.00000E+00      LOAD CASE=  1

LEM          Q
  29     0.34319743E-01
  30     0.32558596E-01
  31     0.27971418
         0.34865421
         0.56813071E-01
         0.17222198
  35     0.24519640
  36      1.3419467
  37     0.27472392E-01
```

← use this # as max. thermal stress in the weld (conservative)

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```
  38      0.18077400
  39      0.10722215
  40      0.15500941E-01
  41      0.50548760E-01
  42      0.45274775E-01

        ***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP      1   ITERATION=       1   SECTION=  1
TIME=    0.00000E+00      LOAD CASE=  1

ELEM          Q
  43      0.36078768
  44      0.10985157
  45      0.88172856E-01
  46      0.93514038E-01
```

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10. ATTACHMENT B – ANSYS INPUT AND OUTPUT FOR CRITICAL PRESSURE LOAD CASE

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```
IST ALL SELECTED NODE   DSYS=   0

N   E        X             Y             Z            THXY     THYZ     THXZ
    1  0.00000E+00  0.00000E+00  0.00000E+00    0.00     0.00     0.00
    2   8.0000      0.00000E+00  0.00000E+00    0.00     0.00     0.00
    3   16.000      0.00000E+00  0.00000E+00    0.00     0.00     0.00
    4   24.000      0.00000E+00  0.00000E+00    0.00     0.00     0.00
    5   28.000      0.00000E+00  0.00000E+00    0.00     0.00     0.00
    6   30.000      0.00000E+00  0.00000E+00    0.00     0.00     0.00
    7   31.000      0.00000E+00  0.00000E+00    0.00     0.00     0.00
    8   31.000        3.0000     0.00000E+00    0.00     0.00     0.00
    9   31.000        9.0000     0.00000E+00    0.00     0.00     0.00
   10   31.000        15.000     0.00000E+00    0.00     0.00     0.00
   11   31.000        21.000     0.00000E+00    0.00     0.00     0.00
   12   31.000        27.000     0.00000E+00    0.00     0.00     0.00
   13   31.000        33.000     0.00000E+00    0.00     0.00     0.00
   14   31.000        39.000     0.00000E+00    0.00     0.00     0.00
   15   31.000        45.000     0.00000E+00    0.00     0.00     0.00
   16   31.000        51.000     0.00000E+00    0.00     0.00     0.00
   17   31.000        57.000     0.00000E+00    0.00     0.00     0.00
   18   31.000        63.000     0.00000E+00    0.00     0.00     0.00
   19   31.000        69.000     0.00000E+00    0.00     0.00     0.00
   20   31.000        75.000     0.00000E+00    0.00     0.00     0.00

NODE         X             Y             Z            THXY     THYZ     THXZ
   21   31.000        81.000     0.00000E+00    0.00     0.00     0.00
   22   31.000        87.000     0.00000E+00    0.00     0.00     0.00
        31.000        93.000     0.00000E+00    0.00     0.00     0.00
        31.000        99.000     0.00000E+00    0.00     0.00     0.00
        31.000        105.00     0.00000E+00    0.00     0.00     0.00
   26   31.000        111.00     0.00000E+00    0.00     0.00     0.00
   27   31.000        117.00     0.00000E+00    0.00     0.00     0.00
   28   31.000        123.00     0.00000E+00    0.00     0.00     0.00
   29   31.000        129.00     0.00000E+00    0.00     0.00     0.00
   30   31.000        137.00     0.00000E+00    0.00     0.00     0.00
   31   31.000        146.00     0.00000E+00    0.00     0.00     0.00
   32   31.000        155.00     0.00000E+00    0.00     0.00     0.00
   33   31.000        163.00     0.00000E+00    0.00     0.00     0.00
   34   31.000        170.00     0.00000E+00    0.00     0.00     0.00
   35   31.000        173.00     0.00000E+00    0.00     0.00     0.00
   36   31.000        175.00     0.00000E+00    0.00     0.00     0.00
   37   31.000        177.00     0.00000E+00    0.00     0.00     0.00
   38   31.000        178.00     0.00000E+00    0.00     0.00     0.00
   39   26.000        178.00     0.00000E+00    0.00     0.00     0.00
   40   20.000        178.00     0.00000E+00    0.00     0.00     0.00

ODE          X             Y             Z            THXY     THYZ     THXZ
   41   14.000        178.00     0.00000E+00    0.00     0.00     0.00
   42   7.0000        178.00     0.00000E+00    0.00     0.00     0.00
   43 0.00000E+00     178.00     0.00000E+00    0.00     0.00     0.00
   44   31.000        179.00     0.00000E+00    0.00     0.00     0.00
   45   31.000        181.00     0.00000E+00    0.00     0.00     0.00

S   LL ELEMENT TYPES

  STIF          KEYOPT VALUES          INOTPR
   51    0  0  0   0  1  0   0  0  0     0   PLASTIC AXISYM. CONIC SHELL
```

```
LIST ALL SELECTED ELEMENTS.   (LIST NODES)

  ELEM MAT TYP REL          NODES

     1    1    1    1          1       2
     2    1    1    1          2       3
     3    1    1    1          3       4
     4    1    1    1          4       5
     5    1    1    1          5       6
     6    1    1    1          6       7
     7    1    1    1          7       8
     8    1    1    1          8       9
     9    1    1    1          9      10
    10    1    1    1         10      11
    11    1    1    1         11      12
    12    1    1    1         12      13
    13    1    1    1         13      14
    14    1    1    1         14      15
    15    1    1    1         15      16
    16    1    1    1         16      17
    17    1    1    1         17      18
    18    1    1    1         18      19
    19    1    1    1         19      20
    20    1    1    1         20      21

  ELEM MAT TYP REL          NODES

    21    1    1    1         21      22
    22    1    1    1         22      23
    23    1    1    1         23      24
    24    1    1    1         24      25
    25    1    1    1         25      26
    26    1    1    1         26      27
    27    1    1    1         27      28
    28    1    1    1         28      29
    29    1    1    1         29      30
    30    1    1    1         30      31
    31    1    1    1         31      32
    32    1    1    1         32      33
    33    1    1    1         33      34
    34    1    1    1         34      35
    35    1    1    1         35      36
    36    1    1    1         36      37
    37    1    1    1         37      38
    38    1    1    4         38      39
    39    1    1    5         39      40
    40    1    1    5         40      41

  ELEM MAT TYP REL          NODES

    41    1    1    5         41      42
    42    1    1    5         42      43
    43    1    1    1         38      44
    44    1    1    1         44      45

    DISPLACEMENTS FOR ALL SELECTED NODES

 NODE  LABEL       DISP              CDISP
    1 UX     0.000000000E+00 0.000000000E+00
   43 UX     0.000000000E+00 0.000000000E+00
```

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```
   1 UY    0.000000000E+00 0.000000000E+00
  45 UX    0.000000000E+00 0.000000000E+00

IST ALL REAL SETS

I   L CONSTANT SET    1   ITEMS    1 TO    6
 0.75000       0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

REAL CONSTANT SET    2   ITEMS    1 TO    6
  3.0000       0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

REAL CONSTANT SET    3   ITEMS    1 TO    6
 0.75000        3.0000      0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

REAL CONSTANT SET    4   ITEMS    1 TO    6
 0.25000        7.0000      0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

REAL CONSTANT SET    5   ITEMS    1 TO    6
  7.0000       0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

IST ALL MATERIALS  PROPERTY= ALL

ROPERTY TABLE EX     MAT=    1  NUM. POINTS=  2
     TEMPERATURE      DATA          TEMPERATURE      DATA
    0.00000E+00  28000.        2300.0        28000.

ROPERTY TABLE ALPX  MAT=    1  NUM. POINTS=  3
     TEMPERATURE      DATA          TEMPERATURE      DATA
     70.000       0.55300E-05  100.00       0.55300E-05
     200.00       0.58900E-05

IST PRESSURES FOR ALL SELECTED NODES

ELEM     FACE          VALUE(S)                      FACE NODES
    1       1        0.28500E-01  0.00000E+00          1      2
    2       1        0.28500E-01  0.00000E+00          2      3
    3       1        0.28500E-01  0.00000E+00          3      4
    4       1        0.28500E-01  0.00000E+00          4      5
    5       1        0.28500E-01  0.00000E+00          5      6
    6       1        0.28500E-01  0.00000E+00          6      7
    7       1        0.28500E-01  0.00000E+00          7      8
    8       1        0.28500E-01  0.00000E+00          8      9
    9       1        0.28500E-01  0.00000E+00          9     10
   10       1        0.28500E-01  0.00000E+00         10     11
   11       1        0.28500E-01  0.00000E+00         11     12
   12       1        0.28500E-01  0.00000E+00         12     13
   13       1        0.28500E-01  0.00000E+00         13     14
   14       1        0.28500E-01  0.00000E+00         14     15
   15       1        0.28500E-01  0.00000E+00         15     16
   16       1        0.28500E-01  0.00000E+00         16     17
   17       1        0.28500E-01  0.00000E+00         17     18
   18       1        0.28500E-01  0.00000E+00         18     19
   19       1        0.28500E-01  0.00000E+00         19     20
   20       1        0.28500E-01  0.00000E+00         20     21

E        FACE          VALUE(S)                      FACE NODES
   21       1        0.28500E-01  0.00000E+00         21     22
   22       1        0.28500E-01  0.00000E+00         22     23
   23       1        0.28500E-01  0.00000E+00         23     24
   24       1        0.28500E-01  0.00000E+00         24     25
```

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```
  25     1          0.28500E-01  0.00000E+00       25     26
  26     1          0.28500E-01  0.00000E+00       26     27
  27     1          0.28500E-01  0.00000E+00       27     28
  28     1          0.28500E-01  0.00000E+00       28     29
  29     1          0.28500E-01  0.00000E+00       29     30
  30     1          0.28500E-01  0.00000E+00       30     31
  31     1          0.28500E-01  0.00000E+00       31     32
  32     1          0.28500E-01  0.00000E+00       32     33
  33     1          0.28500E-01  0.00000E+00       33     34
  34     1          0.28500E-01  0.00000E+00       34     35
  35     1          0.28500E-01  0.00000E+00       35     36
  36     1          0.28500E-01  0.00000E+00       36     37
  37     1          0.28500E-01  0.00000E+00       37     38
  38     1          0.28500E-01  0.00000E+00       38     39
  39     1          0.28500E-01  0.00000E+00       39     40
  40     1          0.28500E-01  0.00000E+00       40     41

ELEM   FACE           VALUE(S)                   FACE NODES
  41     1          0.28500E-01  0.00000E+00       41     42
  42     1          0.28500E-01  0.00000E+00       42     43
```

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```
RINT ELEMENT STRESS ITEMS PER ELEMENT

         ***** POST1 ELEMENT STRESS LISTING *****

I   STEP      1  ITERATION=      1  SECTION=  1
T  E=    0.00000E+00      LOAD CASE=  1

ELEM        FORC
   1   -0.30124026E-09
   2    0.91200000
   3     3.6480000
   4     8.2080000
   5     11.172000
   6     12.825000
   7    -26.554586
   8    -16.775492
   9    0.28702410
  10    0.66117797
  11   -0.23398780E-01
  12   -0.25839920E-01
  13    0.13983543E-02
  14    0.10010862E-02

         ***** POST1 ELEMENT STRESS LISTING *****

OAD STEP      1  ITERATION=      1  SECTION=  1
IME=    0.00000E+00      LOAD CASE=  1

EI          FORC
       -0.73712666E-04
       -0.38429414E-04
  17    0.36254492E-05
  18    0.14607783E-05
  19   -0.17052222E-06
  20   -0.54935269E-07
  21    0.77718560E-08
  22    0.20973059E-08
  23   -0.39794930E-09
  24   -0.14549441E-08
  25    0.19664412E-08
  26    0.33862503E-07
  27   -0.64585464E-07
  28   -0.82287928E-06

         ***** POST1 ELEMENT STRESS LISTING *****

OAD STEP      1  ITERATION=      1  SECTION=  1
IME=    0.00000E+00      LOAD CASE=  1

LEM         FORC
 29     0.20017250E-05
 30     0.21440652E-04
 31    -0.50024221E-03
 32     0.71760172E-02
       -0.45513266E-01
       -0.15598279
 35     0.33840166
 36      1.1960088
 37      2.5279699
```

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```
  38    -13.694250
  39    -9.6330000
  40    -5.7000000
  41    -2.7930000
  42   -0.69825000
```

← use this value as the weld force

```
        ***** POST1 ELEMENT STRESS LISTING *****

 LOAD STEP      1   ITERATION=      1   SECTION=  1
 TIME=    0.00000E+00       LOAD CASE=  1

 ELEM          FORC
   43      1.3592060
   44      1.3237635

PRINT ELEMENT STRESS ITEMS PER ELEMENT

        ***** POST1 ELEMENT STRESS LISTING *****

 LOAD STEP      1   ITERATION=      1   SECTION=  1
 TIME=    0.00000E+00       LOAD CASE=  1

 ELEM          MOM
    1   -0.33219955E-15
    2     -16.746047
    3     -15.454254
    4      21.956691
    5      59.850245
    6      84.581135
    7      98.516040
    8      30.404941
    9     -6.6718405
   10     -1.0898688
   11     0.28167621
   12     0.35052442E-01
   13    -0.14955520E-01
   14    -0.42512949E-02

        ***** POST1 ELEMENT STRESS LISTING *****

 LOAD STEP      1   ITERATION=      1   SECTION=  1
 TIME=    0.00000E+00       LOAD CASE=  1

 ELEM          MOM
   15    -0.24590179E-02
   16    -0.29167512E-02
   17    -0.29796416E-02
   18    -0.29603176E-02
   19    -0.29581699E-02
   20    -0.29589765E-02
   21    -0.29590472E-02
   22    -0.29590138E-02
   23    -0.29590113E-02
   24    -0.29590163E-02
   25    -0.29590220E-02
         -0.29589283E-02
         -0.29588278E-02
   28    -0.29612308E-02

        ***** POST1 ELEMENT STRESS LISTING *****
```

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```
LOAD STEP      1   ITERATION=      1   SECTION=   1
TIME=    0.00000E+00        LOAD CASE=   1

  EM         MOM
  29    -0.29626644E-02
  30    -0.28508432E-02
  31    -0.45035012E-02
  32     0.13059531E-01
  33    -0.17387464E-01
  34    -0.97132314
  35    -0.88485630
  36     0.56526228
  37      4.2242429
  38      11.035433
  39     -42.376447
  40     -65.043764
  41     -62.317236
  42     -37.200590
```

MOMENT ALLW. = 4.2 kips·in/rad

— no.
BAC 7/12/90

```
        ***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP      1   ITERATION=      1   SECTION=   1
TIME=    0.00000E+00        LOAD CASE=   1

ELEM         MOM
  43     -3.9075539
  44     -2.5627969
```

— < 4.2 kips·in/rad

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BNFL Fuel Solutions	CALCULATION PACKAGE	Calc. Pkg No. VSC02.6.2.3.25 File No.: VSC02.6.2.3.25 Revision: 1

PROJECT/CUSTOMER:

VSC02/BNFL Fuel Solutions

TITLE:

MSB Dead Weight and Vertical Drop Bottom Plate Bending Stress Analysis

SCOPE:

Product: ☐ Wesflex™ ☐ TranStor™ ☒ VSC-24 ☐ Other ____________

Service: ☒ Storage ☐ Transportation ☐ Other ____________

Conditions: ☒ Normal ☐ Off-Normal ☒ Accident ☐ Other ____________

Component(s):

MSB structural lid and bottom plate, and ceramic tile supporting MSB bottom plate.

Prepared by:

Name: WARREN PRICE

Signature: WARREN Price

Date: 04/11/00

Verified by:

Name: Soo BEE KOK

Signature: Kokfrofee

Date: 4/11/00

Engineering Manager Approval:

Name: RAM SRINIVASAN

Signature: RSrinivasan

Date: ~~4/12~~ 4/17/00

RECORD OF REVISIONS

REV.	AFFECTED PAGES	AFFECTED MEDIA	DESCRIPTION	NAMES (print or type)	
				PREPARER	CHECKER
0	1 – 18 Appendix Pages A1-A33, B1-B5, & C1-C5		Updates Calculation WEP109-002.25, Rev. 1	J.L. Hibbard	Michelle Heinz
1	All		Editorial re-write. Incorporated changes due to alternative support of MSB by ceramic tiles, as per ECN No. VSC02-ECN-003	Warren Price	Soo Bee Kok

Note: This calculation has been prepared in accordance with QAP 3.2, Revision 8, except that because this calculation is a revision of an existing calculation, the format is essentially based on the superceded calculation. The title page, record of revision page, and record of verification page are per QAP 3.2, Revision 8. Other format requirements of QAP 3.2 have been included where this could be readily accomplished. This approach was approved in BFS Memorandum 99-528, dated December 21, 1999.

RECORD OF VERIFICATION

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

COMMENTS:

All the comments have been satisfactorily resolved.

Verifier: Soo Bee KOK / Kok Soo Bee / 4/11/00

Name/Signature/Date

INDEX OF FIGURES

INDEX OF TABLES

1. INTRODUCTION

The objective/purpose of this calculation is to calculate the stresses in the vicinity of the MSB top and bottom regions for both normal operating and vertical drop conditions. This calculation was generated at the request of the NRC. The calculation scope includes an analysis of the MSB top and bottom regions for end drop onto base and end drop onto shield lid. In addition, the calculation evaluates the ceramic tile that supports the MSB bottom plate for normal operating conditions. This revision incorporates the analysis results of an alternative tile support configuration at the MSB bottom plate.

This calculation supersedes WEP109.002.25, Revision 1. This calculation incorporates comments from CAR 98-50 and the Design Review Record (dated 8/21/98) for Calculation WEP109-002.25, Revision 1.

CAR 98-50 indicates there is a discrepancy in the temperature used to establish the allowable stress for the sleeve. It appears that this comment is an error, since this calculation only models the MSB shell and does not include the sleeve. This comment in the CAR was not addressed in this calculation.

The principal differences between this calculation and WEP109.002.25, Revision 1 are:

- Dimensions for the MSB changed slightly. The ANSYS results were scaled to account for the dimensional changes.
- Calculations were revised for the revised deceleration from the five foot drop calculation in Ref 3.1.2.
- An evaluation was added to calculate the stresses in the bottom plate when the MSB is supported by ceramic tiles. The evaluation considers both normal operating and five foot drop conditions.
- An evaluation was added to calculate the bearing stress in the ceramic tile for normal operating loads (1 g acceleration).

2. REQUIREMENTS

2.1. Design Inputs

2.1.1. American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel Code, *Rules for Construction of Nuclear Power Plant Components*, Section III, Division 1, Appendix F, "*Rules for Evaluation of Service Loadings with Level D Service Limits*", 1992 Edition, 1994 Addenda.

2.1.2. American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel Code, Section II, "*Materials Part D – Properties*", 1992 Edition, 1994 Addenda.

2.1.3. ASME American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel Code, *Rules for Construction of Nuclear Power Plant Components*," Section III, Division 1, Subsection NC, "*Class 2 Components*," 1992 Edition, 1994 Addenda.

2.2. Regulatory Commitments

None.

3. REFERENCES

3.1. BFS Calculation Packages

3.1.1. VSC02.6.2.5.01, Rev. 0, "MTC, MSB, and VCC Weights and Centers of Gravity B&W Fuel". (Mass of shield lid, structural lid, and support lid)

3.1.2. VSC02.6.2.3.15, Rev. 0, "VSC-24 Hypothetical Tipover and Five-foot Drop Analyses." (Vertical deceleration from 5 foot drop)

3.1.3. WEP-109-002.25, Rev. 1, "MSB Vertical Drop Bending Analysis." (ANSYS results provided in Attachment A of this calculation)

3.1.4. WEP-109-003.4, "VSC-24 Thermal Hydraulic Analysis," Revision 2, and WEP-109-003.5, "MSB-24 Thermal Hydraulic Analysis," Revision 5. (MSB design temperature of 300°F)

3.1.5. VSC02.6.3.05, Rev 1, "Normal, Off-Normal, and Maximum Accident Pressure in the MSB".

3.2. General References

3.2.1. BNFL Drawing No. MSB-24-003, "Shield Lid Assembly," Rev. 4.

3.2.2. BNFL Drawing No. MSB-24-002, "MSB Shell and Structural Plates," Sh. 1, Rev. 4.

3.2.3. Roark & Young, "Roarks Formulas for Stress and Strain", 6th Edition, McGraw-Hill Book Company.

3.2.4. BNFL Drawing No. VCC-24-002, "Cask Liner and Lid Assembly," Sh. 1, Rev. 3.

3.2.5. BFS Computer Software Listing, File SOFT.001.001, Rev 0, ANSYS 5.5 (PC)

4. ASSUMPTIONS

4.1. Design Configuration

The main structural members of the MSB (basket) consists of the shell, structural lid, shield lid, and base plate and all associated seam welds and closure welds. Fuel is stored inside the basket, within the storage sleeve assembly. Once inside the concrete cask, the basket sits on a ring of ceramic tiles located around the periphery of the MSB base. The purpose of the ceramic tiles is to prevent contact between the MSB base and the cask liner during normal storage conditions.

Original calculations considered the MSB base to be in direct contact with the cask liner i.e the MSB base was uniformly supported by the cask.

Two support configurations for the MSB have been considered. These are;

- Uniform support on MSB base for the end drop. This is in line with the original design configuration noted above.

- Support to the MSB base for both normal operating and end drop onto base, is provided by ceramic tiles placed around the periphery of the MSB base.

For the end drop condition where the MSB is uniformly supported, the original ANSYS results from Ref 3.1.3 are scaled to account for some slight changes made to the MSB wall thickness.

For the support configuration with the MSB supported on ceramic tiles, additional ANSYS analyses have been completed. These additional analyses cover both the deadweight of the MSB, deadweight plus internal pressure, and five foot end drop onto the MSB base.

In addition, end drop of the MSB onto its structural lid has been considered, the resulting stresses in the MSB base being reported.

The design parameters for the analyses are listed on the following page.

The design parameters for the MSB used in this analysis are as follows;

$m_{shield} := 4368 \cdot lb$	Shield lid mass without support, Ref. 3.1.1
$m_{shield} := 4400 \cdot lb$	Bounding shield lid mass used in calculation
$m_{struct} := 2384 \cdot lb$	Structural lid mass, Ref. 3.1.1
$m_{struct} := 2400 \cdot lb$	Bounding structural lid mass used in calculation
$m_{support} := 2003 \cdot lb$	Support lid mass, Ref. 3.1.1
$m_{support} := 2100 \cdot lb$	Bounding support lid mass used in calculation
$m_{msb\_e} := 21036 \cdot lb$	Mass of MSB, empty. Ref 3.1.1
$m_{MSB} := 70000 \cdot lb$	Bounding mass of loaded MSB with shield lid and structural lid, Ref. 3.1.1
$t_{stl} := 7.5 \cdot in$	Thickness of steel in shield lid, Ref. 3.2.1
$t_{277} := 2.0 \cdot in$	Thickness of RX-277 in shield lid, Ref. 3.2.1
$od_{msb} := 62.5 \cdot in$	od of msb, Ref. 3.2.2
$id_{msb} := 60.5 \cdot in$	id of msb, Ref. 3.2.2
$t_{msb} := 1 \cdot in$	Shell wall thickness of msb, Ref. 3.2.2
$L_{msb} := 180.9 \cdot in$	Length of msb, Ref. 3.2.2
$t_{bot} := .75 \cdot in$	Thickness of bottom plate, Ref. 3.2.2
$w_{cer} := 1.70 \cdot in$	Assumed Width of ceramic tile

4.2. Design Criteria

4.2.1. Allowable Stresses

The MSB basket shell is designed to the allowable stress design criteria of the ASME Code. Stresses resulting from the deadweight loading condition are evaluated against Subsection NC (Ref 2.1.3). Stresses resulting from the end drop condition are evaluated against the ASME service level D limits. In accordance with Table NC 3217-1, Note 4, the stress limits of Appendix F of the ASME code may be applied for Service Level D conditions when a complete analysis is performed.

For a bounding temperature of 300°F (Ref 3.1.4), the following properties of material SA-516 Gr.70 apply (Ref 2.1.2)

S_m = 22.5 ksi

S_y = 33.7 ksi

S_u = 70.0 ksi

4.2.1.1. Normal Operating

Stresses resulting from the deadweight loading condition are evaluated against Subsection NC (Ref 2.1.3) allowables. Hence,

$P_m \leq S_m = 22.5$ ksi

$P_L + P_b \leq 1.5\ S_m = 33.75$ ksi

4.2.1.2. End Drop

In accordance with Appendix F, when elastic system analysis is used to determine loads on components, the stress acceptance criteria for general primary membrane (P_m), local primary membrane (P_L), and primary membrane plus bending stress intensity ($P_L + P_b$) is as follows:

$P_m \leq$ lesser of $2.4S_m$ or $0.7S_u$ [Ref 2.1.1, F-1331.1(a)]

$P_L \leq$ 150% of P_m Allowable [Ref 2.1.1, F-1331.1(b)]

$P_L + P_b \leq$ 150% of P_m Allowable [Ref 2.1.1, F-1331.1(c)(1)]

Hence,

Allowable Primary Membrane, P_m = 49.0 ksi

Allowable Local Primary Membrane plus bending, $P_L + P_b$ = 73.5 ksi

In accordance with Appendix F, when plastic system analysis is used to determine loads on components, certain stress acceptance criteria for general primary membrane (P_m), Maximum Primary stress intensity, and Primary Shear must be satisfied. Since Appendix F does not specify the nomenclature for plastic system analysis Maximum Primary stress intensity or Primary Shear, the following symbols will be used in this calculation.

Maximum Primary Stress Intensity: (P_{max})

Maximum Primary Shear: (P_{shear})

Code allowables for the above are as follows

$P_m \leq 0.7\ S_u = 0.7 . 70 = 49.0$ ksi [Ref 2.1.1F-1341.2(a)]

$P_{max} \leq 0.9\ S_u = 0.9 . 70 = 63.0$ ksi [Ref 2.1.1 F-1341.2(b)]

$P_{shear} \leq 0.42\ S_u = 0.42 . 70 = 29.4$ ksi [Ref 2.1.1 F-1341.2(c)]

4.3. Calculation Assumptions

4.3.1. End Drops, Uniform Support

4.3.1.1. The density of RX-277 is assumed to be

$$\rho_{277} = 0.06 \frac{lb}{in^3}$$

4.3.1.2. ANSYS results are scaled where appropriate to account for a decrease in the applied deceleration, and an increase in the MSB wall thickness. Membrane stress is assumed to be proportional to the applied load and inversely proportional to the wall thickness. Bending stress is assumed to be proportional to the applied load and inversely proportional to the wall thickness squared. These assumptions are consistent with classical hand stress analysis methods.

4.3.2. Dead Weight and End Drop, Ceramic Tile Support

4.3.2.1. For the purpose of this analysis the inner surface of the storage cask impacted by the MSB is considered to be infinitely rigid. Similarly, the ceramic tiles are considered to be infinitely rigid in providing support to the MSB. This simplification is considered to be conservative since both the concrete cask base and the media that the cask is postulated to drop onto contain finite stiffness. The predicted loads will therefore be higher than those experienced by the MSB in a real drop situation.

4.3.2.2. The analysis assumes that the MSB is to be supported by a ring of 24 ceramic tiles of size 1.7 x 1.7 x 0.3 inches. The tiles are equi-spaced around the periphery of the MSB on a radius of 30 inches to the tile centerline.

4.3.2.3. Due to symmetry of MSB geometry as well as loading, a one eighth segment accurately simulates the behavior of the MSB under vertical drop loading.

4.3.2.4. A temperature of 300°F is assumed in the calculation of material properties and allowables.

4.3.2.5. For the elasto-plastic end drop analysis only, the following additional assumption is made.

Calculation of the material hardenability modulus due to plastic analysis is based on the conservative assumption that necking of a test specimen occurs at 2/3 elongation. This allows for inclusion of "true stress" and "true strain" to the hardenability calculation.

5. CALCULATION METHODOLOGY

The basket is analyzed using a combination of finite element analysis and hand calculations. The analytical approach is discussed below.

6. CALCULATIONS

6.1. MSB Top Region Analysis

The finite element model used for this analysis is shown in Figure 6-1. The bottom nodes of the structural lid have been coupled with the top nodes of the shield lid in the vertical direction to model support provided by the shield lid. Node 306 of the shield lid has been coupled with Node 450 of the shield lid support ring.

The shield lid is modeled as a 9.5" thick solid plate. In reality, it is 7.5" of steel plate and a 2" thickness of RX-277. The equivalent density calculated below has been used to correctly represent the weight of the shield lid.

$$\rho_{stl} := .28 \cdot \frac{lb}{in^3}$$

$$\rho_{avg} := \frac{\rho_{stl} \cdot t_{stl} + \rho_{277} \cdot t_{277}}{t_{stl} + t_{277}}$$

$$\rho_{avg} = 0.23 \frac{lb}{in^3}$$

The ANSYS input/output from Reference 3.1.3 is in Attachment A.

The maximum stress intensity in the MSB shell is 12.6 ksi at Node 431. The membrane stress at this section though the MSB wall is approximately the average of the stress intensities at Nodes 427 through 432.

$$\sigma_{m\_old} := \frac{(7.790 + 8.613 + 9.691 + 11.127 + 12.614 + 8.291) \cdot ksi}{6}$$

$$\sigma_{m\_old} = 9.69 ksi$$

The approximate bending stress at the section is

$$\sigma_{b\_old} := 12.614 \cdot ksi - \sigma_{m\_old}$$

$$\sigma_{b\_old} = 2.93 ksi$$

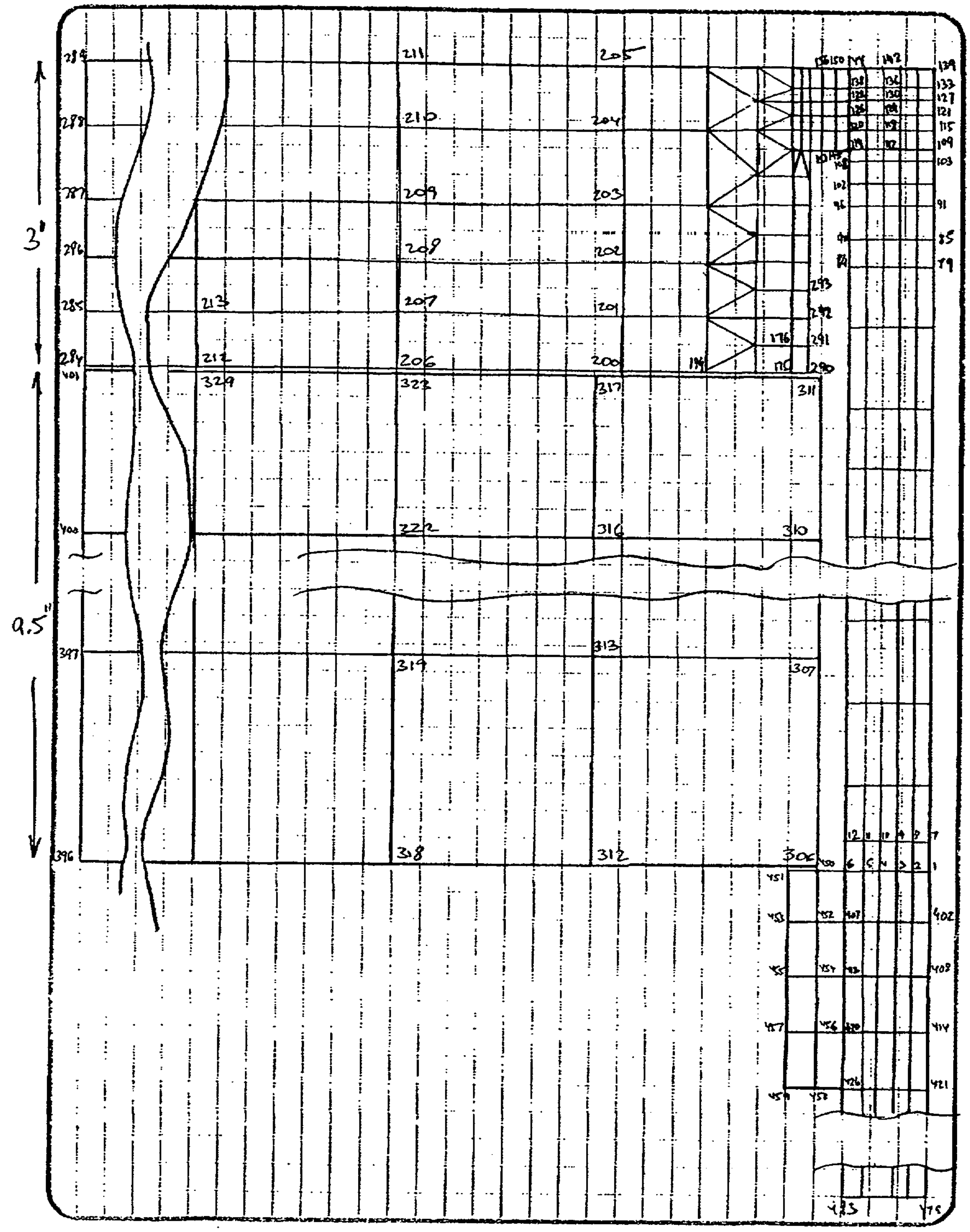

Figure 6-1 Finite Element Model for MSB Top

The revised membrane stress is calculated assuming that stress scales linearly with load and inversely proportional to wall thickness. The MSB wall thickness for the Ref. 3.1.3 ANSYS analysis was

$$t_{msb\_old} := 0.75 \cdot in$$

The acceleration used for the analysis in Ref. 3.1.3 was

$$a_{v\_old} := 124 \cdot g$$

The deceleration from the 5' vertical drop is (Reference 3.1.2)

$$a_v := 108 \cdot g$$ Vertical acceleration, Five-foot Drop Analysis, Ref. 3.1.2

The revised membrane stress is

$$\sigma_{m\_shell1} := \sigma_{m\_old} \cdot \frac{a_v}{a_{v\_old}} \cdot \frac{t_{msb\_old}}{t_{msb}}$$

$$\sigma_{m\_shell1} = 6.3 ksi$$

The revised bending stress is calculated assuming that stress scales linearly with load and inversely proportional to the square of the wall thickness.

$$\sigma_{b\_shell1} := \sigma_{b\_old} \cdot \frac{a_v}{a_{v\_old}} \cdot \left(\frac{t_{msb\_old}}{t_{msb}}\right)^2$$

$$\sigma_{b\_shell1} = 1.4 ksi$$

The maximum stress intensity in the structural lid is 4.8 ksi at Node 162 (note that this is a local stress intensity and not a true membrane or membrane plus bending stress; it is conservative, however, to use this as a membrane plus bending stress). Scaling the stress for the new deceleration gives

$$\sigma_{struct} := 4.8 \cdot ksi \cdot \frac{a_v}{a_{v\_old}}$$

$$\sigma_{struct} = 4.2 ksi$$

The maximum stress in the structural lid weld is 9.4 ksi at Node 145. Scaling the stress for the new deceleration gives

$$\sigma_{struct\_weld} := 9.4 \cdot ksi \cdot \frac{a_v}{a_{v\_old}}$$

$$\sigma_{struct\_weld} = 8.2\,ksi$$

6.2. MSB Bottom Region Analysis, Uniform Support on Base

The shield lid load is;

$$F_{shield} := a_v \cdot \left(m_{shield} + m_{support}\right)$$

$$F_{shield} = 702\,kip$$

The structural lid load is;

$$F_{struct} := a_v \cdot m_{struct}$$

$$F_{struct} = 259.2\,kip$$

The finite element model of the bottom-to-shell junction is shown on Figure 6-2. Axisymmetric shell element STIF 51 has been used.

A uniform support condition is used for the MSB bottom plate. The MSB bottom plate is supported by ceramic tiles that are spaced intermittently, and thus the uniform support condition is approximate. Stress in the MSB bottom plate as it is supported by the ceramic tiles is evaluated in the following section.

Since all local effects die down away from the junction, only the lower 20" of the shell have been modeled with the upper part represented by the load of:

$$L_{modeled} := 20 \cdot in$$

$$F_{top} := \frac{1}{2 \cdot \pi} \cdot \left[F_{shield} + F_{struct} + \frac{\pi}{4} \cdot \left(od_{msb}^{\ 2} - id_{msb}^{\ 2}\right) \cdot \left(L_{msb} - L_{modeled}\right) \cdot \rho_{stl} \cdot a_v\right]$$

$$F_{top} = 302.6 \frac{kip}{rad}$$

The load applied in the ANSYS analysis in Ref. 3.1.3 was

$$F_{top\_old} := 300 \cdot \frac{kip}{rad}$$

The ANSYS input/output from Reference 3.1.3 is in Attachment B.

The maximum stress intensity in the MSB shell is 17.0 ksi at Element 10. The membrane stress at this element is

$$\sigma_{m\_old} := 12.88 \cdot ksi$$

The approximate bending stress at the element is

$$\sigma_{b\_old} := 17.03 \cdot ksi - \sigma_{m\_old}$$

$$\sigma_{b\_old} = 4.15 ksi$$

The revised membrane stress is calculated assuming that stress scales linearly with load and inversely proportional to wall thickness. The revised membrane stress is

$$\sigma_{m\_shell2} := \sigma_{m\_old} \cdot \frac{F_{top}}{F_{top\_old}} \cdot \frac{t_{msb\_old}}{t_{msb}}$$

$$\sigma_{m\_shell2} = 9.7 ksi$$

The revised bending stress is calculated assuming that stress scales linearly with load and inversely proportional to the wall thickness squared.

$$\sigma_{b\_shell2} := \sigma_{b\_old} \cdot \frac{F_{top}}{F_{top\_old}} \cdot \left(\frac{t_{msb\_old}}{t_{msb}}\right)^2$$

$$\sigma_{b\_shell2} = 2.4 ksi$$

The maximum membrane and bending stresses in the shell from the top and bottom models are:

$$\sigma_{m\_shell} := max((\sigma_{m\_shell1} \quad \sigma_{m\_shell2}))$$

$$\sigma_{m\_shell} = 9.7 ksi$$

$$\sigma_{b\_shell} := max((\sigma_{b\_shell1} \quad \sigma_{b\_shell2}))$$

$$\sigma_{b\_shell} = 2.4 ksi$$

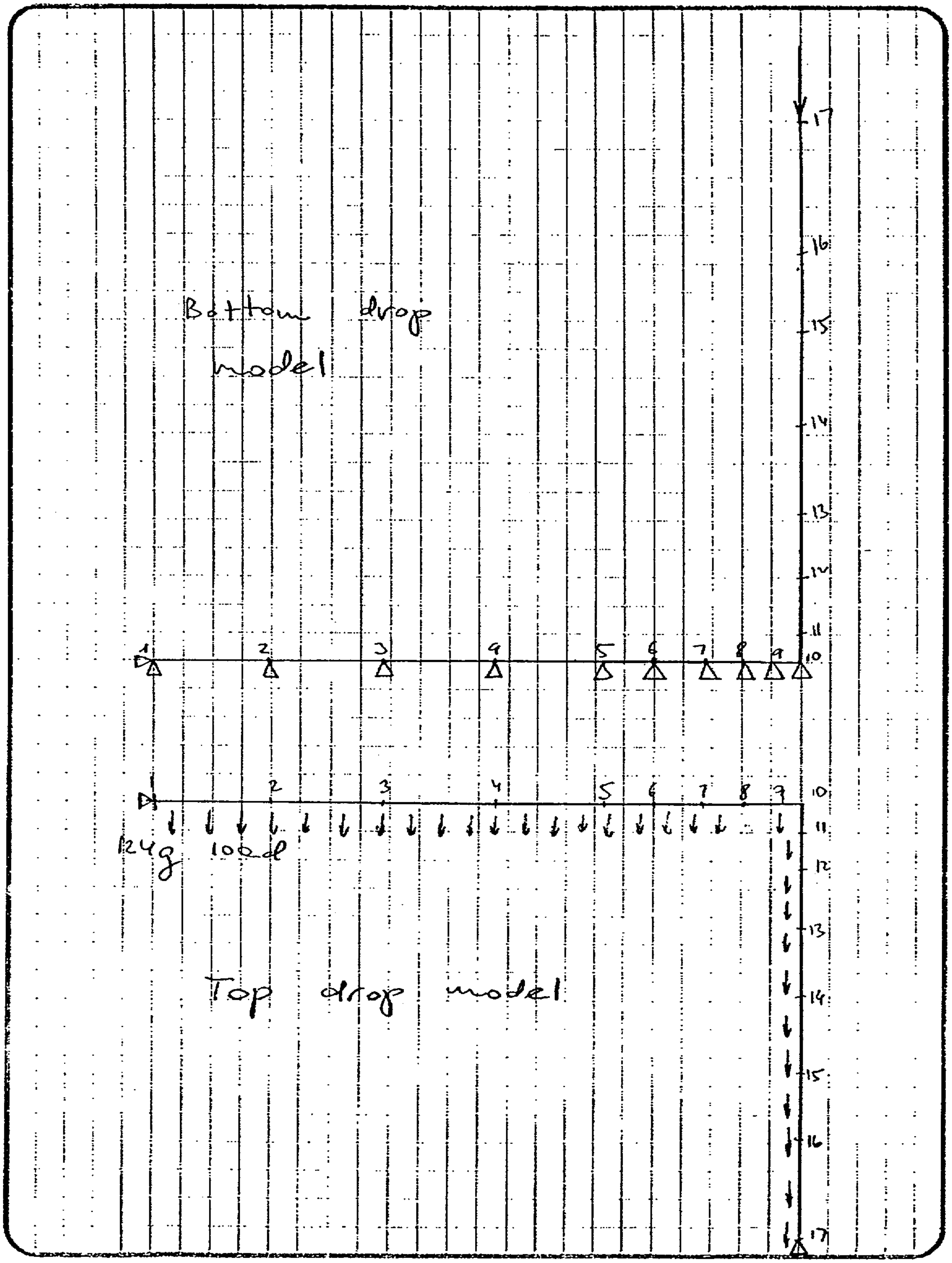

Figure 6-2 Finite Element Models for MSB Top and Bottom Drop.

(The Bottom Drop Model Covers the Uniform Support Condition)

6.3. MSB Bottom Plate Supported by Ceramic Tiles

A further support configuration is where the MSB is supported by ceramic tiles resting on the liner of the concrete cask. The purpose of the ceramic tiles is to prevent contact between the MSB base and the cask liner during normal storage conditions. In this configuration, 24 ceramic tiles are placed equi-spaced around the periphery of the MSB base. In addition to determining the stresses in the MSB base due to normal operating dead weight loading it is also necessary to demonstrate that stresses in the MSB base as a result of a five foot end drop will still be within ASME design code allowables. The normal operating condition and the end drop analyses were completed using similar finite element models and assumptions.

6.3.1. Finite Element Models

A one eighth segment of the MSB has been modeled using the ANSYS finite element computer modeling code (Ref 3.2.5). Due to the geometric symmetry of the MSB and the symmetry of loading, a one eighth segment with appropriate symmetry boundary conditions is preferred to a larger and computationally more intensive full model. For the end drop analysis, ANSYS plastic shell element SHELL143 was used to model the MSB. Large deformation effects were included in the analysis. For the 1g deadweight case, the plastic shell elements were replaced with elastic shell element SHELL63. In addition to the base plate, a section of the MSB wall has been included in the model, to ensure that any interaction effects between MSB base and shell wall are simulated. The length of shell wall included in the model is sufficient to ensure that the general pattern of stress is accurately modeled. This length needs to be sufficient to ensure that local effects at the shell to base interface dissipate. The ASME code uses the length $L = 2.5\sqrt{Rt}$ (R = Radius and t = wall thickness), as that within which local effects are present - beyond this length local effects are diminished. For conservatism, this length has been doubled. Hence, the vertical length of MSB shell modeled is;

$$L = 5.0\sqrt{Rt}$$

$$L = 5.0\sqrt{31.25.1.0}$$

$$L = 27.95 \text{ in.}$$

The actual modeled length was rounded up to 30 in. The stress contour plots confirm the acceptability of this modeled length of MSB shell.

The gap between the underside of the MSB base plate and the inner surface of the storage cask liner plate was modeled using the ANSYS 3D point to point contact element CONTAC52. Contact elements were modeled on all nodes of the MSB base, with the exception of those coincident with the ceramic tiles -these nodes were constrained vertically. All gaps were set initially open, with a physical gap size of 0.3 in – this representing the actual thickness of ceramic tile. The contact stiffness was set at an arbitrarily high value of 1E6 lb/in, in accordance with the ANSYS users manuals.

The finite element model is shown in Figure 6-3.

6.3.2. Boundary Conditions

The MSB is restrained from moving vertically at the location of the ceramic tiles. In addition, the contact elements are fixed at the surface simulating the cask boundary. Symmetric boundary conditions are imposed on the nodes positioned on "cut" edges of the MSB base and wall.

6.3.3. Applied Loading

The load due to the internal components within the MSB is modeled in the finite element analysis as a pressure load. The pressure load is calculated as follows;

Weight of the MSB $= 21036$ lb [Ref 3.1.1]

Weight of the structural lid $= 2384$ lb [Ref 3.1.1]

Weight of the shield lid $= 6371$ lb [Ref 3.1.1]

Weight of the MSB and its contents $= 68191$ lb. [Ref 3.1.1]
The analyses conservatively use $= 70000$ lb.

Weight of contents $= 70000 - (21036 + 2384 + 6371) = 40209$ lb

For Finite Element model using shell Centerlines,

Pressure load on base plate due to contents $= \dfrac{40209}{\frac{\pi}{4}61.5^2} = 13.536$ psi.

Since only a portion of the MSB shell has been modeled, a force must be added to the top nodes of this section to account for weight missing in the model. For the F.E model based on a one eighth symmetrical section, the following calculations apply;

Weight of MSB modeled (30 in vertical section) $= \dfrac{1}{8}\left(\dfrac{\pi}{4}(62.5^2 - 60.5^2)30.0 \quad x \quad 0.284\right)$

$= 205.6$ lb.

Weight of MSB base plate modeled $= 606 / 8 = 75.8$ lb. [606 lb from Ref 3.1.1]

Weight of contents modeled as pressure load $= 40209 / 8 = 5026.1$ lb.

Weight "missing" from F.E model $= 70000 / 8 - (205.6 + 75.8 + 5026.1)$

$= 3442.5$ lb.

This above "missing" weight is evenly applied to the model as forces on the top nodes of the MSB shell.

Finally, a body load of 1g is applied to the model.

For the end drop analysis, the body load is increased to 108g. Also, pressure loads and nodal forces as calculated above are factored by 108g.

Reaction checks confirmed that the required weight was modeled. For the deadweight 1g acceleration, the required model vertical (F_Z) reaction would be expected to be,

Required F_Z Reaction = 70000 / 8 = 8750 lb.

While the 108g end drop vertical (F_Z) reaction would be expected to be,

Required F_Z Reaction = (70000 x 108) / 8 = 0.945 E6 lb.

The finite element model reactions were found to be 8725.8 and 0.94196 E6 lb, for the 1g deadweight and 108g end drop analyses respectively. In each case this accounts for 99.7 % of the required total. This close agreement gives confidence in the accuracy of the finite element model results.

6.3.4. Elastic-Plastic Stress Strain Curve – End Drop Analysis

Due to the high drop acceleration (108g) and consequent high stresses in the MSB, the elastic limits of stress will be exceeded in small local regions. Bending in the unsupported regions of the base plate give rise to high bending stresses and it is these that force the development of limited plasticity in certain regions. An elasto-plastic analysis has therefore been performed to demonstrate that such limited plasticity still falls within the allowables set by the ASME code for such conditions.

The following values were used in representing the non-linear stress-strain curve.

Young's Modulus	= 28.3E6 psi	[Ref 2.1.2]
Yield Stress	= 33.7E3 psi	[Ref 2.1.2]
Tensile Strength	= 70.0E3 psi	[Ref 2.1.2]
Elongation	= 21%	[Ref 2.1.2]

The Tangent modulus is calculated in accordance with the ANSYS theory manual. This takes into account the effect of true stress and true strain, with "necking" occurring at 2/3 elongation.

Strain at yield $$\varepsilon_{yield} = \frac{\sigma_{yield}}{E}$$

$$\varepsilon_{yield} = \frac{33.7E3}{28.3E6}$$

$$\varepsilon_{yield} = 0.00119 \text{ strain}$$

True Strain, $$\varepsilon = \ln(1+\varepsilon_o)$$ [Ref 3.2.3]

Where ε_o is the engineering strain.

Using the assumption that necking occurs at 2/3 elongation, calculate the true strain.

$$\varepsilon = \ln(1 + \{2/3.0.21\})$$

$$\varepsilon = \ln(1.14)$$

$$\varepsilon = 0.131 \text{ strain}$$

True stress (Cauchy stress) is calculated by converting engineering stress, using the assumption that plastic flow occurs at constant volume.

Hence,

$$A_o L_o = AL \qquad \textit{Equation 6.3.4-1}$$

Where

A_o	Is the original cross sectional area.
L_o	Is the original length.
A	Is the deformed cross sectional area.
L	Is the deformed length.

Re-arranging the above formula,

$$A = \frac{A_o L_o}{L} \qquad \textit{Equation 6.3.4-2}$$

Also,

Engineering Strain = Change in length / Original length

i.e $$\varepsilon_o = \frac{L - L_o}{L_o}$$

or $$\frac{L}{L_o} = 1 + \varepsilon_o \qquad \textit{Equation 6.3.4-3}$$

Engineering Stress $\sigma = \frac{P}{A}$.

Substitute the value of A from Equation 6.3.4-2

$$\sigma = \frac{PL}{A_o L_o}$$

Finally, substituting equation 6.3.4-3 into the above, the relationship between engineering stress and true stress is obtained.

$$\sigma_T = \frac{P}{A_o}(1+\varepsilon_o)$$

or

$$\sigma_T = \sigma_E(1+\varepsilon_o)$$

Hence, True Max Tensile Strength σ_{max},

$$\sigma_{Max} = 70\text{ ksi} \;.\; 1.14 \quad = \quad 79.8\text{ ksi}$$

Tangent Modulus $\sigma_T = \dfrac{\sigma_{Max} - \sigma_{Yield}}{\varepsilon - \varepsilon_{yield}}$

$$\sigma_T = 355.1 ksi$$

The resulting stress strain curve is shown in Figure 6-4.

ANSYS input for the dead weight analysis and the end drop analysis is contained in Attachment D and E respectively.

6.3.5. Results for 1g deadweight Analysis

6.3.5.1. Displaced Shape

It is a design requirement that the MSB base and the cask liner do not come into contact during the normal storage condition. To check the maximum displacement, the maximum internal pressure under normal conditions of 8.9 psi (Ref 3.1.5) was added to the pressure (13.536 psi) simulating the presence of the MSB internals. The displaced shape of the MSB model is shown in Figure 6-5. This figure arbitrarily amplifies the actual displacement, allowing the displaced shape to be more readily observed. The maximum displacement is 0.254 inches at the MSB base center. This figure is conservative due to the assumptions made in the MSB loading, and the calculation of the operating pressure. Since the tile thickness is 0.3 inches, it can be concluded that the MSB base and the cask liner will not come into contact under the normal operating condition.

6.3.5.2. Stress Intensity

Stress intensities have been derived from the finite element model. Figure 6-6, Figure 6-7, and Figure 6-8 plot the contours of stress intensity for the shell top, middle, and bottom locations of the MSB model. Values of each of the above stress intensities for the MSB base are recorded in Table 6-1. The presence of the ceramic tiles supporting the base of the MSB is a structural discontinuity and causes high stresses local to the tiles. These local stresses are discounted and hence, not listed in the above tables, although the maximum values are listed for completeness. This is in line with the ASME code definition of primary stress which discounts those stresses occurring at local discontinuities and concentrations. Code allowables are therefore compared with the appropriate primary stress, and not a local stress. The top ten values of stress intensity for the MSB shell is recorded separately in Table 6-2. Since the stresses at the location of the bottom plate weld were found to be lower than those derived for the base plate, the weld stresses have conservatively been taken to be the highest of those used to evaluate the base and the shell.

Table 6-6 compares calculated stresses with allowable stress in the form of Design Margins (DM). The design margins are calculated based on the formula;

$$DM = \left(\frac{Allowable \quad Stress}{Calculated \quad Stress} \right) - 1$$

6.3.6. Results for 108g Five Feet End Drop Analysis

6.3.6.1. Displaced Shape

The displaced shape of the MSB model is shown in Figure 6-9. As with the normal loading displacement plot, this figure arbitrarily amplifies the actual displacement, allowing the displaced shape to be more readily observed. It is noticed that, as expected, the central portion of the MSB base "bottoms out" due its contact with the cask. The vertical displacement of the MSB base is equal to the gap between base and cask liner. The base remains undisplaced in the region where support is provided by the ceramic tiles.

6.3.6.2. Stress Intensity

Stress intensities have been derived from the finite element model. Figure 6-10, Figure 6-11, and Figure 6-12, plot the contours of stress intensity for the shell top, middle, and bottom locations of the MSB model respectively. The top ten values of each of the above stress intensities for the MSB base is recorded in Table 6-3, while the top ten values of stress intensity for the MSB shell is recorded separately in Table 6-4. The stress in the base plate weld is taken as the highest of the base plate and shell stress. Table 6-7 compares calculated stresses with allowable stress in the form of Design Margins (DM). The design margins are calculated as noted in section 6.3.5.2.

Section F1341.2(c) of (Ref 2.1.1), requires a comparison of calculated *pure* shear with a given allowable value. Strictly speaking, neither the MSB base plate nor the MSB shell experience pure shear, rather, they experience a *combination* of bending and shear loading. The value for maximum shear stress, P_{shear} is therefore compared with ASME code allowables for completeness. P_{shear} is calculated as half the maximum stress intensity i.e $P_{max} / 2$.

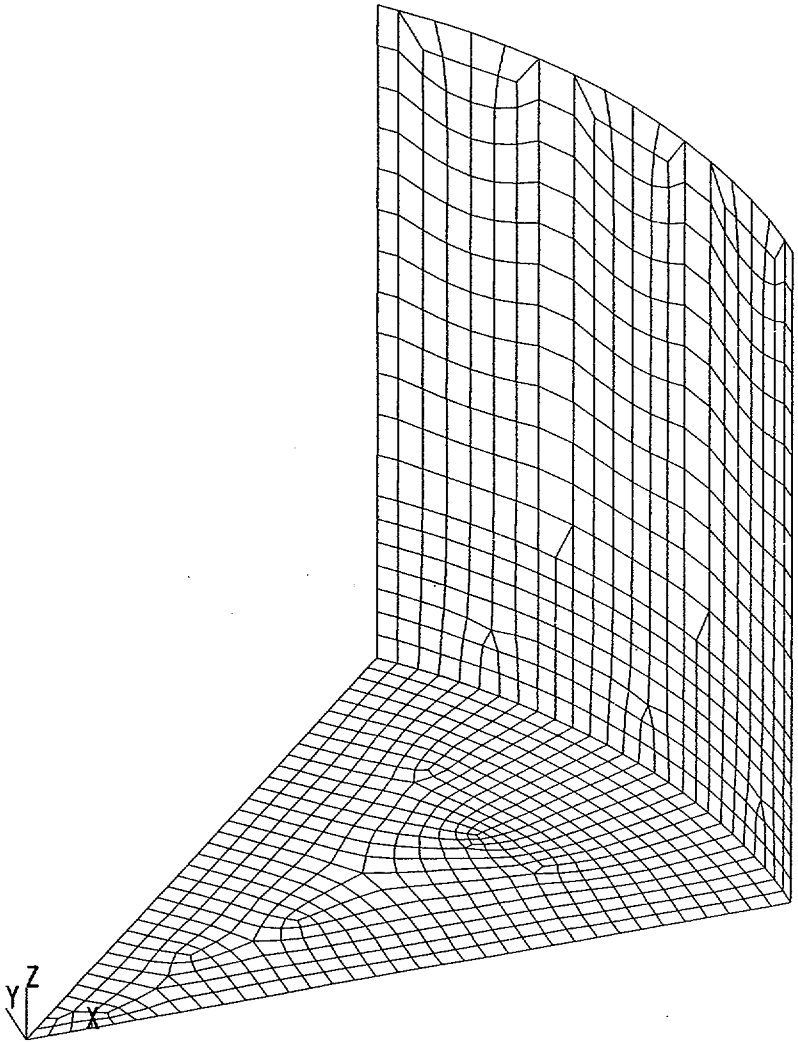

Figure 6-3 Plot of Finite Element Model.

(Gap elements removed for Clarity)

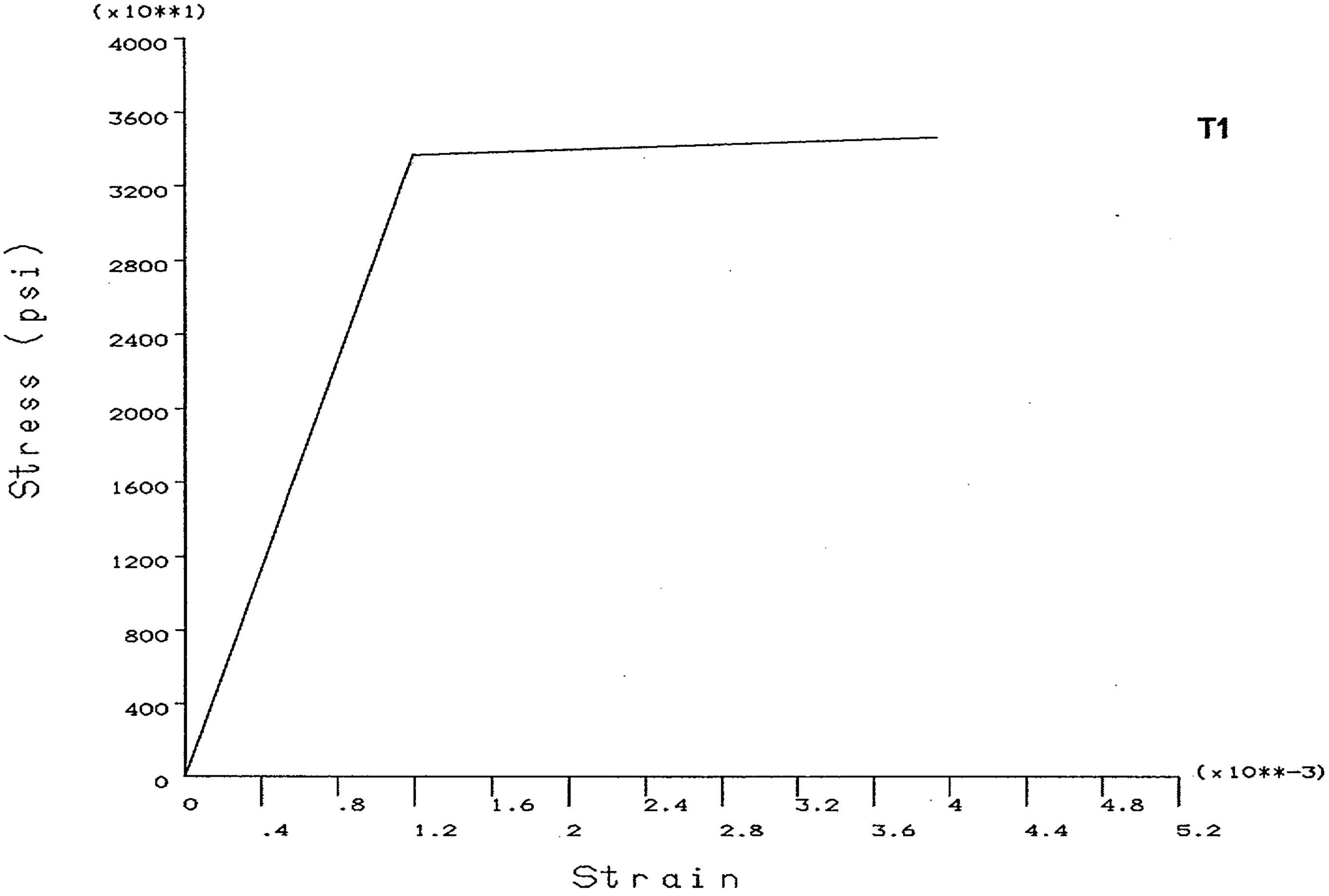

Figure 6-4 Elasto-Plastic Stress Strain Curve

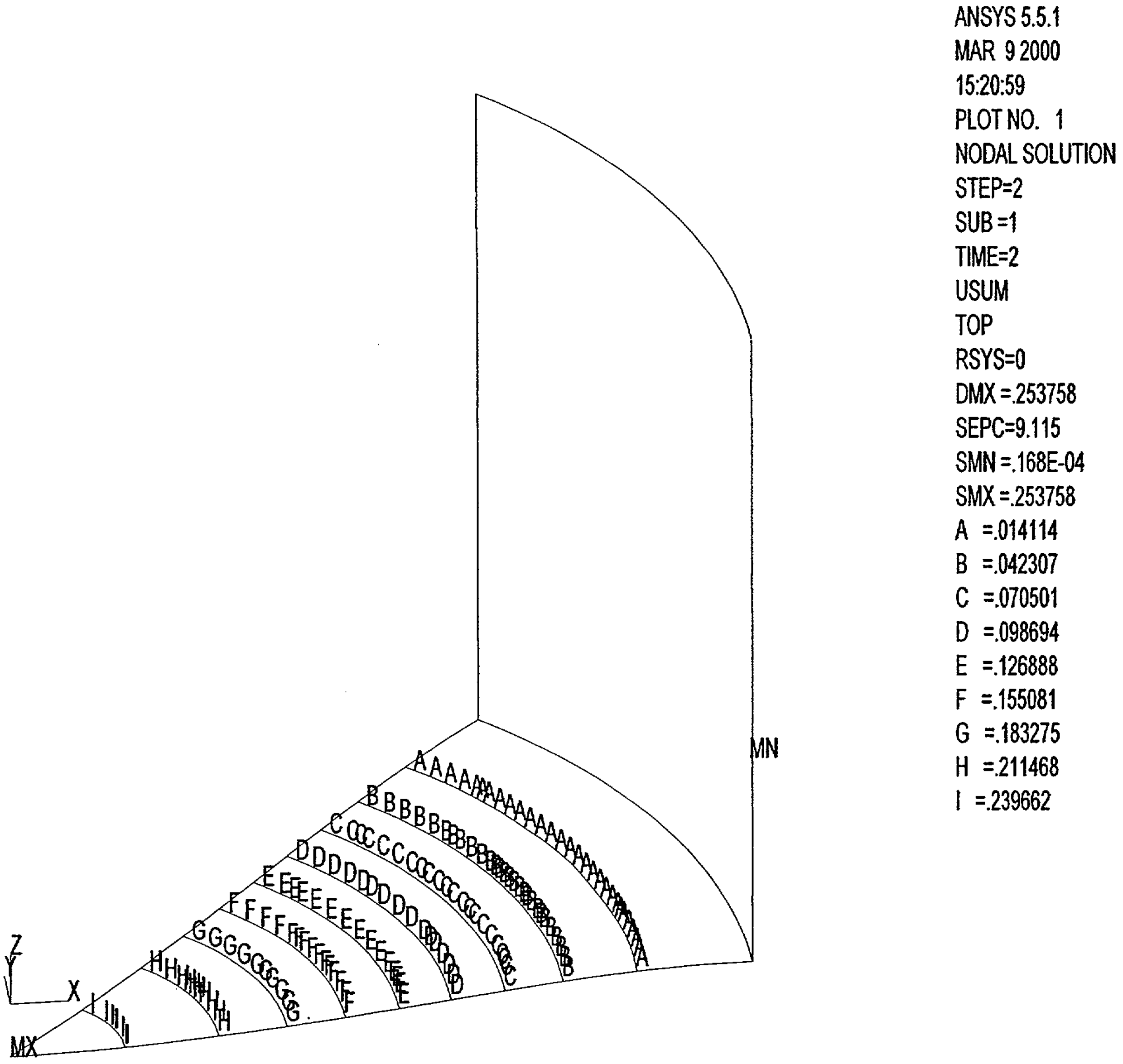

Figure 6-5 Plot of Displaced Shape of the MSB Under Dead Weight + Pressure Loading

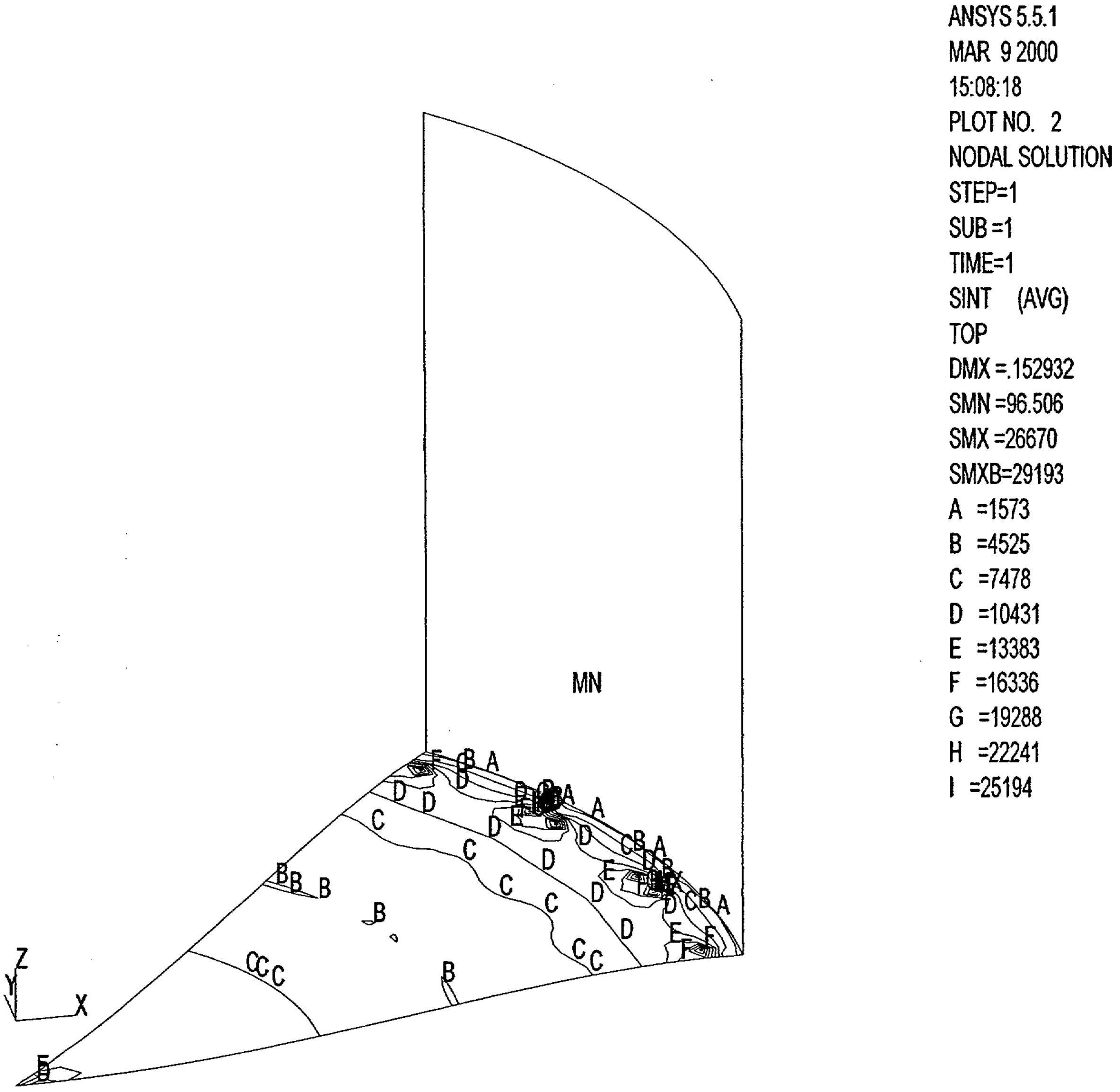

Figure 6-6 Contour Plot of Stress Intensity – Shell Top. Dead Weight Loading

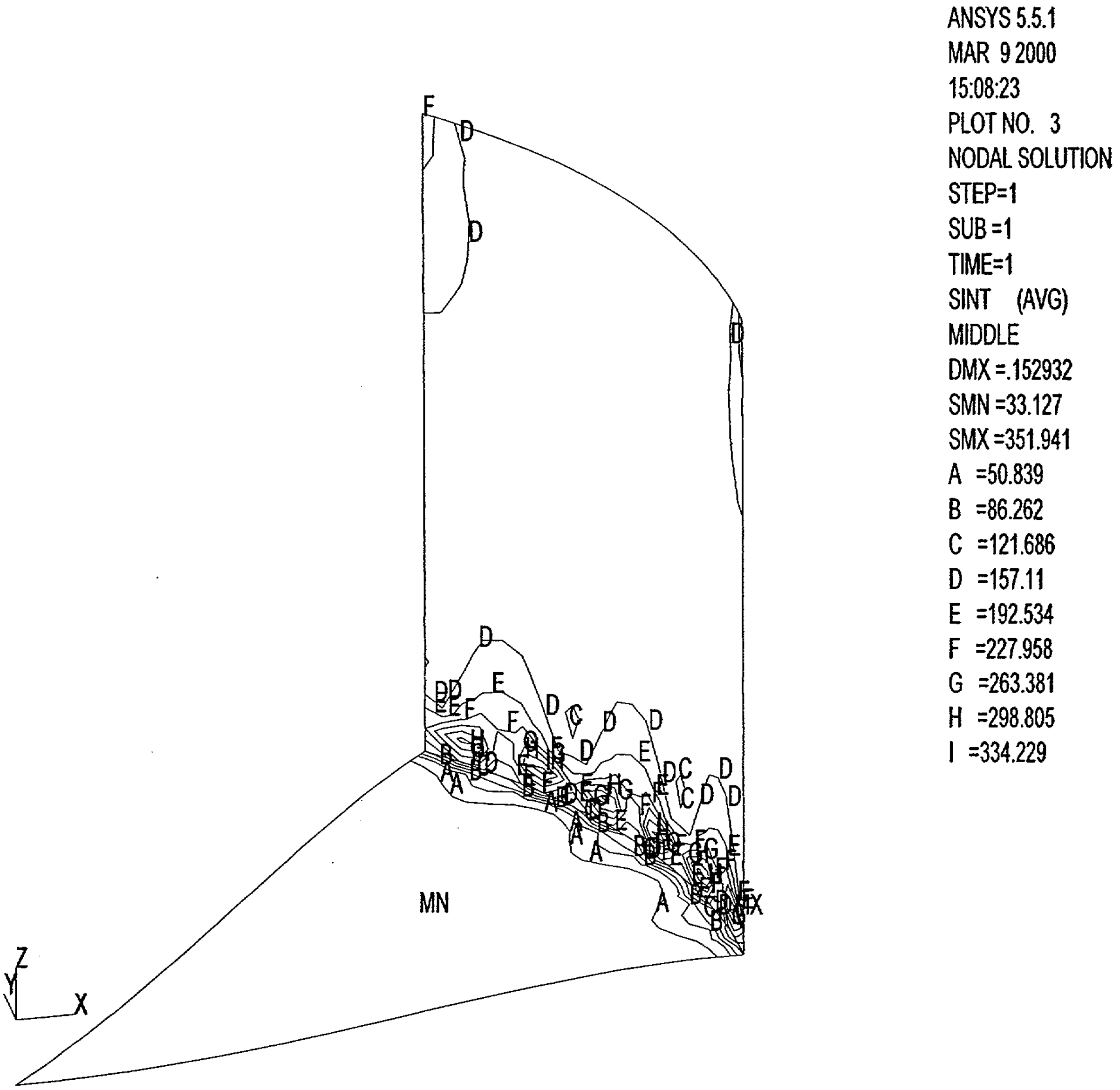

Figure 6-7 Contour Plot of Stress Intensity – Shell Middle. Dead Weight Loading

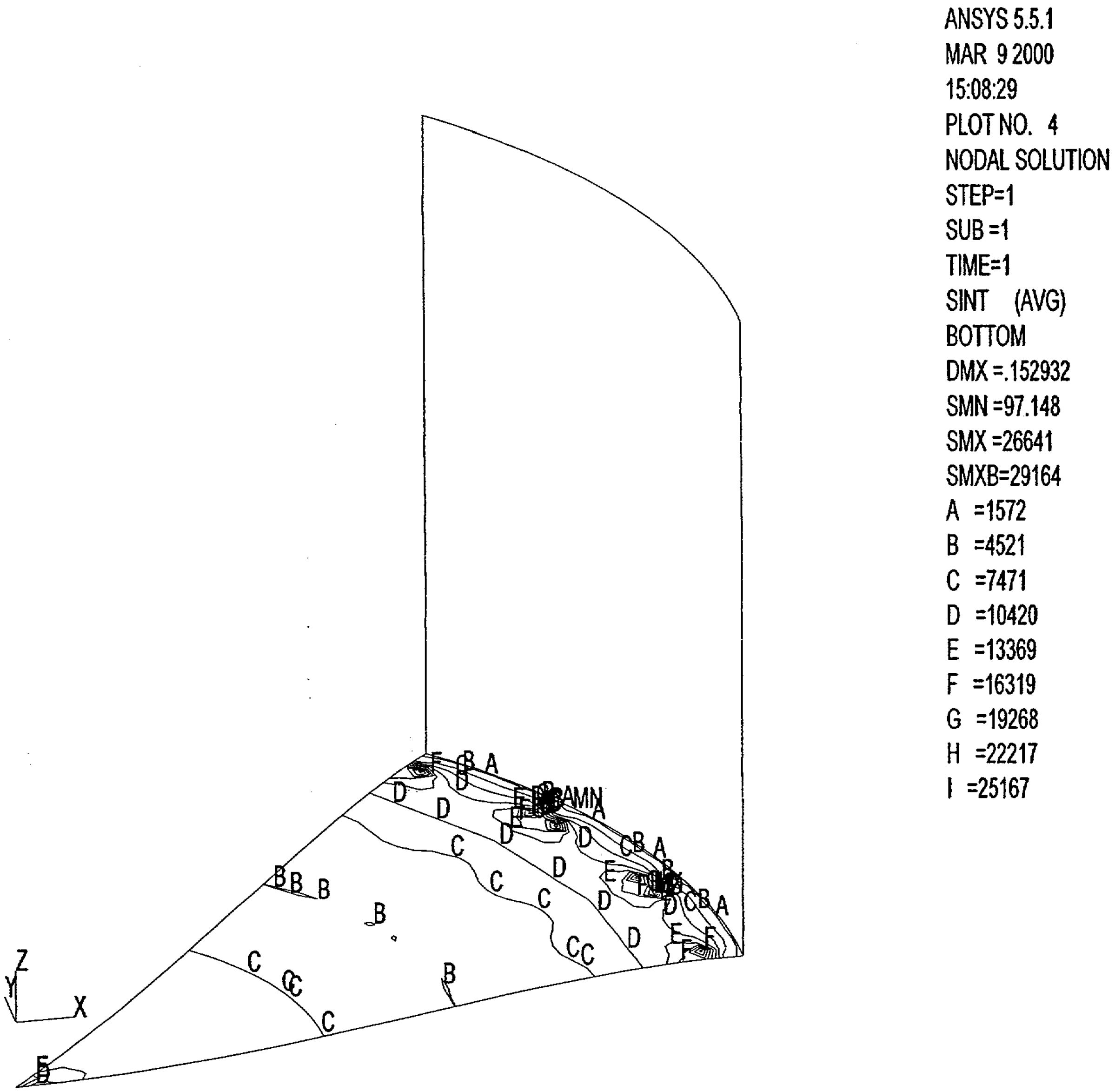

Figure 6-8 Contour Plot of Stress Intensity – Shell Bottom. Dead Weight Loading

Table 6-1 - MSB Base Plate - Stress Intensities at Top, Middle, and Bottom Locations – Dead Weight (1g)

Shell TOP

NODE	S1	S2	S3	SINT	SEQV
7	26656.	15345.	-13.536	26670.	23185.
16	26639.	15336.	-13.536	26653.	23171.
12	26633.	15329.	-13.536	26647.	23165.
•					
•					
•					
263	12153.	1157.9	-13.536	12167.	11625.
271	12138.	1110.8	-13.536	12152.	11630.
276	12120.	1054.4	-13.536	12134.	11636.
268	12098.	1025.1	-13.536	12112.	11627.
279	12048.	985.39	-13.536	12061.	11594.

Shell MIDDLE

NODE	S1	S2	S3	SINT	SEQV
623	9.5408	-0.12302E-01	-342.40	351.94	347.26
681	9.2592	-0.12634E-01	-342.16	351.42	346.88
739	9.2584	-0.12675E-01	-342.07	351.33	346.79
753	6.2894	-0.14272E-01	-340.87	347.16	344.06
695	6.0382	-0.14753E-01	-340.82	346.85	343.87
637	6.0309	-0.14857E-01	-340.80	346.83	343.85
757	0.54954E-02	-29.174	-329.42	329.43	315.85
699	0.54210E-02	-29.341	-329.37	329.37	315.72
641	0.56052E-02	-29.087	-329.26	329.26	315.72
638	0.44508E-02	-33.997	-327.81	327.82	312.21

Shell BOTTOM

NODE	S1	S2	S3	SINT	SEQV
7	0.0000	-15265.	-26641.	26641.	23154.
16	0.0000	-15257.	-26624.	26624.	23139.
12	0.0000	-15250.	-26618.	26618.	23134.
•					
•					
•					
263	0.0000	-1111.7	-12092.	12092.	11576.
271	0.0000	-1065.1	-12077.	12077.	11581.
276	0.0000	-1009.1	-12058.	12058.	11587.
268	0.0000	-980.02	-12036.	12036.	11577.
279	0.0000	-940.57	-11986.	11986.	11544.

Table 6-2 - MSB Shell - Stress Intensities at Top, Middle, and Bottom Locations – Dead Weight (1g)

Shell TOP

NODE	S1	S2	S3	SINT	SEQV
562	1164.7	236.89	0.55782E-01	1164.6	1066.1
574	1164.3	236.24	0.55689E-01	1164.3	1066.0
586	1163.8	236.08	0.55694E-01	1163.7	1065.5
575	1156.1	245.16	0.55858E-01	1156.1	1055.1
563	1155.9	245.01	0.55894E-01	1155.8	1054.9
587	1155.3	245.33	0.55872E-01	1155.2	1054.2
564	569.46	0.37271E-01	-157.04	726.49	662.08
588	569.68	0.37483E-01	-155.99	725.66	661.60
576	569.36	0.37424E-01	-156.12	725.48	661.37
585	563.61	0.32936E-01	-160.16	723.77	658.45

Shell MIDDLE

NODE	S1	S2	S3	SINT	SEQV
589	0.30434E-01	-58.410	-462.47	462.50	436.22
565	0.30230E-01	-58.618	-462.34	462.37	436.02
577	0.30225E-01	-58.600	-462.30	462.33	435.98
560	0.33952E-01	-56.340	-461.90	461.94	436.49
572	0.33695E-01	-56.539	-461.47	461.51	435.98
584	0.33745E-01	-56.496	-461.40	461.44	435.93
564	-0.27225E-01	-145.28	-370.02	369.99	322.88
576	-0.27252E-01	-145.37	-369.82	369.80	322.69
588	-0.27191E-01	-145.10	-369.61	369.59	322.53
585	-0.26725E-01	-146.94	-369.23	369.20	321.95

Shell BOTTOM

NODE	S1	S2	S3	SINT	SEQV
562	-0.77529E-01	-385.21	-1523.8	1523.7	1372.3
574	-0.77588E-01	-385.49	-1523.7	1523.6	1372.1
586	-0.77534E-01	-385.18	-1523.3	1523.2	1371.8
575	-0.76161E-01	-385.68	-1516.6	1516.5	1365.2
563	-0.76068E-01	-385.32	-1516.3	1516.3	1365.0
587	-0.76094E-01	-385.37	-1516.1	1516.0	1364.8
576	-0.44233E-01	-243.70	-1200.0	1199.9	1098.5
564	-0.44125E-01	-243.23	-1199.8	1199.8	1098.6
588	-0.44092E-01	-243.35	-1199.8	1199.8	1098.5
561	-0.51038E-01	-241.07	-1195.5	1195.5	1095.0

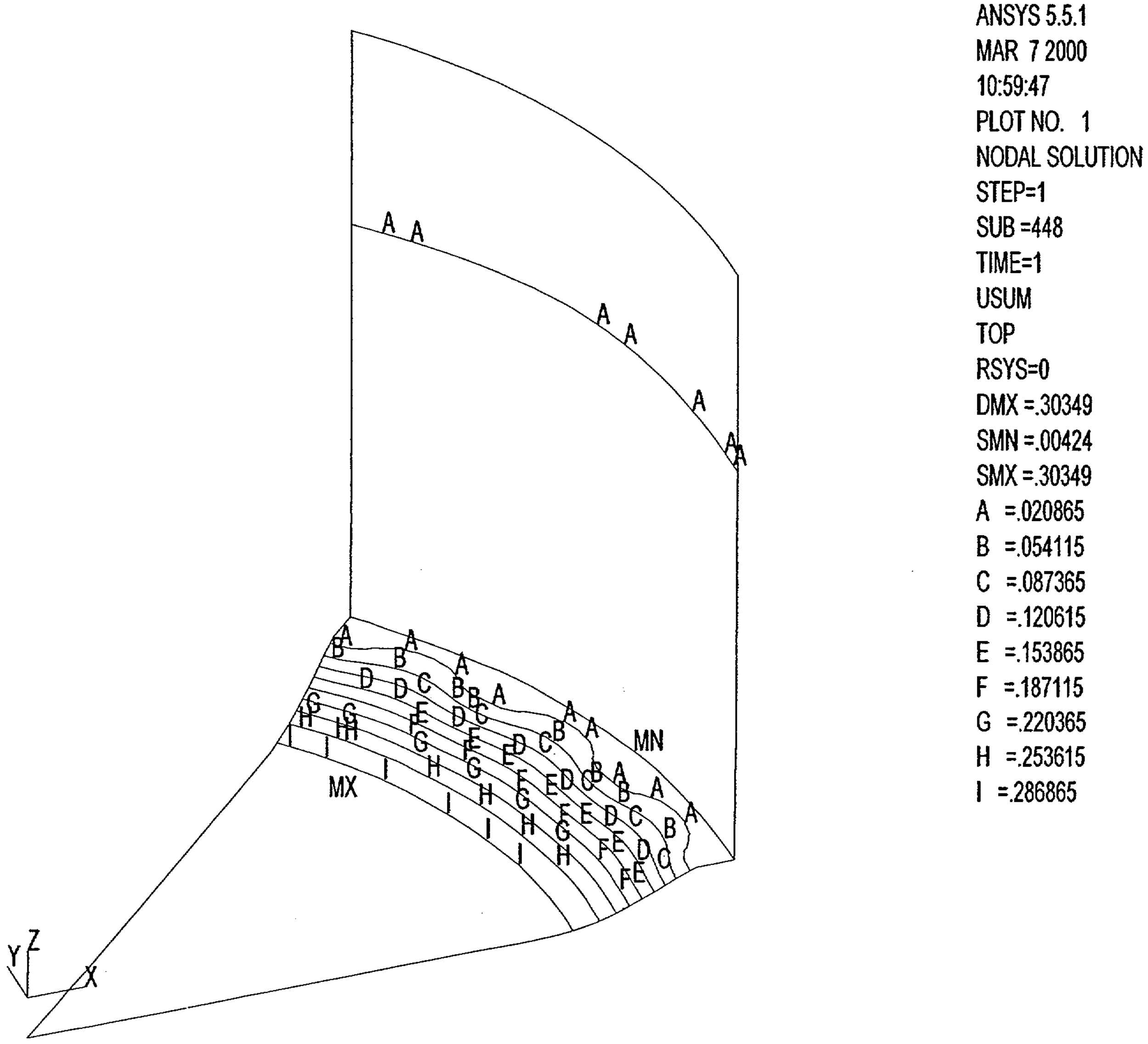

Figure 6-9 Plot of Displaced Shape of the MSB Under End Drop Loading

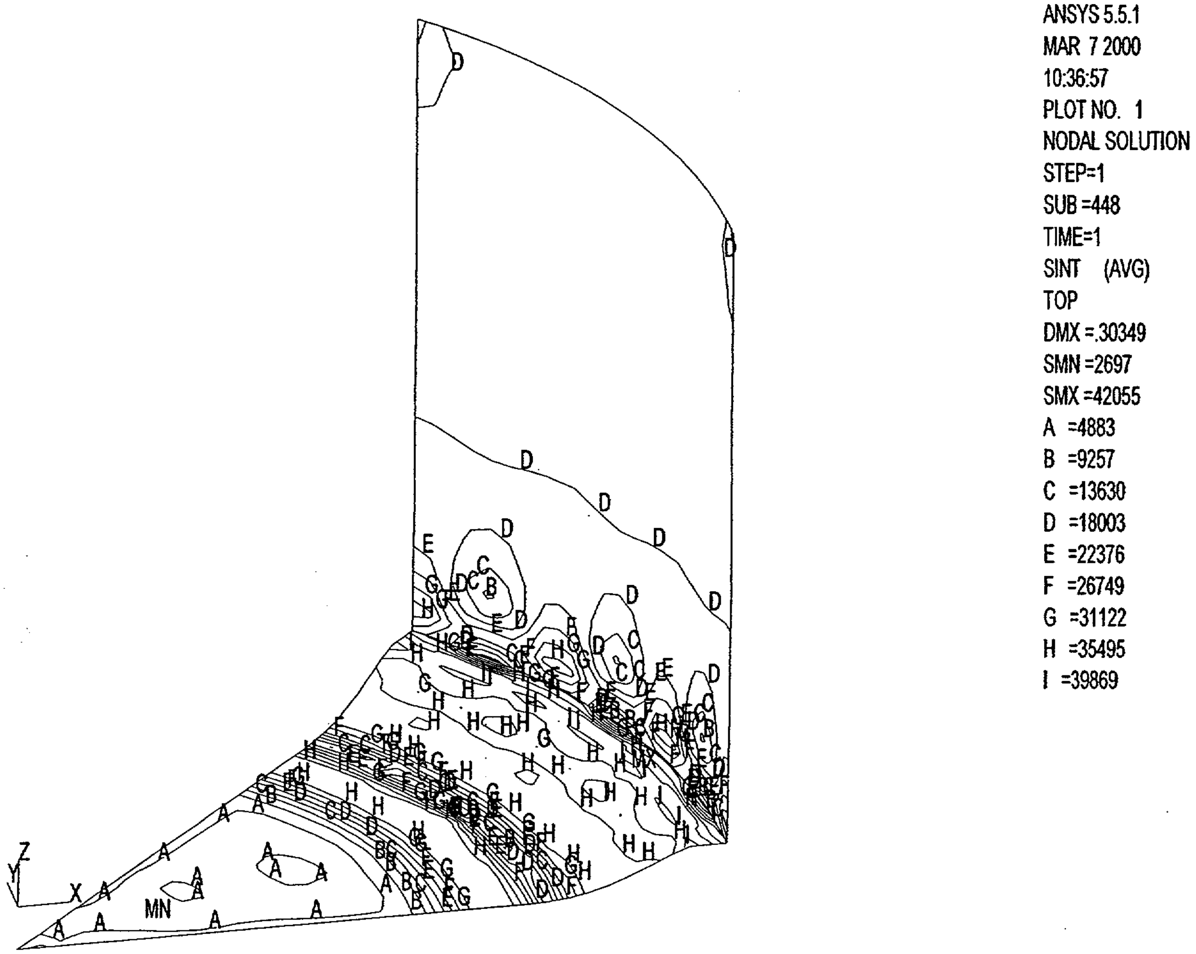

Figure 6-10 Contour Plot of Stress Intensity – Shell Top. End Drop Loading

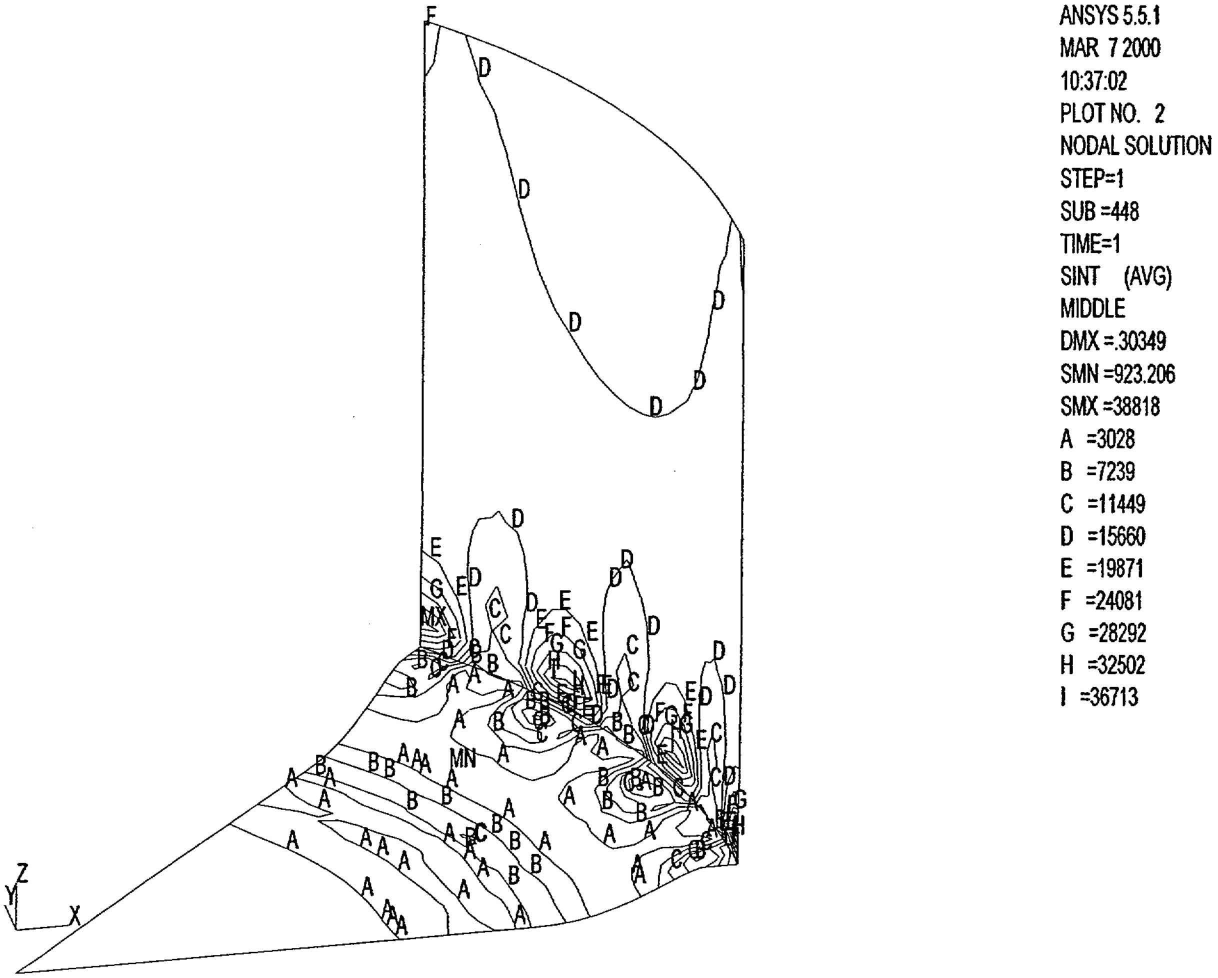

Figure 6-11 Contour Plot of Stress Intensity – Shell Middle. End Drop Loading

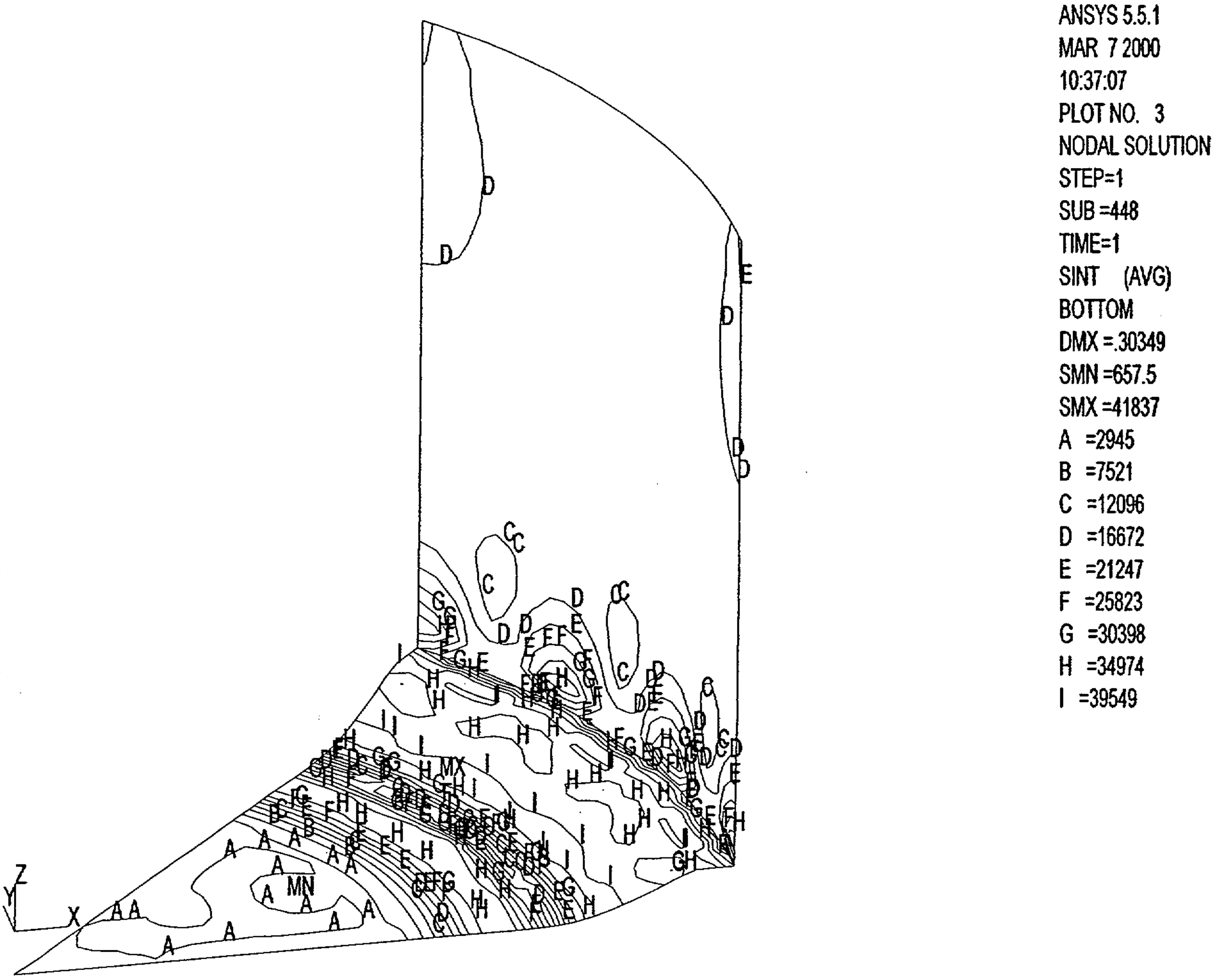

Figure 6-12 Contour Plot of Stress Intensity – Shell Bottom. End Drop Loading

Table 6-3 MSB Base Plate - Top Ten Stress Intensities at Top, Middle, and Bottom Locations– End Drop (108g)

Shell TOP

NODE	S1	S2	S3	SINT	SEQV
563	41855.	16858.	-1619.4	43475.	37791.
586	41856.	16863.	-1618.9	43474.	37790.
587	41845.	16824.	-1620.8	43466.	37786.
562	41841.	16833.	-1619.5	43460.	37780.
575	41838.	16867.	-1620.2	43458.	37775.
574	41837.	16876.	-1619.2	43456.	37772.
14	40591.	36625.	-1463.9	42055.	40219.
1	40011.	37054.	-2041.1	42052.	40655.
29	39990.	37079.	-2041.9	42031.	40654.
23	40544.	36644.	-1463.8	42008.	40200.

Shell MIDDLE

NODE	S1	S2	S3	SINT	SEQV
2	9083.0	650.83	-11666.	20749.	18074.
28	9096.4	682.40	-11648.	20744.	18072.
560	7916.9	194.78	-8681.7	16599.	14386.
577	7898.4	123.67	-8695.4	16594.	14380.
572	7913.3	200.06	-8673.9	16587.	14377.
589	7895.2	136.33	-8689.4	16585.	14373.
584	7903.1	197.37	-8670.0	16573.	14364.
565	7883.8	123.17	-8688.7	16573.	14362.
30	7545.2	907.84	-8426.3	15972.	13897.
3	7541.2	922.81	-8417.0	15958.	13887.

Shell BOTTOM

NODE	S1	S2	S3	SINT	SEQV
528	41833.	19719.	-3.8650	41837.	36251.
419	41405.	20005.	-2.5186	41407.	35866.
420	41377.	20363.	-8.3210	41385.	35842.
408	41368.	19483.	-0.32218	41369.	35846.
409	41357.	19413.	-1.0322	41358.	35839.
418	41349.	19711.	-0.57776	41350.	35823.
417	41296.	19575.	-0.64121E-01	41296.	35779.
521	41283.	21211.	-7.2713	41290.	35763.
410	41273.	19814.	-1.6575	41275.	35755.
520	41256.	21000.	-1.7699	41257.	35732.

Table 6-4 MSB Shell - Top Ten Stress Intensities at Top, Middle, and Bottom Locations – End Drop (108g)

Shell TOP

NODE	S1	S2	S3	SINT	SEQV
2	11.001	-20518.	-41294.	41305.	35771.
28	10.815	-20480.	-41279.	41290.	35758.
11	6.4605	-20505.	-41281.	41288.	35757.
20	6.4747	-20503.	-41280.	41286.	35755.
4	7.2946	-18366.	-40091.	40098.	34766.
10	7.6790	-18357.	-40076.	40084.	34754.
19	7.6391	-18350.	-40075.	40083.	34753.
8	7.5400	-18371.	-40059.	40066.	34738.
26	7.3142	-18362.	-40059.	40066.	34738.
17	7.6109	-18380.	-40058.	40066.	34737.

Shell MIDDLE

NODE	S1	S2	S3	SINT	SEQV
2	9.3288	-20944.	-41805.	41814.	36212.
11	4.7090	-20942.	-41801.	41806.	36205.
20	4.7226	-20940.	-41799.	41804.	36203.
28	9.1434	-20913.	-41792.	41801.	36200.
4	6.2332	-18509.	-40434.	40440.	35063.
10	6.5628	-18509.	-40429.	40435.	35059.
19	6.5180	-18510.	-40429.	40435.	35059.
8	6.4145	-18533.	-40414.	40421.	35045.
17	6.4942	-18529.	-40411.	40418.	35043.
26	6.2292	-18513.	-40406.	40412.	35038.

Shell BOTTOM

NODE	S1	S2	S3	SINT	SEQV
2	7.8136	-21368.	-42317.	42325.	36655.
11	3.1120	-21379.	-42320.	42324.	36654.
20	3.1249	-21377.	-42318.	42321.	36652.
28	7.6311	-21344.	-42306.	42313.	36645.
19	5.4559	-18665.	-40788.	40793.	35370.
10	5.5051	-18655.	-40787.	40792.	35370.
4	5.2261	-18647.	-40782.	40787.	35366.
8	5.3488	-18689.	-40775.	40780.	35357.
17	5.4363	-18674.	-40769.	40775.	35353.
26	5.2009	-18658.	-40758.	40763.	35343.

6.4. Ceramic Tile

This section calculates the bearing stress on the ceramic tile for normal operation. An evaluation of the ceramic tile for a vertical drop is not included because it is not important for the ceramic tile to remain intact for this accident.

$$\sigma_{bearing} = \frac{m_{MSB}}{A_{cer}}$$

Where A_{cer} is the total area of the ceramic tiles in contact with the MSB.

$$\sigma_{bearing} = \frac{70000}{24 \cdot 1.7^2} \quad = \quad 1.0 \text{ ksi}$$

The bearing stress on the tile is negligible.

6.5. MSB Drop Onto Shield Lid

Even though this analysis is not required for Part 72 license (upside down drop is not possible), the analysis has been performed for the future licensing under Part 71.

The same model was used as in Section 6.2, however, the loading was modified as shown on Figure 6-2. The ANSYS input/output from Reference 3.1.3 is in Attachment C. The maximum membrane stress, at Element 12, is

$$\sigma_{m\_old} := 5.88 \cdot ksi$$

The revised membrane stress is calculated assuming that stress scales linearly with load and inversely proportional to MSB wall thickness. The revised membrane stress is

$$\sigma_{m\_down} := \sigma_{m\_old} \cdot \frac{a_v}{a_{v\_old}} \cdot \frac{t_{msb\_old}}{t_{msb}}$$

$$\sigma_{m\_down} = 3.8 ksi$$

The approximate bending stress at Element 1 is (it is conservative to ignore the slight membrane stress at this element)

$$\sigma_{b\_old} := 24.99 \cdot ksi$$

The revised bending stress is calculated assuming that stress scales linearly with load. The revised bending stress is

$$\sigma_{b\_down} := \sigma_{b\_old} \cdot \frac{a_v}{a_{v\_old}}$$

$$\sigma_{b\_down} = 21.8 ksi$$

6.6. Summary of Stress Results, Allowables, and Design Margins

Table 6-5 MSB With Uniform Support to Base, End Drop Loading. Summary of Stresses, Allowables, and Design Margins..

COMPONENT	PRIMARY MEMBRANE			PRIMARY MEMBRANE + BENDING		
	P_m	Allowable P_m	D.M	$P_L + P_b$	Allowable $P_L + P_b$	D.M
Shell (1)	9.7	49.0	4.1	9.7 + 2.4 = 12.1	73.5	5.1
Structural Lid	N.A	N.A	N.A	4.2	73.5	16.5
Structural Lid Weld	N.A	N.A	N.A	8.2	73.5	8.0
Bottom Plate	3.8	49.0	11.9	3.8 + 21.8 = 25.6	73.5	1.87

Note: [1] Values tabulated are worst case for load cases considered.
The stresses summarized above are also used in combination with other load cases in a separate calculation.

Table 6-6 MSB Supported on Ceramic Tiles With Deadwt loading (1g). Summary of Stresses, Allowables, and Design Margins.

MSB SHELL (ksi)					
Primary Membrane Stress Intensity (P_m)			Primary Membrane Plus Bending Stress Intensity (P_L+P_b)		
P_m	Allowable P_m	D.M	P_L+P_b	Allowable P_L+P_b	D.M
0.5	49.0	Large	1.5	73.5	Large

MSB BASE (ksi)					
Primary Membrane Stress Intensity (P_m)			Primary Membrane Plus Bending Stress Intensity (P_L+P_b)		
P_m	Allowable P_m	D.M	P_L+P_b	Allowable P_L+P_b	D.M
0.35	49.0	Large	12.2	73.5	4.5

Note: The stresses summarized above are also used in combination with other load cases in a separate calculation.
The bottom weld stress for both P_m and P_L + P_b is conservatively taken as the worst of both the shell and base stresses.

Table 6-7 MSB Supported on Ceramic Tiles. End Drop Loading (108g). Summary of Stresses, Allowables, and Design Margins.

MSB SHELL (ksi)								
Primary Membrane Stress Intensity (P_m)			Maximum Primary Stress Intensity (P_{max})			Maximum Primary Shear (P_{shear})		
P_m	Allowable P_m	D.M	P_{max}	Allowable P_{max}	D.M	P_{shear}	Allowable P_{shear}	DM
41.8	49.0	0.17	42.3	63.0	0.49	21.2	29.4	0.39

MSB BASE (ksi)								
Primary Membrane Stress Intensity (P_m)			Maximum Primary Stress Intensity (P_{max})			Maximum Primary Shear (P_{shear})		
P_m	Allowable P_m	D.M	P_{max}	Allowable P_{max}	D.M	P_{shear}	Allowable P_{shear}	DM
20.7	49.0	1.37	43.5	63.0	0.45	21.8	29.4	0.35

Note: The stresses summarized above are also used in combination with other load cases in a separate calculation.

The bottom weld stress for both P_m and $P_L + P_b$ is conservatively taken as the worst of both the shell and base stresses.

7. CONCLUSION

The MSB components have been assessed for end drop loading for the uniform support condition. In this support configuration, the calculated stresses are within ASME code service level D allowables.

In addition, MSB components have been assessed for the both the dead weight and end drop conditions, while supported on a ring of ceramic tiles around the periphery of the MSB base. For the end drop condition, some local yielding occurs in regions where the ceramic tiles provide support to the MSB. The analysis has demonstrated that the calculated stresses are within ASME code allowables for acceptance criteria using plastic system analysis. Stresses due to deadweight analysis have also been shown to be acceptable.

It can be seen from the results that, as expected, the support condition of the MSB supported on the ceramic tiles has the smaller design margins, and therefore governs.

8. ELECTRONIC FILES

Filename	File Date	Code	Cat	Version	Platform	Machine
Vscnorm.inp	3/6/00	ANSYS	1	5.5	NT	8834BW323307
Vscnorm.out	3/6/00	ANSYS	1	5.5	NT	8834BW323307
Vscnorm.db	3/6/00	ANSYS	1	5.5	NT	8834BW323307
Vscnorm.rst	3/6/00	ANSYS	1	5.5	NT	8834BW323307
Vscnorm-pp.inp	3/29/00	ANSYS	1	5.5	NT	8834BW323307
Vscnorm-pp.out	3/29/00	ANSYS	1	5.5	NT	8834BW323307
Vscnorm+press.inp	3/6/00	ANSYS	1	5.5	NT	8834BW323307
Vscnorm+press.out	3/6/00	ANSYS	1	5.5	NT	8834BW323307
Vscnorm+press.db	3/6/00	ANSYS	1	5.5	NT	8834BW323307
Vscnorm+press.rst	3/6/00	ANSYS	1	5.5	NT	8834BW323307
Vscedge.inp	3/6/00	ANSYS	1	5.5	NT	8834BW323307
Vscedge.out	3/6/00	ANSYS	1	5.5	NT	8834BW323307
Vscedge.db	3/6/00	ANSYS	1	5.5	NT	8834BW323307
Vscedge.rst	3/6/00	ANSYS	1	5.5	NT	8834BW323307
Vscedge-pp.inp	3/27/00	ANSYS	1	5.5	NT	8834BW323307
Vscedge-pp.out	3/27/00	ANSYS	1	5.5	NT	8834BW323307

File Description

Vscnorm.inp	ANSYS input data file. Deadweight (1g).
Vscnorm.out	ANSYS output data file. Deadweight (1g).
Vscnorm.db	ANSYS database file. Deadweight (1g).
Vscnorm.rst	ANSYS results file. Deadweight (1g).
Vscnorm-pp.inp	ANSYS post processing input file. Deadweight (1g).
Vscnorm-pp.out	ANSYS post processing output file. Deadweight (1g).

Vscnorm+press.inp	ANSYS input data file. Deadweight (1g) + pressure (8.9 psig).
Vscnorm+press.out	ANSYS output data file. Deadweight (1g) + pressure (8.9 psig).
Vscnorm+press.db	ANSYS database file. Deadweight (1g) + pressure (8.9 psig).
Vscnorm+press.rst	ANSYS results file. Deadweight (1g) + pressure (8.9 psig).
Vscedge.inp	ANSYS input data file. End Drop (108g).
Vscedge.out	ANSYS output data file. End Drop (108g).
Vscedge.db	ANSYS database file. End Drop (108g).
Vscedge.rst	ANSYS results file. End Drop (108g).
Vscedge-pp.inp	ANSYS post processing input file. End Drop (108g).
Vscedge-pp.out	ANSYS post processing output file. End Drop (108g).

ATTACHMENT A

FINITE ELEMENT ANALYSIS INPUT AND OUTPUT

MSB TOP REGION

ATTACHMENT B

FINITE ELEMENT ANALYSIS INPUT AND OUTPUT

MSB BOTTOM REGION

ATTACHMENT C

FINITE ELEMENT ANALYSIS INPUT AND OUTPUT

MSB BOTTOM—DROP ONTO SHIELD LID

ATTACHMENT D

FINITE ELEMENT ANALYSIS INPUT

MSB BOTTOM SUPPORTED BY TILES ON BASE, DEADWEIGHT LOADING (1g)

```
! * 3D ANALYSIS OF BASE PLATE STRESS WITH
! * MSB BASE SUPPORTED BY CERAMIC TILES AROUND EDGE
! * NORMAL OPERATING CONDITION 1g

/filname,vscnorm

/Prep7
/Title,VSC Base Plate Stress Analysis

! Element Types
et,1,shell63            ! Elastic Shell elements
et,2,contac52           ! 3-D Point to Point Gap Elements
keyopt,2,3,1            ! Use soft spring across open gap
keyopt,2,7,1            ! Use reasonable time increment

!*** CHECK MATERIAL PROPERTIES
! Material Properties
! SA-516, Grade 70 Ferritic Carbon Steel, 300 deg.F
dens,1,0.284
nuxy,1,0.29
ex,1,28.3E6

*afun,deg                 ! Angles in degrees as default

!******************
!*** Parameters ***
!******************
OD  = 62.5                ! Outside diameter
ID  = 60.5                ! Inside diameter
WTH = (OD-ID)/2           ! Wall thickness
BRAD = ID/2+WTH/2         ! C/L radius of basket
BTH = 0.75                ! Base plate thickness
LET = 1.7                 ! Length of ceramic tile
TTH = 0.30                ! Ceramic tile thickness
TR1 = 30.0                ! C/L radius ceramic tiles
THETA = asin((LET/2)/TR1) ! Angle between center & edge of tiles
VLE = 30.0                ! Length of modeled vertical portion of vessel
TOL = 0.001               ! Select tolerance

! Real constants
r,1,BTH                   ! Thickness of base plate (non tile regions)
r,2,BTH                   ! Thickness of base plate (tiles region)
r,3,WTH                   ! Thickness of basket wall
r,4,1e6,TTH,3             ! Contact stiffness, MSB to base

!*****************
!*** Keypoints ***
!*****************
csys,1
k,1,
k,2,TR1-LET/2,0,0
k,3,BRAD,0,0
k,4,TR1-LET/2,THETA,0
k,5,BRAD,THETA,0
k,6,TR1-LET/2,15-THETA,0
```

```
k,7,BRAD,15-THETA,0
k,8,TR1-LET/2,15+THETA,0
k,9,BRAD,15+THETA,0
k,10,TR1-LET/2,30-THETA,0
k,11,BRAD,30-THETA,0
k,12,TR1-LET/2,30+THETA,0
k,13,BRAD,30+THETA,0
k,14,TR1-LET/2,45-THETA,0
k,15,BRAD,45-THETA,0
k,16,TR1-LET/2,45,0
k,17,BRAD,45,0

ksel,s,loc,x,BRAD
kgen,2,all,,,,,VLE/4,100
ksel,s,loc,z,VLE/4
kgen,2,all,,,,,VLE*3/4,100
ksel,all

! Areas
! Tile areas first
csys,1
a,2,3,5,4
a,6,7,9,8
a,10,11,13,12
a,14,15,17,16
type,1
mat,1
real,2
esize,0.9
amesh,1,4

! Rest of Base
a,1,2,4,6,8,10,12,14,16
a,4,5,7,6
a,8,9,11,10
a,12,13,15,14

lsel,s,line,,22,24
lesize,all,,,7
lsel,all
real,1
amesh,5,8

! Basket shell
numstr,area,21
a,3,103,105,5
a,5,105,107,7
a,7,107,109,9
a,9,109,111,11
a,11,111,113,13
a,13,113,115,15
a,15,115,117,17

a,103,203,205,105
a,105,205,207,107
```

```
a,107,207,209,109
a,109,209,211,111
a,111,211,213,113
a,113,213,215,115
a,115,215,217,117

esize,1.2
real,3
amesh,21,27
esize,2.0
amesh,28,34

!****************
!*** Contacts ***
!****************
! Contact between basket base & cask
! Select nodes on ceramic tile elements
esel,s,real,,1
nsle,s
! Generate coincident set of nodes
ngen,2,2000,all,,,0,0,-TTH
! Generate contact elements
esel,s,real,,1
nsle,s
*get,numnodes,node,,count
nsel,a,node,,1999,3999
*get,nextnode,node,,num,min
type,2
real,4
*do,i,1,numnodes
  *if,i,eq,1,then
     e,nextnode,nextnode+2000
     *get,nextnode,node,nextnode,nxth
  *elseif,i,ge,2,then
     e,nextnode,nextnode+2000
     *get,nextnode,node,nextnode,nxth
  *endif
*enddo

! Remove contacts on periphery of tiles
asel,s,area,,1,4
esla,s
nsle,s,ext
esln,s
esel,r,type,,2
edel,all
nall
eall

!*******************
!*** Constraints ***
!*******************
! Symmetry BC's
esel,s,type,,1
nsle,s
```

```
csys,1
nsel,s,loc,y,45
nrotat,all
dsym,symm,y,1
esel,s,type,,1
nsle,s
nsel,s,loc,y,0
dsym,symm,y

! Contacts at ground
esel,s,type,,2
nsle,s
nsel,r,,,1999,3999
d,all,all,0
nall

! Base of tiles
esel,s,real,,2
nsle
d,all,uz,0

!*********************
!*** Applied Loads ***
!*********************
! Pressure on basket base due to contents
esel,s,real,,1,2
nsle,s
sfe,all,2,pres,,13.536
nall
eall

! Force on side wall due to part of
! Basket not included in model.
! Interior nodes first
FORCE = 3442.5     ! Calculated mass missing in 1/8 model
csys,1
nsel,s,loc,x,BRAD
nsel,r,loc,z,VLE
*get,NUMNODES,node,,count
nsel,r,loc,y,1,44
NODEFORC = FORCE/(NUMNODES-1)
f,all,fz,-NODEFORC
nall
! Exterior nodes (half the load)
csys,1
nsel,s,loc,x,BRAD
nsel,r,loc,z,VLE
nsel,r,loc,y,0
f,all,fz,-NODEFORC/2
nsel,s,loc,x,BRAD
nsel,r,loc,z,VLE
nsel,r,loc,y,45
f,all,fz,-NODEFORC/2
nall
```

```
! Drop Acceleration
acel,,,1          ! 1g Body load acceleration

allsel

!****************
!*** Solution ***
!****************
/solu

solve

finish

/post1
set
prrsol
fini
/exit
```

ATTACHMENT E

FINITE ELEMENT ANALYSIS INPUT

MSB SUPPORTED BY TILES ON BASE, BOTTOM END DROP (108g)

```
!
! * 3D ANALYSIS OF BASE PLATE STRESS WITH
! * MSB BASE SUPPORTED BY CERAMIC TILES AROUND EDGE
! * END DROP ACCELERATION OF 108g

/filname,vscedge

/Prep7
/Title,VSC Base Plate Stress Analysis

! Element Types
et,1,shell143            ! Plastic Shell elements
et,2,contac52            ! 3-D Point to Point Gap Elements
keyopt,2,3,1             ! Use soft spring across open gap
keyopt,2,7,1             ! Use reasonable time increment

!*** CHECK MATERIAL PROPERTIES
! Material Properties
! SA-516, Grade 70 Ferritic Carbon Steel, 300 deg.F
dens,1,0.284
nuxy,1,0.29
ex,1,28.3E6
tb,bkin,1,1
tbdata,1,33.7E3,355.1E3    ! Yield Stress and Tangent Modulus

*afun,deg                  ! Angles in degrees as default

!******************
!*** Parameters ***
!******************
OD  = 62.5                 ! Outside diameter
ID  = 60.5                 ! Inside diameter
WTH = (OD-ID)/2            ! Wall thickness
BRAD = ID/2+WTH/2          ! C/L radius of basket
BTH = 0.75                 ! Base plate thickness
LET = 1.7                  ! Length of ceramic tile
TTH = 0.30                 ! Ceramic tile thickness
TR1 = 30.0                 ! C/L radius ceramic tiles
THETA = asin((LET/2)/TR1)  ! Angle between center & edge of tiles
VLE = 30.0                 ! Length of modeled vertical portion of vessel
ACC = 108                  ! Acceleration due to end drop
TOL = 0.001                ! Select tolerance

! Real constants
r,1,BTH                    ! Thickness of base plate (non tile regions)
r,2,BTH                    ! Thickness of base plate (tiles region)
r,3,WTH                    ! Thickness of basket wall
r,4,1e6,TTH,3              ! Contact stiffness, MSB to base

!*****************
!*** Keypoints ***
!*****************
csys,1
k,1,
k,2,TR1-LET/2,0,0
```

```
k,3,BRAD,0,0
k,4,TR1-LET/2,THETA,0
k,5,BRAD,THETA,0
k,6,TR1-LET/2,15-THETA,0
k,7,BRAD,15-THETA,0
k,8,TR1-LET/2,15+THETA,0
k,9,BRAD,15+THETA,0
k,10,TR1-LET/2,30-THETA,0
k,11,BRAD,30-THETA,0
k,12,TR1-LET/2,30+THETA,0
k,13,BRAD,30+THETA,0
k,14,TR1-LET/2,45-THETA,0
k,15,BRAD,45-THETA,0
k,16,TR1-LET/2,45,0
k,17,BRAD,45,0

ksel,s,loc,x,BRAD
kgen,2,all,,,,,VLE/4,100
ksel,s,loc,z,VLE/4
kgen,2,all,,,,,VLE*3/4,100
ksel,all

! Areas
! Tile areas first
csys,1
a,2,3,5,4
a,6,7,9,8
a,10,11,13,12
a,14,15,17,16
type,1
mat,1
real,2
esize,0.9
amesh,1,4

! Rest of Base
a,1,2,4,6,8,10,12,14,16
a,4,5,7,6
a,8,9,11,10
a,12,13,15,14

lsel,s,line,,22,24
lesize,all,,,7
lsel,all
real,1
amesh,5,8

! Basket shell
numstr,area,21
a,3,103,105,5
a,5,105,107,7
a,7,107,109,9
a,9,109,111,11
a,11,111,113,13
a,13,113,115,15
```

```
a,15,115,117,17

a,103,203,205,105
a,105,205,207,107
a,107,207,209,109
a,109,209,211,111
a,111,211,213,113
a,113,213,215,115
a,115,215,217,117

esize,1.2
real,3

amesh,21,27
esize,2.0
amesh,28,34

!****************
!*** Contacts ***
!****************
! Contact between basket base & cask
! Select nodes on ceramic tile elements
esel,s,real,,1
nsle,s
! Generate coincident set of nodes
ngen,2,2000,all,,,0,0,-TTH
! Generate contact elements
esel,s,real,,1
nsle,s
*get,numnodes,node,,count
nsel,a,node,,1999,3999
*get,nextnode,node,,num,min
type,2
real,4
*do,i,1,numnodes
  *if,i,eq,1,then
     e,nextnode,nextnode+2000
     *get,nextnode,node,nextnode,nxth
  *elseif,i,ge,2,then
     e,nextnode,nextnode+2000
     *get,nextnode,node,nextnode,nxth
  *endif
*enddo

! Remove contacts on periphery of tiles
asel,s,area,,1,4
esla,s
nsle,s,ext
esln,s
esel,r,type,,2
edel,all
nall
eall

!*******************
!*** Constraints ***
```

```
!*******************
! Symmetry BC's
esel,s,type,,1
nsle,s
csys,1
nsel,s,loc,y,45
nrotat,all
dsym,symm,y,1
esel,s,type,,1
nsle,s
nsel,s,loc,y,0
dsym,symm,y

! Contacts at ground
esel,s,type,,2
nsle,s
nsel,r,,,1999,3999
d,all,all,0
nall

! Base of tiles
esel,s,real,,2
nsle
d,all,uz,0

!*********************
!*** Applied Loads ***
!*********************
! Pressure on basket base due to contents
esel,s,real,,1,2
nsle,s
sfe,all,2,pres,,13.536*ACC
nall
eall

! Force on side wall due to part of
! Basket not included in model.
! Interior nodes first
FORCE = 3442.5*ACC   ! Calculated mass missing in 1/8 model
csys,1
nsel,s,loc,x,BRAD
nsel,r,loc,z,VLE
*get,NUMNODES,node,,count
nsel,r,loc,y,1,44
NODEFORC = FORCE/(NUMNODES-1)
f,all,fz,-NODEFORC
nall
! Exterior nodes (half the load)
csys,1
nsel,s,loc,x,BRAD
nsel,r,loc,z,VLE
nsel,r,loc,y,0
f,all,fz,-NODEFORC/2
nsel,s,loc,x,BRAD
nsel,r,loc,z,VLE
```

```
nsel,r,loc,y,45
f,all,fz,-NODEFORC/2
nall

! Drop Acceleration
acel,,,ACC             ! Body load acceleration

allsel

!****************
!*** Solution ***
!****************
/solu
nlgeom,on              ! Include large deformation effects
autots,on              ! Automatic time stepping
nsubst,50,1000,10      ! 50 substeps 1000max 10min for load step
solcon,on,on
cnvtol,f,,0.01         ! Convergence for force at 1%
cnvtol,m,,0.01         ! Convergence for moment at 1%

solve

finish

/post1
set
prrsol
fini
/exit
```

025032

BNFL Fuel Solutions	**CALCULATION PACKAGE**	Calc. Pkg No. VSC02.6.2.3.31 File No.: VSC02.6.2.3.31 Revision: 0

PROJECT/CUSTOMER:

VSC02/BNFL Fuel Solutions

TITLE:

Calculation for Stress on Structural Lid for a Lifting Bolt Radius of 26.5”

SCOPE:

Product:	☐ Wesflex™	☐ TranStor™	☒ VSC-24	☐ Other ________
Service:	☒ Storage	☐ Transportation		☐ Other ________
Conditions:	☒ Normal	☐ Off-Normal	☐ Accident	☐ Other ________

Component(s):

MSB Structural Lid

Prepared by:

Name: ROBERT KEATING

Signature: Rob Kt

Date: 1/12/2000

Verified by:

Name: Michelle M. Heinz

Signature: Michelle M Heinz

Date: 1/12/00

Engineering Manager Approval:

Name: RAM SRINIVASAN

Signature: R Srinivasan

Date: 1/17/00

RECORD OF REVISIONS

REV.	AFFECTED PAGES	AFFECTED MEDIA	DESCRIPTION	NAMES (print or type)	
				PREPARER	CHECKER
0	1 - 18	None	Replaces Calculation WEP109-002.31, Rev. 0 –	Robert Keating	Michelle Heinz
			Per Ecn No.: WEP01-C-018		

Note: This calculation has been prepared in accordance with QAP 3.2, Revision 8, except that because this calculation is a revision of an existing calculation, the format is essentially based on the superceded calculation. The title page, record of revision page, and record of verification page are per QAP 3.2, Revision 8. Other format requirements of QAP 3.2 have been included where this could be readily accomplished. This approach was approved in BFS Memorandum 99-528, dated December 21, 1999.

RECORD OF VERIFICATION

Circle:

(a) The objective is clear and consistent with the analysis. [✓ YES] NO

(b) The inputs are correctly selected and incorporated into the design. [✓ YES] NO N/A

(c) References are complete and accurate. [✓ YES] NO N/A

(d) Basis for engineering judgments is adequately documented. [✓ YES] NO N/A

(e) The assumptions necessary to perform the design activity are adequately described and reasonable. [✓ YES] NO N/A

(f) Assumptions and references which are preliminary are noted as being preliminary. YES NO [✓ N/A]

(g) Methods and units are clearly identified. [✓ YES] NO N/A

(h) Any limits of applicability are identified. YES NO [✓ N/A]

(i) Computer calculations are properly identified. YES NO [✓ N/A]

(j) Computer codes used are under configuration control. YES NO [✓ N/A]

(k) Computer codes used are applicable to the calculation. YES NO [✓ N/A]

(l) Input parameters and boundary conditions are appropriate and correct. [✓ YES] NO

(m) An appropriate design method is used. [✓ YES] NO

(n) The output is reasonable compared to the inputs. [✓ YES] NO

(o) Conclusions are clear and consistent with analysis results. [✓ YES] NO

COMMENTS:

Verifier: Michelle M. Heinz / Michelle M. Heinz / 1/12/00

Name/Signature/Date

1.0 INTRODUCTION

The purpose of this calculation is to determine the effect of moving the MSB Structural Lid lifting bolt holes to a radius of 26 inches (conservative compared to the actual value of 26.5") from their previously analyzed radius of 27 inches will have on the ability of the MSB lifting devices to lift a fully loaded MSB.

This calculation supercedes SNC Calculation WEP 109-002.31, Revision 0. This calculation addresses technical issues identified in CAR 98-50. The principal difference between this calculation and the superceded calculation is the weight of the fully loaded MSB used in the calculation.

2.0 DESIGN INPUTS AND ASSUMPTIONS

2.1 Design Inputs

Radius of MSB Structural Lid	$a := 30 \text{ in}$	Reference 3
Thickness of MSB Structural Lid	$t := 3 \text{ in}$	Reference 3
Radius of Lifting Bolt Holes (Case 1)	$r_{o1} := 27 \text{ in}$	Reference 4
Radius of Lifting Bolt Holes (Case 2)	$r_{o2} := 26 \text{ in}$	
Weight per lifting bolt of MSB used in calculation of maximum stress for case 1. (Based on 6 lifting bolts)	$w_o := 11692 \text{ lb}$	Reference 4
Number of Lifting Bolts	$n_b := 6$	Reference 3
Maximum MSB Structural Lid Stress	$s_{max} := 2.2 \cdot 10^3 \text{ psi}$	Reference 4

<u>Material Properties</u> (Taken at 300 degree F)

Material	SA 516-70	Reference 3
Yield Strength	$s_y := 33.7 \cdot 10^3 \text{ psi}$	Reference 5
Ultimate Tensile Strength	$s_u := 70 \cdot 10^3 \text{ psi}$	Reference 5
Poisson Ratio	$v := 0.33$	Reference 5

$$n := \frac{1}{v}$$

$$n = 3.03$$

2.2 Assumption

A bounding MSB weight value of 70,000 lb will be used for conservatism. (This value corresponds to a fully loaded MSB with shield and structural lids. The basis is that the weight bounds the weight calculated in Reference 7). In addition, the weight of the MSB will be increased by a factor of 1.1, in accordance with NUREG 0612 (Reference 1). The weight of the MSB (w) is taken per lifting bolt.

$$w := \frac{70000\ (\mathrm{lb})}{6} \cdot (1.1)$$

$$w = 1.283 \cdot 10^4\ \mathrm{lb}$$

3.0 CALCULATION

The MSB structural lid and bolt holes are modeled as a uniform load on a concentric circular ring on a flat plate. Based on this, the radial stress (s_r) and tangential stress (s_t) are as follows (Reference 6, page 218). Note that the stresses are calculated at radius (r). In both cases, r is assumed to be 30 inches, the point with the highest stress.

$$r := 30\ \mathrm{in}$$

$$s_r := \frac{\left(-3 \cdot w \cdot n_b\right)}{4 \cdot \pi \cdot n \cdot t^2} \cdot \left[(n+1) \cdot \left(2 \cdot \ln\left(\frac{a}{r}\right) + \frac{r_o^{\,2}}{a^2}\right) + (n-1) \cdot \frac{r_o^{\,2}}{r^2} - 2 \cdot n\right]$$

$$s_t := \frac{\left(-3 \cdot w \cdot n_b\right)}{4 \cdot \pi \cdot n \cdot t^2} \cdot \left[(n+1) \cdot \left(2 \cdot \ln\left(\frac{a}{r}\right) + \frac{r_o^{\,2}}{a^2}\right) - (n-1) \cdot \frac{r_o^{\,2}}{r^2} - 2\right]$$

3.1 Case 1 (r_o=27 inches)

$$s_{r1} := \frac{\left(-3 \cdot w \cdot n_b\right)}{4 \cdot \pi \cdot n \cdot t^2} \cdot \left[(n+1) \cdot \left(2 \cdot \ln\left(\frac{a}{r}\right) + \frac{r_{o1}^{\,2}}{a^2}\right) + (n-1) \cdot \frac{r_{o1}^{\,2}}{r^2} - 2 \cdot n\right]$$

$$s_{r1} = 776.1 \cdot \frac{\mathrm{lb}}{\mathrm{in}^2}$$

$$s_{t1} := \frac{\left(-3 \cdot w \cdot n_b\right)}{4 \cdot \pi \cdot n \cdot t^2} \left[(n+1) \cdot \left(2 \cdot \ln\left(\frac{a}{r}\right) + \frac{r_{o1}^2}{a^2}\right) - (n-1) \cdot \frac{r_{o1}^2}{r^2} - 2\right]$$

$$s_{t1} = 256.1 \circ \frac{lb}{in^2}$$

3.2 Case 2 (r_o=26 inches)

$$s_{r2} := \frac{\left(-3 \cdot w \cdot n_b\right)}{4 \cdot \pi \cdot n \cdot t^2} \cdot \left[(n+1) \cdot \left(2 \cdot \ln\left(\frac{a}{r}\right) + \frac{r_{o2}^2}{a^2}\right) + (n-1) \cdot \frac{r_{o2}^2}{r^2} - 2 \cdot n\right]$$

$$s_{r2} = 1 \cdot 10^3 \circ \frac{lb}{in^2}$$

$$s_{t2} := \frac{\left(-3 \cdot w \cdot n_b\right)}{4 \cdot \pi \cdot n \cdot t^2} \left[(n+1) \cdot \left(2 \cdot \ln\left(\frac{a}{r}\right) + \frac{r_{o2}^2}{a^2}\right) - (n-1) \cdot \frac{r_{o2}^2}{r^2} - 2\right]$$

$$s_{t2} = 335.5 \circ \frac{lb}{in^2}$$

3.3 Determination of Increased Stress

The fractional increase in radial and tangential stress due to the new lifting bolt hole placement is calculated below:

$$\Delta s_r := \frac{s_{r2} - s_{r1}}{s_{r1}} \qquad \Delta s_r = 0.3099$$

$$\Delta s_t := \frac{s_{t2} - s_{t1}}{s_{t1}} \qquad \Delta s_t = 0.3099$$

Reference 4 documents a maximum stress of 2.2 ksi based on an evaluated MSB weight of 63,777 lb. Maximum stress based on the bounding weight can be calculated with the ratio of the bounding to the previously evaluated load. The stress will increase as a result of moving the lifting bolt holes in from a radius of 27 inches to a radius of 26 inches. This results in a new maximum stress of:

$$s_{new} := \left[s_{max} \cdot \left(1 + \Delta s_r \right) \right] \cdot \frac{w}{w_o}$$

$$s_{new} = 3.2 \cdot 10^3 \cdot psi$$

References 1 and 2 specify minimum safety factors for yield and ultimate tensile strength of 6 and 10 respectively. Based on the maximum stress calculated above (s_{new}), safety factors are:

$\phi_y := \frac{s_y}{s_{new}}$ $\phi_y = 10.7$ Minimum ϕ_y=6

$\phi_u := \frac{s_u}{s_{new}}$ $\phi_u = 22.1$ Minimum ϕ_u=10

4.0 CONCLUSION

The yield strength ultimate tensile strength safety factors are both greater than their respective required minimums. Therefore, an MSB structural lid lifting bolt radius of 26 inches will result in acceptable safety factors with respect to yield and ultimate tensile strength.

5.0 REFERENCES

1. NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants-Resolution of Generic Technical Activity A-36", July, 1980.

2. ANSI N14.6-1993, "Special Lifting Devices for Shipping Containers Weighing 10,000 lb or more".

3. BNFL Drawing MSB-24-002, "MSB Shell and Structural Plates", Sheet 1/2, Revision 4.

4. BNFL Calculation VSC02.6.2.3.03, "MSB-24 Lifting Devices", Revision 0.

5. ASME Boiler and Pressure Vessel Code, 1986 Edition.

6. Roark, R.J., *Formulas for Stress and Strain*, Fourth Edition, McGraw-Hill, 1965.

7. BNFL Calculation VSC02.6.2.5.01, "MTC, MSB, and VCC Weights and Centers of Gravity, B&W Fuel", Revision 0.

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BNFL Fuel Solutions	CALCULATION PACKAGE	Calc. Pkg No. VSC02.6.2.3.33 File No.: VSC02.6.2.3.33 Revision: 0

PROJECT/CUSTOMER:

VSC02/BNFL Fuel Solutions

TITLE:

Impact on Fuel Sleeve

SCOPE:

Product: ☐ Wesflex™ ☐ TranStor™ ☒ VSC-24 ☐ Other ____________

Service: ☒ Storage ☐ Transportation ☐ Other ____________

Conditions: ☒ Normal ☐ Off-Normal ☐ Accident ☐ Other ____________

Component(s):

MSB Fuel Sleeve

Prepared by:

Name: ROBERT KEATING

Signature: 1/12/2000

Date:

Verified by:

Name: Michelle M. Heinz

Signature: Michelle M. Heinz

Date: 1/12/00

Engineering Manager Approval:

Name: RAM SRINIVASAN

Signature: RSrinivasan

Date: 1/17/00

RECORD OF REVISIONS

REV.	AFFECTED PAGES	AFFECTED MEDIA	DESCRIPTION	NAMES (print or type)	
				PREPARER	CHECKER
0	1 - 8	None	Replaces Calculation WEP109-002.33, Rev. 0 –	Robert Keating	Michelle Heinz
			Per ECN No.: WEP01-C-018		

Note: This calculation has been prepared in accordance with QAP 3.2, Revision 8, except that because this calculation is a revision of an existing calculation, the format is essentially based on the superceded calculation. The title page, record of revision page, and record of verification page are per QAP 3.2, Revision 8. Other format requirements of QAP 3.2 have been included where this could be readily accomplished. This approach was approved in BFS Memorandum 99-528, dated December 21, 1999.

RECORD OF VERIFICATION

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

COMMENTS:

Verifier: Michelle M. Heinz / Michelle M. Heinz / 1/12/00
Name/Signature/Date

1.0 INTRODUCTION

The purpose of this calculation is to verify the structural adequacy of the fuel sleeves in the event of an accidental drop or side impact of a fuel assembly onto a fuel sleeve during fuel loading.

This calculation was prepared to address technical issues concerning Calculation WEP 109-002.33, Revision 0, discusssed in Car 98-50 (dated 10/2/98) and the Design Review Record (dated 7/31/99). This calculation supercedes WEP 109-002.33, Revision 0. The prinicipal differences between the new and old calculations are:

- A bounding fuel assembly weight is used in the new calculation.
- The correct fuel sleeve inner width is used in the new calculation.
- Material properties at 200°F used in the new calculation.

Changes to this calculation are not known to affect any other calculations.

2.0 DESIGN INPUTS AND ASSUMPTIONS

2.1 Design Inputs

Fuel Sleeve Dimensions (Reference 1)

Wall Thickness	$t := 0.2\ \text{in}$
Outer Width	$w_{out} := 9.2\ \text{in}$
Inner Width	$w := 8.8\ \text{in}$
Material	SA 516-70

Material Properties: (Reference 2)
Properties taken at 200°F (See Assumption 2.2.1)

Yield Strength	$s_y := 34.6 \cdot 10^3\ \text{psi}$
Poisson Ratio	$v := 0.33$
Modulus of Elasticity	$E := 28.8 \cdot 10^6\ \text{psi}$
Modulus of Rigidity	$G_r := \frac{E}{2 \cdot (1 + v)}$

$$G_r = 1.083 \cdot 10^7\ \text{psi}$$

2.2 Assumptions

2.2.1 Material properties are taken at an assumed temperature of 200°F. The postulated fuel assembly drop could only occur during fuel assembly loading or unloading while the MSB is submerged in the Spent Fuel Pool. Nominal Spent Fuel Pool temperature is approximately 90°F, and fuel assembly transfer with pool boiling is not likely. Therefore, this value is considered bounding.

2.2.2 A bounding fuel assembly weight of 1,600 lb is assumed (bounds the value calculated in Reference 4).

$$wt := 1600\ lb$$

2.2.3 For case 1, in which a vertical drop on top of the sleeve is considered, the following assumptions are made:

- Speed of the dropped fuel assembly is 5 in/sec.
- Impact time is 0.01 sec.
- Only the top three inches of the sleeve are credited for the buckling calculation.
- The dynamic amplification factor is 1.5.

$$v_1 := 5\ \frac{in}{sec} \qquad time_1 := 0.01\ sec \qquad lg_1 := 3\ in \qquad amp_1 := 1.5$$

2.2.4 For case 2, in which a horizontal impact on the side of the sleeve is considered, the following assumptions are made:

- Speed of the dropped fuel assembly is 3 in/sec.
- Impact time is 0.05 sec. This is due to the flexibility of the sleeve horizontally.
- Only three inches on either side of the point of impact are credited.
- The dynamic amplification factor is 1.1.

$$v_2 := 3\ \frac{in}{sec} \qquad time_2 := 0.05\ sec \qquad amp_2 := 1.1$$

3.0 CALCULATION

3.1 Case 1: Vertical Drop on Top of Fuel Sleeve

Case 1, in which a fuel assembly drops onto the top of one side of the sleeve, is evaluated as follows. An impulse due to the fuel assembly drop is calculated. This is used to determine the compressive stress. The stability of the sleeve is then evaluated by calculating a critical load, at which the sleeve will buckle, and comparing that to the weight of the fuel assembly.

$$Imp_1 := wt \cdot \frac{v_1}{time_1} \qquad Imp_1 = 2072 \cdot lbf$$

The dynamic amplification factor is applied to the impulse.

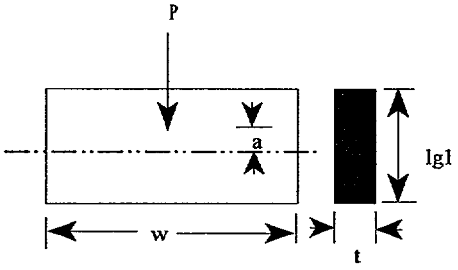
$$wt\_applied := Imp_1 \cdot amp_1 \qquad wt\_applied = 3108 \cdot lbf$$

The compressive stress on one side of the sleeve, due to the impact on top of the sleeve, where w and t are the dimensions of the top of the sleeve, as defined in Section 2.1:

$$\sigma_c := \frac{wt\_applied}{w \cdot t} \qquad \sigma_c = 1766 \cdot psi$$

The compressive stress (σ_c) is less than yield strength ($s_y = 34600 \cdot psi$).

The stability of the fuel sleeve is evaluated next. One wall of the fuel sleeve is modeled as a straight uniform beam with a center load applied at the centroid of the section (Reference 3, page 544, #13). As stated in Section 2.2, only the top three inches of the sleeve are credited in the stability calculation.



where :

$a := 1.5\ in$ **Most Conservative**

$$P_{crit} := \frac{2.82}{w^2} \cdot t^3 \cdot lg_1 \cdot \sqrt{\left[1 - 0.63 \cdot \left(\frac{t}{lg_1}\right)\right] \cdot G_r \cdot E} \cdot \left[1 - \frac{(1.74 \cdot a)}{w} \cdot \sqrt{\frac{E}{G_r \cdot \left[1 - 0.63 \cdot \left(\frac{t}{lg_1}\right)\right]}}\right]$$

$$P_{crit} = 7640 \cdot lbf$$

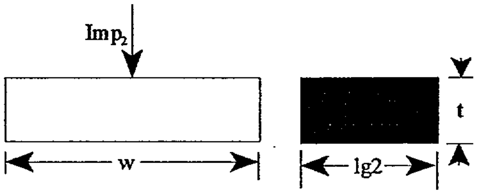
As $P_{crit} >$ wt_applied, the stability of the fuel sleeve is adequate.

3.2 Case 2: Horizontal Impact on Fuel Sleeve Wall

Case 2, in which a fuel assembly strikes the side wall of the fuel sleeve during loading, is solved as follows. The impulse due to the fuel assembly is calculated and corrected with the dynamic amplification factor, and used to determine the stresses on the fuel sleeve.

$$Imp_2 := wt \cdot \frac{v_2}{time_2} \cdot amp_2 \qquad Imp_2 = 273.5 \cdot lbf$$

The stresses on the fuel sleeve are calculated crediting only three inches on either side of the point of impact (Assumption 2.2.4). This is conservative, as crediting the entire sleeve length would produce unreasonably low stresses.



As shown above, the section of fuel sleeve wall is modeled as a rectangular slab simply supported on either end. The following dimensions apply:

$lg_2 := 2 \cdot lg_1$ This credits 3 inches on either side of the point of impact

$lg_2 = 6 \cdot in$

$c := 0.5 \cdot t$ Distance to extreme fiber

$c = 0.1 \cdot in$

Using these dimensions, the moment (Mom), moment of inertia (I), and normal stress (σ), can be calculated.

$$Mom := Imp_2 \cdot \frac{w}{4} \qquad Mom = 601.7 \cdot in \cdot lbf$$

$$I := \frac{lg_2 \cdot t^3}{12} \qquad I = 0.004 \cdot in^4$$

$$\sigma := Mom \cdot \frac{c}{I} \qquad \sigma = 15043 \cdot psi$$

The normal stress (σ) is less than the yield stress ($s_y = 34600 \cdot psi$). This is acceptable.

The shear stress can be evaluated using the same dimensions as above.

$$\tau := \frac{Imp_2}{2 \cdot lg_2 \cdot t} \qquad \tau = 114 \cdot psi$$

The shear strength (s_{yshear}) is calculated and compared to the case 2 shear stress (τ).

$$s_{yshear} := 0.57 \cdot s_y \qquad s_{yshear} = 19722 \cdot psi$$

The shear stress (τ) is less than the shear strength (s_{yshear}). This is acceptable.

4.0 CONCLUSION

This calculation evaluates the structural acceptability of the MSB fuel sleeves in the event of two postulated accidents, a vertical drop of a fuel assembly on top of the fuel sleeve, and a horizontal impact of a fuel assembly on the fuel sleeve wall. Both cases assumed a bounding fuel assembly weight of $wt = 1600\ lb$ and incorporated a dynamic amplification factor. In the first case, the compressive stress is calculated as $\sigma_c = 1766 \cdot psi$, which is less than the yield strength of $s_y = 34600 \cdot psi$. The critical buckling load is calculated as $P_{crit} = 7640 \cdot lbf$, which bounds the applied impulse of $wt\_applied = 3108 \cdot lbf$ (generated by the fuel assembly weight of 1,600 lb). In the second case, normal and shear stresses of $\sigma = 15043 \cdot psi$ and $\tau = 114 \cdot psi$, respectively, are calculated. The normal stress is less than the material yield strength $s_y = 34600 \cdot psi$, and the shear stress is less than the material shear strength $s_{yshear} = 19722 \cdot psi$.

5.0 REFERENCES

1. BNFL Drawing MSB-24-004, "Storage Sleeve Assembly", Sheet 1/3, Revision 4.

2. ASME Boiler and Pressure Vessel Code, 1986 Edition.

3. Roark, R.J., Young, W.C., *Formulas for Stress and Strain*, Fifth Edition, McGraw-Hill, 1975.

4. BNFL Calcuation VSC02.6.2.5.01, "MTC, MSB, and VCC Weights and Centers of Gravity B&W Fuel", Revision 0.

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BNFL
Fuel Solutions

CALCULATION PACKAGE

Calc. Pkg No. VSC02.6.2.5.01
File No.: VSC02.6.2.5.01
Revision: 0

PROJECT/CUSTOMER:

VSC02/BNFL Fuel Solutions

TITLE:

MTC, MSB and VCC Weights and Centers of Gravity B&W Fuel

SCOPE:

Product: ☐ Wesflex™ ☐ TranStor™ ☒ VSC-24 ☐ Other ________
Service: ☒ Storage ☐ Transportation ☐ Other ________
Conditions: ☒ Normal ☐ Off-Normal ☐ Accident ☐ Other ________

Component(s):

MSB, MTC and VCC, including all components and sub components.

Prepared by: ROBERT KEATING
Name:
Signature:
Date: 1/7/2000

Verified by:
Name: Regina Parkerson
Signature: Regina Parkerson
Date: 1/7/2000

Engineering Manager Approval:
Name: RAM SRINIVASAN
Signature: Srinivasan
Date: 1/21/00

RECORD OF REVISIONS

REV.	AFFECTED PAGES	AFFECTED MEDIA	DESCRIPTION	NAMES (print or type)	
				PREPARER	CHECKER
0	1 - 28	None	Replaces Calculation WEP109-004.1, Rev. 2 –	ROBERT KEATING	Regina Parkerson
			Per Ecn No.: WEP01-C-018		

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RECORD OF VERIFICATION

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

COMMENTS:

Verifier: Regina Parkerson Regina Parkerson 1/7/2000
Name/Signature/Date

1.0 INTRODUCTION

This Calculation determines the MSB, MTC, and VCC component weights, volumes and center of gravity. The information is required for different cask analyses as well as for handling of items when empty or loaded. This calculation also determines weights of MSB, MTC, and VCC components that are used by referencing calculations.

This analysis is bounding size (weight and height) and generic for the VSC-24 system. The calculation is the generic version of SNC Calculations WEP-109-004.1, Revision 2 (Ref 3.1.1) and ANO-109.002.001, Revision 5 (Reference 3.1.2). This generic analysis includes the resolution of discrepancies identified in Corrective Action Reports CAR 98-50 and CAR 98-51.

2.0 REQUIREMENTS

2.1 Design Inputs

None.

2.2 Regulatory Commitments

None.

3.0 REFERENCES

3.1 BFS Calculation Packages

3.1.1 SNC Calculation WEP-109-004.001, "MTC, MSB, and VCC Weights and Centers of Gravity (B&W Fuel), Revision 2.

3.1.2 SNC Calculation ANO-109-002.001, "Weight and C.G. Calculation, Revision 5

3.2 General References

3.2.1 Deleted.

3.2.2 Deleted.

3.2.3 Marks Handbook

3.2.4 SNC Drawing MSB-24-001 (0110.005.001), "MSB Assembly", Sheet 1/2, Revision 5.

3.2.5 SNC Drawing MSB-24-001 (0110.005.002), "MSB Assembly", Sheet 2/2, Revision 5.

3.2.6 SNC Drawing MSB-24-002 (0110.005.003), "MSB Shell and Structural Plates", Sheet 1/2, Revision 4.

3.2.7 SNC Drawing MSB-24-002 (0110.005.004), "MSB Shell and Structural Plates", Sheet 2/2, Revision 3.

3.2.8 SNC Drawing MSB-24-003 (0110.005.005), "Shield Lid Assembly", Sheet 1/1, Revision 4.

3.2.9 SNC Drawing MSB-24-004 (0110.005.006), "Storage Sleeve Assembly", Sheet 1/3, Revision 4.

3.2.10 SNC Drawing MSB-24-004 (0110.005.007), "Storage Sleeve Assembly", Sheet 2/3, Revision 1.

3.2.11 SNC Drawing MSB-24-004 (0110.005.008), "Storage Sleeve Assembly", Sheet 3/3, Revision 1.

3.2.12 SNC Drawing MTC-24-001 (0110.006.001), "MSB Transfer Cask (MTC)", Sheet 1/2, Revision 3.

3.2.13 SNC Drawing MTC-24-001 (0110.006.002), "MSB Transfer Cask (MTC)", Sheet 2/2, Revision 3.

3.2.14 SNC Drawing MTC-24-002 (0110.006.003), "Cask Wall Assembly", Sheet 1/2, Revision 3.

3.2.15 SNC Drawing MTC-24-002 (0110.006.004), "Cask Wall Assembly", Sheet 2/2, Revision 3.

3.2.16 SNC Drawing MTC-24-003 (0110.006.005), "Outer Shell", Sheet 1/2, Revision 1.

3.2.17 SNC Drawing MTC-24-003 (0110.006.006), "Outer Shell", Sheet 2/2, Revision 1.

3.2.18 SNC Drawing MTC-24-004 (0110.006.007), "Middle Shell", Sheet 1/1, Revision 2.

3.2.19 SNC Drawing MTC-24-005 (0110.006.008), "Inner Shell", Sheet 1/1, Revision 2.

3.2.20 SNC Drawing MTC-24-006 (0110.006.009), "MTC Lid and Shim Rings", Sheet 1/1, Revision 2.

3.2.21 SNC Drawing MTC-24-007 (0110.006.010), "Rail Assembly", Sheet 1/1, Revision 3.

3.2.22 SNC Drawing MTC-24-008 (0110.006.011), "Trunion Assembly", Sheet 1/1, Revision 3.

3.2.23 SNC Drawing MTC-24-009 (0110.006.012), "Shield Door Assembly", Sheet 1/1, Revision 1.

3.2.24 SNC Drawing VCC-24-001 (0110.004.001), "Ventilated Concrete Cask (VCC) Assembly", Sheet 1/2, Revision 3.

3.2.25 SNC Drawing VCC-24-001 (0110.004.002), "Ventilated Concrete Cask (VCC) Assembly", Sheet 2/2, Revision 2.

3.2.26 SNC Drawing VCC-24-002 (0110.004.003), "Cask Lid and Liner Assembly", Sheet 1/3, Revision 3.

3.2.27 SNC Drawing VCC-24-002 (0110.004.004), "Cask Lid and Liner Assembly", Sheet 2/3, Revision 3.

3.2.28 SNC Drawing VCC-24-002 (0110.004.005), "Cask Lid and Liner Assembly", Sheet 3/3, Revision 3.

3.2.29 SNC Drawing VCC-24-003 (0110.004.006), "Air Inlet Assembly", Sheet 1/1, Revision 2.

3.2.30 SNC Drawing VCC-24-004 (0110.004.007), "Air Outlet Assembly", Sheet 1/1, Revision 2.

3.2.31 SNC Drawing VCC-24-005 (0110.004.008), "VCC Bottom Plate Assembly", Sheet 1/2, Revision 1.

3.2.32 SNC Drawing VCC-24-005 (0110.004.009), "VCC Bottom Plate Assembly", Sheet 2/2, Revision 1.

3.2.33 SNC Drawing VCC-24-006 (0110.004.010), "VCC Reinforcement", Sheet 1/2, Revision 3.

3.2.34 SNC Drawing VCC-24-006 (0110.004.011), "VCC Reinforcement", Sheet 2/2, Revision 3.

3.2.35 SNC Drawing VCC-24-008 (0110.004.012), "Misc Steel Components", Sheet 1/1, Revision 3.

4.0 ASSUMPTIONS

4.1 Design Configuration

4.1.1 Density of Materials

Steel	$\rho_{st} := 0.281 \frac{lbf}{in^3}$	Reference 3.2.3
Concrete	$\rho_{c} := 150 \frac{lbf}{ft^3}$	Reference 3.2.3
Rx-277	$\rho_{Rx} := 0.06 \frac{lbf}{in^3}$	Reference 3.1.1
Lead	$\rho_{lead} := 0.41 \frac{lbf}{in^3}$	Reference 3.2.3
Water	$\rho_{w} := 62.4 \frac{lbf}{ft^3}$	

4.1.2 Weight and Height of the Fuel Assembly

This analysis is based on an assumed bounding fuel weight with control components installed in the fuel assembly during storage. The assumed mass of the fuel bounds the mass in References 3.1.1 and 3.1.2 with some additional margin added.

$M_{fuel} := 1600\ lbf$	Mass of Fuel per Fuel Assembly
$h_{fuel} := 151\ in$	Height of Fuel Pin
$N_{pins} := 14$	Number of Pins Along One Side of Fuel Array
$N_{fuel} := 24$	Number of Fuel Assemblies
$lg_{fuel} := 165\ in$	Length of Fuel
$OD_{fuel} := 0.422\ in$	Outside Diameter of Fuel Pin

4.1.3 MSB Geometry

$OD_{MSB} := 62.5\ \text{in}$	Outside Diameter of MSB-24 (Ref 3.2.6, Part 1)
$ID_{MSB} := 60.5\ \text{in}$	Inside Diameter of MSB-24 (Ref 3.2.7, Part 1)
$h_{MSB} := 180.9\ \text{in}$	Overall Height of MSB-24 (Ref 3.2.6)
$t_{Mbase} := 0.75\ \text{in}$	Thickness of Base of MSB-24 (Ref 3.2.7, Part 2)
$OD_{Mlid} := 60\ \text{in}$	Conservative (i.e. maximum) Outside Diameter of MSB-24 Structural Lid (Ref 3.2.6, Part 4)
$t_{Mlid} := 3\ \text{in}$	Thickness of MSB-24 Structural Lid (Ref 3.2.6, Part 4)
$N_{bar} := 12$	Number of Support Bars (Ref 3.2.9, Part 4)
$lg_{bar} := 28\ \text{in}$	Length of Support Bar (Ref 3.2.9, Part 4)
$w_{bar} := 1.45\ \text{in}$	Width of Support Bars (Ref 3.2.9, Part 4)
$h_{bar} := 2.0\ \text{in}$	Height of Support Bars (Ref 3.2.9, Part 4)
$N_{wall} := 3$	Number of Support Wall Courses (Ref 3.2.9)
$OD_{wall} := 59.2\ \text{in}$	Outside Diameter of Support Walls (Ref 3.2.10, Part 2)
$t_{wall} := 0.5\ \text{in}$	Thickness of Support Wall (Ref 3.2.9, Part 2)
$lg_{wall} := 28\ \text{in}$	Length of Support Wall (Ref 3.2.9 Part 2)
$lg_{sleeve} := 164.0\ \text{in}$	Length of Storage Sleeve (Ref 3.2.9, Part 1)
$w_{sleeve} := 9.2\ \text{in}$	Width of Storage Sleeve (Ref 3.2.9, Part 1)
$t_{sleeve} := 0.20\ \text{in}$	Thickness of Storage Sleeve (Ref 3.2.9, Part 1)
$OD_{shield} := 60.1\ \text{in}$	Outside Diameter of Shield Lid (Ref 3.2.8)
$t_{shieldtop} := 2.5\ \text{in}$	Thickness of Shield Top Plate (Ref 3.2.8, Part 1)
$t_{shieldbot} := 2.5\ \text{in}$	Thickness of Shield Bottom Plate (Ref 3.2.8, Part 2)
$t_{neutron} := 2\ \text{in}$	Thickness of Neutron Shield in Top (Ref 3.2.8, Part 4)
$t_{ring} := 0.5\ \text{in}$	Thickness of Side Ring (Ref 3.2.8, Part 3)
$OD_{support} := 60.25\ \text{in}$	Outside Diameter of Support Plate (Ref 3.2.8, Part 8)
$t_{support} := 2.5\ \text{in}$	Thickness of Support Plate (Ref 3.2.8, Part 8)
$d_{support} := 12.55\ \text{in}$	Distance from Top of MSB to Top of Shield Lid Support Ring (Ref 3.2.6)

4.1.4 MTC Geometry

$OD_{inner} := 65 \text{ in}$	OD of the MTC Inner Shell (Ref 3.2.19, Part 1)
$ID_{inner} := 63.5 \text{ in}$	ID of the MTC Inner Shell (Ref 3.2.19, Part 1)
$h_{MTC} := 178.7 \text{ in}$	Height of MTC Cask Shell (Ref 3.2.14)
$OD_{outer} := 83.5 \text{ in}$	OD of the MTC Outer Shell (Ref 3.2.16, Part 3)
$ID_{outer} := 81.5 \text{ in}$	ID of the MTC Outer Shell (Ref 3.2.16, Part 3)
$OD_{middle} := 73.5 \text{ in}$	OD of the MTC Middle Shell (Ref 3.2.18, Part 1)
$ID_{middle} := 73 \text{ in}$	ID of the MTC Middle Shell (Ref 3.2.18, Part 1)
$t_{Ttop} := 2 \text{ in}$	Thickness of the Top of the MTC (Ref 3.2.15, Part 4)
$t_{Tbot} := 1 \text{ in}$	Thickness of the Bottom of the MTC (Ref 3.2.15, Part 5)
$OD_{Tlid} := 74 \text{ in}$	OD of the MTC Lid (Ref 3.2.20, Part 1)
$ID_{Tlid} := 60.5 \text{ in}$	ID of the MTC Lid (Ref 3.2.20, Part 1)
$t_{Tlid} := 1 \text{ in}$	Thickness of MTC Lid (Ref 3.2.20, Part 1)
$N_{door} := 2$	Number of MTC Doors (Ref 3.2.23, Part 1)
$w_{door} := 42.7 \text{ in}$	Width of MTC Doors (Ref 3.2.23, Part 1)
$lg_{door} := 70 \text{ in}$	Length of the MTC Doors (Ref 3.2.23, Part 1)
$t_{door} := 9 \text{ in}$	Thickness of MTC Doors (Ref 3.2.23, Part 1)
$w_{door\_cut} := 17.7 \text{ in}$	Width of MTC Door Cutout (Ref 3.2.23, Part 1)
$lg_{door\_cut} := 15 \text{ in}$	Length of the MTC Door Cutout (Ref 3.2.23, Part 1)
$N_{trunion} := 2$	Number of Trunions (Ref 3.2.22)
$OD_{trunion} := 10.75 \text{ in}$	OD of Trunion Cylinder (Ref 3.2.22, Part 2)
$ID_{trunion} := 7.75 \text{ in}$	ID of Trunion Cylinder (Ref 3.2.22, Part 2)

$t_{trunion\_shield} := 4\ in$	Thickness of each of the Trunion Shielding (lead and Rx) (Ref 3.2.22, Parts 6 and 7)
$t_{trunion\_plates} := 2.0\ in$	Total Thickness of all three Trunion Plates (Ref 3.2.22, Parts 1, 3 and 8)
$lg_{trunion} := 15.6\ in$	Total Trunion Length (Ref 3.2.22)
$N_{rail} := 2$	Number of MTC Rails (Ref 3.2.21, Part 1)
$w_{rail} := 9.125\ in$	Width of MTC Rails (Ref 3.2.21, Part 1)
$lg_{rail} := 105\ in$	Length of the MTC Rails (Ref 3.2.21, Part 1)
$t_{rail} := 6.5\ in$	Thickness of MTC Rails (Ref 3.2.21, Part 1)
$w_{rail\_sup} := 9.25\ in$	Width of MTC Rail Supports (Ref 3.2.21, Part 2)
$t_{rail\_sup} := 1.5\ in$	Thickness of MTC Rail Support (Ref 3.2.21, Part 2)

4.1.5 VCC Geometry

$OD_{VCC} := 132\ in$	Outside Diameter of the VCC (Ref 3.2.24)
$h_{VCC} := 213.7\ in$	Height of the VCC (Ref 3.2.24)
$OD_{liner} := 74\ in$	Outside Diameter of VCC Steel Liner (Ref 3.2.26, Part 1)
$ID_{liner} := 70.5\ in$	Inside Diameter of the VCC Steel Liner (Ref 3.2.26, Part 1)
$t_{liner\_bot} := 2\ in$	Thickness of the VCC Steel Liner Bottom (Ref 3.2.26, Part 2)
$h_{liner} := 191.7\ in$	Overall Height of the VCC Steel Liner (Ref 3.2.26)
$OD_{liner\_flg} := 90\ in$	Outside Diameter of Liner Flange (Ref 3.2.26, Part 3)
$t_{liner\_flg} := 2\ in$	Thickness of the Liner Flange (Ref 3.2.26, Part 3)
$N_{skid} := 2$	Number of Skid Channels (Ref 3.2.31)
$w_{skid} := 12\ in$	Width of the Skid Channel (Ref 3.2.31)
$h_{skid} := 12.2\ in$	Height of the Skid Channel (Ref 3.2.31)
$lg_{skid} := 100.3\ in$	Average Length of Skid Channels (Ref 3.2.31)
$OD_{VCC\_bot} := 120\ in$	Outside Diameter of VCC Bottom Steel Plate (Ref 3.2.31, Part 1)
$t_{VCC\_bot} := 0.25\ in$	Thickness of VCC Bottom Steel Plate (Ref 3.2.31, Part 1)
$N_{air\_out} := 4$	Number of Air Outlets (Ref 3.2.30)
$w_{air\_out} := 47.8\ in$	Width of the Air Outlet Channels (Ref 3.2.30)
$lg_{air\_out} := 36.3\ in$	Length of Air Outlet Channels with 3 inches of overlap between high and low channels (Ref 3.2.30, Part 7)
$h_{air\_out} := 3\ in$	Height of Air Outlet Channels (Ref 3.2.30)
$t_{air\_out} := 0.5\ in$	Thickness of Air Outlet Channel Liners (Ref 3.2.30)
$e_{out} := 8\ in$	Approximate distance from top of VCC to midpoint of outlet assembly. Estimated as the dimension from the top of the VCC to the top of the outlet on the ID of the liner, per Ref 3.2.28 Detail A

$N_{air\_in} := 4$	Number of Air Inlet Assemblies (Ref 3.2.29)
$w_{in\_tube} := 12\ in$	Width of the Air Inlet Tubes (Ref 3.2.29, Part 4 and 5)
$lg_{in\_tube} := 40\ in$	Approximate Length of Air Inlet Tubes with based on the average length of Parts 4 and 6 (Ref 3.2.29)
$h_{in\_tube} := 12\ in$	Height of Air Inlet Tubes (Ref 3.2.29, Part 6)
$w_{in\_ch} := 4.5\ in$	Width of the Air Inlet Channels (Ref 3.2.29, Part 1 and 3)
$h_{in\_ch} := 5\ in$	Height of Air Inlet Channels (Ref 3.2.29, Part 1 and 3)
$angle_{in\_ch} := 71\ deg$	Angular Extent of Air Inlet Channel (Ref 3.2.29, Part 1)
$r_{in\_ch} := 35.25\ in$	Outer radius of Air Inlet Channels (Ref 3.2.29, Part 1)
$t_{air\_in} := 0.5\ in$	Thickness of Air Inlet Channel Liners (Ref 3.2.29)
$OD_{VCC\_lid} := 82\ in$	Outside Diameter of VCC Lid (Ref 3.2.26, Part 6)
$t_{VCC\_lid} := 0.75\ in$	Thickness of the VCC Lid (Ref 3.2.26, Part 6)
$OD_{shield\_ring} := 66\ in$	Outside Diameter of the VCC Shield Ring (Ref 3.2.35, Part 3)
$ID_{shield\_ring} := 60\ in$	Inside Diameter of the VCC Shield Ring (Ref 3.2.35, Part 1)
$h_{shield\_ring} := 6\ in$	Height of the VCC Shield Ring (Ref 3.2.35, Part 1)

4.2 Design Criteria

None.

4.3 Calculation Assumptions

None.

5.0 CALCULATION METHODOLOGY

The MSB, MTC, and VCC component weights and centers of gravity are determined using appropriate component dimensions and densities from section 4.1 above. The following weights and centers of gravity are calculated for each component, with the exception of the second bullet:

- Empty (no fuel) w/o any lids
- Loaded w/ fuel w/ shield lid w/o structural lid (calculated for MSB only)
- Loaded w/ fuel and all shield lids and structural lids
- Loaded w/fuel and water w/ shield lids and structural lids

The weight of the VCC is calculated based on the gross concrete weight and the weight of the liner. The internal concrete voids are subtracted from the gross weight. The rebars and the thin steel liners are accounted for by use of an appropriate density for the reinforced concrete.

6.0 CALCULATIONS

6.1 Weight of Multi-Assembly Storage Basket (MSB)

Weight of Individual Components in the MSB

$$M_{MSB\_shell} := \frac{\pi}{4}\left(OD_{MSB}^{2} - ID_{MSB}^{2}\right)\cdot h_{MSB}\cdot \rho_{st} \qquad M_{MSB\_shell} = 9821 \circ lbf$$

$$M_{MSB\_base} := \left(\frac{\pi}{4}\cdot ID_{MSB}^{2}\cdot t_{Mbase}\right)\cdot \rho_{st} \qquad M_{MSB\_base} = 606 \circ lbf$$

$$M_{MSB\_lid} := \frac{\pi}{4}\cdot OD_{Mlid}^{2}\cdot t_{Mlid}\cdot \rho_{st}$$

$$M_{MSB\_lid} = 2384 \circ lbf$$

$$M_{per\_sleeve} := \left(w_{sleeve}\cdot 4\cdot lg_{sleeve}\cdot t_{sleeve}\right)\cdot \rho_{st} \qquad M_{per\_sleeve} = 339 \circ lbf$$

$$M_{sleeve} := \left(N_{fuel}\cdot w_{sleeve}\cdot 4\cdot lg_{sleeve}\cdot t_{sleeve}\right)\cdot \rho_{st} \qquad M_{sleeve} = 8140 \circ lbf$$

$$M_{bar} := \left(N_{bar}\cdot lg_{bar}\cdot w_{bar}\cdot h_{bar}\right)\cdot \rho_{st} \qquad M_{bar} = 274 \circ lbf$$

$M_{wall} := \left(N_{wall} \cdot \pi \cdot OD_{wall} \cdot t_{wall} \cdot lg_{wall}\right) \cdot \rho_{st} \qquad M_{wall} = 2195 \cdot lbf$

$M_{sleeve\_assy} := M_{bar} + M_{wall} + M_{sleeve} \qquad M_{sleeve\_assy} = 1.061 \cdot 10^4 \cdot lbf$

$$M_{shield} := \left[\frac{\pi}{4} \cdot OD_{shield}^2 \cdot \left(t_{shieldtop} + t_{shieldbot}\right)\right] \cdot \rho_{st} \cdots + \left[\frac{\pi}{4} \cdot \left(OD_{shield} - 2 \cdot t_{ring}\right)^2 \cdot t_{neutron}\right] \cdot \rho_{Rx} \cdots + \left(\pi \cdot OD_{shield} \cdot t_{ring} \cdot t_{neutron} + \frac{\pi}{4} \cdot OD_{support}^2 \cdot t_{support}\right) \cdot \rho_{st}$$

$M_{shield} = 6371 \cdot lbf$

$M_{support} := \frac{\pi}{4} \cdot OD_{support}^2 \cdot t_{support} \cdot \rho_{st} \qquad M_{support} = 2003 \cdot lbf$

$M_{shield\_wo\_support} := M_{shield} - M_{support}$

$M_{shield\_wo\_support} = 4368 \cdot lbf$

Weight of MSB Empty without any lids

$P_{MSB\_empty} := M_{MSB\_shell} + M_{MSB\_base} + M_{sleeve} + M_{bar} + M_{wall}$

$P_{MSB\_empty} = 21036 \cdot lbf$

Weight of a Fully Loaded MSB with the Shield Lid, but not the Structural Lid

$P_{MSB\_nolid} := P_{MSB\_empty} + M_{shield} + N_{fuel} \cdot M_{fuel}$

$P_{MSB\_nolid} = 65807 \cdot lbf$

Weight of a Fully Loaded and Closed MSB

$P_{MSB} := P_{MSB\_nolid} + M_{MSB\_lid}$

$P_{MSB} = 68191 \cdot lbf$

6.2 Weight of MSB Transfer Cask (MTC)

Weight of Individual Components of the MTC

$$M_{inner} := \frac{\pi}{4}\cdot\left(OD_{inner}^2 - ID_{inner}^2\right)\cdot h_{MTC}\cdot\rho_{st} \qquad M_{inner} = 7602\cdot lbf$$

$$M_{lead} := \frac{\pi}{4}\cdot\left(ID_{middle}^2 - OD_{inner}^2\right)\cdot h_{MTC}\cdot\rho_{lead} \qquad M_{lead} = 63528\cdot lbf$$

$$M_{middle} := \frac{\pi}{4}\cdot\left(OD_{middle}^2 - ID_{middle}^2\right)\cdot h_{MTC}\cdot\rho_{st} \qquad M_{middle} = 2889\cdot lbf$$

$$M_{Rx} := \frac{\pi}{4}\cdot\left(ID_{outer}^2 - OD_{middle}^2\right)\cdot h_{MTC}\cdot\rho_{Rx} \qquad M_{Rx} = 10442\cdot lbf$$

$$M_{outer} := \frac{\pi}{4}\cdot\left(OD_{outer}^2 - ID_{outer}^2\right)\cdot h_{MTC}\cdot\rho_{st} \qquad M_{outer} = 13015\cdot lbf$$

$$M_{Ttop} := \frac{\pi}{4}\cdot\left(OD_{outer}^2 - ID_{inner}^2\right)\cdot t_{Ttop}\cdot\rho_{st} \qquad M_{Ttop} = 1298\cdot lbf$$

$$M_{Tbot} := \frac{\pi}{4}\cdot\left(OD_{outer}^2 - ID_{inner}^2\right)\cdot t_{Tbot}\cdot\rho_{st} \qquad M_{Tbot} = 649\cdot lbf$$

$$M_{Ttopbot} := M_{Ttop} + M_{Tbot} \qquad M_{Ttopbot} = 1947\cdot lbf$$

$$\rho_{shell} := \frac{M_{inner} + M_{lead} + M_{middle} + M_{Rx} + M_{outer}}{\left[\frac{\pi}{4}\cdot\left(OD_{outer}^2 - ID_{inner}^2\right)\right]h_{MTC}} \qquad \rho_{shell} = 0.236\cdot\frac{lbf}{in^3}$$

$$M_{trunion} := N_{trunion}\cdot\left[\left[\frac{\pi}{4}\cdot\left(OD_{trunion}^2 - ID_{trunion}^2\right)\cdot lg_{trunion} \cdots \atop + \frac{\pi}{4}\cdot ID_{trunion}^2\cdot t_{trunion\_plates}\right]\cdot\rho_{st} \cdots \atop + \left(\frac{\pi}{4}\,ID_{trunion}^2\right)\cdot t_{trunion\_shield}\cdot\rho_{lead} \cdots \atop + \left(\frac{\pi}{4}\,ID_{trunion}^2\right)\cdot t_{trunion\_shield}\cdot\rho_{Rx} \cdots \atop + \left(\frac{-\pi}{4}\,OD_{trunion}^2\right)\cdot\frac{\left(OD_{outer} - ID_{inner}\right)}{2}\cdot\rho_{shell}\right]$$

$$M_{trunion} = 184\cdot lbf$$

$$M_{MTC\_shell} := M_{inner} + M_{lead} + M_{middle} + M_{Rx} + M_{outer} \cdots + M_{Ttopbot} + M_{trunion}$$

$$M_{MTC\_shell} = 99606 \cdot lbf$$

$$M_{MTC\_lid} := \left[\frac{\pi}{4}\left(OD_{Tlid}^2 - ID_{Tlid}^2\right)\cdot t_{Tlid}\right]\cdot \rho_{st}$$

$$M_{MTC\_lid} = 401 \cdot lbf$$

$$M_{door} := N_{door}\cdot\left(w_{door}\cdot lg_{door} - w_{door\_cut}\cdot lg_{door\_cut}\right)\cdot t_{door}\cdot \rho_{st}$$

$$M_{door} = 13775 \cdot lbf$$

$M_{rail} := N_{rail}\cdot w_{rail}\cdot lg_{rail}\cdot t_{rail}\cdot \rho_{st}$ $M_{rail} = 3500 \cdot lbf$

$M_{rail\_sup} := N_{rail}\cdot w_{rail\_sup}\cdot lg_{rail}\cdot t_{rail\_sup}\cdot \rho_{st}$ $M_{rail\_sup} = 819 \cdot lbf$

Weight of Empty MTC without any lids

$$P_{MTC\_empty} := M_{MTC\_shell} + M_{door} + M_{rail} + M_{rail\_sup}$$

$$P_{MTC\_empty} = 117700 \cdot lbf$$

Weight of MTC loaded with an Empty MSB (Dry with no lids)

$$P_{MTC\_nolid} := P_{MTC\_empty} + P_{MSB\_empty}$$

$$P_{MTC\_nolid} = 138737 \cdot lbf$$

Weight of MTC with a Fully Loaded MSB (Dry with all lids)

$$P_{MTC} := P_{MTC\_empty} + P_{MSB} + M_{MTC\_lid}$$

$$P_{MTC} = 186292 \cdot lbf$$

6.3 Weight of the Ventilated Concrete Cask (VCC)

Weight of the Individual Components

$$M_{conc\_shell} := \frac{\pi}{4}\cdot\left(OD_{VCC}^2 - OD_{liner}^2\right)\cdot h_{VCC}\cdot\rho_c$$

$$M_{conc\_shell} = 174075 \circ lbf$$

$$M_{conc\_bot} := \frac{\pi}{4}\cdot OD_{liner}^2\cdot\left(h_{VCC} - h_{liner}\right)\cdot\rho_c$$

$$M_{conc\_bot} = 8213 \circ lbf$$

$$M_{liner\_shell} := \begin{bmatrix} \frac{\pi}{4}\cdot\left(OD_{liner}^2 - ID_{liner}^2\right)\cdot h_{liner} \cdots \\ + \frac{\pi}{4}\cdot\left(OD_{liner\_flg}^2 - OD_{liner}^2\right)\cdot t_{liner\_flg} \end{bmatrix}\cdot\rho_{st}$$

$$M_{liner\_shell} = 22555 \circ lbf$$

$$M_{liner\_bot} := \left(\frac{\pi}{4}\cdot ID_{liner}^2\cdot t_{liner\_bot}\right)\cdot\rho_{st}$$

$$M_{liner\_bot} = 2194 \circ lbf$$

$$M_{skid} := N_{skid}\cdot\left(-w_{skid}\cdot h_{skid}\cdot lg_{skid}\cdot\rho_c + 2\cdot h_{skid}\cdot lg_{skid}\cdot t_{VCC\_bot}\cdot\rho_{st}\right)$$

$$M_{liner\_shell} = 22555 \circ lbf$$

$$M_{skid} = -2205 \circ lbf$$

$$M_{VCC\_bot} := \frac{\pi}{4}\cdot OD_{VCC\_bot}^2\cdot t_{VCC\_bot}\cdot\rho_{st} \qquad M_{VCC\_bot} = 795 \circ lbf$$

$$M_{air\_out} := N_{air\_out} \cdot \left[\begin{array}{l} -w_{air\_out} \cdot lg_{air\_out} \cdot h_{air\_out} \cdot \rho_c \cdots \\ + \left(2 \cdot w_{air\_out} + 2 \cdot h_{air\_out}\right) \cdot lg_{air\_out} \cdot t_{air\_out} \cdot \rho_{st} \end{array} \right]$$

$$M_{air\_out} = 265 \cdot lbf$$

$$M_{in\_tube} := N_{air\_in} \cdot \left[\begin{array}{l} -w_{in\_tube} \cdot lg_{in\_tube} \cdot h_{in\_tube} \cdot \rho_c \cdots \\ + \left(2 \cdot w_{in\_tube} + 2 \cdot h_{in\_tube}\right) \cdot lg_{in\_tube} \cdot t_{air\_in} \cdot \rho_{st} \end{array} \right]$$

$$M_{in\_tube} = -921 \cdot lbf$$

$$M_{in\_ch} := N_{air\_in} \cdot \left[\begin{array}{l} -\pi \cdot 2 \cdot r_{in\_ch} \cdot \frac{angle_{in\_ch}}{360\ deg} \cdot w_{in\_ch} \cdot h_{in\_ch} \cdot \rho_c \cdots \\ + \pi \cdot 2 \cdot r_{in\_ch} \cdot \frac{angle_{in\_ch}}{360\ deg} \cdot h_{in\_ch} \cdot 2 \cdot t_{air\_in} \cdot \rho_{st} \end{array} \right]$$

$$M_{in\_ch} = -96 \cdot lbf$$

$$M_{VCC\_lid} := \frac{\pi}{4} \cdot OD_{VCC\_lid}^{2} \cdot t_{VCC\_lid} \cdot \rho_{st}$$

$$M_{VCC\_lid} = 1113 \cdot lbf$$

$$M_{shield\_ring} := \frac{\pi}{4} \cdot \left(OD_{shield\_ring}^{2} - ID_{shield\_ring}^{2}\right) \cdot h_{shield\_ring} \cdot \rho_{st}$$

$$M_{shield\_ring} = 1001 \cdot lbf$$

Weight of empty VCC without the shield ring or lid

$$P_{VCC\_empty} := M_{conc\_shell} + M_{conc\_bot} + M_{liner\_shell} + M_{liner\_bot} + M_{skid} + M_{VCC\_bot} + M_{air\_out} + M_{in\_tube} + M_{in\_ch}$$

$$P_{VCC\_empty} = 204875 \cdot lbf$$

The total weight of the empty VCC and an empty MSB without any lids on either component

$$P_{VCC\_MSB\_empty} := P_{VCC\_empty} + P_{MSB\_empty}$$

$$P_{VCC\_MSB\_empty} = 225912 \cdot lbf$$

The total weight of a VCC with a fully loaded MSB with all lids and shield rings installed

$$P_{VCC} := P_{VCC\_empty} + P_{MSB} + M_{shield\_ring} + M_{VCC\_lid}$$

$$P_{VCC} = 275180 \cdot lbf$$

6.4 Free Volumes

Volume in between the MTC and the MSB

$$V_{gap} := \frac{\pi}{4}\cdot\left(ID_{inner}^2 - OD_{MSB}^2\right)\cdot h_{MSB} \cdots$$
$$+\frac{\pi}{4}\cdot ID_{inner}^2\cdot\left(h_{MTC} + t_{Ttop} + t_{Tbot} - h_{MSB}\right)$$

$V_{gap} = 20435 \cdot in^3$

Volume inside of the MSB (without fuel or baskets)

$$V_{MSB\_empty} := \frac{\pi}{4}\, ID_{MSB}^2\cdot h_{MSB}$$

$V_{MSB\_empty} = 520043 \cdot in^3$

Volume of the Basket and Base

$$V_{basket} := \frac{M_{MSB\_base} + M_{sleeve} + M_{bar} + M_{wall}}{\rho_{st}}$$

$V_{basket} = 39911 \cdot in^3$

Volume of the Shield Lid and Structural Support

$$V_{shield} := \frac{\pi}{4}\cdot OD_{shield}^2\cdot\left(t_{shieldtop} + t_{shieldbot}\right) \cdots$$
$$+\frac{\pi}{4}\cdot\left(OD_{shield} - 2\cdot t_{ring}\right)^2\cdot t_{neutron} \cdots$$
$$+\pi\cdot OD_{shield}\cdot t_{ring}\cdot t_{neutron} \cdots$$
$$+\frac{\pi}{4}\cdot OD_{support}^2\cdot t_{support}$$

$V_{shield} = 26987 \cdot in^3$

Volume of the Fuel Bundle

$$V_{fuel} := \frac{\pi}{4}\cdot OD_{fuel}^2\cdot lg_{fuel}\cdot N_{pins}^2\cdot N_{fuel}$$

$V_{fuel} = 108559 \cdot in^3$

Total Free Volume in the MTC with fully loaded MSB (without Structural Lid)

$$V_{free} := V_{gap} + V_{MSB\_empty} - V_{basket} - V_{shield} - V_{fuel}$$

$V_{free} = 365021 \cdot in^3$

6.5 Weights with Water

Weight of the water in a loaded MSB/MTC Assembly

$$P_{water} := V_{free} \cdot \rho_{w}$$

$$P_{water} = 13181 \cdot lbf$$

Weight of fully loaded and wet MSB (with shields but without Structural Lid)

The weight of the water in the gap between the MTC and the MSB is conservatively included

$$P_{MSB\_wet} := P_{MSB\_nolid} + P_{water} \qquad P_{MSB\_wet} = 78988 \cdot lbf$$

Weight of MTC (without MTC lid) and a fully loaded and wet MSB (with shields but without Structural Lid)

$$P_{MTC\_wet} := P_{MSB\_nolid} + P_{MTC\_empty} + P_{water}$$

$$P_{MTC\_wet} = 196689 \cdot lbf$$

6.6 Centers of Gravity

Note: Centers of Gravity are relative to the bottom of the item or assembly evaluated

Center of Gravity of the MSB empty with no lids installed

$$cg_{MSB\_empty} := \frac{\begin{aligned} &M_{MSB\_shell}\cdot\frac{h_{MSB}}{2} + M_{MSB\_base}\cdot\frac{t_{Mbase}}{2} \cdots \\ &+ \left(M_{sleeve} + M_{bar} + M_{wall}\right)\cdot\left(\frac{lg_{sleeve}}{2} + t_{Mbase}\right)\end{aligned}}{P_{MSB\_empty}}$$

$$cg_{MSB\_empty} = 84\cdot in$$

Center of Gravity of MSB fully loaded with all lids installed

$$cg_{MSB} := \frac{\begin{aligned} &P_{MSB\_empty}\cdot cg_{MSB\_empty} + N_{fuel}\cdot M_{fuel}\cdot\left(\frac{lg_{fuel}}{2} + t_{Mbase}\right) \cdots \\ &+ M_{MSB\_lid}\cdot\left(h_{MSB} - \frac{t_{Mlid}}{2}\right) \cdots \\ &+ M_{shield}\cdot\left(\begin{aligned} &h_{MSB} - d_{support} + t_{support} \cdots \\ &+ \frac{t_{shieldtop} + t_{shieldbot} + t_{neutron}}{2}\end{aligned}\right) \cdots \\ &+ M_{support}\cdot\left[\left(h_{MSB}\right) - d_{support} + \frac{t_{support}}{2}\right]\end{aligned}}{P_{MSB}}$$

$$cg_{MSB} = 100.3\cdot in$$

Center of Gravity of an MSB fully loaded and wet with shield lid, but no structural lid

$$cg_{MSB\_wet} := \frac{cg_{MSB} \cdot P_{MSB} - M_{MSB\_lid} \cdot \left(h_{MSB} - \frac{t_{Mlid}}{2}\right) \ldots \\ + P_{water} \cdot \left[\frac{\left(h_{MSB} - t_{Mlid} - t_{Mbase}\right)}{2} + t_{Mbase}\right]}{P_{MSB\_wet}}$$

$cg_{MSB\_wet} = 96.1 \cdot in$

Center of Gravity of MTC empty with no cover

$$cg_{MTC\_empty} := \frac{M_{MTC\_shell} \cdot \left(\frac{h_{MTC} + t_{Ttop} + t_{Tbot}}{2} + t_{Tbot} + w_{rail} + t_{rail\_sup}\right) \\ + M_{door} \cdot \left(t_{rail\_sup} + \frac{t_{door}}{2}\right) \ldots \\ + M_{rail} \cdot \frac{\left[w_{rail} \cdot t_{rail} \cdot \left(t_{rail\_sup} + \frac{w_{rail}}{2}\right) \ldots \\ + w_{rail\_sup} \cdot t_{rail\_sup} \cdot \frac{t_{rail\_sup}}{2}\right]}{w_{rail} \cdot t_{rail} + w_{rail\_sup} \cdot t_{rail\_sup}}}{P_{MTC\_empty}}$$

$cg_{MTC\_empty} = 87.6 \cdot in$

Center of Gravity of MTC with a fully loaded dry MSB with all lids installed

$$cg_{MTC} := \frac{P_{MTC\_empty} \cdot cg_{MTC\_empty} + P_{MSB} \cdot \left(cg_{MSB} + w_{rail} + t_{rail\_sup}\right) \\ + M_{MTC\_lid} \cdot \left(h_{MTC} + t_{Ttop} + t_{Tbot} + w_{rail} + t_{rail\_sup} + \frac{t_{Tlid}}{2}\right)}{P_{MTC}}$$

$cg_{MTC} = 96.4 \cdot in$

Center of Gravity of an MTC with a full loaded and wet MSB with shield lid, but no structural lids

$$cg_{MTC\_wet} := \frac{P_{MTC\_empty} \cdot cg_{MTC\_empty} \cdots + P_{MSB\_wet} \cdot \left(cg_{MSB\_wet} + w_{rail} + t_{rail\_sup}\right)}{P_{MTC\_wet}}$$

$$cg_{MTC\_wet} = 95.3 \cdot in$$

Center of Gravity with VCC empty, without shield ring or lid

$$cg_{VCC\_empty} := \frac{M_{conc\_shell} \cdot \frac{h_{VCC}}{2} + M_{skid} \cdot \frac{h_{skid}}{2} + M_{air\_out} \cdot \left(h_{VCC} - e_{out}\right) \cdots + \left(M_{conc\_bot} + M_{in\_tube} + M_{in\_ch}\right) \cdot \left(\frac{h_{VCC} - h_{liner}}{2}\right) \cdots + M_{liner\_shell} \cdot \left(h_{VCC} - \frac{h_{liner}}{2}\right) + M_{liner\_bot} \cdot \left(h_{VCC} - h_{liner} \cdots + \frac{t_{liner\_bot}}{2}\right) + M_{VCC\_bot} \cdot \frac{t_{VCC\_bot}}{2}}{P_{VCC\_empty}}$$

$$cg_{VCC\_empty} = 104.6 \cdot in$$

Center of Gravity with VCC with an empty MSB, with no cover shields or lids

$$cg_{VCC\_MSB\_empty} := \frac{P_{VCC\_empty} \cdot cg_{VCC\_empty} \cdots + P_{MSB\_empty} \cdot \left(cg_{MSB\_empty} + h_{VCC} - h_{liner} + t_{liner\_bot}\right)}{P_{VCC\_empty} + P_{MSB\_empty}}$$

$$cg_{VCC\_MSB\_empty} = 104.9 \cdot in$$

Center of Gravity with VCC with a fully loaded MSB (dry) with all covers and lids

$$cg_{VCC} := \frac{\begin{array}{l} cg_{VCC\_empty} \cdot P_{VCC\_empty} \cdots \\ + P_{MSB} \cdot \left(cg_{MSB} + h_{VCC} - h_{liner} + t_{liner\_bot}\right) \cdots \\ + M_{VCC\_lid} \cdot \left(h_{VCC} + \frac{t_{VCC\_lid}}{2}\right) \cdots \\ + M_{shield\_ring} \cdot \left(h_{VCC} - e_{out} + \frac{h_{shield\_ring}}{2}\right) \end{array}}{P_{VCC\_empty} + P_{MSB} + M_{VCC\_lid} + M_{shield\_ring}}$$

$$cg_{VCC} = 110.3 \cdot in$$

7.0 CONCLUSIONS

A summary of the masses and centers of gravity is provided below.

CONDITION	COMPONENT	WEIGHT	CG
Empty (no fuel) w/o any lids	MSB	$P_{\text{MSB\_empty}} = 21036 \cdot \text{lbf}$	$cg_{\text{MSB\_empty}} = 84 \cdot \text{in}$
	MTC	$P_{\text{MTC\_empty}} = 117700 \cdot \text{lbf}$	$cg_{\text{MTC\_empty}} = 87.6 \cdot \text{in}$
	VCC	$P_{\text{VCC\_empty}} = 204875 \cdot \text{lbf}$	$cg_{\text{VCC\_empty}} = 104.6 \cdot \text{in}$
	MTC/MSB	$P_{\text{MTC\_nolid}} = 138737 \cdot \text{lbf}$	
	MSB/VCC	$P_{\text{VCC\_MSB\_empty}} = 225912 \cdot \text{lbf}$	$cg_{\text{VCC\_MSB\_empty}} = 104.9 \cdot \text{i}$
Loaded w/ fuel w/ shields lids w/o structural lids	MSB	$P_{\text{MSB\_nolid}} = 65807 \cdot \text{lbf}$	
Loaded w/ fuel and all shields lids and structural lids	MSB	$P_{\text{MSB}} = 68191 \cdot \text{lbf}$	$cg_{\text{MSB}} = 100.3 \cdot \text{in}$
	MTC/MSB	$P_{\text{MTC}} = 186292 \cdot \text{lbf}$	$cg_{\text{MTC}} = 96.4 \cdot \text{in}$
	VCC/MSB	$P_{\text{VCC}} = 275180 \cdot \text{lbf}$	$cg_{\text{VCC}} = 110.3 \cdot \text{in}$
Loaded w/ fuel and water w/ shields lids w/o structural lids	MSB	$P_{\text{MSB\_wet}} = 78988 \cdot \text{lbf}$	$cg_{\text{MSB\_wet}} = 96.1 \cdot \text{in}$
	MTC/MSB	$P_{\text{MTC\_wet}} = 196689 \cdot \text{lbf}$	$cg_{\text{MTC\_wet}} = 95.3 \cdot \text{in}$

A summary of selected results that are used by referencing calculations is provided below, for convenience.

Weight of the Shield Lid Sandwich Assembly without the Support Plate	$M_{shield} - M_{support} = 4368 \cdot lbf$
Weight of the MSB Shield Lid Support Plate	$M_{support} = 2003 \cdot lbf$
Weight of Shield lid and Support Plate	$M_{shield} = 6371 \cdot lbf$
Weight of the MSB Structural Lid	$M_{MSB\_lid} = 2384 \cdot lbf$
Weight of a single fuel bundle	$M_{fuel} = 1600 \cdot lbf$
Weight of a single fuel sleeve	$M_{per\_sleeve} = 339 \cdot lbf$
Weight of the fuel basket (i.e. all of the sleeves)	$M_{sleeve} = 8140 \cdot lbf$
Weight of the complete sleeve assembly	$M_{sleeve} + M_{bar} + M_{wall} = 10609 \cdot lbf$
Weight of the MTC rails support plates	$M_{rail\_sup} = 819 \cdot lbf$
Weight of the MTC doors	$M_{door} = 13775 \cdot lbf$
Weight of the MTC rails	$M_{rail} = 3500 \cdot lbf$
Weight of the MTC Top Ring	$M_{Ttop} = 1298 \cdot lbf$
Weight of the MTC Cover Plate	$M_{MTC\_lid} = 401 \cdot lbf$
Weight of the VCC Cover Plate	$M_{VCC\_lid} = 1113 \cdot lbf$
Weight of the MSB Shield Lid without support	$M_{shield\_wo\_support} = 4368 \cdot lbf$