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71-9282

February 29, 2000

Mr. Cass R. Chappell, Chief
Licensing Section, Mail Stop 06F18
Spent Fuel Project Office
Office of Nuclear Materials Safety and Safeguards
U.S. Nuclear Regulatory Commission
One White Flint North
11155 Rockville Pike
Rockville, MD 20852

Subject: Docket No.: 71-9282
Application for Model SPEC-300 Package
Response to NRC Request for Additional Information, Supplement No. 4, dated February 29, 2000

Dear Mr. Chappell:

This submittal is in response to the Request for Additional Information (RAI) dated February 1, 2000 and is identified as Supplement No. 4, dated February 29, 2000. As instructed by Mr. Michael D. Waters on February 10, 2000, three color copies of the supplement are being sent. A total of 31 new figures have been added to the application. Changes in the application text, including new verbiage, are indicated by vertical lines in the right margin. To facilitate the review, the RAI items are addressed as follows:

RAI Item No. 2-1 is addressed in pages 15 through 15.10 and pages 35 through 35.5.
RAI Item No. 2-2 is addressed in pages 17 through 17.3.
RAI Items No. 3-1 and 3-2 are addressed in pages 39 through 39.1.

Please do not hesitate to contact me if you need any further assistance or clarification.

Sincerely,

Kenneth N. Carrington

Kenneth N. Carrington
Regulatory Affairs

/knc

Enclosures: Three copies of Supplement No. 4 dated February 29, 2000 to Application for Model SPEC-300 Package, Revision (1) dated October 6, 1999
Docket No.: 71-9282

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NMSS01 Public

# SUPPLEMENT NO. 4
to
Type B(U)-85 Transportation Package
Certificate of Compliance Application, Revision (1),
dated October 6, 1999
Model SPEC-300

February 29, 2000

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$$Pcr = \frac{\pi^2 EI}{L^2}$$

where:

Pcr = the critical load, that load where the plate will buckle

E = Modulus of Elasticity = 30 x $10^6\,psi$

I = Moment of Inertia = $\frac{1}{12}a^3b$ (a = .25", b = 15.5")

L = height of the plate = 10.396"

$$\Pr = \frac{\pi^2(30000000)(.021)}{(10.396)^2} = 57531.77\,lbs(256kN)$$

With the load being applied at 1000 lbs, the device meets the corresponding CFR.

### 2.5.2 External Pressure

An external pressure test was not performed on the SPEC-300 containment vessel. The SPEC-300 containment vessel is the special form capsule. This capsule consists of a cylindrical welded 300 series 316/316L stainless steel capsule with a minimum wall thickness of 0.8 mm (0.030 in). The capsule must resist a 172 kPa (25 lb/in$^2$) external pressure. For this exercise, the capsule is considered to be a thick walled vessel under uniform external loading.

Maximum circumferential stress is calculated as:

$$MaxCircumferentialStress = \frac{-Pressure*2*OutsideDiameter^2}{OutsideDiameter^2 - InsideDiameter^2}$$

$$MaxCircumferentialStress = \frac{-172000Pa*2*.010^2M^2}{0.010^2M^2 - 0.008^2M^2}$$

$$MaximumCircumferentialStress = -956KPa(-138lb/inch^2)$$

Maximum radial stress is calculated as:

$$MaxRadialStress = -pressure$$

$$MaximumRadialStress = -172KPa(-25lb/inch^2)$$

These stress levels are negligible.

Equations taken from <u>Roark's Formulas for Stress and Strain</u>, 6th edition, page 638, table 32.

## 2.6 Normal Conditions of Transport

The SPEC-300, when subjected to the normal conditions of transport specified in 10 CFR part 71, meets the standards specified in paragraph 71.35 of 10 CFR part 71, as demonstrated in the following paragraphs.

10 CFR 71.71(c)(1) requires consideration of heat input due to insolation and maximum ambient temperature. This regulation ensures that the stresses in the material that are caused by temperature changes will not allow the package to fail any of the Normal Conditions tests.

To determine the stress caused by insolation, the temperature effects of insolation must first be considered. These calculations were performed by a finite element analysis program. To determine the temperature changes in the package, the time required to reach steady state conditions must be determined. Steady state temperature conditions for the package and the internal structure are shown on figures 1 and 2 for insolation at 38° C (100° F) and figures 3 and 4 for insolation at -29° C (-20° F). The maximum temperature results for each condition are as follows:
Maximum Temperature on Package for a 38° C (100° F) ambient (figure 1) = 59° C (138°F)
Maximum Temperature on Structural Internals for a 38° C (100° F) ambient (figure 2) = 55° C (131° F)
Maximum Temperature on Package for a -29°C (-20°F) ambient (figure 3) = -8.29°C (47°F)
Maximum Temperature on Structural Internals for a -29° C (-20° F) Ambient (figure 4) = -12° C (10° F)

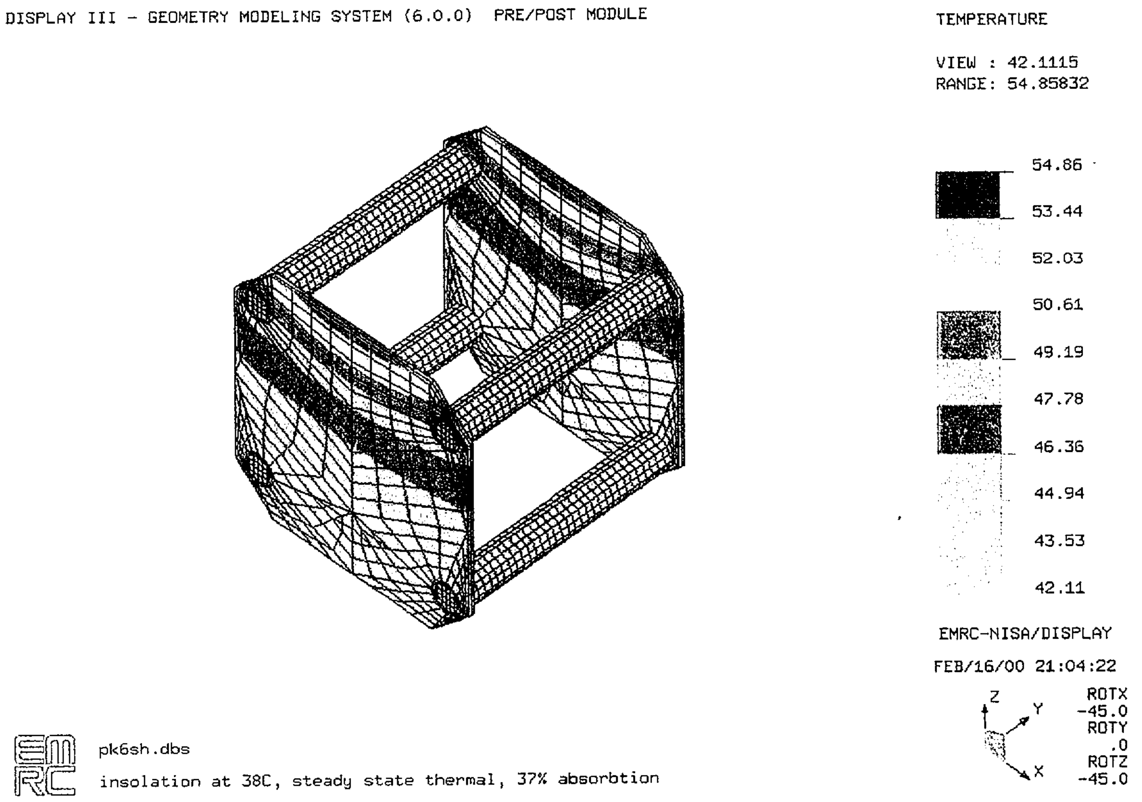


**Figure 1**

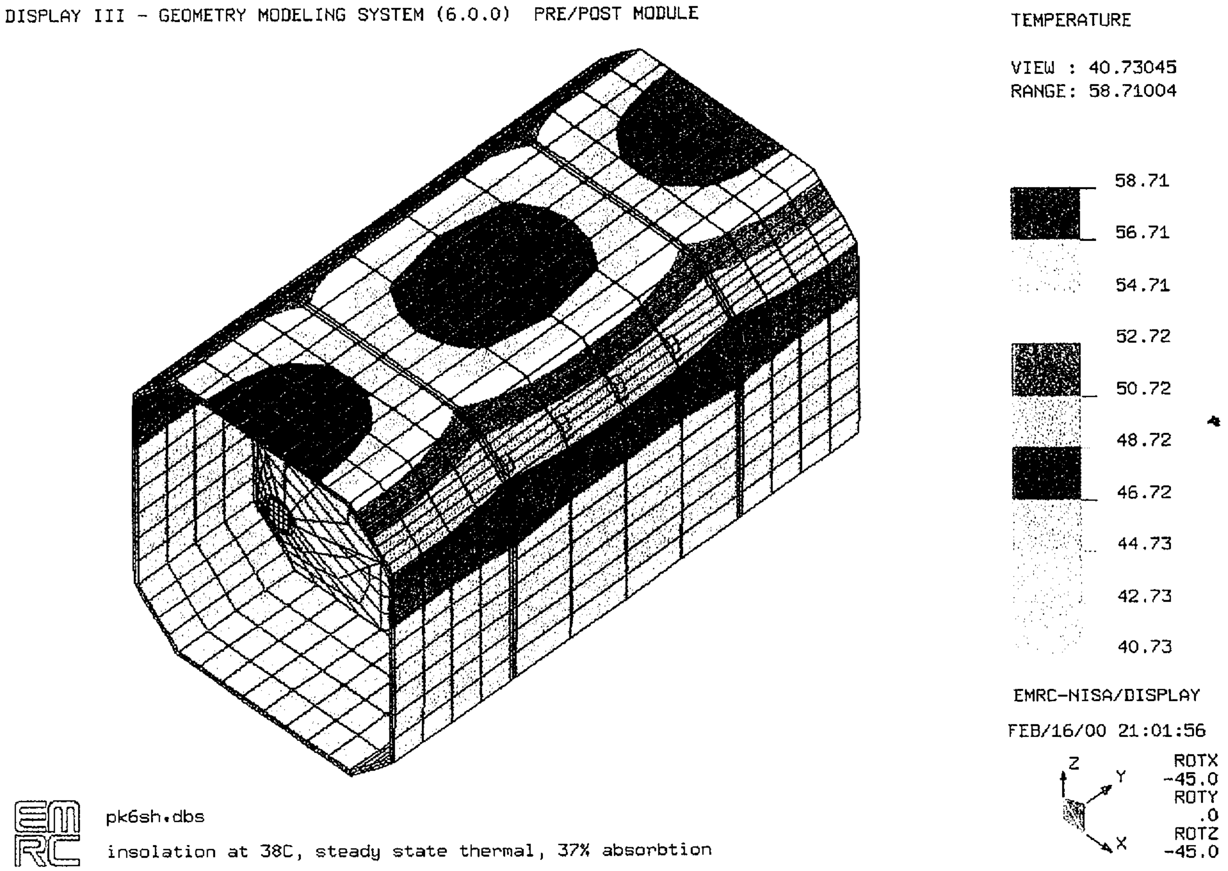


Figure 2

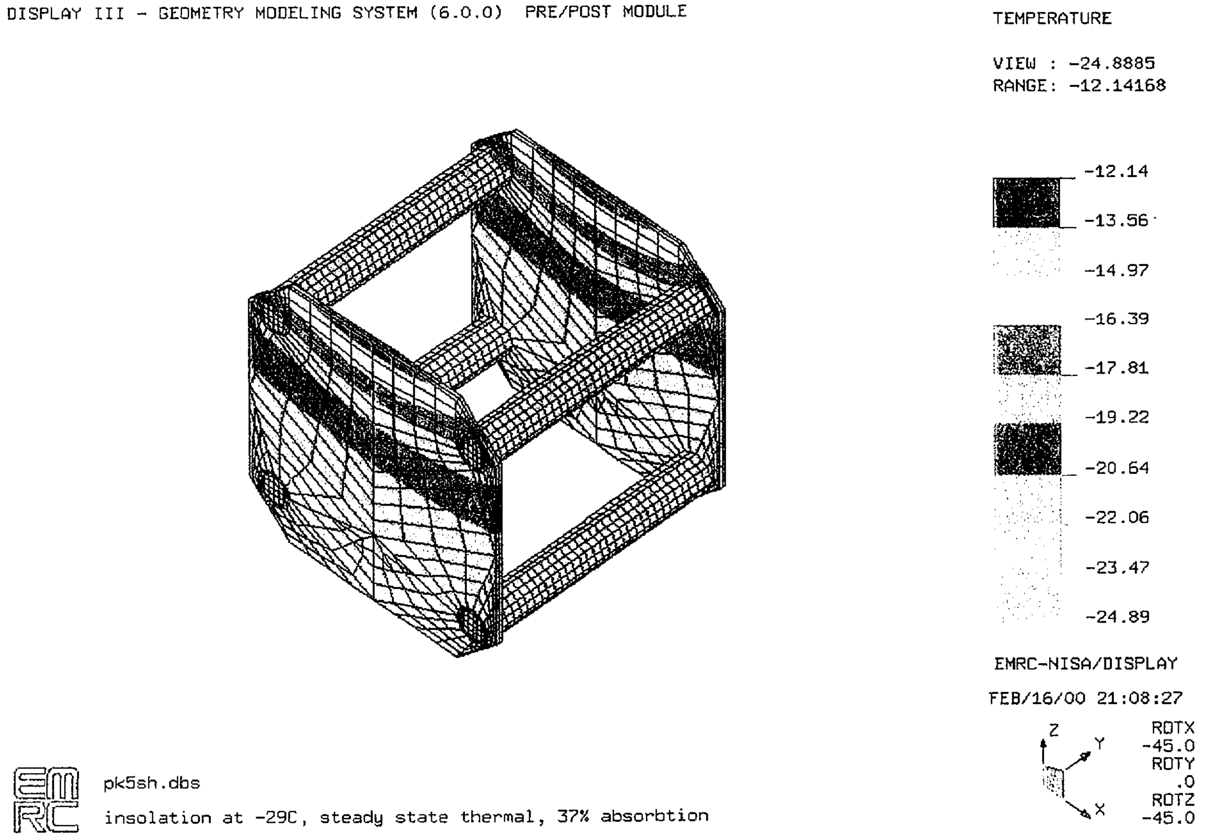


Figure 3

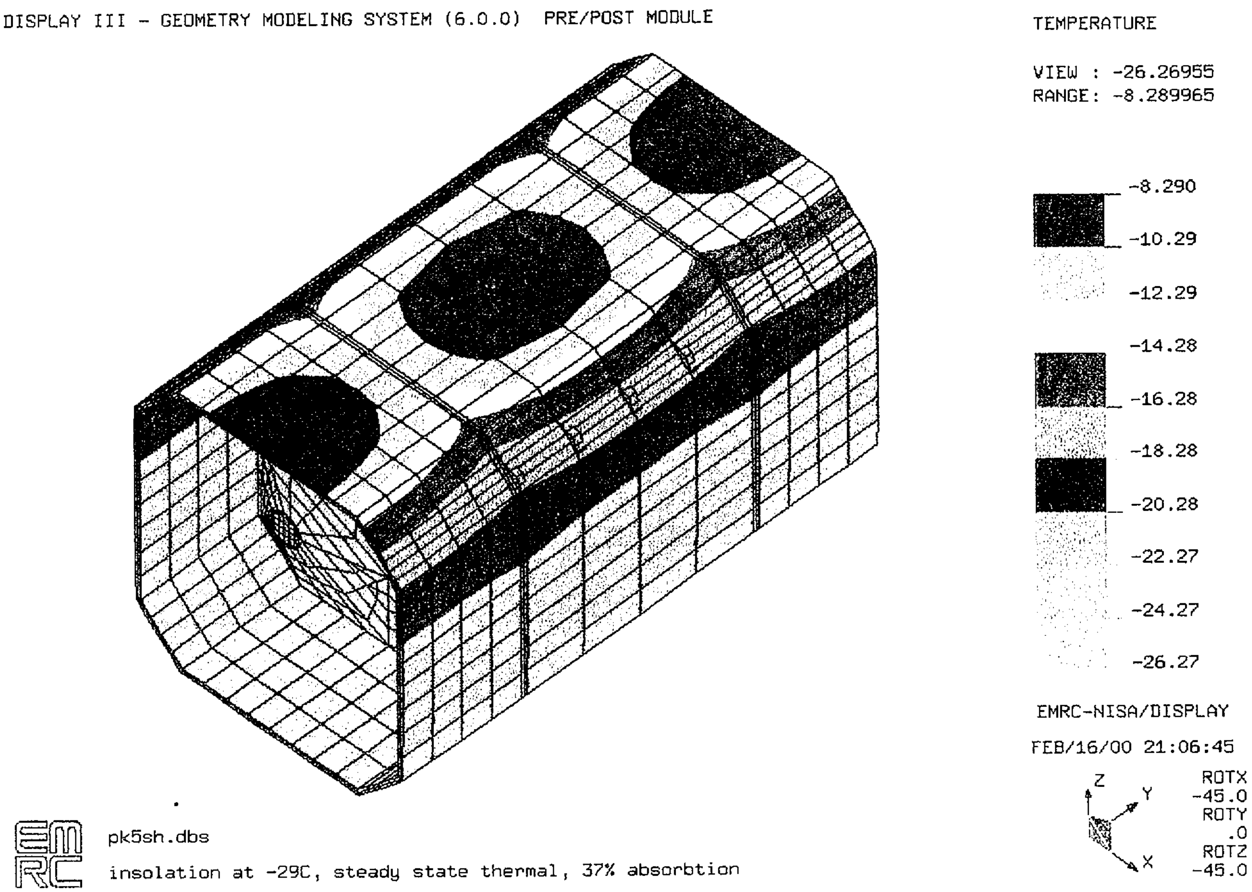


**Figure 4**

In both ambient conditions, the hottest areas were on the top of the package in the middle and on the ends of the flange. The area on top of the package where the cover attaches to the bulkheads was cooler than the middle or the ends of the flange. This is caused by the bulkheads pulling heat away from the top of the package.

After determining the time it takes for the package to reach steady state, the temperature profile across the package due to insolation can be derived for any given moment. The derivation of the temperature profile is obtained through finite element analysis. Figure 5 is a graphical representation of temperature versus time for insolation at 38° C (100° F). From this graph, it can be seen that steady is reached in approximately 5 hours. Figures 6 and 7 show the temperature distribution on the package for the first and fifth hour for a 38° C (100° F) ambient insolation temperature. Figure 8 is a graphical representation of temperature versus time for insolation at -29° C (-20° F) ambient. This graph also depicts that it takes 5 hours for the package to reach steady state. Figures 9 and 10 show the temperature distribution on the package for the first and fifth hour for a -29° C (-20° F) ambient insolation temperature.

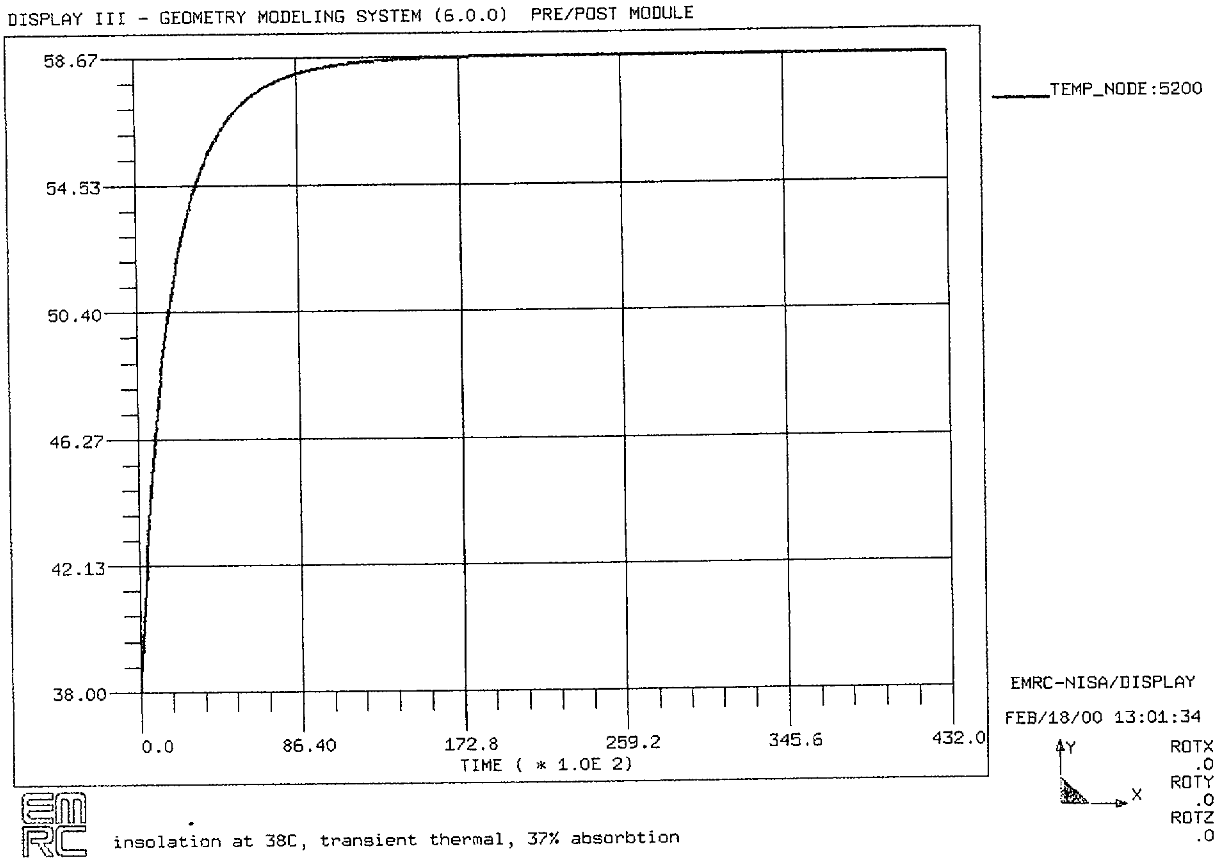


**Figure 5**

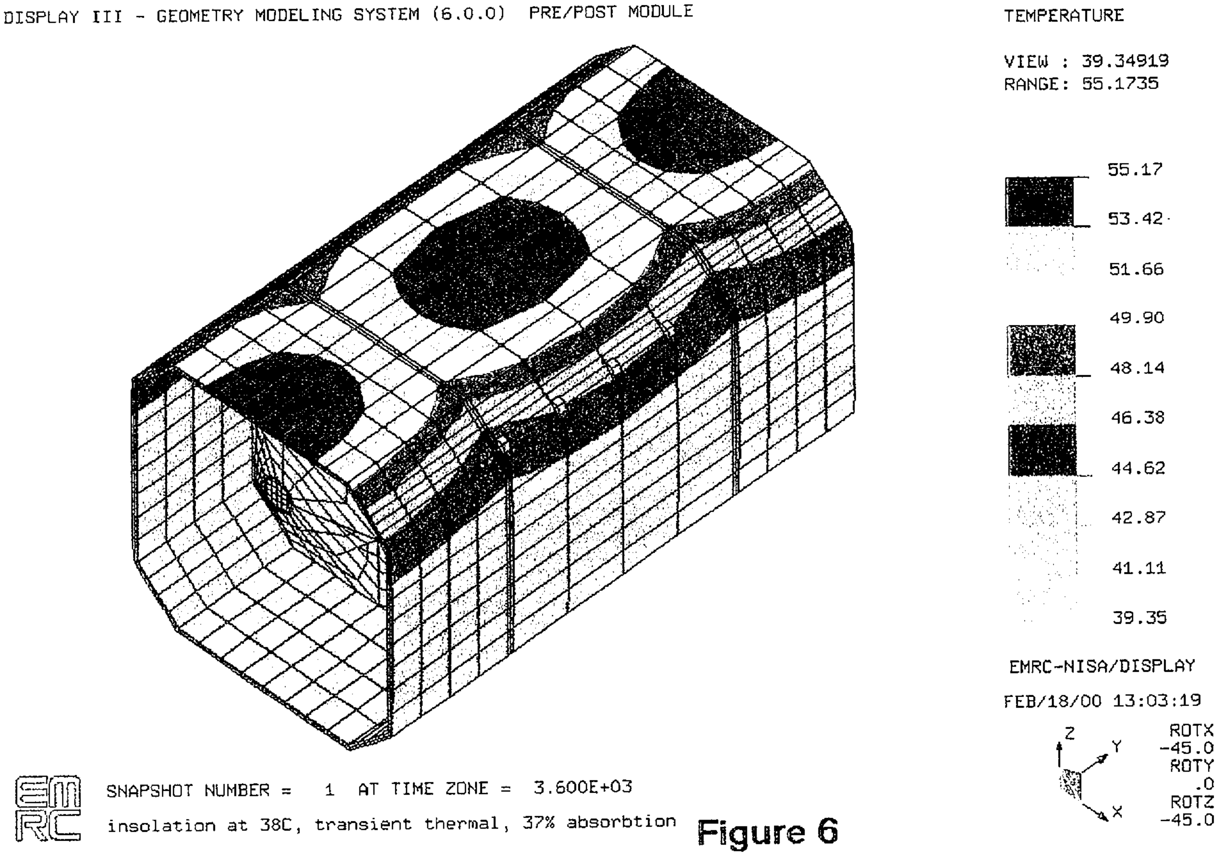


**Figure 6**

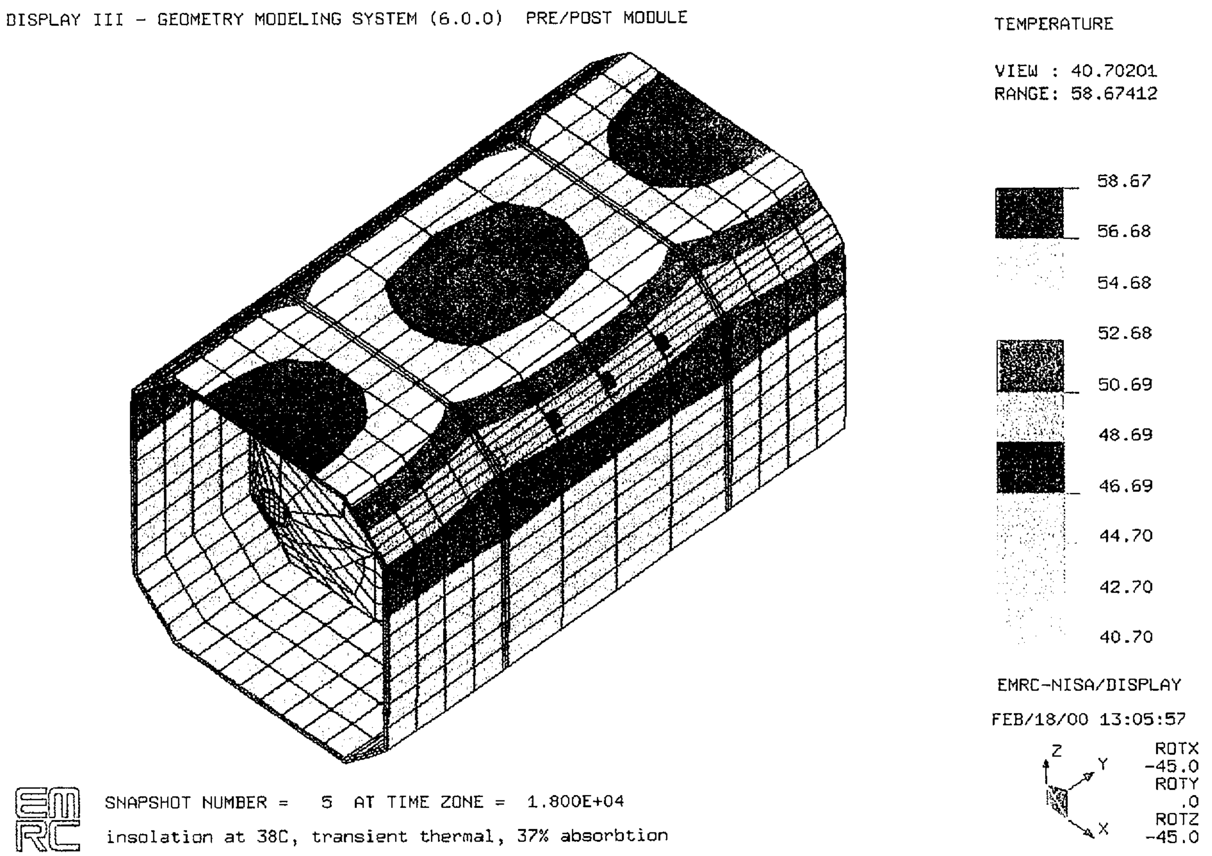


**Figure 7**

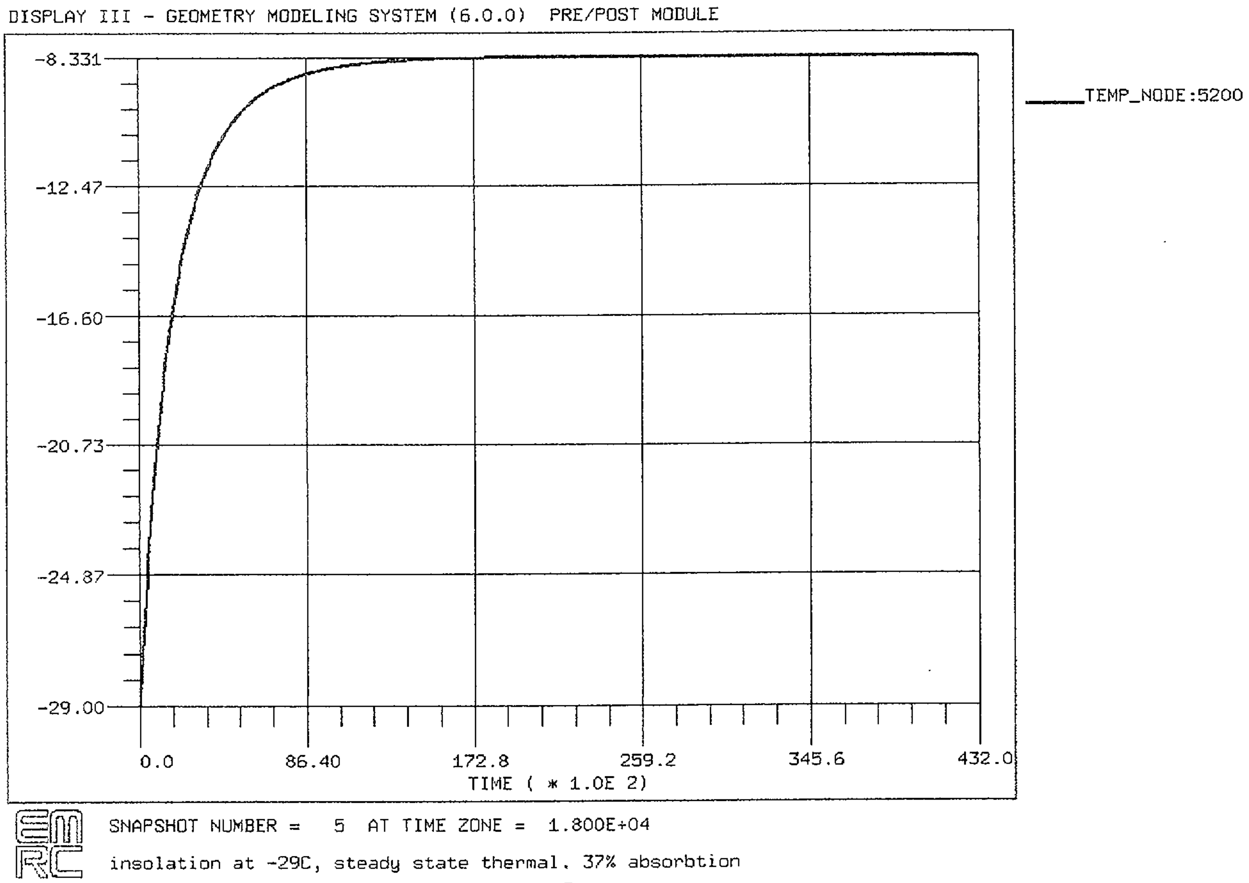
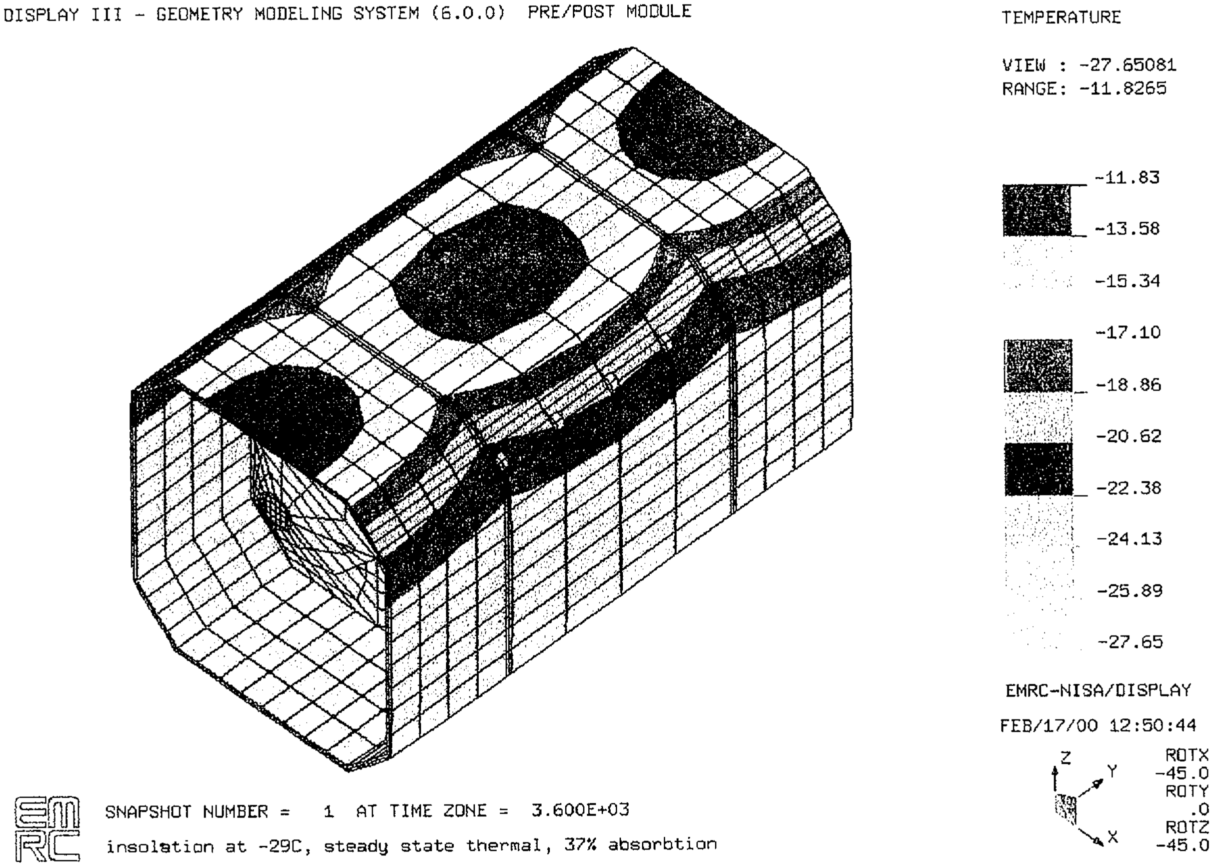


**Figure 8**



DISPLAY III - GEOMETRY MODELING SYSTEM (6.0.0) PRE/POST MODULE

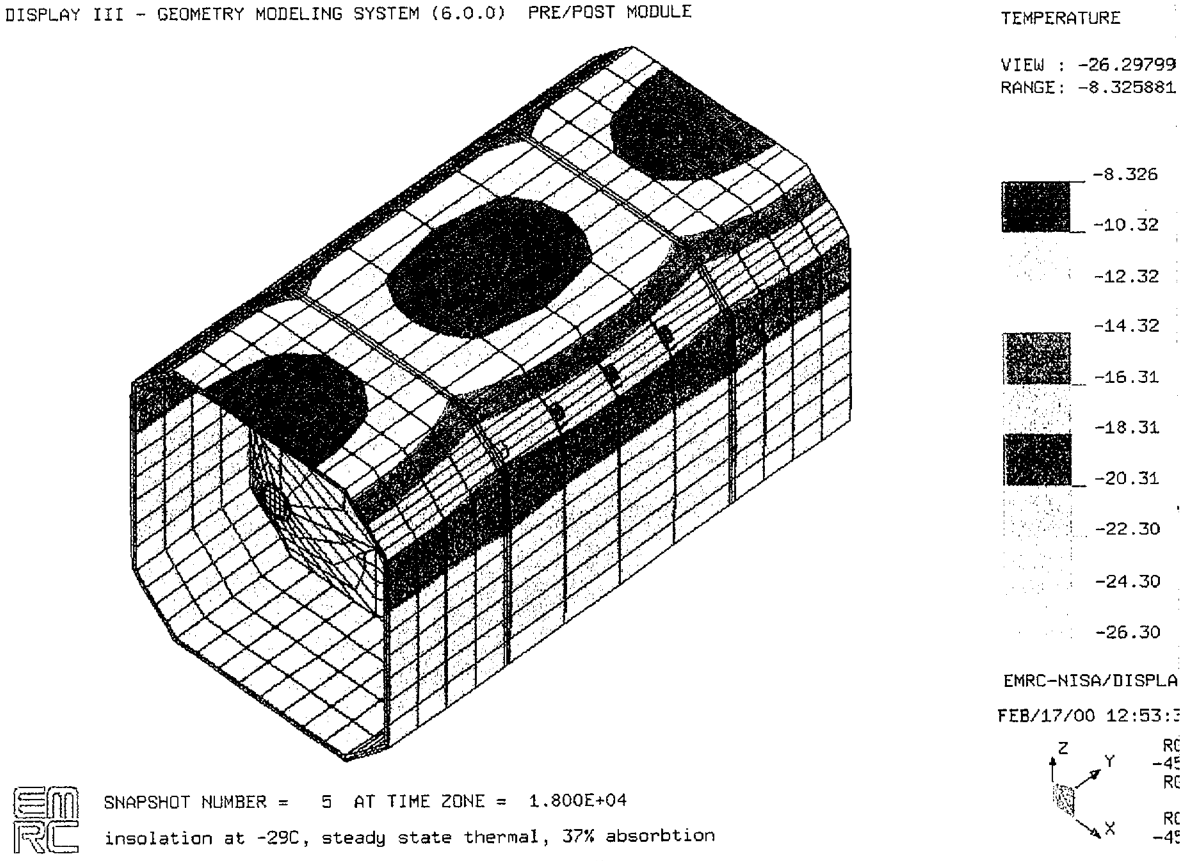
TEMPERATURE

VIEW : -27.65081
RANGE: -11.8265

EMRC-NISA/DISPLAY
FEB/17/00 12:50:44

SNAPSHOT NUMBER = 1 AT TIME ZONE = 3.600E+03
insolation at -29C, steady state thermal, 37% absorbtion

Figure 9



DISPLAY III - GEOMETRY MODELING SYSTEM (6.0.0) PRE/POST MODULE

TEMPERATURE

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RANGE: -8.325881

EMRC-NISA/DISPLA
FEB/17/00 12:53:

SNAPSHOT NUMBER = 5 AT TIME ZONE = 1.800E+04
insolation at -29C, steady state thermal, 37% absorbtion

Figure 10

Once the temperature distribution is calculated, thermal stress on the package can be evaluated. Finite element analysis is also used to determine these stresses. The stresses shown are for both the package and the internal structure of the package. This analysis is done for both 38° C (100° F) and -29° C (-20° F) ambient temperature. The evaluation includes stress calculations at 1 hour intervals until steady state is achieved.

For the -29° C (-20° F) and 38° C (100° F) ambient temperatures, the maximum stress on the outside of the package occurs on the bottom flange near the ends. See figures 11 and 12 for the first hour at 38° C (100° F) and figures 13 and 14 for the first hour at -29° C (-20° F). See figures 15 and 16 for the last hour at 38° C (100° F) and figures 17 and 18 for the last hour at -29° C (-20° F). The reason the highest stresses are on the bottom and not the top where the high temperatures exist is due to expansion of the hotter parts. The hotter an area, the more it will expand. The cooler areas will not expand as much as the hotter areas; however, the cooler areas are constraining the hotter areas. This phenomenon causes the cooler areas to carry more load, thus having more stress. The highest stress levels for a -29° C (-20° F) and 38° C (100° F) ambient temperature occurs within the first hour. This caused by the greatest temperature difference between the package and the surroundings. The maximum stress value is approximately 180 MPa (26 ksi) on the bottom edge of the flanges, and 250 MPa (36 ksi) on the bottom of the bulkheads. These values are very close to the yield point for stainless steel. However, this is not a cause for alarm. There are several assumptions made during the finite element analysis that are ultra conservative. First, the analysis does not consider any of the components inside the package. The components inside the package will help absorb some of the heat and lower the stresses generated. Another point to consider is that these stress values are just a "break in" stress. If the stress on the material reaches the yield point, the material will deform slightly, thus relieving the stress. Once the stress is relieved, the material then will set up a residual stress and no further yielding will occur. The last point to consider is the location of the stress values. They do not occur at weld areas. The finite element analysis for insolation of the SPEC-300 reveals that there will not exist an adverse condition due to insolation. The stresses generated by the thermal load will not affect the package's ability to function properly.

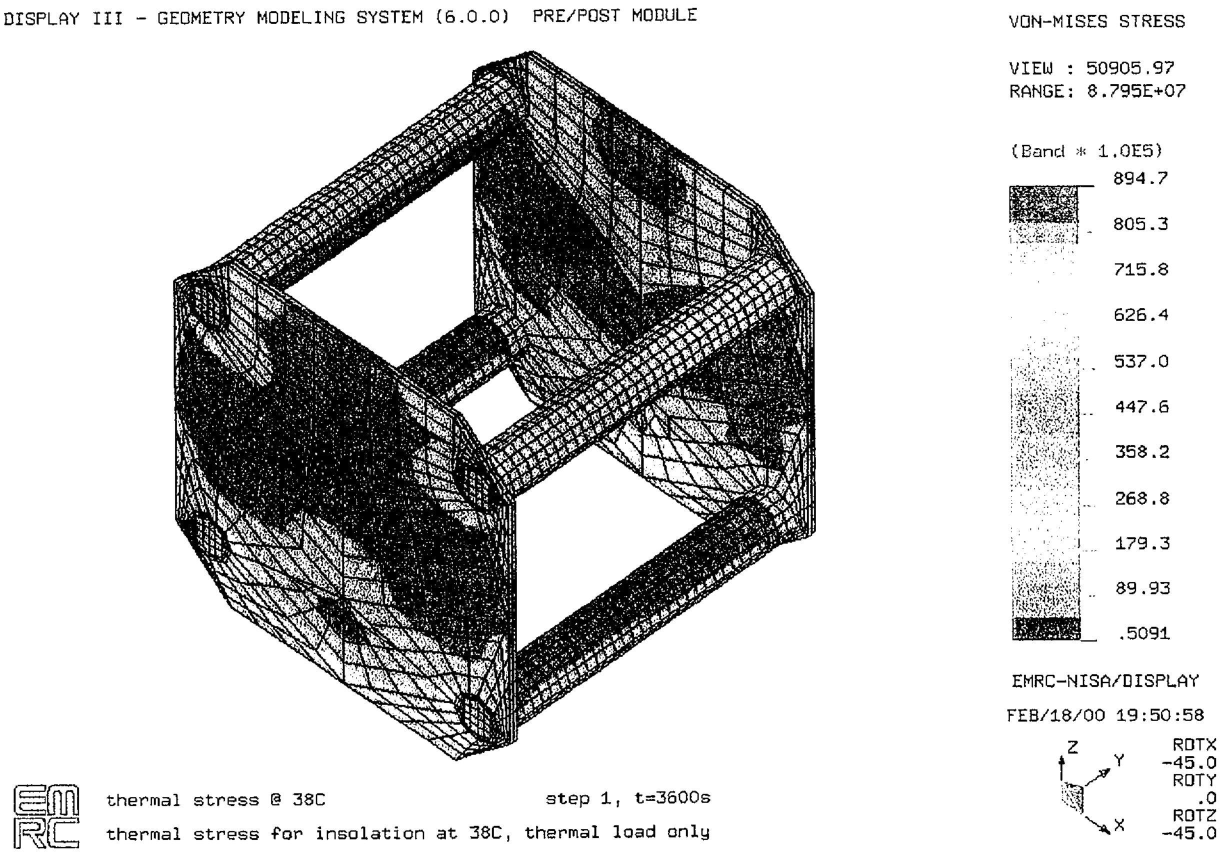


Figure 11

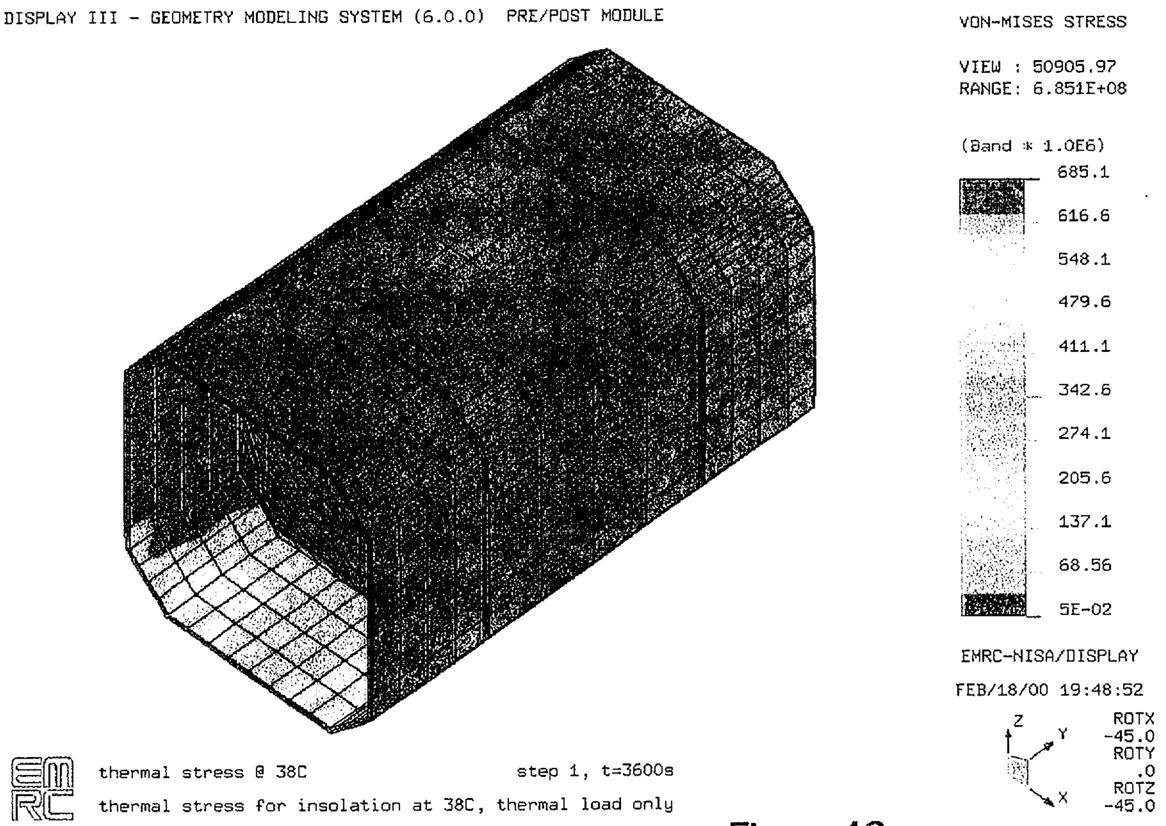


Figure 12

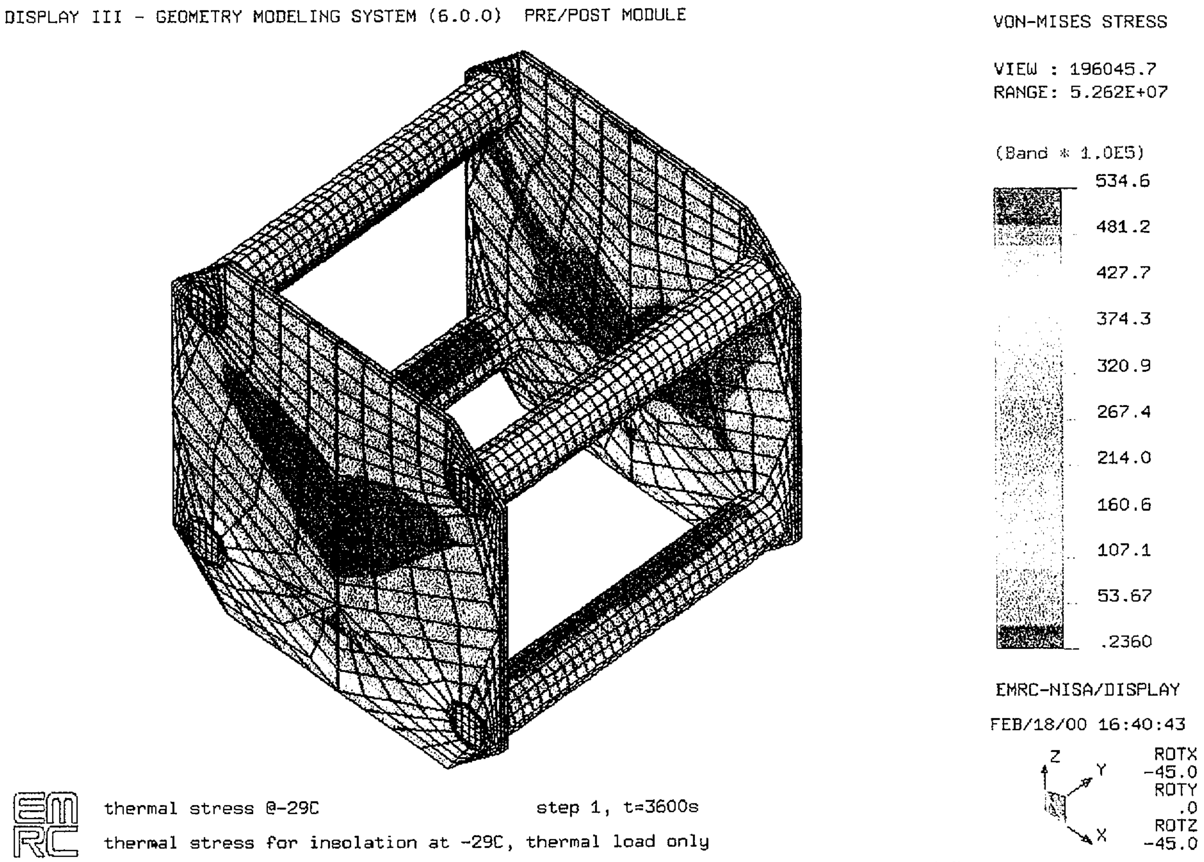


Figure 13

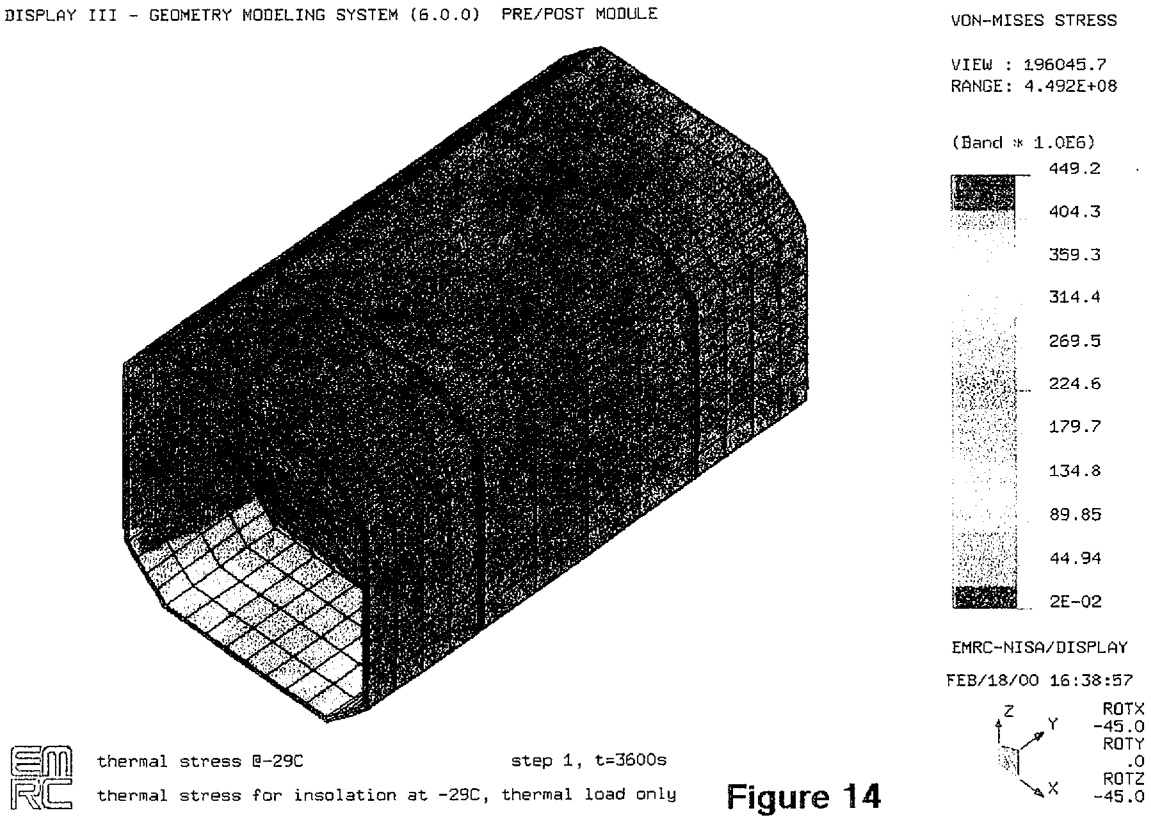


Figure 14

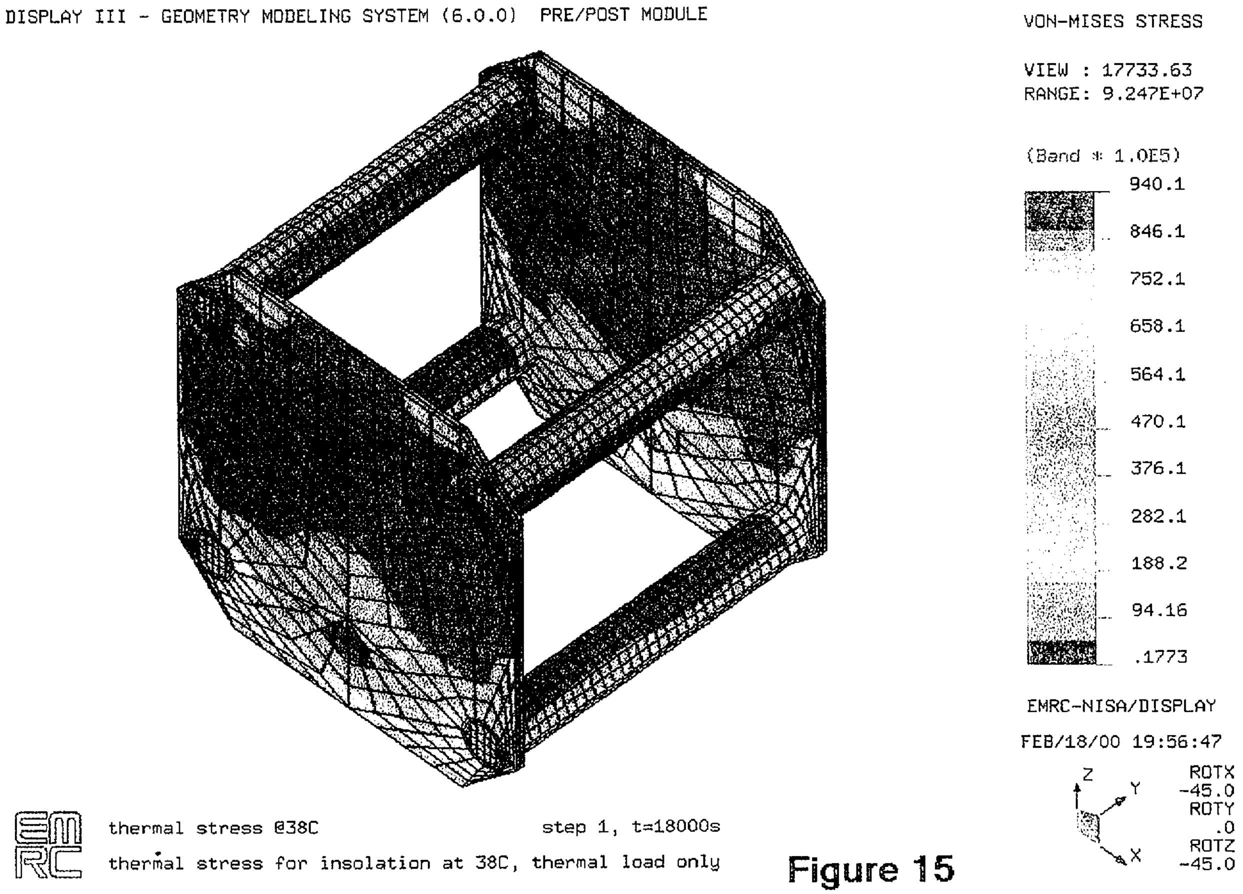


**Figure 15**

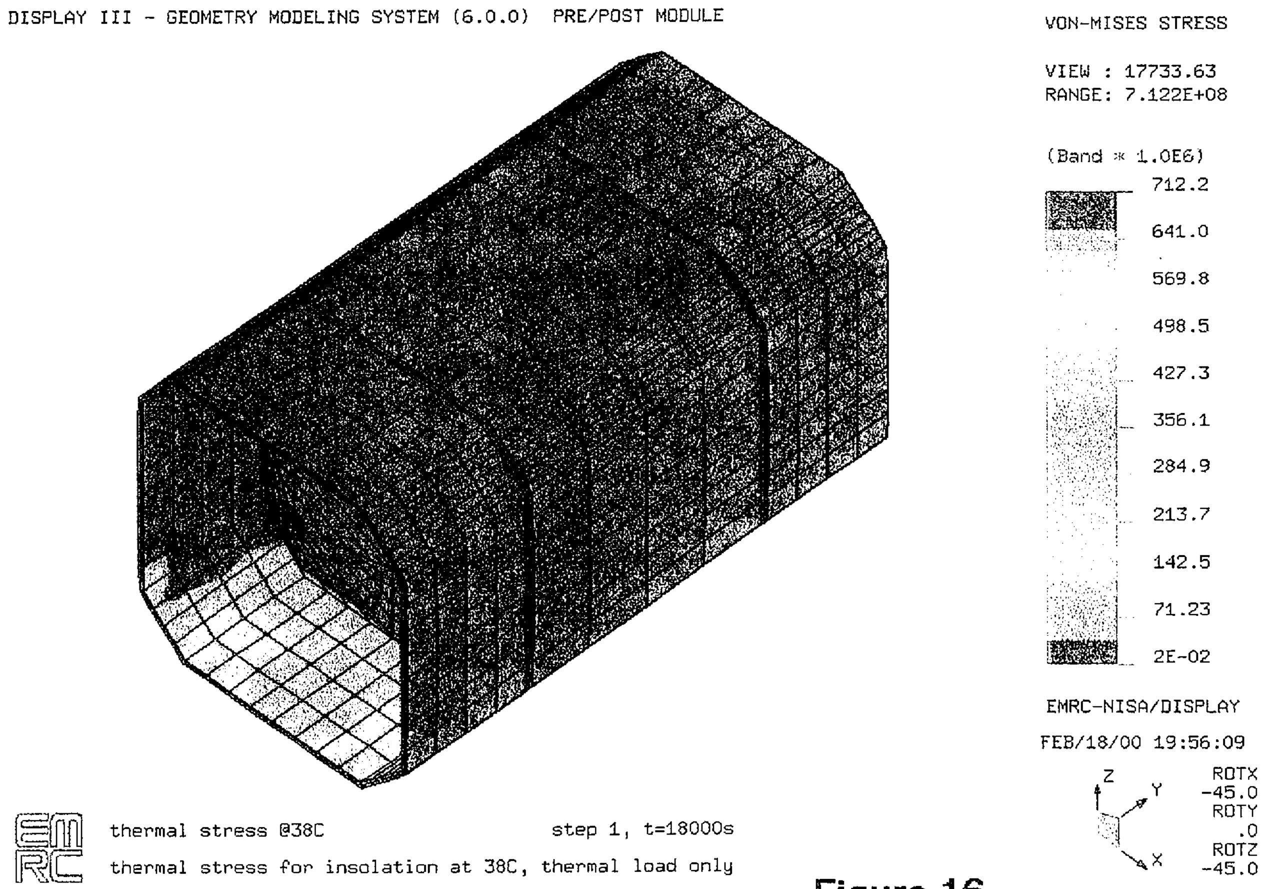


**Figure 16**

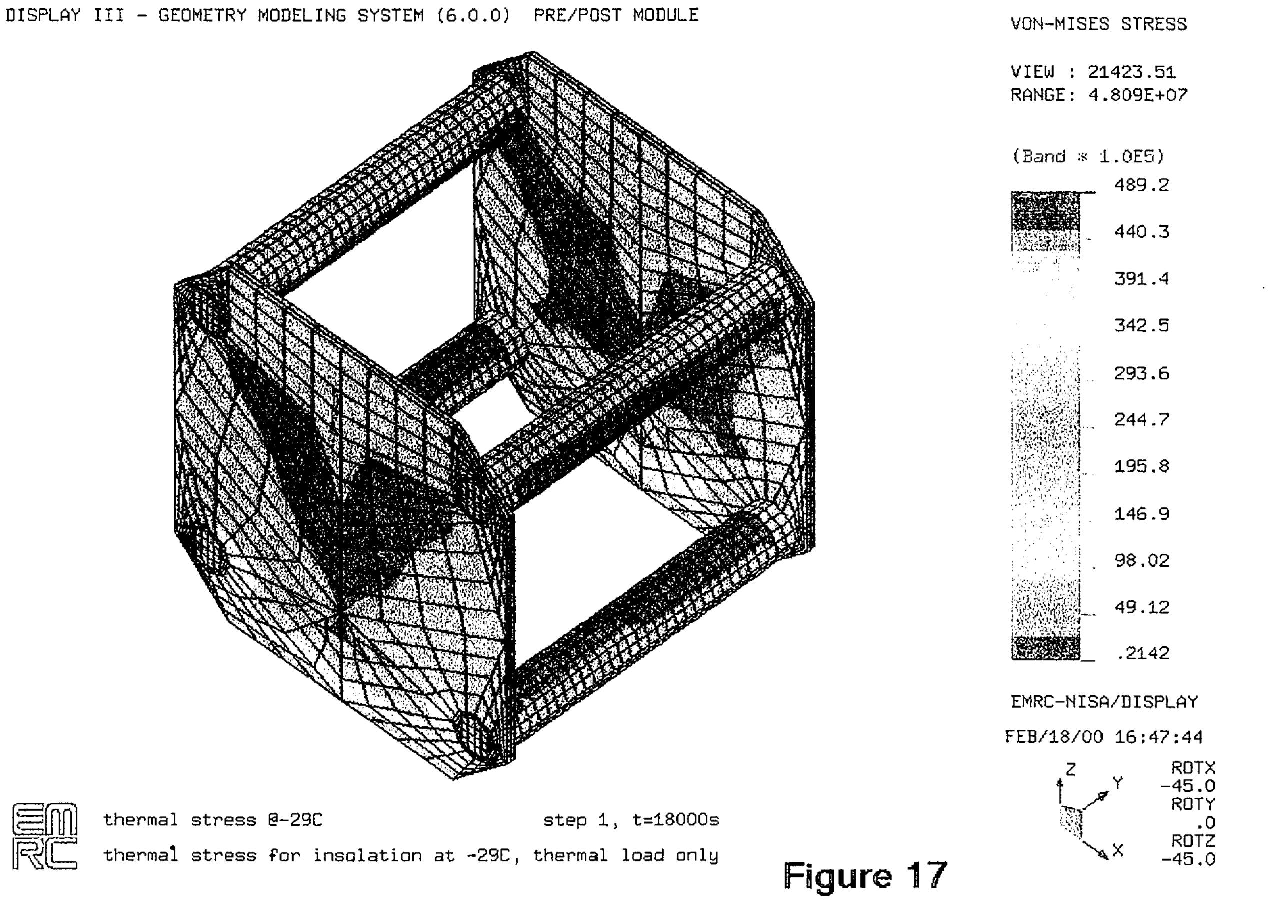


Figure 17

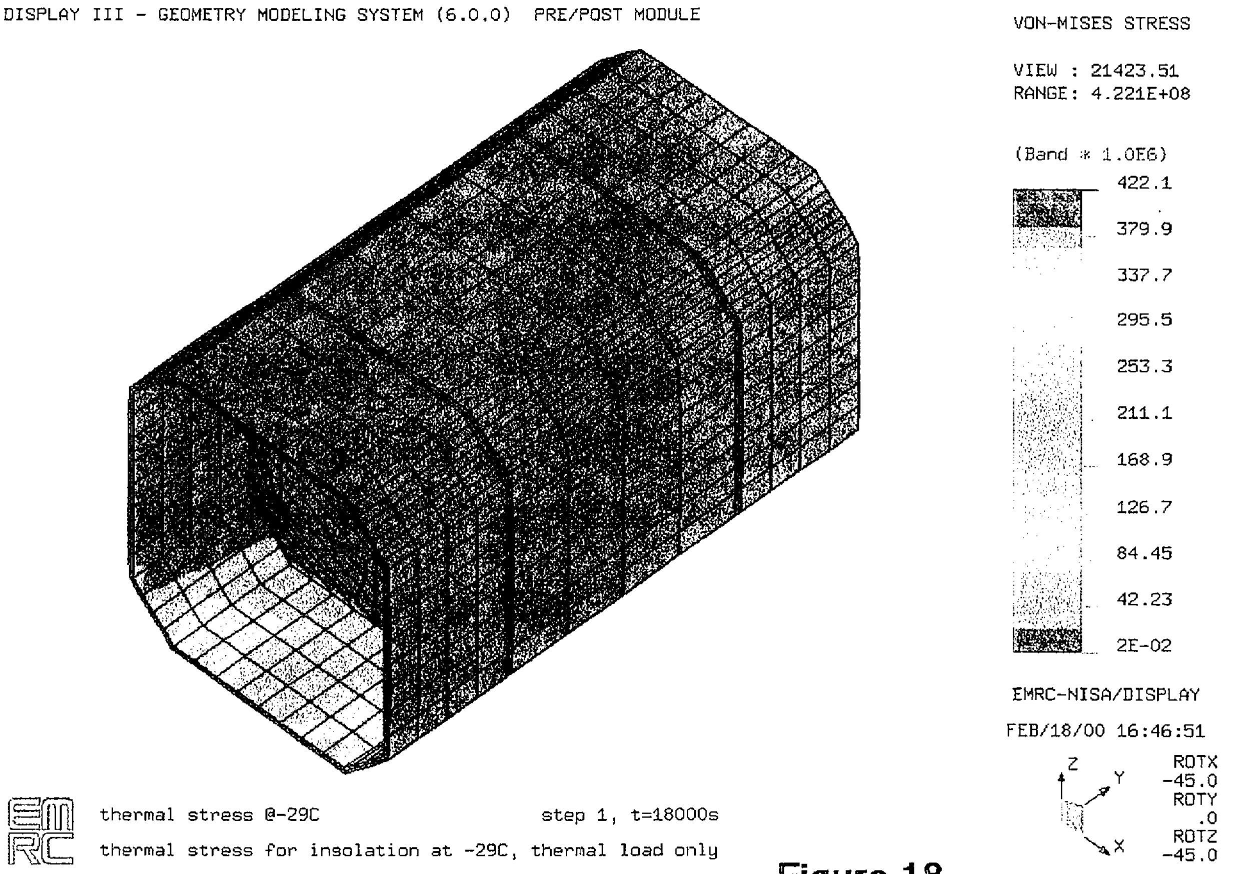


Figure 18

### 2.6.1 Heat

The thermal evaluation for the heat test is reported in section 3.4.

### 2.6.1.1 Summary of Pressures and Temperatures.

The SPEC-300 packaging operating parameters are as follows:

Approximate temperature at which the package was constructed: 27°C (80°F)
Minimum operating temperature: -40 deg.C (-40 deg.F) per 10 CFR 71.71 (c) (2)
Maximum operating temperature: +66 deg.C (+150 deg.F) per SPEC criterion
Minimum operating pressure: 25 kPa (absolute) (3.5 psia) per 10 CFR 71.71 (c) (3).
Maximum operating pressure: 140 kPa (absolute) (20 psia) per 10 CFR 71.71 (c) (4).

### 2.6.1.2 Differential Thermal Expansion.

The SPEC-300 enclosure is made of 316/316L stainless steel. The shield is made of depleted Uranium. The coefficient of thermal expansion of these two materials differs slightly. The only possible significant result of this is a binding condition at low temperature if the enclosure shrinks more than the shield. This is calculated below. The shield is 350mm (13.875 in) long. The thermal expansion coefficients in the equations below are for 316/316L stainless steel and for depleted Uranium, respectively.

$$\Delta ThermalExpansion = Length * \Delta Temperature * \Delta CoefficientOfThermalExpansion$$

$$\Delta ThermExp = 350mm*(27°C-(-40°C))*(1.8*10-5mm/mm*°C)-(1.1*10-5m/m*°C)$$

$$\Delta ThermExp = -0.16mm(-0.006inch)$$

1. Young's modulus at 22°K (-420° F) is 5% to 20% greater than at 294° K (69.5° F).
2. Yield strength at 22°K (-420° F) is considerably greater than at 294° K (69.5° F).
3. Fatigue properties at low temperatures are also improved.

This information was taken from Mark's Mark's Standard Handbook for Mechanical Engineers 10th edition, Page 19-32, 33.

The depleted Uranium shield does exhibit a ductile to brittle transition at approximately 0° C (32°F). For this reason the SPEC-300 was chilled in dry ice to a core temperature below -40° C (-40° F) prior to and during the first 9 m (30 ft) free drop test. A radiation survey performed after this test showed no measurable increase in radiation levels, indicating no significant damage to the shield. Incidentally, three additional 9 m (30 ft) free drop tests were subsequently performed. Had fracture or other damage related to the ductile to brittle transition occurred during the first free drop, it is likely the remaining three free drop tests would have caused some increase in post-test radiation levels. This did not occur.

Information relating to the ductile to brittle transition temperature of depleted Uranium was taken from Physical Metallurgy of Uranium Alloys, Proceedings of the Third Army Materials Technology Conference, Held at Vail, Colorado, February 12-14, 1974. Sponsored by Army Materials and Mechanics Research Center, Watertown, Massachusetts. Pages 315-317.

Effect of freezing liquids:
Not applicable. There are no liquids present in the SPEC-300 under normal conditions.

### 2.6.3 Pressure

The enclosure of the SPEC-300 is vented to the atmosphere. Venting of the SPEC-300 enclosure occurs through the hollow bodies of 20 rivets distributed among the top, left, and right sides of the packaging. Each of these rivets has an open internal diameter of approximately 2mm (0.080 in), for a cumulative vent area of approximately 65 $mm^2$ (0.1 $in^2$). The mandrels in the rivets are driven out after installation to ensure that each rivet acts as a vent. Even though the package is vented through the rivet holes, a finite element analysis was performed treating the package as a sealed container. The analysis considered the effects of insolation at -29° C (-20° F) and 38° C (100° F) with reduced and increased external pressure as specified in 10 CFR Part 71.71(c)(3) and 10 CFR Part 71.71(c)(4). This analysis assumed that the package did not vent through the rivet holes. Figures 19 and 20 show the stresses generated from insolation and pressure at an ambient temperature of 38° C (100° F) with increased external pressure. The stresses generated around the edge of the flange are approximately 200 MPa (29 ksi). The stress at the bottom of the bulkhead is approximately 300 MPa (43 ksi). These values are very close to the yield point for stainless steel, but this is not cause for alarm. For the same reasons that the stresses in section 2.6 were not a problem, the stresses due to insolation and pressure will not cause any problems. Several assumptions are made during the finite element analysis that are ultra conservative. The analysis does not consider any of the components inside the package. The components inside the package will help absorb some of the heat and lower the stresses generated Another issue to consider is that these stress values are just a "break in" stress. If the stress on the material reaches the yield point, the material will deform slightly, thus relieving the stress. Once the stress is relieved, the material then will set up a residual stress and no further yielding will occur. The last point to consider is the location of the stress values. They do not occur at weld areas. The stress generated with an increased pressure with insolation at 38° C (100° F) is similar to the stress generated with an insolation temperature of -29° C (-20° F). Since the stress generated is similar, the graphs and discussion for ambient insolation at -29° C (-20° F) with the addition of pressure are not included. Figures 21 and 22 consider a reduced pressure with an ambient insolation temperature of 38° C (100° F). In this condition the stresses generated are approximately 200 MPa (29 ksi). This situation uses the same assumptions as before; therefore, there are no adverse effects from the stresses generated. Since the stresses generated for reduced pressure at an ambient insolation temperature of 38° C (100° F) are similar to those with an ambient insolation temperature of -29° C (-20° F), the results for the -29° C (-20° F) insolation are not included in this application.

The finite element analysis for insolation with increased and reduced pressure of the SPEC-300 reveals that there will not exist an adverse condition on the package or the welds on the package. The stresses generated by the thermal load and pressure will not affect the package's ability to function properly.

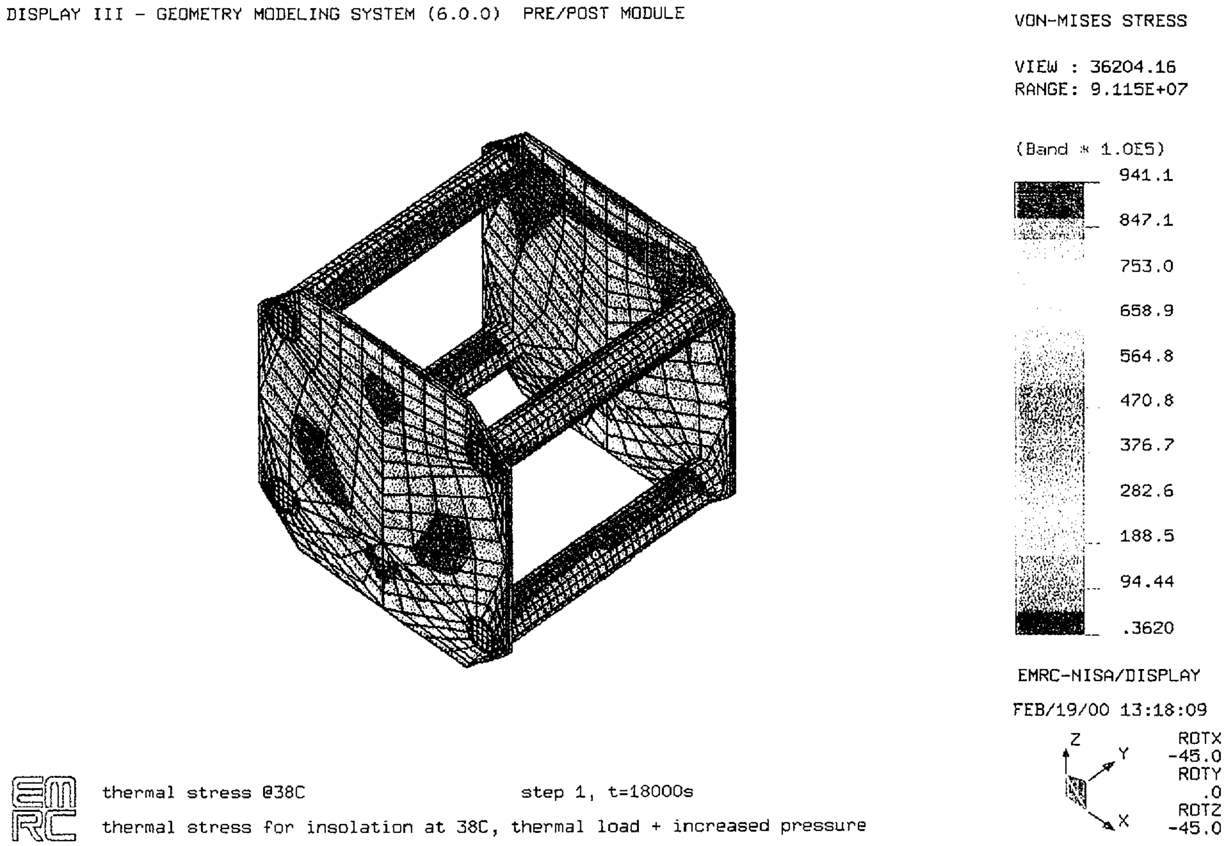
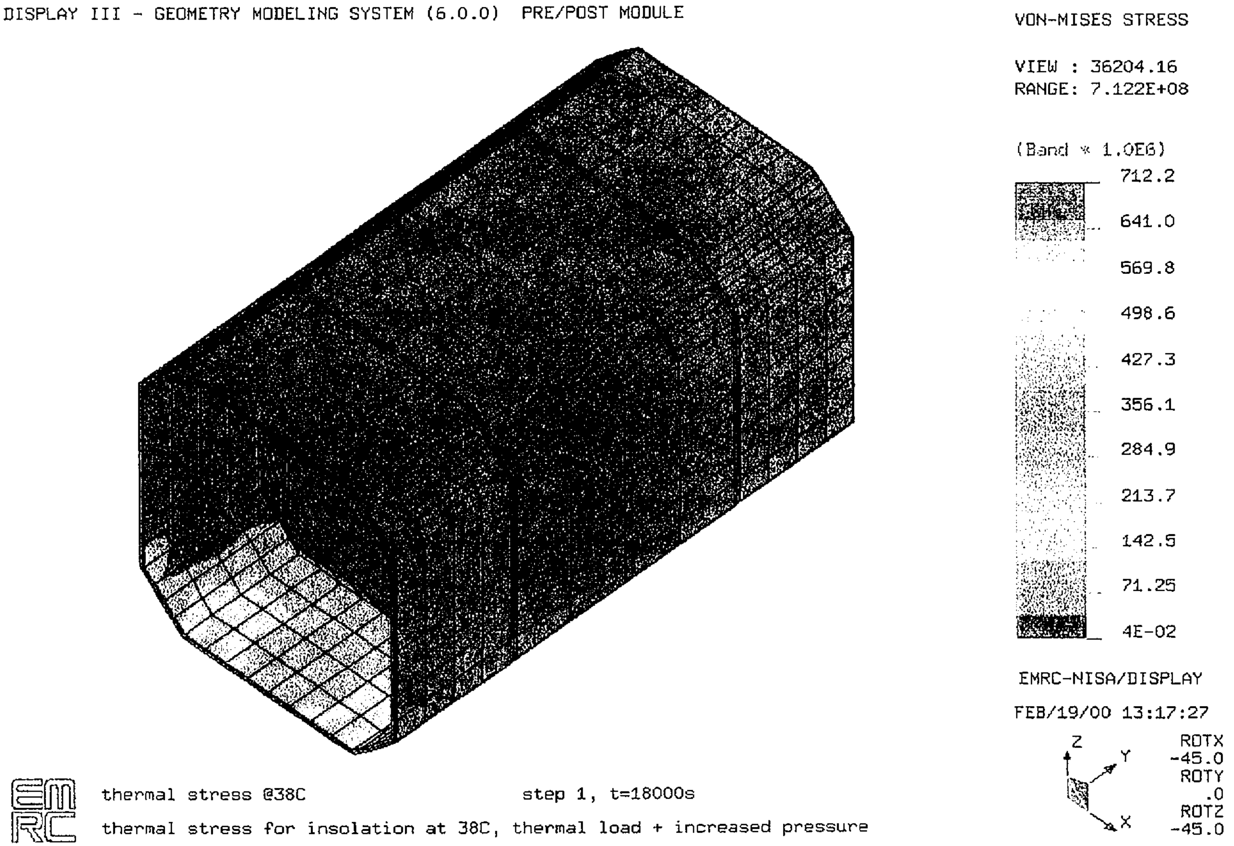


**Figure 19**

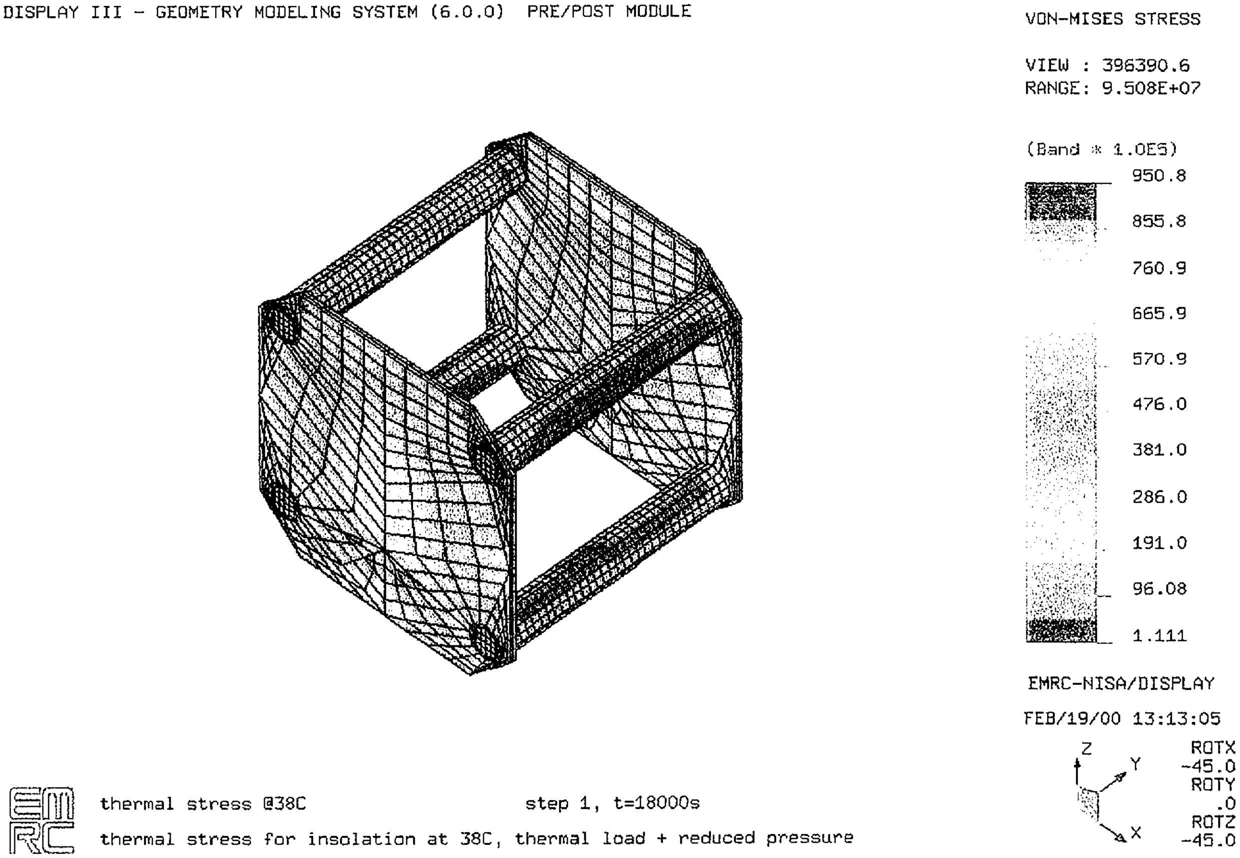


DISPLAY III - GEOMETRY MODELING SYSTEM (6.0.0) PRE/POST MODULE

thermal stress @38C step 1, t=18000s

thermal stress for insolation at 38C, thermal load + increased pressure

Figure 20



DISPLAY III - GEOMETRY MODELING SYSTEM (6.0.0) PRE/POST MODULE

thermal stress @38C step 1, t=18000s

thermal stress for insolation at 38C, thermal load + reduced pressure

Figure 21

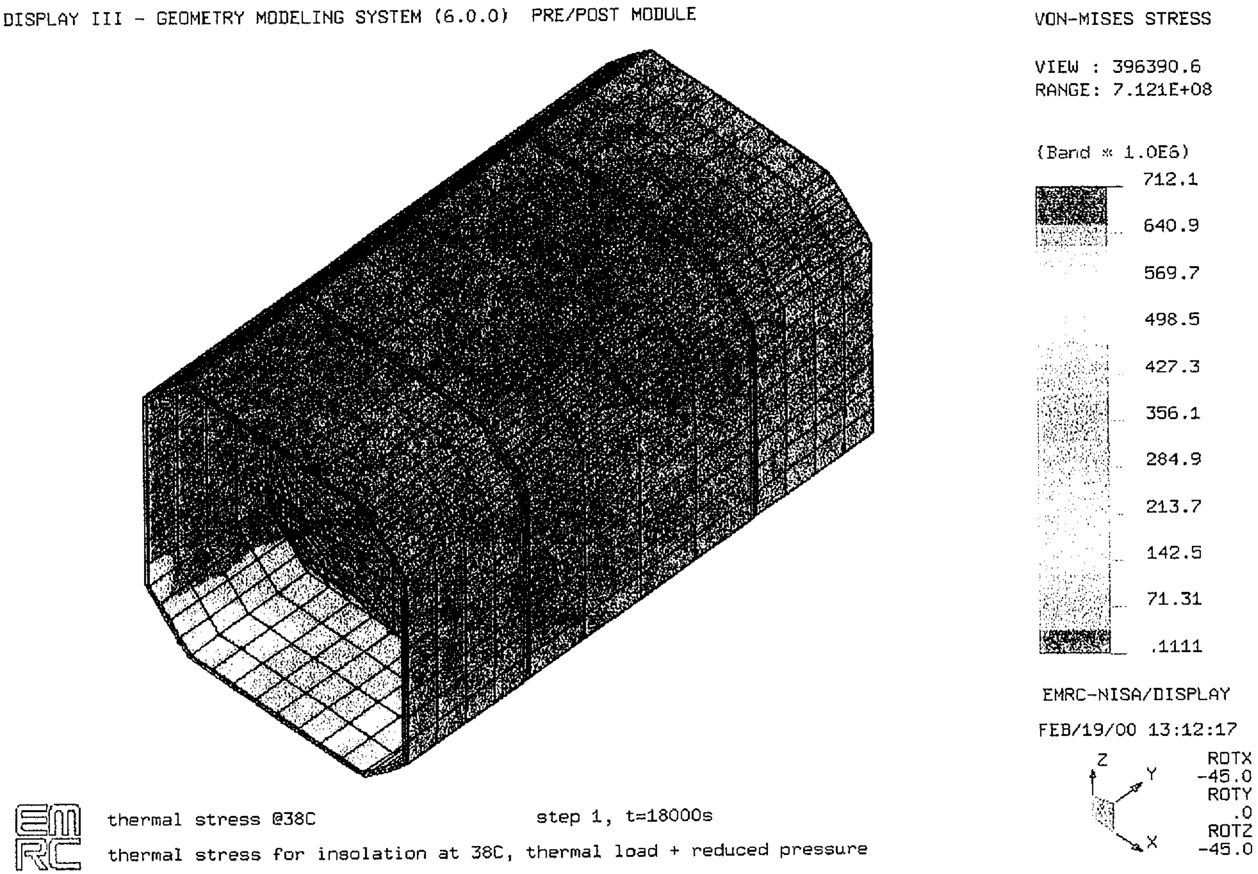


Figure 22

### 2.6.4 Vibration

The effect of vibration on the package and materials of constructions incident to normal

SPEC-300 package when exposed to the thermal test.

The other materials used in this package which are not considered structural parts, but still have a higher melting temperature than 800° C (1475°F) are: copper, tungsten, bronze, and titanium. These materials would neither be affected by a thermal test, nor lead to structural changes which would cause the loss of any radioactive material from the package.

The materials used in the SPEC-300 which are not structural parts and have a lower melting temperature than 800° C (1475°F) are: two-component chocking compound, polyurethane foam, epoxy adhesive, and buna rubber. These materials are expected to melt or volatilize to some degree during a thermal test. When these materials began to melt during the test, some of them will produce gases. These gases will not increase the pressure in the SPEC-300 because the package is not hermetically sealed. The gases will naturally vent to the exterior of the package. Loss of these materials during a thermal test will neither reduce the shielding effectiveness of the package nor lead to structural changes which would cause the loss of any radioactive material from the package.

No shield movement is expected as a result of materials being consumed during the thermal test because in addition to the two-component chocking compound used to restrain the shield, the shield is held in position by a total of twelve 13 mm (0.5 in) diameter jack screws that are used to position the shield during fabrication of the package. These screws clamp directly on the Copper pads contacting the "ears" of the depleted Uranium shield. Even if the two-component chocking compound were to be completely destroyed as a result of the thermal test, the shield would remain in position relative to the device enclosure.

In addition to the statements made above, a finite element thermal analysis was performed on the package. The analysis was set up using the constraints specified in 10 CFR Part 71.73. The analysis assumes that the package is fully engulfed by the fire. Results for the analysis include the temperature distribution on the package. The analysis also includes the stresses generated on the package from the hypothetical fire test.

Figure 23 illustrates the temperature distribution over the package after two minutes of exposure to the fire test. The figure points out the temperature of the fire, 800° C (1475° F). The highest temperature on the package is located on the flanges and is approximately 155° C (311° F).

Figure 24 illustrates the temperature distribution over the package after the required thirty minutes. The highest temperatures are located in the middle of the sides and on the flanges. These locations are approximately 716° C (1320° F) to 800° C (1475° F). The side of the package near the bulkheads are approximately 630° C (1166° F), while the top of the package ranges from 550° C (1022° F) to 380° C (716° F).

Figure 25 demonstrates the temperature distribution over the internal structural after the required thirty minutes. The highest temperatures are found on the bottom and side edges of the bulkheads. These temperatures are approximately 600° C (1112° F) to 675° C (1247° F). The middle of the bulkheads reached a temperature of approximately 330° C (626° F). The structural post temperatures range from 460° C (860° F) on the ends to 50° C (122° F) in the middle.
The temperature distribution on the package is typical. The outside of the package reaches the

temperature of the fire, while in inside of the package is much lower.

When considering the temperature of the package, the stresses generated must also be investigated. The finite element analysis recorded the results of the test at two minute intervals. Figure 26 demonstrates the stress generated on the outside of the package and Figure 27 demonstrates the stress generated on the internal structure after two minutes elapsed time. These two figures (26 and 27) show that the maximum stress generated is approximately 200 MPa (29 ksi). The locations of the highest stress are on the structural posts and where the structural posts connect to the bulkheads.

Figures 28 and 29 depict the stress generated on the package after being exposed to the fire test for thirty minutes. The highest stress generated is approximately 100 MPa (14.5 ksi). The stress after thirty minutes is much less than after two minutes because the temperature gradient across the package is smaller. As the package is exposed to the fire, the package slowly heats up. This heating process reduces the thermal gradient and lowers the stresses generated. Therefore, the worst case for stress generation is within the first two minutes of the fire test.

The stress values during the first two minutes of the fire test are very close to the yield point for stainless steel, but this is not a cause for alarm. There are several assumptions made during the finite element analysis that are ultra conservative. For example, the analysis does not consider any of the components inside the package. The components inside the package will help absorb some of the heat and will considerably lower the stresses generated on the package. Another assumption to consider is that these stress values are just a "break in" stress. If the stresses in the material reach the yield point, the material will deform slightly, thus relieving the stress. . The finite element analysis for the hypothetical fire testing of the SPEC-300 reveals that the stresses generated will not cause an adverse condition to the package.

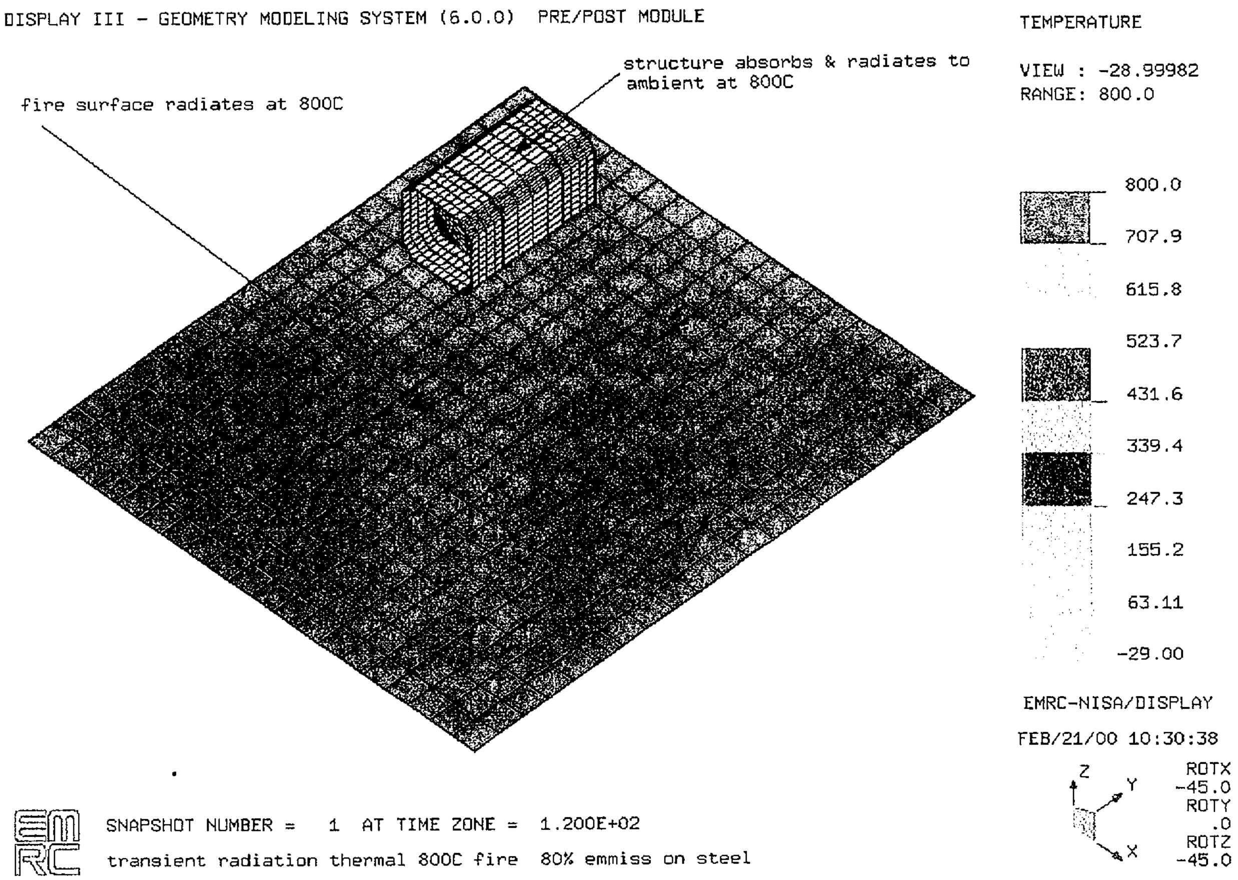


**Figure 23**

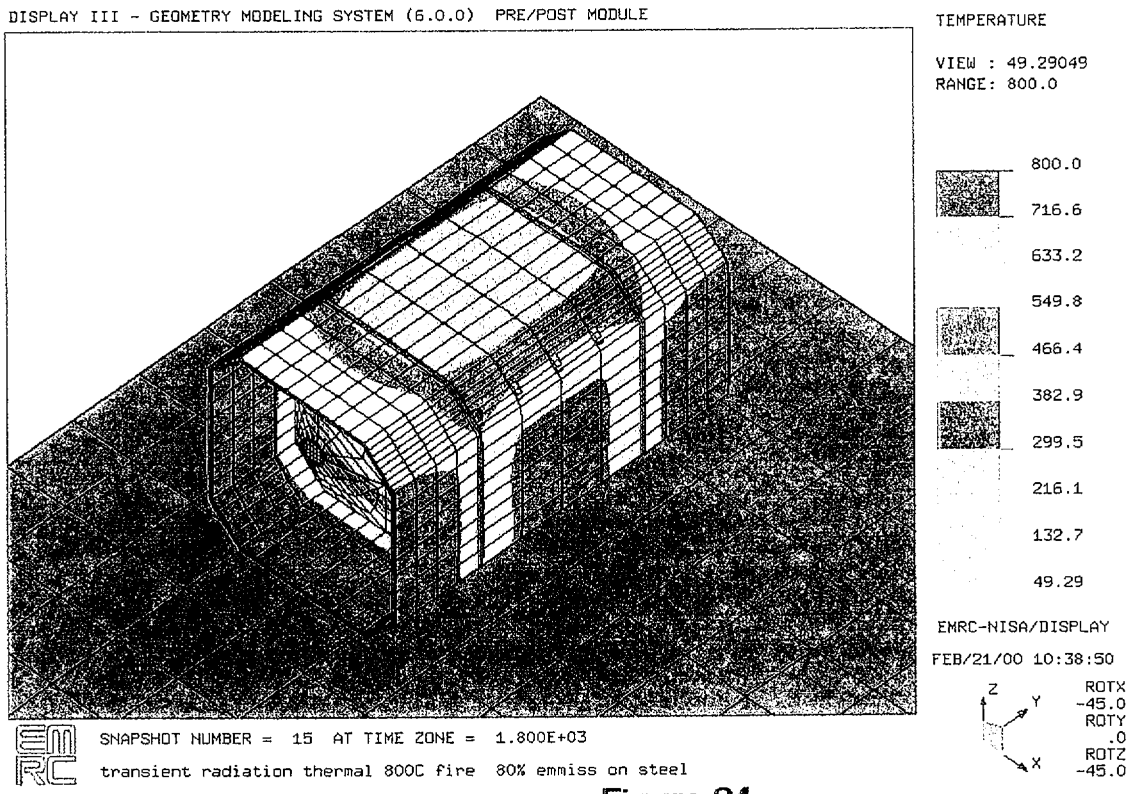


**Figure 24**

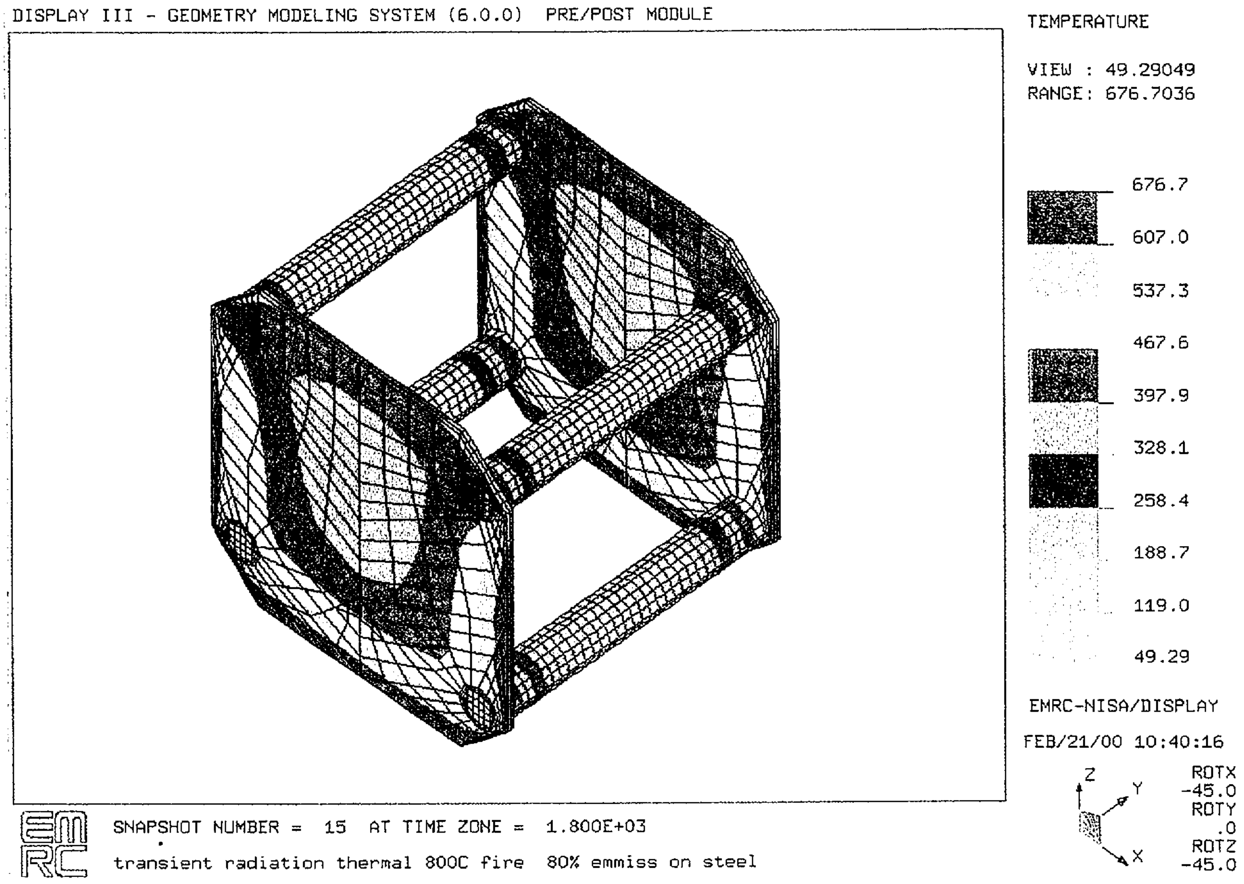


Figure 25

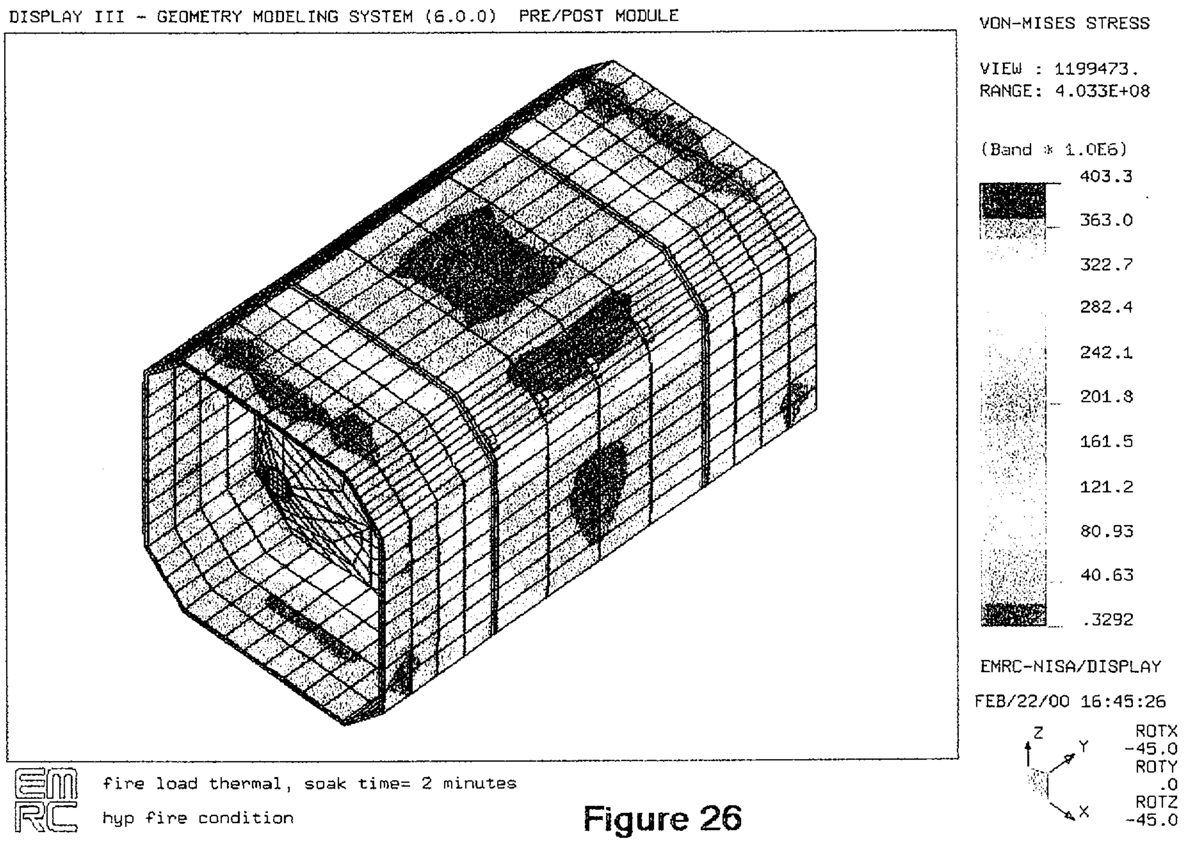


Figure 26

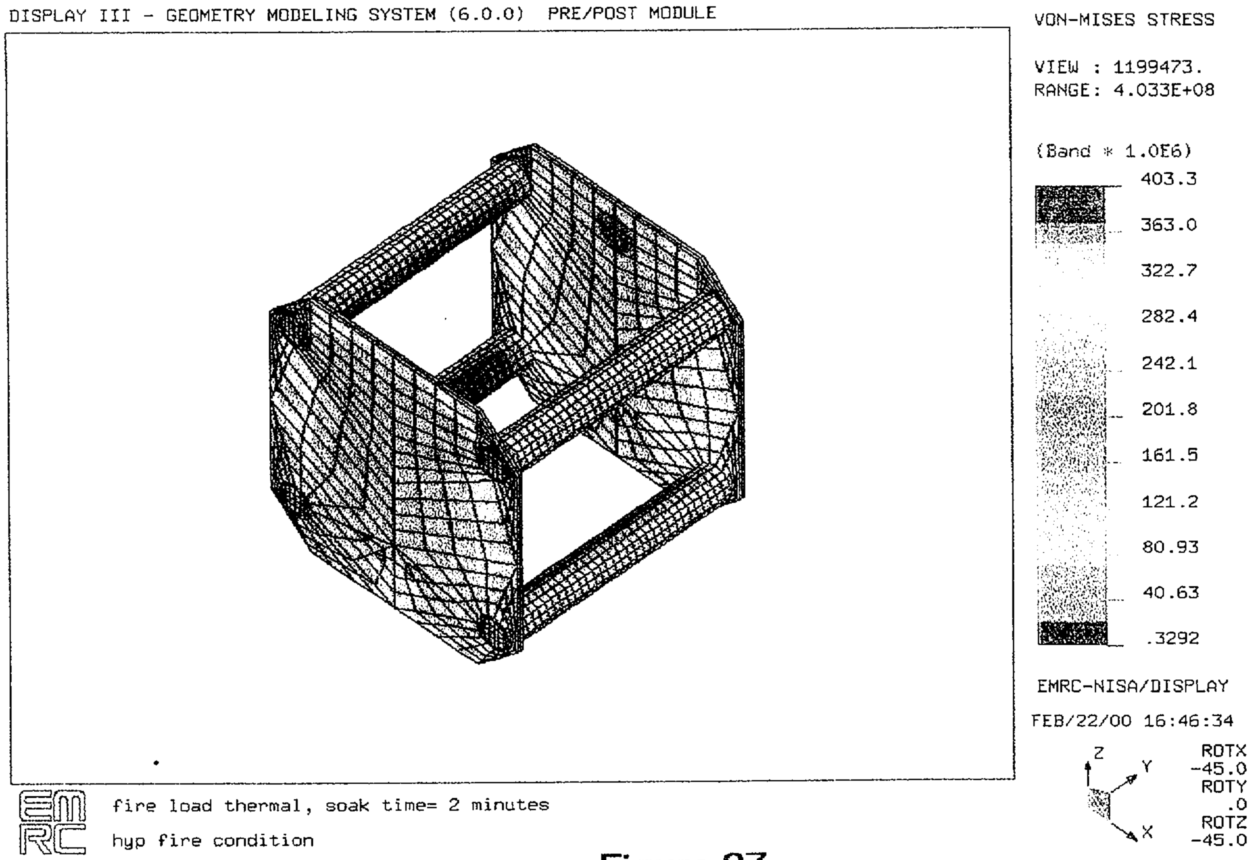


**Figure 27**

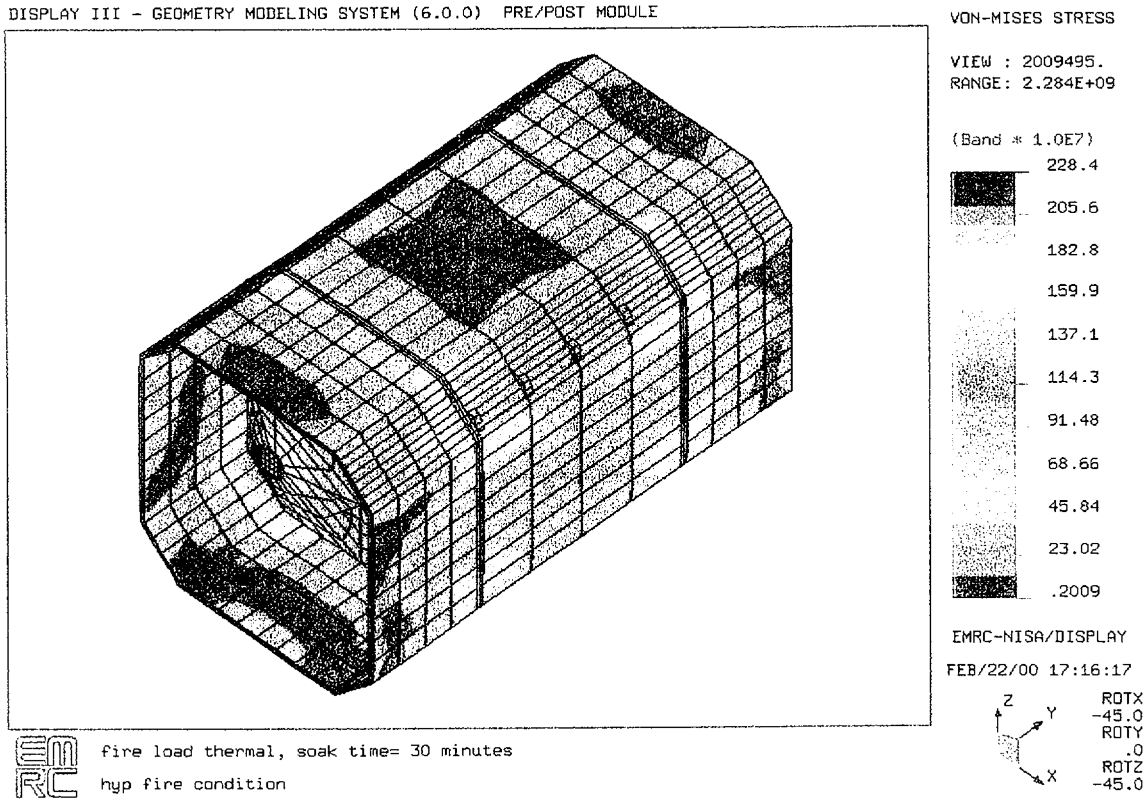


**Figure 28**

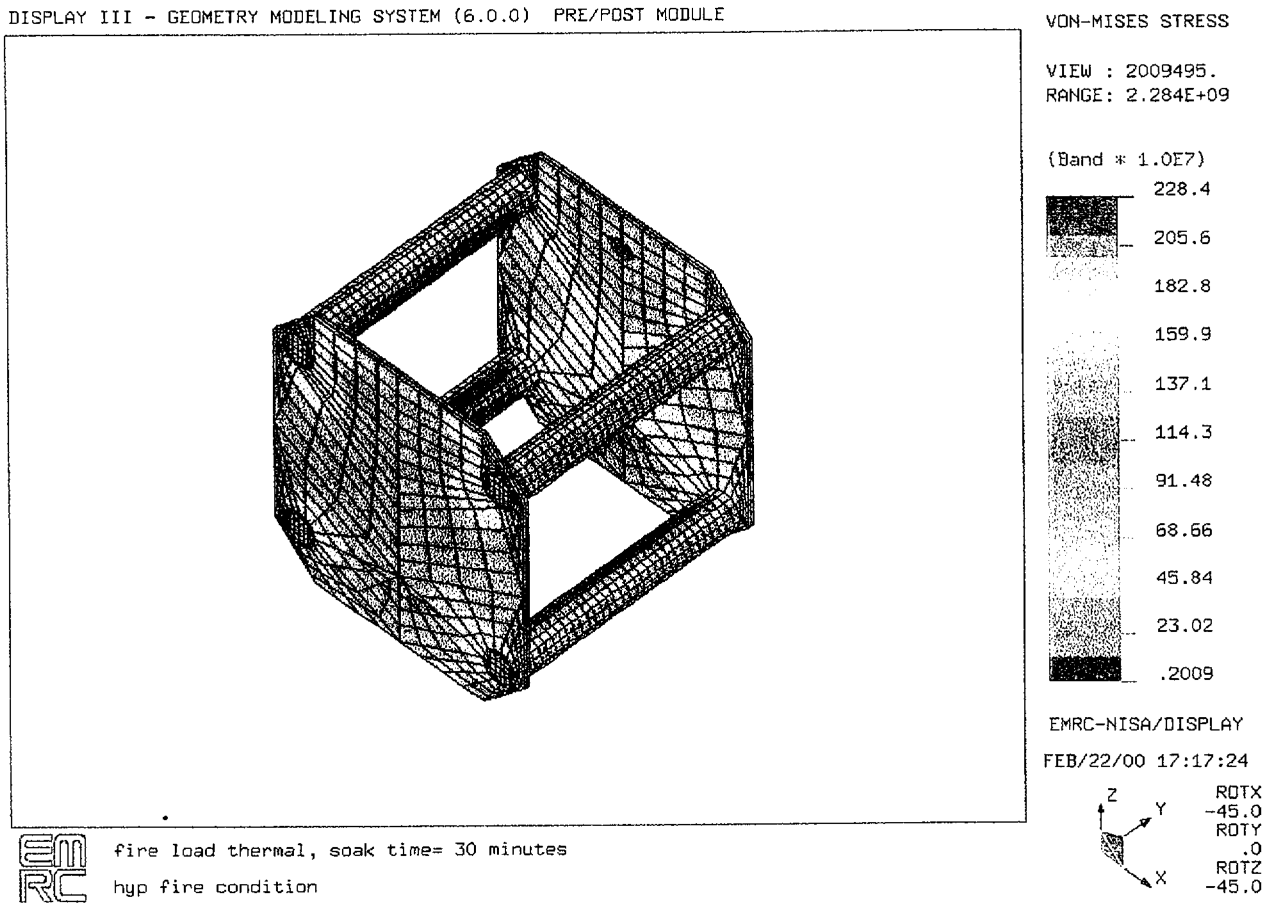


**Figure 29**

Issue #2:

The purpose of this assessment is to supply additional information to support our assertion that the SPEC-300 meets the 10 CFR 71.73 (c) (4) thermal test requirements, with particular emphasis placed on the effects from forced convection (high convective velocity).

The thermal analysis included in discussion #1 was mainly a comparison of the melting temperatures of package materials compared against the specified test temperature. While this analysis is valid, other effects such as high temperature oxidation of the Depleted Uranium casting were not discussed.

The primary concern is the temperature of the Depleted Uranium shield at the end of the test. A recent test on another manufacturer's design has demonstrated that shielding effectiveness can be compromised if the shield reaches a temperature where severe high temperature oxidation occurs. There are three modes by which the shield can increase in temperature during the test; conduction, convection, and radiation.

Conduction:
The means for the shield to be heated by conduction is heat transfer from the 316/316L stainless steel housing of the package through the two-component chocking compound used to constrain the shield and through the polyurethane foam encasing the shield. Assuming the temperature of the stainless

incremental change in temperature of the depleted Uranium shield. This process is repeated using the new temperature resulting from solving Equation 2, until the required overall time period is spanned.

Using the experimentally derived thermal constant C = 3.445, and substituting the parameters for the Hypothetical Accident Thermal Evaluation in accordance with 10 CFR 71.73 (c) (4):
ambient temperature: 800° C (1472° F)
initial device temperature: 48.9°C (120°F) (Assume significant insolation)

Overall heating time: 0.5 hours
View Factor: 1 (worst case)
Mass of shield: 500 lb
Specific heat of DU shield: 0.028 btu/lb/deg f
Time iteration interval: 0.001 hr (3.6 sec)
Emissivity of enclosure: 0.28 ( 316 Stainless steel)
Emissivity of DU shield: 0.91 (painted surface)

results in a final depleted Uranium shield temperature of 434° C (813° F).

See Appendix 3.6, program 2 printout for the computer code used.
See Appendix 3.6, Results printout 2 for the program input variables and results.

This analysis assumes that the enclosure of the device is at ambient temperature 800° C (1472° F). Heat transfer from free convection inside the device is assumed not to occur due to the presence of the polyurethane foam. Even if the polyurethane foam is degraded by the test, it effectively prevents the free movement of gasses necessary for convective heat transfer to the depleted Uranium shield. Informal tests performed at SPEC on this polyurethane foam indicate that the polyurethane foam, when encased in an enclosure, is able to withstand a hydrocarbon flame for 30 minutes without being completely degraded or vaporized..

Assuming a final depleted Uranium shield temperature of 434° C (813° F), any Oxygen entering the device enclosure through the vents will not significantly degrade the shield.

In addition to the mathematical analysis above, a finite element thermal analysis was performed on the shield. The finite element analysis consisted of heating the package as specified in 10 CFR 71.73(c)(4). This analysis considered all three types of heat transfer, conduction, convection, and radiation. The boundary conditions for the analysis used the temperature profile determined in earlier on figure 24. The analysis assumed that the foam in the package was not present, this allows for free convection inside the package.

The results of the finite element thermal analysis reveal that the shield does not reach a temperature where high temperature oxidation can occur. The highest temperature the shield will reach is approximately 340° C (644° F). This highest temperature occurs at the bottom edge of ear. Figure 30 is a graphical representation of the temperature distribution on the shield after thirty minutes. Figure 31 illustrates the temperature profile of the shield and the internal structural after thirty minutes in the fire test.

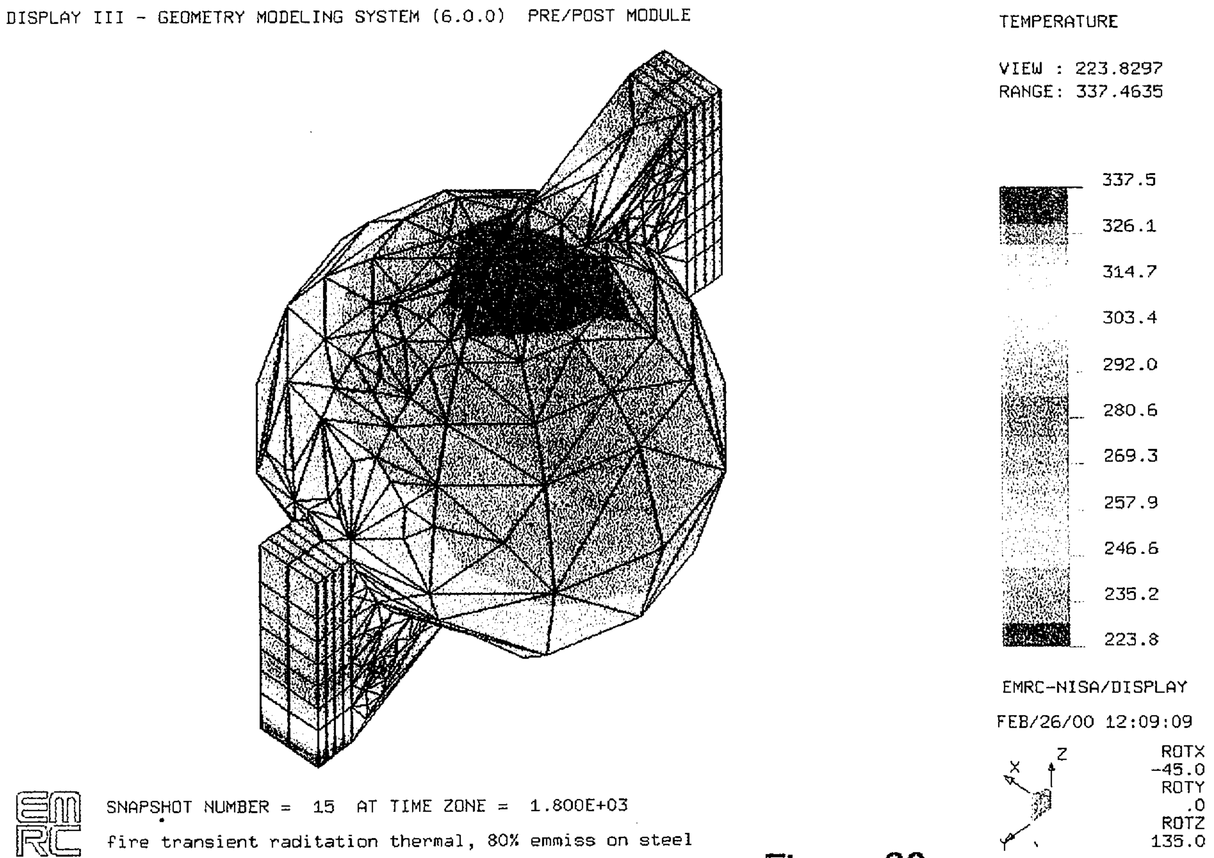


Figure 30

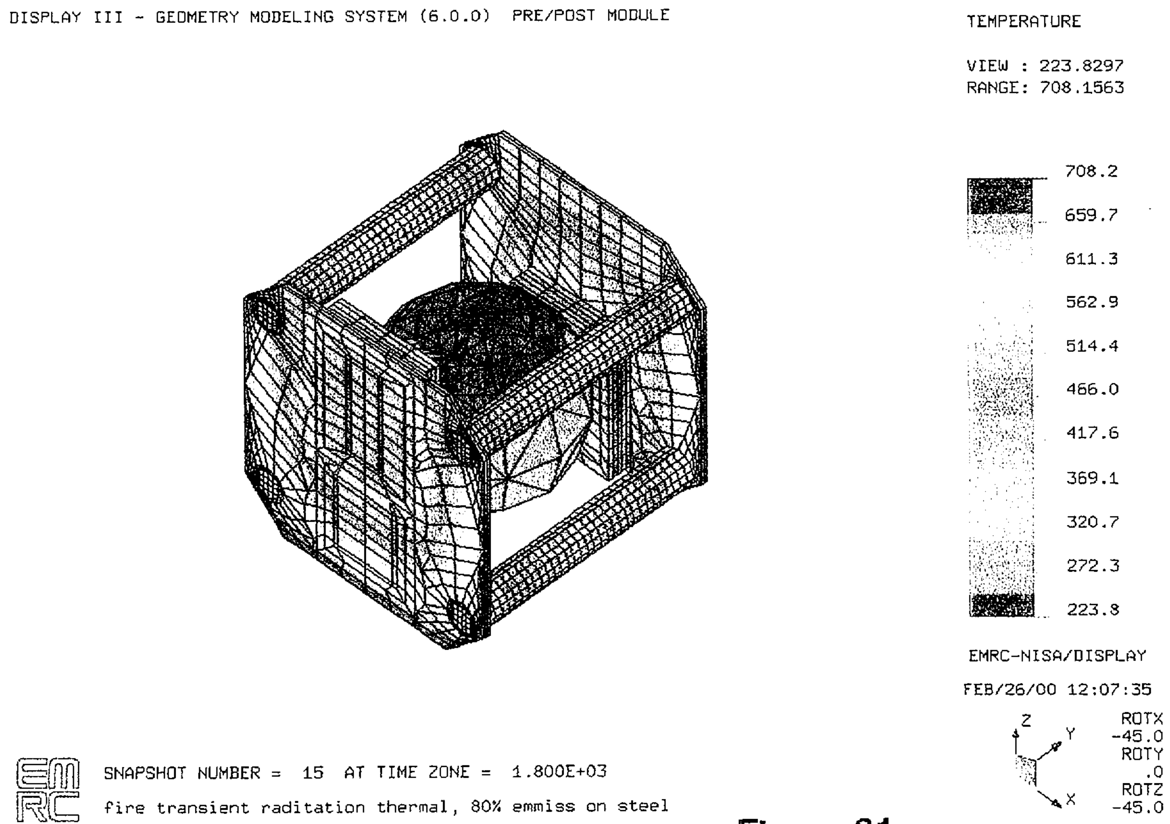


Figure 31

Summary:

To comply with the thermal requirement, the SPEC-300 package was designed such that the Depleted Uranium shield is well protected from the primary means of heat transfer from the fire to the package, convection. The package housing is robust enough not be breached as a result of the four 9 meter (30 ft) tests and a 1 meter (39.4 in) puncture test that precede the thermal test. Prototype testing proved this, and post test inspection confirmed that the welds did not crack. Analysis proves that the depleted Uranium shield will not reach temperatures that would cause loss of shielding from oxidation as a result of the Hypothetical Accident Thermal Evaluation in accordance with 10 CFR 71.73 (c) (4).

Conclusion:

The package meets the 10 CFR 71.73 (c) (4) thermal test criteria because the Depleted Uranium shield is well protected from high convective velocity heat transfer, which is the primary means of heat transfer from the fire to the packaging.