Office of Civilian Radioactive Waste Management

Waste Package Tipover of 21 PWR
CAL-UDC-ME-000005
REV 01

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1. QA: QA

2. Calculation Title
Waste Package Tipover of 21-PWR

3. Document Identifier (including Revision Number)
CAL-UDC-ME-000005 REV 01

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7	I-2, II-1, III-10 Attachments IV, V, VI, & VII are electronic files on one compact disc

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9. Remarks

All Attachments have been moved from REV 01D to REV 01.

Revision History

10. Revision No.	11. Description of Revision
00	Initial Issue
01	Full revision to include maximum 4-mm radial gap between inner and outer waste package shells as stated in *Waste Package Operations Fabrication Report*, TDR-EBS-ND-000003 REV 01.

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1. PURPOSE

The objective of this calculation was to determine the structural response of the 21-pressurized water reactor (PWR) Waste Package (WP) subjected to tipover onto an unyielding surface. The scope of this calculation was limited to reporting the calculation results in terms of maximum stress intensities. The information regarding the type of WP used in this calculation is based on proposed/potential sketches in Attachments I and II. This calculation is associated with the waste package design and was performed by the Waste Package Design Section in accordance with the development plan for *Waste Package Tip-Over of 21-PWR* (Ref. 11). AP-3.12Q, *Calculations*, was used to perform the calculation and develop the document (Ref. 17).

2. METHOD

The finite element calculation was performed using the commercially available ANSYS Version (V) 5.4 and LS-DYNA V950 finite element codes. The results of this calculation are provided in terms of maximum stress intensities.

The methods used to control the electronic management of data as required by AP-SV.1Q, *Control of the Electronic Management of Information* (Ref. 18), were not specified in the Development Plan, *Waste Package Tip-Over of 21-PWR* (Ref. 11). With regard to the development of this calculation, the control of the electronic management of data was evaluated in accordance with AP-SV.1Q. The evaluation (Ref. 9) determined that current work processes and procedures are adequate for the control of electronic management of data for this activity.

3. ASSUMPTIONS

In the course of developing this document, the following assumptions were made regarding the WP structural calculations.

3.1 Some of the temperature-dependent material properties were not available for SB-575 N06022 (Alloy 22), SA-240 S31600 (316NG [nuclear grade] stainless steel [SS]), and SA-516 K02700 (516 carbon steel [CS]). Therefore, room-temperature (20 °C) material properties were assumed for all materials. The impact of using room-temperature material properties was anticipated to be small. The rationale for this assumption was that the mechanical properties of these materials do not change significantly at the temperatures experienced during handling and lifting operations. This assumption was used in Section 5.1.

3.2 Some of the rate-dependent material properties were not available for the materials used. Therefore, the material properties obtained under the static loading conditions were assumed for all materials. The impact of using material properties obtained under static loading conditions was anticipated to be small. The rationale for this assumption was that the

mechanical properties of subject materials do not significantly change at the peak strain rates in the course of the tip-over. This assumption was used in Section 5.1.

3.3 The Poisson's ratio of Alloy 22 was not available in literature. Therefore, the Poisson's ratio of Alloy 625 (SB-443 N06625) was assumed for Alloy 22. The impact of this assumption was anticipated to be negligible. The rationale for this assumption was that the chemical compositions of Alloy 22 and Alloy 625 are similar (Ref. 3 and Ref. 1, respectively). This assumption was used in Section 5.1.

3.4 The thermal shunts were removed for the purpose of this calculation. The rationale for this conservative assumption was that the purpose of the thermal shunts was not to provide structural support. Their removal provided a bounding set of results, while simplifying the finite element representation (FER). This assumption was used in Section 5.5.

3.5 The target surface was conservatively assumed to be unyielding with a large elastic modulus for the target surface material compared to the WP materials. The rationale for this assumption was that a bounding set of results was required in terms of stresses, and it was known that the use of an unyielding surface with high stiffness ensures slightly higher stresses in the WP. This assumption was used in Section 5.5.

3.6 The exact geometry of the PWR Fuel Assembly was simplified for the purpose of this calculation in such a way that its total mass, 773.4 *kg* (see Section 5.3), was assumed to be distributed within a 304 SS bar of square cross section with uniform mass density. The rationale for this conservative assumption was to provide the set of bounding results, while simplifying the FER. This assumption was used in Section 5.5.

3.7 Poisson's ratio was not available for 516 CS. Therefore, Poisson's ratio of cast carbon steel was assumed for 516 CS. The impact of this assumption was anticipated to be negligible. The rationale for this assumption was that the elastic constants of cast carbon steels are only slightly affected by changes in composition and structure (Ref. 2). This assumption was used in Section 5.1.

3.8 The elongation of Alloy 22 and 316NG SS at elevated temperatures was not available from traditional sources. However, vendor data is available (Ref. 15 and Ref. 20). The percent difference between elongation at room temperature and elevated temperatures can be normalized and applied to the data available from accepted codes. The rationale for this assumption was to be as reasonably accurate as possible. It would not be logical for the elongation values to remain constant over the range of temperatures under consideration. This assumption was used in Section 5.1.1.

3.9 Three-stage deformation characteristics are not observed in the stress-strain curves for Alloy 22 or Type 316 stainless steel (Ref. 21). However, in order to capture the peak elongations

of the material from the curves, the total elongation should be conservatively reduced by 10%. The rationale for this assumption is to truncate the last portion of the curve that has decreasing slope. This assumption is used in Section 5.2.2.

4. USE OF COMPUTER SOFTWARE AND MODELS

4.1 SOFTWARE

One of the two finite element analysis computer codes used for this calculation is ANSYS V5.4 (Ref. 23), which was obtained from Software Configuration Management in accordance with appropriate procedures, and is identified by the Computer Software Configuration Item (CSCI) 30040 V5.4. ANSYS V5.4 is a commercially available finite element analysis code and is appropriate for structural calculations of waste packages as performed in this calculation. The calculation using the ANSYS V5.4 software was executed on the Hewlett-Packard (HP) workstation identified with CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) tag number 700315. The software qualification of ANSYS V5.4 was summarized in Reference 7. Qualification of ANSYS V5.4 on the Waste Package Operations (WPO) HP UNIX workstations was documented in Reference 12, 13, 14, and 22. The ANSYS evaluation performed for this calculation is fully within the range of the validation performed for the ANSYS V5.4 code. Access to the code was granted by the Software Configuration Secretariat in accordance with the appropriate procedures.

The input files (identified by .inp file extensions) and output files (identified by .out file extensions) for ANSYS V5.4 are provided in Attachments IV and V.

The second finite element analysis computer code, used for this calculation is Livermore Software Technology Corporation (LSTC) LS-DYNA V950, which is unqualified software (see Ref. 8). The interim use of LS-DYNA V950 (SAN: LV-2000-103, STN: 10300-950-00) in support of the site recommendation is delineated in Section 5.11 of AP-SI.1Q, *Software Management*, (Ref. 19). LS-DYNA V950 qualification is being performed as part of the qualification of ANSYS V5.6 since LS-DYNA V950 is available both as a component (module) of ANSYS and as a separate finite element code. Currently, Waste Package Department licensed LS-DYNA V950 directly from LSTC. Software Activity Plan (SAP) for ANSYS V5.6, SDN: 10145-SAP-5.6-00, SAN: LV-1999-124, identifies the intended use of LS-DYNA V950 prior to qualification. LS-DYNA V950 was obtained from the Software Configuration Secretariat. LS-DYNA V950 is appropriate for its intended use. LS-DYNA V950 validation will be performed in accordance with AP-SI.1Q, *Software Management*, Section 5.11. The calculations were executed on a Hewlett-Packard (HP) 9000 series workstation (CRWMS M&O tag number 117162).

The input files (identified by .k and .inc file extensions) and output files (d3hsp) for LS-DYNA V950 are provided in Attachments IV and V.

4.2 SOFTWARE ROUTINES

None used.

4.3 MODELS

None used.

5. CALCULATION

5.1 MATERIAL PROPERTIES

Material properties used in these calculations are listed in this section. Some of the temperature-dependent and rate-dependent material properties are not available for Alloy 22, 316NG SS, 516 CS, and 304 SS. Therefore, room-temperature density, Poisson's ratio, and elongation obtained under the static loading conditions are used for Alloy 22, 316NG SS, 516 CS, and 304 SS (see Assumption 3.1 and 3.3).

SB-575 N06022 (Alloy 22) (Outer shell, outer shell lids, extended outer shell lid base, outer shell lifting features, upper and lower trunnion collar sleeves, and inner shell support ring):

- Density = 8690 kg/m^3 (0.314 lb/in^3) (at room temperature) (Ref. 3, Section II, SB-575 Section 7.1)

- Yield strength = 310 *MPa* (45 *ksi*) (at room temperature) (Ref. 3, Section II, Table Y-1)
  Yield strength = 236 *MPa* (34.3 *ksi*) (at 400 °F = 204 °C) (Ref. 3, Section II, Table Y-1)
  Yield strength = 211 *MPa* (30.6 *ksi*) (at 600 °F = 316 °C) (Ref. 3, Section II, Table Y-1)

- Tensile strength = 690 *MPa* (100 *ksi*) (at room temperature) (Ref. 3, Section II, Table U)
  Tensile strength = 657 *MPa* (95.3 *ksi*) (at 400 °F = 204 °C) (Ref. 3, Section II, Table U)
  Tensile strength = 628 *MPa* (91.1 *ksi*) (at 600 °F = 316 °C) (Ref. 3, Section II, Table U)

- Elongation = 0.45 (at room temperature) (Ref. 3, Section II, SB-575 Table 3)

- Poisson's ratio = 0.278 (at room temperature) (Ref. 1, p. 143; see Assumption 3.3)

- Modulus of elasticity = 206 *GPa* (at room temperature) (Ref. 15, p. 14)
  Modulus of elasticity = 196 *GPa* (at 400 °F = 204 °C) (Ref. 15, p. 14)
  Modulus of elasticity = 190 *GPa* (at 600 °F = 316 °C) (Ref. 15, p. 14)

SA-240 S31600 (See Ref. 3) (Identical to ASTM A 240) (316NG SS, which is 316 SS with tightened control on carbon and nitrogen content and has the same material properties as 316 SS [see Ref. 16]) (Inner shell, inner shell lids, and inner shell lifting feature):

- Density = 7980 kg/m^3 (at room temperature) (Ref. 4, Table X1, p. 7)

- Yield strength = 207 *MPa* (30 *ksi*) (at room temperature) (Ref. 3, Section II, Table Y-1)
  Yield strength = 148 *MPa* (21.4 *ksi*) (at 400 $^\circ F = 204\ ^\circ C$) (Ref. 3, Section II, Table Y-1)
  Yield strength = 130 *MPa* (18.9 *ksi*) (at 600 $^\circ F = 316\ ^\circ C$) (Ref. 3, Section II, Table Y-1)

- Tensile strength = 515 *MPa* (75 *ksi*) (at room temperature) (Ref. 3, Section II, Table U)
  Tensile strength = 496 *MPa* (71.9 *ksi*) (at 400 $^\circ F = 204\ ^\circ C$) (Ref. 3, Section II, Table U)
  Tensile strength = 495 *MPa* (71.8 *ksi*) (at 600 $^\circ F = 316\ ^\circ C$) (Ref. 3, Section II, Table U)

- Elongation = 0.40 (at room temperature) (Ref. 3, Section II, SA-240 Table 2)

- Poisson's ratio = 0.298 (at room temperature) (Ref. 1, Figure 15, p. 755)

- Modulus of elasticity = 195 *GPa* ($28.3 \cdot 10^6$ *psi*) (at room temperature) (Ref. 3, Section II, Table TM-1)
  Modulus of elasticity = 183 *GPa* ($26.5 \cdot 10^6$ *psi*) (at 400 $^\circ F = 204\ ^\circ C$) (Ref. 3, Section II, Table TM-1)
  Modulus of elasticity = 174 *GPa* ($25.3 \cdot 10^6$ *psi*) (at 600 $^\circ F = 316\ ^\circ C$) (Ref. 3, Section II, Table TM-1)

SA-516 K02700 (516 CS) (Sideguides, stiffeners, and baskets):

- Density = 7850 kg/m^3 (at room temperature) (Ref. 4, Table X1, p. 7)

- Yield strength = 262 *MPa* (38 *ksi*) (at room temperature) (Ref. 3, Table Y-1)
  Yield strength = 224 *MPa* (32.5 *ksi*) (at 400 $^\circ F = 204\ ^\circ C$) (Ref. 3, Table Y-1)
  Yield strength = 201 *MPa* (29.1 *ksi*) (at 600 $^\circ F = 316\ ^\circ C$) (Ref. 3, Table Y-1)

- Tensile strength = 483 *MPa* (70 *ksi*) (at room temperature) (Ref. 3, Table U)
  Tensile strength = 483 *MPa* (70 *ksi*) (at 400 $^\circ F = 204\ ^\circ C$) (Ref. 3, Table U)
  Tensile strength = 483 *MPa* (70 *ksi*) (at 600 $^\circ F = 316\ ^\circ C$) (Ref. 3, Table U)

- Elongation = 0.21 (at room temperature) (Ref. 3, SA-240 Table 2)

- Poisson's ratio = 0.3 (at room temperature) (Ref. 2, p. 374; see Assumption 3.7)

- Modulus of elasticity = 203 GPa ($29.5 \cdot 10^6$ psi) (at room temperature) (Ref. 3, Table TM-1)
  Modulus of elasticity = 191 GPa ($27.7 \cdot 10^6$ psi) (at 400 $^\circ F = 204\ ^\circ C$) (Ref. 3, Table TM-1)
  Modulus of elasticity = 184 GPa ($26.7 \cdot 10^6$ psi) (at 600 $^\circ F = 316\ ^\circ C$) (Ref. 3, Table TM-1)

SA-240 S30400 (see Ref. 3) (304 SS) (PWR Fuel Assembly):

- Yield strength = 205 MPa (30 ksi) (at room temperature) (Ref. 3, Table Y-1)
  Yield strength = 143 MPa (20.7 ksi) (at 400 $^\circ F = 204\ ^\circ C$) (Ref. 3, Table Y-1)
  Yield strength = 127 MPa (18.4 ksi) (at 600 $^\circ F = 316\ ^\circ C$) (Ref. 3, Table Y-1)

- Tensile strength = 517 MPa (75 ksi) (at room temperature) (Ref. 3, Table U)
  Tensile strength = 441 MPa (64 ksi) (at 400 $^\circ F = 204\ ^\circ C$) (Ref. 3, Table U)
  Tensile strength = 437 MPa (63.4 ksi) (at 600 $^\circ F = 316\ ^\circ C$) (Ref. 3, Table U)

- Elongation = 0.40 (at room temperature) (Ref. 3, SA-240 Table 2)

- Poisson's ratio = 0.3 (at room temperature) (Ref. 1, Figure 15, p. 755) (see Assumption 3.8)

- Modulus of elasticity = 195 GPa ($28.3 \cdot 10^6$ psi) (at room temperature) (Ref. 3, Table TM-1)
  Modulus of elasticity = 183 GPa ($26.5 \cdot 10^6$ psi) (at 400 $^\circ F = 204\ ^\circ C$) (Ref. 3, Table TM-1)
  Modulus of elasticity = 174 GPa ($25.3 \cdot 10^6$ psi) (at 600 $^\circ F = 316\ ^\circ C$) (Ref. 3, Table TM-1)

5.1.1 Calculations for Elevated-Temperature Material Properties

The values for elongation at elevated temperatures are not listed in conventional listings such as American Society for Testing and Materials (ASTM) Standards or American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code. However, the elongation values at elevated temperatures are available from vendor data. This vendor data will be used in a *qualitative* manner (see Assumption 3.8).

For Alloy 22, the vendor data shows a 6.1% increase in elongation values between 400 °F and room temperature and a 9.7% increase between 600 °F and room temperature (Ref. 15).

Therefore, the elongation values for Alloy 22 at elevated temperatures will be as follows:

Elongation = $0.45 \cdot 1.061 = 0.48$ (at $400\ ^{o}F = 204\ ^{o}C$)
Elongation = $0.45 \cdot 1.097 = 0.49$ (at $600\ ^{o}F = 316\ ^{o}C$)

For 316NG SS, the vendor data shows a 25% decrease in elongation values between 400 °F and room temperature and a 29% decrease between 600 °F and room temperature (Ref. 20).

Therefore, the elongation values for 316NG SS at elevated temperatures will be as follows:

Elongation = $0.40 \cdot (1 - 0.25) = 0.30$ (at $400\ ^{o}F = 204\ ^{o}C$)
Elongation = $0.40 \cdot (1 - 0.29) = 0.28$ (at $600\ ^{o}F = 316\ ^{o}C$)

Since the components made of 516 CS and 304 SS will not be analyzed for stresses, their elongation is not needed at elevated temperatures. The 516 CS and 304 SS components are only needed for their density.

5.1.2 Calculations for True Measures of Ductility

The material properties in Section 5.1 refer to engineering stress and strain definitions:

$$s = \frac{P}{A_0} \text{ and } e = \frac{L - L_0}{L_0}$$

Where P stands for the force applied during static tensile test, L is the deformed-specimen length, and L_0 and A_0 are original length and cross-sectional area of specimen, respectively. It is generally accepted that the engineering stress-strain curve does not give a true indication of the deformation characteristics of a material during the plastic deformation since it is based entirely on the original dimensions of the specimen. Therefore, the LS-DYNA V950 finite element code requires input in terms of true stress and strain definitions:

$$\sigma = \frac{P}{A} \text{ and } \varepsilon = \ln\left(\frac{L}{L_0}\right)$$

The relationships between the true stress and strain definitions and engineering stress and strain definitions can be readily derived based on constancy of volume ($A_0 \cdot L_0 = A \cdot L$) and strain homogeneity during plastic deformation:

$\sigma = s \cdot (1 + e)$ and $\varepsilon = \ln(1 + e)$

These expressions are applicable only in the hardening region of stress-strain curve that is limited by the onset of necking.

The following parameters are used in the subsequent calculations:

$s_y \approx \sigma_y$ = yield strength
s_u = engineering tensile strength
σ_u = true tensile strength
$e_y \approx \varepsilon_y$ = strain corresponding to yield strength
e_u = engineering strain corresponding to tensile strength (engineering uniform strain)
ε_u = true strain corresponding to tensile strength (true uniform strain)

In absence of the uniform strain data in available literature, it needs to be estimated based on stress-strains curves and elongation (strain corresponding to rupture of the tensile specimen).

The stress-strain curves for Alloy 22, 304 SS and 316NG SS do not manifest three-stage deformation characteristics. Therefore, the elongation, reduced by 10% for the sake of conservativism can be used in place of uniform strain (see Assumption 3.9).

In the case of Alloy 22 the true measures of ductility are:

$e_u = 0.9 \cdot elongation = 0.41$ (at room temperature)
$e_u = 0.9 \cdot 0.48 = 0.43$ (at $400\ ^\circ F = 204\ ^\circ C$)
$e_u = 0.9 \cdot 0.49 = 0.44$ (at $600\ ^\circ F = 316\ ^\circ C$)
$\varepsilon_u = \ln(1 + e_u) = \ln(1 + 0.41) = 0.34$ (at room temperature)
$\varepsilon_u = \ln(1 + e_u) = \ln(1 + 0.43) = 0.36$ (at $400\ ^\circ F = 204\ ^\circ C$)
$\varepsilon_u = \ln(1 + e_u) = \ln(1 + 0.44) = 0.36$ (at $600\ ^\circ F = 316\ ^\circ C$)
$\sigma_u = s_u \cdot (1 + e_u) = 690 \cdot (1 + 0.41) = 973\ MPa$ (at room temperature)
$\sigma_u = s_u \cdot (1 + e_u) = 657 \cdot (1 + 0.43) = 940\ MPa$ (at $400\ ^\circ F = 204\ ^\circ C$)
$\sigma_u = s_u \cdot (1 + e_u) = 641 \cdot (1 + 0.44) = 923\ MPa$ (at $600\ ^\circ F = 316\ ^\circ C$)

For 316NG SS:

$e_u = 0.9 \cdot elongation = 0.36$ (at room temperature)
$e_u = 0.9 \cdot 0.30 = 0.27$ (at $400\ ^\circ F = 204\ ^\circ C$)
$e_u = 0.9 \cdot 0.28 = 0.25$ (at $600\ ^\circ F = 316\ ^\circ C$)
$\varepsilon_u = \ln(1 + e_u) = \ln(1 + 0.36) = 0.31$ (at room temperature)
$\varepsilon_u = \ln(1 + e_u) = \ln(1 + 0.27) = 0.24$ (at $400\ ^\circ F = 204\ ^\circ C$)
$\varepsilon_u = \ln(1 + e_u) = \ln(1 + 0.25) = 0.22$ (at $600\ ^\circ F = 316\ ^\circ C$)
$\sigma_u = s_u \cdot (1 + e_u) = 515 \cdot (1 + 0.36) = 700\ MPa$ (at room temperature)
$\sigma_u = s_u \cdot (1 + e_u) = 496 \cdot (1 + 0.27) = 630\ MPa$ (at $400\ ^\circ F = 204\ ^\circ C$)
$\sigma_u = s_u \cdot (1 + e_u) = 495 \cdot (1 + 0.25) = 619\ MPa$ (at $600\ ^\circ F = 316\ ^\circ C$)

5.2 CALCULATIONS FOR TANGENT MODULI

The results of this simulation were required to include elastic and plastic deformations for Alloy 22, 316NG SS, 516 CS, and 304 SS. When the materials are driven into the plastic range, the slope of stress-strain curve continuously changes. Thus, a simplification for this curve was needed to incorporate plasticity into the FER. A standard approximation commonly used in engineering is to use a straight line that connects the yield point and the ultimate tensile strength point of the material. The parameters used in the subsequent calculations in addition to those defined in Section 5.1.2 are modulus of elasticity (E) and tangent modulus (E_1). The tangent (hardening) modulus represents the slope of the stress-strain curve in the plastic region.

In the case of 316NG SS, the strain corresponding to the yield strength is:

$\varepsilon_y = \sigma_y / E = 205 \cdot 10^6 / 195 \cdot 10^9 = 1.05 \cdot 10^{-3}$ (at room temperature) (see Section 5.1 and Section 5.1.1)

Hence, the tangent modulus is:

$E_1 = (\sigma_u - \sigma_y)/(\varepsilon_u - \varepsilon_y) = (0.700 - 0.205)/(0.31 - 1.05 \cdot 10^{-3}) = 1.6\ GPa$ (at room temperature) (see Section 5.1 and Section 5.1.1)
$E_1 = (\sigma_u - \sigma_y)/(\varepsilon_u - \varepsilon_y) = (0.630 - 0.148)/(0.24 - 0.148/183) = 2.0\ GPa$ (at $400\ ^\circ F = 204\ ^\circ C$) (see Section 5.1 and Section 5.1.1)
$E_1 = (\sigma_u - \sigma_y)/(\varepsilon_u - \varepsilon_y) = (0.619 - 0.130)/(0.22 - 0.130/174) = 2.2\ GPa$ (at $600\ ^\circ F = 316\ ^\circ C$) (see Section 5.1 and Section 5.1.1)

Similarly, for Alloy 22:

$E_1 = (\sigma_u - \sigma_y)/(\varepsilon_u - \varepsilon_y) = (0.973 - 0.310)/(0.34 - 0.310/206) = 2.0\ GPa$ (at room temperature) (see Section 5.1 and Section 5.1.1)
$E_1 = (\sigma_u - \sigma_y)/(\varepsilon_u - \varepsilon_y) = (0.940 - 0.236)/(0.36 - 0.236/196) = 2.0\ GPa$ (at $400\ ^\circ F = 204\ ^\circ C$) (see Section 5.1 and Section 5.1.1)
$E_1 = (\sigma_u - \sigma_y)/(\varepsilon_u - \varepsilon_y) = (0.923 - 0.211)/(0.36 - 0.211/190) = 2.0\ GPa$ (at $600\ ^\circ F = 316\ ^\circ C$) (see Section 5.1 and Section 5.1.1)

For 516 CS:

$E_1 = (\sigma_u - \sigma_y)/(\varepsilon_u - \varepsilon_y) = (0.483 - 0.262)/(0.21 - 0.262/203) = 1.1\ GPa$ (at room temperature) (see Section 5.1 and Section 5.1.1)

And for 304 SS:

$E_1 = (\sigma_u - \sigma_y)/(\varepsilon_u - \varepsilon_y) = (0.517 - 0.205)/(0.40 - 0.205/0.195) = 0.78\ GPa$ (at room temperature) (see Section 5.1 and Section 5.1.1)

Again since the components made of 516 CS and 304 SS will not be analyzed for stresses, the tangent modulus for these materials is not needed at elevated temperatures. The 516 CS and 304 SS components are only needed for their density.

5.3 MASS AND GEOMETRIC DIMENSIONS OF PWR FUEL ASSEMBLY

This calculation was performed by using the following mass and geometric dimensions of the PWR Fuel Assemblies:

Total mass = 773.4 *kg* (Ref. 5, Table 7-1, p. 22)
Width = 216.9 *mm* (Ref. 5, Table 7-1, p. 22)
Overall length = 4.407 *m* (Ref. 5, Table 7-1, p. 22)

5.3.1 Calculation of Density of PWR Fuel Assembly

This calculation was performed by using the following density for the PWR fuel assembly.

Volume $= w^2 \cdot h = 0.217^2 \cdot 4.407 = 0.208\ m^3$

Density $= \frac{m}{v} = \frac{773.4}{0.208} = 3718\ \frac{kg}{m^3}$

5.4 INITIAL VELOCITY OF WASTE PACKAGE

To reduce the computer execution time while preserving all features of the problem relevant to the structural calculation, the WP is set in a position just before impact and given an appropriate initial angular velocity.

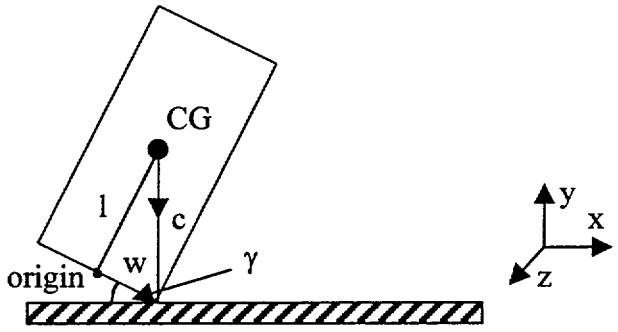

Figure 1. Tipover Geometry

Using the following parameters:

g = acceleration due to gravity $= 9.81\ m/s^2$

M = total mass $= 4.291 \cdot 10^4\ kg$ (See Attachment I, page I-2)

mass moment of inertia about z axis located at the center of gravity (Iz) was calculated using LS-DYNA V950 with the unyielding surface omitted. LS-DYNA V950 calculates the mass properties of the FER prior to solving the problem. The following results block was taken in the exact format from Attachment V, d3hsp, lines 29704 through 29713:

```
m a s s   p r o p e r t i e s   o f   b o d y
     total mass of body          =     .3977E+05
     x-coordinate of mass center =     .2574E+01
     y-coordinate of mass center =     .4492E-02
     z-coordinate of mass center =    -.4536E-06

     inertia tensor of body
     row1=       .1389E+05      -.1455E+03      -.7632E-01
     row2=      -.1455E+03       .9717E+05       .5611E-06
     row3=      -.7632E-01       .5611E-06       .9719E+05
```

NOTE: The mass calculated from LS-DYNA V950 is slightly lower than that listed in Attachment I, due to the 4-*mm* radial gap between the inner and outer shells, as opposed to the 0-*mm* radial gap in Attachment I. The difference was small and the impact was anticipated to be negligible, however the mass listed in Attachment I was used in the subsequent calculations as the bounding mass.

In this case, the WP is rotating about the z axis, thus Iz = Izz= $9.719 \cdot 10^4\ kg \cdot m^2$

The following geometric parameters were also used in subsequent calculations:

x = 2.574 *m* = distance in the x direction to the center of gravity from the origin
y = 0.0045 *m* = distance in the y direction to the center of gravity from the origin

Since this forms a right triangle:

$$l = \sqrt{x^2 + y^2} = \sqrt{2.574^2 + 0.0045^2} = 2.574\ m$$

w = ½ the outer diameter of the trunnion collar sleeve = 0.822 *m* (Attachment I-1)

Again, since this forms a right triangle:

$$c = \sqrt{l^2 + w^2} = \sqrt{2.574^2 + 0.822^2} = 2.702\ m$$

Also,

$$\gamma = \text{angle necessary for tip-over} = \tan^{-1}\left(\frac{w}{l}\right) = 17.7°$$

Using the parallel axis thereom, the mass moment of inertia about the point of rotation:

$$I = Iz + Mc^2 = 9.719 \cdot 10^4 + 4.230 \cdot 10^4 \cdot 2.702^2 = 4.060 \cdot 10^5\ kg \cdot m^2$$

Using Newton's second law of motion:

$$\sum M = I \cdot \alpha$$

$M \cdot g \cdot c \cdot \cos\theta = I \cdot \alpha$, where θ is the angle of rotation and α is the rotational acceleration

It follows that:

$$\alpha = \frac{M \cdot g \cdot c \cdot \cos\theta}{I} = \frac{4.230 \cdot 10^4 \cdot 9.81 \cdot 2.702 \cdot \cos\theta}{4.060 \cdot 10^5} = 2.76 \cdot \cos\theta$$

Knowing:

$v = \frac{ds}{dt}$ and $a = \frac{dv}{dt}$, where s is displacement, v is velocity, and a is acceleration, velocity in terms of acceleration can be found by rearranging and substituting:

$$dt = \frac{dv}{a}$$

$$v = \frac{ds}{\frac{dv}{a}}$$

$$v \cdot \frac{dv}{a} = ds$$

Thus: $v \cdot dv = a \cdot ds$ or for rotational velocity: $\omega \cdot d\omega = \alpha \cdot d\theta$

Integrating over angle of tip-over:

$$\int_0^{\omega} \omega \cdot d\omega = \int_{\frac{\pi}{2}}^{\gamma} \alpha \cdot d\theta$$

$$\frac{\omega^2}{2} = 2.76 \cdot (\sin\theta)\Big|_{\frac{\pi}{2}}^{\gamma} = 2.76 \cdot \left[-\sin\left(17.7 \cdot \frac{\pi}{180}\right) + \sin\left(\frac{\pi}{2}\right) \right] = 1.92$$

$$\omega = 1.96 \ \frac{rad}{s}$$

5.5 FINITE ELEMENT REPRESENTATION

A full three-dimensional (3-D) FER of the WP was developed in ANSYS V5.4 by using the dimensions provided in Attachment I. The FER was created with the largest possible radial gap of 4 *mm* between the inner and outer shells (Ref. 10). The initial orientation of the inner shell maintains this 4-*mm* gap around the circumference of the shell. The internal structure of the WP was simplified in several ways. First, the thermal shunts were removed (Assumption 3.4). Second, the sideguides, stiffeners, and baskets were combined and created as shell elements with an assigned thickness of 10, 15, and 20 *mm* in the respective regions. Next, the structure of the PWR fuel assemblies were reduced to bars with a square cross section and uniform mass density, and assumed to be unyielding (Assumption 3.6). The total mass and geometric dimensions of the PWR fuel assembly (see Section 5.3) define the density. The benefit of using this approach was to reduce the computer execution time while preserving all features of the problem relevant to the structural calculation.

The target surface was conservatively assumed to be unyielding with a large elastic modulus (Assumption 3.5).

The mesh of the FER was appropriately generated and refined in the contact region according to standard engineering practice. Thus, the accuracy and representativeness of the results of this calculation were deemed acceptable.

The initial tipover angle was reduced to 0.1° and the WP was given an appropriate initial angular velocity corresponding to the rigid-body motion of the WP (see Section 5.4).

The FER was then solved in LS-DYNA V950 to perform the transient dynamic analysis for the 21-PWR WP tipover design basis event.

6. RESULTS

This document may be affected by technical product input information that requires confirmation. Any changes to the document that may occur as a result of completing the confirmation activities will be reflected in subsequent revisions. The status of the technical product input information quality may be confirmed by review of the DIRS database.

The results obtained from LS-DYNA V950 were reported in terms of maximum shear stress. Since the maximum stress intensities were desired, the results needed to be converted. The maximum shear stress is defined as one half the difference between maximum and minimum principal stress. Stress intensity is defined as the difference between maximum and minimum principal stress. Therefore, the results obtained from LS-DYNA V950 were multiplied by two, to obtain the corresponding stress intensities.

The maximum stresses were found by carefully examining each time step taken by LS-DYNA V950, which outputs the element with the highest magnitude of stress, at each step, for each defined part. Table 1 lists the maximum stress intensities in the outer shell and inner shell at room temperature, 204 $°C$, and 316 $°C$.

Table 1. Maximum Stress Intensities

Temperature	Outer Shell	Inner Shell
Room Temperature	575 MPa (see Figure III-3)	503 MPa (see Figure III-4)
204 °C	495 MPa (see Figure III-6)	462 MPa (see Figure III-7)
316 °C	485 MPa (see Figure III-9)	446 MPa (see Figure III-10)

The above table shows that for each temperature condition, each part exceeded the yield strength, but the magnitude was less than the tensile strength of the corresponding material (see Section 5.1).

7. REFERENCES

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8. ATTACHMENTS

Attachment I (2 pages): Design sketches (*21-PWR Waste Package Configurations for Site Recommendation* [SK-0175 REV 02]; two sheets)
(This attachment uses Reference 5 and Attachment II)

Attachment II (1 page): Weld configuration sketches (*21-PWR Waste Package Weld Configuration* [SK-0191 REV 00]; one sheet)

Attachment III (10 pages): Figures obtained from LS-DYNA V950

Attachments IV, V, VI, and VII (Compact Disc):
ANSYS V5.4 and LS-DYNA V950 electronic files (Attachments VI and VII use the same .inc, .inp, and .out files as Attachment V)

Table 2 contains the file names, dates, times, and sizes in Attachments IV, V, VI, and VII.

Table 2. Input and Output files in Attachments IV, V, VI, and VII

Attachment IV

Name	Date	Time	Size
nouy.inp	08/22/2000	1:24 pm	40 KB
mainnou.k	08/22/2000	1:19 pm	2 KB
element.inc	08/22/2000	1:19 pm	745 KB
nodes.inc	08/22/2000	1:19 pm	819 KB
bcnodes.inc	08/22/2000	1:19 pm	1 KB
d3hsp	08/22/2000	1:39 pm	2,040 KB
nouy.out	08/22/2000	1:24 pm	552 KB

Attachment V

pwrtip2.inp	08/22/2000	1:27 pm	40 KB
main.k	11/09/2000	2:44 pm	3 KB
element.inc	11/09/2000	2:44 pm	1,248 KB
nodes.inc	11/09/2000	2:44 pm	1,298 KB
bcnodes.inc	11/09/2000	2:44 pm	4 KB
d3hsp	11/09/2000	2:44 pm	7,065 KB
pwrtip.out	08/22/2000	1:27 pm	577 KB

Attachment VI

main.k	11/09/2000	2:45 pm	3 KB
d3hsp	11/09/2000	2:46 pm	7,580 KB

Attachment VII

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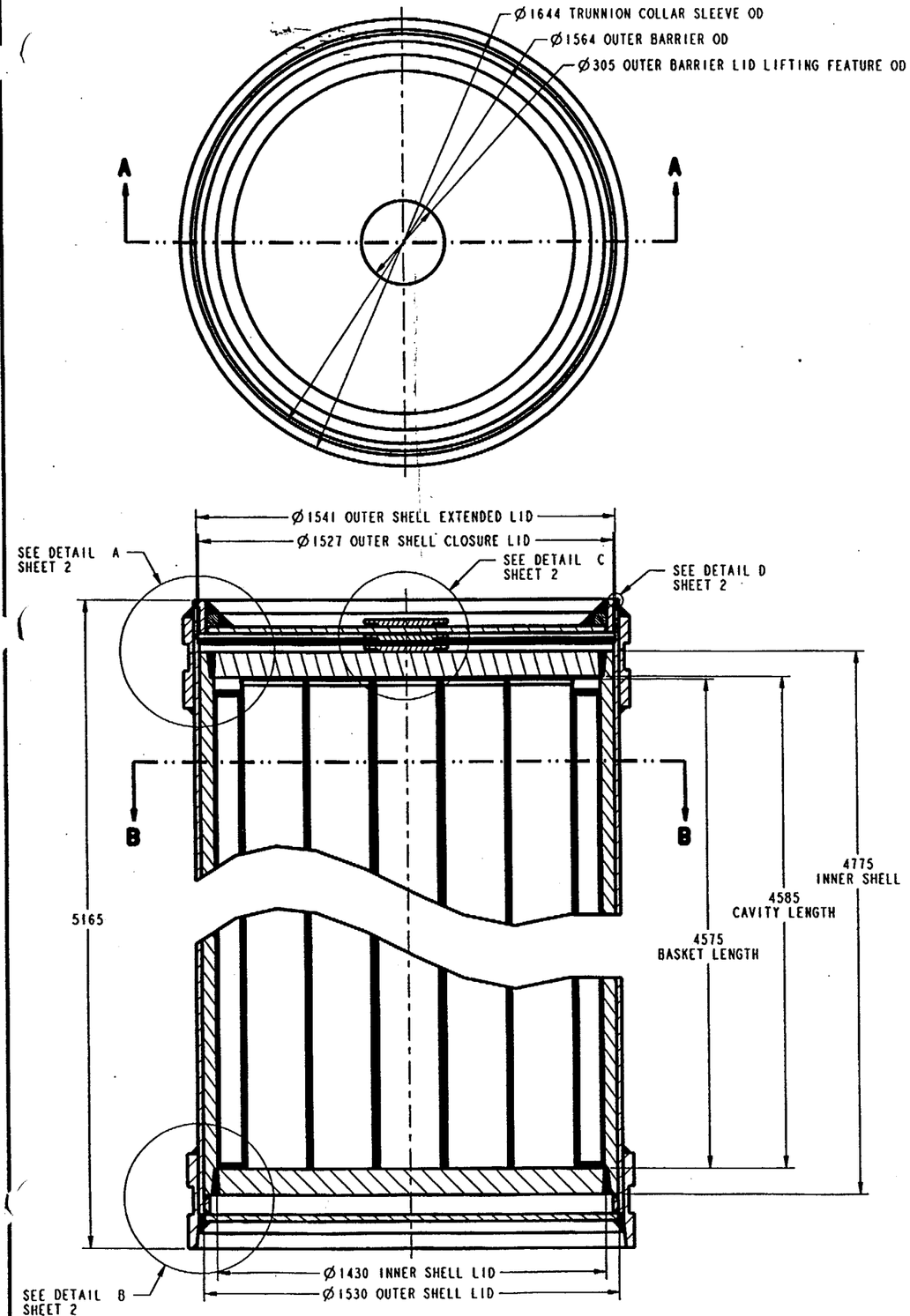
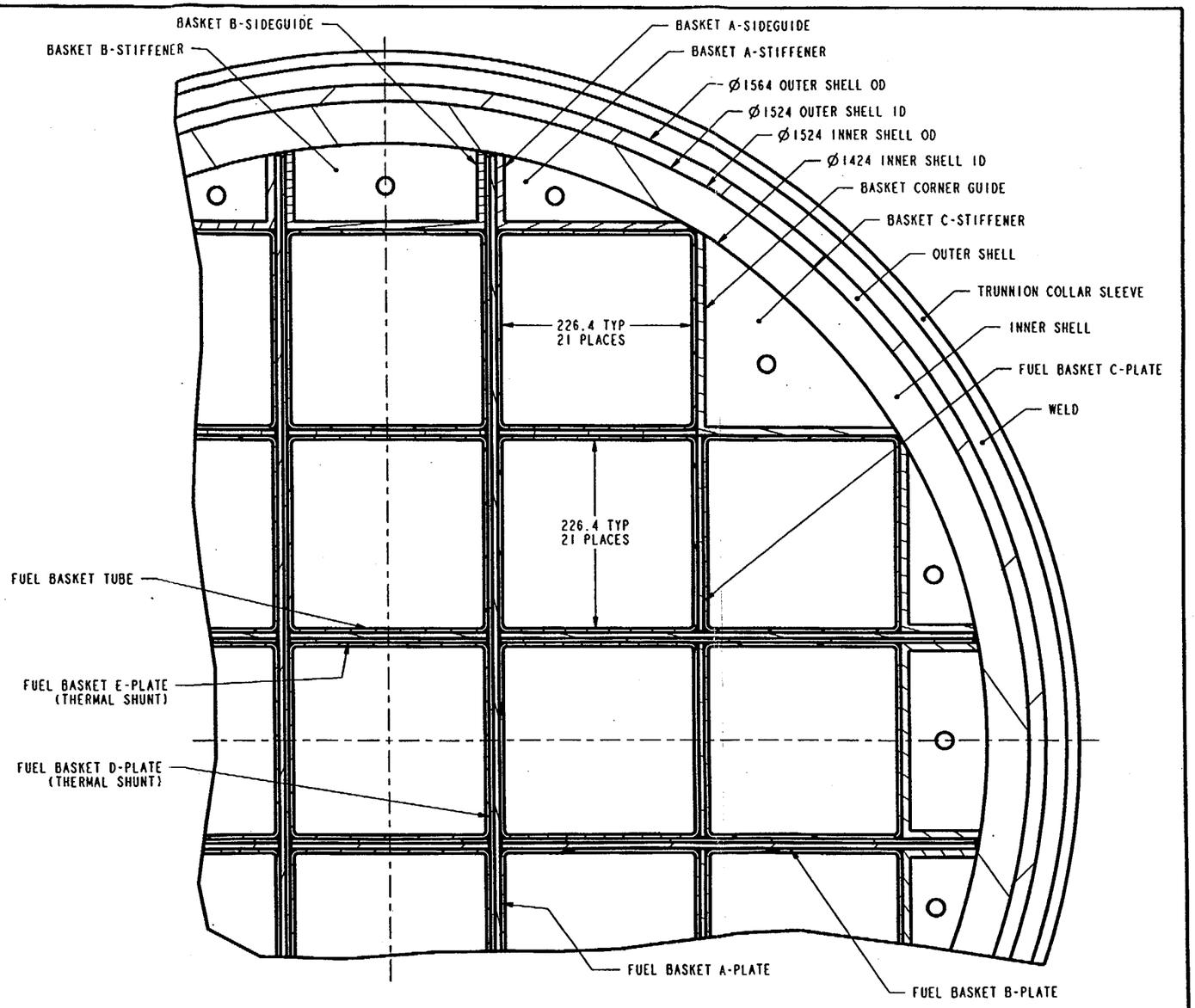
NOTE: The file sizes may vary with operating system.



SECTION A-A



SECTION B-B

"FOR INFORMATION ONLY"

UNITS: mm

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21-PWR WASTE PACKAGE CONFIGURATIONS FOR SITE RECOMMENDATION	
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SKETCHED BY: BRYAN HARKINS BH 26Jan00 JAA 1/26/00 SMB 01/26/00	
DATE: 01/26/00	
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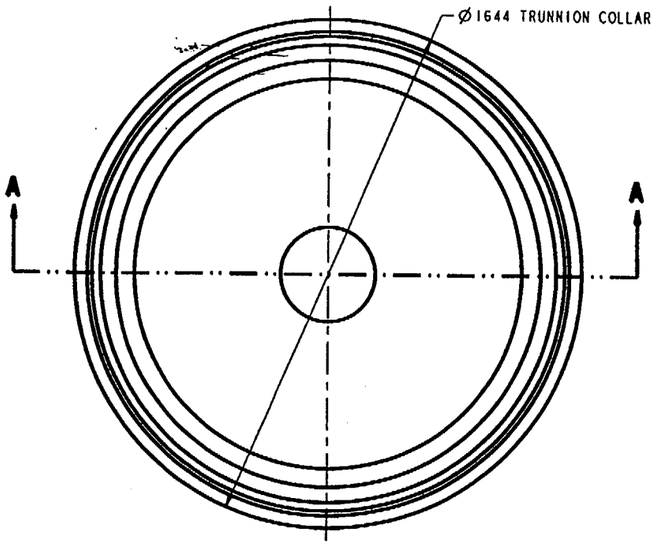
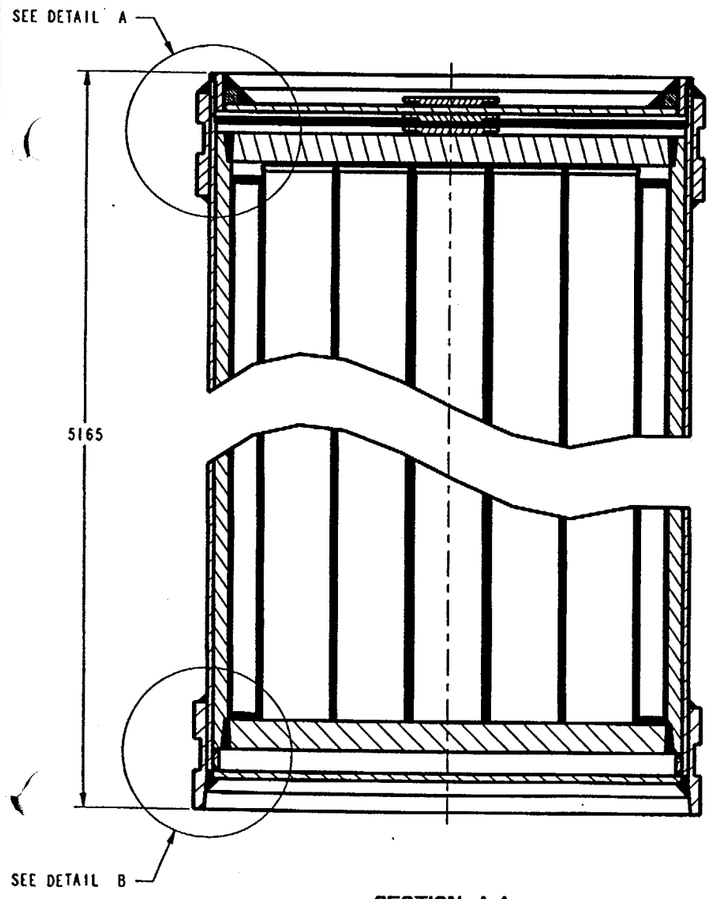
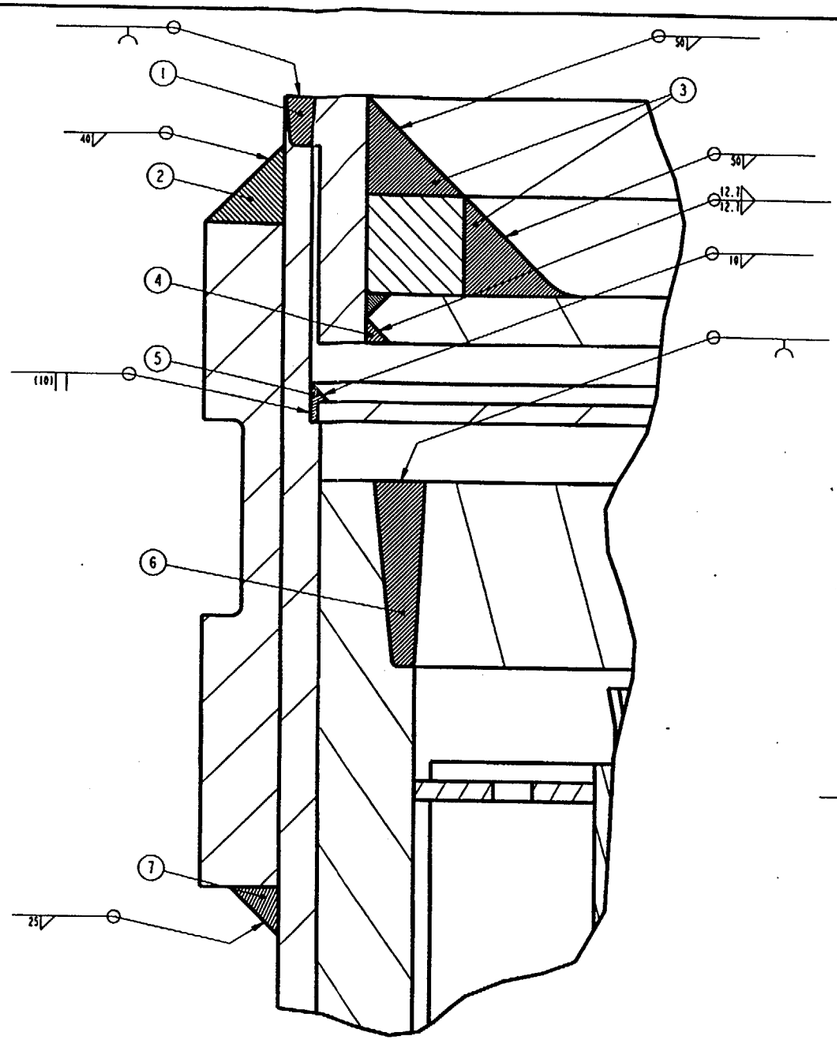
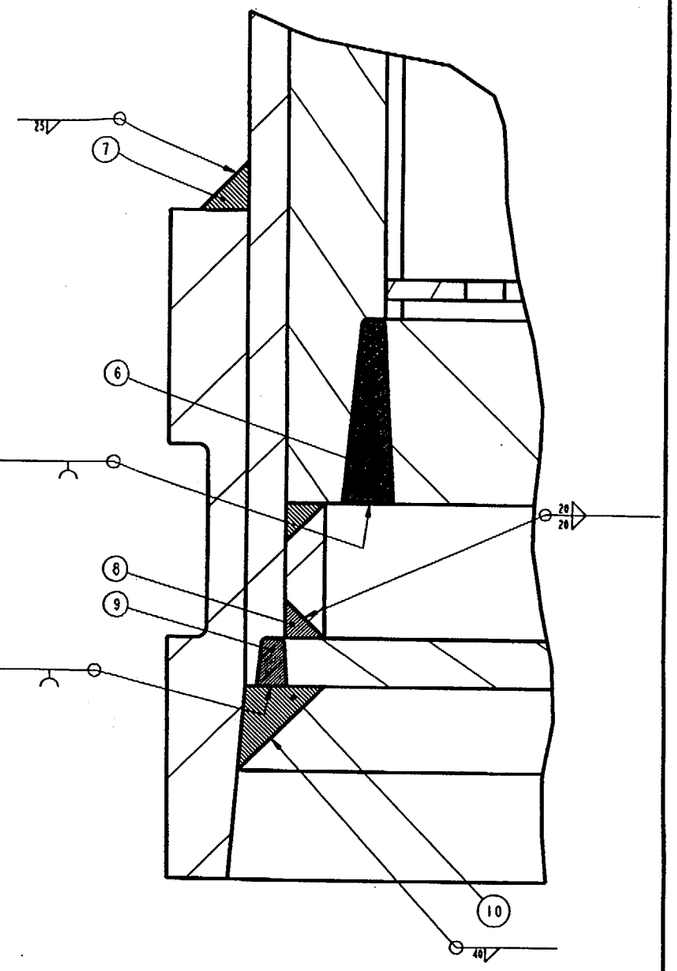




SECTION A-A



DETAIL A



DETAIL B

WELD	MATERIAL	MASS (KG)	QTY REQD
1	SFA-5.14 N06022	14	1
2	SFA-5.14 N06022	35	1
3	SFA-5.14 N06022	96	1
4	SFA-5.14 N06022	3.1	2
5	SFA-5.14 N06022	3.8	1
6	SFA-5.9 S31680	64	2
7	SFA-5.14 N06022	13	2
8	SFA-5.14 N06022	8.2	2
9	SFA-5.14 N06022	14	1
10	SFA-5.14 N06022	37	1
TOTAL ALLOY 22 WELDS	SFA-5.14 N06022	249	-
TOTAL 316 WELDS	SFA-5.9 S31680	128	-

UNITS: mm

DO NOT SCALE FROM SKETCH

REVISIONS			
REV	DESCRIPTION	DRW BY	DATE
00	ISSUED APPROVED	BH	03/09/00

"FOR INFORMATION ONLY"

21-PWR WASTE PACKAGE WELD CONFIGURATION

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SKETCHED BY:	BRYAN HARKINS
DATE:	03/09/00
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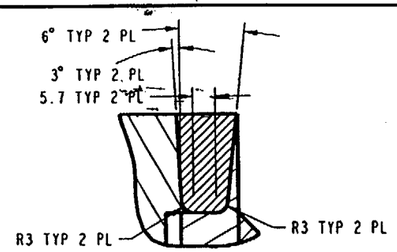

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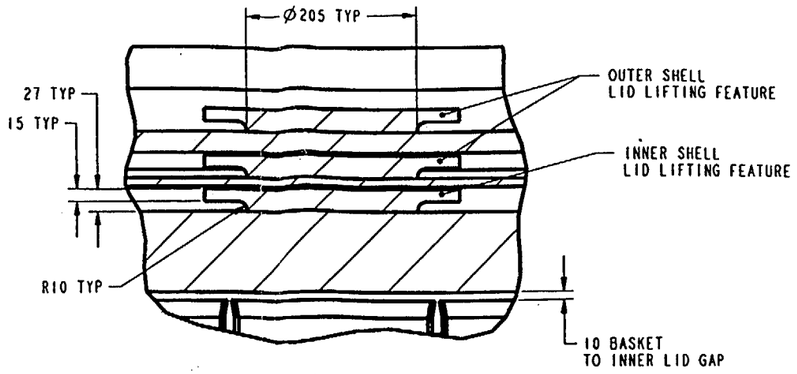

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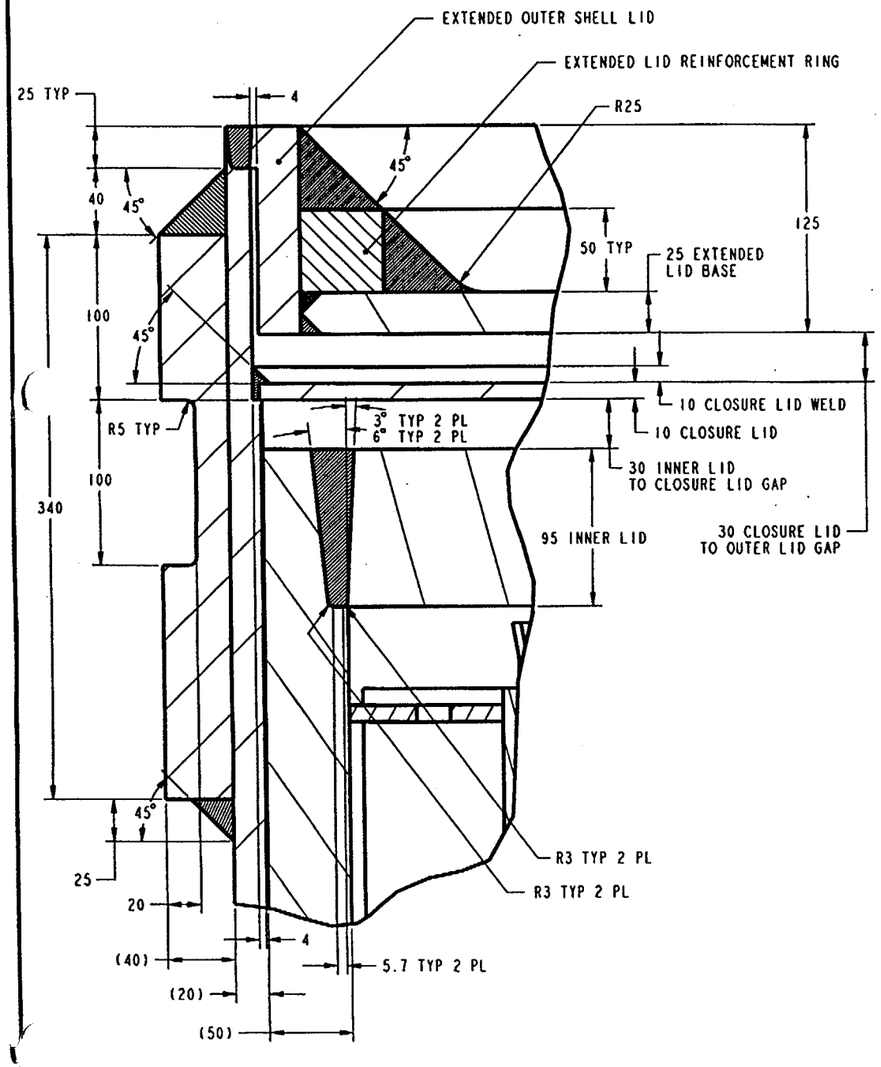
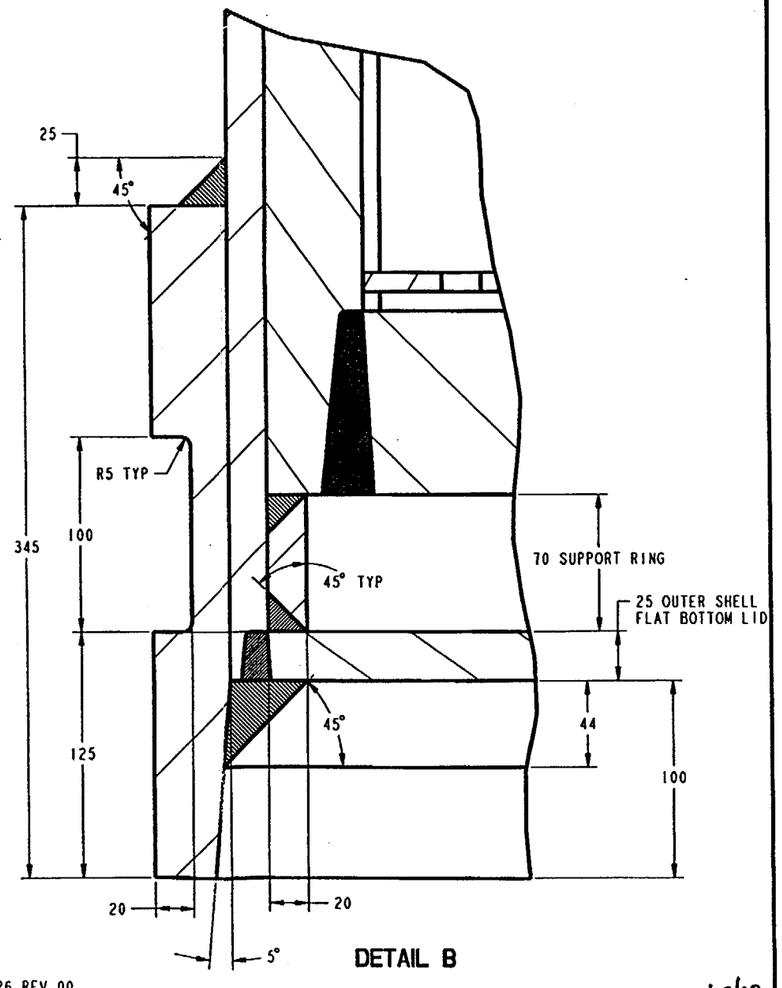


DETAIL A

21-PWR WASTE PACKAGE ASSEMBLY WITH STAINLESS STEEL/BORON PLATES

21-PWR CONTROL ROD WASTE PACKAGE ASSEMBLY WITH CARBON STEEL PLATES

COMPONENT NAME	MATERIAL	THICKNESS	MASS (KG)	QTY ROD
BASKET A-SIDEGUIDE	SA-516 K02700	10	27	32
BASKET A-STIFFENER	SA-516 K02700	10	0.72	64
BASKET B-SIDEGUIDE	SA-516 K02700	10	36	16
BASKET B-STIFFENER	SA-516 K02700	10	1.5	32
BASKET C-STIFFENER	SA-516 K02700	10	2.3	32
BASKET CORNERGUIDE	SA-516 K02700	10	42	16
FUEL BASKET A-PLATE	NEUTRONIT A 978	7	85	8
	#SA-516 K02700	#7	#86	#8
FUEL BASKET B-PLATE	NEUTRONIT A 978	7	85	8
	#SA-516 K02700	#7	#86	#8
FUEL BASKET C-PLATE	NEUTRONIT A 978	7	44	16
	#SA-516 K02700	#7	#45	#16
FUEL BASKET D-PLATE	SB-209 A96061 T4	5	21	8
FUEL BASKET E-PLATE	SB-209 A96061 T4	5	21	8
FUEL BASKET TUBE	SA-516 K02700	5	164	21
INNER SHELL	SA-240 S31600	50	8709	1
INNER SHELL LID	SA-240 S31600	95	1200	2
INNER LID LIFTING FEATURE	SA-240 S31600	27	12	1
OUTER SHELL	SB-575 N06022	20	4193	1
EXTENDED OUTER SHELL LID	SB-575 N06022	25	132	1
EXTENDED OUTER SHELL LID BASE	SB-575 N06022	25	366	1
OUTER LID LIFTING FEATURE	SB-575 N06022	27	13	2
EXTENDED LID REINFORCEMENT RING	SB-575 N06022	50	97	1
OUTER SHELL FLAT CLOSURE LID	SB-575 N06022	10	159	1
OUTER SHELL FLAT BOTTOM LID	SB-575 N0-6022	25	396	1
UPPER TRUNNION COLLAR SLEEVE	SB-575 N06022	40	507	1
LOWER TRUNNION COLLAR SLEEVE	SB-575 N06022	40	497	1
INNER SHELL SUPPORT RING	SB-575 N06022	20	41	1
TOTAL ALLOY 22 WELDS	SFA-5.14 N06022	-	249	**
TOTAL 316 WELDS	SFA-5.9 S31680	-	128	**
WASTE PACKAGE ASSEMBLY	-	-	26035	1
	-	-	#26059	#1
PWR FUEL ASSEMBLY	-	-	773.4#	21
WP ASSEMBLY WITH SNF	-	-	42277	1
	-	-	#42301	#1



DETAIL B

CRWMS M&O 1997. WASTE CONTAINER CAVITY SIZE DETERMINATION. BBAA00000-01717-0200-00026 REV 00. LAS VEGAS, NV: CRWMS M&O. ACC: MOL.19980106.0061

** REFER TO SK-0191 REV 00 "21-PWR WASTE PACKAGE WELD CONFIGURATION"

02 SMB 01/27/00

SK-0175 REV ~~01~~ | SHEET 2 OF 2

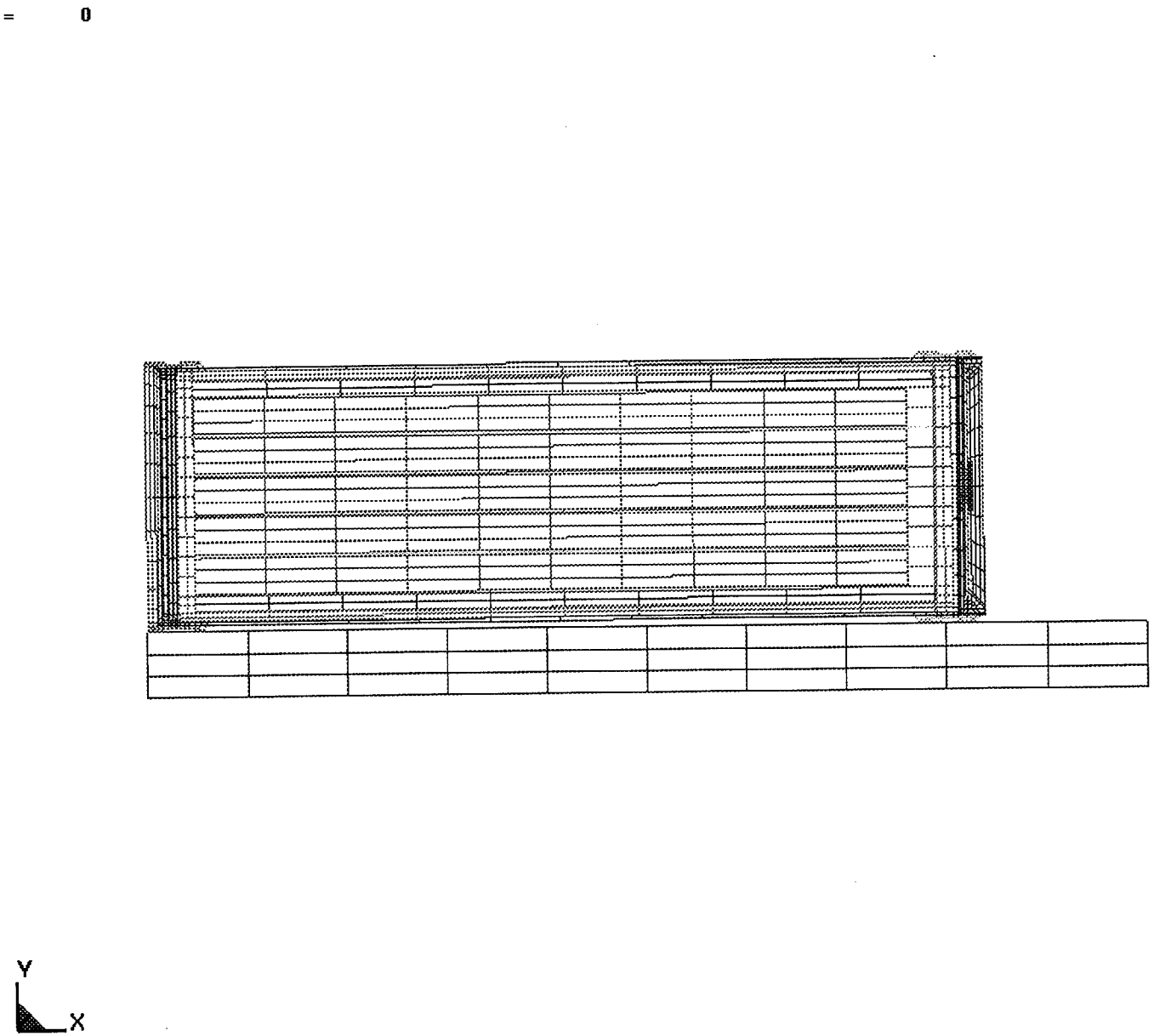


Figure III-1. Cross-Sectional View of Finite Element Representation of the 21-PWR WP

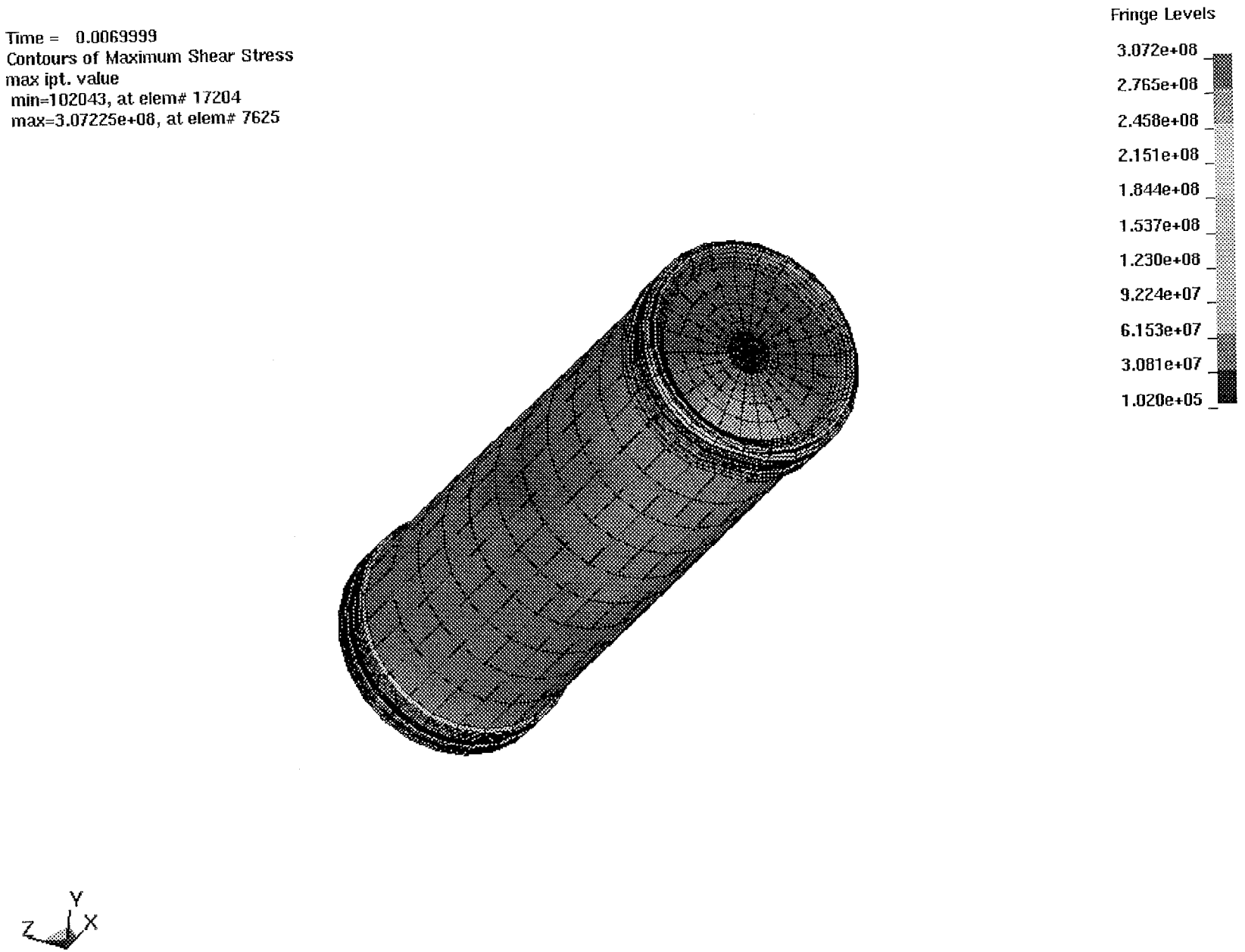


Figure III-2. Shear Stress Plot of Complete Waste Package (at room temperature)

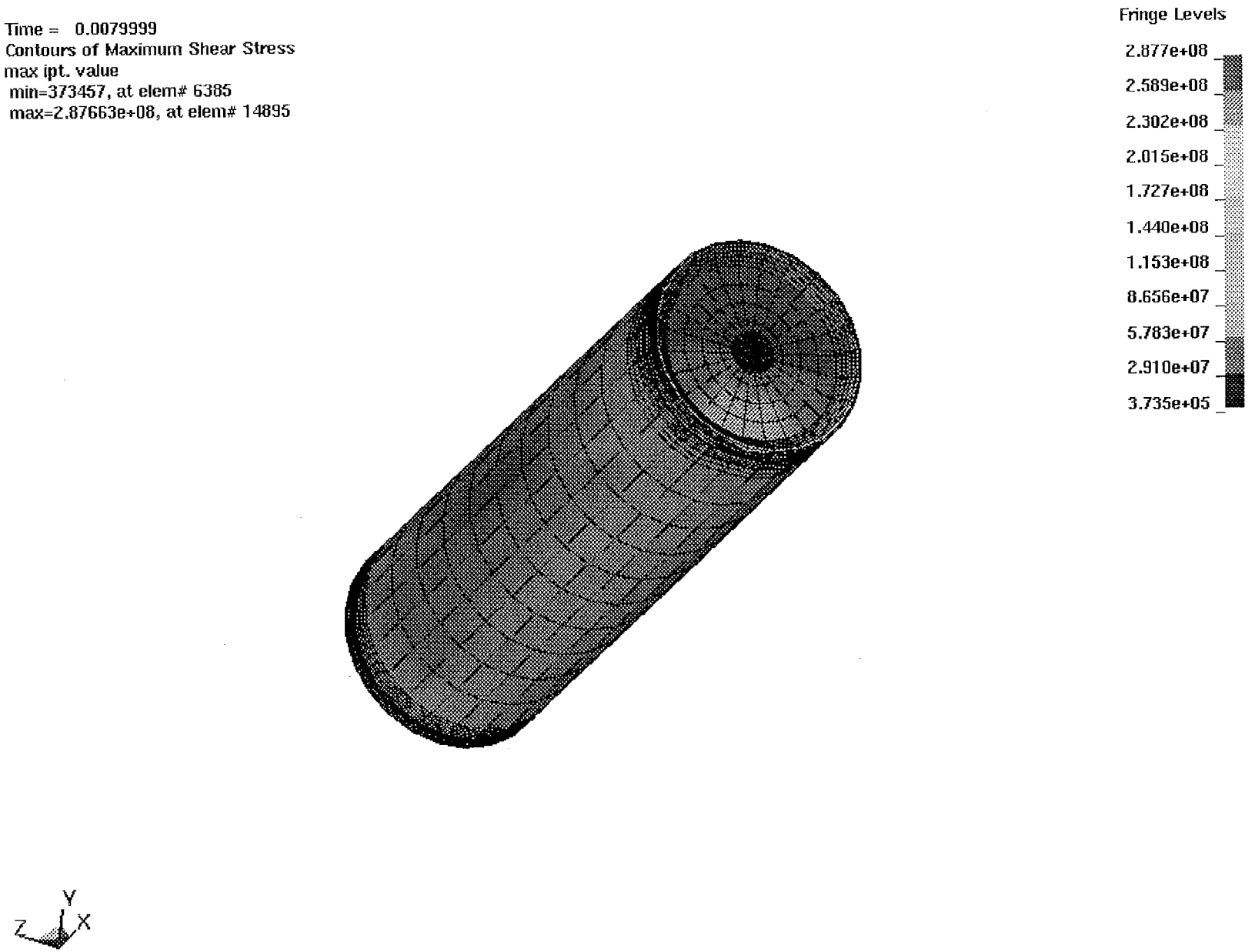


Figure III-3. Shear Stress Plot of Outer Shell and Lids (at room temperature)

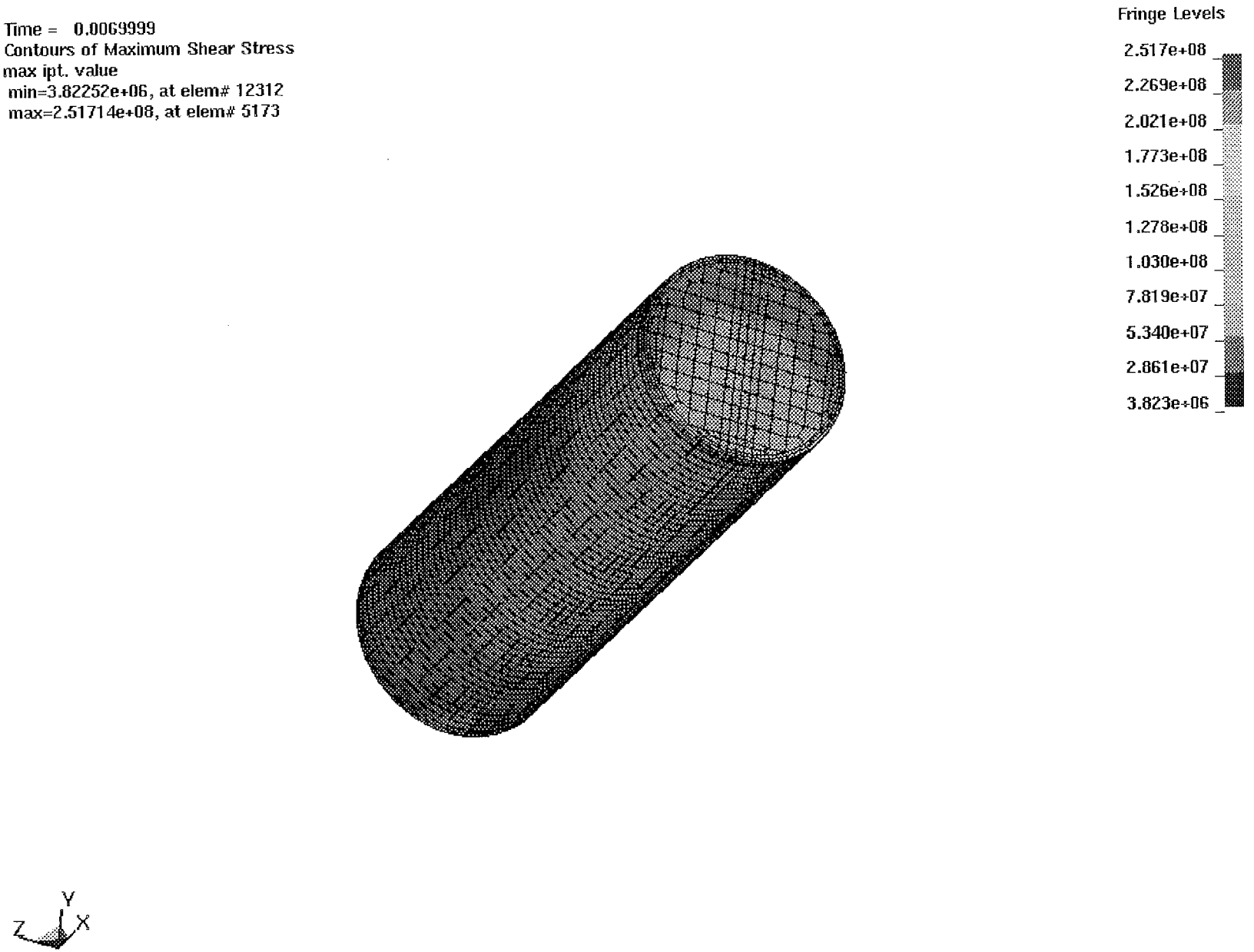


Figure III-4. Shear Stress Plot of Inner Shell and Inner Lid (at room temperature)

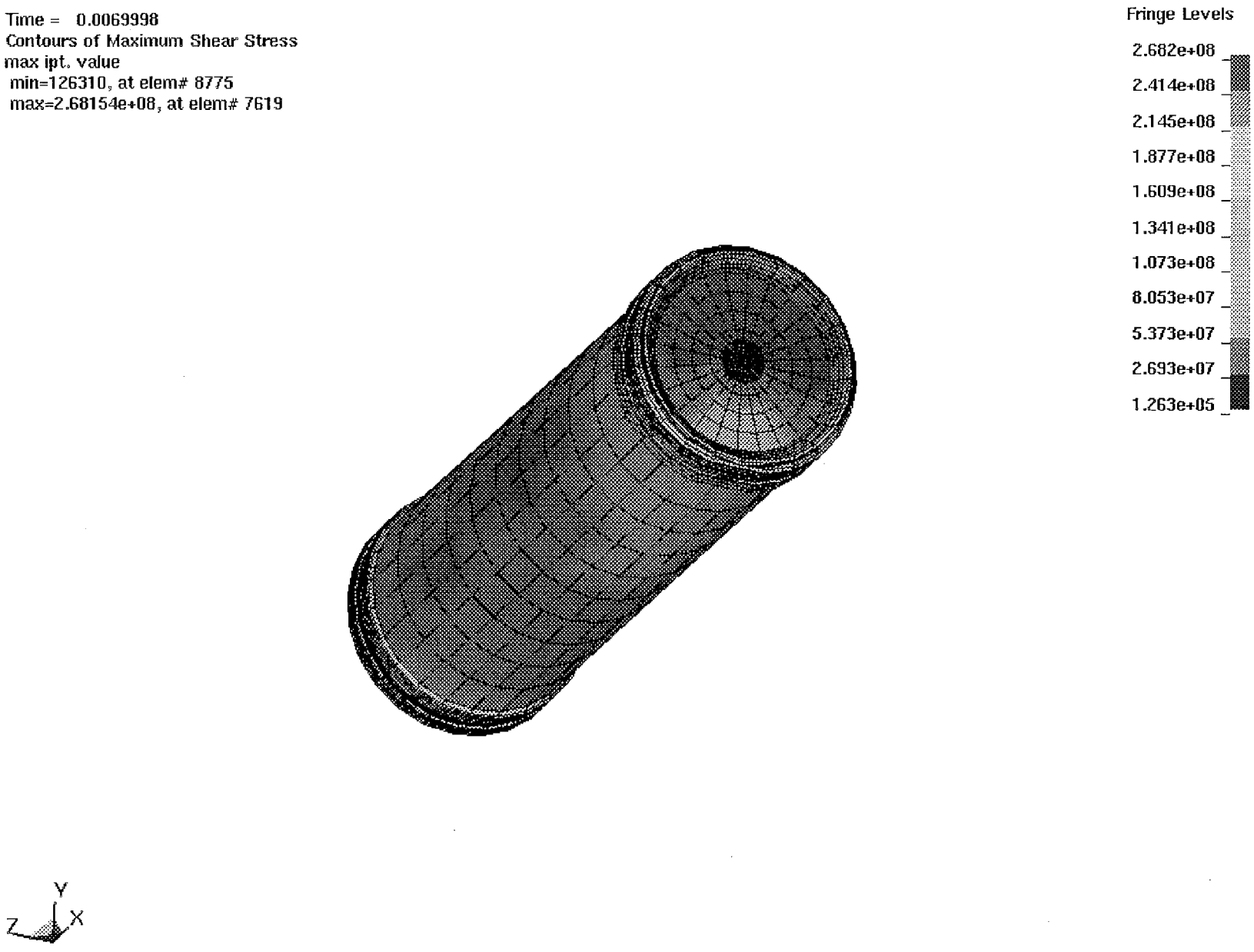


Figure III-5. Shear Stress Plot of Complete Waste Package (at 204 °C)

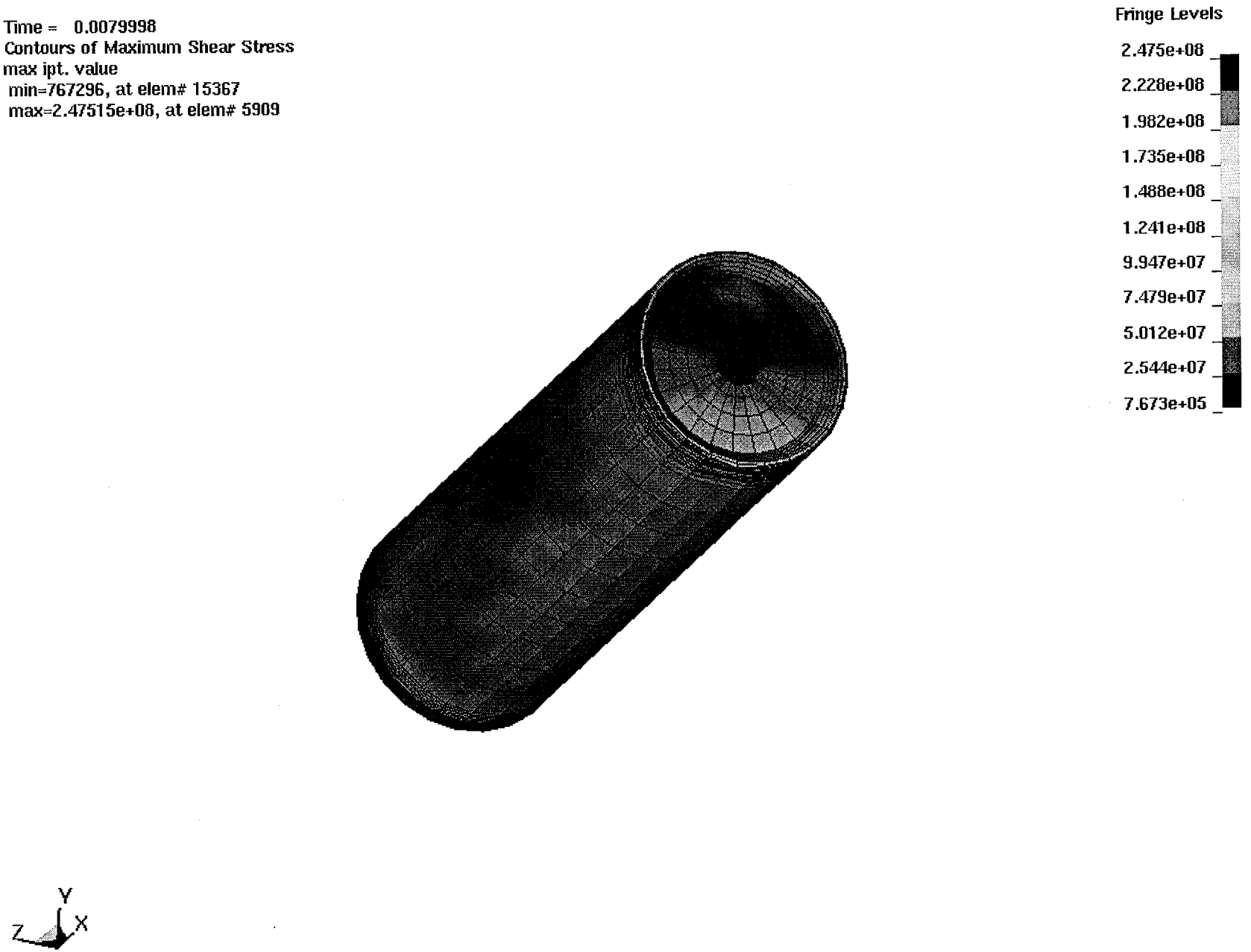


Figure III-6. Shear Stress Plot of Outer Shell and Lids (at 204 °*C*)

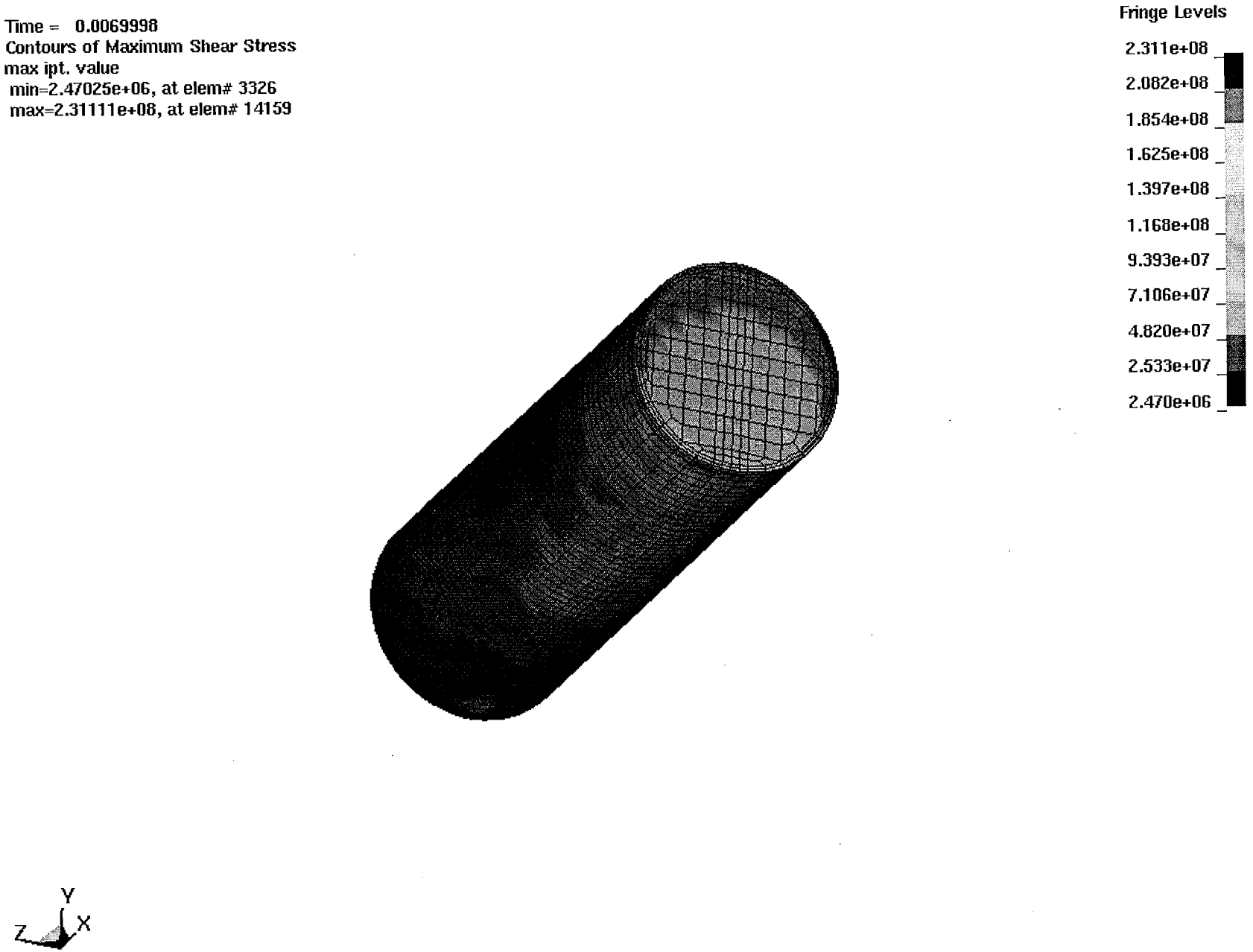


Figure III-7. Shear Stress Plot of Inner Shell and Inner Lid (at 204 °C)

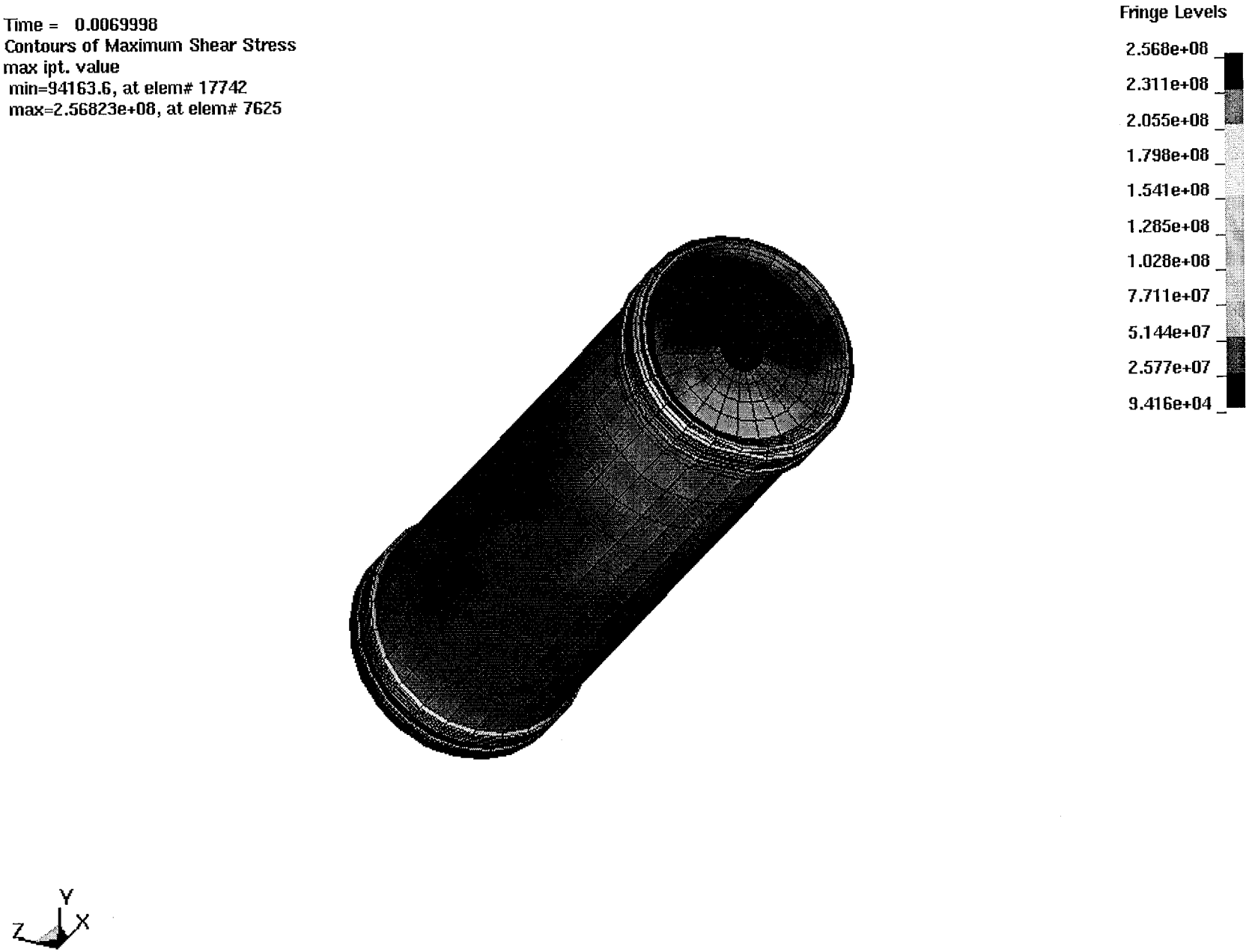


Figure III-8. Shear Stress Plot of Complete Waste Package (at 316 °*C*)

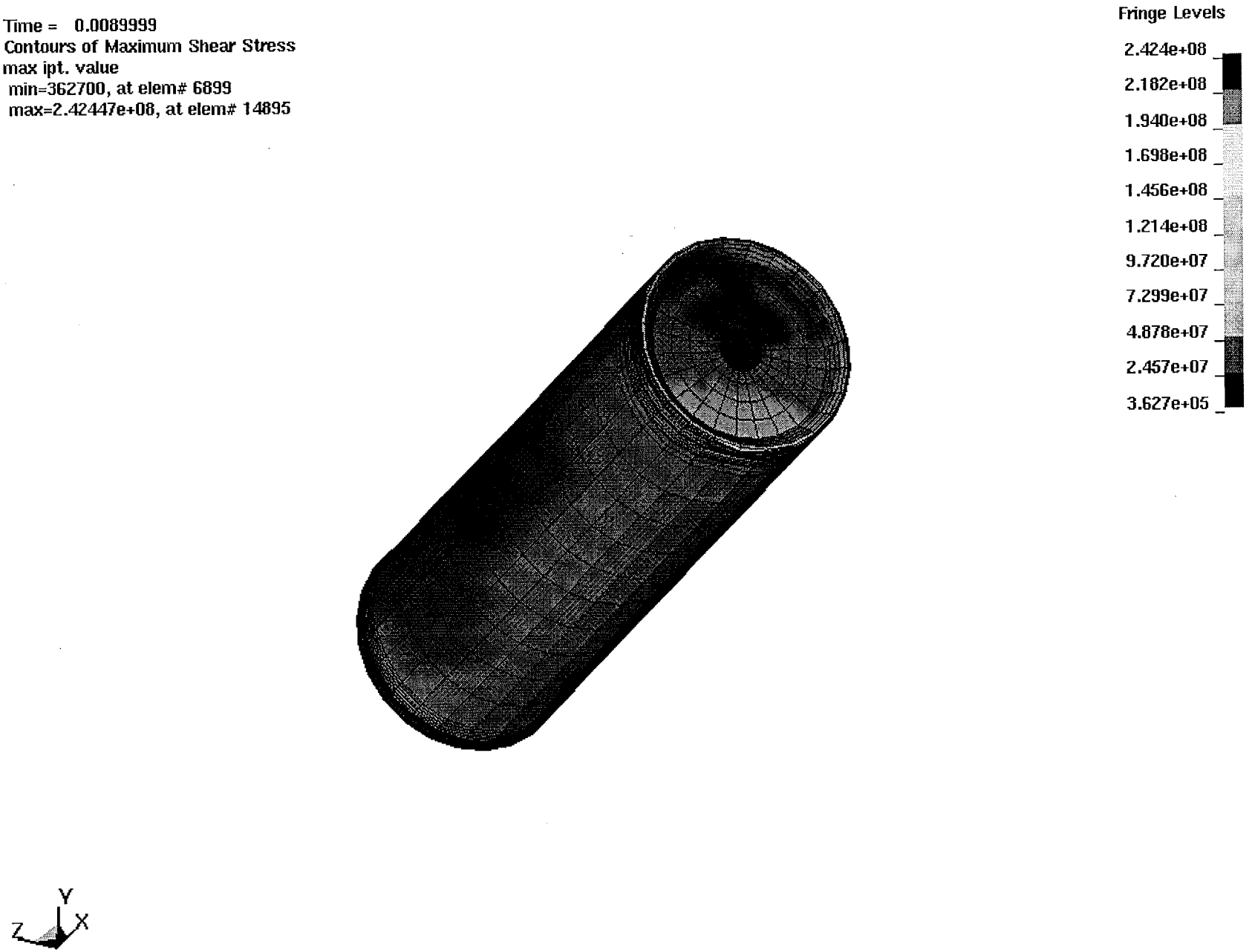


Figure III-9. Shear Stress Plot of Outer Shell and Lids (at 316 °C)

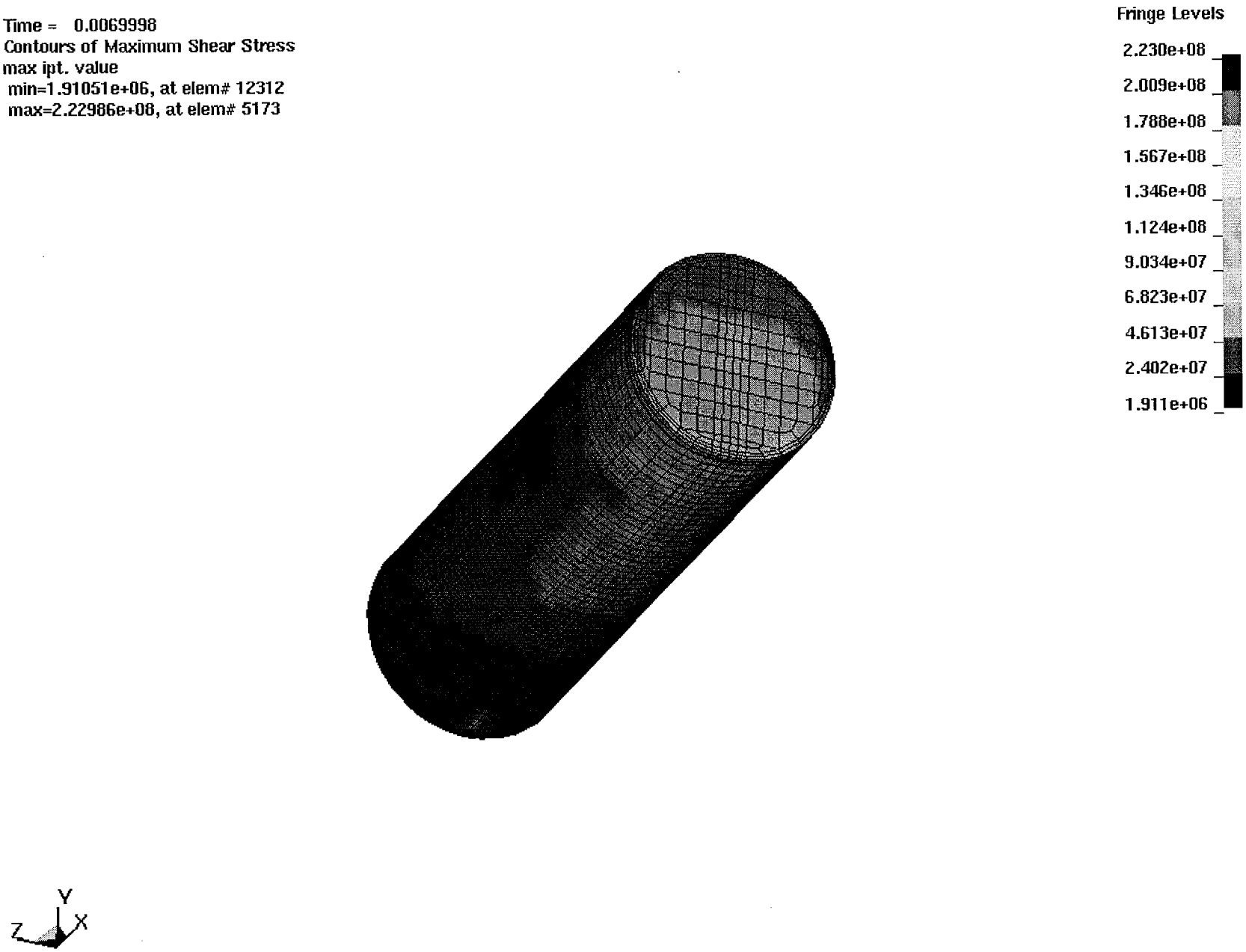


Figure III-10. Shear Stress Plot of Inner Shell and Inner Lid (at 316 °C)