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<td>7. Checker</td>
<td>Tim Schmitt</td>
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<td>8. Lead</td>
<td>Scott Bennett</td>
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**Revision History**

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1. PURPOSE

The objective of this calculation is to determine the structural response of the waste package (WP) swinging down from a horizontally suspended height. The WP used for that purpose is the 21-Pressurized Water Reactor (PWR) WP. The scope of this document is limited to reporting the calculation results in terms of stress intensities. This calculation is associated with the WP design and was performed by the Waste Package Design group in accordance with the Technical Work Plan for: Waste Package Design Description for LA (Ref. 13). AP-3.12Q, Calculations (Ref. 18) is used to perform the calculation and develop the document. The information provided by the sketches attached to this calculation is that of the potential design of the type of 21-PWR WP design considered in this calculation and provides the potential dimensions and materials for the 21-PWR WP design.

2. METHOD

The finite element calculation was performed by using the commercially available ANSYS Version (V) 5.6.2 (Computer Software Configuration Item [CSCI] 10364 V5.6.2; Ref. 5) and LS-DYNA V950.C (Software Tracking Number [STN] 10300-950-00; Ref. 7) finite element codes. The results of this calculation were provided in terms of maximum stress intensities in the outer shell (OS), inner shell (IS), and Shear Ring.

With regard to the development of this calculation, the control of electronic management of data was evaluated in accordance with AP-SV.1Q, Control of the Electronic Management of Information (Ref. 17). The evaluation (Addendum B of Ref. 13) determined that current work processes and procedures are adequate for the control of the electronic management of data for this activity.

3. ASSUMPTIONS

In the course of developing this document, the following assumptions are made regarding the structural calculation. The assumptions do not require confirmation.

3.1 Some of the temperature-dependent material properties, such as Poisson's Ratio, Coefficient of Thermal Expansion, and density, are not available or are negligible for SB-575 N06022 (Alloy 22), SA-516 K02700 (516 carbon steel [CS]), and SA-240 S31600 (316 stainless steel [SS]). The room-temperature (20 °C) material properties are assumed for these materials. The impact of using room-temperature material properties is anticipated to be small. The rationale for this assumption is that undetermined material properties of said materials will not significantly impact the results. This assumption is used in Section 5.2.

3.2 The Poisson's ratio of Alloy 22 is not available in literature. The Poisson’s ratio of Alloy 625 (SB-443 N06625) is assumed for Alloy 22. The impact of this assumption is anticipated to be negligible. The rationale for this assumption is that the chemical compositions of Alloy 22 and Alloy 625 are similar (see Ref. 2, Table 1 and Ref. 10, p. 143, respectively). This assumption is used in Section 5.2.
3.3 Strain rate hardening material properties are not available for SB-575 N06022 (Alloy 22), SA-516 K02700 (516 carbon steel [CS]), and SA-240 S31600 (316 stainless steel [SS]). The effects of this phenomena are neglected. The impact of ignoring these properties is anticipated to be conservative. The rationale for this assumption is that strain rate hardening would make the material stronger. This assumption is used in Section 5.2.

3.4 Poisson’s ratio is not available for 516 CS. Therefore, Poisson’s ratio of cast carbon steel is assumed for 516 CS. The impact of this assumption is anticipated to be negligible. The rationale for this assumption is that the elastic constants of cast carbon steels are only slightly affected by changes in composition and structure (see Ref. 3). This assumption is used in Section 5.2.

3.5 The exact geometry of the loaded internals is simplified for the purpose of this calculation. The spent fuel was modeled as 21 separate solid rectangles made from SS304L, but the thermal shunts, fuel tubes, and dividers between the fuel assemblies were omitted. The density of the spent fuel was increased to account for the missing mass. However, the sideguides, cornerguides, and stiffeners were included to accurately represent the contact with the inner shell. The rationale for this assumption is to simplify the finite element representation (FER), thus reducing processing time and file size, without compromising the accuracy of the calculation. This assumption is used in Section 5.2 and Section 5.4.

3.6 The elongations of Alloy 22 and 316NG SS at elevated temperatures are not available from traditional sources. However, vendor data is available (Ref. 6 and Ref. 14). The percent difference between elongations at room temperature and elevated temperatures can be normalized and applied to the data available from accepted codes. The rationale for this assumption is that the relative change of typical elongations should be bounding for the relative change of minimum elongation. Even though the values are not from traditional sources, the values are conservative and create higher stress intensities for the same temperature. This assumption is used in Section 5.2.1.

3.7 The impact surface that the WP is to be dropped on is conservatively assumed to be perfectly rigid (unyielding). Such a material does not exist. LS-DYNA V950.C (Ref. 7) is able to simulate such a surface. The result will be that the stresses produced by this calculation will be a small percentage higher than those that would result if a realistic surface were used. The rationale is that this is a conservative assumption. This assumption is used in Section 5.4.

3.8 Three-stage deformation characteristics are not observed in the stress-strain curves for Alloy 22 or Type 316 stainless steel (Ref. 9). However, in order to capture the uniform strain 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.

3.9 The uniform strain of A 516 Grade 70 CS is not available in literature. Therefore, it is conservatively assumed that the uniform strain is 50% of the elongation. The rationale for
this assumption is the character of stress-strain curve for A36 CS (see Refs. 8 and 12) that has similar chemical composition with A516 Grade 70 CS (see Ref. 2, SA-516/SA-516M and SA-36/SA-36M). This assumption is used in Section 5.2.2.

3.10 For the purposes of analyzing the initial angular velocity of the waste package before impact, the WP will be assumed to be a solid cylinder. This is necessary to calculate the rotary moment of inertia. The impact of this assumption on the results is negligible. The rationale for this assumption is the overall cylindrical shape of the WP and the relatively solid packing of the contents. This assumption is used in Section 5.3.

4. USE OF COMPUTER SOFTWARE AND MODELS

4.1 SOFTWARE

The first finite element analysis (FEA) computer code used for this calculation is ANSYS V5.6.2 (Ref. 5), which is identified with the Software Tracking Number (STN) 10364 V5.6.2 and was obtained from Software Configuration Management in accordance with appropriate procedures. ANSYS V5.6.2 is a commercially available finite element analysis code and is appropriate for structural calculations of WPs as performed in this calculation. The calculations using the ANSYS V5.6.2 software were executed on a Hewlett-Packard (HP) UNIX workstation, Bechtel SAIC Company, LLC (BSC) tag number 700314. The ANSYS evaluations performed for these designs are fully within the range of the validation performed for the ANSYS V5.6.2 code. The code used to perform these calculations was obtained from the Software Configuration Secretariat in accordance with the appropriate procedures.

The second FEA code used is Livermore Software Technology Corporation (LSTC) LS-DYNA V950.C (Ref. 7). LS-DYNA V950.C was obtained from the Software Configuration Secretariat in accordance with the appropriate procedures and is identified by STN 10300-950-00. LS-DYNA V950.C is appropriate for its intended use. The LS-DYNA evaluation performed for this calculation is fully within the range of the validation performed for the LS-DYNA V950.C code. The calculations were executed on HP 9000 series UNIX workstations identified with YMP tag numbers 117161 and 114435 located in Las Vegas, NV.

The input and output files are defined in Section 8 of this document. They are located in Attachment II to this document.
4.2 SOFTWARE ROUTINES

None used.

4.3 MODELS

None used.
5. CALCULATION

5.1 MASS AND GEOMETRIC DIMENSIONS OF WASTE PACKAGE

This calculation was performed using mass and geometric dimensions of the 21-PWR waste package (see pp. I-1, I-15 and I-24):

Total mass of the loaded WP = 41,598 kg
Length = 5.129 m
Outer diameter of outer shell = 1.574 m
Outer diameter of trunnion collar sleeve = 1.654 m

5.2 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, and 516 CS. Therefore, room-temperature density and Poisson’s ratio obtained under the static loading conditions are used for for Alloy 22, 316NG SS, and 516 CS (see Assumptions 3.1 and 3.3).

SB-575 NO6022 (Alloy 22) (Outer shell, outer shell lids, upper and lower trunnion collar sleeves):

- Density = 8690 kg/m³ (0.314 lb/in³) (at room temperature) (Ref. 2, SB-575 Section 7.1)
- Yield strength = 310 MPa (45 ksi) (at room temperature) (Ref. 2, Table Y-1)
  Yield strength = 236 MPa (34.3 ksi) (at 400 °F = 204 °C) (Ref. 2, Table Y-1)
  Yield strength = 211 MPa (30.6 ksi) (at 600 °F = 316 °C) (Ref. 2, Table Y-1)
- Tensile strength = 690 MPa (100 ksi) (at room temperature) (Ref. 2, Table U)
  Tensile strength = 657 MPa (95.3 ksi) (at 400 °F = 204 °C) (Ref. 2, Table U)
  Tensile strength = 628 MPa (91.1 ksi) (at 600 °F = 316 °C) (Ref. 2, Table U)
- Elongation = 0.45 (at room temperature) (Ref. 2, SB-575 Table 3)
- Poisson's ratio = 0.278 (at room temperature) (Ref. 10, p. 143; see Assumption 3.2)
- Modulus of elasticity = 206 GPa (at room temperature) (Ref. 6, p. 14)
  Modulus of elasticity = 196 GPa (at 400 °F = 204 °C) (Ref. 6, p. 14)
  Modulus of elasticity = 190 GPa (at 600 °F = 316 °C) (Ref. 6, p. 14)

SA-240 S31600 (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. 15, page 931 and Ref. 2, Section II, SA-240 Table 1]) (Inner shell, inner shell lids, and inner shell lifting feature):
### Waste Package Department Calculation

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#### Document Identifier: CAL-UDC-ME-000013 REV 00

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<td>Poisson's ratio</td>
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<td>Ref. 10, Figure 15, p. 755</td>
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<tr>
<td>Modulus of elasticity</td>
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<td>183 GPa (26.5 * 10⁶ psi)</td>
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<td></td>
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<td></td>
<td>127 MPa (29.1 ksi)</td>
<td>600 °F = 316 °C</td>
<td>Ref. 2, Table Y-1</td>
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5.2.1 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 to estimate elevated temperature elongation normalized to the room temperature values from accepted codes (see Assumption 3.6).

For Alloy 22, the vendor data shows a 13% increase between 600 °F and room temperature (Ref. 6).

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

\[
\text{Elongation}_{600°F} = 0.45 \times 1.13 = 0.51
\]

For SS 316, the vendor data shows a 30% decrease between 600 °F and room temperature (Ref. 14).

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

\[
\text{Elongation}_{600°F} = 0.40 \times (1 - 0.30) = 0.28
\]

Since the components made of SA-516 will not be analyzed for stresses, its elongation is not needed at elevated temperatures. The SA-516 components are only needed for their density.

5.2.2 Calculations for True Measures of Ductility

The material properties in Sections 5.2 and 5.2.1 refer to engineering stress and strain definitions:

\[
s = \frac{P}{A_0} \quad \text{and} \quad e = \frac{L - L_0}{L_0}
\]

(Ref. 4)
Where \( P \) stands for the force applied during static tensile test, \( L \) is the deformed-specimen length, and \( L_o \) and \( A_o \) 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.C finite element code requires input in terms of true stress and strain definitions:

\[
\sigma = \frac{P}{A} \quad \text{and} \quad \varepsilon = \ln\left(\frac{L}{L_o}\right) \quad \text{(Ref. 4)}
\]

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

\[
\sigma = s \cdot (1 + e) \quad \text{and} \quad \varepsilon = \ln(1 + e) \quad \text{(Ref. 4)}
\]

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:

- \( s_y \approx \sigma_y \approx \) yield strength
- \( s_e \approx \sigma_e \approx \) engineering tensile strength
- \( \sigma_u \approx \) true tensile strength
- \( e_y \approx \varepsilon_y \approx \) strain corresponding to yield strength
- \( e_e \approx \varepsilon_e \approx \) engineering strain corresponding to tensile strength (engineering uniform strain)
- \( e_u \approx \varepsilon_u \approx \) 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, 316 SS and 316NG SS do not manifest three-stage deformation character (Ref. 9). Therefore, the elongation, reduced by 10% for the sake of conservativism, can be used in place of uniform strain (Assumption 3.8).

In the case of Alloy 22 \((e_u = 0.9 \times \text{elongation} = 0.41 \text{ at room temperature})\), the true measures of ductility are

\[
\varepsilon_u = \ln(1 + e_u) = \ln(1 + 0.41) = 0.34
\]

\[
\sigma_u = s_u \cdot (1 + e_u) = 690 \cdot (1 + 0.41) = 973 \text{ MPa}.
\]
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400 °F (204 °C) Alloy 22
\[ \varepsilon_u = \ln(1 + e_u) = \ln(1 + 0.41) = 0.34 \]
\[ \sigma_u = s_u * (1 + e_u) = 657 * (1 + 0.41) = 926 \text{ MPa} \]

600 °F (316 °C) Alloy 22
\[ \varepsilon_u = \ln(1 + e_u) = \ln(1 + 0.41) = 0.34 \] (ASME values)
\[ \sigma_u = s_u * (1 + e_u) = 628 * (1 + 0.41) = 885 \text{ MPa} \] (ASME values)

\[ \varepsilon_u = \ln(1 + e_u) = \ln(1 + 0.45) = 0.37 \] (vendor data)
\[ \sigma_u = s_u * (1 + e_u) = 628 * (1 + 0.45) = 911 \text{ MPa} \] (vendor data)

For 316NG SS at room temperature, \( e_u = 0.9 \times \text{elongation} = 0.36 \), therefore:
\[ \varepsilon_u = \ln(1 + e_u) = \ln(1 + 0.36) = 0.31 \]
\[ \sigma_u = s_u * (1 + e_u) = 517 * (1 + 0.36) = 703 \text{ MPa} \]

400 °F (204 °C) SS 316NG
\[ \varepsilon_u = \ln(1 + e_u) = \ln(1 + 0.36) = 0.31 \]
\[ \sigma_u = s_u * (1 + e_u) = 496 * (1 + 0.36) = 675 \text{ MPa} \]

600 °F (316 °C) SS 316NG
\[ \varepsilon_u = \ln(1 + e_u) = \ln(1 + 0.36) = 0.31 \] (ASME values)
\[ \sigma_u = s_u * (1 + e_u) = 495 * (1 + 0.36) = 673 \text{ MPa} \] (ASME values)

600 °F (316 °C) SS 316NG (cont’d)
\[ \varepsilon_u = \ln(1 + e_u) = \ln(1 + 0.25) = 0.22 \] (vendor data)
\[ \sigma_u = s_u * (1 + e_u) = 495 * (1 + 0.25) = 619 \text{ MPa} \] (vendor data)

For 516 CS at room temperature, \( e_u = 0.5 \times \text{elongation} = 0.11 \), therefore:
\[ \varepsilon_u = \ln(1 + e_u) = \ln(1 + 0.11) = 0.10 \]
\[ \sigma_u = s_u * (1 + e_u) = 483 * (1 + 0.11) = 536 \text{ MPa} \]

400 °F (204 °C) 516 CS
\[ \varepsilon_u = \ln(1 + e_u) = \ln(1 + 0.11) = 0.10 \]
\[ \sigma_u = s_u * (1 + e_u) = 483 * (1 + 0.11) = 536 \text{ MPa} \]

600 °F (316 °C) 516 CS
\[ \varepsilon_u = \ln(1 + e_u) = \ln(1 + 0.11) = 0.10 \]
\[ \sigma_u = s_u * (1 + e_u) = 483 * (1 + 0.11) = 536 \text{ MPa} \]

For 304 SS at room temperature, \( e_u = 0.75 \times \text{elongation} = 0.30 \), therefore:
\[ \varepsilon_u = \ln(1 + e_u) = \ln(1 + 0.30) = 0.26 \]
\[ \sigma_u = s_u * (1 + e_u) = 517 * (1 + 0.30) = 672 \text{ MPa} \]

400 °F (204 °C) 304 SS
\[ \varepsilon_u = \ln(1 + e_u) = \ln(1 + 0.30) = 0.26 \]
\[ \sigma_u = s_u * (1 + e_u) = 441 * (1 + 0.30) = 573 \text{ MPa} \]

600 °F (316 °C) 304 SS
\[ \varepsilon_u = \ln(1 + e_u) = \ln(1 + 0.30) = 0.26 \]
\[ \sigma_u = s_u * (1 + e_u) = 437 * (1 + 0.30) = 568 \text{ MPa} \]

5.2.3 Calculations for Tangent Moduli

As previously discussed, the results of this simulation are required to include elastic and plastic deformations for Alloy 22, 516 CS, and 316NG SS. When the materials are driven into the plastic range, the slope of stress-strain curve continuously changes. Thus, a simplification for this curve is 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 tensile strength point of the material. The parameters used in the subsequent calculations in addition to those defined in Section 5.2.2 are modulus of elasticity (\(E\)) and tangent modulus (\(E_t\)). The tangent (hardening) modulus represents the slope of the stress-strain curve in the plastic region. In the case of Alloy 22, the strain corresponding to the yield strength is:

\[ \varepsilon_{pl} = \frac{\sigma_{pl}}{E} = 310 \times 10^6 / 206 \times 10^9 = 0.0015 \text{ (see Section 5.2.1)} \]

Hence, the tangent modulus at room temperature is:

\[ E_{t,rt} = \frac{(\sigma_{u,rt} - \sigma_{p,rt})}{(\varepsilon_{u,rt} - \varepsilon_{p,rt})} = (0.973 - 0.310)/(0.34 - 0.0015) = 2.0 \text{ GPa (see Section 5.2, 5.2.1, and 5.2.2)} \]

For Alloy 22 at 400 °F (204 °C)
\[ E_{t,400°F} = \frac{(\sigma_{u,400°F} - \sigma_{p,400°F})}{(\varepsilon_{u,400°F} - \varepsilon_{p,400°F}/\varepsilon_{400°F})} = (0.926 - 0.236)/0.34 - 0.236/196e3 = 2.0 \text{ GPa (see Section 5.2, 5.2.1, and 5.2.2)} \]

For Alloy 22 at 600 °F (316 °C, ASME values)
\[ E_{t,600°F} = \frac{(\sigma_{u,600°F} - \sigma_{p,600°F})}{(\varepsilon_{u,600°F} - \varepsilon_{p,600°F}/\varepsilon_{600°F})} = (0.885 - 0.211)/0.34 - 0.211/190e3 = 2.0 \text{ GPa (see Section 5.2, 5.2.1, and 5.2.2)} \]

For Alloy 22 at 600 °F (316 °C, vendor data)
\[ E_{t,600°F} = \frac{(\sigma_{u,600°F} - \sigma_{p,600°F})}{(\varepsilon_{u,600°F} - \varepsilon_{p,600°F}/\varepsilon_{600°F})} = (0.911 - 0.211)/0.37 - 0.211/190e3 = 1.9 \text{ GPa (see Section 5.2, 5.2.1, and 5.2.2)} \]
Similarly, for 316NG SS at room temperature:

\[ E_{1,rt} = \frac{(\sigma_{u,rt} - \sigma_{y,rt})}{(\varepsilon_{u,rt} - \sigma_{y,rt}/E_{rt})} = (0.703 - 0.207)/(0.31 - 207/195e3) = 1.6 \text{ GPa} \]  
(see Section 5.2, 5.2.1, and 5.2.2)

For 316NG SS at 400 °F (204 °C)

\[ E_{1,400°F} = \frac{(\sigma_{u,400°F} - \sigma_{y,400°F})}{(\varepsilon_{u,400°F} - \sigma_{y,400°F}/E_{400°F})} = (0.675 - 0.148)/(0.31 - 148/183e3) = 1.7 \text{ GPa} \]  
(see Section 5.2, 5.2.1, and 5.2.2)

For 316NG SS at 600 °F (316 °C, ASME values)

\[ E_{1,600°F} = \frac{(\sigma_{u,600°F} - \sigma_{y,600°F})}{(\varepsilon_{u,600°F} - \sigma_{y,600°F}/E_{600°F})} = (0.673 - 0.130)/(0.31 - 130/174e3) = 1.8 \text{ GPa} \]  
(see Section 5.2, 5.2.1, and 5.2.2)

For 316NG SS at 600 °F (316 °C, vendor data)

\[ E_{1,600°F} = \frac{(\sigma_{u,600°F} - \sigma_{y,600°F})}{(\varepsilon_{u,600°F} - \sigma_{y,600°F}/E_{600°F})} = (0.619 - 0.130)/(0.22 - 130/174e3) = 2.2 \text{ GPa} \]  
(see Section 5.2, 5.2.1, and 5.2.2)

Tangent Modulus of 516 CS at room temperature:

\[ E_{1,rt} = \frac{(\sigma_{u,rt} - \sigma_{y,rt})}{(\varepsilon_{u,rt} - \sigma_{y,rt}/E_{rt})} = (0.536 - 0.262)/(0.10 - 262/203e3) = 2.8 \text{ GPa} \]  
(see Section 5.2, 5.2.1, and 5.2.2)

516 CS at 400 °F (204 °C)

\[ E_{1,400°F} = \frac{(\sigma_{u,400°F} - \sigma_{y,400°F})}{(\varepsilon_{u,400°F} - \sigma_{y,400°F}/E_{400°F})} = (0.536 - 0.224)/(0.10 - 224/191e3) = 3.2 \text{ GPa} \]  
(see Section 5.2, 5.2.1, and 5.2.2)

516 CS at 600 °F (316 °C)

\[ E_{1,600°F} = \frac{(\sigma_{u,600°F} - \sigma_{y,600°F})}{(\varepsilon_{u,600°F} - \sigma_{y,600°F}/E_{600°F})} = (0.536 - 0.201)/(0.10 - 201/184e3) = 3.4 \text{ GPa} \]  
(see Section 5.2, 5.2.1, and 5.2.2)

Tangent Modulus of 304 SS at room temperature:

\[ E_{1,rt} = \frac{(\sigma_{u,rt} - \sigma_{y,rt})}{(\varepsilon_{u,rt} - \sigma_{y,rt}/E_{rt})} = (0.672 - 0.207)/(0.26 - 207/195e3) = 1.8 \text{ GPa} \]  
(see Section 5.2, 5.2.1, and 5.2.2)

304 SS at 400 °F (204 °C)

\[ E_{1,400°F} = \frac{(\sigma_{u,400°F} - \sigma_{y,400°F})}{(\varepsilon_{u,400°F} - \sigma_{y,400°F}/E_{400°F})} = (0.573 - 0.143)/(0.26 - 143/183e3) = 1.7 \text{ GPa} \]  
(see Section 5.2, 5.2.1, and 5.2.2)

304 SS at 600 °F (316 °C)

\[ E_{1,600°F} = \frac{(\sigma_{u,600°F} - \sigma_{y,600°F})}{(\varepsilon_{u,600°F} - \sigma_{y,600°F}/E_{600°F})} = (0.568 - 0.127)/(0.26 - 127/174e3) = 1.7 \text{ GPa} \]  
(see Section 5.2, 5.2.1, and 5.2.2)
5.3 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 velocity.

\[ g \equiv \text{acceleration due to gravity} = 9.81 \text{ m/s}^2 \]

\[ S \equiv \text{Drop Height} = 2.4 \text{ m (Ref. 1)} \]

\[ b \equiv \text{Distance between Trunnion and Corner of WP} \]

\[
\begin{align*}
    b &= (1.654^2 + (5.129 - 0.1725)^2)^{0.5} = 5.225 \text{ m} \\
    \theta_1 &= \text{Angle between } b \text{ and top horizontal of WP} \\
    \tan \theta_1 &= \frac{\text{opposite}}{\text{adjacent}} = \frac{1.654}{(5.129 - 0.1725)} = \frac{1.654}{4.957} \\
    \therefore \theta_1 &= 18.45^\circ
\end{align*}
\]
Figure 3. Overlaid Geometry

\[ \theta_2 = \text{Angle between b after swing-down and original top horizontal of WP} \]

\[ \sin \theta_2 = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{4.054}{5.225} \]

\[ \therefore \theta_2 = 50.89^\circ \]

\[ \gamma = \theta_2 - \theta_1 = 50.89^\circ - 18.45^\circ = 32.44^\circ \]

\[ \tan 32.44^\circ = \frac{1.654}{A} \] (A from Figure 2)

\[ A = 2.602 \text{ m}, \frac{A_1}{A} = 1.301 \text{ m} \]

Length of WP \[ \frac{A_2}{A} + \frac{A_2}{A} = 3.866 \text{ m} \]

The final height of the center of mass over the surface is equal to

\[ \sin 32.44^\circ = \frac{\text{opposite}}{\text{hypotenuse}} \]

\[ 3.866 \times \sin 32.44^\circ = \text{opposite} \]

\[ \text{opposite} = 2.074 \text{ m} \]

The total change in height of the center of mass of the WP is equal to

\[ \Delta h = (2.4 + \frac{1.654}{A}) - 2.074 = 1.153 \text{ m} \]

The initial angular velocity may be calculated using the energy method:

\[ mg\Delta h = \frac{1}{2}I_o\omega^2 \]

The rotary inertia \( I_o \) of a solid cylinder (Assumption 5.10) is known to equal to

\[ I_o = \frac{m}{48}(3d^2 + 4l^2) \]

\[ I_o = 41.568 \text{ kg-m}^2 \]

\[ = 98,304 \text{ kg-m}^2 \]

\[ l \] is about the centroid of the WP, which is in the center of the WP. The parallel axis theorem may be used to find the rotary moment of inertia about the corner of the WP.
Waste Package Department

Title: Swing-Down of 21-PWR Waste Package

I₁ = Iₐ + Mc²

\[ c = \left( \frac{\text{length of WP}}{2} \right)^{0.5} + \left( \frac{\text{Diameter of WP}}{2} \right)^{0.5} = (2.565^2 + 0.827^2)^{0.5} = 2.695 \text{ m} \]

\[ I₁ = 98,304 \text{ kg-m}^2 + (41,598 \text{ kg})*(2.695 \text{ m})^2 = 400,431 \text{ kg-m}^2 \]

Now the initial angular velocity may be found.

\[ mg\Delta h = \frac{1}{2}I₁\omega^2 \]

\[ (41,598 \text{ kg})*(9.81 \text{ m/s}^2)*(1.153 \text{ m}) = \frac{1}{2}(400,431 \text{ kg-m}^2)\omega^2 \]

\[ \omega = 2.35 \text{ rad/s} \]

\[ \omega = 1.53 \text{ rad/s} \]

5.4 FINITE ELEMENT REPRESENTATION

A full three-dimensional (3-D) FER of the WP was developed in ANSYS V5.4 using the dimensions provided in Attachment I. The internal structure of the WP was simplified. The internal components of the Inner Shell (thermal shunts, side guides, spent nuclear fuel, etc.) were represented using solid elements (Assumption 3.5). This significantly lowered the number of contacts within the FER while still maintaining the proper mass needed for the computer run. However, the sideguides and stiffeners between the spent nuclear fuel and the IS were accurately modeled using shell elements to accurately model the contacts in this region.

The target surface was conservatively assumed to be unyielding (Assumption 3.7). This was accomplished using the *RIGIDWALL command within LS-DYNA. This command creates an invisible rigid wall within LS-DYNA. All nodes are slaves to the RIGIDWALL, and the RIGIDWALL is immovable.

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

The initial drop height of the WP was reduced to 0.01 m before impact and the WP was given an initial angular velocity equal to 1.55 rad/s, which is conservative (see Section 5.3).

The FER was then used in LS-DYNA V950.C to perform the transient dynamic analysis for the 21-PWR Waste Package swing-down.
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.

Attachment II includes the input files and results files that show execution of the programs occurred correctly. The stresses were reported via plots that have been made interactively using the postprocessor LSPOST. The stresses were recorded every 0.002 seconds after impact. The stresses in all components peaked between 0.002 and 0.030 seconds. However, the solution was allowed to reach 0.038 seconds to ensure that all stresses had climaxed.

The results file, d3hsp (Attachment II), lists the calculated masses used by LS-DYNA. The sum of the masses of the WP equals 42,550 kg, with the mass of the loaded WP 41,598 kg from Section 5.1. The percent difference in mass would then be ~2.3%. However, this difference is on the positive side, and thus considered to be conservative and negligible.

The following pages contain figures that show various parts at states of maximum stress. These start on the next page with Figure 4, which shows the maximum shear stress in the inner shell at room temperature.
Figure 4. Inner Shell Stresses at Room Temperature

All of the stresses that are reported in the legends of the plots are Tresca Stresses or Maximum Shear Stresses. The units are Pascals. Figure 4 shows that the maximum stress intensity in inner shell is 360 MPa at 0.028 seconds.

Figure 5 may be found on the next page. It shows the maximum stress intensity in the same part, but at 400 degrees Fahrenheit.
Figure 5. Inner Shell Stresses at 400 °F

Figure 5 shows that the maximum stress intensity in the inner shell is 268 MPa at 0.030 seconds. This is slightly lower than the room temperature value, which is to be expected.

Figure 6 may be found on the next page. It shows the maximum stress intensity in the same part, but at 600 degrees Fahrenheit.
Figure 6. Inner Shell Stresses at 600 °F

Figure 6 shows that the maximum stress intensity in the inner shell is 278 MPa at 0.030 seconds. This is slightly higher than the 400 °F value.

Figure 7 may be found on the next page. It shows the maximum stress intensity in the inner shell at 600 degrees Fahrenheit using vendor data for elongation values.
Figure 7 shows that the maximum stress intensity in the inner shell is 286 MPa at 0.030 seconds. This is slightly higher than the 600 °F ASME value, but is to be expected considering the elongation values of 316NG SS at elevated temperatures.

Figure 8 may be found on the next page. It shows the maximum stress intensity in the outer shell at room temperature.
Figure 8. Outer Shell Stresses at Room Temperature

Figure 8 figure shows that the maximum stress intensity in the outer shell is 1,050 MPa at 0.002 seconds.

Figure 9 may be found on the next page. It shows the maximum stress intensity in the same part, but at 400 degrees Fahrenheit.
Figure 9 shows that the maximum stress intensity in the outer shell is 908 MPa at 0.002 seconds. This is slightly lower than the room temperature value, which is to be expected.

Figure 10 may be found on the next page. It shows the maximum stress intensity in the same part, but at 600 degrees Fahrenheit.
Figure 10. Outer Shell Maximum Stresses at 600 °F

Figure 10 shows that the maximum stress intensity in the outer shell is 851 MPa at 0.002 seconds. This is slightly lower than the 400 °F value, which is to be expected.

Figure 11 may be found on the next page. It shows the maximum stress intensity in the outer shell at 600 degrees Fahrenheit using vendor elongation data.
Figure 11. Outer Shell Maximum Stresses at 600 °F Using Vendor Elongation

Figure 11 shows that the maximum stress intensity in the upper trunnion collar is 836 MPa at 0.002 seconds. This is slightly higher than the 600 °F ASME value, which is to be expected due to the elongation values of Alloy 22 at elevated temperatures.

Figure 12 may be found on the next page. It shows the maximum stress intensity in the Shear Ring at room temperature.
Figure 12. Shear Ring Stresses at Room Temperature

Figure 12 shows that the maximum stress intensity in the Shear Ring is 347 MPa at 0.02 seconds.

Figure 13 may be found on the next page. It shows the maximum stress in the same part, but at 400 degrees Fahrenheit.
Figure 13. Shear Ring Stresses at 400 °F

Figure 13 shows that the maximum stress intensity in the Shear Ring is 258 MPa at 0.032 seconds. This is lower than the room temperature value.

Figure 14 may be found on the next page. It shows the maximum stress in the same part, but at 600 degrees Fahrenheit.
Figure 14. Shear Ring Stresses at 600 °F

Figure 14 shows that the maximum stress intensity in the Shear Ring is 264 MPa at 0.032 seconds. This is slightly higher than the 400 °F value.

Figure 15 may be found on the next page. It shows the maximum stress in the same part at 600 degrees Fahrenheit, but using vendor elongation data.
Figure 15. Shear Ring Stresses at 600 °F Using Vendor Elongation

Figure 15 shows that the maximum stress intensity in the Shear Ring is 273 MPa at 0.032 seconds. This is slightly higher than the 600 °F ASME value, which is to be expected due to 316NG SS elongation properties at elevated temperatures.
Table 6-1 provides a list maximum Stress Intensities sorted by Part, Temperature, and Elongation Value per Load Case.

### Table 6-1. Maximum Stress Intensity by Load Case

<table>
<thead>
<tr>
<th>Part</th>
<th>Temperature</th>
<th>Elongation Value</th>
<th>Max Stress Intensity</th>
<th>$S_{int} / S_{allowable}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner Shell</td>
<td>70 °F</td>
<td>ASME</td>
<td>360 MPa</td>
<td>0.568</td>
</tr>
<tr>
<td>Outer Shell</td>
<td>70 °F</td>
<td>ASME</td>
<td>1,050 MPa</td>
<td>1.20</td>
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<tr>
<td>Shear Ring</td>
<td>70 °F</td>
<td>ASME</td>
<td>347 MPa</td>
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<td>ASME</td>
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<td>ASME</td>
<td>278 MPa</td>
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<td>1.02</td>
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<td>ASME - 30%</td>
<td>273 MPa</td>
<td>0.490</td>
</tr>
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</table>

Note: $S_{allowable}$ is equal to 90% of $\sigma_a$.

Even though Table 6-1 shows that the Outer Shell has a ratio of $S_{int} / S_{allowable}$ equal to 1.20, this does not mean that the OS fails completely through the thickness. Figure 16 on the next page shows a plot of the Max Shear Stress in the elements through the thickness of the OS where the maximum stress occurs. If the ratio of $S_{int} / S_{allowable}$ does not exceed 1, then the OS does not fail completely through the thickness.
Figure 16 shows that element 52069 has a Maximum Shear Stress of approximately 270 MPa, which is equal to a Stress Intensity of 540 MPa. The ratio of $S_{\text{int}}/S_{\text{allowable}}$ is equal to 0.616, which is less than unity. Room temperature was the worst case for the OS. Therefore, the other temperature cases do not need to be investigated.
7. REFERENCES


7.1 PROCEDURE REFERENCES


8. ATTACHMENTS

Attachment I (25 pages): Design sketches (*21-PWR Waste Package Concept for License Application [SK-0219 REV 01, 25 sheets]*)

Attachment II (on compact disc): contains electronic files (see Table 8-1 for a complete list). The *.k files are input files for LS-DYNA at the three temperatures and they call the *.inc files. The d3hspt files are the LS-DYNA output files at the three temperatures. The file *.inp is used in ANSYS to create the *.inc files.

Table 8-1 provides a list of attachments submitted in the form of electronic files (compact disc) in Attachment II.

Table 8-1. List of Attachments Submitted in the Form of Electronic Files in Attachment II

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NOTE: The file sizes may vary with operating system.
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ASSEMBLY - 8
SIDE GUIDE ASSEMBLY
SCALE 1.000

ASSEMBLY - 9
CORNER GUIDE ASSEMBLY
SCALE 0.750
ASSEMBLY - 10
FUEL PLATE ASSEMBLY
SCALE 0.175
ITEM 3
LOWER TRUNNION COLLAR SLEEVE
SCALE 0.150

SECTION J-J
SCALE 0.150

ITEM 4
SHELL INTERFACE RING
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ITEM 5
INNER SHELL SUPPORT RING
SCALE 0.125

DETAIL N
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ITEM 9
LARGE REINFORCEMENT RING
SCALE 0.100

ITEM 10
SMALL REINFORCEMENT RING - TOP
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ITEM 11
SMALL REINFORCEMENT RING - BOTTOM
SCALE 0.100

ITEM 12
OUTER SHELL LID LIFTING FEATURE PLATE-1
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ITEM 13
OUTER SHELL LID LIFTING FEATURE PLATE-2
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SECTION Y-Y
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CONTINUED FROM SHEET 2A

ITEM 21 WAS ADDED IN ZONES 03-20 WITH SECTION M-1 AND G-24

ITEM 22 WAS ADDED IN ZONES 03-20 WITH SECTION M-1 AND G-24
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NOTE: SEE ATTACHMENT OF ELECTRONIC SOURCE FILE VERIFICATION FORM PER AP-17.1/Q/ICN 3, SECTION 5.1 (C), ELECTRONIC RECORDS.

THIS DATA SUBMITTAL TO THE RECORDS PROCESSING CENTER IS FOR ARCHIVE PURPOSES ONLY, AND IS NOT AVAILABLE FOR VIEWING OR REPRODUCTION.
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#### ELECTRONIC SOURCE FILE NAME WITH FILE EXTENSION PROVIDED BY THE SOFTWARE:

| calME9r01.doc |

#### DATE LAST MODIFIED:

05/04/2001

#### ELECTRONIC SOURCE FILE APPLICATION:

MS Word

#### FILE SIZE IN KILOBYTES:

906 KB

#### ATTACHMENT I FOR CAL-UDC-ME0000013 REV. 00

SEE ATTACHED #5 & 7 FOR INFORMATION ON ATTACHMENT

#### CERTIFICATION

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#### DC USE ONLY

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#### REV. 05/07/2000
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CAL-UDC-ME-000013 REV 00
Swing-Down of 21-PWR Waste Package
Attachment II

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Note: The file sizes may vary with operating system.

CAL-UDC-ME-000013 Rev. 00