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1. PURPOSE

The objective of this calculation is to determine the structural response of the standard high-level waste (HLW) canister and the canister containing the cans of immobilized plutonium (Pu) ("can-in-canister" [CIC] throughout this document) subjected to drop DBEs (design basis events) during the handling operation. The evaluated DBE in the former case is 7-m (23-ft) vertical (flat-bottom) drop. In the latter case, two 2-ft (0.61-m) corner (oblique) drops are evaluated in addition to the 7-m vertical drop. These Pu CIC calculations are performed at three different temperatures: room temperature (RT) (20°C), $T = 200^{\circ}\text{F} = 93.3^{\circ}\text{C}$, and $T = 400^{\circ}\text{F} = 204^{\circ}\text{C}$; in addition to these the calculation characterized by the highest maximum stress intensity is performed at $T = 750^{\circ}\text{F} = 399^{\circ}\text{C}$ as well. The scope of the HLW canister calculation is limited to reporting the calculation results in terms of: stress intensity and effective plastic strain in the canister, directional residual strains at the canister outer surface, and change of canister dimensions. The scope of Pu CIC calculation is limited to reporting the calculation results in terms of stress intensity, and effective plastic strain in the canister. The information provided by the sketches from Reference 26 (Attachments 5.3, 5.5, 5.8, and 5.9) is that of the potential CIC design considered in this calculation, and all obtained results are valid for this design only. This calculation is associated with the Plutonium Immobilization Project and is performed by the Waste Package Design Section in accordance with Reference 24. It should be noted that the 9-m vertical drop DBE, included in Reference 24, is not included in the objective of this calculation since it did not become a waste acceptance requirement. AP-3.12Q, *Calculations*, is used to perform the calculation and develop the document (see Ref. 23).

2. METHOD

The finite element (FE) calculation is performed by using the commercially available ANSYS Version (V) 5.6.2 (Software Tracking Number [STN]: 10364-562-00; see Ref. 1) and LS-DYNA V950 (STN: 10300-950-00; see Ref. 2) FE codes. ANSYS V5.6.2 is used for preprocessing, i.e. to create FE representation used subsequently in LS-DYNA V950 to obtain solution.

With regard to the development of this calculation, the control of electronic management of information is evaluated in accordance with AP-SV.1Q, *Control of the Electronic Management of Information* (Ref. 25). Electronic management of data has been controlled in accordance with Reference 24, Section 13.

3. ASSUMPTIONS

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

- 3.1 Some of the temperature-dependent material properties (specifically: density and Poisson's ratio) are not available for SA-240 S30403 (304L stainless steel [SS]) except at RT. The RT density and RT Poisson's ratio are assumed for 304L SS. The impact of using RT density and RT Poisson's ratio is anticipated to be small. The rationale for this assumption is twofold: in the first place the density and Poisson's ratio do not change significantly from RT to $T = 204\text{ }^{\circ}\text{C}$; and secondly, the material properties in question do not have dominant impact on the calculation results. This assumption is used in Section 5.1.
- 3.2 The temperature-dependent material properties are not available for glass except at RT. The corresponding RT material properties are assumed for glass. The impact of using RT material properties is anticipated to be small. The rationale for this assumption is that the mechanical properties relevant for representing the glass as an elastic ideally-plastic solid either do not change significantly from RT to $T = 204\text{ }^{\circ}\text{C}$ (density, modulus of elasticity, Poisson's ratio), or are used as a parameter (yield strength) in this calculation. Additionally, the stress state in the glass is not of interest in this calculation. This assumption is used in Section 5.1.
- 3.3 The rate-dependent material properties are not available for glass at any strain rate. The material properties obtained under the static loading conditions are assumed for the glass. The impact of using material properties obtained under static loading conditions is anticipated to be small. The rationale for this assumption is that the relevant mechanical properties of glass (namely: density, modulus of elasticity, Poisson's ratio) do not significantly change at the maximum strain rates that occur during the drops. An exception is the yield strength that is used as a parameter in this calculation. This assumption is used in Section 5.1.
- 3.4 The Poisson's ratio of 304L SS is not available in literature. The Poisson's ratio of 304 SS (SA-240 S30400) is assumed for 304L SS. The impact of this assumption is anticipated to be negligible. The rationale for this assumption is that the chemical compositions of these two stainless steels are similar (see Ref. 3, Sect. II, SA-240, Table 1). This assumption is used in Section 5.1.
- 3.5 The uniform strain (strain corresponding to tensile strength) of 304L SS is not available in literature. Therefore, it is conservatively assumed that the uniform strain is 75% of the elongation (engineering strain corresponding to rupture point in tensile test). The rationale for this assumption is the character of stress-strain curve for 304 SS (see Ref. 4, p. 294), which has a similar chemical composition as 304L SS (see Ref. 3, Sect. II, SA-240, Table

- 1). This assumption is used in Section 5.1.1.
- 3.6 The change of minimum elongation with increase of temperature for the materials used in this calculation is not available in literature. Therefore, the magnitude of this change at $T = 400^{\circ}F$ and $T = 800^{\circ}F$ for 304L SS is assumed to be -16.7% and 28.3%, respectively, based on the relative change of typical elongation for 304L SS available in a vendor catalogue (see Ref. 20 [p. 6], and Section 5.1.3 for details). The rationale for this conservative assumption is that the relative change of typical elongation should be bounding for the relative change of minimum elongation. This assumption is used in Section 5.1.3.
- 3.7 The friction coefficient for contacts occurring among 304L SS parts is not available in literature. It is, therefore, assumed that the dynamic (sliding) friction coefficient for contacts involving SS on SS is 0.4. The rationale for this assumption is that this friction coefficient represents the lower bound for the steel-on-steel contacts (see Refs. 5 [Table 3.2.1, p. 3-26] and 6 [p. 441]). This assumption is used in Sections 5.4.1 and 5.4.2.
- 3.8 The friction coefficient for contacts involving 304L SS and glass is not available in literature. It is, therefore, assumed that the dynamic (sliding) friction coefficient for 304L SS-on-glass contact is 0.55. The rationale for this assumption is that the dry sliding friction coefficient for nickel-on-glass and copper-on-glass contact is 0.56 and 0.53, respectively (see Ref. 5, Table 3.2.1, p. 3-26). This assumption is used in Sections 5.4.1 and 5.4.2.
- 3.9 The variation of functional friction coefficient between the static and dynamic value as a function of relative velocity of the surfaces in contact is not available in literature for the materials used in this calculation (see Section 5.4). Therefore, the effect of relative velocity of the surfaces in contact is neglected in these calculations by assuming that the functional friction coefficient and static friction coefficient are both equal to the dynamic friction coefficient. The impact of this assumption on results presented in this document is anticipated to be negligible. The rationale for this conservative assumption is that it provides the bounding set of results by minimizing the friction coefficient within the given FE-analysis framework. This assumption is used in Sections 5.4.1 and 5.4.2.
- 3.10 The strain-rate data (the stress-strain curves for different strain rates, or the change of yield strength with the strain rate) for 304L SS are not available in literature. The strain-rate data for 304 SS are assumed for 304L SS. The impact of this assumption is anticipated to be negligible. The rationale for this assumption is that the chemical compositions of these two stainless steels are similar (see Ref. 3, Sect. II, SA-240, Table 1). This assumption is used in Sections 5.1 and 5.1.4.
- 3.11 The uniform strain of SA-36 K02600 (A-36 carbon steel [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 A-36 CS (see Ref. 4, pages 186 and 189). This assumption is used in Section 5.1.1.

- 3.12 The Poisson's ratio of A-36 CS is not available in literature. The Poisson's ratio of CS is assumed for A-36 CS. The impact of this assumption is anticipated to be negligible. The rationale for this assumption is that the elastic constants of CSs are only slightly affected by changes in composition and structure (Ref. 9, p. 374). This assumption is used in Section 5.1.
- 3.13 The density of the Savannah River Site HLW form at RT is assumed for the HLW glass. The rationale for this assumption is that the Savannah River Site HLW form is the only HLW form that is currently intended to be used in the Pu CIC. This assumption is not significant since the calculation results are primarily affected by the glass mass, not the glass density. This assumption is used in Section 5.1.
- 3.14 The Poisson's ratio and modulus of elasticity of the HLW glass are not available in literature. The Poisson's ratio and modulus of elasticity of borosilicate glass are assumed for the HLW glass. The rationale for this assumption is that the vitrified HLW form is essentially the borosilicate glass (see Ref. 18, Section 4.2.3.1, p. 18). This assumption is used in Section 5.1.
- 3.15 The bounding mass of the Pu CIC is assumed to be 2600 kg. The rationale for this assumption is that the preliminary mass of the Pu CIC is 2500 kg (see Ref. 15, p. 2-1), for the purpose of this calculation this mass is increased for 4% to accommodate the possibility of small design changes. This assumption is used in Section 5.3.
- 3.16 The mass of filled HLW canister is assumed to be 2130 kg. The rationale for this assumption is that this corresponds to the average mass of filled standard DWPF (Defense Waste Processing Facility) canisters used in drop testing (Ref. 16, Fig. 1, p. 4). This assumption is used in Section 5.3.
- 3.17 The impact surface for the HLW drop calculations is assumed to be 0.216-m thick A-36 CS with constrained bottom nodes. The test report (Ref. 16, p. 3) specifies that the impact pad was 0.216-m (8.5-in) thick steel plate on top of a reinforced concrete slab. The rationale for this assumption is, therefore, that the A-36 CS is a commonly used steel, and that the constraint of the plate-bottom nodes is slightly conservative compared to the actual experimental setup. This assumption has negligible effects on the calculation results. This assumption is used in Section 5.4.1.

4. USE OF COMPUTER SOFTWARE AND MODELS

4.1 SOFTWARE

One of the FE-analysis computer codes used for this calculation is ANSYS V5.6.2, which is obtained from Software Configuration Management in accordance with appropriate procedures, and is identified by STN 10364-562-00 (Ref. 1). ANSYS V5.6.2 is a qualified commercially available FE code and is appropriate for structural calculations of canisters as performed in this calculation. The calculations using ANSYS V5.6.2 software were executed on the Hewlett-Packard (HP) 9000 series UNIX workstation identified with the YMP (Yucca Mountain Project) property tag number 117162, located in Las Vegas, Nevada. The ANSYS evaluation performed for this calculation is fully within the range of the validation performed for ANSYS V5.6.2 code. Access to the code is 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 V5.6.2 are provided in Attachments III and IV.

The second FE computer code used for this calculation is the Livermore Software Technology Corporation LS-DYNA V950, which is obtained from Software Configuration Management in accordance with appropriate procedures, and is identified by STN 10300-950-00 (see Ref. 2). LS-DYNA V950 is a qualified commercially available FE code and is appropriate for structural calculations of canisters as performed in this calculation. The calculations were executed on HP 9000 series UNIX workstations identified with the YMP property tag numbers 117161 and 117162, located in Las Vegas, Nevada. The LS-DYNA evaluation performed for this calculation is fully within the range of the validation performed for LS-DYNA V950 code. Access to the code is granted by the Software Configuration Secretariat in accordance with the appropriate procedures.

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

4.2 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 material properties are not available for 304L SS and glass. Therefore, RT density and RT Poisson's ratio are used for 304L SS (see Assumption 3.1), while the RT material properties are used for glass (Assumptions 3.2). For the evaluated target materials, A-36 CS and concrete, the RT material properties are considered appropriate. The strain-rate data is not available for 304L SS. The strain-rate data for 304 SS is, therefore, assumed for 304L SS (see Assumption 3.10). The rate-dependent material properties are also not available for glass at any strain rate. The material properties obtained under the static loading conditions are assumed for the glass (Assumption 3.3).

SA-240 S30403 (304L SS) (Canisters, cans, magazines, and rack):

- Density = 7940 kg/m^3 (at RT) (Ref. 7, Table X1.1, p. 7)
- Yield strength = 172 MPa (25.0 ksi) (at RT) (Ref. 3, Sect. II, Table Y-1)
Yield strength = 148 MPa (21.4 ksi) (at $200^\circ\text{F} = 93.3^\circ\text{C}$) (Ref. 3, Sect. II, Table Y-1)
Yield strength = 121 MPa (17.5 ksi) (at $400^\circ\text{F} = 204^\circ\text{C}$) (Ref. 3, Sect. II, Table Y-1)
Yield strength = 103 MPa (15.0 ksi) (at $750^\circ\text{F} = 399^\circ\text{C}$) (Ref. 3, Sect. II, Table Y-1)
- Tensile strength = 483 MPa (70.0 ksi) (at RT) (Ref. 3, Sect. II, Table U)
Tensile strength = 456 MPa (66.1 ksi) (at $200^\circ\text{F} = 93.3^\circ\text{C}$) (Ref. 3, Sect. II, Table U)
Tensile strength = 405 MPa (58.7 ksi) (at $400^\circ\text{F} = 204^\circ\text{C}$) (Ref. 3, Sect. II, Table U)
Tensile strength = 389 MPa (56.4 ksi) (at $750^\circ\text{F} = 399^\circ\text{C}$) (Ref. 3, Sect. II, Table U)
- Elongation = 0.40 (at RT) (Ref. 3, Sect. II, SA-240, Table 2)
- Poisson's ratio = 0.29 (at RT) (Ref. 8, Fig. 15, p. 755; see Assumption 3.4)
- Modulus of elasticity = 195 GPa ($28.3 \cdot 10^6 \text{ psi}$) (at RT) (Ref. 3, Sect. II, Table TM-1)
Modulus of elasticity = 190 GPa ($27.6 \cdot 10^6 \text{ psi}$) (at $200^\circ\text{F} = 93.3^\circ\text{C}$) (Ref. 3, Sect. II, Table TM-1)
Modulus of elasticity = 183 GPa ($26.5 \cdot 10^6 \text{ psi}$) (at $400^\circ\text{F} = 204^\circ\text{C}$) (Ref. 3, Sect. II, Table TM-1)
Modulus of elasticity = 169 GPa ($24.45 \cdot 10^6 \text{ psi}$) (at $750^\circ\text{F} = 399^\circ\text{C}$; interpolated by using $T = 700^\circ\text{F}$ and $T = 800^\circ\text{F}$ values) (Ref. 3, Sect. II, Table TM-1)

- Reduction of area = 0.40 (at RT) (Ref. 3, Sect. II, SA-479/SA-479M, Table 2)

SA-36 K02600 (SA-36 CS) (Target plate):

- Density = 7860 kg/m^3 (at RT) (Ref. 7, Table X1.1, p. 7)
- Yield strength = 248 MPa (36.0 ksi) (at RT) (Ref. 3, Sect. II, Table Y-1)
- Tensile strength = 400 MPa (58.0 ksi) (at RT) (Ref. 3, Sect. II, Table U)
- Elongation = 0.23 (at RT) (Ref. 3, Sect. II, SA-36/SA-36M, Table 3)
- Poisson's ratio = 0.30 (at RT) (Ref. 9, p. 374; see Assumption 3.12)
- Modulus of elasticity = 203 GPa ($29.5 \cdot 10^6 \text{ psi}$) (at RT) (Ref. 3, Sect. II, Table TM-1)

Borosilicate Glass:

- Density = 2230 kg/m^3 (at RT) (Ref. 10, Table 1, p. 18)
- Poisson's ratio = 0.20 (at RT) (Ref. 10, Table 1, p. 18)
- Modulus of elasticity = 64 GPa (at RT) (Ref. 10, Table 1, p. 18)

HLW Glass:

- Density = 2850 kg/m^3 (at RT) (Ref. 11, Table 6.4, p. 2.2.1.1-4; see Assumption 3.13)
- Poisson's ratio = 0.20 (at RT) (Ref. 10, Table 1, p. 18; see Assumption 3.14)
- Modulus of elasticity = 64 GPa (at RT) (Ref. 10, Table 1, p. 18; see Assumption 3.14)

Concrete (high strength) (Target plate):

- Density = 2400 kg/m^3 (150 lb/ft^3) (at RT) (Ref. 12, p. 418)
- Poisson's ratio = 0.19 (at RT) (Ref. 12, p. 421)
- Modulus of elasticity = 43 GPa (at RT) (Ref. 12, Fig. 13.10, p. 685)

5.1.1 Calculations for True Measures of Ductility

The stress and strain properties in Section 5.1 refer to engineering stress and strain definitions: $s = P/A_0$ and $e = L/L_0 - 1$ (see Ref. 13, Chapter 9). Where P stands for the force applied during a static tensile test, L is the length of the deformed specimen, and L_0 and A_0 are the original length and cross-sectional area of the specimen, respectively. The engineering stress-strain curve does not give a true indication of the deformation characteristics of a material during plastic deformation since it is based entirely on the original dimensions of the specimen. In addition, ductile metal that is pulled in tension becomes unstable and necks down in the course of the test. Hence, LS-DYNA V950 FE code requires input in terms of true stress and strain definitions: $\sigma = P/A$ and $\epsilon = \ln(L/L_0)$ (see Ref. 13, Chapter 9).

The relationships between the true stress and strain definitions and the engineering stress and strain definitions, $\sigma = s \cdot (1 + e)$ and $\epsilon = \ln(1 + e)$, can be readily derived based on constancy of volume ($A_0 \cdot L_0 = A \cdot L$) and strain homogeneity during plastic deformation (see Ref. 13, Chapter 9). These expressions are applicable only in the hardening region of the 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

$e_y \approx \epsilon_y$ = 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)

q = reduction of area

ϵ_f = true fracture (rupture) strain

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

The stress-strain curves for 304L SS exhibit pronounced three-stage (elastic-hardening-softening) deformation character. The uniform strain is, therefore, estimated to be 75% of elongation based on the available stress-strain curves (see Assumption 3.5). Consequently, at RT:

$$\begin{aligned}e_u &= 0.75 \cdot \text{elongation} = 0.75 \cdot 0.40 = 0.30 \\ \epsilon_u &= \ln(1 + e_u) = \ln(1 + 0.30) = 0.26 \\ \sigma_u &= s_u \cdot (1 + e_u) = 483 \cdot (1 + 0.30) = 628 \text{ MPa}\end{aligned}$$

Thus the true tensile strength of 304L SS at RT is estimated to be 628 MPa.

The elongation is one of the conventional measures of ductility obtained from the tension test and available in literature. Unfortunately this property is of doubtful usefulness for the nonlinear analysis. However, the true fracture (rupture) strain is related to the reduction of area by the relationship (see Ref. 13, Chapter 9):

$$\epsilon_f = \ln \frac{1}{1 - q} = \ln \frac{1}{1 - 0.40} = 0.51$$

Therefore, the minimum fracture strain of 304L SS at RT is 51%. It should be emphasized, though, that this is a very conservative value based on Reference 3 (Section II, SA-479/SA-479M, Table 2); Reference 14 (Figure 3.03115, Code 1303, p. 14), for example, reports the fracture strain of 304 SS at RT to be $\epsilon_f = 180\%$.

Finally, the stress-strain curves for A-36 CS exhibit the stress-strain-curve character typical for CS. The uniform strain is estimated to be 50% of elongation based on the stress-strain curves presented in Reference 4 (pages 186 and 189) (see Assumption 3.11). Hence

$$\begin{aligned}e_u &= 0.50 \cdot \text{elongation} = 0.50 \cdot 0.23 = 0.12 \\ \epsilon_u &= \ln(1 + e_u) = \ln(1 + 0.12) = 0.11 \\ \sigma_u &= s_u \cdot (1 + e_u) = 400 \cdot (1 + 0.12) = 448 \text{ MPa}\end{aligned}$$

5.1.2 Calculations for Tangent Moduli

As previously discussed, the results of these FE simulations are required to include elastic and plastic deformations for 304L SS and, to a certain extent, A-36 CS (depending on whether it is represented as elastic or elasto-plastic material). When the materials are driven into the plastic range, the slope of stress-strain curve continuously changes. A ductile failure is preceded by a protracted regime of hardening and substantial accumulation of inelastic strains. Thus, a simplification for stress-strain curve is needed to incorporate plasticity into the FE analysis. 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. This simplification is justified by true stress-strain curve of 304 SS at RT presented in Reference 14 (Figure 3.03115, Code 1303, p. 14), which exhibits almost linear hardening. The parameters used in the subsequent calculations, in addition to those defined already

in Section 5.1.1, are modulus of elasticity (E) and tangent (hardening) modulus (E_1). The tangent modulus represents the slope of the stress-strain curve in the plastic region.

In the case of 304L SS the tangent modulus at RT is:

$$E_1 = (\sigma_u - \sigma_y) / (\epsilon_u - \sigma_y / E) = (0.628 - 0.172) / (0.26 - 172 \cdot 10^6 / 195 \cdot 10^9) = 1.76 \text{ GPa} \text{ (see Section 5.1 and 5.1.1)}$$

Similarly, for A-36 CS the tangent modulus at RT is:

$$E_1 = (\sigma_u - \sigma_y) / (\epsilon_u - \sigma_y / E) = (0.448 - 0.248) / (0.11 - 248 \cdot 10^6 / 203 \cdot 10^9) = 1.84 \text{ GPa} \text{ (see Sections 5.1 and 5.1.1)}$$

5.1.3 Effect of Change of Elongation on Material Properties

The change of minimum elongation of 304L SS with increase of temperature is not available in literature. Therefore, the magnitudes of this change at $T = 93.3^\circ\text{C}$, $T = 204^\circ\text{C}$, and $T = 399^\circ\text{C}$ are estimated based on the change of typical elongation (Assumption 3.6).

The Reference 20 (p. 6) indicates 16.7% and 28.3% decrease of typical elongation of 304L SS at $T = 400^\circ\text{F}$ and $T = 800^\circ\text{F}$, respectively, with respect to RT value. Hence, by using linear interpolation the decrease of elongation corresponding to increase of temperature from RT to $T = 200^\circ\text{F} = 93.3^\circ\text{C}$ and from RT to $T = 750^\circ\text{F} = 399^\circ\text{C}$ is 6.6% and 26.8%, respectively.

Consequently, the true measure of ductility and tangent modulus, calculated in Section 5.1.1 and 5.1.2, have to change to accommodate the variability of elongation due to change of temperature.

At $T = 93.3^\circ\text{C}$:

$$e_u = (1 - 0.066) \cdot (0.75 \cdot \text{elongation}) = 0.934 \cdot (0.75 \cdot 0.40) = 0.28$$

$$\epsilon_u = \ln(1 + e_u) = \ln(1 + 0.28) = 0.25$$

$$\sigma_u = s_u \cdot (1 + e_u) = 456 \cdot (1 + 0.28) = 584 \text{ MPa}$$

Consequently, the tangent modulus of 304L SS at $T = 93.3^\circ\text{C}$ becomes

$$E_1 = (\sigma_u - \sigma_y) / (\epsilon_u - \sigma_y / E) = (0.584 - 0.148) / (0.25 - 148 \cdot 10^6 / 190 \cdot 10^9) = 1.75 \text{ GPa}$$

At $T = 204^\circ\text{C}$:

$$e_u = (1 - 0.167) \cdot (0.75 \cdot \text{elongation}) = 0.833 \cdot (0.75 \cdot 0.40) = 0.25$$

$$\epsilon_u = \ln(1 + e_u) = \ln(1 + 0.25) = 0.22$$

$$\sigma_u = s_u \cdot (1 + e_u) = 405 \cdot (1 + 0.25) = 506 \text{ MPa}$$

Consequently, the tangent modulus of 304L SS at $T = 204^\circ\text{C}$ becomes

$$E_t = (\sigma_u - \sigma_y) / (\epsilon_u - \sigma_y / E) = (0.506 - 0.121) / (0.22 - 121 \cdot 10^6 / 183 \cdot 10^9) = 1.76 \text{ GPa}$$

The tangent modulus of 304L SS is, therefore, not affected by the increase of temperature from RT to $T = 93.9^\circ\text{C}$ and $T = 204^\circ\text{C}$.

Finally, at $T = 399^\circ\text{C}$:

$$e_u = (1 - 0.268) \cdot (0.75 \cdot \text{elongation}) = 0.732 \cdot (0.75 \cdot 0.40) = 0.22$$

$$\epsilon_u = \ln(1 + e_u) = \ln(1 + 0.25) = 0.20$$

$$\sigma_u = s_u \cdot (1 + e_u) = 389 \cdot (1 + 0.22) = 475 \text{ MPa}$$

Consequently, the tangent modulus of 304L SS at $T = 399^\circ\text{C}$ becomes

$$E_t = (\sigma_u - \sigma_y) / (\epsilon_u - \sigma_y / E) = (0.475 - 0.103) / (0.20 - 103 \cdot 10^6 / 169 \cdot 10^9) = 1.87 \text{ GPa}$$

The tangent modulus of 304L SS is, therefore, slightly affected by the increase of temperature from RT to $T = 399^\circ\text{C}$.

5.1.4 Effect of Strain Rate on Material Properties

The plastic behavior of materials is sensitive to strain rate, which is known as material strain-rate sensitivity, or viscoplasticity. The effect on strain rate on the material properties of 304L SS is accounted in this calculation by scaling the yield strength with the factor

$$\beta = 1 + \left(\frac{\dot{\epsilon}}{C} \right)^{1/p} \quad (1)$$

where $\dot{\epsilon}$ is the strain rate, and C and p are LS-DYNA input parameters obtained by fitting the experimental data (see Ref. 22, p. 16.37).

The strain-rate data (the stress-strain curves for different strain rates, or the change of yield strength with strain rate) of 304L SS are not available in literature. The strain-rate data of 304 SS (Ref. 17, Figs. 10 and 27) are assumed for 304L SS (Assumption 3.10). The test results provided in the Reference 17 (Figs. 10 and 27) indicate that on average $\beta(\dot{\epsilon} = 20 s^{-1}) = 1.2$ and $\beta(\dot{\epsilon} = 900 s^{-1}) = 1.45$. These values can be used as the boundary conditions for determination of strain-rate parameters in Eq. (1). Therefore, the calculation of the strain-rate parameters is straightforward. By substituting the first boundary condition in Eq. (1):

$$1.2 = 1 + \left(\frac{20}{C} \right)^{1/p} \Rightarrow C = \frac{20}{0.2^p} \quad (2)$$

Similarly, by substituting the second boundary condition in Eq. (1)

$$1.45 = 1 + \left(\frac{900}{C} \right)^{1/p}$$

and adding the Eq. (2), the parameter p can be readily calculated:

$$0.45 = \left(\frac{900}{20/0.2^p} \right)^{1/p} \Rightarrow p = \frac{\ln(45)}{\ln(0.45) - \ln(0.2)} = 4.7$$

From Eq. (2) it follows directly that $C = 38 \cdot 10^3 s^{-1}$.

Therefore, the strain-rate parameters used for 304L SS in these calculations are $p = 4.7$ and $C = 38 \cdot 10^3 s^{-1}$. This implies, according to Eq. (1), that the yield strength of 304L SS would double at $\dot{\epsilon} = 38 \cdot 10^3 s^{-1}$, which is admittedly rather high. Nonetheless it should be recognized that: (1) the strain-rate parameters p and C are evaluated by fitting of the experimental data for 304 SS within a relatively moderate strain-rate range ($\leq 900 s^{-1}$), and (2) the intention is to capture the strain-rate sensitivity only within an even narrower strain-rate range ($\leq 700 s^{-1}$) that is of interest in this calculation (see the slopes of the effective plastic strain curves in Attachments I and II, especially Figs. I-6, I-8, and II-30 characterized by the maximum effective plastic strain rates). It should be also emphasized that, due to the scatter of the 304 SS data reported in Reference 17 (Figs. 10 and 27), these parameters are only the best available estimates whose appropriateness will be evaluated by comparing the experimental results of the 7-m vertical drop of the standard glass canister (Ref. 16, Table 3, and pages 2 and 28) with the corresponding simulation results.

It should be noted that based on Eq. (1) and the estimated strain-rate parameters p and C , the strength increase due to the maximum strain rate encountered during these drop calculations $\dot{\epsilon} \approx 700 \text{ s}^{-1}$ (see for example Figs. I-6, I-8, and II-30) is approximately 43%. Lastly, according to Reference 21 (Fig. 7, p. 863), up to the strain rate of 330 s^{-1} ($20,000 \text{ min}^{-1}$) the reduction of area – and, consequently, the fracture strain – is not significantly affected by strain rate at RT (the reported maximum decrease is approximately 10%).

As far as the glass is concerned, the stress-strain curves for different strain rates, or the change of yield strength with strain rate are not available in literature. The strain-rate effect on glass properties is, therefore, included in the parametric evaluation of yield strength of the glass throughout this document. In other words, it is considered that the different yield strengths of glass used in this calculation (50 MPa, 200 MPa, and 500 MPa; see Section 5.1.5) take into account the strain-rate scaling of the yield strength.

5.1.5 Effects of Glass Properties on Calculation

The constitutive representation (stress-strain relation) of glass behavior under compression is still a challenge for FE analysis. In contrast to the elastic ideally-brittle behavior of glass under tension, the stress-strain behavior of glass under compression can take various forms depending on the loading conditions (lateral confinement is a notable example), and the geometry of the material components (i.e. the slenderness ratio of the test specimen). The brittle materials in general, when subjected to compression, exhibit the wide range of nonlinear stress-strain behaviors due to the nucleation, propagation, and coalescence of microcracks under different boundary conditions. Moreover, the compressive strength of brittle materials (including glass) is significantly higher than their tensile strength. The constitutive representation of glass in this calculation is further complicated by the fact that, in the case of Pu CIC at least, the glass is significantly shattered during the solidification phase (see Ref. 19, Figs. 7.2 and 7.3, and Attachment 13.4). The importance of this cannot be overemphasized having in mind that the strength of glass is more dependent on the surface condition and the amount of pre-existing damage than on the chemical composition (Ref. 10, p. 43). It should be also noted that the stress in glass is of interest only as much as it affects the stress/strain state in the canister, which is the objective of this calculation.

It is, therefore, considered appropriate to conservatively represent the glass behavior as elastic ideally-plastic (see Fig. 1). This representation of nonlinear behavior seems to be the conservative under the given loading conditions. The yield strength of glass is one of the parameters in this study that significantly affect the results. Three different values are evaluated for the Pu CIC calculations: 50 MPa, 200 MPa, and 500 MPa. Having in mind the glass condition upon solidification (Ref. 19, Figs. 7.2 and 7.3, and Attachment 13.4), and the loading conditions that are – in the case of oblique drops – not necessarily as predominantly compressive as in the case of vertical drop, these values provide a range of glass strengths that seems to be reasonable under the specified circumstances (see Ref. 10, p. 18). On the other hand, in the case of HLW canister the stress state in glass is

predominantly compressive, and the glass is not expected to be as damaged as the one in Pu CIC since there is no the complex internal steel structure to promote the cracking. Consequently 500 MPa seems to be not only an appropriate lower bound but also probably very reasonable estimate of the glass strength in this case.

Figure 1. Elastic-Ideally-Plastic Constitutive Representation (Stress-Strain Curve)

5.2 CALCULATIONS FOR IMPACT VELOCITY

To reduce the computer execution time while preserving all features of the problem relevant to the structural calculation, the canister is set in a position just before impact and given an appropriate initial velocity. The magnitude of the initial velocity is defined by the drop height (H).

In the case of 7-m drop the magnitude of the impact velocity (Ref. 27, Chapter 1, Table 2, p. 20) is:

$$V = \sqrt{2 \cdot g \cdot H} = \sqrt{2 \cdot 9.81 \cdot 7} = 11.7 \text{ m/s}$$

while in the case of 2-ft drop ($2 \text{ ft} = 0.61 \text{ m}$)

$$V = \sqrt{2 \cdot g \cdot H} = \sqrt{2 \cdot 9.81 \cdot 0.61} = 3.46 \text{ m/s}$$

5.3 MASS AND GEOMETRICAL DIMENSIONS OF CANISTERS

This calculation is performed by using geometric dimensions of the standard DWPF canister, specifically, the outside diameter and overall length are 0.61 m and 3.00 m, respectively (Ref. 18, Section 4.2.3.1, p. 18).

The mass of filled standard HLW canister is 2130 kg (see Assumption 3.16), while the mass of the Pu CIC is 2600 kg (see Assumption 3.15).

5.4 FINITE ELEMENT REPRESENTATION

5.4.1 HLW Canister FE Representation

The first part of this calculation is the simulation of the 7-m vertical drop of the HLW canister. These results are subsequently compared with the impact-testing data presented in Reference 16 (Table 3, and pages 2 and 28). The objective of these calculations is twofold: (1) to determine the most appropriate FE representation by comparing the computational and experimental results, and (2) to evaluate stresses, strains, and deformation in the canister for two different constitutive representations of glass.

Before going into the details of different FE representations developed in this calculation, it should be noted that regardless of the FE representation a kinematic hardening is used for all materials driven into the plastic range. The kinematic hardening represents a translation of the yield surface by shifting its origin while the shape and size of the yield surface remain unchanged. This representation is in good agreement with the Bauschinger effect for those materials whose stress-strain curve in the work-hardening range can be approximated by a straight line. The kinematic hardening also maximizes the effective plastic strain (see Section 6).

Two sets of three-dimensional (3-D) quarter-symmetry FE representations are developed for the purpose of determining the most appropriate FE representation. The first set of FE representations has the bottom of the canister represented by the brick (hexagonal solid) elements, while the second set has the bottom of the canister represented by the quadrilateral shell elements. The brick elements are much more time-consuming and intention behind this inquiry is to determine whether the whole canister can be represented with reasonable accuracy with the shell elements. Since the extent of damage in the glass upon solidification is not exactly known for the HLW canister, each set of FE representations is further developed in order to capture the salient features of the deformation process. Specifically, the first set of FE representations consists of three different subsets with regards to the possible connection between the glass and the canister upon solidification. In the first pair of FE representation (the fifth and sixth in Appendix I) the glass-canister connection is continuous (solid connection) throughout the deformation process (see Fig. I-1). It should be noted from Figure I-1 that while the canister bottom is represented by the brick elements the remaining part of the canister – characterized by negligible deformation – is represented by the shell elements. The reason for this simplification is to optimize the running time while preserving all features important to FE solution. Thus, since the upper part of the canister is not so heavily loaded during the vertical drop compared to the bottom part, it is deemed unnecessary to represent it by the time-consuming brick elements. Appropriateness of this approach is confirmed by the obtained calculation results. In order to evaluate different possible glass strengths, the first two FE calculations are performed by using the elastic and the elastic-ideally-plastic (with $\sigma_y = 500 \text{ MPa}$) constitutive representation for the glass. Since the extent of damage in the glass upon solidification is not exactly known for the HLW canister, a yield strength of 500 MPa is not only a lower bound but probably a value close to

reality knowing that the stress state in glass is predominantly compressive during vertical drops (see Ref. 10 [p. 18] and Section 5.1.5).

In the second pair of FE representations (the third and fourth in Appendix I) featuring the representation of canister bottom by brick elements, the glass-canister connection is represented by a thin layer of eroding brick elements. The appearance of the initial FE representation is the same as the previous one presented in Figure I-1. The important difference is that - unlike in the previous case where connectivity between glass and canister remains unchanged throughout the deformation process - in this representation the thin layer of elements can erode (i.e. removed from the FE mesh) when the effective plastic strain in the element reaches certain limit (see Figs. I-42 and I-43 for an illustration). The intention is to capture different possible levels of adhesion between the glass and the HLW canister upon glass solidification by varying this erosion-threshold strain limit. Two bounding strain limits are used as parameters in this study: 0.1% and 2.3%. This failure-strain range is obtained by dividing the typical bounding glass strengths (50 MPa and 1500 MPa; see Ref. 10, p. 18) with the modulus of elasticity of glass (Section 5.1), and rounding to the nearest 0.1%-value. The resulting failure-strain range envelopes all glass strengths reasonable under the given loading conditions. These FE calculations are performed by using the elastic-ideally-plastic constitutive representation for the glass (with $\sigma_y = 500 \text{ MPa}$).

The last pair of FE representations with the canister bottom represented by the brick elements (the first and second in Appendix I) is characterized by the loose glass within the canister. This is achieved by specifying a very small gap between the two FE representation entities (see Fig. I-2). The glass is, therefore, free to move inside the canister, and can establish the contact with the canister by using the contact elements. The calculations are, again, performed by using both the elastic and the elastic-ideally-plastic (with $\sigma_y = 500 \text{ MPa}$) constitutive representation of the glass.

The second large set of FE representations is developed with the bottom of the canister represented by the shell elements (see Figs. I-3 and I-4). The FE calculations are performed by using the elastic-ideally-plastic constitutive representation of the glass (with $\sigma_y = 500 \text{ MPa}$). The glass is represented as either solidly connected to the canister (the eighth FE representation in Appendix I, see Fig. I-3) or loose within the canister (the seventh FE representation in Appendix I, see Fig. I-4).

Contact elements are used to represent contact between the HLW canister and the A-36 CS plate, and between the glass and the HLW canister when applicable. The dynamic friction coefficient for steel-on-steel contact is assumed to be 0.4 (Assumption 3.7). In absence of more appropriate data on friction coefficients for contacts involving 304L SS and glass, the dynamic friction coefficient is assumed to be 0.55 (Assumption 3.8). Moreover, the functional friction coefficient used by LS-DYNA V950 FE code is defined in terms of static and dynamic friction coefficients, and relative velocity of the surfaces in contact. The effect of the relative velocity of the surfaces in contact is introduced by the way of a fitting parameter - exponential decay coefficient. The variation of friction coefficient between the static and dynamic value as a function of relative velocity of the surfaces in

contact is not available in literature for the materials used in this calculation. Therefore, it is not possible to objectively evaluate the exponential decay coefficient. Hence, the effect of relative velocity of the surfaces in contact is neglected in these calculations by assuming that the functional friction coefficient and the static friction coefficient are equal to the dynamic friction coefficient. This approach provides the bounding set of results by minimizing the friction coefficient within the given FE-analysis framework (Assumption 3.9).

The target for HLW drop calculations is assumed to be made of A-36 CS, with thickness being equal to the thickness of the steel impact pad used in the actual experiment (Assumption 3.17). While in the drop experiment the steel impact pad was on top of the slab of reinforced concrete (see Ref. 16, p. 3), in this simulation the concrete support is conservatively disregarded and the bottom nodes of the A-36 CS plate are constrained to ensure the bounding set of results. The FE representation of the target plate has a circular shape with a central hole in order to ensure axially symmetric FE representation and minimize computation time. The non-reflecting boundary is used to avoid artificial reflections of the stress waves from the sides of A-36 CS plate. Consequently, the CS target truly represents an infinite plate of defined thickness, since the contamination of results due to the reflections of the stress waves from target sides is prevented.

These FE representations are then used in LS-DYNA V950 to perform transient dynamic analyses of the HLW canister impacting the A-36 CS plate. In order to reduce the computer execution time the finite element calculation is started on the verge of impact between the canister and the A-36 CS plate. The drop height is taken into account by applying the initial velocity (see Section 5.2) to all HLW canister nodes.

The mesh of the FE representation is appropriately generated and refined in the contact region according to standard engineering practice. The size of both brick and shell elements representing the bottom of the HLW canister approximately matches the size of the strain circles in the DWPF canister impact testing (see Ref. 16, p. 26). Thus, the accuracy and representativeness of the results of this calculation are deemed acceptable (see Table 2).

5.4.2 Pu Can-in-Canister FE Representation

Three different sets of the Pu CIC calculations are performed herein for three DBEs:

- (1) 7-m vertical (flat-bottom) drop (Fig. II-1),
- (2) 2-ft 70-degrees oblique drop (the corner drop with center of gravity above the initial-impact region, Fig. II-2), and
- (3) 2-ft 10-degrees oblique drop with slap down (the secondary impact at the opposite end of canister, Fig. II-3).

The complete set of these calculations is performed at RT and $T = 200^{\circ}\text{F} = 93.3^{\circ}\text{C}$. The 7-m vertical drops and the 70-degrees oblique drops are performed at $T = 400^{\circ}\text{F} = 204^{\circ}\text{C}$ as well. The calculations of the 2-ft 10-degrees oblique drops are not performed at this temperature since the results of these time-consuming simulations are bounded by the first two DBEs. Finally, one FE calculation – characterized by the highest maximum stress intensity – is performed at $T = 750^{\circ}\text{F} = 399^{\circ}\text{C}$ to illustrate the trend of very high temperature cases.

The yield strength of glass is, as discussed in Section 5.1.5, one of the parameters that significantly affect the results. Three different values of glass strength are evaluated for the Pu CIC calculations: 50 MPa, 200 MPa, and 500 MPa. Having in mind the typical glass strengths reported in Reference 10 (p. 18), these values provide a range of glass strengths that seems plausible primarily due to the glass condition upon solidification: Reference 19 (Figs. 7.2 and 7.3, and Attachment 13.4) indicates that the glass is significantly shattered. Additionally, the loading conditions, in the case of oblique drops, are not necessarily as predominantly compressive as in the case of vertical drop. Both of these circumstances tend to reduce the glass strength.

The three 3-D half-symmetry FE representations are developed for the purpose of simulating these events. The FE representation of Pu CIC is the same in all three cases; the only difference is the orientation and the FE representation of the target (see Figs. II-1, II-2, and II-3). Unlike the HLW canister where brick and shell elements are combined in the FE representation of the canister, the FE representation of canister in the Pu-CIC case is made exclusively of the brick (hexahedral solid) elements. The reason for this modification is that the oblique drops – especially the 10-degrees drop with the secondary impact at the canister top – are much more complex than the vertical drop in which the deformation is localized in the region close to the canister bottom.

The first three Pu-CIC calculations are performed with three different target representations: (1) A-36 CS target with elasto-plastic deformation (identical to the one used in the HLW canister drop calculations), (2) unyielding target with A-36 CS mechanical properties, and (3) unyielding target with mechanical properties of high-strength concrete. The purpose of this set of FE calculations is to evaluate the effect of the FE representation of the target on the calculation results.

The FE representation of the Pu CIC is presented in Figures II-4, II-5, and II-6. The FE representation includes all canister components relevant to the structural calculation. The internal structure of the Pu CIC, characterized by a plethora of details (see Refs. 26 [Attachments 5.3, 5.5, 5.8, and 5.9] and 19 [Fig. 3.2] for a detailed description), is complex enough to render FE-representation development a very delicate problem, having in mind available computational capabilities. Some structural details are not included in the FE representation and the others are simplified in order to reduce the computer execution time while preserving all structural features essential for the calculation. The magazine tubes (see Ref. 26 [Attachment 5.8] and Figs. II-4 and II-6) are represented as continuous shells without perforations. Similarly, the radial supports (Ref. 26 [Attachment 5.3] and Figs. II-4 through II-6) are represented without the central opening. Four scalloped plates (see Ref. 26 [Attachment 5.3]) are not included in the FE representation since their only purpose is to fix the Pu CIC structure during the pouring of the glass. Their mass, though, is added to the mass of Pu cans. The Pu cans are also simplified by being reduced to four solid tubes (Fig. II-4).

The contact elements are used to represent contact between various structural parts: glass and canister, canister and target, internal steel structure (base plate, magazine tubes, and radial supports) and canister, glass and internal steel structure, and Pu cans and magazine tubes. The contact elements are also used to represent the contact between different glass parts. The dynamic friction coefficient for steel-on-steel contact is assumed to be 0.4 (Assumption 3.7). In absence of more appropriate data on friction coefficients for contacts involving 304L SS and glass, the dynamic friction coefficient is assumed to be 0.55 (Assumption 3.8). Lastly, the dynamic friction coefficient for dry glass-on-glass contact, 0.4, is obtained from Reference 5 (Table 3.2.1, p. 3-26). Moreover, the variation of friction coefficient between the static and dynamic value as a function of relative velocity of the surfaces in contact is neglected in these calculations by assuming that the functional friction coefficient and the static friction coefficient are equal to the dynamic friction coefficient (see Assumption 3.9 and Section 5.4.1 for details).

In order to reduce the computer execution time, the finite element calculation is started on the verge of impact between the canister and the A-36 CS plate. The drop height is taken into account by applying the initial velocity (see Section 5.2) to all Pu CIC nodes.

The mesh of the FE representation is appropriately generated and refined in the contact region according to standard engineering practice. Thus, the accuracy and representativeness of the results of this calculation are deemed acceptable (see Table 17).

6. RESULTS

LS-DYNA stress and strain results include high-frequency response. In the case of strain histories used for determination of residual strains for the HLW canister drops, these results are filtered using a Butterworth low-pass filter with cut-off frequency of 20 Hz. The purpose of the filtering is to obtain steady-state residual strains by removing the high-frequency response. Since the strain results after the filtering produced steady-state values anticipated by visual inspection of unfiltered (raw) strain histories, this type of filtering was deemed acceptable. Consequently, all longitudinal and circumferential strain histories on the outer surface of the HLW canister, presented in Attachment I (Figures I-47 through I-61), are filtered in this manner.

The stress-history plots obtained from LS-DYNA V950 are reported in Attachments I and II in terms of maximum shear stress. Since the stress intensities are desired, the maximum-shear-stress results need to be translated appropriately. 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 in terms of maximum shear stress, presented in Attachments I and II, need to be multiplied by two, to obtain the corresponding stress intensities, reported in this section.

6.1 RESULTS FOR HLW CANISTER

The first set of results, presented in Table 1, refers to the different FE representation of HLW canister described in Section 5.4.1.

The effective (equivalent) plastic strain presented in Table 1 is defined as

$$\epsilon_{eff}^p = \int_0^t \left(\frac{2}{3} \dot{\epsilon}_{ij}^p \dot{\epsilon}_{ij}^p \right)^{1/2} dt$$

where $\dot{\epsilon}_{ij}^p$ is plastic strain rate tensor (see Ref. 22, p. 16.11), t is time, and repeated indices imply summation. The effective plastic strain is a hardening parameter that, similarly to plastic work, provides a measure of the plastic distortion. If a specimen of an isotropic material, characterized by plastic incompressibility, is subjected to a uniaxial tensile (or compressive) test the effective plastic strain reduces to the true strain. The use of the kinematic hardening for all materials driven into the plastic range (see Section 5.4.1) ensures that the estimate of the effective plastic strain is conservative.

The stress intensity and the effective plastic strain histories presented in Table 1 refer to the elements in which the maximum (peak) value of corresponding parameters is attained in the HLW canister in the course of drop simulation. Needless to say, both the stress intensity (see Fig. II-21; notice

accurately captured axial symmetry of the problem) and the effective plastic strain (see Figs. I-63 and I-64) change significantly across the thickness of the canister.

Table 1. Stress Intensity and Effective Plastic Strain for 7-m Drop of HLW Canister for Different FE Representations

Canister-Bottom Representation	Connection between Glass and Canister	Constitutive Representation for Glass	Stress Intensity (MPa)	Effective Plastic Strain (%)
Brick Elements	Loose Glass	Elastic	695 (Figure I-5)	37.7 (Figure I-6)
		Elastic Ideally-Plastic	623 (Figure I-7)	29.5 (Figure I-8)
	Thin Layer of Eroding Glass	Failure Strain = 0.1%	600 (Figure I-9)	31.0 (Figure I-10)
		Failure Strain = 2.3%	538 (Figure I-11)	28.0 (Figure I-12)
	Solid Connection	Elastic	523 (Figure I-13)	20.0 (Figure I-14)
		Elastic Ideally-Plastic	562 (Figure I-15)	20.8 (Figure I-16)
Shell Elements	Loose Glass	Elastic Ideally-Plastic	561 (Figure I-17)	19.5 (Figure I-18)
	Solid Connection	Elastic Ideally-Plastic	442 (Figure I-19)	12.8 (Figure I-20)

The average of the effective plastic strains across the canister-wall thickness at the locations corresponding to the maximum effective plastic strains presented in Table 1 for the two loose-glass brick-elements FE representations are respectively 32.8% (see Fig. I-63) and 25.3% (Fig. I-64).

Notice that the true ultimate tensile strength, uniform strain, and fracture strain for 304L SS at RT are 628 MPa, 26%, and 51%, respectively (Section 5.1.1). It should also be emphasized that the helium-leak testing and dye-penetrant examination of the welds after the 7-m DWPF canister drops (see Ref. 16, p. 2) revealed that the structural integrity of all tested canisters was not affected by the impact.

The highest maximum stress intensities and the maximum effective plastic strains are observed for the elastic loose glass representation. The results for eroding glass-canister connection are bridging the gap between the solid connection and loose glass, as expected. There is significant difference between the results for the brick- and shell-element FE representations of the HLW canister bottom for the same constitutive representation of the glass (elastic ideally-plastic). The shell-element FE representation underestimates both the maximum stress intensities and the maximum effective plastic strains.

The calculation results for two different FE-representation mesh densities (see Section 5.4.1) are presented in Table 2. The purpose of this inquiry is to demonstrate the objectivity of the mesh, i.e.

that the calculation results are not mesh-sensitive. Having that purpose in mind the canister mesh of the second FE representation is refined more in the impact region compared to the first one (circumferential discretization is increased by 33% - from 30 to 40; see sav6.inp files [line #179] in Attachment III: /Brick/Loose/EIP/Mesh1 and /Brick/Loose/EIP/Mesh2).

The calculation results presented in Table 2 indicate that the increase of number of elements of 33% results in the stress intensity and the effective plastic strain decrease of 0.8% and 1.7%, respectively.

Table 2. Results for Two Different FE-Representation Meshes for Brick-Elements HLW Canister with Loose Elastic-Ideally-Plastic Glass

Number of Divisions in Hoop Direction	Stress Intensity (MPa)	Effective Plastic Strain (%)
30	623 (Figure I-7)	29.5 (Figure I-8)
40	618 (Figure I-22)	29.0 (Figure I-23)

The original FE-representation mesh is, therefore, deemed acceptable, i.e. further mesh refinement is unnecessary since results are not mesh-sensitive. Consequently, the remaining calculations are performed with the coarser mesh.

One of the objectives of this calculation is to perform a benchmark study, i.e. to compare its results against the experimentally obtained results in Reference 16 (Tab. 3, p. 2 and p. 28). The change of the canister dimensions (diameter and height) were reported among others test results. The diameter of the HLW canister increases and the height decreases in the region close to the impact (bottom part of the canister) in the course of the 7-m vertical drop. The change of the HLW canister dimensions, obtained from the FE simulation for the different FE representations, is presented in Table 3.

The canister-deformation results presented in Table 3 can be compared with the test results reported in the Reference 16 (Table 3, page 39). These measurements indicate that the canister height decreased by about 0.89 cm (from 0.75 cm to 0.98 cm) after the vertical (flat-bottom) drops. The average diameter increase was 1.25 cm (from 1.01 cm to 1.47 cm) in the area closest to (5.1 cm from) the canister bottom. Having in mind the measurement accuracy (indicated by the scatter of the test results), the agreement between the experimental and computational results for the loose glass representation with brick elements is exceptional. These results clearly indicate that the loose glass representation with brick elements is the most appropriate under the given circumstances.

The deformed configurations of the HLW canisters are presented (at the same instant of time) in Figures I-40 and I-41 for the loose glass and the solid glass-canister connection, respectively. The reduction of canister thickness – impossible to capture by the constant-thickness shell elements - is clearly visible. It should be also noted from Figure I-40 that the most of the canister deformation is localized in the region close to the canister bottom.

Table 3. Height Decrease and Diameter Increase for 7-m Drop of HLW Canister for Different FE Representations

Canister-Bottom Representation	Connection between Glass and Canister	Constitutive Representation for Glass	Height Decrease (cm)	Diameter Increase (cm)
Brick elements	Loose Glass	Elastic	1.03 (Figure I-24)	1.25 (Figure I-25)
		Elastic Ideally-Plastic	1.03 (Figure I-26)	1.25 (Figure I-27)
	Thin Layer of Eroding Glass	Failure Strain = 0.1%	0.34 (Figure I-28)	0.14 (Figure I-29)
		Failure Strain = 2.3%	0.31 (Figure I-30)	0.09 (Figure I-31)
	Solid Connection	Elastic	0.07 (Figure I-32)	0.02 (Figure I-33)
		Elastic Ideally-Plastic	0.20 (Figure I-34)	0.10 (Figure I-35)
Shell Elements	Loose Glass	Elastic Ideally-Plastic	2.11 (Figure I-36)	1.83 (Figure I-37)
	Solid Connection	Elastic Ideally-Plastic	0.15 (Figure I-38)	0.09 (Figure I-39)

Figures I-42 and I-43 present two successive deformed configurations of the HLW canister, with the glass-canister connection being represented by the thin layer of eroding brick elements. In Figure I-42 the canister gets in contact with the target. When effective plastic strain in any element belonging to the thin interface glass layer between the bulk glass and steel canister is reached, that element is removed from the mesh. Finally, as depicted in Figure I-43, the remaining (bulk) glass and the canister initiate contact. The dynamics and the extent of the interface erosion depend on the failure strain.

The comparison of results, presented in Table 3, between the two different FE representations of the HLW canister bottom (brick vs. shell elements) with the same glass representation (the elastic-ideally-plastic loose glass) reveals that the shell-element FE representation overestimates the canister deformation.

Figure 2. Strain measurement locations and designations

Finally, the Tables 4 and 5 respectively present the residual (steady-state) longitudinal and the residual circumferential (tangential) strains at eight different locations (see Fig. 2) on the outer surface of the canister bottom (see also Figs. I-44 through I-46).

Table 4. Residual Longitudinal Strains at Outer Surface of HLW Canister's Bottom for Different FE Representations

Canister-Bottom Representation	Glass-Canister Connection	Constitutive Representation for Glass	Residual Longitudinal Strain (%)							
			A	B	C	D	E	F	G	H
Brick elements	Loose Glass	Elastic	1.2	2.8	2.7	1.0	-1.0	-1.8	0.3	0.8
		Figure I-47								
		Elastic Ideally-Plastic	1.7	2.8	2.7	1.4	-0.6	-1.8	0.3	0.8
	Thin Layer of Eroding Glass	Figure I-49								
		Failure Strain = 0.1%	2.9	5.1	5.1	3.2	0.6	-0.7	-0.6	-1.2
		Figure I-51								
		Failure Strain = 2.3%	2.0	4.6	5.1	3.2	0.1	-1.3	-0.8	-0.7
	Solid Connection	Figure I-53								
		Elastic	3.2	7.2	6.5	2.2	-1.3	-1.4	-0.3	-0.1
Figure I-55										
Shell Elements	Loose Glass	Elastic Ideally-Plastic	3.7	5.6	6.4	5.4	2.3	-0.7	-0.4	-0.4
		Figure I-57								
		Figure I-59								
	Solid Connect.	Elastic Ideally-Plastic	-6.2	-6.2	-9.9	-9.8	-7.1	0	2.8	5.5
		Figure I-61								

Table 5. Residual Circumferential Strains at Outer Surface of HLW Canister's Bottom for Different FE Representations

Canister-Bottom Representation	Glass-Canister Connection	Constitutive Representat. for Glass	Residual Circumferential Strain (%)							
			A	B	C	D	E	F	G	H
Brick elements	Loose Glass	Elastic	-0.35	-0.3	-0.25	-0.2	-0.1	0.3	0.8	1.7
		Figure I-48								
		Elastic Ideally-Plastic	-0.3	-0.25	-0.2	-0.1	0	0.3	0.8	1.7
	Thin Layer of Eroding Glass	Figure I-50								
		Failure Strain = 0.1%	-0.3	-0.2	-0.1	0.05	0.15	0.3	0.4	0.3
		Figure I-52								
		Failure Strain = 2.3%	-0.2	-0.1	0.03	0.15	0.25	0.35	0.35	0.2
	Solid Connection	Figure I-54								
		Elastic	-0.3	-0.2	-0.1	0.05	0.1	0.1	0.05	0.05
Figure I-56										
Elastic Ideally-Plastic		-0.20	-0.10	0	0.15	0.3	0.35	0.3	0.2	
Figure I-58										
Shell Elements	Loose Glass	Elastic	-0.5	-0.7	-1.0	-1.0	-1.0	-0.4	0.8	2.6
		Ideally-Plastic	Figure I-60							
	Solid Connection	Elastic	0.1	0.1	0.15	0.2	0.25	0.25	0.25	0.2
		Ideally-Plastic	Figure I-62							

The strains reported in Tables 4 and 5 are respectively rounded to the nearest 0.1% and 0.05% value.

The Reference 16 (p. 28) reports that the all strains were less than 2% after the 7-m vertical drop. Having in mind that the reported accuracy of strain-circle data is $\pm 2\%$ (Ref. 16, p. 26) the computational results presented in Tables 4 and 5 are in very good agreement with the experiment.

6.2 RESULTS FOR Pu CAN-IN-CANISTER

The objective of the first part of Pu CIC calculation is to examine the effect of different target materials and the FE representations on the calculation results. The computer simulations of 7-m vertical drop are, therefore, performed for three different target materials. The first two targets are made of A-36 CS, in the first one the constitutive representation of the CS is elasto-plastic (the same one used in the calculations of the HLW canister presented in Section 6.1) while in the second the CS target is essentially unyielding (i.e. elastic). The comparison of the results obtained for these two targets will enable us to access the effects of the use of unyielding surface in drop calculations. The third target is also unyielding but the material properties of concrete are used instead of the CS properties. Since the modulus of elasticity of the high-strength concrete is almost five times smaller than the one of the CS (see Section 5.1), the comparison of the results will offer a chance to examine the influence of the modulus of elasticity of the target on the results in the canister. The calculations are performed at RT.

Table 6. Maximum Stress Intensity and Maximum Effective Plastic Strain During 7-m Vertical Drop of Pu CIC

Target Representation	Glass Representation	Stress Intensity (MPa)	Effective Plastic Strain (%)
A-36 Carbon Steel, Elastic-Plastic	Elastic Ideally-Plastic ($\sigma_y = 500 \text{ MPa}$)	666 (Figure II-7)	31.0 (Figure II-8)
A-36 Carbon Steel, Elastic (Unyielding)		677 (Figure II-9)	33.6 (Figure II-10)
Concrete, Elastic (Unyielding)		656 (Figure II-11)	31.3 (Figure II-12)

The comparison of results obtained for two different CS target representations confirms that the unyielding target ensures the bounding set of results. The difference in maximum (peak) stress intensity and maximum effective plastic strain between the more realistic elastic-plastic representation and the more conservative elastic representation is 1.6% and 7.7% respectively.

The comparison of results obtained for two different unyielding targets with widely different moduli of elasticity (203 GPa for the A-36 CS vs. 43 GPa for the high-strength concrete [Section 5.1]) indicates that the calculation results are not dominated by the modulus of elasticity, the difference in maximum stress intensity and maximum effective plastic strain being only 3.1% and 6.8%, respectively.

Hence, all remaining calculations are conservatively performed with A-36 CS unyielding target.

The Pu CIC drop calculations are performed at three different temperatures: RT, $200^{\circ}\text{F} = 93.3^{\circ}\text{C}$, and $400^{\circ}\text{F} = 204^{\circ}\text{C}$. An additional calculation – characterized by the maximum stress intensity – is performed at $750^{\circ}\text{F} = 399^{\circ}\text{C}$ as well.

6.2.1 7-m Vertical Drop

The maximum stress intensities achieved in the course of 7-m vertical drop are summarized in Table 7 for three different glass strengths. The results indicate expected increase of maximum stress intensity with increase of glass strength and decrease of temperature.

Table 7. Maximum Stress Intensity in the Course of 7-m Vertical Drop of Pu CIC

		Temperature		
		RT	93.3 °C	204 °C
Glass Strength (MPa)	50	521 MPa (Figure II-13)	491 MPa (Figure II-14)	449 MPa (Figure II-15)
	200	606 MPa (Figure II-16)	564 MPa (Figure II-17)	540 MPa (Figure II-18)
	500	677 MPa (Figure II-19)	658 MPa (Figure II-20)	644 MPa (Figure II-21)

The same maximum stress intensities are reported in Table 8 in non-dimensional form: the maximum stress intensity is divided by static tensile strength at corresponding temperature (see Sections 5.1.1 and 5.1.3).

Table 8. Maximum Stress Intensity – Static Tensile Strength Ratio in the Course of 7-m Vertical Drop of Pu CIC for Three Different Glass Strengths

		Temperature		
		RT	93.3 °C	204 °C
Glass Strength (MPa)	50	0.830	0.841	0.887
	200	0.965	0.966	1.07
	500	1.08	1.13	1.27

The results from Table 8 indicate that although the maximum stress intensity decreases with the increase of temperature, the ratio of the maximum stress intensity and the static tensile strength increases with the increase of temperature. The increase of temperature, therefore, has an adverse effect on the canister.

It should be also noted that the non-dimensional maximum stress intensities presented in Table 8 (as well as in Tables 13 and 19 afterward) refer to the static tensile strength. The drop simulations are, on the other hand, performed with strain-rate effects included (see Section 5.1.4). The estimated increase of tensile strength due to the strain rate is from 20% to 43% in the strain rate range from

$20 s^{-1}$ to $700 s^{-1}$ (see Section 5.1.4).

The average maximum stress intensity across the canister-wall thickness during 7-m vertical drop is summarized in Table 9 for three different glass strengths at three different temperatures.

Table 9. Average Stress Intensity at the Maximum Stress Intensity Location (7-m Vertical Drop of Pu CIC)

		Temperature		
		RT	93.3 °C	204 °C
Glass Strength (MPa)	50	456 MPa (Figure II-13)	440 MPa (Figure II-14)	410 MPa (Figure II-15)
	200	578 MPa (Figure II-16)	532 MPa (Figure II-17)	516 MPa (Figure II-18)
	500	563 MPa (Figure II-19)	540 MPa (Figure II-20)	508 MPa (Figure II-21)

The average values are obtained from Figures II-13 through II-21 at the locations characterized by the maximum stress intensity, and at the time corresponding to the peak value of maximum stress intensity (i.e. maximum shear stress in the Appendix II). Needless to say that the value of maximum average stress intensity does not have to coincide with the maximum stress intensity. It is interesting to note that while the maximum stress intensity continuously increases with the increase of glass strength (see Table 7) it appears that the average stress intensity reaches a certain constant level.

The maximum effective plastic strains recorded during 7-m vertical drop are presented in Table 10.

Table 10. Maximum Effective Plastic Strain in the Course of 7-m Vertical Drop of Pu CIC

		Temperature		
		RT	93.3 °C	204 °C
Glass Strength (MPa)	50	20.6% (Figure II-22)	21.5% (Figure II-23)	22.9% (Figure II-24)
	200	24.2% (Figure II-25)	26.6% (Figure II-26)	30.0% (Figure II-27)
	500	33.6% (Figure II-28)	38.0% (Figure II-29)	43.5% (Figure II-30)

The results presented in Table 10 indicate that the maximum effective plastic strain increases with increase of both the glass strength and the temperature.

The average effective plastic strains across the canister-wall thickness during 7-m vertical drop are summarized in Table 11 for three different glass strengths at three different temperatures. The average values are obtained from Figures II-22 through II-30 at the locations characterized by the maximum effective plastic strain.

Table 11. Average Effective Plastic Strain at the Maximum Effective Plastic Strain Location (7-m Vertical Drop of Pu CIC)

		Temperature		
		RT	93.3 °C	204 °C
Glass Strength (MPa)	50	16.3% (Figure II-22)	17.7% (Figure II-23)	19.7% (Figure II-24)
	200	23.1% (Figure II-25)	25.0% (Figure II-26)	23.0% (Figure II-27)
	500	25.9% (Figure II-28)	30.5% (Figure II-29)	35.6% (Figure II-30)

Similarly to the maximum effective plastic strain results, the effective plastic strains averaged across the canister-wall thickness increase with increase of both the glass strength and the temperature. It should be also noted that the average values are smaller by, on average, 20% than the peak values.

6.2.2 2-ft 70-degrees Oblique Drop

The maximum stress intensities achieved in the course of 2-ft 70-degrees oblique drop are summarized in Table 12.

Table 12. Maximum Stress Intensity in the Course of 2-ft 70-degrees Oblique Drop of Pu CIC

		Temperature			
		RT	93.3 °C	204 °C	399 °C
Glass Strength (MPa)	50	527 MPa (Figure II-31)	493 MPa (Figure II-32)	456 MPa (Figure II-33)	
	200	544 MPa (Figure II-34)	512 MPa (Figure II-35)	503 MPa (Figure II-36)	
	500	674 MPa (Figure II-37)	641 MPa (Figure II-38)	634 MPa (Figure II-39)	646 MPa (Figure II-40)

The results demonstrate the expected trend of increase of the maximum stress intensity with the increase of the glass strength and the decrease of temperature. It is interesting to note that the maximum stress intensities are close to the ones reported for the 7-m vertical drop although the drop height is more that ten times smaller.

Table 13. Maximum Stress Intensity – Static Tensile Strength Ratio in the Course of 2-ft 70-degrees Oblique Drop of Pu CIC

		Temperature			
		RT	93.3 °C	204 °C	399 °C
Glass Strength (MPa)	50	0.839	0.844	0.901	
	200	0.866	0.877	0.994	
	500	1.07	1.10	1.25	1.36

The same results are reported in Table 13 in non-dimensional form: the maximum stress intensity is divided by static tensile strength at corresponding temperature (Sections 5.1.1 and 5.1.3).

The average maximum stress intensity across the canister-wall thickness during 2-ft 70-degrees oblique drop is summarized in Table 14 for three different glass strengths at three different temperatures. The average values are obtained from Figures II-31 through II-40 at the locations characterized by the maximum stress intensity, and at the time corresponding to the peak value of maximum stress intensity (i.e. maximum shear stress in the Attachment II).

Table 14. Average Stress Intensity in the Course of 2-ft 70-degrees Oblique Drop of Pu CIC

		Temperature			
		RT	93.3 °C	204 °C	399 °C
Glass Strength (MPa)	50	482 MPa (Figure II-31)	456 MPa (Figure II-32)	421 MPa (Figure II-33)	
	200	511 MPa (Figure II-34)	386 MPa (Figure II-35)	372 MPa (Figure II-36)	
	500	494 MPa (Figure II-37)	462 MPa (Figure II-38)	431 MPa (Figure II-39)	
					416 MPa (Figure II-40)

The maximum effective plastic strains recorded during 2-ft 70-degrees oblique drop are presented in Table 15.

Table 15. Effective Plastic Strain in the Course of 2-ft 70-degrees Oblique Drop of Pu CIC

		Temperature			
		RT	93.3 °C	204 °C	399 °C
Glass Strength (MPa)	50	24.7% (Figure II-41)	26.1% (Figure II-42)	27.4% (Figure II-43)	
	200	27.3% (Figure II-44)	28.0% (Figure II-45)	30.7% (Figure II-46)	
	500	32.8% (Figure II-47)	36.3% (Figure II-48)	40.3% (Figure II-49)	
					43.9% (Figure II-50)

The results presented in Table 15 indicate that the maximum effective plastic strain increases with increase of both the glass strength and the temperature.

The average effective plastic strains are summarized in Table 16 for three different glass strengths at three different temperatures. The effective plastic strains averaged across the canister-wall thickness rise with increases of both the glass strength and the temperature.

The deformed Pu CIC configuration in course of the 2-ft 70-degrees oblique drop is presented in Figure I-51 for the calculation performed at $T = 93.3\text{ }^{\circ}\text{C}$ with the glass strength of 500 MPa.

Table 16. Average Effective Plastic Strain in the Course of 2-ft 70-degrees Oblique Drop of Pu CIC

		Temperature			
		RT	93.3 °C	204 °C	399 °C
Glass Strength (MPa)	50	22.4% (Figure II-41)	23.8% (Figure II-42)	25.4% (Figure II-43)	
	200	24.8% (Figure II-44)	26.2% (Figure II-45)	26.2% (Figure II-46)	
	500	26.7% (Figure II-47)	29.6% (Figure II-48)	33.0% (Figure II-49)	34.1% (Figure II-50)

The calculations of 2-ft 70-degrees oblique drop of Pu CIC are performed for two different FE-representation mesh densities (see Section 5.3) and the corresponding results are presented in Table 17. The purpose of this inquiry is to demonstrate the objectivity of the mesh (i.e. that the calculation results are mesh-insensitive); having that in mind the second FER mesh is more refined compared to the first.

Table 17. Results for Two Different FE-Representation Meshes for 70-degrees Oblique Drop of Pu CIC

Number of Divisions in Hoop Direction	Stress Intensity (MPa)	Effective Plastic Strain (%)
30	677 (Figure II-19)	33.6 (Figure II-28)
40	662 (Figure II-52)	34.5 (Figure II-53)

The calculation results presented in Table 17 indicate that the increase of number of elements in the contact region of 33% (circumferential discretization is increased from 30 to 40; see savpu5c.inp files [line #195] in Attachment IV: /70-degrees/Mesh1 and /70-degrees/Mesh2/RT/500MPa) results in the stress intensity and the effective plastic strain difference of -2.3% and +2.6%, respectively. The original mesh is, therefore, deemed acceptable, i.e. further mesh refinement seems to be unnecessary. Consequently, all calculations are performed with the coarser mesh.

6.2.3 2-ft 10-degrees Oblique Drop with Slap-down

The results for 2-ft 10-degrees oblique drop are presented in Tables 18 through 20. The numbers separated by a slash refer to the corresponding quantity in the bottom and top part of the canister (subjected to the primary and secondary impact) respectively. The first set of results, reported in Table 18, refers to the maximum stress intensity in the 304L SS canister.

The results in Table 18 indicate that the maximum stress intensities achieved during the 2-ft 10-degrees oblique drop are lower than those reached in the course of 7-m vertical drop and 2-ft 70-degrees oblique drop. This is especially true for the secondary impact at the top region of the canister that is characterized by comparably rather modest maximum stress intensity levels.

Table 18. Maximum Stress Intensity in Bottom / Top Part of Pu CIC in the Course of 2-ft 10-degrees Oblique Drop

		Temperature	
		RT	93.3 °C
Glass Strength (MPa)	50	422 MPa / 345 MPa (Figures II-54)	388 MPa / 317 MPa (Figures II-55)
	200	485 MPa / 356 MPa (Figures II-56)	459 MPa / 321 MPa (Figures II-57)
	500	580 MPa / 383 MPa (Figures II-58)	564 MPa / 341 MPa (Figures II-59)

The maximum stress intensities are reported in Table 19 in non-dimensional form, i.e. they are divided by the static tensile strength at the corresponding temperature (see Sections 5.1.1 and 5.1.3).

Table 19. Maximum Stress Intensity – Static Tensile Strength Ratio in Bottom / Top Part of Pu CIC in the Course of 2-ft 10-degrees Oblique Drop

		Temperature	
		RT	93.3 °C
Glass Strength (MPa)	50	0.672 / 0.549	0.664 / 0.543
	200	0.772 / 0.567	0.786 / 0.550
	500	0.924 / 0.610	0.966 / 0.584

Finally, the maximum effective plastic strain in the canister during the 2-ft 10-degrees oblique drop is presented in Table 20:

Table 20. Maximum Effective Plastic Strain in Bottom / Top Part of Pu CIC in the Course of 2-ft 10-degrees Oblique Drop

		Temperature	
		RT	93.3 °C
Glass Strength (MPa)	50	17.1% / 9.2% (Figures II-60)	18.1% / 9.5% (Figures II-61)
	200	18.5% / 9.6% (Figures II-62)	20.0% / 9.8% (Figures II-63)
	500	28.7% / 11.7% (Figures II-64)	31.9% / 12.3% (Figures II-65)

The results in Table 20 indicate that the maximum effective plastic strains achieved during the 2-ft 10-degrees oblique drop are lower than those reached in the two other evaluated DBEs. This is, again, especially true for the secondary impact. It is interesting to note that the change of glass strength from 200 MPa to 500 MPa is followed by relatively significant increase in the maximum effective plastic strains. In the same time there is hardly an increase in the effective plastic strain following the increase of glass strength from 50 MPa to 200 MPa.

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8. ATTACHMENTS

Attachment I (33 pages): Figures obtained from LS-DYNA V950 for HLW canister calculation

Attachment II (41 pages): Figures obtained from LS-DYNA V950 for Pu CIC calculation

Attachments III (1 Compact Disc): ANSYS V5.6.2 and LS-DYNA V950 electronic files for HLW canister calculation

Attachments IV (3 Compact Discs): ANSYS V5.6.2 and LS-DYNA V950 electronic files for Pu CIC calculation

Table 21. Attachment III: File Directories, Names, Dates, Times, and Sizes for HLW Canister Calculation

Directory	Name	Date	Time	Size
Brick/Loose/Elastic	d3hsp	07/02/01	11:51 a.m.	14,437 KB
	element.inc	07/02/01	11:51 a.m.	4,114 KB
	main.k	07/02/01	11:51 a.m.	7 KB
	nodes.inc	07/02/01	11:51 a.m.	3,293 KB
	nodeset1.inc	07/02/01	11:51 a.m.	23 KB
	nodeset2.inc	07/02/01	11:51 a.m.	23 KB
	nodeset3.inc	07/02/01	11:51 a.m.	5 KB
	nodeset4.inc	07/02/01	11:51 a.m.	1 KB
	nodeset5.inc	07/02/01	11:51 a.m.	2 KB
	sav6.db	07/02/01	11:51 a.m.	38,976 KB
	sav6.inp	07/02/01	11:51 a.m.	15 KB
	sav6.out	07/02/01	11:51 a.m.	862 KB
	segment.inc	07/02/01	11:51 a.m.	8 KB
Brick/Loose/EIP/mesh1	d3hsp	07/02/01	11:54 a.m.	14,438 KB
	element.inc	07/02/01	11:54 a.m.	4,114 KB
	main.k	07/02/01	11:54 a.m.	7 KB
	nodes.inc	07/02/01	11:54 a.m.	3,293 KB
	nodeset1.inc	07/02/01	11:54 a.m.	23 KB
	nodeset2.inc	07/02/01	11:54 a.m.	23 KB
	nodeset3.inc	07/02/01	11:54 a.m.	5 KB
	nodeset4.inc	07/02/01	11:54 a.m.	1 KB
	nodeset5.inc	07/02/01	11:54 a.m.	2 KB
	sav6.db	07/02/01	11:53 a.m.	38,976 KB
	sav6.inp	07/02/01	11:52 a.m.	15 KB
	sav6.out	07/02/01	11:52 a.m.	862 KB
	segment.inc	07/02/01	11:54 a.m.	8 KB
Brick/Loose/EIP/mesh2	d3hsp	07/02/01	11:55 a.m.	23,446 KB
	element.inc	07/02/01	11:55 a.m.	6,829 KB
	main.k	07/02/01	11:55 a.m.	7 KB
	nodes.inc	07/02/01	11:55 a.m.	5,364 KB
	nodeset1.inc	07/02/01	11:55 a.m.	29 KB
	nodeset2.inc	07/02/01	11:55 a.m.	29 KB
	nodeset3.inc	07/02/01	11:55 a.m.	6 KB

	nodeset4.inc	07/02/01	11:55 a.m.	1 KB
	nodeset5.inc	07/02/01	11:55 a.m.	3 KB
	sav6.db	07/02/01	11:55 a.m.	62,464 KB
	sav6.inp	07/02/01	11:54 a.m.	15 KB
	sav6.out	07/02/01	11:54 a.m.	1,073 KB
	segment.inc	07/02/01	11:54 a.m.	10 KB
Brick/Eroding/FS=0.1%	d3hsp	07/02/01	11:57 a.m.	14,786 KB
	element.inc	07/02/01	11:56 a.m.	4,295 KB
	main.k	07/02/01	11:56 a.m.	7 KB
	nodes.inc	07/02/01	11:56 a.m.	3,278 KB
	nodeset1.inc	07/02/01	11:56 a.m.	23 KB
	nodeset2.inc	07/02/01	11:56 a.m.	23 KB
	nodeset3.inc	07/02/01	11:56 a.m.	5 KB
	nodeset4.inc	07/02/01	11:56 a.m.	1 KB
	nodeset5.inc	07/02/01	11:56 a.m.	2 KB
	sav6.db	07/02/01	11:57 a.m.	38,784 KB
	sav6.inp	07/02/01	11:57 a.m.	15 KB
	sav6.out	07/02/01	11:57 a.m.	663 KB
Brick/Eroding/FS=2.3%	segment.inc	07/02/01	11:56 a.m.	8 KB
	d3hsp	07/02/01	11:58 a.m.	14,726 KB
	element.inc	07/02/01	11:57 a.m.	4,295 KB
	main.k	07/02/01	11:57 a.m.	7 KB
	nodes.inc	07/02/01	11:57 a.m.	3,278 KB
	nodeset1.inc	07/02/01	11:57 a.m.	23 KB
	nodeset2.inc	07/02/01	11:57 a.m.	23 KB
	nodeset3.inc	07/02/01	11:57 a.m.	5 KB
	nodeset4.inc	07/02/01	11:57 a.m.	1 KB
	nodeset5.inc	07/02/01	11:57 a.m.	2 KB
	sav6.db	07/02/01	11:58 a.m.	38,784 KB
	sav6.inp	07/02/01	11:58 a.m.	15 KB
Brick/Connected/Elastic	sav6.out	07/02/01	11:58 a.m.	663 KB
	segment.inc	07/02/01	11:57 a.m.	8 KB
	d3hsp	07/02/01	11:59 a.m.	14,458 KB
	element.inc	07/02/01	11:59 a.m.	4,242 KB
	main.k	07/02/01	11:59 a.m.	7 KB
	nodes.inc	07/02/01	11:59 a.m.	3,239 KB
	nodeset1.inc	07/02/01	11:59 a.m.	23 KB
	nodeset2.inc	07/02/01	11:59 a.m.	23 KB
	nodeset3.inc	07/02/01	11:59 a.m.	5 KB
	nodeset4.inc	07/02/01	11:59 a.m.	1 KB
	nodeset5.inc	07/02/01	11:59 a.m.	2 KB
	sav6.db	07/02/01	11:59 a.m.	38,336 KB
Brick/Connected/EIP	sav6.inp	07/02/01	11:59 a.m.	15 KB
	sav6.out	07/02/01	11:59 a.m.	634 KB
	segment.inc	07/02/01	11:59 a.m.	8 KB
	d3hsp	07/02/01	12:00 a.m.	14,459 KB
	element.inc	07/02/01	12:00 a.m.	4,242 KB
	main.k	07/02/01	12:00 a.m.	7 KB
	nodes.inc	07/02/01	12:00 a.m.	3,239 KB
	nodeset1.inc	07/02/01	12:00 a.m.	23 KB
	nodeset2.inc	07/02/01	12:00 a.m.	23 KB
	nodeset3.inc	07/02/01	12:00 a.m.	5 KB
	nodeset4.inc	07/02/01	12:00 a.m.	1 KB

	nodeset5.inc	07/02/01	12:00 a.m.	2 KB
	sav6.db	07/02/01	12:01 a.m.	38,336 KB
Shell/Loose/EIP	sav6.inp	07/02/01	12:00 a.m.	15 KB
	sav6.out	07/02/01	12:00 a.m.	634 KB
	segment.inc	07/02/01	12:00 a.m.	8 KB
	d3hsp	07/03/01	07:35 a.m.	10,663 KB
	element.inc	07/03/01	07:35 a.m.	2,959 KB
	main.k	07/03/01	07:35 a.m.	7 KB
	nodes.inc	07/03/01	07:35 a.m.	2,367 KB
	nodeset1.inc	07/03/01	07:35 a.m.	18 KB
	nodeset2.inc	07/03/01	07:35 a.m.	18 KB
	nodeset3.inc	07/03/01	07:35 a.m.	5 KB
	nodeset4.inc	07/03/01	07:35 a.m.	1 KB
	nodeset5.inc	07/03/01	07:35 a.m.	2 KB
	sav3.db	07/03/01	07:35 a.m.	27,456 KB
	sav3.inp	07/03/01	07:35 a.m.	13 KB
	sav3.out	07/03/01	07:35 a.m.	188 KB
	segment.inc	07/03/01	07:35 a.m.	8 KB
Shell/Connected/EIP	d3hsp	07/03/01	07:36 a.m.	10,571 KB
	element.inc	07/03/01	07:36 a.m.	3,072 KB
	main.k	07/03/01	07:36 a.m.	7 KB
	nodes.inc	07/03/01	07:36 a.m.	2,323 KB
	nodeset1.inc	07/03/01	07:36 a.m.	17 KB
	nodeset2.inc	07/03/01	07:36 a.m.	17 KB
	nodeset3.inc	07/03/01	07:36 a.m.	5 KB
	nodeset4.inc	07/03/01	07:36 a.m.	1 KB
	nodeset5.inc	07/03/01	07:36 a.m.	2 KB
	sav3b.db	07/03/01	07:36 a.m.	27,584 KB
	sav3b.inp	07/03/01	07:36 a.m.	12 KB
	sav3b.out	07/03/01	07:36 a.m.	330 KB
	segment.inc	07/03/01	07:36 a.m.	8 KB

NOTE: The file sizes may vary with operating system.

Table 22. Attachment IV: File Directories, Names, Dates, Times, and Sizes for Pu CIC Calculation

Directory	Name	Date	Time	Size
Vertical	savpu4g.db	07/02/01	03:44 p.m.	86,272 KB
Vertical	savpu4g.inp	07/02/01	03:43 p.m.	31 KB
Vertical	savpu4g.out	07/02/01	03:43 p.m.	731 KB
Vertical	element.inc	07/02/01	03:45 p.m.	7,906 KB
Vertical	nodes.inc	07/02/01	03:44 p.m.	7,145 KB
Vertical	nodeset1.inc	07/02/01	03:44 p.m.	51 KB
Vertical	nodeset2.inc	07/02/01	03:44 p.m.	9 KB
Vertical	nodeset3.inc	07/02/01	03:44 p.m.	4 KB
Vertical	segment10.inc	07/02/01	03:44 p.m.	98 KB
Vertical	segment11.inc	07/02/01	03:44 p.m.	4 KB
Vertical	segment12.inc	07/02/01	03:44 p.m.	5 KB
Vertical	segment6.inc	07/02/01	03:44 p.m.	13 KB
Vertical	segment7.inc	07/02/01	03:44 p.m.	40 KB
Vertical	segment8.inc	07/02/01	03:44 p.m.	28 KB
Vertical	segment9.inc	07/02/01	03:44 p.m.	76 KB

Vertical/RT/500MPa/A-36ElaPlast	d3hsp	07/02/01	04:22 p.m.	31,323 KB
	main1.k	07/02/01	04:22 p.m.	9 KB
Vertical/RT/500MPa/A-36Ela	d3hsp	07/02/01	04:21 p.m.	31,323 KB
	main1.k	07/02/01	04:21 p.m.	9 KB
Vertical/RT/500MPa/ConcreteEla	d3hsp	07/02/01	04:23 p.m.	31,323 KB
	main1.k	07/02/01	04:22 p.m.	9 KB
Vertical/RT/200MPa	d3hsp	07/02/01	04:38 p.m.	31,323 KB
	main1.k	07/02/01	04:38 p.m.	9 KB
Vertical/RT/50MPa	d3hsp	07/03/01	08:00 a.m.	31,323 KB
	main1.k	07/03/01	08:00 a.m.	9 KB
Vertical/93C/500MPa	d3hsp	07/02/01	04:41 p.m.	31,323 KB
	main1.k	07/02/01	04:41 p.m.	9 KB
Vertical/93C/200MPa	d3hsp	07/02/01	04:42 p.m.	31,323 KB
	main1.k	07/02/01	04:42 p.m.	9 KB
Vertical/93C/50MPa	d3hsp	07/02/01	04:43 p.m.	31,323 KB
	main1.k	07/02/01	04:43 p.m.	9 KB
Vertical/204C/500MPa	d3hsp	07/02/01	04:45 p.m.	31,323 KB
	main1.k	07/02/01	04:44 p.m.	9 KB
Vertical/204C/200MPa	d3hsp	07/02/01	04:44 p.m.	31,323 KB
	main1.k	07/02/01	04:44 p.m.	9 KB
Vertical/204C/50MPa	d3hsp	07/02/01	04:45 p.m.	31,323 KB
	main1.k	07/02/01	04:45 p.m.	9 KB
70-degrees/Mesh1	savpu5c.db	07/02/01	03:46 p.m.	83,840 KB
70-degrees/Mesh1	savpu5c.inp	07/02/01	03:45 p.m.	31 KB
70-degrees/Mesh1	savpu5c.out	07/02/01	03:45 p.m.	739 KB
70-degrees/Mesh1	element.inc	07/02/01	03:47 p.m.	7,646 KB
70-degrees/Mesh1	nodes.inc	07/02/01	03:47 p.m.	6,906 KB
70-degrees/Mesh1	nodeset1.inc	07/02/01	03:47 p.m.	50 KB
70-degrees/Mesh1	nodeset2.inc	07/02/01	03:47 p.m.	2 KB
70-degrees/Mesh1	segment10.inc	07/02/01	03:47 p.m.	98 KB
70-degrees/Mesh1	segment11.inc	07/02/01	03:47 p.m.	4 KB
70-degrees/Mesh1	segment12.inc	07/02/01	03:46 p.m.	5 KB
70-degrees/Mesh1	segment6.inc	07/02/01	03:46 p.m.	9 KB
70-degrees/Mesh1	segment7.inc	07/02/01	03:46 p.m.	40 KB
70-degrees/Mesh1	segment8.inc	07/02/01	03:46 p.m.	28 KB
70-degrees/Mesh1	segment9.inc	07/02/01	03:46 p.m.	76 KB
70-degrees/Mesh1/RT/500MPa	d3hsp	07/02/01	04:36 p.m.	30,417 KB
	main2.k	07/02/01	04:35 p.m.	9 KB
70-degrees/Mesh1/RT/200MPa	d3hsp	07/02/01	04:25 p.m.	30,417 KB
	main2.k	07/02/01	04:25 p.m.	9 KB
70-degrees/Mesh1/RT/50MPa	d3hsp	07/02/01	04:24 p.m.	30,418 KB
	main2.k	07/02/01	04:24 p.m.	9 KB
70-degrees/Mesh1/93C/500MPa	d3hsp	07/02/01	04:57 p.m.	30,417 KB
	main2.k	07/02/01	04:56 p.m.	9 KB
70-degrees/Mesh1/93C/200MPa	d3hsp	07/02/01	04:56 p.m.	30,417 KB
	main2.k	07/02/01	04:55 p.m.	9 KB
70-degrees/Mesh1/93C/50MPa	d3hsp	07/02/01	04:56 p.m.	30,418 KB
	main2.k	07/02/01	04:56 p.m.	9 KB
70-degrees/Mesh1/204C/500MPa	d3hsp	07/02/01	04:48 p.m.	30,417 KB
	main2.k	07/02/01	04:48 p.m.	9 KB
70-degrees/Mesh1/204C/200MPa	d3hsp	07/02/01	04:47 p.m.	30,417 KB
	main2.k	07/02/01	04:47 p.m.	9 KB
70-degrees/Mesh1/204C/50MPa	d3hsp	07/02/01	04:48 p.m.	30,418 KB

	main2.k	07/02/01	04:47 p.m.	9 KB
70-degrees/Mesh1/399C/500MPa	d3hsp	07/03/01	07:57 a.m.	30,417 KB
	main2.k	07/03/01	07:56 a.m.	9 KB
	d3hsp	07/02/01	04:34 p.m.	34,616 KB
	main2.k	07/02/01	04:34 p.m.	9 KB
	savpu5c.db	07/02/01	04:34 p.m.	94,336 KB
	savpu5c.inp	07/02/01	04:33 p.m.	31 KB
	savpu5c.out	07/02/01	04:33 p.m.	754 KB
	element.inc	07/02/01	04:34 p.m.	8,796 KB
	nodes.inc	07/02/01	04:34 p.m.	7,926 KB
	nodeset1.inc	07/02/01	04:34 p.m.	51 KB
	nodeset2.inc	07/02/01	04:34 p.m.	2 KB
	segment10.inc	07/02/01	04:33 p.m.	98 KB
	segment11.inc	07/02/01	04:33 p.m.	4 KB
	segment12.inc	07/02/01	04:33 p.m.	5 KB
	segment6.inc	07/02/01	04:33 p.m.	9 KB
	segment7.inc	07/02/01	04:33 p.m.	40 KB
	segment8.inc	07/02/01	04:33 p.m.	28 KB
	segment9.inc	07/02/01	04:33 p.m.	76 KB
10-degrees	savpu5e.db	07/02/01	03:50 p.m.	84,864 KB
10-degrees	savpu5e.inp	07/02/01	03:49 p.m.	32 KB
10-degrees	savpu5e.out	07/02/01	03:49 p.m.	739 KB
10-degrees	element.inc	07/02/01	03:51 p.m.	7,737 KB
10-degrees	nodes.inc	07/02/01	03:51 p.m.	6,997 KB
10-degrees	nodeset1.inc	07/02/01	03:51 p.m.	52 KB
10-degrees	nodeset2.inc	07/02/01	03:51 p.m.	4 KB
10-degrees	segment10.inc	07/02/01	03:51 p.m.	98 KB
10-degrees	segment11.inc	07/02/01	03:51 p.m.	4 KB
10-degrees	segment12.inc	07/02/01	03:51 p.m.	5 KB
10-degrees	segment6.inc	07/02/01	03:50 p.m.	26 KB
10-degrees	segment7.inc	07/02/01	03:50 p.m.	40 KB
10-degrees	segment8.inc	07/02/01	03:50 p.m.	28 KB
10-degrees	segment9.inc	07/02/01	03:50 p.m.	76 KB
10-degrees/RT/500MPa	d3hsp	07/02/01	04:53 p.m.	30,862 KB
	main3.k	07/02/01	04:53 p.m.	10 KB
10-degrees/RT/200MPa	d3hsp	07/02/01	04:52 p.m.	30,863 KB
	main3.k	07/02/01	04:52 p.m.	10 KB
	d3hsp	07/02/01	04:37 p.m.	30,860 KB
	d3hsp1	07/02/01	04:36 p.m.	29 KB
	d3hsp2	07/02/01	04:36 p.m.	28 KB
	main3.k	07/02/01	04:36 p.m.	10 KB
10-degrees/93C/500MPa	d3hsp	07/02/01	04:50 p.m.	30,859 KB
	d3hsp1	07/02/01	04:50 p.m.	10 KB
	main3.k	07/02/01	04:50 p.m.	10 KB
10-degrees/93C/200MPa	d3hsp	07/02/01	04:49 p.m.	30,858 KB
	d3hsp1	07/02/01	04:49 p.m.	11 KB
	main3.k	07/02/01	04:49 p.m.	10 KB
10-degrees/93C/50MPa	d3hsp	07/02/01	04:54 p.m.	30,862 KB
	main3.k	07/02/01	04:54 p.m.	10 KB

NOTE: The file sizes may vary with operating system.

Figure I-1. Quarter-Symmetry FE Representation of the HLW Canister with the Canister Bottom Represented by the Solid Elements and the Solid- (or Eroding-) Element Layer between the Glass and Canister.

Figure I-2. Detail of the FE Representation of the HLW Canister with the Canister Bottom Represented by the Solid Elements and the Gap between the Glass and Canister.

Figure I-3. Quarter-Symmetry FE Representation of the HLW Canister with the Canister Bottom Represented by the Shell Elements and the Solid-Element Connection between the Glass and Canister.

Figure I-4. Detail of the FE Representation of the HLW Canister with the Canister Bottom Represented by the Shell Elements and the Gap between the Glass and Canister.

Figure I-5. Maximum Shear Stress in HLW Canister for First FE Representation (Solid Canister Bottom, Loose Elastic Glass)

Figure I-6. Effective Plastic Strain in HLW Canister for First FE Representation (Solid Canister Bottom, Loose Elastic Glass)

Figure I-7. Maximum Shear Stress in HLW Canister for Second FE Representation (Solid Canister Bottom, Loose Elastic-Ideally-Plastic Glass)

Figure I-8. Effective Plastic Strain in HLW Canister for Second FE Representation (Solid Canister Bottom, Loose Elastic-Ideally-Plastic Glass)

Figure I-9. Maximum Shear Stress in HLW Canister for Third FE Representation (Solid Canister Bottom, Eroding Glass with Failure Strain 0.1%)

Figure I-10. Effective Plastic Strain in HLW Canister for Third FE representation (Solid Canister Bottom, Eroding Glass with Failure Strain 0.1%)

Figure I-11. Maximum Shear Stress in HLW Canister for Forth FE Representation (Solid Canister Bottom, Eroding Glass with Failure Strain 2.3%)

Figure I-12. Effective Plastic Strain in HLW Canister for Forth FE Representation (Solid Canister Bottom, Eroding Glass with Failure Strain 2.3%)

Figure I-13. Maximum Shear Stress in HLW Canister for Fifth FE Representation (Solid Canister Bottom, Connected Elastic Glass)

Figure I-14. Effective Plastic Strain in HLW Canister for Fifth FE Representation (Solid Canister Bottom, Connected Elastic Glass)

Figure I-15. Maximum Shear Stress in HLW Canister for Sixth FE Representation (Solid Canister Bottom, Connected Elastic-Ideally-Plastic Glass)

Figure I-16. Effective Plastic Strain in HLW Canister for Sixth FE Representation (Solid Canister Bottom, Connected Elastic-Ideally-Plastic Glass)

Figure I-17. Maximum Shear Stress in HLW Canister for Seventh FE Representation (Shell Canister Bottom, Loose Elastic-Ideally-Plastic Glass)

Figure I-18. Effective Plastic Strain in HLW Canister for Seventh FE Representation (Shell Canister Bottom; Loose Elastic-Ideally-Plastic Glass)

Figure I-19. Maximum Shear Stress in HLW Canister for Eighth FE Representation (Shell Canister Bottom, Connected Elastic-Ideally-Plastic Glass)

Figure I-20. Effective Plastic Strain in HLW Canister for Eighth FE Representation (Shell Canister Bottom, Connected Elastic-Ideally-Plastic Glass)

Figure I-21. Maximum Shear Stress Plot in Bottom Region of HLW Canister for Second FE Representation (Solid Canister Bottom, Loose Elastic-Ideally-Plastic Glass)

Figure I-22. Maximum Shear Stress in HLW Canister for Mesh-Refined Second FE Representation (Solid Canister Bottom, Loose Elastic-Ideally-Plastic Glass)

Figure I-23. Effective Plastic Strain in HLW Canister for Mesh-Refined Second FE Representation (Solid Canister Bottom, Loose Elastic-Ideally-Plastic Glass)

Figure I-24. Change of HLW Canister Height for First FE Representation (Solid Canister Bottom, Loose Elastic Glass)

Figure I-25. Change of HLW Canister Diameter for First FE Representation (Solid Canister Bottom, Loose Elastic Glass)

Figure I-26. Change of HLW Canister Height for Second FE Representation (Solid Canister Bottom, Loose Elastic-Ideally-Plastic Glass)

Figure I-27. Change of HLW Canister Diameter for Second FE Representation (Solid Canister Bottom, Loose Elastic-Ideally-Plastic Glass)

Figure I-28. Change of HLW Canister Height for Third FE Representation (Solid Canister Bottom, Eroding Glass with Failure Strain 0.1%)

Figure I-29. Change of HLW Canister Diameter for Third FE Representation (Solid Canister Bottom, Eroding Glass with Failure Strain 0.1%)

Figure I-30. Change of HLW Canister Height for Forth FE Representation (Solid Canister Bottom, Eroding Glass with Failure Strain 2.3%)

Figure I-31. Change of HLW Canister Diameter for Forth FE Representation (Solid Canister Bottom, Eroding Glass with Failure Strain 2.3%)

Figure I-32. Change of HLW Canister Height for Fifth FE Representation (Solid Canister Bottom, Connected Elastic Glass)

Figure I-33. Change of HLW Canister Diameter for Fifth FE Representation (Solid Canister Bottom, Connected Elastic Glass)

Figure I-34. Change of HLW Canister Height for Sixth FE Representation (Solid Canister Bottom, Connected Elastic-Ideally-Plastic Glass)

Figure I-35. Change of HLW Canister Diameter for Sixth FE Representation (Solid Canister Bottom, Connected Elastic-Ideally-Plastic Glass)

Figure I-36. Change of HLW Canister Height for Seventh FE Representation (Shell Canister Bottom, Loose Elastic-Ideally-Plastic Glass)

Figure I-37. Change of HLW Canister Diameter for Seventh FE Representation (Shell Canister Bottom, Loose Elastic-Ideally-Plastic Glass)

Figure I-38. Change of HLW Canister Height for Eighth FE Representation (Shell Canister Bottom, Connected Elastic-Ideally-Plastic Glass)

Figure I-39. Change of HLW Canister Diameter for Eighth FE Representation (Shell Canister Bottom, Connected Elastic-Ideally-Plastic Glass)

Figure I-40. Deformed Configuration of HLW Canister for Second FE Representation (Solid Canister Bottom, Loose Elastic-Ideally-Plastic Glass, $t = 0.00145 s$)

Figure I-41. Deformed Configuration of HLW Canister for Sixth FE Representation (Solid Canister Bottom, Connected Elastic-Ideally-Plastic Glass, $t = 0.00145 s$)

Figure I-42. Maximum Shear Stress Plot of HLW Canister for Third FE Representation at $t = 0.00015\text{ s}$ (Solid Canister Bottom, Eroding Glass with Failure Strain 0.1%)

Figure I-43. Maximum Shear Stress Plot of HLW Canister for Third FE Representation at $t = 0.00040\text{ s}$ (Solid Canister Bottom, Eroding Glass with Failure Strain 0.1%)

Time = 0

Figure I-44. Locations of Strain-Evaluation Elements for FE Representations with Canister Bottom Represented by Brick Elements

Figure I-45. Locations of Strain-Evaluation Elements for Seventh FE Representation (Shell Canister Bottom, Loose Elastic-Ideally-Plastic Glass)

Figure I-46. Locations of Strain-Evaluation Elements for Eighth FE Representation (Shell Canister Bottom, Connected Elastic-Ideally-Plastic Glass)

Figure I-47. Longitudinal Strains at Outer Surface of HLW Canister Bottom for First FE Representation (Solid Canister Bottom, Loose Elastic Glass)

Figure I-48. Circumferential Strains at Outer Surface of HLW Canister Bottom for First FE Representation (Solid Canister Bottom, Loose Elastic Glass)

Figure I-49. Longitudinal Strains at Outer Surface of HLW Canister Bottom for Second FE Representation (Solid Canister Bottom, Loose Elastic-Ideally-Plastic Glass)

Figure I-50. Circumferential Strains at Outer Surface of HLW Canister Bottom for Second FE Representation (Solid Canister Bottom, Loose Elastic-Ideally-Plastic Glass)

Figure I-51. Longitudinal Strains at Outer Surface of HLW Canister Bottom for Third FE Representation (Solid Canister Bottom, Eroding Glass with Failure Strain 0.1%)

Figure I-52. Circumferential Strains at Outer Surface of HLW Canister Bottom for Third FE representation (Solid Canister Bottom, Eroding Glass with Failure Strain 0.1%)

Figure I-53. Longitudinal Strains at Outer Surface of HLW Canister Bottom for Forth FE Representation (Solid Canister Bottom, Eroding Glass with Failure Strain 2.3%)

Figure I-54. Circumferential Strains at Outer Surface of HLW Canister Bottom for Forth FE Representation (Solid Canister Bottom, Eroding Glass with Failure Strain 2.3%)

Figure I-55. Longitudinal Strains at Outer Surface of HLW Canister Bottom for Fifth FE Representation (Solid Canister Bottom, Connected Elastic Glass)

Figure I-56. Circumferential Strains at Outer Surface of HLW Canister Bottom for Fifth FE Representation (Solid Canister Bottom, Connected Elastic Glass)

Figure I-57. Longitudinal Strains at Outer Surface of HLW Canister Bottom for Sixth FE Representation (Solid Canister Bottom, Connected Elastic-Ideally-Plastic Glass)

Figure I-58. Circumferential Strains at Outer Surface of HLW Canister Bottom for Sixth FE Representation (Solid Canister Bottom, Connected Elastic-Ideally-Plastic Glass)

Figure I-59. Longitudinal Strains at Outer Surface of HLW Canister Bottom for Seventh FE Representation (Shell Canister Bottom, Loose Elastic-Ideally-Plastic Glass)

Figure I-60. Circumferential Strains at Outer Surface of HLW Canister Bottom for Seventh FE Representation (Shell Canister Bottom; Loose Elastic-Ideally-Plastic Glass)

Figure I-61. Longitudinal Strains at Outer Surface of HLW Canister Bottom for Eighth FE Representation (Shell Canister Bottom, Connected Elastic-Ideally-Plastic Glass)

Figure I-62. Circumferential Strains at Outer Surface of HLW Canister Bottom for Eighth FE Representation (Shell Canister Bottom, Connected Elastic-Ideally-Plastic Glass)

Figure I-63. Effective Plastic Strain Across Canister-Wall Thickness for First FE Representation (Solid Canister Bottom, Loose Elastic Glass) at Peak Effective-Plastic-Strain Location

Figure I-64. Effective Plastic Strain Across Canister-Wall Thickness for Second FE Representation (Solid Canister Bottom, Loose Elastic-Ideally-Plastic Glass) at Peak Effective-Plastic-Strain Location

0.0

Time = 0

Figure II-1. FE Representation of the Vertical Drop of the Pu CIC (Initial Configuration).

Time = 0

Figure II-2. FE Representation of the 2-ft 70-degrees Oblique Drop of the Pu CIC (Initial Configuration).

Time = 0

Figure II-3. FE Representation of the 2-ft 10-degrees Oblique Drop of the Pu CIC (Initial Configuration).

Time = 0

Figure II-4. FE Representation of the Internal Structure of the Pu CIC

Time = 0

Figure II-5. FE Representation of the Bottom Part of the Pu CIC (Detail).

Time = 0

Figure II-6. Detail of the FE Representation of the Internal Structure of the Pu CIC.

Figure II-7. Maximum Shear Stress in Pu CIC for Elasto-Plastic A-36 CS Target (7-m Vertical Drop)

Figure II-8. Effective Plastic Strain in Pu CIC for Elasto-Plastic A-36 CS Target (7-m Vertical Drop)

Figure II-9. Maximum Shear Stress in Pu CIC for Unyielding (Elastic) A-36 CS Target (7-m Vertical Drop)

Figure II-10. Effective Plastic Strain in Pu CIC for Unyielding (Elastic) A-36 CS Target (7-m Vertical Drop)

Figure II-11. Maximum Shear Stress in Pu CIC for Unyielding (Elastic) Concrete Target (7-m Vertical Drop)

Figure II-12. Effective Plastic Strain in Pu CIC for Unyielding (Elastic) Concrete Target (7-m Vertical Drop)

Figure II-13. Maximum Shear Stress Across Canister-Wall Thickness at RT for Glass Strength of 50 MPa (at Peak Maximum-Shear-Stress Location; 7-m Vertical Drop)

Figure II-14. Maximum Shear Stress Across Canister-Wall Thickness at $T = 93.9\text{ }^{\circ}\text{C}$ for Glass Strength of 50 MPa (at Peak Maximum-Shear-Stress Location; 7-m Vertical Drop)

Figure II-15. Maximum Shear Stress Across Canister-Wall Thickness at $T = 204\text{ }^{\circ}\text{C}$ for Glass Strength of 50 MPa (at Peak Maximum-Shear-Stress Location; 7-m Vertical Drop)

Figure II-16. Maximum Shear Stress Across Canister-Wall Thickness at RT for Glass Strength of 200 MPa (at Peak Maximum-Shear-Stress Location; 7-m Vertical Drop)

Figure II-17. Maximum Shear Stress Across Canister-Wall Thickness at $T = 93.9^{\circ}\text{C}$ for Glass Strength of 200 MPa (at Peak Maximum-Shear-Stress Location; 7-m Vertical Drop)

Figure II-18. Maximum Shear Stress Across Canister-Wall Thickness at $T = 204^{\circ}\text{C}$ for Glass Strength of 200 MPa (at Peak Maximum-Shear-Stress Location; 7-m Vertical Drop)

Figure II-19. Maximum Shear Stress Across Canister-Wall Thickness at RT for Glass Strength of 500 MPa (at Peak Maximum-Shear-Stress Location; 7-m Vertical Drop)

Figure II-20. Maximum Shear Stress Across Canister-Wall Thickness at $T = 93.9^{\circ}\text{C}$ for Glass Strength of 500 MPa (at Peak Maximum-Shear-Stress Location; 7-m Vertical Drop)

Figure II-21. Maximum Shear Stress Across Canister-Wall Thickness at $T = 204\text{ }^{\circ}\text{C}$ for Glass Strength of 500 MPa (at Peak Maximum-Shear-Stress Location; 7-m Vertical Drop)

Figure II-22. Effective Plastic Strain Across Canister-Wall Thickness at RT for Glass Strength of 50 MPa (at Peak Effective-Plastic-Strain Location; 7-m Vertical Drop)

Figure II-23. Effective Plastic Strain Across Canister-Wall Thickness at $T = 93.9^{\circ}\text{C}$ for Glass Strength of 50 MPa (at Peak Effective-Plastic-Strain Location; 7-m Vertical Drop)

Figure II-24. Effective Plastic Strain Across Canister-Wall Thickness at $T = 204^{\circ}\text{C}$ for Glass Strength of 50 MPa (at Peak Effective-Plastic-Strain Location; 7-m Vertical Drop)

Figure II-25. Effective Plastic Strain Across Canister-Wall Thickness at RT for Glass Strength of 200 MPa (at Peak Effective-Plastic-Strain Location; 7-m Vertical Drop)

Figure II-26. Effective Plastic Strain Across Canister-Wall Thickness at $T = 93.9^{\circ}\text{C}$ for Glass Strength of 200 MPa (at Peak Effective-Plastic-Strain Location; 7-m Vertical Drop)

Figure II-27. Effective Plastic Strain Across Canister-Wall Thickness at $T = 204^{\circ}\text{C}$ for Glass Strength of 200 MPa (at Peak Effective-Plastic-Strain Location; 7-m Vertical Drop)

Figure II-28. Effective Plastic Strain Across Canister-Wall Thickness at RT for Glass Strength of 500 MPa (at Peak Effective-Plastic-Strain Location; 7-m Vertical Drop)

Figure II-29. Effective Plastic Strain Across Canister-Wall Thickness at $T = 93.9^\circ\text{C}$ for Glass Strength of 500 MPa (at Peak Effective-Plastic-Strain Location; 7-m Vertical Drop)

Figure II-30. Effective Plastic Strain Across Canister-Wall Thickness at $T = 204^\circ\text{C}$ for Glass Strength of 500 MPa (at Peak Effective-Plastic-Strain Location; 7-m Vertical Drop)

Figure II-31. Maximum Shear Stress Across Canister-Wall Thickness at RT for Glass Strength of 50 MPa (at Peak Maximum-Shear-Stress Location, 2-ft 70-degrees Oblique Drop)

Figure II-32. Maximum Shear Stress Across Canister-Wall Thickness at $T = 93.9^{\circ}\text{C}$ for Glass Strength of 50 MPa (at Peak Maximum-Shear-Stress Location, 2-ft 70-degrees Oblique Drop)

Figure II-33. Maximum Shear Stress Across Canister-Wall Thickness at $T = 204^{\circ}\text{C}$ for Glass Strength of 50 MPa (at Peak Maximum-Shear-Stress Location, 2-ft 70-degrees Oblique Drop)

Figure II-34. Maximum Shear Stress Across Canister-Wall Thickness at RT for Glass Strength of 200 MPa (at Peak Maximum-Shear-Stress Location, 2-ft 70-degrees Oblique Drop)

Figure II-35. Maximum Shear Stress Across Canister-Wall Thickness at $T = 93.9^{\circ}\text{C}$ for Glass Strength of 200 MPa (at Peak Maximum-Shear-Stress Location, 2-ft 70-degrees Oblique Drop)

Figure II-36. Maximum Shear Stress Across Canister-Wall Thickness at $T = 204^{\circ}\text{C}$ for Glass Strength of 200 MPa (at Peak Maximum-Shear-Stress Location, 2-ft 70-degrees Oblique Drop)

Figure II-37. Maximum Shear Stress Across Canister-Wall Thickness at RT for Glass Strength of 500 MPa (at Peak Maximum-Shear-Stress Location, 2-ft 70-degrees Oblique Drop)

Figure II-38. Maximum Shear Stress Across Canister-Wall Thickness at $T = 93.9^{\circ}\text{C}$ for Glass Strength of 500 MPa (at Peak Maximum-Shear-Stress Location, 2-ft 70-degrees Oblique Drop)

Figure II-39. Maximum Shear Stress Across Canister-Wall Thickness at $T = 204^{\circ}\text{C}$ for Glass Strength of 500 MPa (at Peak Maximum-Shear-Stress Location, 2-ft 70-degrees Oblique Drop)

Figure II-40. Maximum Shear Stress Across Canister-Wall Thickness at $T = 399^{\circ}\text{C}$ for Glass Strength of 500 MPa (at Peak Maximum-Shear-Stress Location, 2-ft 70-degrees Oblique Drop)

Figure II-41. Effective Plastic Strain Across Canister-Wall Thickness at RT for Glass Strength of 50 MPa (at Peak Effective-Plastic-Strain Location, 2-ft 70-degrees Oblique Drop)

Figure II-42. Effective Plastic Strain Across Canister-Wall Thickness at $T = 93.9\text{ }^{\circ}\text{C}$ for Glass Strength of 50 MPa (at Peak Effective-Plastic-Strain Location, 2-ft 70-degrees Oblique Drop)

Figure II-43. Effective Plastic Strain Across Canister-Wall Thickness at $T = 204\text{ }^{\circ}\text{C}$ for Glass Strength of 50 MPa (at Peak Effective-Plastic-Strain Location, 2-ft 70-degrees Oblique Drop)

Figure II-44. Effective Plastic Strain Across Canister-Wall Thickness at RT for Glass Strength of 200 MPa (at Peak Effective-Plastic-Strain Location, 2-ft 70-degrees Oblique Drop)

Figure II-45. Effective Plastic Strain Across Canister-Wall Thickness at $T = 93.9^{\circ}\text{C}$ for Glass Strength of 200 MPa (at Peak Effective-Plastic-Strain Location, 2-ft 70-degrees Oblique Drop)

Figure II-46. Effective Plastic Strain Across Canister-Wall Thickness at $T = 204^{\circ}\text{C}$ for Glass Strength of 200 MPa (at Peak Effective-Plastic-Strain Location, 2-ft 70-degrees Oblique Drop)

Figure II-47. Effective Plastic Strain Across Canister-Wall Thickness at RT for Glass Strength of 500 MPa (at Peak Effective-Plastic-Strain Location, 2-ft 70-degrees Oblique Drop)

Figure II-48. Effective Plastic Strain Across Canister-Wall Thickness at $T = 93.9^{\circ}\text{C}$ for Glass Strength of 500 MPa (at Peak Effective-Plastic-Strain Location, 2-ft 70-degrees Oblique Drop)

Figure II-49. Effective Plastic Strain Across Canister-Wall Thickness at $T = 204\text{ }^{\circ}\text{C}$ for Glass Strength of 500 MPa (at Peak Effective-Plastic-Strain Location, 2-ft 70-degrees Oblique Drop)

Figure II-50. Effective Plastic Strain Across Canister-Wall Thickness at $T = 399\text{ }^{\circ}\text{C}$ for Glass Strength of 500 MPa (at Peak Effective-Plastic-Strain Location, 2-ft 70-degrees Oblique Drop)

Figure II-51. Deformed Pu CIC Configuration (canister only) During 2-ft 70-degrees Oblique Drop (at $T = 93.3\text{ }^{\circ}\text{C}$ for Glass Strength of 500 MPa)

Figure II-52. Maximum Shear Stress in Pu CIC for FE Representation with Refined Mesh (Glass Strength 500 MPa, RT)

Figure II-53. Effective Plastic Strain in Pu CIC for FE Representation with Refined Mesh (Glass Strength 500 MPa, RT)

Figure II-54. Maximum Shear Stress During 2-ft 10-degrees Oblique Drop at RT (Glass Strength of 50 MPa); (a) canister bottom, (b) canister top

Figure II-55. Maximum Shear Stress During 2-ft 10-degrees Oblique Drop at $T = 93.3\text{ }^{\circ}\text{C}$ (Glass Strength of 50 MPa); (a) canister bottom, (b) canister top

Figure II-56. Maximum Shear Stress During 2-ft 10-degrees Oblique Drop at RT (Glass Strength of 200 MPa); (a) canister bottom, (b) canister top

Figure II-57. Maximum Shear Stress During 2-ft 10-degrees Oblique Drop at $T = 93.3^{\circ}\text{C}$ (Glass Strength of 200 MPa); (a) canister bottom, (b) canister top

Figure II-58. Maximum Shear Stress During 2-ft 10-degrees Oblique Drop at RT (Glass Strength of 500 MPa); (a) canister bottom, (b) canister top

(a)

(b)

Figure II-59. Maximum Shear Stress During 2-ft 10-degrees Oblique Drop at $T = 93.3\text{ }^{\circ}\text{C}$ (Glass Strength of 500 MPa); (a) canister bottom, (b) canister top

Figure II-60. Effective Plastic Strain During 2-ft 10-degrees Oblique Drop at RT (Glass Strength of 50 MPa); (a) canister bottom, (b) canister top

Figure II-61. Effective Plastic Strain During 2-ft 10-degrees Oblique Drop at $T = 93.3^{\circ}\text{C}$ (Glass Strength of 50 MPa); (a) canister bottom, (b) canister top

Figure II-62. Effective Plastic Strain During 2-ft 10-degrees Oblique Drop at RT (Glass Strength of 200 MPa); (a) canister bottom, (b) canister top

Figure II-63. Effective Plastic Strain During 2-ft 10-degrees Oblique Drop at $T = 93.3\text{ }^{\circ}\text{C}$ (Glass Strength of 200 MPa); (a) canister bottom, (b) canister top

(a)

(b)

Figure II-64. Effective Plastic Strain During 2-ft 10-degrees Oblique Drop at RT (Glass Strength of 500 MPa); (a) canister bottom, (b) canister top

(a)

(b)

Figure II-65. Effective Plastic Strain During 2-ft 10-degrees Oblique Drop at $T = 93.3^\circ\text{C}$ (Glass Strength of 500 MPa); (a) canister bottom, (b) canister top

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1. QA: QA

Page: 1 of: 4

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Drop Calculation of HLW Canister and Pu Can-in-Canister

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PC#116724

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None

COMMENTS/SPECIAL INSTRUCTIONS

15. IS SOFTWARE AVAILABLE FROM SOFTWARE CONFIGURATION MANAGEMENT?

☒ YES☐ NOSOFTWARE MEDIA TRACKING NUMBER N/A

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***SEE ATTACHED FOR ATTACHMENT III-CD 1 OF 1

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Heena Reeder Trina Reeder

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8. ATTACHMENTS

Attachment I (33 pages): Figures obtained from LS-DYNA V950 for HLW canister calculation

Attachment II (41 pages): Figures obtained from LS-DYNA V950 for Pu CIC calculation

Attachments III (1 Compact Disc): ANSYS V5.6.2 and LS-DYNA V950 electronic files for HLW canister calculation

Attachments IV (3 Compact Discs): ANSYS V5.6.2 and LS-DYNA V950 electronic files for Pu CIC calculation

Table 21. Attachment III: File Directories, Names, Dates, Times, and Sizes for HLW Canister Calculation

Directory	Name	Date	Time	Size
Brick/Loose/Elastic	d3hsp	07/02/01	11:51 a.m.	14,437 KB
	element.inc	07/02/01	11:51 a.m.	4,114 KB
	main.k	07/02/01	11:51 a.m.	7 KB
	nodes.inc	07/02/01	11:51 a.m.	3,293 KB
	nodeset1.inc	07/02/01	11:51 a.m.	23 KB
	nodeset2.inc	07/02/01	11:51 a.m.	23 KB
	nodeset3.inc	07/02/01	11:51 a.m.	5 KB
	nodeset4.inc	07/02/01	11:51 a.m.	1 KB
	nodeset5.inc	07/02/01	11:51 a.m.	2 KB
	sav6.db	07/02/01	11:51 a.m.	38,976 KB
	sav6.inp	07/02/01	11:51 a.m.	15 KB
	sav6.out	07/02/01	11:51 a.m.	862 KB
Brick/Loose/EIP/mesh1	segment.inc	07/02/01	11:51 a.m.	8 KB
	d3hsp	07/02/01	11:54 a.m.	14,438 KB
	element.inc	07/02/01	11:54 a.m.	4,114 KB
	main.k	07/02/01	11:54 a.m.	7 KB
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	nodeset2.inc	07/02/01	11:54 a.m.	23 KB
	nodeset3.inc	07/02/01	11:54 a.m.	5 KB
	nodeset4.inc	07/02/01	11:54 a.m.	1 KB
	nodeset5.inc	07/02/01	11:54 a.m.	2 KB
	sav6.db	07/02/01	11:53 a.m.	38,976 KB
	sav6.inp	07/02/01	11:52 a.m.	15 KB
Brick/Loose/EIP/mesh2	sav6.out	07/02/01	11:52 a.m.	862 KB
	segment.inc	07/02/01	11:54 a.m.	8 KB
	d3hsp	07/02/01	11:55 a.m.	23,446 KB
	element.inc	07/02/01	11:55 a.m.	6,829 KB
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	nodeset1.inc	07/02/01	11:55 a.m.	29 KB
	nodeset2.inc	07/02/01	11:55 a.m.	29 KB
	nodeset3.inc	07/02/01	11:55 a.m.	6 KB

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303 MB 8/8/01

	nodeset4.inc	07/02/01	11:55 a.m.	1 KB
	nodeset5.inc	07/02/01	11:55 a.m.	3 KB
	sav6.db	07/02/01	11:55 a.m.	62,464 KB
	sav6.inp	07/02/01	11:54 a.m.	15 KB
	sav6.out	07/02/01	11:54 a.m.	1,073 KB
	segment.inc	07/02/01	11:54 a.m.	10 KB
Brick/Eroding/FS=0.1%	d3hsp	07/02/01	11:57 a.m.	14,786 KB
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	sav6.inp	07/02/01	11:58 a.m.	15 KB
	sav6.out	07/02/01	11:58 a.m.	663 KB
	segment.inc	07/02/01	11:57 a.m.	8 KB
	d3hsp	07/02/01	11:59 a.m.	14,458 KB
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Brick/Connected/Elastic	main.k	07/02/01	11:59 a.m.	7 KB
	nodes.inc	07/02/01	11:59 a.m.	3,239 KB
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	sav6.db	07/02/01	11:59 a.m.	38,336 KB
	sav6.inp	07/02/01	11:59 a.m.	15 KB
	sav6.out	07/02/01	11:59 a.m.	634 KB
	segment.inc	07/02/01	11:59 a.m.	8 KB
	d3hsp	07/02/01	12:00 a.m.	14,459 KB
	element.inc	07/02/01	12:00 a.m.	4,242 KB
	main.k	07/02/01	12:00 a.m.	7 KB
Brick/Connected/EIP	nodes.inc	07/02/01	12:00 a.m.	3,239 KB
	nodeset1.inc	07/02/01	12:00 a.m.	23 KB
	nodeset2.inc	07/02/01	12:00 a.m.	23 KB
	nodeset3.inc	07/02/01	12:00 a.m.	5 KB
	nodeset4.inc	07/02/01	12:00 a.m.	1 KB

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9. FILE LINKAGE INSTRUCTIONS/INFORMATION:

Standard

10. PRINTER SPECIFICATION (i.e., HP4Si) INCLUDING POSTSCRIPT INFORMATION (i.e., PRINTER DRIVER) AND PRINTING PAGE SETUP: (i.e., LANDSCAPE, 11 X 17 PAPER)

Hewlett Packard Color Laser Jet 5m & Hewlett Packard Laser Jet 5Si mx - 8.5 x 11

11. COMPUTING PLATFORM USED: (i.e., PC, SUN, WIN 95, NT, HP)

PC#116724

12. OPERATING SYSTEM AND VERSION: (i.e., WINDOWS UNIX, SOLARIS)

Windows

13. ADDITIONAL HARDWARE/SOFTWARE REQUIREMENT USED TO CREATE FILE(S):

None

14. ACCESS RESTRICTIONS: (COPYRIGHT OR LICENSE ISSUES)

None

COMMENTS/SPECIAL INSTRUCTIONS

15. IS SOFTWARE AVAILABLE FROM SOFTWARE CONFIGURATION MANAGEMENT?

☒

YES

☐

NO

SOFTWARE MEDIA TRACKING NUMBER N/A

NOTE: The software product(s) to develop this document are Commercial-Off -The Shelf (COTS) software products which require no Software Media Number (SMN). The COTS software products are under Software Configuration Management (SCM) control.

***SEE ATTACHED FOR ATTACHMENT IV-CD 1 OF 3, 2 OF 3 & 3 OF 3

CERTIFICATION

16. DOCUMENT OWNER (Print and Sign):

Sreten Mastilovic

17. DATE:

08/02/01

18. ORGANIZATION:

BSC

19. DEPARTMENT:

WPD

20. LOCATION/MAIL STOP:

MS423/1030N

21. PHONE:

295-5046

22. SUBMITTED BY (Print and Sign):

Trina Reeder Trina Reeder

23. DATE:

8/2/01

DC USE ONLY

24. DATE RECEIVED:

8/2/01

25. DATE FILES TRANSFERRED:

N/A

26. DC NO.:

29022

27. NAME (Print and Sign):

N/A

28. DATE:

N/A

Shell/Loose/EIP	nodeset5.inc	07/02/01	12:00 a.m.	2 KB
	sav6.db	07/02/01	12:01 a.m.	38,336 KB
	sav6.inp	07/02/01	12:00 a.m.	15 KB
	sav6.out	07/02/01	12:00 a.m.	634 KB
	segment.inc	07/02/01	12:00 a.m.	8 KB
	d3hsp	07/03/01	07:35 a.m.	10,663 KB
	element.inc	07/03/01	07:35 a.m.	2,959 KB
	main.k	07/03/01	07:35 a.m.	7 KB
	nodes.inc	07/03/01	07:35 a.m.	2,367 KB
	nodeset1.inc	07/03/01	07:35 a.m.	18 KB
	nodeset2.inc	07/03/01	07:35 a.m.	18 KB
	nodeset3.inc	07/03/01	07:35 a.m.	5 KB
	nodeset4.inc	07/03/01	07:35 a.m.	1 KB
	nodeset5.inc	07/03/01	07:35 a.m.	2 KB
	sav3.db	07/03/01	07:35 a.m.	27,456 KB
	sav3.inp	07/03/01	07:35 a.m.	13 KB
	sav3.out	07/03/01	07:35 a.m.	188 KB
	segment.inc	07/03/01	07:35 a.m.	8 KB
	d3hsp	07/03/01	07:36 a.m.	10,571 KB
	element.inc	07/03/01	07:36 a.m.	3,072 KB
Shell/Connected/EIP	main.k	07/03/01	07:36 a.m.	7 KB
	nodes.inc	07/03/01	07:36 a.m.	2,323 KB
	nodeset1.inc	07/03/01	07:36 a.m.	17 KB
	nodeset2.inc	07/03/01	07:36 a.m.	17 KB
	nodeset3.inc	07/03/01	07:36 a.m.	5 KB
	nodeset4.inc	07/03/01	07:36 a.m.	1 KB
	nodeset5.inc	07/03/01	07:36 a.m.	2 KB
	sav3b.db	07/03/01	07:36 a.m.	27,584 KB
	sav3b.inp	07/03/01	07:36 a.m.	12 KB
	sav3b.out	07/03/01	07:36 a.m.	330 KB
	segment.inc	07/03/01	07:36 a.m.	8 KB

NOTE: The file sizes may vary with operating system.

Table 22. Attachment IV: File Directories, Names, Dates, Times, and Sizes for Pu CIC Calculation

Directory	Name	Date	Time	Size
Vertical	savpu4g.db	07/02/01	03:44 p.m.	86,272 KB
Vertical	savpu4g.inp	07/02/01	03:43 p.m.	31 KB
Vertical	savpu4g.out	07/02/01	03:43 p.m.	731 KB
Vertical	element.inc	07/02/01	03:45 p.m.	7,906 KB
Vertical	nodes.inc	07/02/01	03:44 p.m.	7,145 KB
Vertical	nodeset1.inc	07/02/01	03:44 p.m.	51 KB
Vertical	nodeset2.inc	07/02/01	03:44 p.m.	9 KB
Vertical	nodeset3.inc	07/02/01	03:44 p.m.	4 KB
Vertical	segment10.inc	07/02/01	03:44 p.m.	98 KB
Vertical	segment11.inc	07/02/01	03:44 p.m.	4 KB
Vertical	segment12.inc	07/02/01	03:44 p.m.	5 KB
Vertical	segment6.inc	07/02/01	03:44 p.m.	13 KB
Vertical	segment7.inc	07/02/01	03:44 p.m.	40 KB
Vertical	segment8.inc	07/02/01	03:44 p.m.	28 KB
Vertical	segment9.inc	07/02/01	03:44 p.m.	76 KB

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Vertical/RT/500MPa/A-36ElaPlast	d3hsp	07/02/01	04:22 p.m.	31,323 KB
	main1.k	07/02/01	04:22 p.m.	9 KB
Vertical/RT/500MPa/A-36Ela	d3hsp	07/02/01	04:21 p.m.	31,323 KB
	main1.k	07/02/01	04:21 p.m.	9 KB
Vertical/RT/500MPa/ConcreteEla	d3hsp	07/02/01	04:23 p.m.	31,323 KB
	main1.k	07/02/01	04:22 p.m.	9 KB
Vertical/RT/200MPa	d3hsp	07/02/01	04:38 p.m.	31,323 KB
	main1.k	07/02/01	04:38 p.m.	9 KB
Vertical/RT/50MPa	d3hsp	07/03/01	08:00 a.m.	31,323 KB
	main1.k	07/03/01	08:00 a.m.	9 KB
Vertical/93C/500MPa	d3hsp	07/02/01	04:41 p.m.	31,323 KB
	main1.k	07/02/01	04:41 p.m.	9 KB
Vertical/93C/200MPa	d3hsp	07/02/01	04:42 p.m.	31,323 KB
	main1.k	07/02/01	04:42 p.m.	9 KB
Vertical/93C/50MPa	d3hsp	07/02/01	04:43 p.m.	31,323 KB
	main1.k	07/02/01	04:43 p.m.	9 KB
Vertical/204C/500MPa	d3hsp	07/02/01	04:45 p.m.	31,323 KB
	main1.k	07/02/01	04:44 p.m.	9 KB
Vertical/204C/200MPa	d3hsp	07/02/01	04:44 p.m.	31,323 KB
	main1.k	07/02/01	04:44 p.m.	9 KB
Vertical/204C/50MPa	d3hsp	07/02/01	04:45 p.m.	31,323 KB
	main1.k	07/02/01	04:45 p.m.	9 KB
70-degrees/Mesh1	savpu5c.db	07/02/01	03:46 p.m.	83,840 KB
70-degrees/Mesh1	savpu5c.inp	07/02/01	03:45 p.m.	31 KB
70-degrees/Mesh1	savpu5c.out	07/02/01	03:45 p.m.	739 KB
70-degrees/Mesh1	element.inc	07/02/01	03:47 p.m.	7,646 KB
70-degrees/Mesh1	nodes.inc	07/02/01	03:47 p.m.	6,906 KB
70-degrees/Mesh1	nodeset1.inc	07/02/01	03:47 p.m.	50 KB
70-degrees/Mesh1	nodeset2.inc	07/02/01	03:47 p.m.	2 KB
70-degrees/Mesh1	segment10.inc	07/02/01	03:47 p.m.	98 KB
70-degrees/Mesh1	segment11.inc	07/02/01	03:47 p.m.	4 KB
70-degrees/Mesh1	segment12.inc	07/02/01	03:46 p.m.	5 KB
70-degrees/Mesh1	segment6.inc	07/02/01	03:46 p.m.	9 KB
70-degrees/Mesh1	segment7.inc	07/02/01	03:46 p.m.	40 KB
70-degrees/Mesh1	segment8.inc	07/02/01	03:46 p.m.	28 KB
70-degrees/Mesh1	segment9.inc	07/02/01	03:46 p.m.	76 KB
70-degrees/Mesh1/RT/500MPa	d3hsp	07/02/01	04:36 p.m.	30,417 KB
	main2.k	07/02/01	04:35 p.m.	9 KB
70-degrees/Mesh1/RT/200MPa	d3hsp	07/02/01	04:25 p.m.	30,417 KB
	main2.k	07/02/01	04:25 p.m.	9 KB
70-degrees/Mesh1/RT/50MPa	d3hsp	07/02/01	04:24 p.m.	30,418 KB
	main2.k	07/02/01	04:24 p.m.	9 KB
70-degrees/Mesh1/93C/500MPa	d3hsp	07/02/01	04:57 p.m.	30,417 KB
	main2.k	07/02/01	04:56 p.m.	9 KB
70-degrees/Mesh1/93C/200MPa	d3hsp	07/02/01	04:56 p.m.	30,417 KB
	main2.k	07/02/01	04:55 p.m.	9 KB
70-degrees/Mesh1/93C/50MPa	d3hsp	07/02/01	04:56 p.m.	30,418 KB
	main2.k	07/02/01	04:56 p.m.	9 KB
70-degrees/Mesh1/204C/500MPa	d3hsp	07/02/01	04:48 p.m.	30,417 KB
	main2.k	07/02/01	04:48 p.m.	9 KB
70-degrees/Mesh1/204C/200MPa	d3hsp	07/02/01	04:47 p.m.	30,417 KB
	main2.k	07/02/01	04:47 p.m.	9 KB
70-degrees/Mesh1/204C/50MPa	d3hsp	07/02/01	04:48 p.m.	30,418 KB

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70-degrees/Mesh1/399C/500MPa	main2.k	07/02/01	04:47 p.m.	9 KB
	d3hsp	07/03/01	07:57 a.m.	30,417 KB
	main2.k	07/03/01	07:56 a.m.	9 KB
70-degrees/Mesh2/RT/500MPa	d3hsp	07/02/01	04:34 p.m.	34,616 KB
	main2.k	07/02/01	04:34 p.m.	9 KB
	savpu5c.db	07/02/01	04:34 p.m.	94,336 KB
	savpu5c.inp	07/02/01	04:33 p.m.	31 KB
	savpu5c.out	07/02/01	04:33 p.m.	754 KB
	element.inc	07/02/01	04:34 p.m.	8,796 KB
	nodes.inc	07/02/01	04:34 p.m.	7,926 KB
	nodeset1.inc	07/02/01	04:34 p.m.	51 KB
	nodeset2.inc	07/02/01	04:34 p.m.	2 KB
	segment10.inc	07/02/01	04:33 p.m.	98 KB
	segment11.inc	07/02/01	04:33 p.m.	4 KB
	segment12.inc	07/02/01	04:33 p.m.	5 KB
	segment6.inc	07/02/01	04:33 p.m.	9 KB
	segment7.inc	07/02/01	04:33 p.m.	40 KB
	segment8.inc	07/02/01	04:33 p.m.	28 KB
	segment9.inc	07/02/01	04:33 p.m.	76 KB
10-degrees	savpu5e.db	07/02/01	03:50 p.m.	84,864 KB
10-degrees	savpu5e.inp	07/02/01	03:49 p.m.	32 KB
10-degrees	savpu5e.out	07/02/01	03:49 p.m.	739 KB
10-degrees	element.inc	07/02/01	03:51 p.m.	7,737 KB
10-degrees	nodes.inc	07/02/01	03:51 p.m.	6,997 KB
10-degrees	nodeset1.inc	07/02/01	03:51 p.m.	52 KB
10-degrees	nodeset2.inc	07/02/01	03:51 p.m.	4 KB
10-degrees	segment10.inc	07/02/01	03:51 p.m.	98 KB
10-degrees	segment11.inc	07/02/01	03:51 p.m.	4 KB
10-degrees	segment12.inc	07/02/01	03:51 p.m.	5 KB
10-degrees	segment6.inc	07/02/01	03:50 p.m.	26 KB
10-degrees	segment7.inc	07/02/01	03:50 p.m.	40 KB
10-degrees	segment8.inc	07/02/01	03:50 p.m.	28 KB
10-degrees	segment9.inc	07/02/01	03:50 p.m.	76 KB
10-degrees/RT/500MPa	d3hsp	07/02/01	04:53 p.m.	30,862 KB
	main3.k	07/02/01	04:53 p.m.	10 KB
10-degrees/RT/200MPa	d3hsp	07/02/01	04:52 p.m.	30,863 KB
	main3.k	07/02/01	04:52 p.m.	10 KB
10-degrees/RT/50MPa	d3hsp	07/02/01	04:37 p.m.	30,860 KB
	d3hsp1	07/02/01	04:36 p.m.	29 KB
	d3hsp2	07/02/01	04:36 p.m.	28 KB
	main3.k	07/02/01	04:36 p.m.	10 KB
10-degrees/93C/500MPa	d3hsp	07/02/01	04:50 p.m.	30,859 KB
	d3hsp1	07/02/01	04:50 p.m.	10 KB
	main3.k	07/02/01	04:50 p.m.	10 KB
10-degrees/93C/200MPa	d3hsp	07/02/01	04:49 p.m.	30,858 KB
	d3hsp1	07/02/01	04:49 p.m.	11 KB
	main3.k	07/02/01	04:49 p.m.	10 KB
10-degrees/93C/50MPa	d3hsp	07/02/01	04:54 p.m.	30,862 KB
	main3.k	07/02/01	04:54 p.m.	10 KB

NOTE: The file sizes may vary with operating system.