## 1.0 OBJECTIVE

Perform the buckling evaluation of the 3-60B Cask under normal conditions of transport (NCT) and hypothetical accident conditions (HAC) loading using the ASME Boiler and Pressure Vessel Code Case N-284.

## 2.0 INTRODUCTION

The buckling evaluation of the 3-60B Cask is performed on the ASME Boiler & Pressure Vessel Code Case N-284 (Reference 1) criteria. The buckling requirement of Paragraph C.5 of Regulatory Guide 7.6 (Reference 2) ("buckling should not occur as the result of any normal or accident condition loading") are satisfied by demonstrating that the 3-60B Cask meets the requirements of this Code Case. Consistent with Regulatory Guide 7.6 philosophy, the NCT is considered to be the ASME Service Level A condition; and HAC is considered to be Service Level D condition.

The most vulnerable component of the 3-60B Cask for buckling is its inner shell since it is the thinnest component and is subjected to both axial and hoop compressions. The axial compressive stress in this shell arises from the end and corner drops and the hoop compression occurs due to shrinkage of the lead over the inner shell in the cold environment. In order to obtain the maximum components of these stresses, all the loading combinations are examined. The NCT and HAC drop analyses performed under various environmental conditions in Reference 3 have been used to obtain the stress components needed for the evaluation of the shell buckling. The maximum components of axial compression, hoop compression, and the in-plane shear stress for various loading obtained from Reference 3 analyses are summarized in Table 1. Conservatively, the largest value of each component is assumed to occur concurrently and they have been used for the NCT and HAC condition's evaluation.

## 3.0 REFERENCES

(1) American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel Code, Section III, Division 1, Class MC, Code Case N-284, Metal Containment Shell Buckling Design Method, August 25, 1980.

(2) U.S.N.R.C. Regulatory Guide 7.6, Design Criteria for the Structural Analysis of Shipping Package Containment Vessel, Revision 1, March 1978.

(3) Energy*Solutions* Document No. ST-504, Rev.1, Structural Analyses of the 3-60B Cask under Drop Conditions.

## 4.0 CODE CASE EVALUATION PROCESS

ASME Code Case N-284 addresses both elastic and inelastic buckling and employs a factor of safety of 2.0 for service Level A (NCT) and 1.34 for service Level D (HAC). Interaction equations are employed which account for the effect of combined axial compressive, hoop compressive, and in-plane shear loadings. The basic analytical approach is summarized as follows:

1. Theoretical elastic buckling stresses are determined using classical theory.

2. Capacity reduction factors are applied which account for the difference between classical theory and predicted instability stresses for fabricated shells.
3. Plasticity reduction factors are applied for those cases where elastically determined buckling stresses are above the proportional limit.
4. Elastic and inelastic buckling checks which employ appropriate factors of safety and appropriate interaction equations are made using worst case applied compressive and in-plane shear stresses.

All terminology used herein is consistent with that in ASME Code Case N-284.

## 4.1 Theoretical Elastic Buckling Stresses

a) Axial compression

The theoretical axial buckling stress ($\sigma_{\phi eL}$) is:

$$\sigma_{\phi eL} = C_\phi \frac{Et}{R}$$

where,

$$C_\phi = \frac{0.904}{M_\phi^2} + (0.1013)M_\phi^2 \quad \text{if } 1.5 \le M_\phi \le 1.73$$

$$C_\phi = 0.605 \quad \text{if } M_\phi \ge 1.73$$

b) Hoop Compression

i) No End Pressure

The theoretical hoop buckling stress ($\sigma_{\theta eL}$) is:

$$\sigma_{\theta eL} = \sigma_{reL} = C_{\theta r} \frac{Et}{R}$$

where,

$$C_{\theta r} = \frac{2.41}{M_\phi^{1.49} - 0.338} \quad \text{if } 1.5 \le M_\phi < 3.0$$

$$C_{\theta r} = \frac{0.92}{M_\phi - 1.17} \quad \text{if } 3.0 \le M_\phi < (1.65)(R/t)$$

$$C_{\theta r} = (0.275)\left(\frac{t}{R}\right) + \left(\frac{2.1}{M_\phi^4}\right)\left(\frac{R}{t}\right)^3 \quad \text{if } M_\phi \ge (1.65)(R/t)$$

ii) End Pressure Included

The theoretical hoop buckling stress ($\sigma_{\theta eL}$) is:

$$\sigma_{\theta eL} = \sigma_{heL} = C_{\theta h}\frac{Et}{R}$$

where,

$$C_{\theta h} = \frac{1.08}{M_\phi^{1.07} - 0.45} \qquad \text{if } 1.5 \le M_\phi < 3.0$$

$$C_{\theta h} = \frac{0.92}{M_\phi - 0.636} \qquad \text{if } 3.0 \le M_\phi < (1.65)(R/t)$$

$$C_{\theta h} = (0.275)\left(\frac{t}{R}\right) + \left(\frac{2.1}{M_\phi^4}\right)\left(\frac{R}{t}\right)^3 \qquad \text{if } M_\phi \ge (1.65)(R/t)$$

c) <u>In-Plane Shear</u>

The theoretical in-plane shear buckling stress, $\sigma_{\phi\theta eL}$, is:

$$\sigma_{\phi\theta eL} = C_{\phi\theta}\frac{Et}{R}$$

where,

$$C_{\phi\theta} = \left(\frac{4.82}{M_\phi^2}\right)\sqrt{1 + (0.0239)M_\phi^3} \qquad \text{if } 1.5 \le M_\phi < 26$$

$$C_{\phi\theta} = \frac{0.746}{\sqrt{M_\phi}} \qquad \text{if } 26 \le M_\phi < (8.69)(R/t)$$

$$C_{\phi\theta} = 0.253\sqrt{\frac{t}{R}} \qquad \text{if } M_\phi \ge (8.69)(R/t)$$

## 4.2 Capacity Reduction Factors

a) <u>For Axial Compression</u>, the larger of (i) or (ii) is used:

i) <u>Effect of R/t</u>:

$$\alpha_{\phi L} = 0.207 \qquad \text{if } R/t \ge 600$$

$$\left.\begin{aligned} \alpha_{\phi L} &= 1.52 - (0.473)\log_{10}(R/t) \\ \alpha_{\phi L} &= (10^{-5})\sigma_y - 0.033 \end{aligned}\right. \qquad \text{if } R/t < 600 \text{ (use smaller value)}$$

ii) <u>Effect of Length</u>

$$\alpha_{\phi L} = 0.837 - (0.14)M \qquad \text{if } 1.5 \le M < 1.73$$

$$\alpha_{\phi L} = \frac{0.837}{M^{0.6}} \qquad \text{if } 1.73 \le M < 10$$

$$\alpha_{\phi L} = 0.207 \qquad \text{if } M \ge 10$$

b) For Hoop Compression

$$\alpha_{\theta L} = 0.8$$

c) For Shear:

$$\alpha_{\phi\theta L} = 0.8 \qquad \text{if } R/t \le 250$$

$$\alpha_{\phi\theta L} = 1.323 - (0.218)\log_{10}(R/t) \qquad \text{if } 250 < R/t < 1000$$

## 4.3 Plasticity Reduction Factors

a) For Axial Compression

$$\eta_\theta = 1.0 \qquad \text{if } \sigma_\phi(FS)/\sigma_y \le 0.55$$

$$\eta_\phi = \frac{0.18}{1 - \dfrac{(0.45)\sigma_y}{(FS)\sigma_\phi}} \qquad \text{if } 0.55 < \sigma_\phi(FS)/\sigma_y \le 0.738$$

$$\eta_\phi = 1.31 - \frac{(1.15)\sigma_\phi(FS)}{\sigma_y} \qquad \text{if } 0.738 < \sigma_\phi(FS)/\sigma_y \le 1.0$$

b) For Hoop Compression

$$\eta_\theta = 1.0 \qquad \text{if } \sigma_\theta(FS)/\sigma_y \le 0.67$$

$$\eta_\theta = 2.53 - \frac{(2.29)\sigma_\theta(FS)}{\sigma_y} \qquad \text{if } 0.67 < \sigma_\theta(FS)/\sigma_y \le 1.0$$

c) For Shear

$$\eta_{\phi\theta} = 1.0 \qquad \text{if } \sigma_{\phi\theta}(FS)/\sigma_y \le 0.48$$

$$\eta_{\phi\theta} = \frac{0.1}{1 - \dfrac{(0.43)\sigma_y}{(FS)\sigma_{\phi\theta}}} \qquad \text{if } 0.48 < \sigma_{\phi\theta}(FS)/\sigma_y \le 0.6$$

## 4.4 Interaction Equations

Elastic and inelastic equations must be satisfied for all states of compressive and in-plane shear stresses. The interaction equations for cylindrical shells obtained from Code Case N-284 are as follows:

Elastic Buckling (Paragraph--1713.1.1 of the Code Case)

a) Axial compression-plus-hoop compression $(\sigma_{\phi s} < \frac{1}{2}\sigma_{\theta s})$

Not Applicable (n/a)

b) Axial compression-plus-hoop compression $(\sigma_{\phi s} \geq \frac{1}{2}\sigma_{\theta s})$:

$$\frac{\sigma_{\phi s} - \frac{1}{2}\sigma_{heL}}{\sigma_{\phi eL} - \frac{1}{2}\sigma_{heL}} + \left(\frac{\sigma_{\theta s}}{\sigma_{heL}}\right)^2 \leq 1.0$$

c) Axial compression-plus-shear:

$$\frac{\sigma_{\phi s}}{\sigma_{\phi eL}} + \left(\frac{\sigma_{\phi\theta s}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

d) Hoop compression-plus-shear

$$\frac{\sigma_{\theta s}}{\sigma_{reL}} + \left(\frac{\sigma_{\phi\theta s}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

Inelastic Buckling (Paragraph—1713.2.1 of the Code Case)

a) Axial compression:

$$\frac{\sigma_{\phi p}}{\sigma_{\phi eL}} \leq 1.0$$

b) Hoop compression:

$$\frac{\sigma_{\theta p}}{\sigma_{\theta eL}} \leq 1.0$$

c) Axial compression-plus-shear:

$$\left(\frac{\sigma_{\phi p}}{\sigma_{\phi eL}}\right)^2 + \left(\frac{\sigma_{\phi\theta p}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

d) Hoop compression-plus-shear

$$\left(\frac{\sigma_{\theta p}}{\sigma_{reL}}\right)^2 + \left(\frac{\sigma_{\phi\theta p}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

## 5.0 EVALUATION OF THE 3-60B CASK INNER SHELL

The inner shell of the 3-60B cask is made of A-240 Gr. 45 (UNS S30815) material for which the mechanical properties versus temperature are listed in Reference xx, Table xx). Since the largest compressive loading on the shell occurs in the cold environment, its mechanical properties at the lowest shell temperature (i.e. -20°F) are used for the buckling evaluation. Also, since the largest stress occur under the dynamic loading conditions; the yield stress of the material has been increased by a factor of 1.33.

$R$ = Mean radius of the shell = 17.875 in

$t$ = Thickness of the shell = 0.75 in

$l_f$ = Length of the shell = 110 in

$E$ = Modulus of elasticity = $28\times10^6$ psi (see Material Properties Table of Reference 3)

$s_y$ = Yield stress = 1.333×45,000 = 60,000 psi

$$M_\phi = \frac{l_\phi}{\sqrt{Rt}} = \frac{110}{\sqrt{17.875\times0.75}} = 30 > 1.73$$

### 5.1 Theoretical Elastic Buckling Stresses (Independent of Loading)

Axial Compression

Since $M_f > 1.73$

$$C_\phi = 0.605$$

$$\sigma_{\phi eL} = C_\phi \frac{Et}{R} = 0.605\times\frac{28\times10^6\times0.75}{17.875} = 710{,}769 \text{ psi}$$

Hoop Compression

$1.65\times R/t = 1.65\times17.875/0.75 = 39.3$

Since, $3 < M_f < 1.65\times R/t$

$$C_{\theta h} = \frac{0.92}{M_\phi - 0.636} = \frac{0.92}{30-0.636} = 0.0313$$

$$\sigma_{\theta eL} = \sigma_{heL} = C_{\theta h}\frac{Et}{R} = 0.0313\times\frac{28\times10^6\times0.75}{17.875} = 36{,}772 \text{ psi}$$

In-Plane Shear

$8.69\times R/t = 8.69\times17.875/0.75 = 207$

Since, $26 \le M_\phi < (8.69)(R/t)$

$$C_{\phi\theta} = \frac{0.746}{\sqrt{M_\phi}} = \frac{0.746}{\sqrt{30}} = 0.1362$$

$$\sigma_{\phi\theta eL} = C_{\phi\theta}\frac{Et}{R} = 0.1362 \times \frac{28\times10^6 \times 0.75}{17.875} = 160{,}011 \text{ psi}$$

**5.2 Capacity Reduction Factors** (Independent of Loading)

$R/t = 17.875/0.75 = 23.83$

Effect of $R/t$

$R/t$ is < 600

$a_{fL}$ = smaller of [{1.52 – 0.473×log$_{10}$ ($R/t$)} and {$10^{-5}\times s_y$ -0.033}]

1.52 – 0.473×log$_{10}$ ($R/t$) = 1.52 – 0.473×log$_{10}$ (*23.83*) = 0.869

The material is specified as A-240 Gr. 45 which has a static yield stress of 45,000 psi. Since the loadings considered here are dynamic, the dynamic yield stress is used for $s_y$.

$s_y$ = 1.333 × 45,000 = 60,000 psi

$10^{-5}\times s_y$ -0.033 = $10^{-5}$×60,000 -0.033 = 0.567

$a_{fL}$ = smaller of ( 0.8213 & 0.567) = 0.567

Effect of Length

$M = M_f = 30 > 10$

$a_{fL} = 0.207$

For the combination the larger of the two $a_{fL}$ are used. Thus,

$a_{fL} = 0.567$

For Hoop Compression

$a_{\theta L} = 0.8$

For Shear

Since, $R/t = 23.83 < 250$

$a_{\varphi\theta L} = 0.8$

**5.3 Plasticity Reduction Factors for NCT**

Plasticity reduction factors are function of applied stresses. For NCT conditions the maximum values of each loading components are used for the calculation of plasticity reduction factors. From Table 1 these values are:

$s_f$ = maximum longitudinal stress = 18,494 psi

$s_\theta$ = maximum hoop stress = 10,718 psi

$\sigma_{\varphi\theta}$ = maximum in-plane shear stress = 1,590 psi

The factor of safety for the NCT loading is 2.0. Therefore,

$$\sigma_\phi(FS) = 18{,}494 \times 2.0 = 36{,}988 \text{ psi}$$

$$\sigma_\theta(FS) = 10{,}718 \times 2.0 = 21{,}436 \text{ psi}$$

$$\sigma_{\theta\phi}(FS) = 1{,}590 \times 2.0 = 3{,}180 \text{ psi}$$

Plasticity reduction factors are calculated using the equations presented in Section 4.3,

$$\sigma_\phi(FS)/\sigma_y = 18{,}494 \times 2.0/60{,}000 = 0.616$$

$$\sigma_\theta(FS)/\sigma_y = 10{,}718 \times 2.0/60{,}000 = 0.357$$

$$\sigma_{\phi\theta}(FS)/\sigma_y = 1{,}590 \times 2.0/60{,}000 = 0.053$$

Since, $0.55 < \sigma_\phi(FS)/\sigma_y \le 0.738$

$$\eta_\phi = \frac{0.18}{1 - \dfrac{(0.45)\sigma_y}{(FS)\sigma_\phi}} = \frac{0.18}{1 - \dfrac{(0.45) \times 60{,}000}{36{,}988}} = 0.667$$

Since, $\sigma_\theta(FS)/\sigma_y \le 0.67$

$$\eta_\theta = 1.0$$

Since, $\sigma_{\phi\theta}(FS)/\sigma_y \le 0.48$

$$\eta_{\phi\theta} = 1.0$$

Compute the elastic stress components:

$$\sigma_{\phi s} = \frac{(FS)\sigma_\phi}{\alpha_{\phi L}} = \frac{36{,}988}{0.567} = 65{,}235 \text{ psi}$$

$$\sigma_{\theta s} = \frac{(FS)\sigma_\theta}{\alpha_{\theta L}} = \frac{21{,}436}{0.8} = 26{,}795 \text{ psi}$$

$$\sigma_{\phi\theta s} = \frac{(FS)\sigma_{\phi\theta}}{\alpha_{\phi\theta L}} = \frac{3{,}180}{0.8} = 3{,}975 \text{ psi}$$

Compute the inelastic stress components:

$$\sigma_{\phi p} = \frac{\sigma_{\phi s}}{\eta_\phi} = \frac{65{,}235}{0.667} = 97{,}804 \text{ psi}$$

$$\sigma_{\theta p} = \frac{\sigma_{\theta s}}{\eta_\theta} = \frac{26{,}795}{1.0} = 26{,}795 \text{ psi}$$

$$\sigma_{\phi\theta p} = \frac{\sigma_{\phi\theta s}}{\eta_{\phi\theta}} = \frac{3{,}975}{1.0} = 3{,}975 \text{ psi}$$

## 5.4 Interaction Equations for NCT

Elastic Buckling

a) Axial compression-plus-hoop compression $(\sigma_{\phi s} < \frac{1}{2}\sigma_{\theta s})$

Not Applicable (n/a)

b) Axial compression-plus-hoop compression $(\sigma_{\phi s} \geq \frac{1}{2}\sigma_{\theta s})$:

$$\frac{\sigma_{\phi s} - \frac{1}{2}\sigma_{heL}}{\sigma_{\phi eL} - \frac{1}{2}\sigma_{heL}} + \left(\frac{\sigma_{\theta s}}{\sigma_{heL}}\right)^2 \leq 1.0$$

$$\frac{65{,}235 - \frac{1}{2} \times 36{,}772}{710{,}769 - \frac{1}{2} \times 36{,}772} + \left(\frac{26{,}795}{36{,}772}\right)^2 = 0.599 < 1.0 \qquad \text{O.K.}$$

c) Axial compression-plus-shear:

$$\frac{\sigma_{\phi s}}{\sigma_{\phi eL}} + \left(\frac{\sigma_{\phi\theta s}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

$$\frac{65{,}235}{710{,}769} + \left(\frac{3{,}975}{160{,}011}\right)^2 = 0.0924 < 1.0 \qquad \text{O.K.}$$

d) Hoop compression-plus-shear

$$\frac{\sigma_{\theta s}}{\sigma_{reL}} + \left(\frac{\sigma_{\phi\theta s}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

$$\frac{26{,}795}{36{,}772} + \left(\frac{3{,}975}{160{,}011}\right)^2 = 0.729 < 1.0 \qquad \text{O.K.}$$

Inelastic Buckling

e) Axial compression:

$$\frac{\sigma_{\phi p}}{\sigma_{\phi eL}} \leq 1.0$$

$$\frac{97{,}804}{710{,}769} = 0.138 \leq 1.0 \qquad \text{O.K.}$$

f) Hoop compression:

$$\frac{\sigma_{\theta p}}{\sigma_{\theta eL}} \leq 1.0$$

$$\frac{26{,}795}{36{,}772} = 0.729 < 1.0 \qquad \text{O.K.}$$

g) Axial compression-plus-shear:

$$\left(\frac{\sigma_{\phi p}}{\sigma_{\phi eL}}\right)^2 + \left(\frac{\sigma_{\phi\theta p}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

$$\left(\frac{97{,}804}{710{,}769}\right)^2 + \left(\frac{3{,}975}{160{,}011}\right)^2 = 0.0196 < 1.0 \qquad \text{O.K.}$$

h) Hoop compression-plus-shear

$$\left(\frac{\sigma_{\theta p}}{\sigma_{reL}}\right)^2 + \left(\frac{\sigma_{\phi\theta p}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

$$\left(\frac{26{,}795}{36{,}772}\right)^2 + \left(\frac{3{,}975}{160{,}011}\right)^2 = 0.532 < 1.0 \qquad \text{O.K.}$$

## 5.5 Plasticity Reduction Factors for HAC

Plasticity reduction factors are function of applied stresses. For HAC conditions the maximum values of each loading components are used for the calculation of plasticity reduction factors. From Table 1 these values are:

$s_f$ = maximum longitudinal stress = 35,285 psi

$s_\theta$ = maximum hoop stress = 16,363 psi

$\sigma_{\varphi\theta}$ = maximum in-plane shear stress = 3,731 psi

The factor of safety for the HAC loading is 1.34. Therefore,

$$\sigma_\phi(FS) = 35{,}285 \times 1.34 = 47{,}282 \text{ psi}$$

$$\sigma_\theta(FS) = 16{,}363 \times 1.34 = 21{,}926 \text{ psi}$$

$$\sigma_{\theta\phi}(FS) = 3{,}731 \times 1.34 = 5{,}000 \text{ psi}$$

Plasticity reduction factors are calculated using the equations presented in Section 4.3,

$$\sigma_\phi(FS)/\sigma_y = 35{,}285 \times 1.34 / 60{,}000 = 0.788$$

$$\sigma_\theta(FS)/\sigma_y = 16{,}363 \times 1.34 / 60{,}000 = 0.365$$

$$\sigma_{\phi\theta}(FS)/\sigma_y = 3{,}731 \times 1.34/60{,}000 = 0.083$$

Since, $0.738 < \sigma_\phi(FS)/\sigma_y \le 1.0$

$$\eta_\phi = 1.31 - \frac{(1.15)\sigma_\phi(FS)}{\sigma_y} = 1.31 - \frac{1.15 \times 47{,}282}{60{,}000} = 0.404$$

Since, $\sigma_\theta(FS)/\sigma_y \le 0.67$

$$\eta_\theta = 1.0$$

Since, $\sigma_{\phi\theta}(FS)/\sigma_y \le 0.48$

$$\eta_{\phi\theta} = 1.0$$

Compute the elastic stress components:

$$\sigma_{\phi s} = \frac{(FS)\sigma_\phi}{\alpha_{\phi L}} = \frac{47{,}282}{0.567} = 83{,}390 \text{ psi}$$

$$\sigma_{\theta s} = \frac{(FS)\sigma_\theta}{\alpha_{\theta L}} = \frac{21{,}926}{0.8} = 27{,}408 \text{ psi}$$

$$\sigma_{\phi\theta s} = \frac{(FS)\sigma_{\phi\theta}}{\alpha_{\phi\theta L}} = \frac{5{,}000}{0.8} = 6{,}250 \text{ psi}$$

Compute the inelastic stress components:

$$\sigma_{\phi p} = \frac{\sigma_{\phi s}}{\eta_\phi} = \frac{83{,}390}{0.404} = 206{,}410 \text{ psi}$$

$$\sigma_{\theta p} = \frac{\sigma_{\theta s}}{\eta_\theta} = \frac{27{,}408}{1} = 27{,}408 \text{ psi}$$

$$\sigma_{\phi\theta p} = \frac{\sigma_{\phi\theta s}}{\eta_{\phi\theta}} = \frac{6{,}250}{1.0} = 6{,}250 \text{ psi}$$

## 5.6 Interaction Equations for HAC

Elastic Buckling

a) Axial compression-plus-hoop compression $(\sigma_{\phi s} < \frac{1}{2}\sigma_{\theta s})$

Not Applicable (n/a)

b) Axial compression-plus-hoop compression $(\sigma_{\phi s} \ge \frac{1}{2}\sigma_{\theta s})$:

$$\frac{\sigma_{\phi s} - \frac{1}{2}\sigma_{heL}}{\sigma_{\phi eL} - \frac{1}{2}\sigma_{heL}} + \left(\frac{\sigma_{\theta s}}{\sigma_{heL}}\right)^2 \le 1.0$$

$$\frac{83{,}390 - \frac{1}{2}\times 36{,}772}{710{,}769 - \frac{1}{2}\times 36{,}772} + \left(\frac{27{,}408}{36{,}772}\right)^2 = 0.649 < 1.0 \qquad \text{O.K.}$$

c) Axial compression-plus-shear:

$$\frac{\sigma_{\phi s}}{\sigma_{\phi eL}} + \left(\frac{\sigma_{\phi\theta s}}{\sigma_{\phi\theta eL}}\right)^2 \le 1.0$$

$$\frac{83{,}390}{710{,}769} + \left(\frac{6{,}250}{160{,}011}\right)^2 = 0.119 < 1.0 \qquad \text{O.K.}$$

d) Hoop compression-plus-shear

$$\frac{\sigma_{\theta s}}{\sigma_{reL}} + \left(\frac{\sigma_{\phi\theta s}}{\sigma_{\phi\theta eL}}\right)^2 \le 1.0$$

$$\frac{27{,}408}{36{,}772} + \left(\frac{6{,}250}{160{,}011}\right)^2 = 0.747 < 1.0 \qquad \text{O.K.}$$

<u>Inelastic Buckling</u>

i) Axial compression:

$$\frac{\sigma_{\phi p}}{\sigma_{\phi eL}} \le 1.0$$

$$\frac{206{,}410}{710{,}769} = 0.290 \le 1.0 \qquad \text{O.K.}$$

j) Hoop compression:

$$\frac{\sigma_{\theta p}}{\sigma_{\theta eL}} \le 1.0$$

$$\frac{27{,}408}{36{,}772} = 0.745 < 1.0 \qquad \text{O.K.}$$

k) Axial compression-plus-shear:

$$\left(\frac{\sigma_{\phi p}}{\sigma_{\phi eL}}\right)^2 + \left(\frac{\sigma_{\phi\theta p}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

$$\left(\frac{206{,}410}{710{,}769}\right)^2 + \left(\frac{6{,}250}{160{,}011}\right)^2 = 0.086 < 1.0 \qquad \text{O.K.}$$

l) Hoop compression-plus-shear

$$\left(\frac{\sigma_{\theta p}}{\sigma_{reL}}\right)^2 + \left(\frac{\sigma_{\phi\theta p}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

$$\left(\frac{27{,}408}{36{,}772}\right)^2 + \left(\frac{6{,}250}{160{,}011}\right)^2 = 0.557 < 1.0 \qquad \text{O.K.}$$

## 6.0 SUMMARY & CONCLUSIONS

The results of the buckling evaluation of the 3-60B Cask are summarized in Table 2. It is observed from the table that all the stress combination requirements of the ASME Code Case N-284 are satisfied by the cask inner shell for the NCT and HAC loading conditions for the combination of maximum stress components arising under all the operating environments. Therefore, it is concluded that buckling will not occur as the result of any normal or accident condition loading and the buckling requirement of Paragraph C.5 of Regulatory Guide 7.6 is satisfied.

**Table 1**

Maximum Compressive Stress Components in the Inner Shell
Under Various NCT & HAC Drop Orientation & Environments

| Condition | Orientation | Environment | $S_y$ (psi) | $S_z$ (psi) | $S_{yz}$ (psi) |
|---|---|---|---|---|---|
| NCT | End | Hot | 112.5 | -1,035 | -0.1098 |
| | | Cold-1 | -5,800 | -14,437 | -0.3013 |
| | | Cold-2 | -9,195 | -18,494 | -0.2798 |
| | Side | Hot | -847.39 | -2,724 | -60.848 |
| | | Cold-1 | -7,733 | -12,520 | -3.864 |
| | | Cold-2 | -10,718 | -15,416 | -9.063 |
| | Corner | Hot | -460.1 | -1,527 | -1,590 |
| | | Cold-1 | -6,780 | -12,845 | -1,519 |
| | | Cold-2 | -10,094 | -16,487 | -1,441 |
| HAC | End | Hot | -183.6 | -12,577 | -1.587 |
| | | Cold-1 | -5,039 | -31,241 | -0.7761 |
| | | Cold-2 | -8,435 | -35,285 | -0.8368 |
| | Side | Hot | -3,555 | -17,725 | 2.068 |
| | | Cold-1 | -13,327 | -29,549 | 1.245 |
| | | Cold-2 | -16,363 | -33,136 | 0.3436 |
| | Corner | Hot | -1,308 | -7,292 | -3,731 |
| | | Cold-1 | -7,901 | -20,975 | -3,691 |
| | | Cold-2 | -11,113 | -24,709 | -3,557 |

Reference: Analyses of ST-504 (Reference 3).

**Table 2**

3-60B Cask Inner Shell Summary of the Interaction Ratios

| | Interaction | NCT | HAC |
|---|---|---|---|
| Elastic | Axial Compression + Hoop Compression [Code Case N-284, 1713.1.1 (b)] | 0.599 | 0.649 |
| | Axial Compression + Shear [Code Case N-284, 1713.1.1 (c)] | 0.0924 | 0.119 |
| | Hoop Compression + Shear [Code Case N-284, 1713.1.1 (d)] | 0.729 | 0.747 |
| Inelastic | Axial Compression [Code Case N-284, 1600] | 0.138 | 0.290 |
| | Hoop Compression [Code Case N-284, 1600] | 0.729 | 0.745 |
| | Axial Compression + Shear [Code Case N-284, 1713.2.1 (a)] | 0.0196 | 0.086 |
| | Hoop Compression + Shear [Code Case N-284, 1713.2.1 (b)] | 0.532 | 0.557 |

Acceptable Values are ≤ 1.0

Appendix 1

Print-Out of the Stress Data for Various Loading Conditions

(Reference 3)

(11 Pages)

```
***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 11.0SP1  *****
ANSYS Mechanical/Emag
00222442          VERSION=WINDOWS x64   16:26:56  JUN 18, 2009 CP=      3.266

1-ft End Drop - Cold Condition (No Decay Heat)


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

ENTER  /SHOW,DEVICE-NAME  TO ENABLE GRAPHIC DISPLAY
ENTER  FINISH             TO LEAVE POST1

*** NOTE ***                            CP =       3.266   TIME= 16:26:56
Reading results into the database (SET command) will update the current
displacement and force boundary conditions in the database with the
values from the results file for that load set.  Note that any
subsequent solutions will use these values unless action is taken to
either SAVE the current values or not overwrite them (/EXIT,NOSAVE).

*** NOTE ***                            CP =       3.266   TIME= 16:26:56
An active coordinate system is not zero.
 RSYS= 0 CSYS= 12 DSYS= 0.

ACTIVE COORDINATE SYSTEM SET TO      1  (CYLINDRICAL) Z- CYL. AXIS

RSYS KEY SET TO   1

USE COORDINATE SYSTEM   1 FOR SOLUTION RESULTS


USE LOAD STEP     1  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     1  SUBSTEP=     3  CUMULATIVE ITERATION=    11
  TIME/FREQUENCY=  1.0000
TITLE= 1-ft End Drop - Hot Condition

PRINT S    NODAL SOLUTION PER NODE

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

 LOAD STEP=     1  SUBSTEP=     3
  TIME=    1.0000      LOAD CASE=   0

MINIMUM VALUES
NODE      43831       31790       46753        1870        1870       25832
VALUE   -31.790      112.47     -1034.9     -4.3964    -0.10977     -4.4316

MAXIMUM VALUES
NODE      43713        7870        1870       25870       25870       19713
VALUE   -31.679      147.28     -991.08      4.3968     0.10775     -4.1974


USE LOAD STEP     2  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     2  SUBSTEP=     3  CUMULATIVE ITERATION=    36
  TIME/FREQUENCY=  2.0000
```

```
TITLE= 1-ft End Drop - Cold Condition (Max. Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

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

 LOAD STEP=     2  SUBSTEP=     3
  TIME=    2.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE      19751       22752       10752       25790        1790       22832
VALUE   -123.63     -5799.8     -14437.     -139.44    -0.30127     -12.389

MAXIMUM VALUES
NODE      43832       46832       34831        1790       25790       25790
VALUE   -123.10     -5428.9     -14301.      139.44     0.30086     -11.939


USE LOAD STEP     3  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     3  SUBSTEP=     3  CUMULATIVE ITERATION=    41
  TIME/FREQUENCY=  3.0000
TITLE= 1-ft End Drop - Cold Condition (No Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

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

 LOAD STEP=     3  SUBSTEP=     3
  TIME=    3.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE       7751       22751       22752       25790        1790       22832
VALUE   -196.57     -9195.3     -18494.     -221.06    -0.27977     -11.693

MAXIMUM VALUES
NODE      31832       46832       34831        1790       25790       13790
VALUE   -196.33     -8667.9     -18326.      221.06     0.27974     -10.963


***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 11.0SP1  *****
ANSYS Mechanical/Emag
00222442          VERSION=WINDOWS x64   16:28:12  JUN 18, 2009 CP=      3.219

1-ft Side Drop - Cold Condition (No Decay Heat)


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

ENTER  /SHOW,DEVICE-NAME  TO ENABLE GRAPHIC DISPLAY
ENTER  FINISH             TO LEAVE POST1

*** NOTE ***                            CP =       3.234   TIME= 16:28:12
Reading results into the database (SET command) will update the current
displacement and force boundary conditions in the database with the
values from the results file for that load set.  Note that any
```

```
subsequent solutions will use these values unless action is taken to
either SAVE the current values or not overwrite them (/EXIT,NOSAVE).

*** NOTE ***                            CP =       3.234   TIME= 16:28:12
An active coordinate system is not zero.
 RSYS= 0 CSYS= 12 DSYS= 0.

ACTIVE COORDINATE SYSTEM SET TO      1  (CYLINDRICAL) Z- CYL. AXIS

RSYS KEY SET TO   1

USE COORDINATE SYSTEM   1 FOR SOLUTION RESULTS


USE LOAD STEP     1  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     1  SUBSTEP=     1  CUMULATIVE ITERATION=    12
  TIME/FREQUENCY=  1.0000
TITLE= 1-ft Side Drop - Hot Condition

PRINT S    NODAL SOLUTION PER NODE

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

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

 MINIMUM VALUES
NODE        1790       25832       25870        1790       31790       13833
VALUE    -115.22     -847.39     -2723.6     -36.230     -60.848      4.1833

MAXIMUM VALUES
NODE       37751        1790        1870        7752        4751        1870
VALUE    -27.129      1367.1      8777.0      3.0805      1.7409      10.968


USE LOAD STEP     2  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     2  SUBSTEP=     1  CUMULATIVE ITERATION=    22
  TIME/FREQUENCY=  2.0000
TITLE= 1-ft Side Drop - Cold Condition (Max. Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

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

 LOAD STEP=     2  SUBSTEP=     1
  TIME=    2.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE        1790       43751       25870       25870       28752       13833
VALUE    -224.71     -7733.3     -12520.     -182.91     -3.8640      11.430

MAXIMUM VALUES
NODE       25870        1870        1870        1790       19751        1693
VALUE    -118.81     -5237.3      2059.1      134.81      117.11      18.357
```

```
USE LOAD STEP     3  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     3  SUBSTEP=     1  CUMULATIVE ITERATION=    26
  TIME/FREQUENCY=  3.0000
TITLE= 1-ft Side Drop - Cold Condition (No Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

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

 LOAD STEP=     3  SUBSTEP=     1
  TIME=    3.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE       1790       46751       25870       25870       28753       25752
VALUE   -282.32     -10718.     -15416.     -252.19     -9.0627      37.473

MAXIMUM VALUES
NODE      25832        1870        1870        1790       19753       19832
VALUE   -174.75     -8093.0      256.72      204.73      68.238      47.432


***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 11.0SP1  *****
ANSYS Mechanical/Emag
00222442          VERSION=WINDOWS x64   16:25:55  JUN 18, 2009 CP=      2.656

1-ft Corner Drop - Hot Condition


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

ENTER  /SHOW,DEVICE-NAME  TO ENABLE GRAPHIC DISPLAY
ENTER  FINISH             TO LEAVE POST1

*** NOTE ***                            CP =       2.656   TIME= 16:25:55
Reading results into the database (SET command) will update the current
displacement and force boundary conditions in the database with the
values from the results file for that load set.  Note that any
subsequent solutions will use these values unless action is taken to
either SAVE the current values or not overwrite them (/EXIT,NOSAVE).

ACTIVE COORDINATE SYSTEM SET TO      1  (CYLINDRICAL) Z- CYL. AXIS

RSYS KEY SET TO   1

USE COORDINATE SYSTEM   1 FOR SOLUTION RESULTS


USE LOAD STEP     1  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     1  SUBSTEP=     1  CUMULATIVE ITERATION=    11
  TIME/FREQUENCY=  1.0000
TITLE= 1-ft Corner Drop - Hot Condition

PRINT S    NODAL SOLUTION PER NODE
```

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

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

 MINIMUM VALUES
NODE       1790       25870        1870        1790       13753       25833
VALUE   -67.553     -460.14     -1527.4     -23.755     -1590.0     -9.1219

MAXIMUM VALUES
NODE      46833        1790       25870        7752       25790        1870
VALUE   -33.019      907.87      2192.0      4.4971     -35.234      10.558


USE LOAD STEP     2  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     2  SUBSTEP=     1  CUMULATIVE ITERATION=    23
  TIME/FREQUENCY=  2.0000
TITLE= 1-ft Corner Drop - Cold Condition (Max. Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

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

 LOAD STEP=     2  SUBSTEP=     1
  TIME=    2.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE       1870       40753        1870       25870       37753        1752
VALUE   -160.60     -6780.3     -12845.     -161.12     -1518.9     -26.782

MAXIMUM VALUES
NODE      25832        1790       25790        1870        1870       13752
VALUE   -128.93     -5299.0     -10238.      130.14     -33.689     -14.732


USE LOAD STEP     3  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     3  SUBSTEP=     1  CUMULATIVE ITERATION=    28
  TIME/FREQUENCY=  3.0000
TITLE= 1-ft Corner Drop - Cold Condition (No Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

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

 LOAD STEP=     3  SUBSTEP=     1
  TIME=    3.0000      LOAD CASE=   0

MINIMUM VALUES
NODE       1870       40753        1870       25870       37752        1752
VALUE   -232.19     -10094.     -16487.     -238.18     -1440.8     -25.036

MAXIMUM VALUES
NODE      25832       10832       25790        1790        1870       25870
VALUE   -197.84     -8616.2     -14410.      206.65     -30.338     -9.0511
```

```
***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 11.0SP1  *****
ANSYS Mechanical/Emag
00222442          VERSION=WINDOWS x64   16:23:51  JUN 18, 2009 CP=      3.172

30-ft End Drop - Cold Condition (No Decay Heat)


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

ENTER  /SHOW,DEVICE-NAME  TO ENABLE GRAPHIC DISPLAY
ENTER  FINISH             TO LEAVE POST1

*** NOTE ***                            CP =       3.172   TIME= 16:23:51
Reading results into the database (SET command) will update the current
displacement and force boundary conditions in the database with the
values from the results file for that load set.  Note that any
subsequent solutions will use these values unless action is taken to
either SAVE the current values or not overwrite them (/EXIT,NOSAVE).

*** NOTE ***                            CP =       3.172   TIME= 16:23:51
An active coordinate system is not zero.
 RSYS= 1 CSYS= 12 DSYS= 0.

ACTIVE COORDINATE SYSTEM SET TO      1  (CYLINDRICAL) Z- CYL. AXIS

RSYS KEY SET TO   1

USE COORDINATE SYSTEM   1 FOR SOLUTION RESULTS


USE LOAD STEP     1  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     1  SUBSTEP=     1  CUMULATIVE ITERATION=     6
  TIME/FREQUENCY=  1.0000
TITLE= 30-ft End Drop - Hot Condition

PRINT S    NODAL SOLUTION PER NODE

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

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

 MINIMUM VALUES
NODE        7790       40751       31753       25790       16753        1833
VALUE    -40.194     -183.58     -12577.     -3.6271     -1.5866     -8.3154

MAXIMUM VALUES
NODE        1790        7870        7870        1790       46753        4751
VALUE    -34.414     -123.52     -12517.      3.6580      2.7845     -3.3607


USE LOAD STEP     2  SUBSTEP     0  FOR LOAD CASE 0
```

```
SET COMMAND GOT LOAD STEP=      2  SUBSTEP=      1  CUMULATIVE ITERATION=     19
  TIME/FREQUENCY=  2.0000
TITLE= 30-ft End Drop - Cold Condition (Max. Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

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

 LOAD STEP=      2  SUBSTEP=      1
  TIME=    2.0000      LOAD CASE=    0

 MINIMUM VALUES
NODE        1870        19752         1752        25790         1790        25752
VALUE    -104.64      -5039.0      -31241.      -121.25     -0.77611      -31.252

MAXIMUM VALUES
NODE        1790        28832        31832         1790        25790        28870
VALUE    -103.73      -4693.5      -31056.       121.25      0.77515      -30.321


USE LOAD STEP     3  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=      3  SUBSTEP=      1  CUMULATIVE ITERATION=     22
  TIME/FREQUENCY=  3.0000
TITLE= 30-ft End Drop - Cold Condition (No Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

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

 LOAD STEP=      3  SUBSTEP=      1
  TIME=    3.0000      LOAD CASE=    0

 MINIMUM VALUES
NODE       25870        31752        25752        25790         1790        28752
VALUE    -182.43      -8434.6      -35285.      -202.73     -0.83680      -33.666

MAXIMUM VALUES
NODE       40832        16832        13832         1790        25790         4870
VALUE    -182.27      -7950.6      -35129.       202.73      0.84711      -32.545


***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 11.0SP1  *****
ANSYS Mechanical/Emag
00222442          VERSION=WINDOWS x64   16:24:48  JUN 18, 2009 CP=      3.109

30-ft Side Drop - Cold Condition (No Decay Heat)


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

ENTER  /SHOW,DEVICE-NAME  TO ENABLE GRAPHIC DISPLAY
ENTER  FINISH             TO LEAVE POST1

*** NOTE ***                            CP =       3.109   TIME= 16:24:48
Reading results into the database (SET command) will update the current
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```
displacement and force boundary conditions in the database with the
values from the results file for that load set.  Note that any
subsequent solutions will use these values unless action is taken to
either SAVE the current values or not overwrite them (/EXIT,NOSAVE).

*** NOTE ***                            CP =       3.109   TIME= 16:24:48
An active coordinate system is not zero.
 RSYS= 0 CSYS= 12 DSYS= 0.

ACTIVE COORDINATE SYSTEM SET TO      1  (CYLINDRICAL) Z- CYL. AXIS

RSYS KEY SET TO   1

USE COORDINATE SYSTEM   1 FOR SOLUTION RESULTS


USE LOAD STEP     1  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     1  SUBSTEP=     1  CUMULATIVE ITERATION=    11
  TIME/FREQUENCY=  1.0000
TITLE= 30-ft Side Drop - Hot Condition

PRINT S    NODAL SOLUTION PER NODE

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

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

 MINIMUM VALUES
NODE       1790       25831       25870        1790       25790       13870
VALUE   -358.91     -3555.4     -17725.     -178.51      2.0680     0.63220

MAXIMUM VALUES
NODE      37753        1790        1870        7713       22753       25713
VALUE    8.4213      6941.6      27427.      13.240      807.50      27.800


USE LOAD STEP     2  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     2  SUBSTEP=     1  CUMULATIVE ITERATION=    18
  TIME/FREQUENCY=  2.0000
TITLE= 30-ft Side Drop - Cold Condition (Max. Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

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

 LOAD STEP=     2  SUBSTEP=     1
  TIME=    2.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE       1790       25870       25870       25870       25790       13833
VALUE   -550.64     -13327.     -29549.     -325.25      1.2447     -5.6047

MAXIMUM VALUES
NODE      37753        1870        1870        1790       22752        1870
```

```
VALUE   -158.06     -3300.6      21007.      77.588      851.09      20.412


USE LOAD STEP     3  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     3  SUBSTEP=     1  CUMULATIVE ITERATION=    21
  TIME/FREQUENCY=  3.0000
TITLE= 30-ft Side Drop - Cold Condition (No Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

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

 LOAD STEP=     3  SUBSTEP=     1
  TIME=    3.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE       1790       25870       25870       25870       25790       13833
VALUE   -622.39     -16363.     -33136.     -398.34     0.34364      3.7155

MAXIMUM VALUES
NODE      37753        1870        1870        1790       22752        1870
VALUE   -223.08     -6468.0      19042.      161.15      821.27      27.999


***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 11.0SP1  *****
ANSYS Mechanical/Emag
00222442          VERSION=WINDOWS x64   16:22:13  JUN 18, 2009 CP=      3.000

30-ft Corner Drop - Cold Condition (No Decay Heat)


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

ENTER  /SHOW,DEVICE-NAME  TO ENABLE GRAPHIC DISPLAY
ENTER  FINISH             TO LEAVE POST1

*** NOTE ***                            CP =       3.000   TIME= 16:22:13
Reading results into the database (SET command) will update the current
displacement and force boundary conditions in the database with the
values from the results file for that load set.  Note that any
subsequent solutions will use these values unless action is taken to
either SAVE the current values or not overwrite them (/EXIT,NOSAVE).

*** NOTE ***                            CP =       3.000   TIME= 16:22:13
An active coordinate system is not zero.
 RSYS= 0 CSYS= 12 DSYS= 0.

ACTIVE COORDINATE SYSTEM SET TO      1  (CYLINDRICAL) Z- CYL. AXIS

RSYS KEY SET TO   1

USE COORDINATE SYSTEM   1 FOR SOLUTION RESULTS


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

```
SET COMMAND GOT LOAD STEP=     1  SUBSTEP=     1  CUMULATIVE ITERATION=     6
  TIME/FREQUENCY=  1.0000
TITLE= 30-ft Corner Drop - Hot Condition

PRINT S    NODAL SOLUTION PER NODE

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

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

 MINIMUM VALUES
NODE       4752       25870        1870        1790       13751        7751
VALUE   -160.15     -1307.6     -7292.4     -55.077     -3731.4     -24.102

MAXIMUM VALUES
NODE      37752        1790       25790        4752       25790        4832
VALUE   -26.915      2246.0      631.81      15.764     -80.850      31.292


USE LOAD STEP     2  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     2  SUBSTEP=     1  CUMULATIVE ITERATION=    19
  TIME/FREQUENCY=  2.0000
TITLE= 30-ft Corner Drop - Cold Condition (Max. Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

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

 LOAD STEP=     2  SUBSTEP=     1
  TIME=    2.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE       1870       25870        1870       25870       13753        7713
VALUE   -201.26     -7901.4     -20975.     -191.34     -3690.5     -47.008

MAXIMUM VALUES
NODE      37833        1790       25790        1870       25790       25870
VALUE   -128.08     -4204.4     -13185.      116.85     -88.245     -20.825


USE LOAD STEP     3  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     3  SUBSTEP=     1  CUMULATIVE ITERATION=    24
  TIME/FREQUENCY=  3.0000
TITLE= 30-ft Corner Drop - Cold Condition (No Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

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

 LOAD STEP=     3  SUBSTEP=     1
  TIME=    3.0000      LOAD CASE=   0

 MINIMUM VALUES
```

| | | | | | | |
|---|---|---|---|---|---|---|
| NODE | 1870 | 25870 | 1870 | 25870 | 13753 | 7713 |
| VALUE | -271.34 | -11113. | -24709. | -268.53 | -3557.1 | -45.552 |

MAXIMUM VALUES

| | | | | | | |
|---|---|---|---|---|---|---|
| NODE | 13870 | 1790 | 25790 | 1870 | 25790 | 25870 |
| VALUE | -200.65 | -7466.4 | -17489. | 192.38 | -86.722 | -17.783 |