factors for all loading conditions (basket baseline g loads are provided in Section 2.7.1 of Chapter 2) except for the slapdown impact when the ambient condition is -20 °F. For the -20 °F ambient conditions, the top and bottom portions of the basket are at lower temperatures than the temperatures used in the buckling analyses and lower temperature will increase the buckling load. The average temperatures in the basket periphery for each condition are provided in the table below. The temperature dependent material properties for SA-240 Gr. 304 and SB-209 6061-T651 at these temperatures are interpolated from data provided in Table 2.10.5-1. It is seen that the Young's modulus for SA-240 Gr. 304 and SB-209 6061-T651 increase by 2.2% and 4.4%, respectively, when the temperature decreases from 330 °F to 210 °F. Also the yield strength for SA-240 Gr. 304 and SB-209 6061-T651 increase by 15.7% and 31.0%, respectively, when the temperature decreases from 330 °F to 210 °F.

The effect of basket temperature on the buckling load is evaluated using the results from limit load tests presented in Section 2.10.5.5.3. The limit load tests were performed at room temperature (70 °F) as well as elevated temperatures (365 to 529 °F). It is seen that because of the higher Young's modulus and yield strength at lower temperatures, the load at collapse for the tests performed at room temperature is much higher then the load at collapse for higher temperature. Using the test results from Section 2.10.5.5.3:

Average load at collapse at room temperature: 13,777 lb/in.

Average load at collapse at elevated temperature: 10,858 lb/in.

Average elevated temperature: 433 °F

Room temperature: 70 °F

The buckling load is 27% higher for the room temperature tests than at elevated temperature. Assuming a linear relationship the buckling load would increase by 9.4% for a 126 °F decrease in temperature. Therefore, the adjusted buckling load at 210 °F for the -20 °F ambient condition is 96.9 g (88.54 x 1.094).

Therefore, the safety factors for buckling load with its respective g load are:

Ambient Condition	Drop Orientation	Average Temperature in the Basket Periphery[1] (°F)	Average Temperature in the Basket Periphery used in the Analysis (°F)	Lowest Buckling G Load (g)	Baseline G Load (g)	Safety Factor
100 °F	Side drop	336	336	88.5	55	1.61
	Slapdown	312	336	88.5	63	1.40
-20 °F	Side drop	234	336	88.5	63	1.40
	Slapdown	210	210	96.9	72	1.35

[1] The average temperatures in the basket periphery are calculated from the ANSYS results files generated in the Section 3.4 NCT thermal analysis.

Based on the above basket analyses, it is shown that the calculated basket stresses meet the ASME Code allowables. In addition, the minimum safety factor for buckling is 1.35. This buckling safety factor is considered sufficient to assure the structural performance of the basket. The following discussion is provided in support of this conclusion:

1. *The factors of safety required by the ASME code for stainless steel (1.41 to 2.21 as calculated following NUREG/CR-6322 [9]) are based on elastic analysis. As discussed in NUREG/CR-6322, the magnitude of these factors of safety are intended to provide additional conservatism due to the following factors:*

   a. *The analysis approach taken in NUREG/CR-6322 is based on the design practice where the entire structure is designed by sizing the individual members of the assemblies. The compressive load in a member will influence the critical buckling load of not only the member itself but also other adjacent members that are connected to the same structural joint. If the basket design is based on one individual member, then the individual member interacts with other members will not be included.*

      A full 360 degree sector of the basket model with elastic-plastic material and large deflection effects is used to calculate the buckling limit. The full 360 degree basket model takes into account all the interactions among all the basket members.

   b. *A real member may have imperfections that include initial curvature of a member, eccentric loads on initially straight member, and residual stresses due to forming or assembly. These imperfections tend to make the actual failure load lower than the theoretical critical load.*

      The configuration and analysis methodology used for the TN-40 basket tend to mitigate these concerns. First, a sensitivity study (Section 2.10.5.5.2 of the SAR) was performed to evaluate the impact of geometrical imperfections. Based on the study, the buckling load remained the same. It concluded that for this type of basket design (composite structural with fusion welds), the buckling effect due to initial imperfections is minimal. Second, the fuel compartment panels are part of a complete tube such that pressure loads on a horizontal panel will produce bending loads and deflections in the adjoining vertical panels. This in effect imposes an eccentric load that is addressed in the determination of the buckling load.

2. *Buckling evaluations are also addressed in the ASME Section III, Division 3, Subsection WD [10]. The rules in Subsection WD originate from Subsection NG (Core Support Structures) and Subsection NF (Supports) and are intended to be used for transportation and storage basket design. The*

buckling analysis methodology is described in Subsection WD-3229. Subsections WD-3229.2 and 3229.3 describe the analysis of rectangular plates under compressive loading. The allowable compressive stresses given are as follows:

a. *Normal condition:* $F_{normal} = 0.5\ F_{critical}$
b. *Accident condition:* $F_{accident} = 1.5 \times F_{normal} = 1.5 \times 0.5\ F_{critical} = 0.75 \times F_{critical}$

The safety factor for the accident condition is therefore 1/0.75 = 1.33

3. *The yield strengths of stainless steel and aluminum increase at high strain rates comparable to those resulting from a 30 foot drop. The resulting yield stress for stainless material (304/304L) at 300° F is expected to increase approximately 16% to 31% [11]. Thus the basket buckling load and resulting safety factor will increase if the strain rate effects are included in the analyses.*

4. *A conservative fuel weight is also used in the analysis. The total length of the fuel assembly is 161.3 in. as shown in Chapter 1, Section 1.2.3 (page 1-8). For the basket buckling analysis, the fuel weight is distributed over 144 in. of the basket (based on the active fuel length, Section 2.10.5.3.2, page 2.10.5-10). During the slapdown load case (bounding safety factor), the maximum g load occurs at either the top or bottom end of the basket, depending on drop orientation. However, the weights of the fuel assembly at top region (fuel-gas plenum zone and top end fitting zone, 17.68 kg (38.98 lbs), Table 5-4 of Chapter 5) and bottom region (bottom end fitting zone, 7.89 kg (17.39 lbs), Table 5-4 of Chapter 5) is much lower than the fuel assembly weight of an equal length in the active fuel region. Using the same approach as used in the SAR Section 2.10.5.3.2, the fuel pressure load on the basket panels at the ends of the basket are:*

   Basket length = (total length – active fuel region) / 2
   = (160 – 144) / 2 = 8 in

   Pressure = (bounding weight of the top or bottom region) / compartment area
   = 38.98 / (8.14 x 8) = 0.6 psi

   This pressure (0.6 psi) is much smaller than the pressure in the active fuel region (1.109 psi). With this smaller pressure (0.6 psi), the safety factor for the buckling load due to slapdown is approximately 2.5 (1.35 x 1.109/0.6).

In view of the discussion above the calculated minimum safety factor of 1.35 is sufficient to ensure that the basket is capable of withstanding the accident impact loadings.

2.10.5.7 References

1. ANSYS Engineering Analysis System User's Manual, Releases 8.0 and 10.0.
2. ASME Boiler and Pressure Vessel Code, 1989, Section III, Subsection NB, NF & Appendices; Section VIII, Divs I &2.
3. “Aluminum Standards and Data,” The Aluminum Association, Inc., 1976.
4. Prairie Island ISFSI Technical Specification and Safety Analysis Report, Revision 1, 1991.
5. “An Assessment of Stress-Strain Data Suitable for Finite Element Elastic-Plastic Analysis of Shipping Containers” NUREG/CR-0481, SAND77-1872.
6. Kaufman, J. Gilbert, “Properties of Aluminum Alloys: Tensile, Creep, and Fatigue Data at High and Low Temperatures,” 1999.
7. Scavuzzo, R. J., Lam, P. C., Gau, J. S., “Buckling Tests of Fusion Welded Composite Stainless Steel Aluminum Plates,” Dept. of Mechanical Engineering, The University of Akron, May, 1990.
8. Young, Warren C. and Budynas, Richard G., "Roark's Formulas for Stress and Strain," Seventh Edition, McGraw-Hill, New York, 2002.
9. *“Buckling Analysis of Spent Fuel Basket,” NUREG/CR-6322, May 1995.*
10. *ASME Boiler and Pressure Vessel Code, Section III, Division 3, Subsection WD “Internal Support Structures,” Draft, November 2010.*
11. *Dana K. Morton, Robert K. Blandford, Spencer D. Snow, “Impact Testing of Stainless Steel Material at Cold Temperatures,” PVP2008-61215.*