Project No. M-50

DEC 11 1990

General Nuclear Systems, Inc.
ATTN: Charles Witt
220 Stoneridge Drive
Columbia, SC 29210

Gentlemen:

SUBJECT: STRUCTURAL QUESTIONS CONCERNING THE GNS CASTOR X TSAR, REVISION 4.

REFERENCE: Topical Safety Analysis Report (TSAR) for the CASTOR X Cask for an Independent Spent Fuel Storage Installation (Dry Storage), Revision 4.

Revision 4 to the GNS CASTOR X TSAR referenced above was received September 14, 1990. Revision 4 was our first opportunity for a complete review of the CASTOR X TSAR for structural content with a complete description of the impact limiter and its method of attachment along with the correct dimensions of the cask components. The review covers all the information contained in the TSAR and its revision referenced above. The review indicates several critical areas that cause safety concerns which should be resolved before the review proceeds further. Some of these safety concerns were related to General Nuclear Systems, Inc. (GNSI) by telephone on October 25, 1990.

The attached discussion and comments provide further information about these concerns and a few new findings. The critical issues are related to the tipover and the 15-inch drop accident analyses. The present GNSI structural analysis of the tipover accident is not conservative. A corrected analysis would show stress limits specified by GNSI in the TSAR to be exceeded in the basket and in the cask body.

A discussion of the non-conservatisms can be found in the enclosure. If you have any question about our comments, please contact Jim Schneider at (301) 492-0692.

Sincerely,

Original Signed by
John P. Roberts

John P. Roberts, Section Leader
Irradiated Fuel Section
Fuel Cycle Safety Branch
Division of Industrial and
Medical Nuclear Safety, NMSS

Enclosure: As stated

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ENCLOSURE

DISCUSSION AND COMMENTS ON THE CASTOR X CASK TSAR REVISION 4,
STRUCTURAL ANALYSIS WITH IMPACT LIMITER

The present GNSI structural analysis of the tipover accident is not conservative. The non-conservatism is caused by one or more of the following: (a) the use of a uniaxial stress property (the flow stress) to estimate the impact pressure existing in the impact limiter (see Item 2 below for further explanation), (b) the use of a lower impact acceleration load for stress analysis (Item 1), (c) the use of a tensile stress limit to check compressive stress levels (Item 5), (d) the use of an inadequate analysis model (Item 6), and (e) the use of non-conservative tensile stress limits for the ductile cast iron (Item 2). The problem with the cask body is due to (a) and (e). The problem with the basket is due to (b), (c), and (d). The specific issues with the analyses are detailed below.

1. Even with the protection of the aluminum impact limiter, the impact acceleration of 52 g used in the GNSI basket tipover impact analysis is unrealistically low. A detailed dynamic impact analysis conducted by Lawrence Livermore National Laboratory (LLNL) using the DYNA3D finite element program predicts an acceleration of 70 g at the impact limiter section of the cask and 83 g at the cask top. GNSI's own rigid body impact analysis on page 8.2-14 indicates even higher accelerations (three times 41 g at the cask top). GNSI's prediction would have been even higher if it did not underestimate the pressure in the impact limiter at the point of impact. GNSI's impact analysis contains two other major errors. First, the impact limiter force is applied at the cask top and not at the actual location of the limiter, which is about 40 inches from the top. Second, the total cask length is taken to be 88 inches instead of the actual length of 188 inches. Nevertheless, these errors do not change the conclusion that the 52 g used for the basket stress analysis is low.

2. As pointed out in the preceding paragraph, the GNSI tipover analysis uses a low impact pressure which is set equal to the uniaxial stress of the impact limiter material. In the actual impact, the pressure at the impact point can be appreciably higher than the uniaxial stress, or flow stress, because the lateral movement of impact limiter material is constrained not only by the material's own inertia, but also by the friction between the impact limiter and its neighbors. The state of stress at the impact point is different than the one dimensional stress assumed in the GNSI analysis. Using a nominal coefficient of friction of 0.6 between the impact limiter and the cask exterior surface, but no friction between the limiter and the unyielding ground, LLNL finds from a tipover analysis using DYNA that the average impact pressure is more than two times the 26 ksi estimated by GNSI using the uniaxial stress properties of the material. The DYNA analysis also indicates a smaller impact area than GNSI assumes (a 90 degree sector of the impact limiter) for its impact-stress analysis of the cask body. If the

higher impact pressure and lower impact area, both predicted by the DYNA impact analysis, had been used by GNSI, the same GNSI stress analysis of the cask body would have given a higher axial tensile stress for the cask wall located behind the impact point.

Also, GNSI uses a higher stress limit to compare with this underestimated calculated stress. GNSI considers this cask stress to be a membrane stress caused by an accident condition, and its value should be kept below 0.7 times the tensile strength of the ductile cast iron material. This GNSI stress limit is higher than the 0.5 times the tensile strength which was recommended by LLNL to NRC for the analysis of transportation casks made of ductile cast iron (NUREG/CR-3760 by M. W. Schwartz, January 1986). If the LLNL recommended criterion is used, the stress limit will be lowered to 21.6 ksi, which is already exceeded by the present low GNSI estimate of the cask body stress of 23.66 ksi. However, LLNL also considers it to be appropriate for GNSI to change its original classification of this particular stress of the cask body from a primary to a bending stress, which is allowed a limit 1.5 times higher than a membrane stress, i.e., 0.75 times the tensile strength of the material. Thus, the effect of GNSI's use of a less conservative stress criterion for the ductile cast iron may be neutralized for this particular stress. However, it is recommended that the more conservative NUREG/CR-3760 stress criteria be adopted for the casks body and all stresses in the cask body be reevaluated against the new criteria.

The LLNL DYNA impact analysis also shows a very high strain of the impact limiter at the point of impact. The strain reaches a value of 72 percent, which is much larger than the rupture strain of the material under uniaxial tension that is about 18 percent. Although the large impact strain occurs mainly under a hydrostatic compression, which is known to produce strain without failure, the strain's high magnitude cast doubts about the integrity of the impact limiter. This fact and the others described earlier appear to provide sufficient evidence that the present impact limiter is not adequate for the tipover accident.

3. In addition to the tipover analysis discussed in the foregoing paragraphs, the TSAR contains another analysis of tipping onto a trunnion. Similar to the analysis of tipping onto the impact limiter, this analysis also uses a uniaxial stress property to estimate the impact pressure. Accordingly, it is very likely that this analysis also underpredicts the impact stress in the cask wall. To avoid similar difficulties that the impact limiter has encountered, it is suggested that the impact limiter be designed to also protect the trunnion.

4. In GNSI's basket stress analysis, if the assumed 52 g tipover impact acceleration is replaced with the higher accelerations (70 to 80 g) predicted by the DYNA analysis, the analysis will show the GNSI

specified basket stress limits to be exceeded in more than a few components of the basket. Even for the 52 g acceleration, GNSI's results presented in Table 8.2-2a (page 8.2-44 and 44.1) for the X/33 basket already show the stress limit is exceeded in Gusset 20x60x200. It is unclear to LLNL why the basket was not redesigned to eliminate this over-stress condition.

5. The stress limits specified by GNSI for the basket tipover analysis are adequate only for preventing ductile failures involving large or progressively increasing plastic deformations. The limits do not address buckling failures which can occur in the basket under the compressive impact stress. To check buckling, a different set of stress limits must be used which is based on the buckling strength of each of the basket structural components. The buckling or compressive stress limits will depend not only on the properties of the structural material, but also on the geometry of the structure. The ASME BPV Code Section III Subsection NB does not provide extensive coverage of the compressive stress limits because buckling is not a prevailing failure mode for the structures discussed therein. However, extensive information on compressive stress limits is given in Subsection NF for the design and analysis of component supports which often fail by buckling. The subsection also provides formulas for determining the stress limits for one-dimensional column-like structures made of austenitic and ferritic stainless steels. For a Level D accident load, the subsection refers to Appendix F of the code, but unfortunately Appendix F does not provide similar information for austenitic steel. Therefore, the reviewers recommend using the Level C limit of Subsection NF for the tipover and the 15-inch drop accident analyses.

   Using this approach, and assuming the column to have hinged ends, the reviewers have found the compressive stress limits of the sleeve and separation plates numbered 1, 2, and 4 (in drawing C110-D-19005-006, sheet 2 of 5) for the X/33 basket to be 0, 6.8, 11.2, and 9.4 ksi, respectively. All these limits are much lower than the tensile stress limit used in the GNSI analysis. (The compressive stress limit of 0 ksi for the sleeve implies that the ASME code does not allow the sleeve to carry any compressive load.) If these compressive stress limits were used in lieu of the tensile stress limits, the GNSI tipover analysis would have shown that both the X/33 and X/28 baskets fail by the tipover accident.

6. If the sleeves are not allowed to bear compressive load, then the present GNSI finite element models for the baskets must be revised to eliminate the sleeves. This revision would weaken the basket model and result in higher stresses showing even less margin of safety for the tipover accident.

7. Load eccentricity or bending moment plays a significant role in buckling. It is possible that the same load applied in a slightly

different direction would cause buckling. Therefore, it is essential that the basket be analyzed with the impact load applied in several additional directions rather than just the two orthogonal directions (0-180 degrees and 90-270 degrees) reported in the GNSI TSAR.

8. Buckling failure is also a concern in the 15-inch end drop accident. Therefore, the stress in the cask body and the basket must be analyzed for buckling. LLNL has also performed a finite-element impact analysis of the 15-inch end drop accident. The analysis results show that the impact response of the cask is dominated by wave motions and that the rigid body acceleration of the cask body is of the order of 200 g. The basket must be shown to survive this severe impact condition without buckling.

   The present GNSI 15-inch drop analysis using the PRONTO 2-D program assumes that the contents mass is uniformly distributed in the cask body. This mass distribution is contrary to the actual situation where all the contents mass is supported by the cask bottom. While the GNSI model provides a conservative prediction of the stress in the cask wall and closure lid, it may underpredict the stress in the cask bottom. The GNSI model may also underpredict the vibration frequencies of the cask body. These effects should be evaluated and reported in the TSAR. Additional plots of other stress components at other locations will help convince readers of the TSAR that only the stresses presented are critical and need evaluation. If contour plots are not available, it will be helpful to have time history plots of the maximum stress intensity at the following locations: the center, the edge, and the mid-point between the center and edge of the cask top and bottom, respectively; the top, the mid-point and the bottom sections of the cask wall.

9. The LLNL 15-inch end drop accident analysis also indicates that the drop would produce a high tensile stress in the primary lid bolts. Therefore, GNSI must provide additional analysis data to assure the safety of this component.

10. For the normal operation condition, a fatigue analysis of the cask wall is reported on page 4.2-26 of the TSAR. A similar analysis of the lid bolts should be carried out, especially in view of the high bending stress reported for the secondary lid bolts.

11. During the tipover, the lid bolts will experience a tensile force because of centrifugal acceleration. This tensile bolt stress should be analyzed for analysis completeness, although the stress is not expected to be critical.

1.1.2.2 Description of Installation

The cask weight given in paragraph 3 on Page 1.1-6 does not include the weight of the impact limiter and the impact limiter collars.

The sum of the primary and secondary lid thicknesses is 338 mm. It is not clear to what the 350 mm dimension in Figure 1.1-3 is referring.

1.2.4 Structural Features

GNSI responds in the 7/24/90 submittal that the "primary lid is not dimensioned on Drawing D501.20-02" and that the primary lid thickness is 258 mm as given in Table 1.2-2. What is the 255 mm dimension referring to in Drawing D501.20-02?

Table 1.2-3 does not include the weight of the impact limiter and the impact limiter collars. This table should be modified to include those weights.

3.2.5.2 Structural Design Criteria

Several different failure criteria are used in the GNSI TSAR. On Pages 3.2-21 through 3.2-23, the allowable primary membrane stresses at room temperature are calculated for the cask components. On Pages 8.2-47 and 8.2-48 of the allowable primary membrane plus bending stresses at elevated temperature (100 degrees Celsius) are calculated for the cask body and primary lid. Failure criteria for the aluminum impact limiter based on normal conditions is included in the 8/14/90 submittal. Finally, the structural design criteria for the cask is listed in Table 3.2-1 and Table 3.2-2. The criteria used for the cask body does not follow the recommendations of NUREG/CR-3760 which applies to ductile cast iron. Please review all the criteria in the TSAR and change the cask body, or ductile cast iron, allowable stresses to reflect the requirements in NUREG/CR-3760 and the elevated temperatures in the cask wall.

3.2.5.3 Material Properties

GNSI provides the elastic properties of the lid material in the 11/1/89 and 3/19/90 submittals. These properties should be added to Table 3.2-3(b).

GNSI responds in the 3/19/90 submittal that the polyethylene moderator material properties are included in Appendix 1, but cannot be found in Appendix 1. Appendix 3 of the TSAR contains the material specifications of other cask components. The material properties should be included in a table in Section 3.2.5.3 since the properties of all the other cask materials are in this section.

GNSI responds in the 3/19/90 submittal that the moderator plugs are fabricated from material specification GGG40. The material properties should be included in a table in Section 3.2.5.3.

GNSI does not provide detailed information about the impact limiter material properties. The material properties of the aluminum ring, impact limiter bolts, and aluminum collar should be provided in Section 3.2.5.3.

3.3.2.2 Activity Release

Using Drawing C501.20-55, the secondary lid does not appear the same in Figure 3.3-5. These figures show a ledge near the bolt circle which does not appear in Drawing C501.20-55. The figures should be modified to show the correct lid geometry. The inter-lid space shown in Figures 3.3-4 and 3.3-5 should be dimensioned in Drawing C501.20-55.

3.3.5.2 Shielding

GNSI responds in the 3/19/90 submittal that "the impact limiter will not be required until the cask has been placed on its pad." The TSAR specifies that the impact limiter will be installed at all times of cask handling and storage. Tables 3.3-10 and 3.3-11 list the installation of the environmental cover, but do not show the installation of the impact limiter. Is the impact limiter installed at the same time as the environmental cover?

4.2.1.1 Cask Body

In Table 4.2-1 GNSI provides the predicted cask body stress components along the cask orthogonal axes due to pressure loading. In order to use ASME stress criteria, stress intensities or Tresca stresses must be computed based on the orthogonal stress components. What is the maximum stress state in the cask body due to the applied pressure?

The figure on Page 4.2-6 does not show the impact limiters. Is the cas[illegible] shipped with the impact limiters and if so, how do the impact limiter[illegible] [illegible]fect the cask body stress calculations due to shipping and handling load[illegible] Please discuss the difference in height between the shipping saddle, the [illegible] trunnions, and the cask impact limiter.

GNSI responds in the 11/1/89 and 3/19/90 submittals that not[illegible] [illegible]re added on pages 4.2-7 and 4.2-9 concerning the weight of the cask, but these notes cannot be found. The notes should refer to the fact that the mass given on these pages includes the weight of the impact limiter.

GNSI responds in the 11/1/89 and 3/19/90 submittals that the moment arm is 105 mm because the width of the bearing surface is 90 mm and the distance to the back face of the trunnion is an additional 60 mm (see Figure 4.2-43). The sum of 90 mm and 60 mm is 150 mm, not 105 mm. Please review.

Figure 4.2-3 shows a stepped ledge in the cask wall in which the trunnion rests. Referring to Figure 4.2-43, the 3/19/90 submittal notes that the "surface delineated by II in this figure fits flush against the cask body outer surface." Does the trunnion fit flush to the cask wall or not? If not, what are the engagement lengths of the trunnion into the steps of the ledge? By referring to Figure 4.2-43, it appears that the inner ledge step length is greater than 25 mm due to the 25 mm trunnion lip which appears to rest in the cask wall.

GNSI responds in the 11/1/89 and 3/19/90 submittals that there is approximately one-inch of bearing area between the cask and the trunnion base. What shear area (units of square inches) is GNSI referring to?

4.2.1.2 Analysis of Primary Lid

Is the 3 g shipping and handling load applied as an inertial load or as a concentrated force in the ANSYS analysis? If it is a concentrated force, what weight is used for calculating that force?

GNSI responds in the 11/1/89 and 3/19/90 submittals that the preload pressure in the ANSYS model is 8,750 psi. With a temperature difference of 316 degrees F, a bolt elastic modulus of 28 x 10^6 psi (see 11/1/89 GNSI submittal), and a coefficient of thermal expansion of 7 x 10^{-6}, LLNL calculates the bolt stress to be about 60,000 psi. Please review.

Is the bolt stress due to thermal expansion of 8,750 psi modeling the preload force or the preload and gasket forces? If it is modeling both the preload and gasket forces, how is the 8,750 psi accounting for both loads?

GNSI responds in the 11/1/89 and 3/19/90 submittals the elastic modulus of the lid is changed in the ANSYS analysis to account for the "bolt-hole" area. Should the modulus be changed? The bolts will have a stiffening effect at the bolt circle diameter and it is expected that the lid will flex less in this area, not more. GNSI notes in the submittals that the lid will flex more in that area.

Figure 4.2-10 should be modified to show the correct lid thickness.

The labels in Table 4.2-3 do not match the description of the analyses. Case 1 should refer to 7 bar + 3g (up) and Case 2 should refer to 6.2 bar + 3g (down). Please review.

4.2.1.3 Analysis of the Secondary Lid

Is the 3 g shipping and handling load applied as an inertial load or as a concentrated force in the ANSYS analysis? If it is a concentrated force, what weight is used for calculating that force?

GNSI responds in the 11/1/89 and 3/19/90 submittals that the preload pressure in the ANSYS model is 12,465 psi. With a temperature difference of 226 degrees F, a bolt elastic modulus of 28 x 10^6 psi (see 11/1/89 GNSI submittal), and a coefficient of thermal expansion of 7 x 10^{-6}, LLNL calculates the bolt stress to be about 44,000 psi. Please review.

GNSI responds in the 11/1/89 and 3/19/90 submittals the elastic modulus of the lid is changed in the ANSYS analysis to account for the "bolt-hole" area? Should the modulus be changed? The bolts will have a stiffening effect at the bolt circle diameter and it is expected that the lid will flex less in this area, not more. GNSI notes that the lid will flex more in that area.

The labels in Table 4.2-4 do not match the description of the analyses. Case 1 should refer to 6 bar + 3g UP, and Case 2 should refer to 6 bar + 3g UP + TEMP. Please review.

4.2.1.4.1 Structural Analysis Normal Handling

GNSI responds in the 11/1/89 and 3/19/90 submittals that vertical loading was not analyzed in the X/33 basket since vertical loads do not cause the fuel rods to bear on the sleeves. Vertical loads can cause buckling failure and this needs to be addressed. At the accelerations due to the 15-inch end drop and tipover accident, the buckling loads must be addressed.

GNSI responds in the 11/1/89 submittal that each "component is evaluated at the orientation at which it must carry the most load and/or experience the largest bending moments." There are no results or calculations which substantiate the GNSI claim. For the tipover and end drop, the buckling loads may determine failure and they are different at different cask orientations. All the possible drop orientations (0, 15, 30, and 45 degrees for example) need to be strictly accounted for.

GNSI responds in the 11/1/89 and 3/19/90 submittals that vertical loading was not applied to the X/28 basket since there is no end plate. GNSI states that the "only load the basket will experience is due to its own weight bearing on the end of the cask. This load is much less severe than the lateral load and would not tend to cause any structural failure." Vertical loads can cause buckling failure and this needs to be addressed. At the accelerations due to the 15-inch end drop and tipover accident, the buckling loads must be addressed.

What are the shear loads in the M12 bolts in the X/33 basket? These loads are due to the acceleration from a tipover or side impact.

4.2.1.5 Calculation of the Primary Lid Bolts

Please provide further details concerning the gasket used with the primary lid. Specifically, how is the gasket parameter of KD < 500 N/mm, which is given on Pages 4.2-96 and 4.2-101 determined?

GNSI responds on Page 4.2-94 that a stud-nut alternative may be used for the primary lid bolts. When is this alternative used and how does it affect the cask assembly procedures?

GNSI calculates the bolt preload as 1.01×10^5 N in Table 4.2-7 not 500 N/mm as listed on Page 3.2-28. Please review.

What distance is the bolt hole tapped into the cask body? Is the bolt hole which is dimensioned as M52 in Figure C501.20-20 a through-hole for the bolts? If so, how is the stud-nut arrangement assembled?

4.2.1.6 Calculation of the Secondary Lid Bolts

GNSI calculates the bolt preload as 85,351 N in Table 4.2-9 not 500 N/mm as listed on Page 3.2-28. Please review.

What distance is the bolt hole tapped into the cask body? Is the bolt hole which is dimensioned as M39 in Figure C501.20-55 a through-hole for the bolts? If so, how is the stud-nut arrangement assembled?

On Page 4.2-100 the seal gas pressure is listed as p bar, instead of 6 bar. Please review.

4.2.1.7 Calculation of Trunnions

GNSI responds in the 11/1/89 and 3/19/90 submittals that the lever arm is 45 mm. For a conservative analysis, LLNL recommends a lever arm of 150 mm (90 mm plus 60 mm, see 4th paragraph in Section 4.2.1.1 of this report).

GNSI responds in the 11/1/89 and 3/19/90 submittals that the hole radius has been corrected to 62.5 mm and that the calculations were modified. Revision 2 does not show this correction on page 4.2-109 or in the analysis on the following pages.

GNSI responds in the 11/1/89 and 3/19/90 submittals that stress levels corresponding to 1.0 g are presented since the dynamic load factor is 1.42. Why are the stress levels at 1 g provided considering that the applied loads are at levels greater than 1 g?

GNSI responds in the 11/1/89 and 3/19/90 submittals that the "von-mises stresses in the lifting device are compared with the membrane stress allowable values." This does not satisfy the shear stress criteria in Section 3.2-9 which is listed as: shear stress < 0.6 Sm / 3. Additionally, Von Mises stress is not applicable for ASME criteria since the ASME criteria is based on Tresca stress limits.

GNSI responds in the 11/1/89 and 3/19/90 submittals that the lever arm is 105 mm. The sum of 90 mm and 60 mm is 150 mm, not 105 mm (see 4th paragraph in Section 4.2.1.1 of this report). Please review.

In calculating the bolt force due to load on the trunnion, how does the tightening torque, MA, relate to the maximum bolt force during crane transport, Fsmax?

5.1.2 Flow Sheets

GNSI responds in the 3/19/90 submittal that "the impact limiter will only be necessary once the cask is in place at the storage area." The TSAR specifies that the impact limiter will be installed at all times of cask handling and storage. Is the impact limiter installed before being handled and then kept on the cask for storage?

7.3.2.2.1 Shielding Calculation

Why isn't the 5 mm step height in the secondary lid referred to by GNSI shown in Drawing C501.20-55?

8.2.1.2.3 Accident Drop and Tip-Over Analysis

GNSI describes revisions to the cask handling procedures in the 3/19/90 submittal, but the paragraph is not complete. It ends with the phrase, "The aluminum ring is designed to be an integral." Where is the rest of the GNSI response?

GNSI does not consider the effects on the lids or the lid bolts of the accelerations from the 15-inch end drop and the tipover accident. The lid analyses contained in the TSAR only pertain to the 3 g shipping and handling loads. These analyses need to be scaled to the accident accelerations.

Dynamic amplification effects between the cask and basket need to be considered. If these effects are large, the accelerations on the basket components will be higher than that predicted by the cask accident analyses.

8.2.1.2.3.1 Tipover Analysis

On Page 8.2-11 the reference to Figure 3 should be changed to Figure 8.2-3.

The information provided by GNSI concerning the impact limiters is not consistent between the third revision and the submittals listed earlier. GNSI does not provide detailed design drawings of the impact limiter and of its attachment to the cask body, instead GNSI provides schematic drawings of the impact limiter and its dimensions (Figures 8.2-1A and 8.2-1B of Revision 3, Figure 1.1-3 in the 7/24/90 submittal, and the figure in the 8/14/90 submittal). One or two drawings which all the information in the listed drawings would have been helpful. Figure 1.1-3 of Revision 2, which shows the entire Castor X cask, does not contain the impact limiters like the figure in the 7/24/90 submittal. There is a dimensional inconsistency between Figure 8.2-1A of Revision 3 which gives the inside radius of the impact limiter as 47.25 inches and Figure 1.1-3 of Revision 2 which gives the outside radius of the cask as 47.165 inches. Additionally, GNSI does not provide detailed material specifications for the aluminum impact limiter and the impact limiter bolts as is done for the other cask components in Table 3.2-3 of Revisions 0 and 2. Besides confusion with the drawings, the design of the impact limiters is different in the two submittals and the third revision. GNSI responds in the 7/24/90 submittal that the impact limiter has three segments and that the segments are clamped together by butt joints with 4 bolts at each joint. Figure 8.2-1A of Revision 3 and the 8/14/90 submittal both show that the impact limiter has only two segments that are clamped together by lap joints with 4 bolts at each joint.

Contained in the 8/14/90 submittal are detailed calculations concerning the design of the impact limiter and its trunnion collar. The shear stress analysis for the collar is not understood, especially since the stress is found on a plane inclined to the plane of interest. There are also calculations concerning the weld between the trunnion collar and the aluminum impact limiter. The weld drawings are inadequate for verification analyses and GNSI does not provide justification for the allowable stress limits in the base material. After the weld analysis, the limiting moment, Mo in the limiter is calculated based on a formula which cannot be verified. Shear contributions are not considered in the GNSI analysis either and they should be. Finally, GNSI provides calculations concerning the bolts holding the impact limiter segments together. These calculations do not account for the tipover accident loads and do not provide information concerning the preload and torque requirements as is done in other bolt analyses contained in the TSAR. Detailed dimensions showing the location of the bolts relative to the impact limiter and the cask components are also not provided in Revision 3 or the submittals.

8.2.1.2.3.2 15-Inch Drop Analysis

GNSI uses a "bilinear stress-strain curve ... with a strain-hardening rate inferred from" elastic-plastic material properties. In order to use the failure criteria in the ASME Boiler and Pressure Vessel Code, linear elastic material properties must be used for the cask components. Additionally, the ASME criteria is based on comparing calculated stress intensities with allowable stress limits. On Pages 8.2-31 and 8.2-32 G limits and stress intensities must be computed at the areas of interest and these intensities can then be compared to ASME limits.

GNSI incorrectly references Table 3.2-41 (a) on Page 8.2-31 as the source for the accident condition allowable stress while the reference is actually on Page 8.2-47.

Referring to Table 1.2-3, the cask weight is greater than 236,000 lbs as given on Page 8.2-30.

Figure 8.2-16 shows the natural frequencies and mode shapes for the cask. It is not clear from the description on Page 8.2-31 whether or not the cask is supported for the frequency analysis and how it was determined that "the highest frequency of interest for the bottom head is less than 1,000 Hz (848 to be exact)." It is expected that the frequency analysis was done for an unsupported cask and if so, the effects of supporting the cask must be reviewed. Typically, constraining or supporting the cask along the bottom surface would cause the frequencies to shift downward and the motion of the cask bottom would be much less than that shown in Figure 8.2-16. There is also no description or determination of the displacement amplitudes at each mode and of the forcing function used to determine the mode shapes. For most structures in an impact calculation, the energy is contained within the first fundamental modes.

A reflected tensile wave passes through the cask after the peak acceleration. This tensile wave places a large tensile load on the primary and secondary lid bolts. Table 4.2-6 and Table 4.2-8 list 80 g as the accident condition acceleration for the primary and secondary lid bolts. The predicted DYNA2D (LLNL finite element structural analysis program) acceleration in the bolts is about 700 g and thus these bolts must be reviewed. The interface force at the location where the primary lid bolts connect the cask sidewall to the primary lid has a maximum value of 1.569×10^7 lbf and an average value of about 1.005×10^7 lbf. Based on the average interface force or the 700 g acceleration, the primary lid bolts exceed the ASME allowable stress limit for accident conditions (2/3 sigmavy). The secondary lid bolts, on the other hand, do not exceed the stress limit, but GNSI did not analyze either bolts for the accident loads. Besides the tensile load from the impact, shear loads in the bolts should also be addressed by GNSI. Besides the primary and secondary lid bolts, GNSI does not evaluate the effects of the end drop accelerations on the basket components. Even though the DYNA2D results indicate that the basket rebound from the end drop shock pulse is significantly less than the clearance length between the basket and the cask body, the large compressive wave could cause buckling concerns in the vertical members of the basket.

8.2.1.2.3.5 Fuel Basket Analysis (Accident Conditions)

Large compressive forces are transmitted by the cask body to the basket during the tipover accident. These forces could cause buckling failure in the sleeves and separator plates in the basket. From plate theory, the critical load can be computed for a plate being loaded, which is simply supported along the edges. According to critical load calculations though, the current basket design is not adequate for the design acceleration of 52 g. Considering only the X/33 basket in the 0-180 orientation as described on Page 4.2-47 the limiting acceleration for the 3 mm thick Radionox sleeves is 48 g, the limiting acceleration for the 3 mm thick AISI 321 sleeves is 49 g, and the limiting acceleration for the 15 mm thick AISI 321 separator plates is 24 g. Since the GNSI basket fails the design acceleration of 52 g, the basket will definitely not be adequate for the higher impact acceleration predicted by LLNL using the nonlinear dynamic analysis code, DYNA3D.

The title on Page 8.2-49 needs to be changed from 8.2.1.2.3.3 to 8.2.1.2.3.5.

On Page 8.2-49 the stated for deceleration for the cask body in the lateral direction is less than the 52 g design deceleration. Additionally, the 15-inch end drop deceleration needs to be also considered in the vertical direction. GNSI responds in the 11/1/89 and 3/19/90 submittals that vertical loading was not analyzed in the X/33 basket since vertical loads do not cause the fuel rods to bear on the sleeves. Vertical loads can cause buckling failure and this needs to be addressed. At the decelerations due to the 15-inch end drop and tipover accident, the buckling loads must be addressed.

GNSI responds in the 11/1/89 submittal that each "component is evaluated at the orientation at which it must carry the most load and/or experience the largest bending moments." There are no results or calculations which substantiate the GNSI claim. For the tipover and end drop, the buckling loads may determine failure and they are different at different cask orientations. All the possible drop orientations (0, 15, 30, and 45 degrees for example) need to be strictly accounted for.