April 21, 2005

Mr. Michael Mason
Chief Engineer
Transnuclear, Inc.
Four Skyline Drive
Hawthorne, NY 10532

SUBJECT: SECOND REQUEST FOR ADDITIONAL INFORMATION REGARDING THE TRANSNUCLEAR NUHOMS® HD HORIZONTAL MODULAR STORAGE SYSTEM (TAC NO. L23738)

Dear Mr. Mason:

By letter dated May 5, 2004, as supplemented July 6 and October 28, 2004, Transnuclear, Inc., (TN) submitted an application for NUHOMS® HD Certificate of Compliance (CoC) No. 1030. This application proposes a new horizontal modular storage system, designated the NUHOMS® HD. In a letter dated December 13, 2004, the staff sent you a request for additional information (RAI) regarding this design. In letters dated February 18, 2005, and March 7, 2005, you provided responses to the staff's RAI.

The staff has reviewed your responses and has determined that we need additional information in the structural area that is identified in the enclosure to this letter. We request that you provide this information by May 23, 2005. Inform us at your earliest convenience, but no later than May 9, 2005, if you are not able to provide the information by that date. To assist us in rescheduling your review, you should include a new proposed submittal date and the reasons for the delay.

Please reference Docket No. 72-1030 and TAC No. L23738 in future correspondence related to this request. The staff is available to meet to discuss your proposed responses. If you have any questions regarding this matter, I may be contacted at (301) 415-1132.

Sincerely,

**/RA/**

Joseph M. Sebrosky, Senior Project Manager
Licensing Section
Spent Fuel Project Office
Office of Nuclear Material Safety
and Safeguards

Docket No.: 72-1030
TAC No. L23738

Enclosure: Request for Additional Information

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Distribution:
Docket SBaggett
**ML051120048** * See Previous Concurrence

| **OFC** | SFPO | E | SFPO | E | SFPO | E | SFPO | E | SFPO | C | SFPO | C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **NAME** | JSebrosky | | EZiegler | | CBrown | | HLee | | GBjorkman | | RLewis | |
| **DATE** | 4/21/05 | | 4/21/05 | | 4/21/05 | | 4/21/05 | | 4/21/05 | | 4/21/05 | |

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**REQUEST FOR ADDITIONAL INFORMATION**
**TRANSNUCLEAR, INC.**
**DOCKET NO. 72-1030**

By application dated, May 5, 2004, as supplemented July 6 and October 28, 2004, Transnuclear, Inc. (TN) requested approval of the NUHOMS® HD Horizontal Modular Storage System. In a letter dated December 13, 2004, the staff sent you a request for additional information (RAI) regarding this design. In letters dated February 18, 2005, and March 7, 2005, TN provided responses to the staff's RAI. The staff has reviewed your responses and has determined that more information is needed in the structural area to assess compliance with 10 CFR Part 72. This request for additional information (RAI) identifies additional information needed by the U. S. Nuclear Regulatory Commission (NRC) staff in connection with its review of the application. The requested information is listed by chapter number and title used in the applicant's safety analysis report (SAR). NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems (SRP)," was used by the staff in its review of the application.

Each individual RAI describes information needed by the staff for it to complete its review of the application and/or the SAR and to determine whether the applicant has demonstrated compliance with the regulatory requirements.

**Chapter 2 Principal Design Criteria**

2-6 (Related to First Round RAI 2-2)

Revise the technical specification and Chapter 2 of the SAR to include the definition of damaged fuel as defined in ISG-1, rev.1.

The applicant's response (RAI response 2-2) is not consistent with the guidance in ISG-1, rev.1 for damaged fuel. The applicant's definition of damaged fuel can be broader than that specified in the definition section of ISG-1, Rev. 1, but should as a minimum include those items listed in that section.

In accordance with 10 CFR 72.236(c), the spent fuel must be maintained subcritical under credible conditions. Further, 10 CFR 72.236(m) seeks to ensure safe fuel storage and handling and to minimize post-operational safety problems with respect to retrievability of the fuel from the storage system.

**Chapter 3 Structural Evaluation**

3-19 (Related to First Round RAI 3-13)

Provide analyses demonstrating that fuel rod cladding integrity is maintained for the drop scenarios evaluated in SAR Section 3.5.3.1 "Side Drop" and Appendix 3.9.8, Section 3.9.8.11.1 "Structural Integrity Evaluation." Analysis assumptions should be justified based on the physical and behavioral characteristics of the fuel rods in the assemblies. Cladding material properties should be consistent with high burnup fuel and include a thickness reduction due to oxidation.

First round RAI 3-13 requested justification for the fuel rod moment of inertia (MI) used in performing the side drop fuel rod structural integrity evaluation in Appendix 3.9.8, Section 3.9.8.11.1. Therein TN used a MI equal to ½ the MI of the cladding plus ½ the MI of the fuel. TN's response justified this approach by assuming composite behavior between the fuel and cladding based on physical conditions that exist during in-reactor operations that result in compressive radial stresses between the fuel and cladding. The staff found these in-reactor conditions to not be applicable to spent fuel in storage due to the significant difference in the pressure and temperature environments between in-reactor operation and storage conditions. (Essentially, in storage the fuel is in a highly fractured condition with little or no radial compression forces acting on the fuel.) It is also noted that in this first round response the applicant did not mention nor address the fact that for the drop analysis performed in Section 3.5.3.1 Table 3-12 the full MI of both the cladding and fuel was used.

After discussions with TN, the staff received a second analysis in an email dated March 25, 2005, (this second analysis is documented below) that did not rely on composite behavior between the fuel and cladding, and addressed both Appendix 3.9.8, Section 3.9.8.11.1 and Section 3.5.3.1. Part A of the second analysis addressed Appendix 3.9.8 - a one foot side drop load of 30g. This analysis treated the fuel rod as a continuous beam over multiple supports and considered the bending resistance (MI) of only the cladding. The staff found this approach acceptable. Part B of the second analysis addressed Section 3.5.3.1 Table 3-12 - a side drop load of 75g. For this analysis TN abandoned the approach used in Part A and instead pursued a displacement limited approach. TN assumed the fuel rod was not a continuous beam over multiple supports (the model that had been used in Part A), but rather assumed that it was a simply supported beam spanning between adjacent grid spacers - the most flexible condition possible - and imposed a displacement limit approximately equal to the maximum total gap between adjacent fuel rods plus the gap between the assembly and basket. Because of the simply supported beam assumption, the staff found the approach in Part B to be non conservative and inconsistent with actual fuel rod behavior during a side drop event and, therefore, unacceptable.

This information is requested by the staff to assess compliance with 10 CFR 72.236 (b), (c), (d), (h) and (I).

3-20 Provide an analysis demonstrating that fuel cladding integrity is maintained for the end drop event evaluated in SAR Section 3.5.3.2. Analysis assumptions should be justified based on the physical and behavioral characteristics of the fuel rods (cladding and fuel) in the assemblies. Cladding material properties should be consistent with high burnup fuel and include a thickness reduction due to oxidation.

In Section 3.5.3.2 "End Drop" TN performed a static nonlinear ANSYS analysis of a simply supported fuel rod "column" with initial curvature loaded by an incrementally increasing axial force. Cladding and fuels were assumed to act as a composite (i.e., "fused with each other"). The cladding was given elastic-plastic properties and a tensile failure strain of 1.6%, while the fuel was given only elastic properties and no failure strain. Because the fuel has an elastic modulus more than twice that of the cladding and a solid cross-section, almost all of the lateral load resisting capacity ("buckling" strength) of the fuel rod, in the applicant's analysis, is provided by the fuel, not the cladding. The fuel is basically a coarse granular material with little tensile strength and therefore cannot be relied upon to resist tensile stress. This natural state of the fuel is not reflected in TN's analysis, which assumes that the fuel is a continuous solid with unlimited strength. The staff finds TN's analysis unacceptable.

This information is requested by the staff to assess compliance with 10 CFR 72.236(b), (c), (d). (h) and (l).

Second Structural Analysis
Sent by email from Michael Mason To Mary Jane Ross-Lee
dated March 25, 2005

**RAI 3-3:**

In our response to RAI 3-3, the maximum shear stresses in the canister covers welds are directly taken from half of the ANSYS reported maximum **nodal** stress intensity and compared with the shear allowable. The following tables list the maximum **element** stress intensities for the same loads. The shear stresses are taken as half of the maximum element stress intensities and compared with the shear allowable.

**Summary of Weld Shear Stresses and Allowables**
**75g Side Drop with Internal & External Pressures**

<table>
<tr><th>Weld</th><th>Load Case</th><th>Maximum Element Stress Intensity (ksi)</th><th>Maximum Shear Stress (ksi)</th><th>Allowable (ksi)</th><th>Factor of Safety</th></tr>
<tr><td rowspan="2">Between Outer Top Cover and Shell</td><td>75g Side Drop + 30 psig Internal Pressure</td><td>24.48</td><td>12.24</td><td>18.64</td><td>1.52</td></tr>
<tr><td>75g Side Drop +15 psig External Pressure</td><td>24.58</td><td>12.29</td><td>18.64</td><td>1.52</td></tr>
<tr><td rowspan="2">Between Inner Top Cover and Shell</td><td>75g Side Drop + 30 psig Internal</td><td>26.60</td><td>13.30</td><td>17.40</td><td>1.31</td></tr>
<tr><td>75g Side Drop +15 psig External Pressure</td><td>26.73</td><td>13.37</td><td>17.40</td><td>1.30</td></tr>
</table>

**Summary of Weld Shear Stresses and Allowables**
**Canister Corner Drop with Internal Pressure**

<table>
<tr><th>Weld</th><th>Load Case</th><th>Maximum Element Stress Intensity (ksi)</th><th>Maximum Shear Stress (ksi)</th><th>Allowable (ksi)</th><th>Factor of Safety</th></tr>
<tr><td>Between Outer Top Cover and Shell</td><td rowspan="2">Canister Corner Drop + 30 psi Internal Pressure</td><td>19.20</td><td>9.60</td><td>18.64</td><td>1.94</td></tr>
<tr><td>Between Inner Top Cover and Shell</td><td>19.31</td><td>9.66</td><td>17.4</td><td>1.80</td></tr>
</table>

The maximum element stress intensities are very close to maximum nodal stress intensities. For some load cases the two stress intensities are identical.

## RAI 3-13:

**A. <u>Fuel Rod Stresses Reported in Appendix 3.9.8, page 3.9.8-18 table</u>**
(Based on one Foot Side Drop Normal Load-30g)

The maximum fuel rod bending stresses reported in the above table are based on:

Moment of Inertia, $I_{total} = ½ (I_{rod} + I_{fuel})$

The stresses reported in the following table are based on $I_{total} = I_{rod,}$ no structural credit is taken for the fuel pellets.

<u>Summary of Maximum Bending Stresses Due to 30g Side Drop Normal Load</u>

| Fuel Assembly Type | WE15x15 | WE 17x17std | 17x17 MkBW | WE 17x17 Vantage5H | WE 17x17OFA | CE14X14 Std |
|---|---|---|---|---|---|---|
| Fuel Rod OD, D (in) | 0.4193 | 0.3713 | 0.3713 | 0.3713 | 0.3573 | 0.4373 |
| Clad Thickness, t (in) | 0.0216 | 0.0198 | 0.0213 | 0.0198 | 0.0198 | 0.0253 |
| Average Radius, R (in) | 0.1989 | 0.1758 | 0.1750 | 0.1758 | 0.1688 | 0.2060 |
| Fuel Rod M.I. ($in^4$) | 5.35E-04 | 3.39E-04 | 3.60E-04 | 3.39E-04 | 3.00E-04 | 6.97E-04 |
| Span Length, S (in) | 27.0 | 25.0 | 25.0 | 25.0 | 25.0 | 17.0 |
| (2a/W) | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Y | 2.11 | 2.11 | 2.11 | 2.11 | 2.11 | 2.11 |
| W (in) | 0.62 | 0.55 | 0.55 | 0.55 | 0.53 | 0.65 |
| Fuel Assembly Weight (lb) | 1,555 | 1,575 | 1,575 | 1,575 | 1,575 | 1,450 |
| No.of Rods | 204 | 264 | 264 | 264 | 264 | 176 |
| Active Fuel Length (in) | 144.0 | 144.0 | 144.0 | 144.0 | 144.0 | 137.0 |
| 1-Foot Side Drop Equivalent g load | 30 | 30 | 30 | 30 | 30 | 30 |
| $W_s$ (lb/in) | 1.59 | 1.24 | 1.24 | 1.24 | 1.24 | 1.80 |
| Moment, M (kip.in) | 0.12 | 0.08 | 0.08 | 0.08 | 0.08 | 0.06 |
| Bending Stress (psi) | 47,990 | 45,040 | 42,390 | 45,040 | 48,950 | 17,300 |

The above calculated stresses are all less than the yield stress of the cladding material (69,500 psi). Fracture evaluations of the cladding based on these new calculated stresses are redone and summarized in the following table.

Summary of Fracture Evaluations

| Fuel Assembly Type | WE15x15 | WE 17x17std | 17x17 MkBW | WE 17x17 Vantage5H | WE 17x17OFA | CE14X14 Std |
|---|---|---|---|---|---|---|
| $K_1$ (ksi in$^{1/2}$) (Based on Geometry #1, Figure 3.9.8-1) | 24.2 | 21.3 | 19.9 | 21.3 | 22.6 | 8.8 |
| $K_1$ (ksi in$^{1/2}$) (Based on Geometry #2, Figure 3.9.8-2) | 33.8 | 29.9 | 28.0 | 29.9 | 31.8 | 12.4 |
| $K_{IC}$ (ksi in$^{1/2}$) | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 |

This table compares the computed stress intensity factors to critical crack initiation fracture toughness. Based on results shown on this table, the fuel rods will maintain their structural integrity.

## B. Fuel Rod Stresses Reported in Chapter 3, Table 3-12
(Based on 75g Side Drop Accident Load)

The rod stress evaluation presented in the previous Section (A) due to 30g side drop is based on methodology described on LLNL report (Reference 1) and is based on modeling the fuel rod as a simply supported beam. In this methodology, the deflection of the rod is a function of the applied g-load and spacer grid span. In reality, as described in SANDIA report (Reference 2), as the g load increases due to the accident drop load, the deformation of the fuel rod is limited by the continuous support provided by the basket fuel compartments. The fuel compartment tube structure provides a rigid support structure to the fuel assembly. Figure III-6 from the referenced SANDIA report (reproduced here as Figure 1) shows that the maximum displacement of the center rod is limited by rod-to-rod contact and assembly/basket gaps during the accident end drop load. A similar situation can occur during the side drop accident load. Figure 2 illustrates the process by which the lateral deformation is limited to the sum of the gaps between individual rods in the assembly plus the thickness of the support grid.

The lateral restraint, shown in Figure 2, is based on all fuel rods having the same deformation pattern, with their lateral deformation constrained by the assembly and basket. This deformation is the maximum deformation possible regardless the applied g load. This assumption is justified since the basket structural stiffness is very large relative to the structural stiffness of the fuel assemblies and the deformation of the basket is very small compared to the fuel rod deformation calculated by this methodology.

Following is the example of this methodology based on the geometry of WE15x15:

$\delta$ = [(rod pitch-rod OD) - (no. of rods in a row -1)] + {assembly width - [rod pitch x (no. of rods in a row -1)] – rod OD}/2

Maximum deformation:
$\delta$ = [(0.563" – 0.4193") - (15-1)] + {8.426" - [0.563" x (15-1)] – 0.4193}/2
   = 2.0118" + 0.06235"
   = 2.07415"

For simple support beam, the maximum deformation at center is:

$\delta = 5wL^4/(384EI)$, rearranging the formula gives:
$WL^2 = 384EI(\delta)/(5L^2)$ and maximum moment at center is:

$M = wL^2/8$, therefore by substituting the above formula gives:

$M = 384EI(\delta)/(5L^2)(8)$

For WE15x15, $E=10.6 \times 10^6$ psi, $I = 5.35 \times 10^{-4}$ in$^4$, $\delta = 2.07415"$, L = 27"

$M = 384(10.6 \times 10^6 \times 5.35 \times 10^{-4})(2.07415)/(5 \times 27^2)(8) = 154.9$ in-lb

Maximum Bending Stress, $S = MC/I = 154.9 \times (0.4193/2)/5.35 \times 10^{-4} = 60{,}700$ psi

The following table summarizes the stress results for different type of fuel assemblies:

Summary of the Maximum Bending Stress Based on Calculated Maximum Deformation

| Fuel Assembly Type | WE15x15 | WE 17x17 std | 17x17 MkBW | WE 17x17 Vantage5H | WE 17x17OFA |
|---|---|---|---|---|---|
| Fuel Rod OD, D (in) | 0.4193 | 0.3713 | 0.3713 | 0.3713 | 0.3573 |
| Clad Thickness, t (in) | 0.0216 | 0.0198 | 0.0213 | 0.0198 | 0.0198 |
| Young's modulus of fuel rod (psi) | 1.06E+07 | 1.06E+07 | 1.06E+07 | 1.06E+07 | 1.06E+07 |
| Fuel Tube M.I. ($in^4$) | 5.35E-04 | 3.39E-04 | 3.60E-04 | 3.39E-04 | 3.00E-04 |
| Rod Pitch (in) | 5.63E-01 | 4.96E-01 | 4.96E-01 | 4.96E-01 | 4.96E-01 |
| Span Length, S (in) | 27.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| Number of fuel tube array | 15.0 | 17.0 | 17.0 | 17.0 | 17.0 |
| Fuel assembly Width (in) | 8.426 | 8.426 | 8.426 | 8.426 | 8.426 |
| Max. Deflection (in) | 2.0742 | 2.0546 | 2.0546 | 2.0546 | 2.2856 |
| Moment, M (lb.in) | 154.93 | 113.32 | 120.41 | 113.32 | 111.62 |
| Bending Stress, $S_b$ (psi) | 60,700 | 62,100 | 62,100 | 62,100 | 66,480 |

The membrane stresses in the rod due to internal pressure are summarized in the following table.

Summary of the Membrane Stress due to Internal Pressure

| Fuel Assembly Type | WE15x15 | WE 17x17 std | 17x17 MkBW | WE 17x17 Vantage5H | WE 17x17OFA |
|---|---|---|---|---|---|
| Internal Pressure, P (psi) | 2,235 | 2,235 | 2,235 | 2,235 | 2,235 |
| Membrane Stress (psi) $S = PR/2t$ | 10,289 | 9,921 | 9,183 | 9,921 | 9,525 |

The maximum combined membrane plus bending stress in the rods is 76,005 psi (WE17x17 OFA).

The yield stress of the cladding materials is 69,500 psi based on mechanical tests reported in reference 3 and RAI response 3-17. These tests do not include the increase in yield stress due to strain rate effects associated with drop accident condition. Section 2.3 of reference 1 [UCID 21246] indicates that the strain rate during a cask drop is expected to be at least 0.5 in/in/sec. Section 2.3 and Figure 5 of reference 1 [UCID 21246] show that for Zirconium type material the yield strength will increase by 10,000 psi per each order of magnitude increase in strain rate, i.e., the yield strength of 69,500 psi would increase by 30,000 psi to 99,500 psi at a strain rate approaching 0.5 in/in/sec. Conservatively assuming only a 10,000 psi increase due to strain rate effect provides a 79,500 psi yield strength. Thus, the maximum combined stress due to internal pressure and cask drop (76,005 psi, WE17x17 OFA) is less than the yield strength.

The stress for CE 14x14 Std fuel assembly is not included in the above table. This type of fuel assembly has a much smaller span (17 in.), bigger rod OD (0.4373 in.), and higher moment inertia (0.000696 $in^4$). Therefore, the stress in this fuel assembly is calculated using the same formula described in LLNL as described in A above. The stress for CE 14x14 Std fuel assembly during 75g side drop is calculated as follow (reference to Chapter 3, Table 3-12, rev.2):

Maximum bending stress, $S_b$ = MC/I = (0.14)(0.4373/2)/0.000697 = 43.91 ksi

The Stress due to pressure, $S_p$ = PR/2t = (2235) (0.206)/(2x0.0253) = 9.1 ksi

Total stress = $S_b + S_p$ = 43.91 + 9.1 = 53.01 ksi

The stress in this type of fuel assembly is much smaller than other type of fuel assemblies and is bounded by other type of fuels.

## C. Conclusion

The calculated stresses shown in the above tables demonstrate that the fuel rod in the NUHOMS 32PTH DSC will retain their structural integrity when subject to storage and on site transfer loads.

All the above rod stresses are calculated using the fuel rod moment of inertia only; no structural credit is taken for the fuel pellets. This assumption is conservative; based on the information provided in response to RAI 3-13, the pellets and rod cladding will bond together at the end of cycle life. The rod cladding and pellets will act together as a solid rod. The finite element model simulation also indicates that the interferences forces between cladding and pellets result in a much stiffer composite structure than zircaloy rod cladding alone.

Therefore, the stresses calculated in the above tables are conservative based on:

1. No structural credit is taken for fuel pellets. The interference forces between the cladding and pellets result in a much stiffer structure and the pellets inside the rod will help fuel rod withstand bending affect in the compressive side.

2. The support grid deformation is not accounted in the fuel rod deformation calculation. By including the support grid deformation, the maximum deformation of the fuel rod will be reduced.

References:

1. UCID-21246, “Dynamic Impact Effects on Spent Fuel Assemblies”, Lawrence Livermore National Laboratory, October 1987.

2. SAND90-2406, “A Method for Determining the Spent Fuel Contribution to Transport Cask Containment Requirements”, SANDIA National Laboratories, November 1992.

3. EPRI Report-1003218, “Hot Cell Examination of ZIRLO PWR Fuel-Irradiated to 70 GWd/MTU”, December 2003.

**Figure 1**

Lateral Displacement of Assembly Limited by Rod-to-Rod Contact and Assembly-Basket Gaps During End Drop (reproduced from Figure III-6 of reference 2)

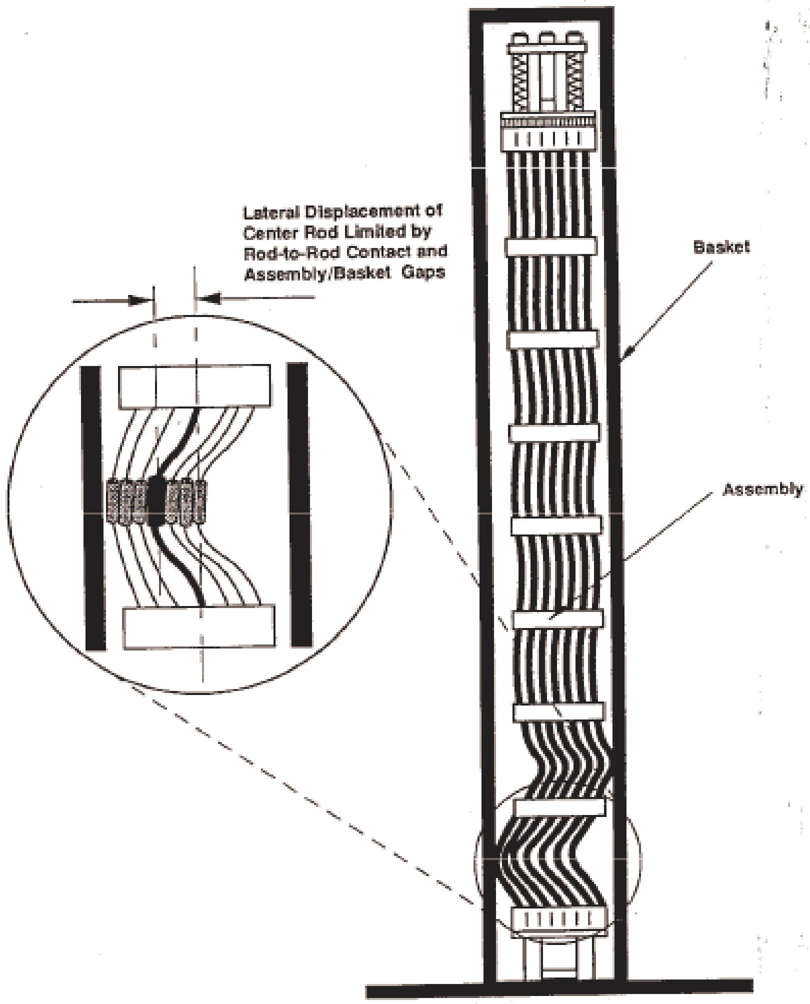
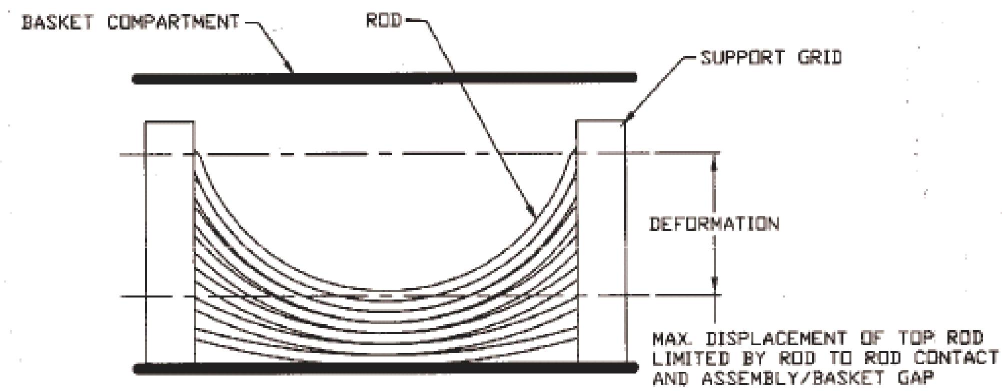


**Figure 2**

Maximum displacement of Top rod limited by Rod-to-rod Contact and Assembly/Basket Gaps During Side Drop




DEFORMATION = [(ROD PITCH-ROD O.D.) X (No. OF RODS IN ARRAY - 1)]
+{ASSEMBLY WIDTH - [ROD PITCH X (No. OF RODS IN ARRAY - 1)] - ROD O.D.} / 2