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Document ID 5014644

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
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January 18, 2008

Reference:
1. USNRC Docket No. 71-9261 (HI-STAR 100), TAC L24029
2. Holtec Project 5014
3. Holtec Letter 5014605, dated October 5, 2006
4. Holtec Letter 5014631, dated August 3, 2007
5. Holtec Letter 5014641, dated December 18, 2007

Subject: Supplement to License Amendment Request (LAR) 9261-5 to HI-STAR 100 CoC

Dear Sir:

In Reference [3] Holtec submitted a License Amendment Request (LAR) 9261-5 for the HI-STAR 100 Certificate of Compliance. Reference [4] contained Holtec responses to a request for additional information (RAI) by the SFST staff. In Reference [5] Holtec requested Revision 4 of drawing 4082 to be included in the LAR review. Since Reference [5] was submitted, minor changes have been made to two licensing drawings included in the LAR as supplemented. Holtec requests the attached revised drawings be included for review as part of the LAR 9261-5. Holtec is proposing to change the SAR text in Section 1.1 to reflect the updated drawing revisions.

In addition, the safety factors for the Humboldt Bay specific damaged fuel container (DFC) (depicted in Drawing 4113) were not reported in the original LAR. Holtec is proposing to change the SAR text in Appendix 2.B and Section 2.I to reflect the safety factors for the Humboldt Bay DFC. The attachments to this letter provide the changes and justification for all changes and the accompanying drawings and SAR text as follows:

Attachment 1: Change and Justification for the Drawing/SAR Text Revisions.
Attachment 2: Drawing 4113, Revision 2, "Damaged Fuel Container"
Attachment 3: Drawing 4082, Revision 5, "HI-STAR HB Overpack"
Attachment 4: Proposed Revision 13c of SAR Sections 1.I, 2.I, Appendix 2.B

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Please contact us if you have any questions.

Sincerely,

Tammy Morin
Project Manager, LAR 9261-5
Acting Licensing Manager, Holtec International

cc: Ms. Kimberly Hardin, NRC
Mr. Robert Nelson, NRC
Dr. Edwin Hackett, NRC
Group 1, Holtec

Attachment 1 to Holtec Letter 5014644
Change and Justification for the Drawing and SAR Text Revisions
(Total 2 Pages)

Drawing Change - 4113 Revision 1 to 2:

1. Sheet 2, note 2, clarification of the type of material to be used for the bolt.
2. Sheet 2, bolt dimension, bolt length shortened from 2.00 to 1.75 inches.

Justification for Change:

1. Editorial/Clarification; The bolt was called out as Class 2 material. Class 2 material is not required (default Class 1 is strong enough to lift loaded DFC).
2. Minor; The bolt was shortened to 1.75 inches so that it would not extend past to top of the DFC lid. This change does not affect the thread engagement length therefore the structural analysis is not affected and 1.75 inch bolt length is sufficient.

Drawing Change - 4082 Revision 4 to 5:

1. Sheet 2: Detail A and Detail B: Add "WHERE POSSIBLE" on the 3/8" all around weld between the fourth intermediate shell and the top flange.

Justification for Change:

1. Editorial/Clarification; A design change was made to machine the overpack flat near the lifting trunnions (Revision 4 of drawing). As a result, the welds that are applied are not all around welds. Where the overpack is machined flat, the weld pattern is depicted in Detail B and where the overpack is not machined flat, the weld pattern is depicted in Detail A.

SAR Section 1.I

1. Modified Table in Section 1.I.4 to reflect the latest drawing revisions, 4113 – Revision 2, 4082 - Revision 5.

Justification for Change

1. Editorial; As a result of the drawing revisions this table is updated.

SAR Section 2.I

1. Added text and table to Subsection 2.I.5.4 discussing the DFC for HB and providing the safety factors for lifting the DFC.
2. Added text and table to Subsection 2.I.7 discussing the DFC for HB and providing the safety factors for a 60g end drop of the DFC.

Justification for Change:

1. Minor; The lifting safety factor presented for the HB DFC in Appendix 2.B was for Dresden/HB DFC that was designed for use in the generic HI-STAR 100, not the DFC designed specifically for use in the HI-STAR 100 HB. It is noted that the safety factor for lifting of the HB specific DFC is higher than the safety factor for the Dresden/HB DFC.
2. Minor; The end drop safety factor presented for the HB DFC in Appendix 2.B was for the Dresden/HB DFC that was designed for use in the generic HI-STAR 100 not the DFC designed specifically for use in the HI-STAR 100 HB. It is noted that the safety factor for 60g end drop of the HB specific DFC is lower than the safety factor reported for the Dresden/HB DFC, however it is still greater than 1 and therefore acceptable.

SAR Section 2.B

1. Deleted "/HB" from the description of the Dresden/HB (BWR) DFC in Table 2.B.1.

Justification for Change

1. Editorial; there is an HB specific DFC design described in Supplement 2.I. Safety factors for the HB specific DFC design are also provided in Supplement 2.I as stated above. HB fuel will not be transported in the generic HI-STAR 100 using the Dresden/HB DFC therefore reference to this is removed from the SAR

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Attachment 2

Attachment 2 to Holtec Letter 5014644
Drawing 4113, Revision 2, "Damaged Fuel Container"
(Total 3 Pages, including this cover sheet)

Figure Withheld Under 10 CFR 2.390

HOLTEC INTERNATIONAL HOLTEC CENTER 555 LINCOLN DRIVE WEST MARLTON NJ 08053	CLIENT: PG & E HUMBOLDT BAY
	DESCRIPTION: DAMAGED FUEL CONTAINER
PROJECT NO. 1125	DRAWING NO. 4113	SHEET 1	TOTAL SHEETS 2
P.O. NO. 3500120394	FILE PATH

Figure Withheld Under 10 CFR 2.390

HOLTEC INTERNATIONAL HOLTEC CENTER 555 LINCOLN DRIVE WEST MARLTON NJ 08053	CLIENT: PG & E HUMBOLDT BAY			
	DESCRIPTION: DAMAGED FUEL CONTAINER			
COMPANION DRAWINGS: -	SIZE: D	DRAWING NO.: 4113	SHEET: 2	REV: 2
	SCALE: 1:2	FILE PATH: G:\DRAWINGS\1125-4113		

1

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Attachment 3

Attachment 3 to Holtec Letter 5014644
Drawing 4082, Revision 5, "HI-STAR HB Overpack"
(Total 8 Pages, including this cover sheet)

Figure Withheld Under 10 CFR 2.390

HOLTEC INTERNATIONAL HOLTEC CENTER 555 LINCOLN DRIVE WEST MARLTON, NJ 08053	CLIENT PG&E DESCRIPTION HI-STAR HB OVERPACK			
PROJECT NO. 1125	DRAWING NO. 4082	SHEET 1	TOTAL SHEETS 7	
P.O. NO. 3500120394	FILE PATH			

Figure Withheld Under 10 CFR 2.390

HOLTEC INTERNATIONAL HOLTEC CENTER 555 LINCOLN DRIVE WEST MARLTON, NJ 08053	PG&E			
	HI-STAR HB OVERPACK ELEVATION VIEW			
	D	4082	2	5
	NTS			

Figure Withheld Under 10 CFR 2.390

HOLTEC INTERNATIONAL HOLTEC CENTER 555 LINCOLN DRIVE WEST MARLTON, NJ 08053	CLIENT	PG&E		
COMPANION DRAWINGS	DESCRIPTION	HI-STAR HB OVERPACK DETAIL OF TOP FLANGE AT 0° & 180°		
	SIZE D	DRAWING NO. 4082	SHEET 3	REV 5
	SCALE NTS	FILE PATH		

Figure Withheld Under 10 CFR 2.390

HOLTEC INTERNATIONAL HOLTEC CENTER 555 LINCOLN DRIVE WEST MARLTON, NJ 08053	CLIENT: PG&E DESCRIPTION: HI-STAR HB OVERPACK CLOSURE PLATE BOLT HOLE & BOLT
COMPANION DRAWINGS	SIZE: D · DRAWING NO.: 4082 · SHEET: 4 · REV: 5 SCALE: NTS

Figure Withheld Under 10 CFR 2.390

HOLTEC INTERNATIONAL HOLTEC CENTER 555 LINCOLN DRIVE WEST MARLTON, NJ 08053	CLIENT: PG&E			
	DESCRIPTION: HI-STAR HB OVERPACK TOP PLAN VIEW "D" - "D"			
COMPANION DRAWINGS	SIZE: D	DRAWING NO.: 4082	SHEET: 5	REV: 5
	SCALE: NTS			

Figure Withheld Under 10 CFR 2.390

HOLTEC INTERNATIONAL
HOLTEC CENTER
555 LINCOLN DRIVE WEST
MARLTON, NJ 08053

CLIENT	PG&E
DESCRIPTION	HI-STAR HB OVERPACK MID-PLANE SECTION "E" - "E"
SIZE	D
DRAWING NO.	4082
SHEET	6
REV	5
SCALE	NTS

Figure Withheld Under 10 CFR 2.390

HOLTEC INTERNATIONAL HOLTEC CENTER 555 LINCOLN DRIVE WEST MARLTON, NJ 08053	PG&E HI-STAR HB OVERPACK TEST, VENT AND DRAIN PORT DETAILS			
	D	4082	7	5
	NTS			

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Attachment 4

Attachment 4 to Holtec Letter 5014644

Proposed Revision 13c of SAR Section 1.I, 2.I and Appendix 2.B

(Total 56 Pages, including this cover sheet)

SUPPLEMENT 1.I

GENERAL DESCRIPTION OF THE HI-STAR 100 SYSTEM FOR HUMBOLDT BAY

1.I.0 GENERAL INFORMATION

The HI-STAR 100 System has been expanded to include options specific for use at PG&E's Humboldt Bay (HB) plant for dry storage and future transportation of spent nuclear fuel (SNF)[1.0.8]. HB fuel assemblies are considerably shorter in length than the typical BWR fuel assemblies. As a result, the HI-STAR 100 system now includes an overpack assembly and MPC for use at HB; the HI-STAR 100 Version HB (also called HI-STAR HB) and the MPC-HB. Note that the HB fuel has a cooling time of more than 25 years and relatively low burnup. The heat load and nuclear source terms of this fuel are therefore substantially lower than the design basis fuel described in the main part of this chapter. Consequently, peak cladding temperatures and dose rates are below the regulatory limits with a substantial margin. Nevertheless, all major dimensions and features, such as diameter, wall thickness, flange design, top and bottom thicknesses, are maintained identical to the standard design. Therefore, from a structural perspective, the HI-STAR HB will be even more robust than the standard overpack, due to its shorter length. Information pertaining to the HI-STAR HB System is generally contained in the "I" supplements to each chapter of this SAR. Certain sections of the main SAR are also affected and are appropriately modified for continuity with the "I" supplements. Unless superseded or specifically modified by information in the "I" supplements, the information in the main SAR is applicable to the HI-STAR System for use at HB.

1.I.1 INTRODUCTION

The HI-STAR 100 System as deployed at Humboldt Bay will consist of a HI-STAR HB overpack, an MPC-HB that includes a fuel basket assembly and enclosure vessel specific to HB, and impact limiters. The HB specific components are described below and key parameters for HI-STAR HB are presented in Table 1.I.1. Section 1.I.3 provides the HI-STAR HB design code applicability and details any alternatives to the ASME Code if different than HI-STAR 100. All discussion is supplemented by a set of drawings in Section 1.I.4.

1.I.2 PACKAGE DESCRIPTION

1.I.2.1 Packaging

1.I.2.1.1 Gross Weight

Table 2.I.2.1 summarizes the maximum calculated weights for the HI-STAR HB overpack, impact limiters, and each MPC loaded to maximum capacity with design basis SNF. Table 2.I.2.1 also provides the location of the center of gravity of the fully loaded package.

1.I.2.1.2 Materials of Construction, Dimensions, and Fabrication

Humboldt Bay specific materials of construction along with outline dimensions for important-to safety items are provided in the drawings in Section 1.I.4.

1.I.2.1.2.1 *HI-STAR HB Overpack*

The HI-STAR HB overpack is a heavy-walled, steel cylindrical vessel identical to the standard HI-STAR, except that the outer and inner heights are approximately 128 and 115 inches, respectively. Unlike the HI-STAR 100, the HI-STAR HB overpack does not contain radial channels vertically welded to the outside surface of the outermost intermediate shell.

1.I.2.1.2.2 *MPC-HB*

MPC-HB is similar to the MPC-68F except it is approximately 114 inches high. Key parameters of the MPC-HB are given in Table 1.I.2. The MPC-HB is designed to transport up to 80 Humboldt Bay BWR spent nuclear fuel assemblies meeting the specifications in Table 1.I.4. Damaged SNF and fuel debris must be placed into a Holtec damaged fuel container or other authorized canister for transportation inside the MPC-HB and the HI-STAR HB overpack. Figure 1.I.1 provides a sketch of the container authorized for transportation of damaged fuel and fuel debris in the HI-STAR HB System.

1.I.2.2 *Operational Features*

The sequence of basic operations necessary to load fuel and prepare the HI-STAR HB system for transport is identical to that of HI-STAR 100. The supporting drawings for HB can be found in Section 1.I.4.

1.I.2.3 *Contents of Package*

This section delineates the authorized contents permitted for shipment in the HI-STAR HB System, including fuel assembly types; non-fuel hardware; neutron sources; physical parameter limits for fuel assemblies and sub-components; enrichment, burnup, cooling time, and decay heat limits; location requirements; and requirements for canning the material, as applicable.

1.I.2.3.1 *Determination of Design Basis Fuel*

The HI-STAR HB package is designed to transport Humboldt Bay fuel assemblies. The HB fuel assembly designs evaluated are listed in Table 1.I.3. Table 1.I.4 provides the fuel characteristics determined to be acceptable for transport in the HI-STAR HB System. Each "array/class" listed in this table represents a bounding set of parameters for one or more fuel assembly types. The array/classes are defined for HB in Section 6.I.2. Table 1.I.5 lists the fuel assembly designs that are found to govern for the qualification criteria. Tables 1.I.4 and 1.I.7 provide the specific limits for all material authorized to be transported in the HI-STAR HB System.

1.I.2.3.2 Design Payload for Intact Fuel

The fuel characteristics specified in Table 1.I.4 have been evaluated in this SAR and are acceptable for transport in the HI-STAR HB System.

1.I.2.3.3 Design Payload for Damaged Fuel and Fuel Debris

Limits for transporting HB damaged fuel and fuel debris are given in Table 1.I.7. Damaged HB fuel and fuel debris must be transported in the Holtec designed Humboldt Bay Damaged Fuel Container (DFC) as shown in Figure 1.I.1.

1.I.2.3.4 Structural Payload Parameters

The main physical parameters of an SNF assembly applicable to the structural evaluation are the fuel assembly length, envelope (cross sectional dimensions), and weight. In order to qualify for transport in the HI-STAR HB MPC, the SNF must satisfy the physical parameters listed in Table 1.I.7. The center of gravity for HB, reported in Chapter 2.I, is based on the maximum fuel assembly weight. Upper fuel spacers (as appropriate) in the form of welded I-beams, approximately 4 inches high, maintain the axial position of the fuel assembly within the MPC basket and, therefore, the location of the center of gravity. The upper spacers are designed to withstand normal and accident conditions of transport. An axial clearance of approximately 2 inches is provided to account for the irradiation and thermal growth of the fuel assemblies.

1.I.2.3.5 Thermal Payload Parameters

Table 1.I.7 provides the maximum heat generation for all fuel assemblies authorized for transportation in the HI-STAR HB System.

1.I.2.3.6 Radiological Payload Parameters

The design basis dose rates are met by the burnup level, cooling time, and minimum enrichment presented in Table 1.I.6 for HI-STAR HB.

1.I.2.3.7 Criticality Payload Parameters

The neutron absorber's minimum ^{10}B areal density loading for MPC-HB is specified in Table 1.I.2.

1.I.2.3.8 Non-Fuel Hardware and Neutron Sources

None.

1.I.2.3.9 Summary of Authorized Contents

Table 1.I.1 summarizes the key system data for the HI-STAR HB. Table 1.I.2 summarizes the key parameters and limits for the MPC-HB. Tables 1.I.4 and 1.I.7 and other tables referenced from these tables provide the limiting conditions for all material to be transported in the HI-STAR HB.

1.I.3 DESIGN CODE APPLICABILITY

Design code applicability for the HI-STAR HB is identical to HI-STAR 100 as presented in Section 1.3, except that the internal surfaces of the intermediate shells will not be coated with a silicone encapsulant due to its lower heat loads.

1.I.4 DRAWINGS

Drawing Number/Sheet	***Description***	***Rev.***
4082	*Licensing Drawing for HI-STAR HB Overpack Assembly*	5~~3~~
4102	*Licensing Drawing for MPC HB Enclosure Vessel*	*1*
4103	*Licensing Drawing for MPC HB Fuel Basket Assembly*	3~~2~~
4113	*Licensing Drawing for Damaged Fuel Container*	2~~1~~

1.I.5 COMPLIANCE WITH 10CFR71

Same as in Section 1.5.

1.I.6 REFERENCES

Same as in Section 1.6.

Table 1.I.1

SUMMARY OF KEY SYSTEM DATA FOR HI-STAR HB

PARAMETER	*VALUE (Nominal)*	
Types of MPCs in this Supplement	*1*	*MPC HB*
MPC capacity	*MPC HB*	*- Up to 80 intact ZR Humboldt Bay fuel assemblies.* *- Up to 28 Damaged Fuel Assemblies/Fuel Debris in DFCs located in the peripheral basket cells, remaining cells loaded with intact ZR Humboldt Bay fuel assemblies; or,* *- Up to 40 Damaged Fuel Assemblies/Fuel Debris in DFCs arranged in a checkerboard pattern with 40 intact ZR Humboldt Bay fuel assemblies*

Table 1.I.2
KEY PARAMETERS FOR MPC-HB

PARAMETER	***VALUE (Nominal)***
Unloaded MPC weight (lb)	*See Table 2.I.2.1*
Fixed neutron absorber (Metamic) ^{10}B loading density (g/cm^2)	*0.01*
Pre-disposal service life (years)	*40*
Design temperature, max. /min. (°F)	*725°/-40°*
Design Internal pressure (psig) *Normal Conditions* *Off-normal Conditions* *Accident Conditions*	 *100* *100* *200*
Total heat load, max. (kW)	*2*
Maximum permissible peak fuel cladding temperature (°F)	*752* *(Normal conditions)* *1058* *(Accident conditions)*
MPC internal environment Helium filled (psig)	*≥ 0 and ≤ 48.8 psig at a reference temperature of 70°F*
MPC external environment/overpack internal environment Helium filled initial pressure (psig, at STP)	*≥ 10 and ≤ 14*
Maximum permissible reactivity including all uncertainty and biases	*<0.95*
End closure(s)	*Welded*
Fuel handling	*Opening compatible with standard grapples*
Heat dissipation	*Passive*

Table 1.I.3

HUMBOLDT BAY FUEL ASSEMBLIES EVALUATED TO DETERMINE DESIGN BASIS SNF

Assembly Class	***Array Type***	
Humboldt Bay	*All 6x6*	*All 7x7*

Table 1.I.4
HUMBOLDT BAY FUEL ASSEMBLY CHARACTERISTICS

Fuel Assembly Array/Class	*6x6D*	*7x7C*
Clad Material	*ZR*	*ZR*
Design Initial U (kg/assy.)	*≤ 78*	*≤ 78*
Initial Maximum Rod Enrichment (wt.% ^{235}U)	*≤ 4.0 (see Note 1)*	*≤ 4.0~~5.5~~*
Maximum planar-average initial enrichment (wt.% ^{235}U)	*≤ 2.6*	*≤ 2.6*
No. of Fuel Rod Locations	*36*	*49*
Fuel Clad O.D. (in.)	*≥ 0.5585*	*≥ 0.4860*
Fuel Clad I.D. (in.)	*≤ 0.5050*	*≤ 0.426*
Fuel Pellet Dia. (in.)	*≤ 0.4880*	*≤ 0.4110*
Fuel Rod Pitch (in.)	*≤ 0.740*	*≤ 0.631*
Active Fuel Length (in.)	*≤ 80*	*≤ 80*
No. of Water Rods	*0*	*0*
Channel Thickness (in.)	*≤ 0.060*	*≤ 0.060*

Note 1: *Two 6x6D assemblies contain one high power test rod with an initial enrichment of 5.5%.*

Table 1.I.5

DESIGN BASIS FUEL ASSEMBLY FOR EACH DESIGN CRITERION

Criterion	***MPC-HB***
Reactivity	*6x6D and 7x7C*
Shielding (Source Term)	*6x6D*
Fuel Assembly Effective Planar Thermal Conductivity	*7x7C*
Fuel Basket Effective Axial Thermal Conductivity	*6x6D*

Table 1.I.6

HUMBOLDT BAY FUEL ASSEMBLY COOLING, AVERAGE BURNUP, AND MINIMUM ENRICHMENT LIMITS

Post-irradiation Cooling Time (years)	***Assembly Burnup (MWD/MTU)***	***Assembly Minimum Enrichment (wt. % ^{235}U)***
≥ 29	*≤ 23,000*	*≥ 2.09*

Table 1.I.7
LIMITS FOR MATERIAL TO BE TRANSPORTED IN MPC-HB

PARAMETER	***VALUE (Note 1)***	
Fuel Type (Note 2)	*Uranium oxide, HB BWR intact fuel assemblies meeting the limits in Table 1.I.4 for the applicable array/class, with or without Zircaloy channels*	*Uranium oxide, HB BWR damaged fuel assemblies or fuel debris meeting the limits in Table 1.I.4 for array/class 6x6D or 7x7C with or without Zircaloy channels, placed in HB Damaged Fuel Containers (DFCs)*
Cladding Type	*ZR*	*ZR*
Maximum Initial Enrichment	*As specified in Table 1.I.4 for the applicable array/class*	*As specified in Table 1.I.4 for the applicable array/class*
Post-irradiation Cooling Time, Average Burnup, and Minimum Initial Enrichment per Assembly	*As specified in Table 1.I.6.*	*As specified in Table 1.I.6.*
Decay Heat Per Assembly	*≤ 50 Watts*	*Fuel debris up to a maximum of one equivalent fuel assembly is allowed (Note 4)*
Fuel Assembly Length	*≤ 96.91 in. (nominal design)*	*≤ 96.91 in. (nominal design)*
Fuel Assembly Width	*≤ 4.70 in. (nominal design)*	*≤ 4.70 in. (nominal design)*
Fuel Assembly Weight	*≤ 400 lbs (including channels)*	*≤ 400 lbs, (including channels and DFC)(Note 3)*
Quantity per MPC	*Up to 80 HB BWR intact fuel assemblies*	*Up to 28 DFCs loaded in the peripheral cells of the basket with 52 intact assemblies in the remainder (figure 6.I.3) **or** Up to 40 DFCs with 40 intact assemblies loaded in a checkerboard pattern (figure 6.I.4)*
Other Limitations	*Stainless steel channels are not permitted.*	

Table 1.I.7 (cont.)
LIMITS FOR MATERIAL TO BE TRANSPORTED IN MPC-HB

Notes:

1. *A fuel assembly must meet the requirements of any one column and the other limitations to be authorized for transportation.*
2. *Fuel assemblies with channels may be stored in any fuel cell location.*
3. *The total quantity of damaged fuel permitted in a single DAMAGED FUEL CONTAINER is limited to the equivalent weight and special nuclear material quantity of one intact assembly.*
4. *Fuel debris in the form of loose debris consisting of zirconium clad pellets, stainless steel clad pellets, unclad pellets or rod segments up to a maximum of one equivalent fuel assembly is allowed.*

SUPPLEMENT 2.I: HI-STAR HB STRUCTURAL EVALUATION

2.I.0 OVERVIEW

In this supplement, the structural adequacy of the HI-STAR HB is evaluated pursuant to the guidelines of NUREG-1617 and the requirements of 10CFR71. The organization of this supplement mirrors the format and content of Chapter 2 except it only contains material directly pertinent to the HI-STAR HB.

The HI-STAR HB is a shortened version of the HI-STAR 100 that is evaluated in Chapter 2. All dimensions (radius, thickness) of the HI-STAR HB are identical to those of the HI-STAR 100 except for the overall length of the layered cylinders and the threaded diameter of the lifting trunnions. The impact limiters for the HI-STAR HB *are identical in all respects to* those of the HI-STAR 100 *except for the crush strength of the internal aluminum honeycomb material, which is reduced to ensure that the deceleration limits are met with the lighter weight HI-STAR HB. The HI-STAR HB is configured to carry the MPC HB that has the appropriate length and fuel basket design to carry 80 spent fuel assemblies from the closed Humboldt Bay Nuclear Plant. The qualification of the MPC HB to withstand a 60g deceleration has been documented in the Part 72 license for Humboldt Bay (Humboldt Bay ISFSI, Pacific Gas and Electric Company, Final Safety Analysis Report Update, Revision 0 January 2006, NRC Docket No. 72-27). Therefore, no new analyses of the MPC HB are required in this Supplement 2.I as long as the design basis remains the same.*

The applicable design codes and standards, and the design criteria for the HI-STAR HB are identical to those applied to the HI-STAR 100. Therefore, since the differences between the HI-STAR HB and HI-STAR 100 are limited to

- *Shorter overall length;*
- *Lower package weight;*
- *Reduced strength of impact limiter crush material;*
- *Smaller diameter threads on lifting trunnions,*

Tthe supplement is focused on documenting the results from new evaluations required because of the reported differences in length, weight, impact limiter crush strength, and thread diameter. The reduced length and weight of the HI-STAR HB ensures that all stress-based evaluations performed on the HI-STAR 100 produce safety factors that are lower bounds for the same evaluation on the HI-STAR HB. The only evaluations that are cask specific are those that involve deceleration limits, because of the impact limiters, and those that involve the lifting trunnions, because of the smaller diameter threads; this supplement focuses only on providing summaries for the new evaluations performed for the HI-STAR HB.

2.I.1 STRUCTURAL DESIGN

2.I.1.1 <u>Discussion</u>

The general discussion presented in Subsection 2.1.1 applies to the HI-STAR HB package. Drawings for the components of the HI-STAR HB package are provided in Section 1.I.4.

2.I.1.2 <u>Design Criteria</u>

The HI-STAR HB package meets the design criteria espoused in Section 2.1.2 in its entirety. For the HI-STAR HB overpack, however, the option to replace the SA203-E plate used for the 2.5" thick inner shell with comparable SA350 LF3 ring forgings, stacked to form the inner shell and welded together with full penetrant welds, has been added to the drawings. The Nil Ductility Transition Temperature is still required to be less than –70 degrees F when this option is used (per Subsection 2.1.2.3). Accordingly, Table 2.1.22 lists SA350 LF3 as aon optional material for the inner shell. Similarly, Table 2.1.23 lists SA350 LF3 as an option for the port cover plates.

2.I.2 WEIGHTS AND CENTERS OF GRAVITY

Table 2.I.2.1 provides the weights of HI-STAR HB components as well as the total package weight. The weight of the impact limiter is also provided. Table 2.I.2.1 also provides the location of the calculated center of gravity for the HI-STAR HB package.

2.I.3 MECHANICAL PROPERTIES OF MATERIALS

Materials for the HI-STAR HB package are identical to those used for the HI-STAR 100 package.

2.I.4 GENERAL STANDARDS FOR ALL PACKAGES

The HI-STAR HB is a shorter and lighter version of the HI-STAR 100. Therefore, the features presented in Section 2.4 apply to the HI-STAR HB.

2.I.5 LIFTING AND TIE-DOWN STANDARDS

2.I.5.1 Lifting Devices

The lifting devices for the HI-STAR HB package are identical to those for the HI-STAR 100, except that the threaded portion of the lifting trunnions has a slightly smaller diameter. Therefore, even though the HI-STAR HB is lighter than the HI-STAR 100, the safety factors for the HI-STAR HB lifting trunnions and the top flange interface are recalculated based on the smaller trunnion diameter.

The embedded trunnion is analyzed as a cantilever beam in the same manner as described in Subsection 2.5.1.1. Calculations demonstrate that the stresses in the trunnions comply with NUREG-0612 provisions.

Specifically, the following results are obtained:

Safety Factors from HI-STAR HB Lifting Trunnion Stress Analysis†			
Item	*Value (ksi) or (lb) or (lb-in)*	*Allowable (ksi) or (lb) or (lb-in)*	*Safety Factor*
Bending stress (Comparison with Yield Stress/6)	*11.2*	*24.5*	*2.19*
Shear stress (Comparison with Yield Stress/6)	*4.76*	*14.7*	*3.09*
Bending Moment (Comparison with Ultimate Moment/10)	*208,600*	*574,400*	*2.75*
Shear Force (Comparison with Ultimate Force/10)	*92,690*	*282,500*	*3.05*

† *The bounding lifted load is 161,200 lb. (per Table 2.I.2.1).*

We note from the above that all safety factors are greater than 1.0. A factor of safety of exactly 1.0 means that the maximum stress, under apparent lift load D, is equal to the yield stress in tension or shear divided by 6, or that the section moment or shear force is equal to the ultimate section moment capacity or section force capacity divided by 10.*

It is also important to note that safety factors associated with satisfaction of 10CFR71.45(a) are double those reported in the table since 10CFR71.45 only requires a factor of safety of 3 on the yield strength.

The top flange interface with the trunnion under the lifted load is analyzed in the same manner as described in Subsection 2.5.1.2.2. The interface region is conservatively considered as subject to the provisions of NUREG-0612, and the thread shear stress and bearing stress are compared to 1/6 of the top forging yield stress in shear or compression. The following table summarizes the results:

Top Flange B Minimum Safety Factors (Interface with Trunnion) for HI-STAR HB			
Item	*Value (ksi)*	*Allowable (ksi)*	*Safety Factor*
Bearing Stress (NUREG-0612 Comparison)	*2.555*	*5.975*	*2.34*
Thread Shear Stress (NUREG-0612 Comparison)	*2.466*	*3.585*	*1.45*
Stress Intensity (NB Comparison)	*5.655*	*34.6*	*6.12*

It is noted from the above that all safety factors are greater than 1.0 and that the safety factors for bearing stress and thread shear stress represent the additional margin over the factor of safety inherent in the member by virtue of the load multiplier mandated in NUREG-0612.

2.I.5.2 <u>Tie-Down Devices</u>

Since the HI-STAR HB is shorter and lighter, but otherwise identical to the HI-STAR 100, the tie-down devices and the resulting tables of reaction loads in Section 2.5 bound those for the HI-STAR HB. The span between tie-down locations is less, reflecting the shorter overall length of *the HI-STAR HB. The equilibrium equations presented in Subsection 2.5.2 also apply to the HI-STAR HB. No new analyses are performed.*

2.I.5.3 <u>Failure of Lifting and Tie-Down Devices</u>

The discussion in Subsection 2.5.3 for the HI-STAR 100 also applies to the HI-STAR HB, except for the following. New calculations have been performed for the HI-STAR HB to demonstrate that the ultimate load carrying capacity of the lifting trunnions is governed by the cross section of the trunnion external to the overpack top forging rather than by any section within the top forging. It is concluded that the trunnion shank reaches ultimate load capacity limit prior to the top forging reaching its corresponding ultimate load capacity limit. Loss of the external shank of the lifting trunnion will not cause loss of any other structural or shielding function of the HI-STAR HB overpack; therefore, the requirement imposed by 10CFR71.45(a) is satisfied.

The following safety factors are established:

> *(Ultimate Bearing Capacity at Trunnion/Top Forging Interface)/(Ultimate Trunnion Load) = 1.04*
>
> *(Ultimate Moment Capacity at Trunnion/Top Forging Thread Interface)/(Ultimate Trunnion Moment Capacity) = 1.51*

2.I.5.4 <u>Lifting of Humboldt Bay Damaged Fuel Container</u>

The Humboldt Bay Damaged Fuel Container (DFC) has been analyzed for structural integrity during a lifting operation consistent with the methodology described in Appendix 2.B of the SAR.

The safety factor for the HB DFC during lifting is provided in the following table, and shows that the factor of safety is greater than 1.0.

Unit	*Component*	*Calculated Stress (ksi)*	*Allowable Stress (ksi)*	*Safety Factor = (Allowable Value)/(Calculated Value)*
Holtec Designed HB DFC	*Lifting – Lifting Bolt*	*5.936*	*7.300*	*1.23*

2.I.6 NORMAL CONDITIONS OF TRANSPORT

The HI-STAR HB package, when subjected to the normal conditions of transport specified in 10CFR71.71, meets the design criteria in Subsection 2.1.2 (derived from the stipulations in 10CFR71.43 and 10CFR71.51). The HI-STAR HB is identical to the HI-STAR 100 in all respects except for the length of the overpack (and the MPC HB), the crush strength of the impact limiter material, and the lifting trunnion thread diameter; the total package weight is bounded by the package weights listed for the HI-STAR 100. Component diameters and thicknesses for the HI-STAR HB overpack and its closures are identical to those of the HI-STAR 100. Therefore, with the exception of the lifting trunnions, all stress analysis results associated with the HI-STAR HB overpack are bounded by the available results for the HI-STAR 100. No new analyses are reported in this supplement except for those associated with the performance of the impact limiter and the lifting trunnions. Stress results for the MPC HB have been reported in detail in the update to the Humboldt Bay FSAR [2.I.6.1]; the MPC HB analyses were performed using the design basis deceleration of 60g's.

2.I.6.1 Heat

Consistent with Regulatory Guide 7.9, the thermal evaluation of the HI-STAR HB is performed in Supplement 3.I and sets material temperatures, which are used in the structural evaluations discussed in this section and in Section 2.I.7. As the Humboldt Bay fuel is "old and cold", the operating temperatures are at or below comparable temperatures for the HI-STAR 100 analyses. This adds additional margins since the allowable strengths will generally be higher in a comparable strength analysis using the HI-STAR HB.

Design pressures and design temperatures for all conditions of transport are listed in Tables 2.1.1 and 2.1.2, respectively.

In summary, because of the lower weight and shorter length, all stress analyses performed for the HI-STAR 100 using the bounding deceleration inputs give stress results that are equal to or greater than results using the HI-STAR HB.

2.I.6.2 Cold

No new or modified calculations or discussions are required for this subsection.

2.I.6.3 <u>Reduced External Pressure</u>

No new or modified calculations or discussions are required for this subsection.

2.I.6.4 <u>Increased External Pressure</u>

No additional analyses need be performed here to demonstrate package performance of the HI-STAR HB.

2.I.6.5 <u>Vibration</u>

No new or modified calculations or discussions are required for this subsection.

2.I.6.6 <u>Water Spray</u>

The condition is not applicable to the HI-STAR HB System per Reg. Guide 7.8 [2.1.2].

2.I.6.7 <u>Free Drop</u>

The structural analysis of a 1-foot side drop ~~under heat and cold conditions~~ has been performed for the HI-STAR 100 in Subsections 2.6.1 and 2.6.2 for heat and cold conditions of normal transport. As demonstrated in Subsections 2.6.1 and 2.6.2, safety factors are well above~~over~~ 1.0. Since the HI-STAR HB is shorter and lighter than the HI-STAR 100, the safety factors determined in Subsections 2.6.1 and 2.6.2 are lower bounds for comparable safety factors for the HI-STAR HB. As final verification, the decelerations for the free drop for the HI-STAR HB are determined in Section 2.I.7 using LS-DYNA and shown to be comparable to~~less than~~ the design basis limits for the 1-foot free drop.

2.I.6.8 <u>Corner Drop</u>

This condition is not applicable to the HI-STAR HB System per [2.1.2].

2.I.6.9 <u>Compression</u>

The condition is not applicable to the HI-STAR HB System per [2.1.2].

2.I.7 HYPOTHETICAL ACCIDENT CONDITIONS

The hypothetical accident conditions, as defined in 10CFR71.73 and Regulatory Guide 7.9, have been applied to the HI-STAR 100 System in the required sequence in Subsection 2.7.

It is shown in the following subsections that the HI-STAR HB System also meets the standards set forth in 10CFR71, when it is subjected to the hypothetical accident conditions specified in 10CFR71.73.

2.I.7.1 Free Drop

In this subsection the performance and structural integrity of the HI-STAR HB System is evaluated for the most severe drop events. The drop events that are potentially most damaging are the end drops (top or bottom), the side drop, the orientation for which the center of gravity is directly over the point of impact, an oblique drop where the angle of impact is somewhere between center of gravity over corner and a near side drop, and an orientation where package rotation after an impact at one end induces a larger impact deceleration when the other end impacts the target (i.e., slapdown).

As has been noted, the HI-STAR HB is shorter and lighter than the HI-STAR 100, but is identical to the HI-STAR 100 in all other aspects of geometry. The impact limiter crush strengths are adjusted from those used in the HI-STAR 100 in order to ensure that the design basis deceleration limits for the HI-STAR family continue to be met. In Section 2.7, the analysis was performed in two parts. Initially, 1/8 and 1/4 scale testing was performed to establish the characteristics of the impact limiter and to demonstrate that the experimentally obtained decelerations for all orientations of the cask were below the design basis. Simplified analytical models were then developed and demonstrated to be capable of predicting the observed responses from the experimental results. These simplified models were used to evaluate sensitivity to crush strength change and cask weight change. Once it was established that the impact limiter configuration and crush strengths successfully limited the rigid body decelerations of the cask to below the prescribed limits, various strength analyses were performed to assess the state of stress in the cask components and ensure that the preescribed stress limits were satisfied.

As the impact limiter for the HI-STAR HB has the same ~~geometry~~internal and external geometry as the HI-STAR 100 with the sole difference being the impact limiter crush material, no new qualification testing is performed~~employed~~. In lieu of testing, the~~a the more sophisticated~~ 3-D finite element code LS-DYNA [2.I.7.1] is used to simulate the free drop tests and demonstrate the performance of the impact limiter for the HI-STAR HB. In order to employ LS-DYNA, it is first demonstrated that the finite element model of the cask structure and the impact limiters is benchmarked. That is, it is shown~~demonstrated~~ that the LS-DYNA simulation model proposed for the HI-STAR HB adequately matches existing experimental results obtained for the HI-STAR 100 when the model is altered to match the geometry and the impact limiter crush strength used in the HI-STAR 100. The calculations associated with the development of the ¼-scale model of the HI-STAR 100 are documented in [2.I.7.2].

Figures 2.I.7.1through- 2.I.7.4 show details of the LS-DYNA model constructed for the HI-STAR 100 and used here to reproduce the experimental results for the four free-drop tests (end drop, side drop, center-of-gravity-over-corner (CGOC) drop at 67.5 degree orientation from the rigid target, and slapdown drop at 7.2 degree orientation from the rigid target). Figure 2.I.7.1 shows the complete half-model in the slapdown orientation. Figure 2.I.7.2 shows the details of the finite element grid for the overpack. Figure 2.I.7.3 shows the grid density employed to simulate the steel structure (skin and "backbone" stiffeners) of the top impact limiter, and Figure 2.I.7.4 shows the grid density used and the orientation of the different honeycomb blocks (with different material strengths) that make up the top impact limiter crush material volume. The MPC and its contents are modeled by a cylindrical body with appropriate dimensions and material density to replicate a loaded MPC. This is not an exact replica of the structure used to simulate the MPC in the ¼-scale test model; however, the MPC in the LS-DYNA model ~~provides a good match for~~matches the weight, the mass center, and the ~~value for the~~ rotatory mass moment of inertia of the tested model within 5%, as demonstrated in ~~. This is shown in~~ [2.I.7.2]~~]~~ and [2.I.7.4~~3~~]. The HI-STAR 100 overpack density is adjusted so that the total weight of the overpack in LS-DYNA matches the weight of the one-quarter-scale model of the HI-STAR 100 after scaling back to the full-size cask using the principal of similarity.– The half-models of the HI-STAR 100 overpack and the MPC are modeled with *adequate details to ensure correct representation of the geometry and mass distribution. The total weight of the modeled (full size) loaded HI-STAR 100 overpack is 244,412 lbs.*

*The HI-STAR impact limiters are fabricated from carbon steel for the internal backbone structure, stainless steel for the thin enclosure, and aluminum honeycomb (with ~~a~~ specific crush strength for each honeycomb block). Of the impact limiter steel members, the stainless steel enclosure experiences the most significant deformation during the drop events, and its material behavior is characterized in LS-DYNA using an appropriate true stress-true strain curve in MAT_024 (*MAT_PIECEWISE_LINEAR_PLASTICITY). Based on the engineering stress-strain data obtained from the original tests of the honeycomb material for the HI-STAR 100 impact limiters, the material characteristics of the honeycomb material are simulated by MAT_026 (*MAT_HONEYCOMB) in the LS-DYNA model, with the stress strain data for the material input to capture initial elastic behavior, a region of constant crush resistance, and a region where the material experiences "lock-up". The impact limiter crush ~~material~~strength is not scaled; rather it is considered as a material property of the impact limiter. The crush strength of the honeycomb blocks used in the ¼-scale tests is ~~used~~input identically in the LS-DYNA simulation model of the full size HI-STAR 100 LS-DYNA model. The total weight of the modeled HI-STAR 100 top and bottom impact limiters is 36,553 lb., which matches well with the tabulated data in Section 2.2. Apart from the its crush strength, the~~The~~ impact limiter for the HI-STAR HB is identical to the impact limiter for the HI-STAR 100; therefore, since ~~The impact limiter-to-cask connection is modeled as a rigid connection, which conservatively neglects any energy absorption by the actual connection elements.~~the tested connection between the ¼-scale impact limiter and ¼-scale overpack maintained structural integrity [2.I.7.3] in all successful drops, this connection is simply made rigid in the LS-DYNA model.*

The following table provides geometry information for impact limiters from the full-size LS-DYNA model, from ~~a~~the ¼-scale LS-DYNA model developed by applying similarity principles to the full-size LS-DYNA model, and from the actual ¼-scale model test.~~:~~ Only parameters where there is a difference between ~~a~~the 1/4-scale LS-DYNA model and the "as-constructed" ¼-scale tested model are reported in the table.

~~Key~~ Geometryic ~~Parameters That~~ Differences Between LS-DYNA Model of Full Size Impact Limiters, LS-DYNA Model Scaled to ¼ of Full Size, and ¼-Scale Tested Model

ITEM	*FULL SIZE LS-DYNA MODEL*	*¼-SCALE LS-DYNA MODEL*	*¼- SCALE TESTED MODEL*
Impact limiter 1/8" plate	*0.125~~1/8~~"*	*0.03125"*	*0.0336" and 0.0293"*
Outer/Inner gussets	*0.5"*	*0.125"*	*0.12"*
¼" thick disc	*0.25"*	*0.0625"*	*0.0595"*

From the table, it is clear that all geometry differences occurred in impact limiter components where ~~thin metal~~ parts could not be scaled exactly because of commercially available material thickness limitations. However, since the differences are minor, it is apparent that a similarity scaling of a full-size LS-DYNA model does produce a faithful representation of the actual tested model.

Summarizing, the current benchmark analysis is focused only on the impact limiter behavior; successful benchmarking permits the LS-DYNA model to be used to evaluate the effect of changing the crush characteristics of the energy absorbing material.

The free drop tests are simulated*~~performed~~ using the HI-STAR 100 LS-DYNA finite element model of the full-size cask.* The results from each simulation are documented in [2.I.7.4~~3~~]. *Each test is performed by orienting the model appropriate to the rigid target, and imposing an initial velocity of 527 inch/second to every node; this simulates the 30-foot drop at the instant of initial impact with the target. Consistent with the locations of the embedded accelerometers on the tested ¼-scale HI-STAR 100 model, cask drop acceleration-time histories are obtained at three locations on the finite element model (top flange, mid-height, and cask bottom) so that comparisons could be made with the test data. Table 2.I.7.1 shows a comparison of key results from the finite element simulation with results from the tests (after scaling the test data* up*~~back~~ to the full size cask and calculating average accelerations where multiple accelerometer data is available).* Figures 2.I.7.5 -through 2.I.7.9 present a typical deceleration vs. time plot for each of the simulated drop ~~events~~tests. Since the results in Table 2.I.7.1represent average decelerations obtained from multiple accelerometers, the plot maximum may *be different from the results in the table. It is clear that the simulation model is in excellent agreement with the test results in terms of prediction of peak acceleration, maximum impact limiter crush, and duration of impact; iIn particular, Figures 2.I.7.10 through 2.I.7.14 show the plotted comparisons of the filtered acceleration data from the test [2.I.7.3] with similar filtered acceleration data from the LS-DYNA simulation at the same location. ~~the test results from to~~The plots demonstrate that the duration of the event and the pulse shape are captured by the LS-DYNA simulation (after applying the similarity principle). Full details of the benchmark model and the completed analyses are in [2.I.7.43].~~To also demonstrate that the LS-DYNA simulation matches test data throughout the entire event duration, filtered acceleration data from the test [2.I.7.2] is compared with similar filtered acceleration data from the LS-DYNA simulation at the same location; the comparison of results for all drop tests demonstrates that the HI-STAR 100 Package response is appropriately captured by the LS-DYNA simulations through the entire strong response duration of the event.~~*

Based on the tabular results and comparison of acceleration data vs. time, the benchmarking of the HI-STAR 100 LS-DYNA model is complete, insofar as predicting impact limiter performance, and the simulation model can be used to evaluate the performance of the HI-STAR HB impact limiters.

The HI-STAR HB model is now obtained by reducing the axial length of the elements (making up the cylindrical body) without changing the numbering of nodes or elements, until the appropriate HI-STAR HB dimension is achieved. The final weight of the loaded HI-STAR HB (without impact limiters) is 156,611 lb, which compares well with the tabulated bounding weight in Table 2.I.2.1. The final weight of the impact limiters for the HI-STAR HB is calculated by LS-DYNA as 24,774 lb. The drawings for the HI-STAR HB impact limiter, with specified crush strengths, are found in Section 1.4. Figure 2.I.7.15 shows the HI-STAR HB finite element model oriented for the end drop.

The results from the four free drop simulations of the HI-STAR HB are documented in Table 2.I.7.2 (because of the reduced length of the HI-STAR HB Package, the CGOC and slapdown *angles are 31.1 degrees and 6 degrees from the target plane, respectively)*~~-and~~. ~~Details from the calculations are in [2.I.7.3].~~ *Figures 2.I.7.16 through -2.I.7.20 present a typical deceleration vs. time plot from each LS-DYNA simulation of the HI-STAR HB drop. Table 2.I.7.2 documents key average decelerations from the drop events, along with other key information. The complete set of results for all items listed in the table is in the calculation package for Humboldt Bay [2.I.7.4~~3~~]. The results show that the HI-STAR HB impact limiters effectively protect the HI-STAR HB cask under the Hypothetical Conditions of Transport postulated 30-foot drop events by maintaining the peak cask rigid body deceleration below the cask design basis limit of 60 g's.- Since the peak decelerations are below the corresponding values for the HI-STAR 100, and since the connections between the HI-STAR HB impact limiters and the HI-STAR HB body are the same as in the HI-STAR 100, it is assured that the pin/bolt connections between the HI-STAR HB impact limiters and the HI-STAR HB body maintain their structural integrity.*

As noted in Section 2.I.6, t~~T~~he HI-STAR HB spent fuel basket has been analyzed previously for a 60g deceleration as part of satisfying Part 72 storage requirements. A 2-D finite element model of the fuel basket ~~subject~~ has been performed using a lateral inertia load from the spent fuel and from the self-weight of the fuel basket. The solution can be applied here to determine results for the fuel basket stress intensity under a side or near-side drop (where the longitudinal axis of the HI-STAR is parallel to the ground). An oblique 9-meter drop of the HI-STAR HB, at any angle "A" from the horizontal, imposing a vertically oriented deceleration D = 60g, imparts both a longitudinal deceleration "Dsin(A)" and a lateral deceleration "Dcos(A)" to the basket. The lateral deceleration induces lateral inertia load from the spent fuel and from the self-weight of the basket panel which is reacted by panel bending (it is this lateral component of deceleration that has been previously considered by the 2-D finite element analysis); the longitudinal deceleration induces longitudinal inertia load only from the self-weight of the fuel basket~~panel~~ and induces an additional longitudinal membrane stress in the basket panels. The maximum stress intensity in the basket panel from these two inertial loadings acting simultaneously occurs at the location of maximum compressive bending stress (the center of a simply supported panel strip). A parameter "e" is defined as the *ratio of a fuel basket panel weight to the weight of a fuel assembly; then the relationship between the stress intensity arising from an oblique drop event, angle of impact, e, and ratio of panel width to panel thickness can be developed. This relationship is developed below by combining the bending stress in the panel with the longitudinal stress from the panel amplified self-weight.*

-Define "SI_o" as the stress intensity calculated for a side drop (drop angle = 0 degrees) where only lateral deceleration is considered, and "SI" as the stress intensity for an oblique drop, then

$$\frac{SI}{SI_0} = \cos\theta + \frac{4e}{3(1+e)}\left(\frac{t}{w}\right)^2\left(\frac{L}{t}\right)\sin\theta$$

where the quantity "(t/w)" is the ratio of panel thickness to panel width, and "L" is the length of the panel. For the geometry and weight of the HI-STAR HB, the maximum value of the SI ratio occurs at a small angle greater than zero. However, since the stress analysis of the MPC HB has been performed using the bounding design basis deceleration of 60g's, and the maximum deceleration from any of the drop events is only 50g's, the 2-D basket stress analysis, using the design basis deceleration value, bounds results from a combination of lateral and longitudinal decelerations using the maximum computed deceleration reported in Table 2.I.7.2.

Finally cConsistent with the requirements for 1-foot free drops as part of the Normal Conditions of Transport, two free drops (end drop and side drop) are also analyzed for the HI-STAR HB Package. The maximum decelerations sustained by the package, as well as the maximum impact limiter crush and impact durations, are summarized in Table 2.I.7.3. Note that the peak end drop deceleration slightly exceeds the design basis value specified for the HI-STAR 100 (17g's per Table 2.1.10), but this has no adverse structural consequence on the package components as stress intensities remain below ASME Section III Level A limits for an NB structure.

Analysis of the HB DFC to be transported in the HI-STAR 100 HB package is performed to demonstrate structural integrity under end drop condition consistent with those described in Appendix 2.B of the SAR.

The safety factor for the HB DFC during end drop is provided in the following table, and shows that the factor of safety is greater than 1.0.

Unit	Component	Calculated Stress (ksi)	Allowable Stress (ksi)	Safety Factor = (Allowable Value)/(Calculated Value)	Remarks
Holtec Designed HB DFC	60g End Drop	13.260	26.586	2.00	Spot Welds

~~2.I.7.2~~2. I.7.2 Puncture

No new or modified calculations need be performed to qualify the HI-STAR HB, as the structure at the puncture locations is unchanged from the HI-STAR 100.

~~2.I.7.3~~2. ~~Thermal~~I.7.3 Thermal

Thermal evaluation of the fire accident is presented in Supplement 3.I. No new or modified structural calculations need be performed to qualify the HI-STAR HB for the fire accident.

2.I.7.4 Immersion - Fissile Material

No new or modified calculations need be performed to qualify the HI-STAR HB.

2.I.7.5 Immersion - All Packages

No new or modified calculations need be performed to qualify the HI-STAR HB.

2.I.7.6 Summary of Damage

The results presented in Subsections 2.I.7.1 through 2.I.7.5 show that the HI-STAR HB System meets the requirements of 10CFR71.61 and 10CFR71.73. All safety factors are greater than 1.0 by virtue of comparison with the corresponding calculations for the HI-STAR 100 for the hypothetical accident conditions of transport. Therefore, the HI-STAR 100 HB package, under *the hypothetical accident conditions of transport, has adequate structural integrity to satisfy the subcriticality, containment, shielding, and temperature requirements of 10CFR71.*

2.I.8 SPECIAL FORM

This section is not applicable to the HI-STAR 100 System. This application does not seek approval for transport of special form radioactive material as defined in 10CFR71.4.

2.I.9 FUEL RODS

The Humboldt Bay fuel is shorter than the design basis fuel carried by the HI-STAR 100; therefore, the computations and conclusions in Section 2.9 encompass the HI-STAR HB.

2.I.10 MISCELLANEOUS ITEMS

No new appendices are introduced in Supplement 2.I. Also, since the HI-STAR 100 Package meets applicable NUREG 1617/10CFR71 requirements, so does the HI-STAR HB.

2.I.11 REFERENCES

[2.I.6.1] *Pacific Gas and Electric Company, NRC Docket Number 72-27, Humboldt Bay ISFSI, Final Safety Analysis Report Update, Revision 0, January 2006.*

[2.I.7.1] *LS-DYNA 970, Livermore Software Technology, 2003.*

[2.I.7.2] *HI-STAR 100 Quarter Scale Test Model, Holtec Rpt. HI-961590, Rev. 1.**

[2.I.7.3] *Impact Limiter Drop Test Report – 2nd Series, Holtec Rpt. HI-981891, Rev. 2. **

~~[2.I.7.2] Impact Limiter Drop Test Report – 2nd Series, Holtec Rpt. HI-981891, Rev. 2.~~ [2.I.7.4~~3~~] *Calculation Package of Humboldt Bay HI-STAR Impact Limiters, Holtec Rpt. HI-2063486, Rev.2.**

** Submitted to NRC on this Docket*

Table 2.I.2.1 Weights and Center of Gravity of HI-STAR HB Package			
Item	*Component Weight (lb.)*	*Total Weight (lb.)*	*Location of C.G. above base of cask (inch)*
Impact Limiter	*13,000*	*26,000*	-
MPC HB	*59,000*	-	-
HI-STAR HB (with loaded MPC HB)	*161,200*	-	-
Total Package Weight	-	*187,200*	-
Loaded Package Center of Gravity	-	-	*61.4*

Table 2.I.7.1; Comparison of HI-STAR 100 Test Results and LS-DYNA Simulation Results							
Drop Case		*Deceleration (g's)[A]*		*Crush Depth (in)*		*Impact Duration (ms)*	
		Measured	*Predicted*	*Measured*	*Predicted*	*Measured*	*Predicted*
1. End Drop		*53.9*	*55.35*	*10.6*	*10.34*	*37.2/ 40.7[B]*	*44*
2. C.G. Over Corner		*38.8*	*37.13*	*9.82/ 15.25[C]*	*18.91*	*61*	*62.5*
3. Side Drop		*45.7*	*49.18*	*12.5*	*12.65*	*53.1*	*47.5*
4. Slap-Down	*Primary*	*49.0*	*48.04*	*10.7*	*9.77[D]*	*44.4*	*45*
	Secondary	*59.0*	*62.74*	*13.5*	*14.63[E]*	*41.2*	*42*

Notes:

A. Averaged deceleration (except the slap-down case) from tracked locations consistent with the tests.

B. The impact duration would be 40.7 milli-seconds if the entire duration of positive deceleration were considered.

C. For CGOC impact the axis of the dropped cask is 22.5° off the vertical direction. Approximately half of the 10" thick small protruding ring (at the end of the ϕ128" impact limiter) is deformed, which indicates that the minimum vertical crush depth can be estimated as d_{min}=[64"×tan(22.5°)-10"]×cos(22.5°) =15.25". For the reported value of 9.82", only crush at the external interface was reported in the final test report.

D. 9.77"=64"-83.25"/2 (radius of HI-STAR top flange)-28.954" (initial vertical distance to ground)+16.35" (cask top vertical displacement).

E. 14.63"=64"-83.25"/2 (radius of HI-STAR bottom plate)-52.747" (initial vertical distance to ground)+45.0" (cask bottom vertical displacement).

Table 2.I.7.2; LS-DYNA Analyses Results for HI-STAR HB Impact Limiters				
Drop Case		*Deceleration (g's)[A]*	*Crush Depth (in)*	*Impact Duration (ms)*
1. End Drop		*45.95*	*11.18*	*52*
2. C.G. Over Corner		*31.16*	*23.83*	*80*
3. Side Drop		*45.13*	*13.32*	*54.5*
4. Slap-Down	*Primary*	*36.26 (37.32[B])*	*11.72[C]*	*93*
	Secondary	*47.48 (49.72[B])*	*14.37[D]*	*54*

Notes:

A. Averaged deceleration (except the slap-down case) from tracked locations.

B. Deceleration results in the parenthesis are obtained for the additional case with upper bound honeycomb crush strengths (i.e., 10% greater than nominal values).

C. 11.72"=64"-83.25"/2 (radius of HI-STAR top flange)-27.903" (initial vertical distance to ground)+17.27" (cask top vertical displacement).

D. 14.37"=64"-83.25"/2 (radius of HI-STAR bottom plate)-39.822" (initial vertical distance to ground)+31.82" (cask bottom vertical displacement).

Table 2.I.7.3; LS-DYNA Analysis Results of HI-STAR HB Package One-Foot Drop Events			
Drop Case	*Deceleration (g's)[A]*	*Crush Depth (in)*	*Impact Duration (ms)*
1. End Drop	*17.96*	*0.90*	*41.7*
2. Side Drop	*10.31*	*1.95*	*57.5*

Note:

A. Averaged deceleration from tracked locations.

2.I.12 ~~ADDITIONAL~~ FIGURES FOR SUPPLEMENT 2.I

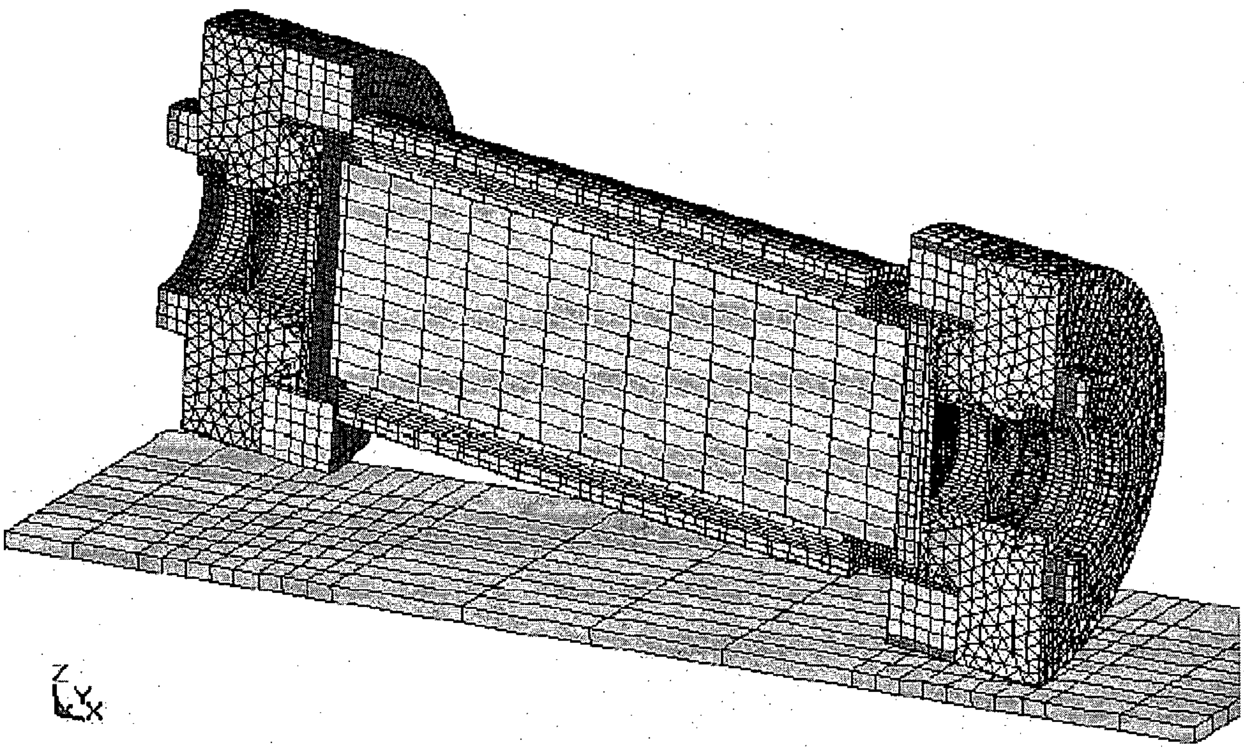


Figure 2.I.7.1 LS-DYNA Model of HI-STAR 100 for Slapdown Simulation

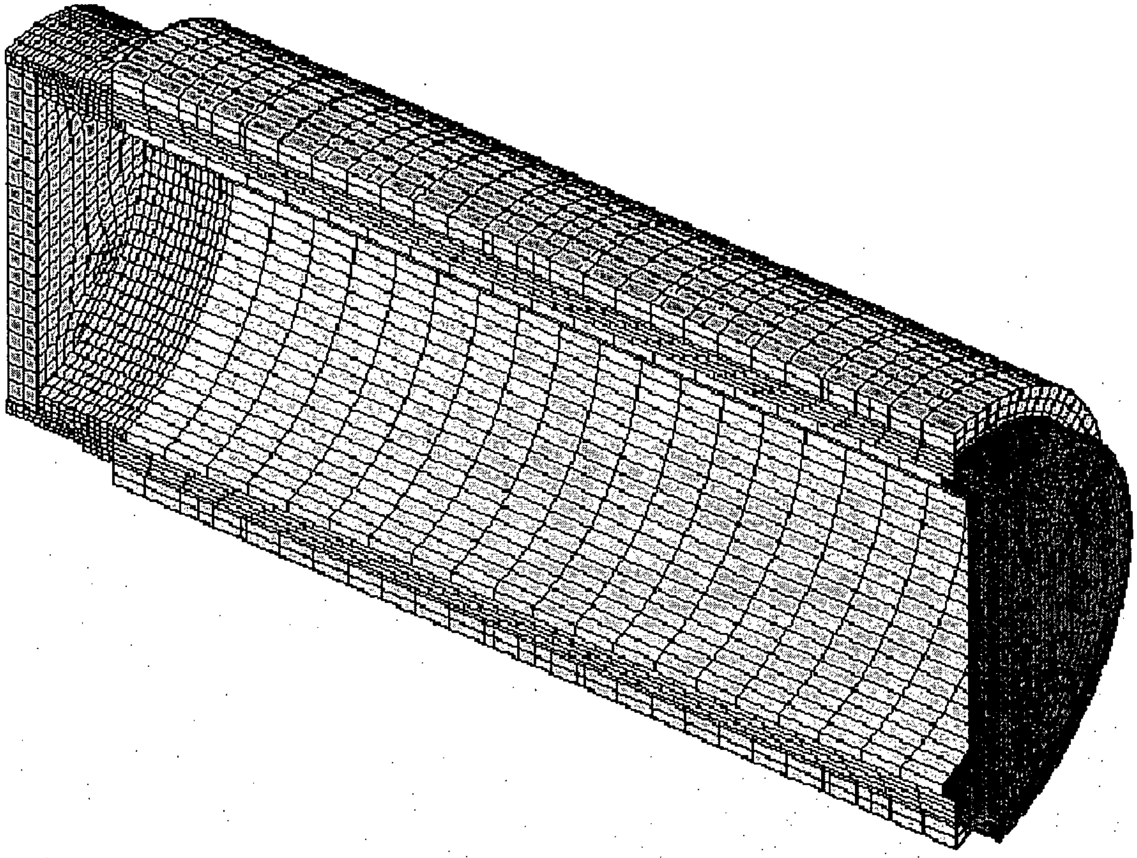


Figure 2.I.7.2 LS-DYNA Model of HI-STAR 100 Overpack

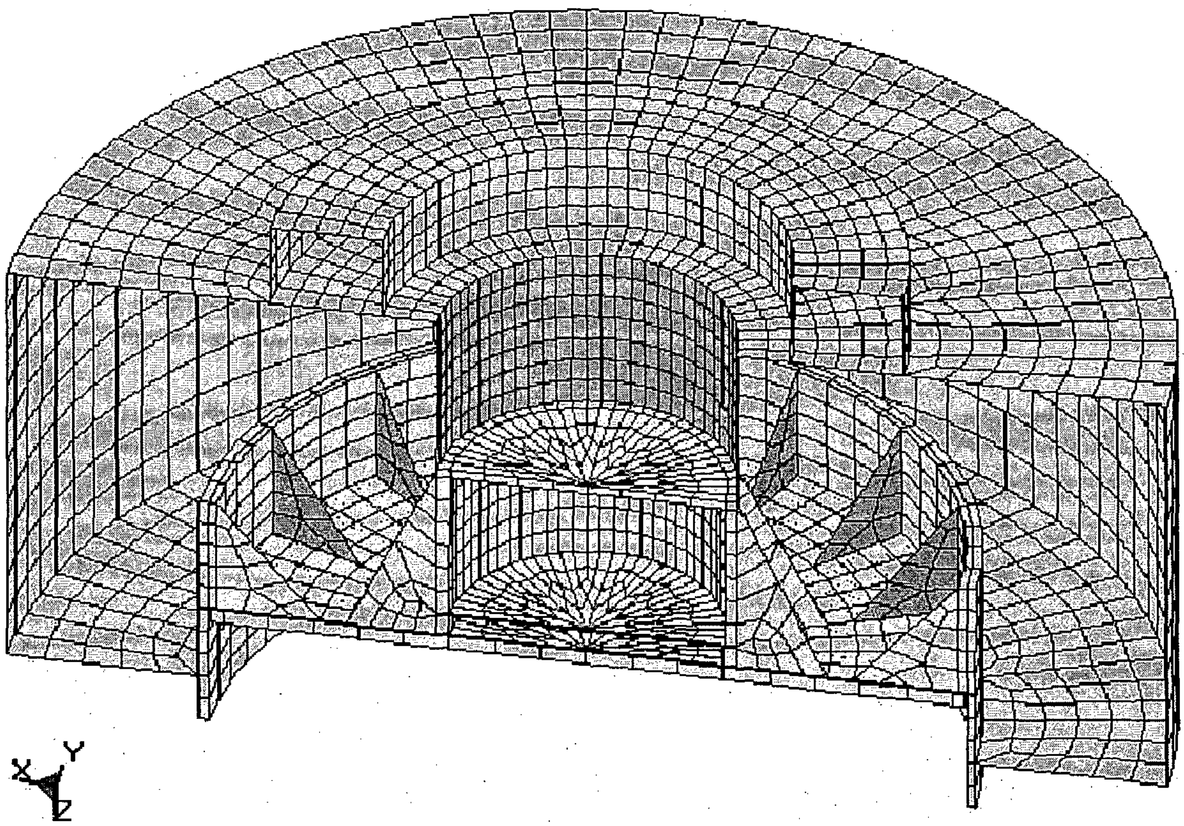


Figure 2.I.7.3 Top Impact Limiter Steel Structure

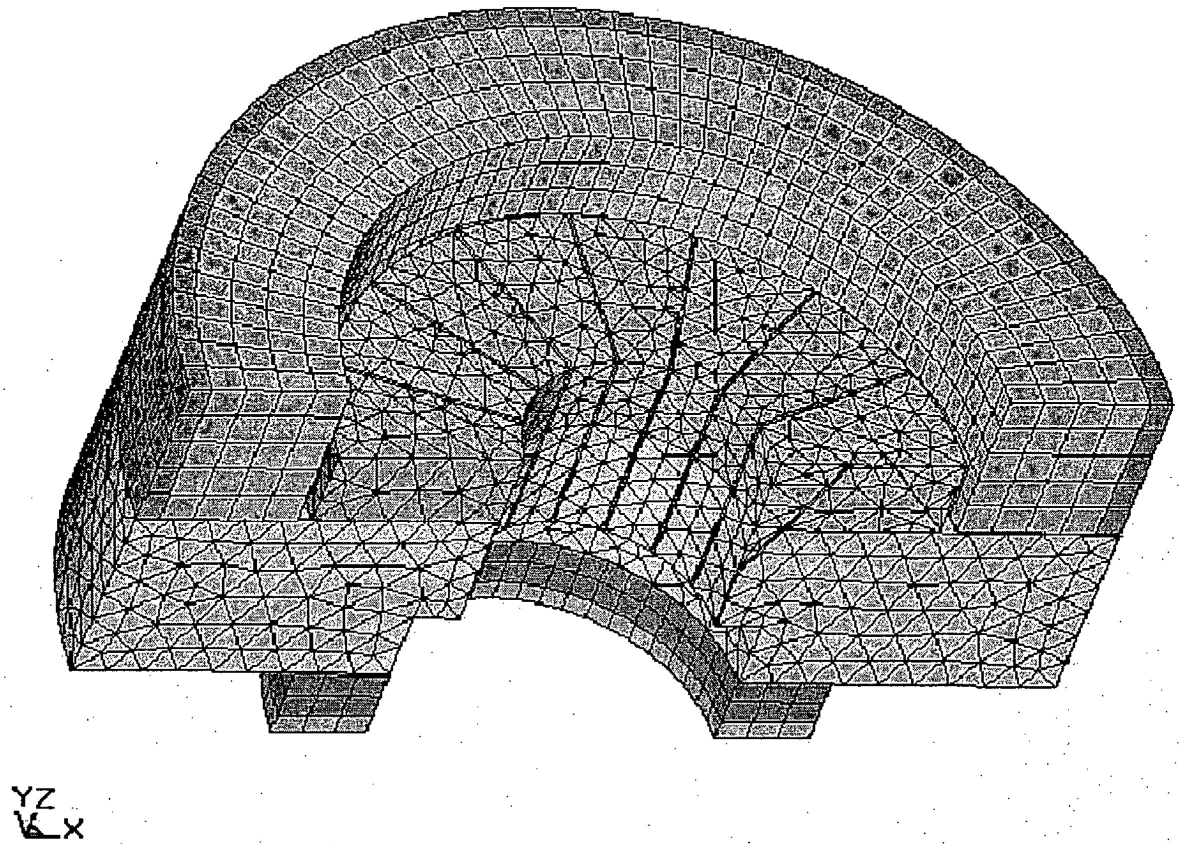


Figure 2.I.7.4 Top Impact Limiter Honeycomb Crush Material

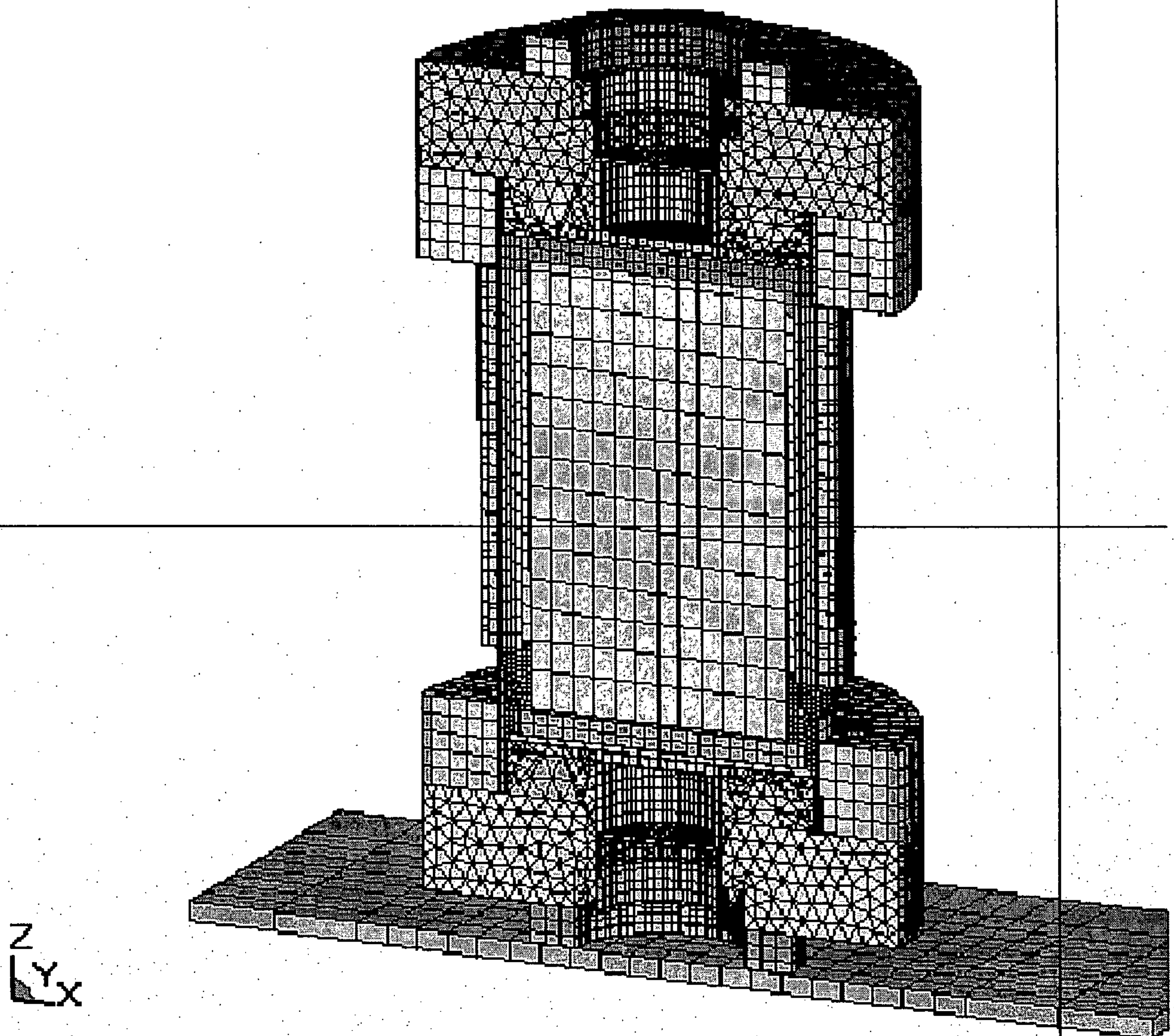
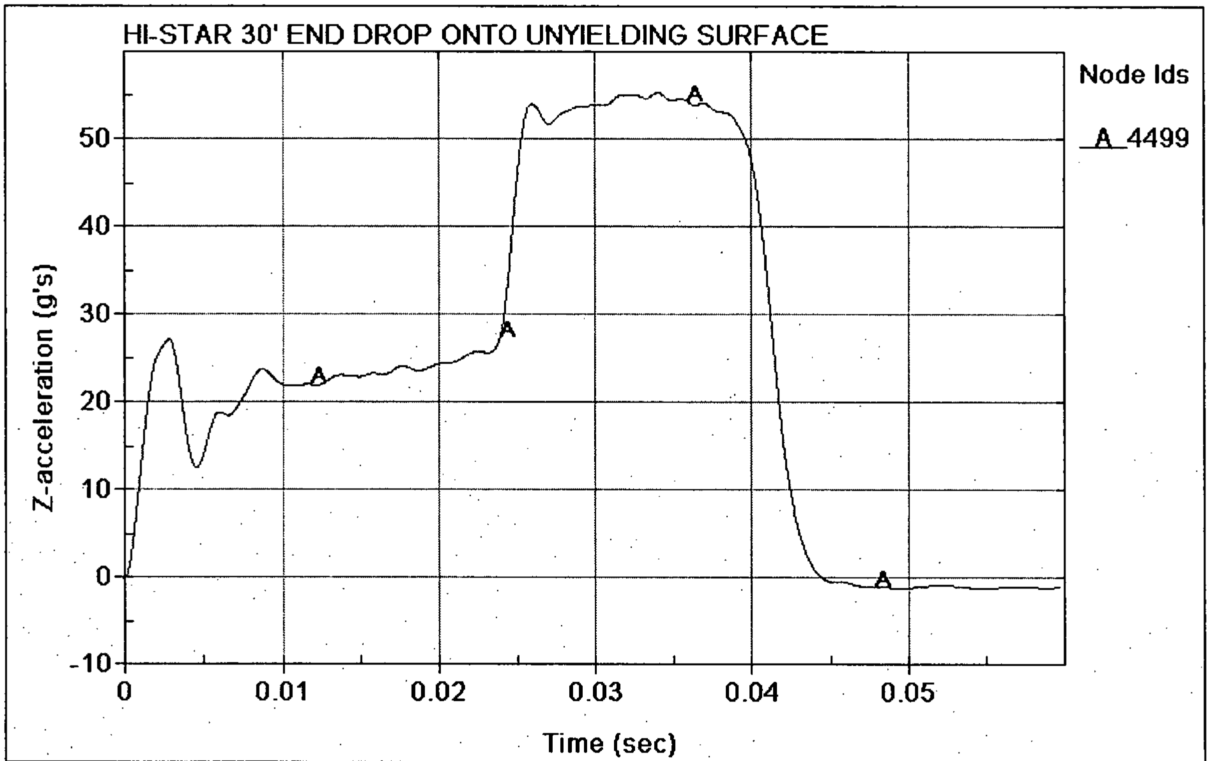


Figure 2.I.7.5 HI-STAR HB Finite Element Model in End Drop Orientation


HI-STAR 30' END DROP ONTO UNYIELDING SURFACE
Node Ids
A 4499
Z-acceleration (g's)
50
40
30
20
10
0
-10
0
0.01
0.02
0.03
0.04
0.05
Time (sec)

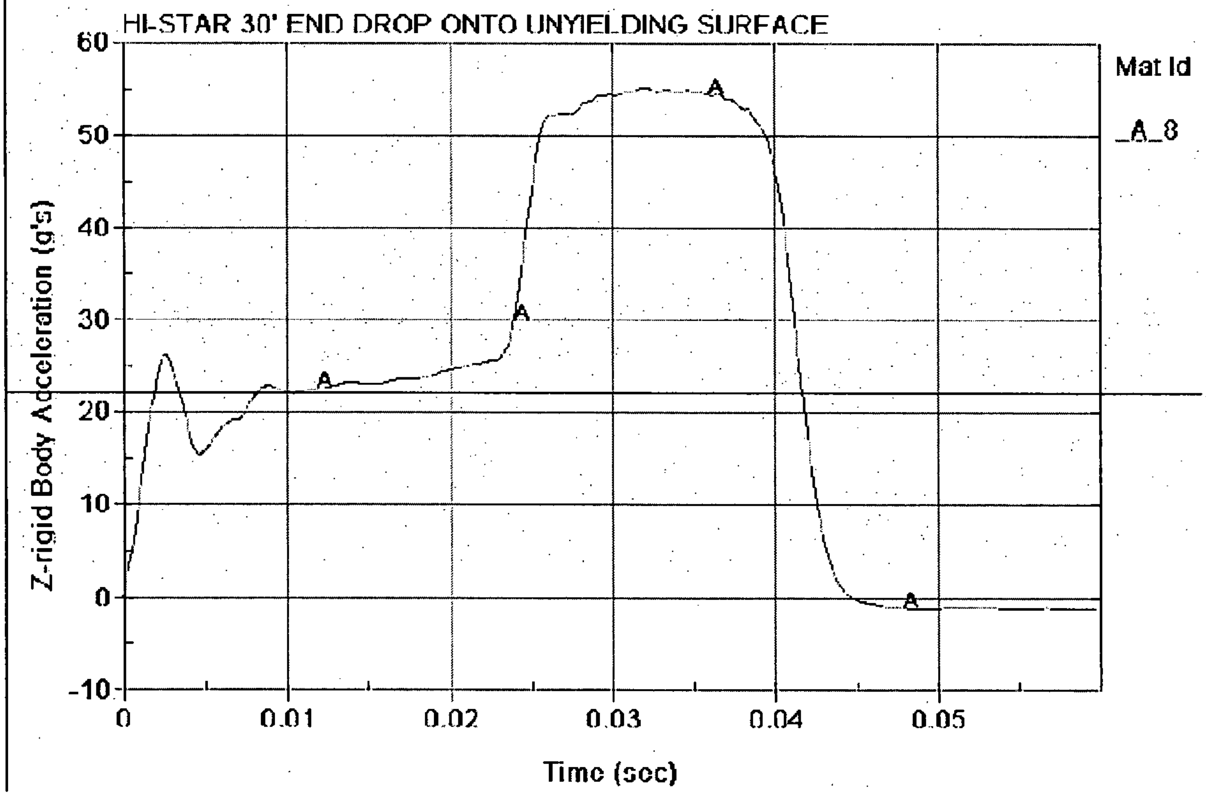

HI-STAR 30' END DROP ONTO UNYIELDING SURFACE
Mat Id
A 8
Z-rigid Body Acceleration (g's)
60
50
40
30
20
10
0
-10
0
0.01
0.02
0.03
0.04
0.05
Time (sec)

Figure 2.I.7.5 HI-STAR 100 Top End Drop Deceleration vs. Time from LS-DYNA Model of Full-Size HI-STAR 100

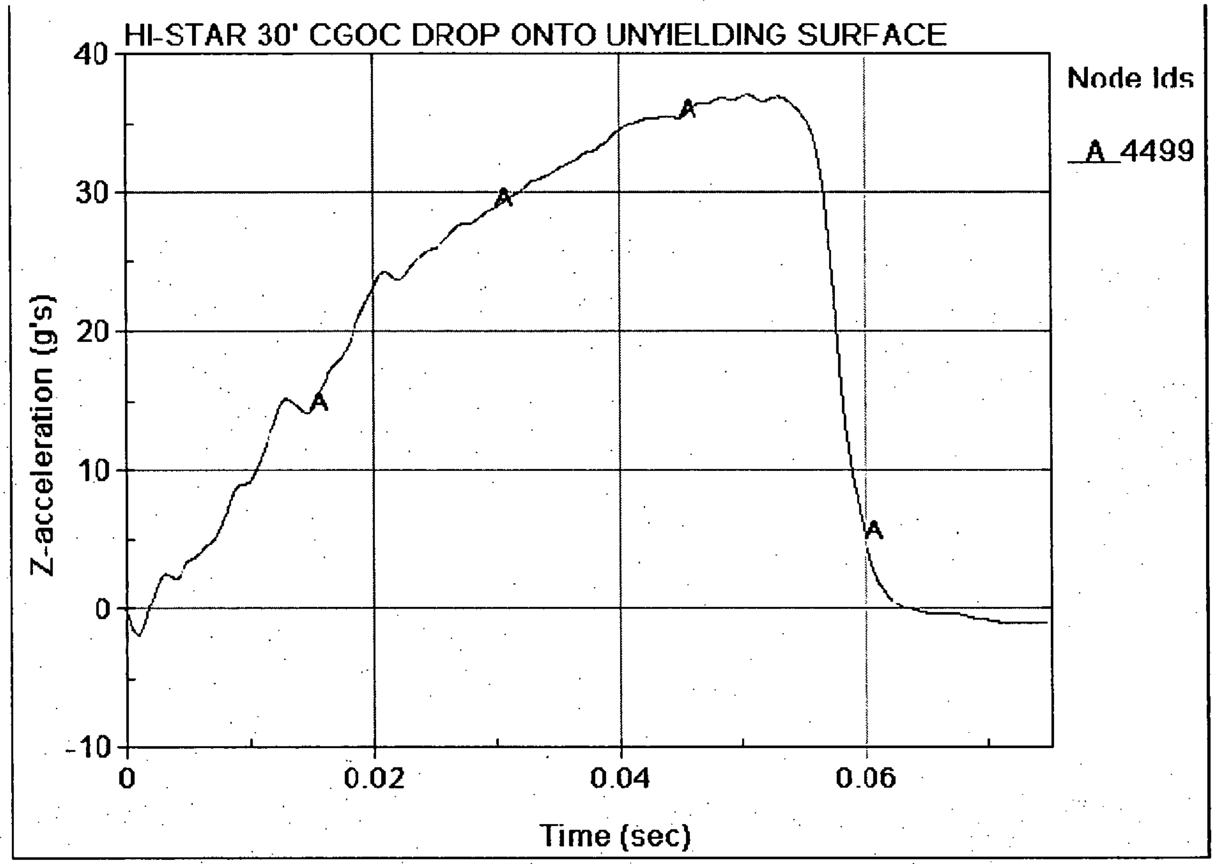


Figure 2.I.7.6 HI-STAR 100 C.G.O.C Deceleration vs. Time Results from LS-DYNA Model of Full-Size HI-STAR 100

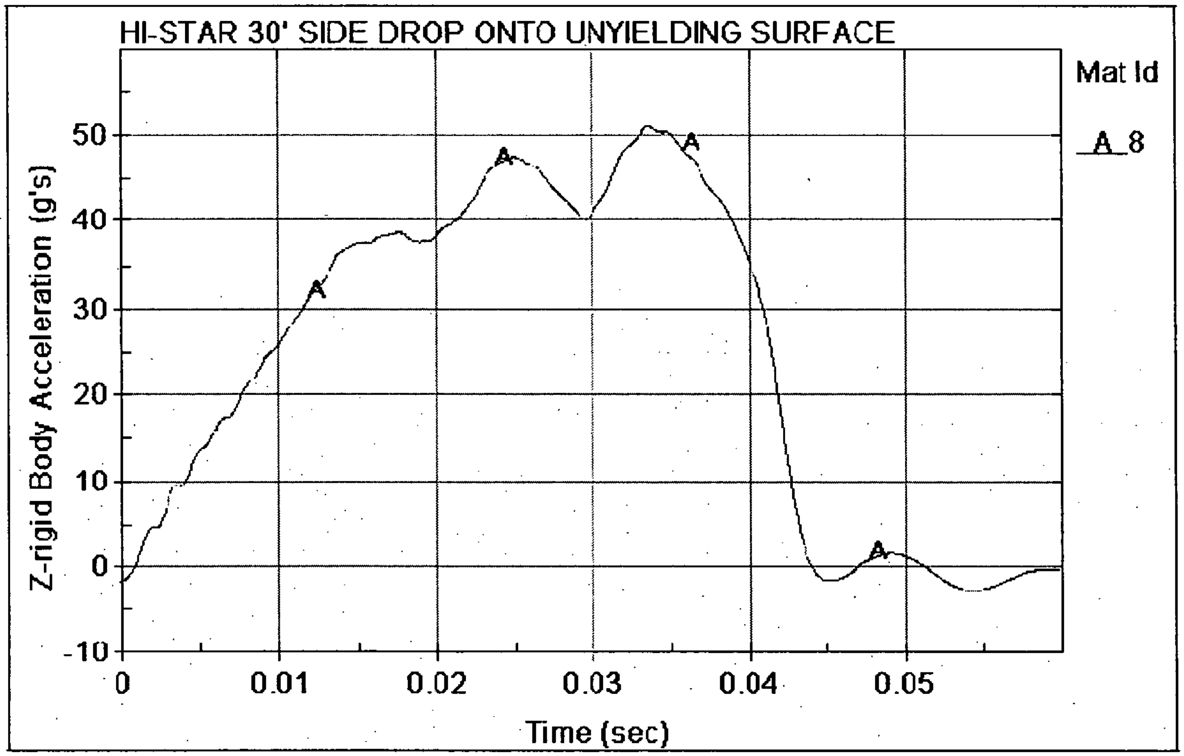


Figure 2.I.7.7: HI-STAR 100 Side Drop Deceleration vs. Time Results from LS-DYNA Model of Full-Size HI-STAR 100

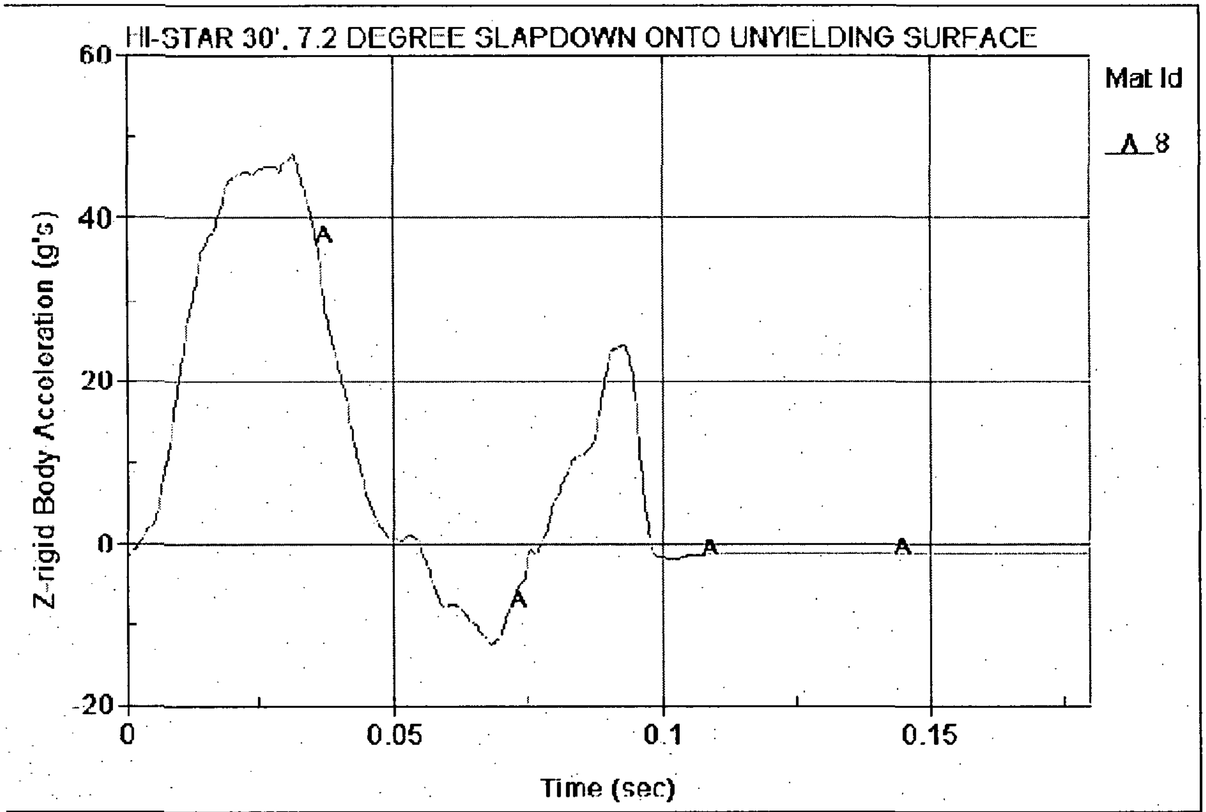
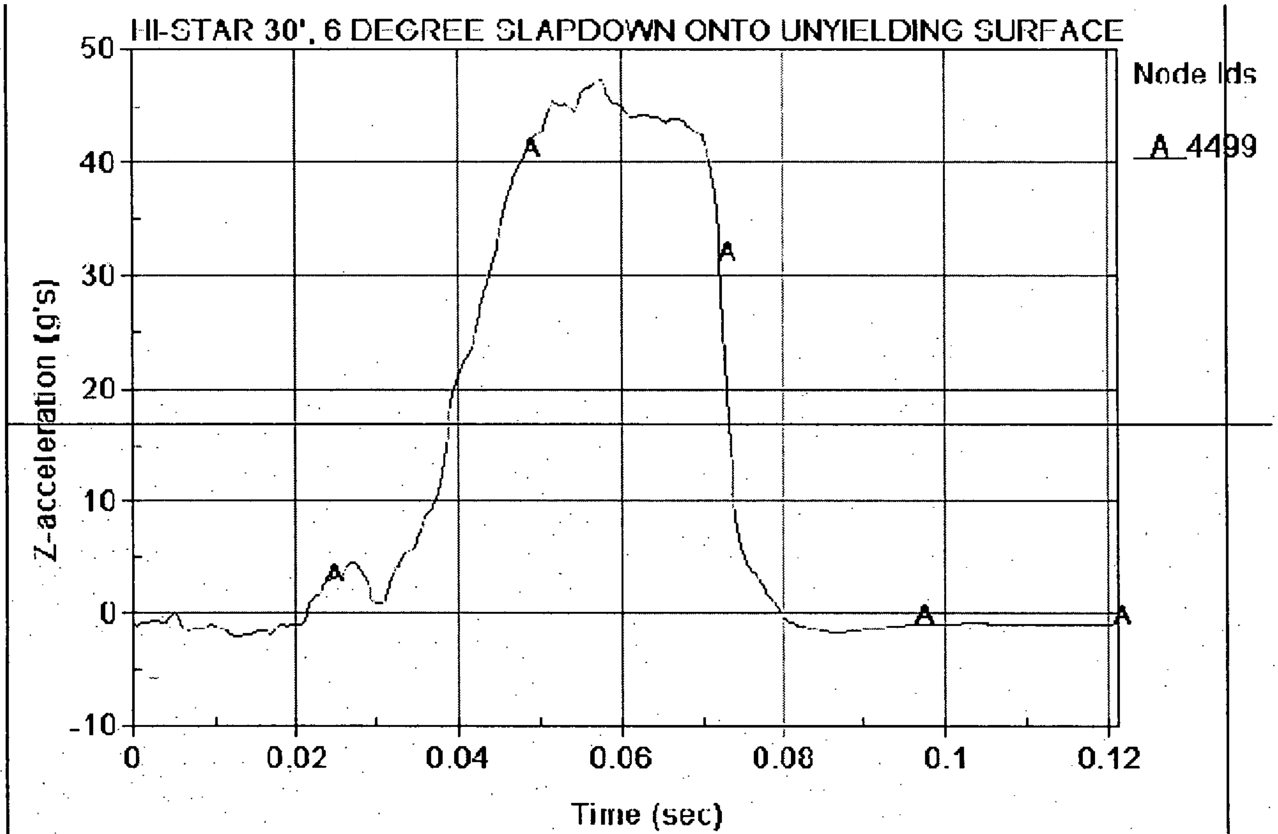


Figure 2.I.7.8 HI-STAR 100 Slapdown Deceleration (Primary Impact) vs. Time Results from LS-DYNA Model of Full-Size HI-STAR 100~~(Primary Impact)~~


HI-STAR 30', 6 DEGREE SLAPDOWN ONTO UNYIELDING SURFACE
Node Ids
A 4499
Z-acceleration (g's)
Time (sec)
50
40
30
20
10
0
-10
0
0.02
0.04
0.06
0.08
0.1
0.12

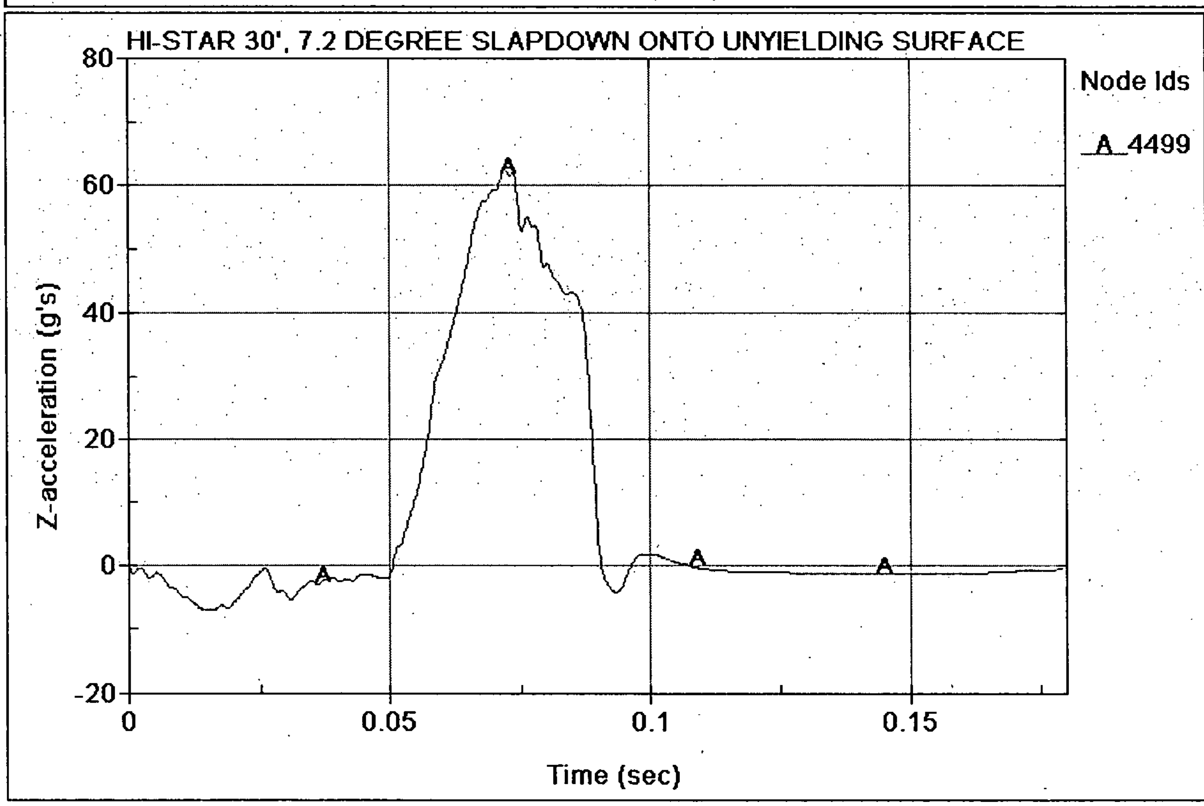

HI-STAR 30', 7.2 DEGREE SLAPDOWN ONTO UNYIELDING SURFACE
Node Ids
A 4499
Z-acceleration (g's)
Time (sec)
80
60
40
20
0
-20
0
0.05
0.1
0.15

Figure 2.I.7.9 HI-STAR 100 Slapdown Deceleration (Secondary Impact) vs. Time Results from LS-DYNA ~~(Secondary Impact)~~ Model of Full-Size HI-STAR 100

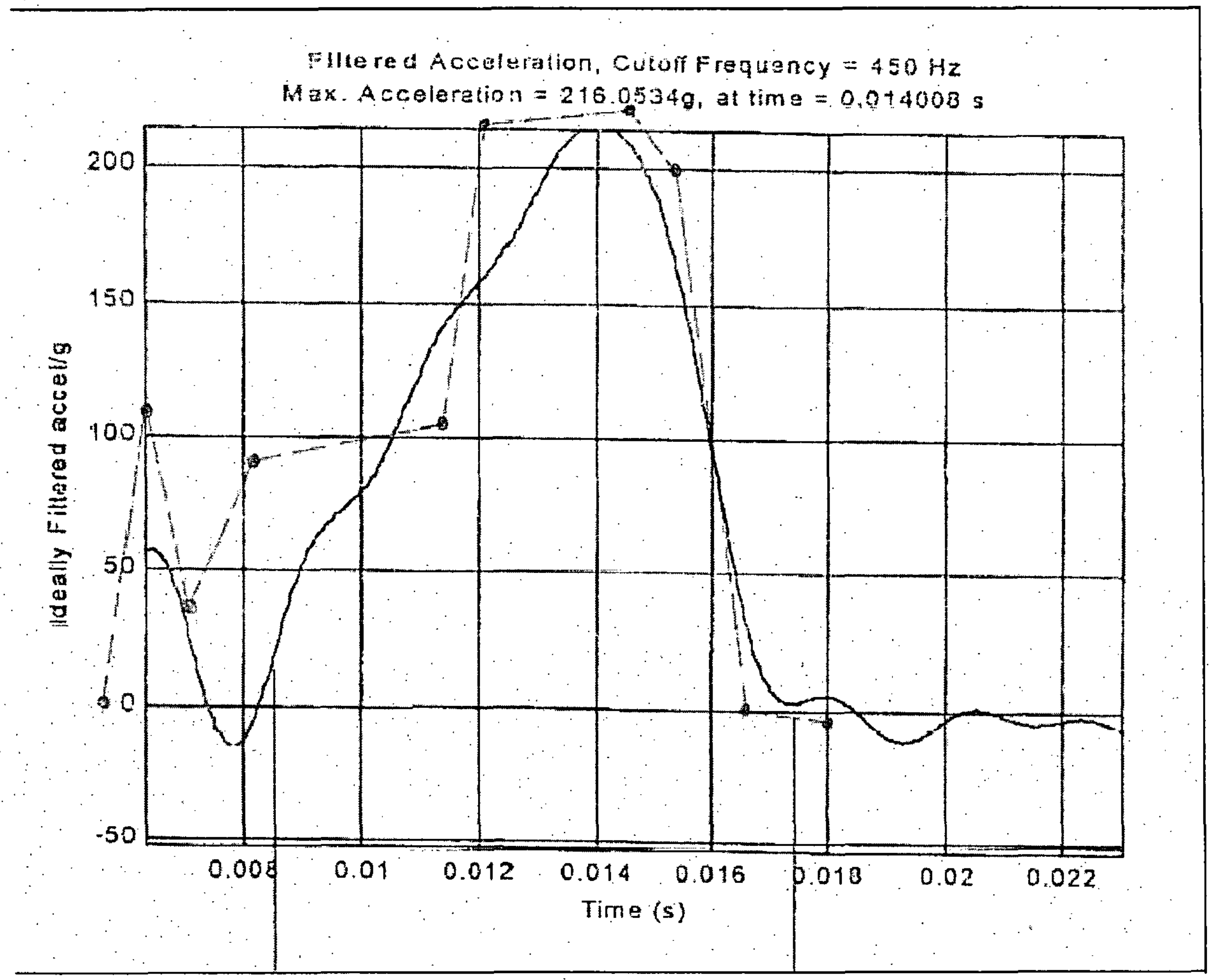


Figure 2.I.7.10 Comparison of Results for Top End Drop – LS-DYNA model (scaled by similarity principle to ¼-scale) vs. Results from ¼-scale drop testing

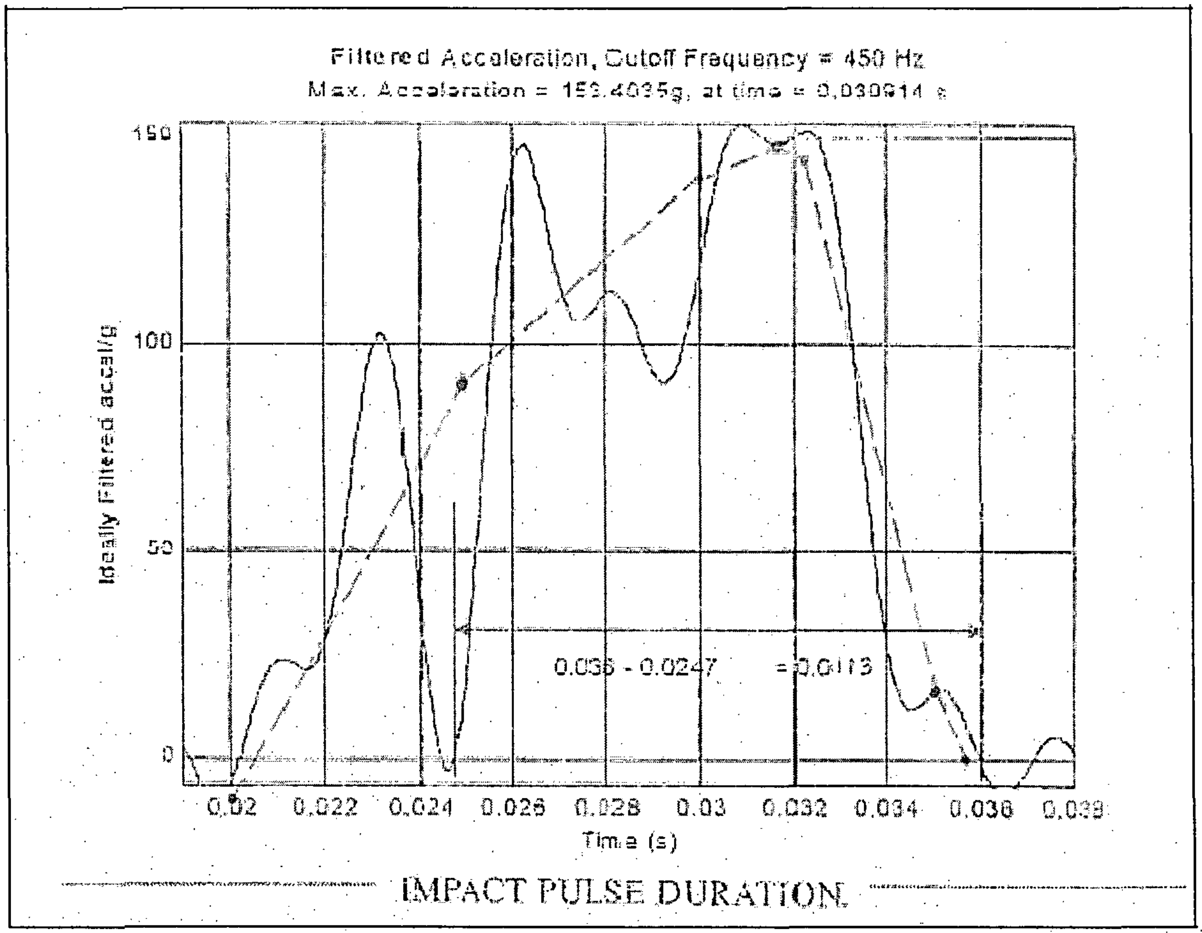
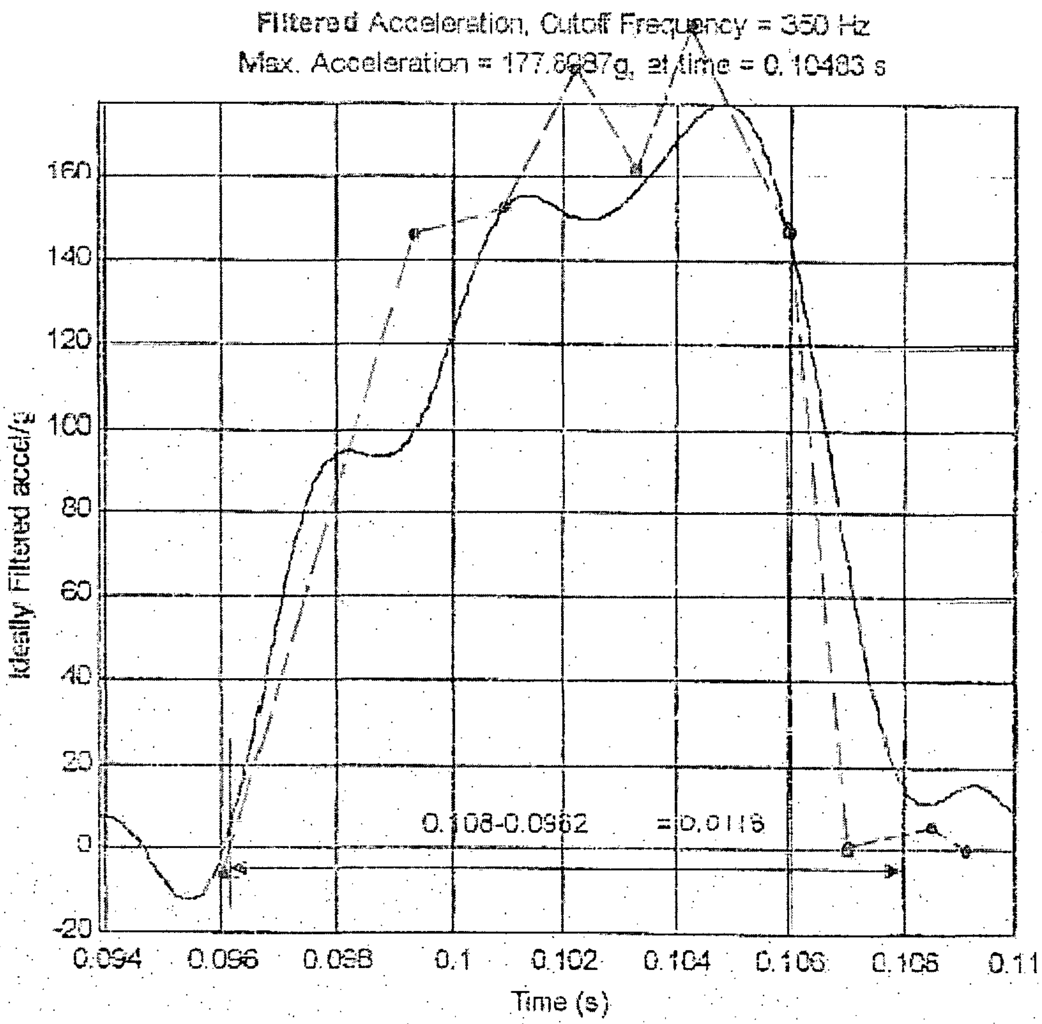


Figure 2.I.7.11 Comparison of Results for C.G.O.C Drop – LS-DYNA model (scaled by similarity principle to ¼-scale) vs. Results from ¼-scale drop testing



IMPACT PULSE DURATION

Figure 2.I.7.12 Comparison of Results for Side Drop – LS-DYNA model (scaled by similarity principle to ¼-scale) vs. Results from ¼-scale drop testing

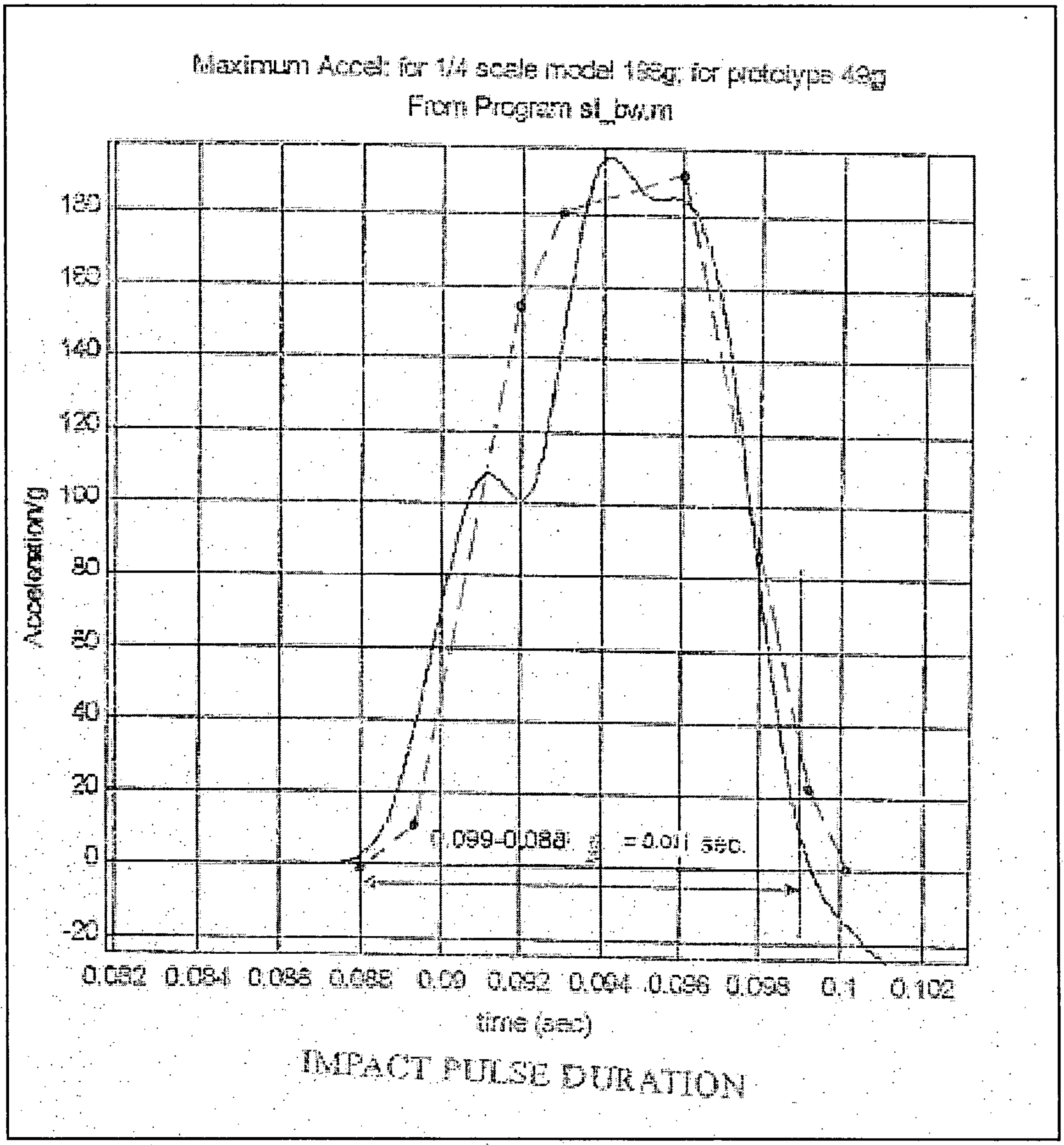
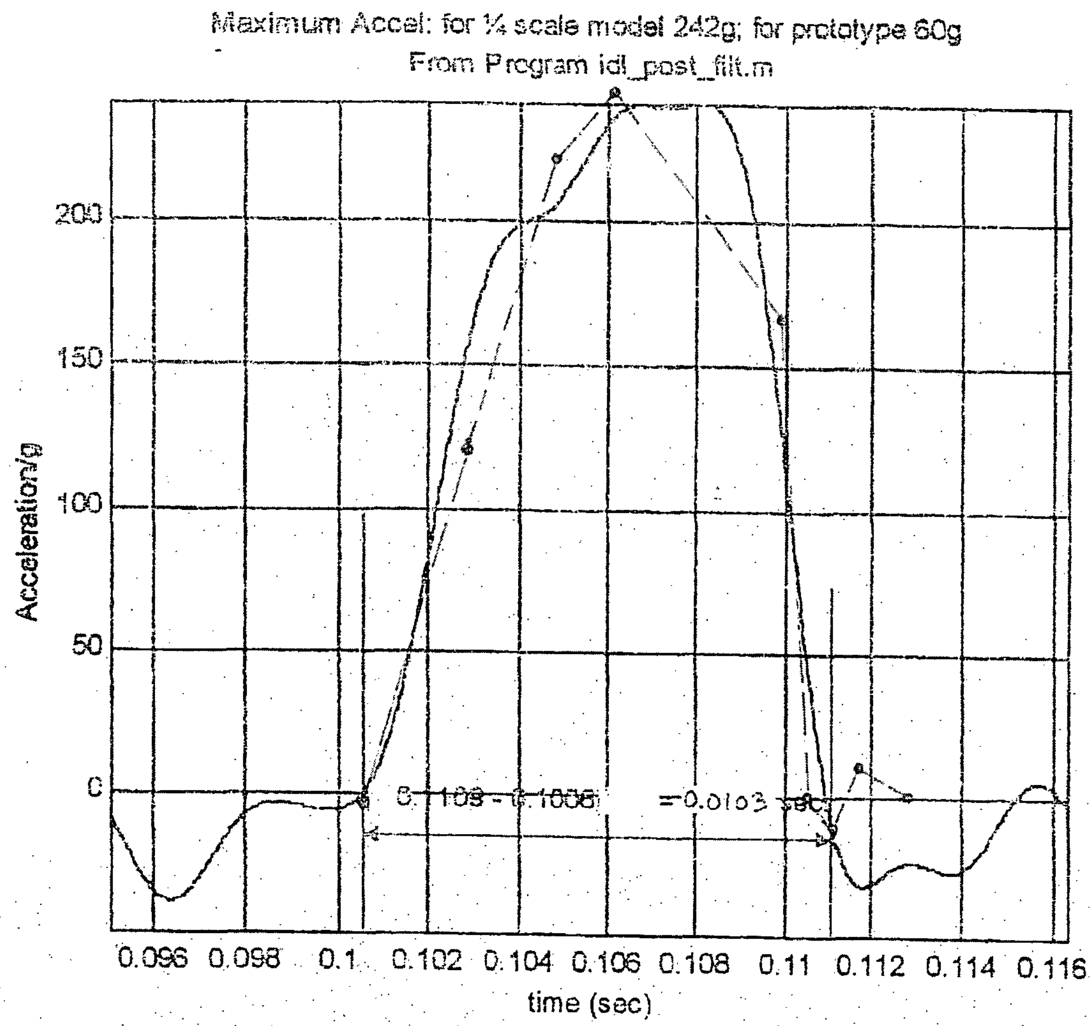


Figure 2.I.7.13 Comparison of Results for Slapdown (Primary Impact) – LS-DYNA model (scaled by similarity principle to ¼-scale) vs. Results from ¼-scale drop testing



IMPACT PULSE DURATION

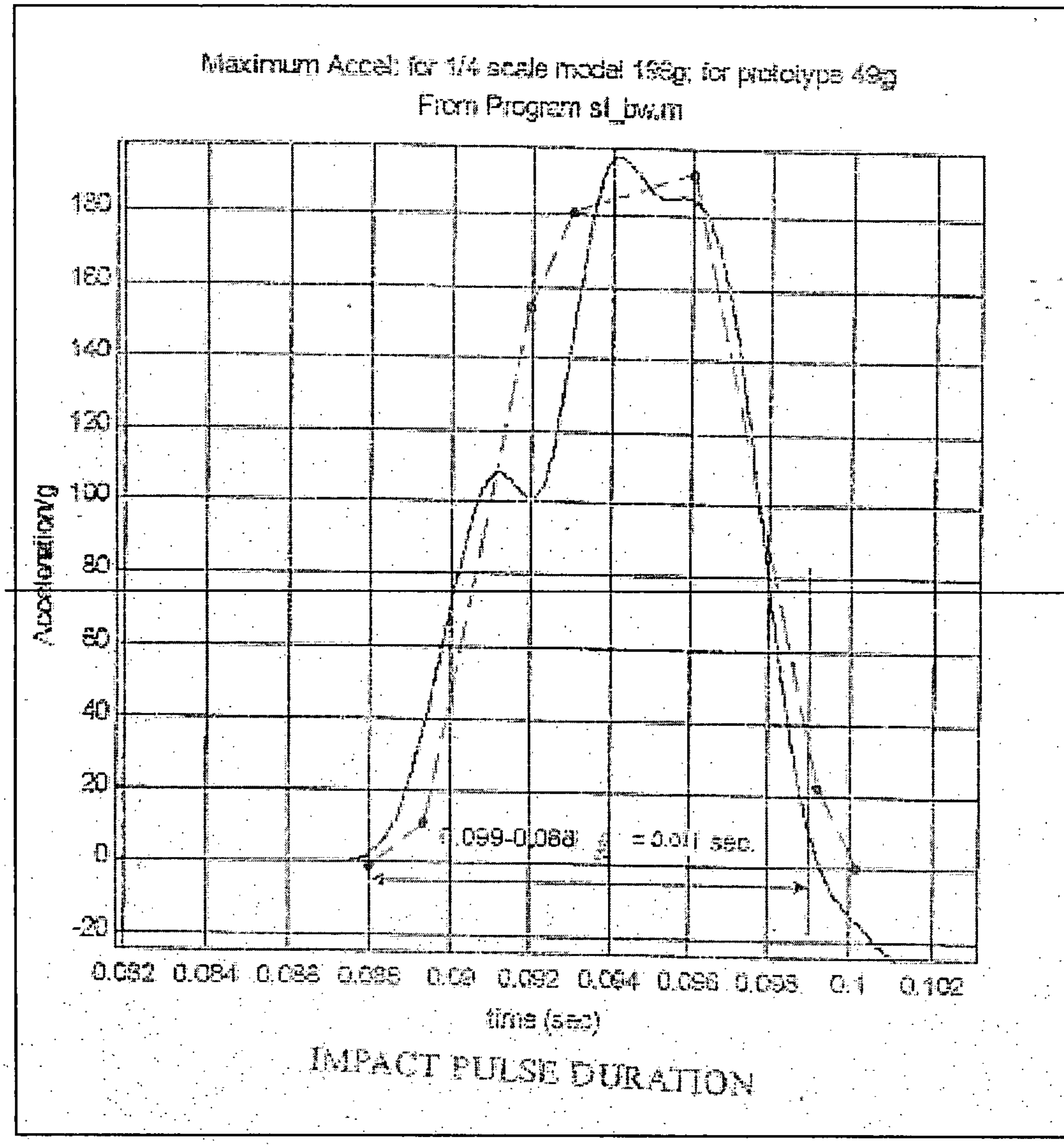


Figure 2.I.7.14 Comparison of Results for Slapdown (Secondary Impact) – LS-DYNA model (scaled by similarity principle to ¼-scale) vs. Results from ¼-scale drop testing

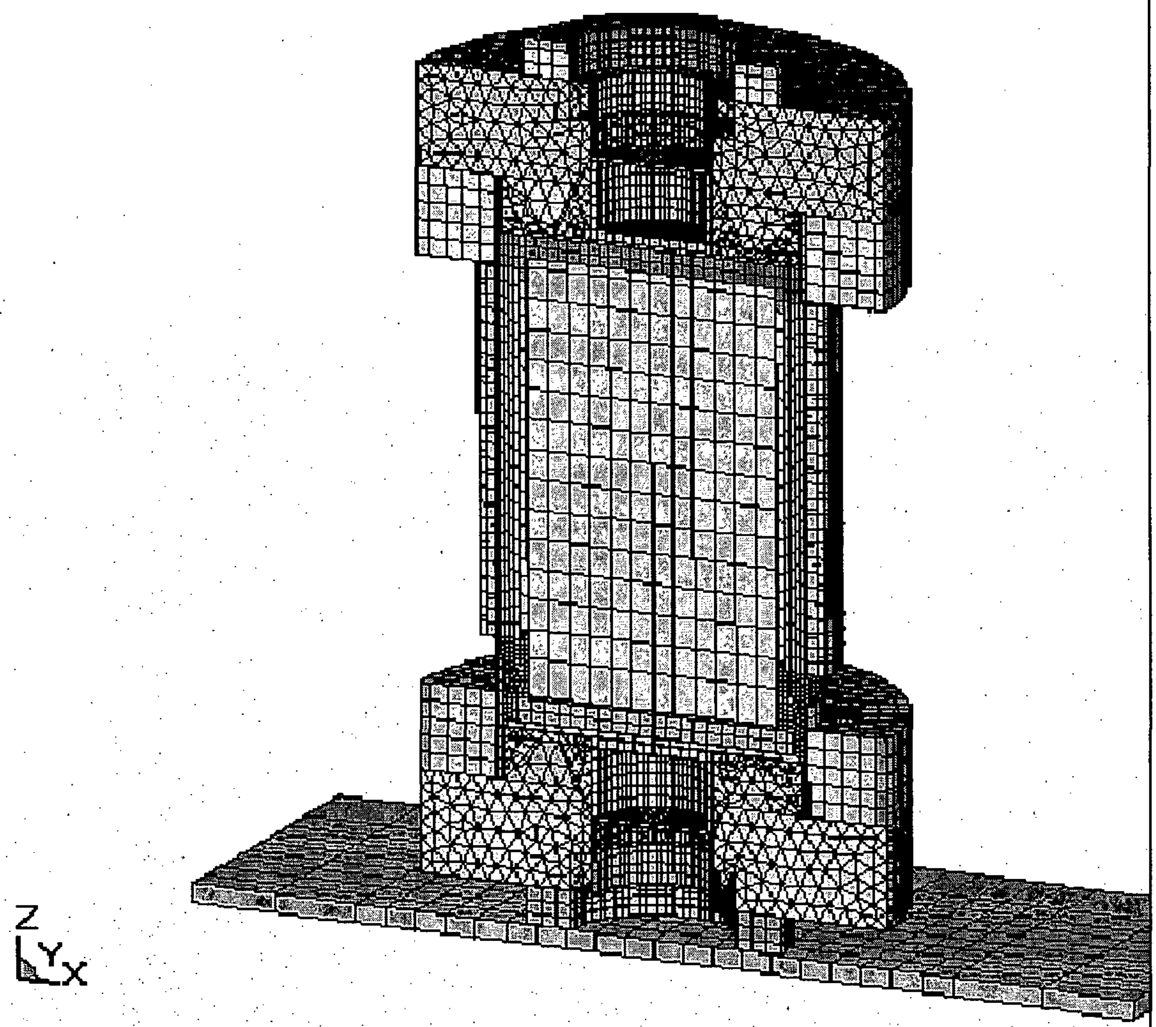


Figure 2.I.7.15 HI-STAR HB Finite Element Model in End Drop Orientation

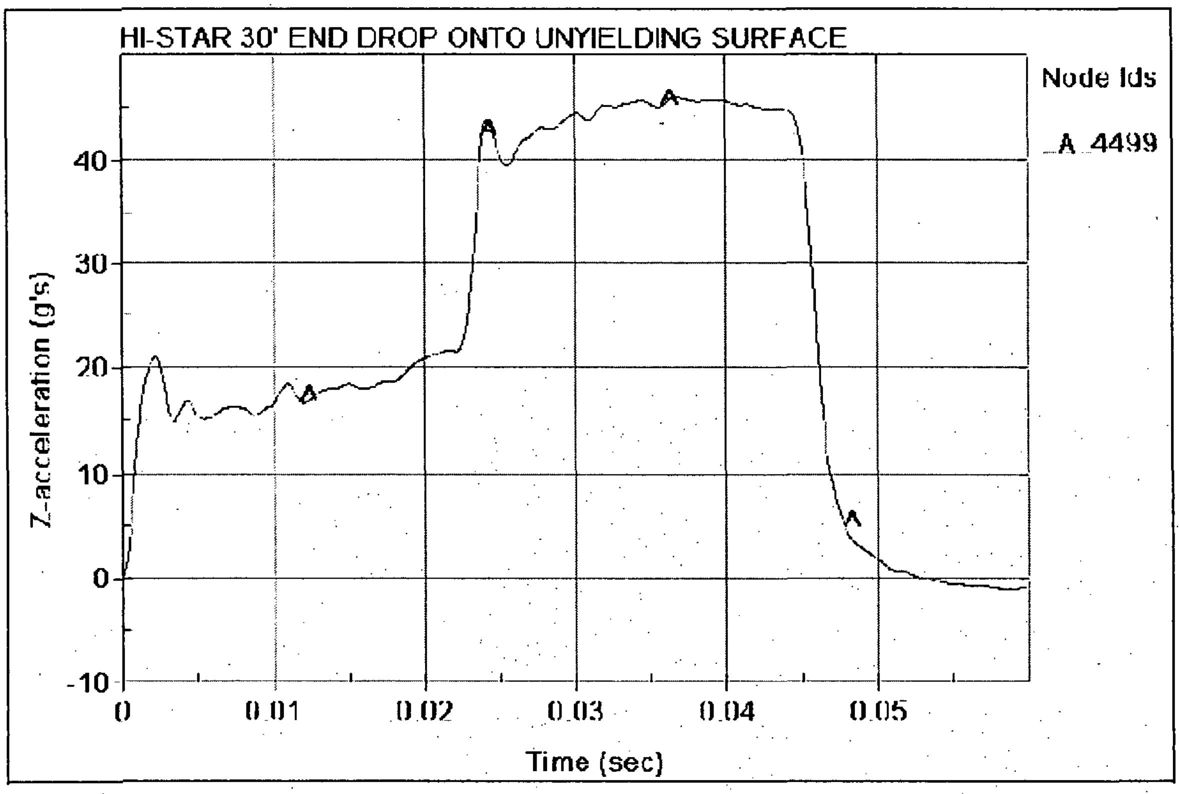
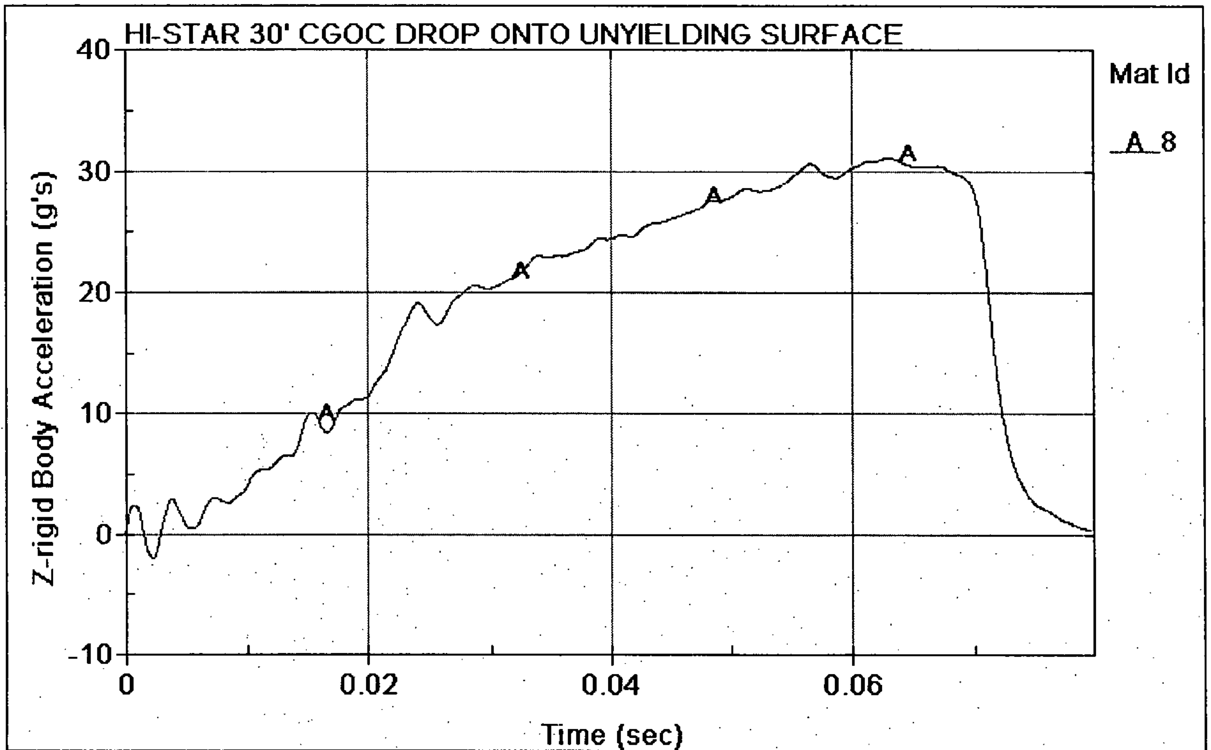


Figure 2.I.7.16 HI-STAR HB End Drop Deceleration vs. Time Results from LS-DYNA Model of Full-Size HI-STAR HB


HI-STAR 30' CGOC DROP ONTO UNYIELDING SURFACE
Mat Id
A 8
Z-rigid Body Acceleration (g's)
40
30
20
10
0
-10
0
0.02
0.04
0.06
Time (sec)

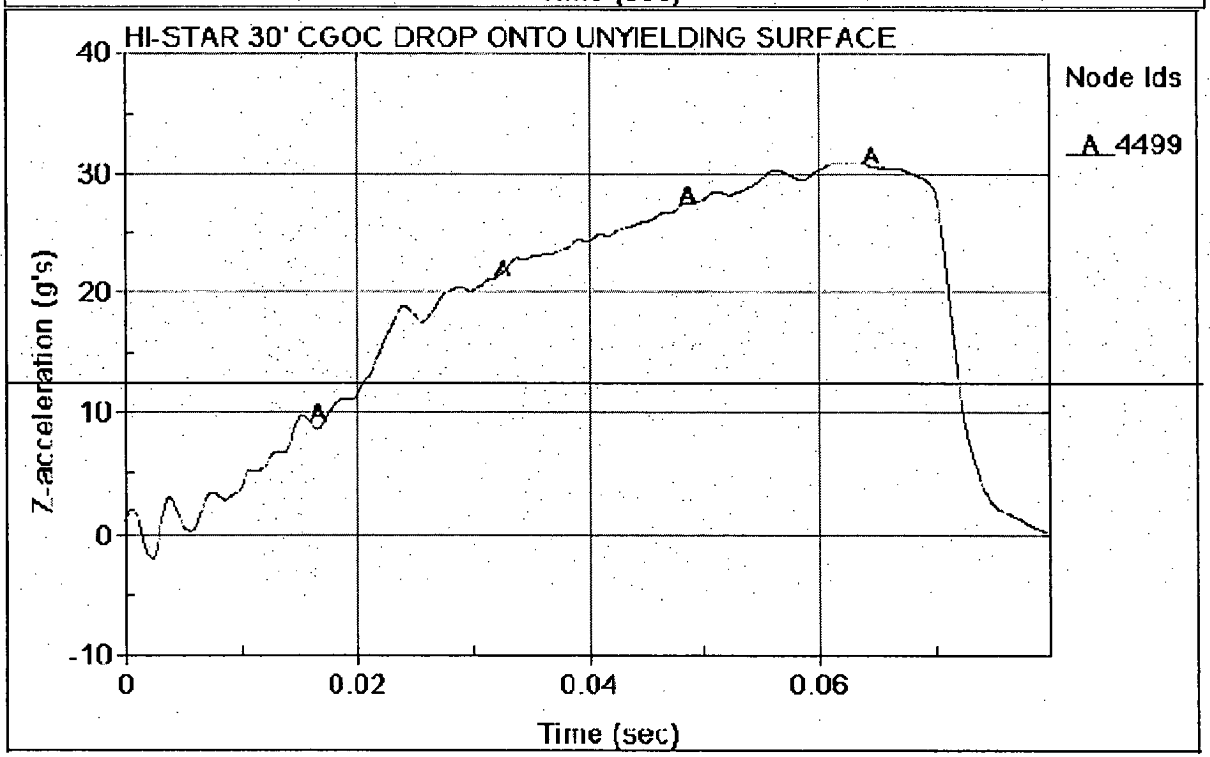

HI-STAR 30' CGOC DROP ONTO UNYIELDING SURFACE
Node Ids
A 4499
Z-acceleration (g's)
40
30
20
10
0
-10
0
0.02
0.04
0.06
Time (sec)

Figure 2.I.7.17 HI-STAR HB C.G.O.C. Drop Deceleration vs. Time Results from LS-DYNA Model of Full-Size HI-STAR HB

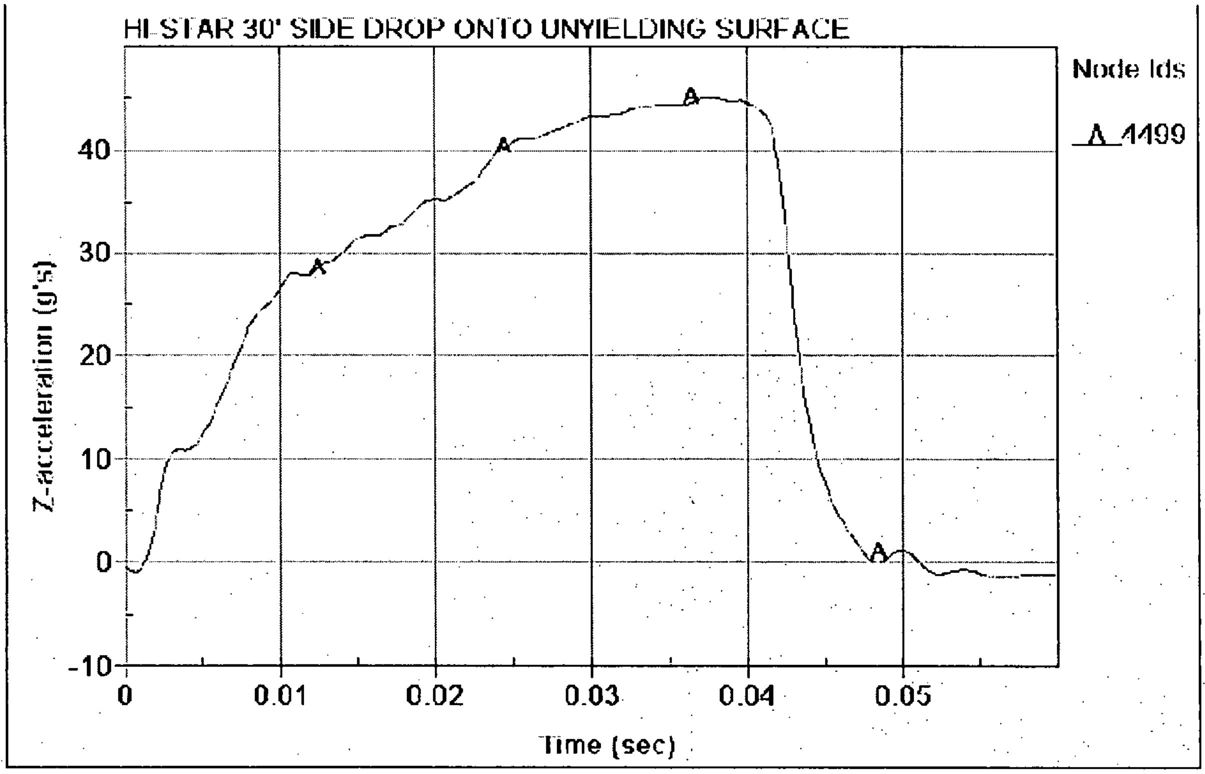


Figure 2.I.7.18 HI-STAR HB Side Drop Deceleration vs. Time Results from LS-DYNA Model of Full-Size HI-STAR HB

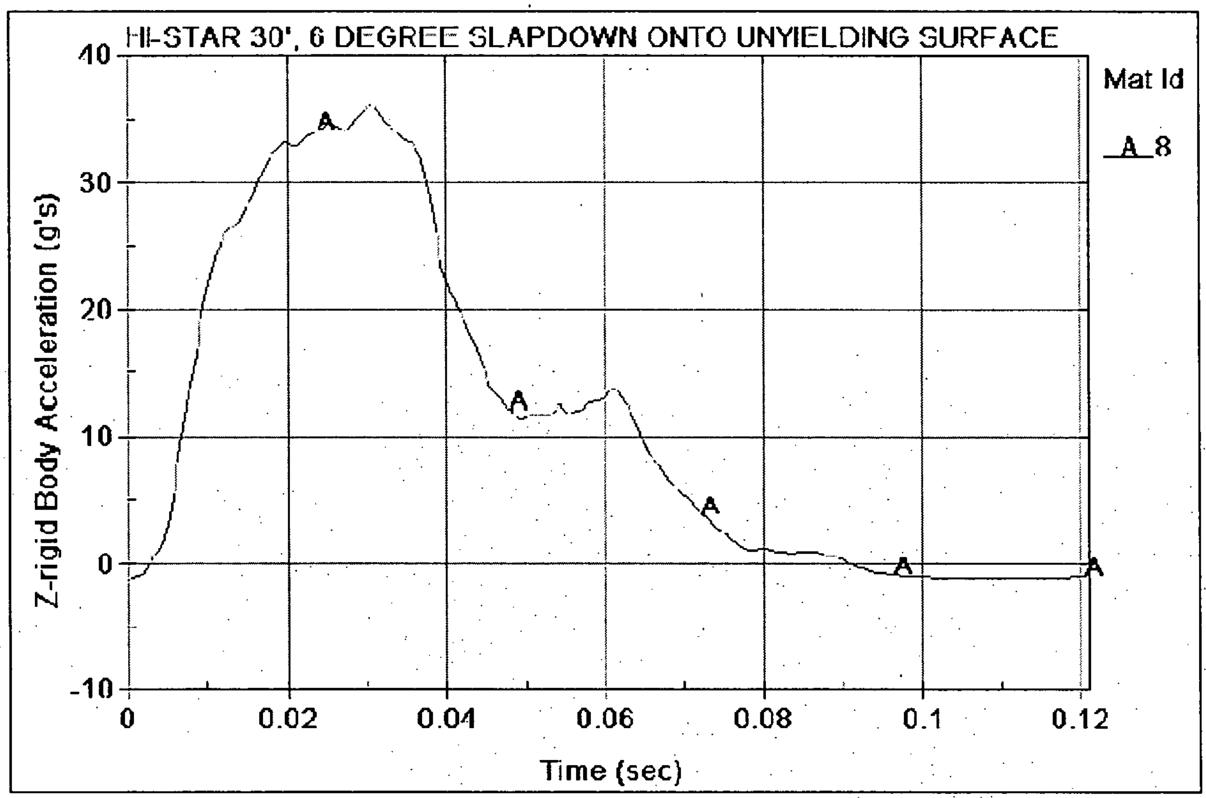


Figure 2.I.7.19 HI-STAR HB Slapdown Deceleration (Primary Impact) vs. Time Results from LS-DYNA Model of Full-Size HI-STAR HB ~~(Primary Impact)~~

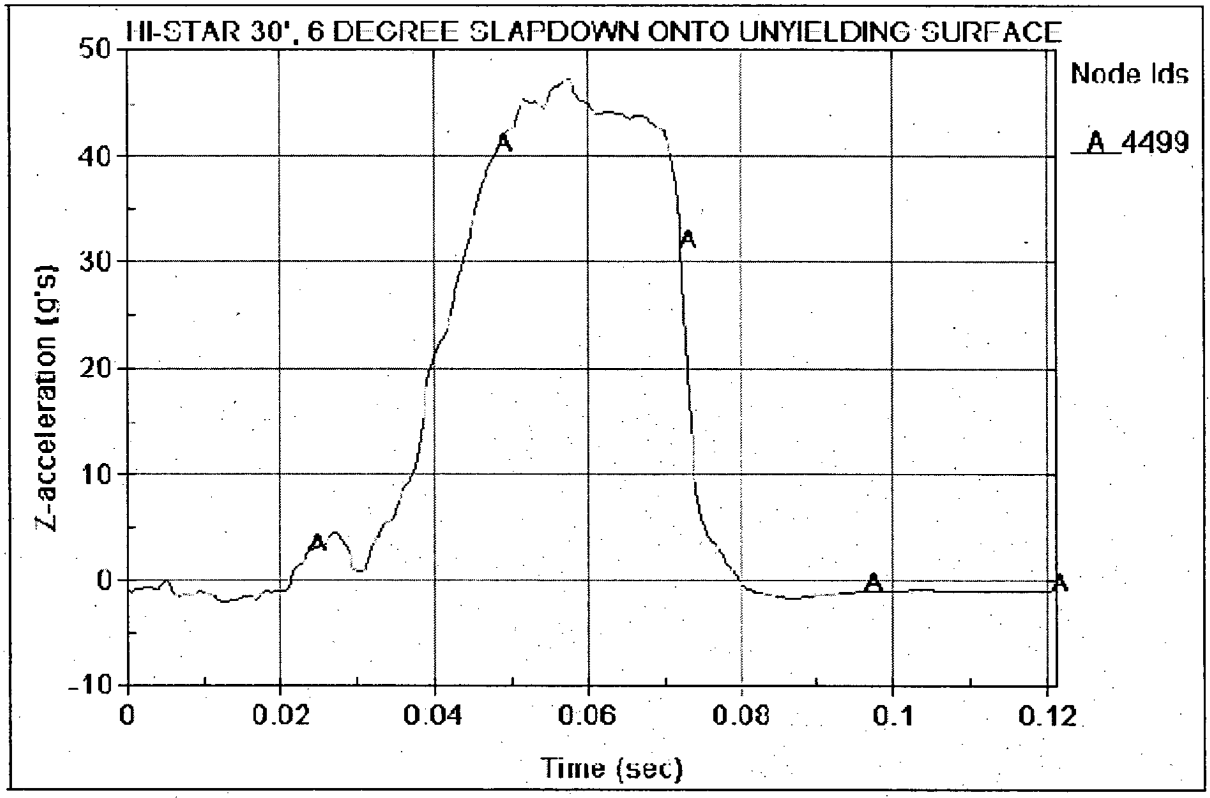


Figure 2.I.7.20 HI-STAR HB Slapdown Deceleration (Secondary Impact) vs. Time Results from LS-DYNA ~~(Secondary Impact)~~Model of Full-Size HI-STAR HB

Appendix 2.B

SUMMARY OF RESULTS FOR STRUCTURAL INTEGRITY OF DAMAGED FUEL CANISTERS

2.B.1 Introduction

Damaged Fuel Canisters or Containers (DFCs) to be deployed in the HI-STAR 100 System transport package have been evaluated to demonstrate that the canisters are structurally adequate to support the mechanical loads postulated during normal lifting operations while in long-term storage, and during a hypothetical end drop accident condition. The evaluations address the following damaged/failed fuel canisters for transportation in the Hi-STAR 100 System:

- Holtec-designed DFC for Dresden Unit 1 and Humboldt Bay fuel
- Transnuclear designed DFC for Dresden Unit 1 fuel
- Dresden Unit 1 Thoria Rod Canister
- Holtec-designed DFC for Trojan plant fuel
- Sierra Nuclear Corporation (SNC)-designed Failed Fuel Can for Trojan plant fuel

2.B.2 Methodology

The structural load path in each of the analyzed canisters was evaluated using basic strength of materials formulations. The various structural components were modeled as axial or bending members and stresses computed. Depending on the particular DFC, the load path includes components such as the container sleeve and collar, various weld configurations, load tabs, closure components and lifting bolts. Axial plus bending stresses were computed, together with applicable bearing stresses and weld stresses. Comparison with appropriate allowable strengths at temperature was performed. Input data for all applicable DFC's came from the drawings. The design temperature for lifting evaluation was 150°F (since the DFC is in the spent fuel pool). The design temperature for accident conditions is 725°F.

For the SNC-designed Trojan Failed Fuel Can, the existing calculations prepared by SNC were reviewed by Holtec and determined to bound the loadings applicable to the HI-STAR 100 System. Therefore, no new calculations were prepared for the Trojan Failed Fuel Can.

2.B.3 Acceptance Criteria

The upper closure assembly must meet the requirements set forth for special lifting devices used in nuclear applications [1]. The remaining components of the damaged fuel canister are governed by the stress limits of the ASME Code Section III, Subsection NG and Section III, Appendix F, as applicable [2].

2.B.4 Assumptions

Buckling is not a concern during an accident since during a drop, the canister will be supported by the walls of the fuel basket.

The strength of welds is assumed to decrease the same as the base metal as temperatures increase.

An inertia load factor 1.15 is applied to all loads during a lifting analysis, except for the lifting analysis of the Trojan failed fuel can which assumes a 10% dynamic load factor.

2.B.5 Summary of Results

Table 2.B.1 presents minimum safety factors for each DFC from among all of the computations and evaluations performed on the different damaged fuel canisters to be certified for transport in the HI-STAR 100 System.

2.B.6 References

[1] ANSI N14-6-1993, "American National Standard for Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4,500 kg) or More for Nuclear Materials", ANSI, Inc.

[2] ASME Boiler and Pressure Vessel Code, Section III, Subsection NG and Appendix F, 1995.

Table 2.B.1

SUMMARY OF SAFETY FACTORS FOR DAMAGED FUEL CONTAINERS

Unit – (Maximum weight including contents -lbs)	**Component**	**Calculated Stress (ksi)**	**Allowable Stress (ksi)**	**Safety Factor = (Allowable Value)/(Calculated Value)**	**Remarks**
Holtec-designed Dresden/~~HB~~ (BWR) DFC	Lifting – Upper Closure Assembly	1.687	1.9251	1.141	Allowable weld stress includes a 0.35 quality factor
	60g end drop	10.667	37.920	3.6	Level D stress limits
Transnuclear DFC (550 lb.)	Lifting – Lid Frame Assembly	0.526	4.583	8.7	Bearing Stress
	60g end drop	12.316	37.920	3.1	Level D stress limits
Dresden Thoria Rod Canister (390 lb.)	Lifting – Lid Frame Assembly	0.3735	4.583	12.27	Bearing Stress
	60g end drop	8.733	37.920	4.3	Level D stress limits
Holtec-designed Trojan DFC (1680 lb.)	Lifting – Lifting Bolt	13.702	25.000	1.825	
	60g end drop	11.618	26.586	2.3	Spot welds
Trojan Failed Fuel Can	Lifting – Lifting Bar	6.2	6.37†	1.03	Bending Stress
	124g end drop	8.25	11.7	1.42††	Level D stress limits

† Allowable stress is equal to 1/3 of yield stress per [1].

†† Conservatively based on bounding 124g vertical end drop used in SNC calculations. Per Table 2.1.10, the design basis deceleration for the HI-STAR 100 is 60g.

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