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UMS®

UNIVERSAL MPC SYSTEM®

SAFETY ANALYSIS REPORT

for the

UMS® Universal Transport Cask

JULY 2002 UMST-02C

VOLUME 1 OF 2

NAC INTERNATIONAL

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Radioactive material shipments in the Universal Transport Cask shall be subject to the following limits:

1. The maximum contents weight for the Universal Transport Cask shall not exceed 77,500 lb.

2. The design basis fuel characteristics shall be in accordance Tables 1.2-4 and 1.2-5.

3. The total decay heat of the cavity contents shall not exceed 20 kW for PWR fuel and 16 kW for BWR fuel.

4. The total weight of the PWR fuel assemblies, including standard inserts such as burnable poison rods or guide tube thimble plugs, shall not exceed 38,500 lb.

5. The total weight of the BWR fuel assemblies shall not exceed 39,000 lb.

6. Radiation levels shall not exceed the requirements of 10 CFR 71.47, 10 CFR 71.51, and IAEA Safety Series No. 6, paragraph 469.

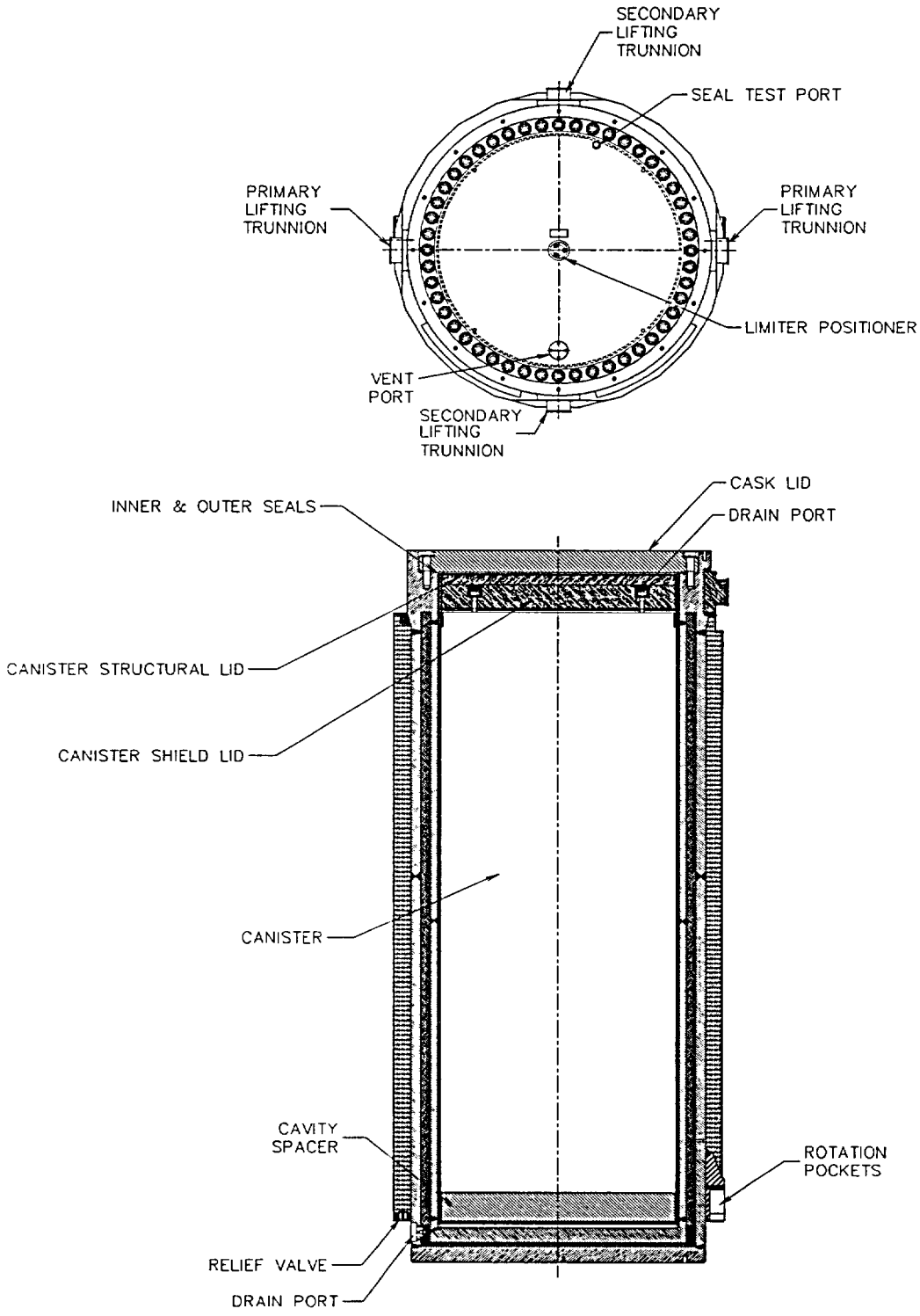
7. Surface contamination levels shall not exceed the requirements of 10 CFR 71.87(i)(1) and IAEA Safety Series No. 6, paragraph 408.

8. Cask general spent fuel contents shall be in accordance with the limiting values shown below, and must be loaded in accordance with Tables 1.2-6 (PWR) and 1.2-7 (BWR):

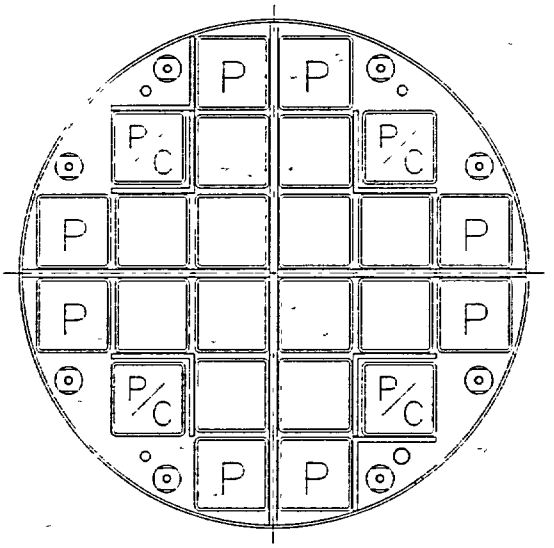
Parameter	PWR Cask	BWR Cask
Number of assemblies	24	56
Max. UO_2 weight (MTU)	11.53	11.08
Max initial enrichment (wt % ^{235}U)	4.2	4.0
Min. initial enrichment (wt.% ^{235}U)	1.9	1.9
Max. Burnup (MWD/MTU)	45,000	45,000
Min. cooling time (years)	5	5

9. Cask site-specific contents may include Maine Yankee fuel with maximum burnup up to 50,000 MWD/MTU and GTCC waste as described in Section 1.3.1.1 based on the site-specific fuel characteristics and preferential loading pattern.

Figure 1.2-1 Operational Schematic for the Universal Transport Cask



Preferential Loading Diagram for Maine Yankee Site Specific Spent Fuel



The canister loading procedures will indicate that the loading of a fuel assembly with removed fuel or poison rods, or a consolidated fuel lattice, is administratively controlled to ensure the correct loading in one of the corner positions and that only one consolidated fuel lattice is loaded in any single canister.

The configurations of the Maine Yankee site specific fuel assemblies that have been evaluated and found to be acceptable contents include:

- Fuel assemblies with up to 176 fuel rods removed from the assembly lattice.
- Fuel assemblies with fuel rods replaced with either stainless steel rods, solid Zircaloy rods or fuel rods enriched to 1.95 wt %.
- Fuel assemblies with burnable poison rods replaced with hollow Zircaloy tubes.
- Fuel assemblies that are variably enriched.
- Fuel assemblies with annular axial blankets.
- Fuel assemblies with a control element inserted.
- Fuel assemblies with an instrument thimble inserted in the center guide tube.
- Fuel assemblies with up to two fuel rods inserted in any or all of the guide tubes.
- Consolidated fuel lattices.
- High burnup fuel assemblies.
- Fuel assemblies with start-up sources and other non-fuel items inserted in the guide tubes.
- Damaged fuel.

A fuel assembly, with a Control Element Assembly (CEA), CEA flow plug, or thimble plug inserted, will be loaded in a Class 2 canister and basket for storage and transport due to the increased length of the assembly with the control element installed; however, such an assembly is not restricted to any specific location within the basket.

A fuel assembly having fuel rods replaced by solid stainless steel or Zircaloy rods may be loaded in any location in the basket.

Intact fuel assemblies may have non-fuel items inserted in the guide tubes. The non-fuel items are irradiated and unirradiated start-up sources, CEA fingertips, and a segment of an in-core instrument (ICI) thimble. Start-up sources are inserted in a center guide tube position. The remaining items must be installed in corner guide tube positions. These guide tubes are closed on the bottom end by the assembly end plate and are closed on the top end by a CEA flow plug. Only one start-up source may be loaded in any fuel assembly; however, a fuel assembly with a start-up source may also hold all of the remaining non-fuel items. Any fuel assembly with a start-up source must be loaded in one of the corner fuel positions of the basket.

The structural evaluation of the Maine Yankee site specific fuel configurations is provided in Section 2.11.1.1. The thermal, containment, shielding and criticality evaluations are provided in Sections 3.6.1.1, 4.5.1.1.1, 5.5.1.1 and 6.6.1.1, respectively. As shown in those evaluations, the design basis spent fuel assembly analyses generally bound the loading of the Maine Yankee spent fuel. Where the design basis analysis is not bounding, preferential loading is required.

Table 1.3.1-1 shows the currently known population of Maine Yankee fuel assemblies. This table also shows the proposed loading scheme for those fuel assemblies in the Transportable Storage Canister.

Acceptable cool times for transport of Maine Yankee fuel without non-fuel material are shown in Table 1.3.1-2. Transport cool times for assemblies containing CEAs or ICI thimbles are given in Tables 1.3.1-3 and 1.3.1-4, respectively. Minimum cool times for the six assemblies containing stainless steel replacement rods are shown in Table 1.3.1-5. Cool times for damaged fuel assemblies loaded into Maine Yankee Damaged Fuel Cans are shown in Table 1.3.1-6. The minimum cool time for the two consolidated fuel assemblies, CN-1 and CN-10, is six years. No additional cool time restraints exist for assemblies loaded with start-up sources or other non-fuel items inserted in guide tubes.

Table 1.3.1-1 Maine Yankee Spent Fuel Population

Spent Fuel Configuration	Number of Assemblies	Canister Loading Position	Canister Class
Standard	1,434	Any	1
Inserted Control Component	168	Any	2
Inserted Instrument Thimble	138	Any	1
Consolidated Fuel	2	P/C	1
Fuel Rod Replaced by Rod Enriched to 1.95 wt.%	8	Any	1
Fuel Rod Replaced by Stainless Steel Rod or Zircaloy Rod	18	Any	1
Fuel Rods Removed	10	P/C	1
Variable Enrichment	72	Any	1
Axial Blanket	68	Any	1
Burnable Poison Rod Replaced by Hollow Zircaloy Rod	80	P/C	1 or 2
Burnup between 45,000 and 50,000 MWD/MTU	90	Any	1
Maine Yankee Fuel Can	As Required	P/C	1
Inserted Start-up Source	5	P/C	1
Inserted CEA Fingertips or ICI String Segment	1	Any	2

1. Only one consolidated fuel lattice may be loaded in any Transportable Storage Canister.

Table 1.3.1-2 Loading Table for Maine Yankee CE14x14 Fuel without Non-Fuel Material – Required Cool Time in Years Before Assembly is Acceptable

Enrichment [wt.%]	Burnup (B) [GWD/MTU]				
	B ≤ 30	30 < B ≤ 35	35 < B ≤ 40	40 < B ≤ 45	45 < B ≤ 50
1.9 ≤ E < 2.1	6 years	8 years	11 years	18 years	27 years
2.1 ≤ E < 2.3	6 years	7 years	10 years	15 years	24 years
2.3 ≤ E < 2.5	6 years	7 years	9 years	14 years	22 years
2.5 ≤ E < 2.7	6 years	7 years	9 years	12 years	19 years
2.7 ≤ E < 2.9	6 years	6 years	8 years	11 years	17 years
2.9 ≤ E < 3.1	5 years	6 years	8 years	10 years	15 years
3.1 ≤ E < 3.3	5 years	6 years	7 years	10 years	15 years
3.3 ≤ E < 3.5	5 years	6 years	7 years	9 years	15 years
3.5 ≤ E < 3.7	5 years	6 years	7 years	9 years	14 years
3.7 ≤ E ≤ 4.2	5 years	6 years	7 years	9 years	14 years

Table 1.3.1-3 Loading Table for Maine Yankee CE14x14 Fuel Containing CEA Cooled to Indicated Time

Loading Table for ce14x14 Fuel - Minimum Required Cool Time in Years						
Burnup	30 GWD/MTU	Minimum Cool Time [y] for				
Enrichment	No CEA (Class 1)	No CEA (Class 2)	5 Yr CEA	10 Yr CEA	15 Yr CEA	20 Yr CEA
1.9	6	6	7	6	6	6
2.1	6	6	7	6	6	6
2.3	6	6	6	6	6	6
2.5	6	6	6	6	6	6
2.7	6	6	6	6	6	6
2.9	5	6	6	6	6	6
3.1	5	5	6	6	6	5
3.3	5	5	6	6	5	5
3.5	5	5	6	5	5	5
3.7	5	5	6	5	5	5
Burnup	35 GWD/MTU	Minimum Cool Time [y] for				
Enrichment	No CEA (Class 1)	No CEA (Class 2)	5 Yr CEA	10 Yr CEA	15 Yr CEA	20 Yr CEA
1.9	8	8	9	8	8	8
2.1	7	7	9	8	8	8
2.3	7	7	8	7	7	7
2.5	7	7	8	7	7	7
2.7	6	7	7	7	7	7
2.9	6	6	7	7	6	6
3.1	6	6	7	6	6	6
3.3	6	6	7	6	6	6
3.5	6	6	6	6	6	6
3.7	6	6	6	6	6	6
Burnup	40 GWD/MTU	Minimum Cool Time [y] for				
Enrichment	No CEA (Class 1)	No CEA (Class 2)	5 Yr CEA	10 Yr CEA	15 Yr CEA	20 Yr CEA
1.9	11	12	14	13	12	12
2.1	10	10	13	11	11	11
2.3	9	9	12	10	10	10
2.5	9	9	10	9	9	9
2.7	8	8	10	9	8	8
2.9	8	8	9	8	8	8
3.1	7	7	8	8	8	8
3.3	7	7	8	7	7	7
3.5	7	7	8	7	7	7
3.7	7	7	7	7	7	7
Burnup	45 GWD/MTU	Minimum Cool Time [y] for				
Enrichment	No CEA (Class 1)	No CEA (Class 2)	5 Yr CEA	10 Yr CEA	15 Yr CEA	20 Yr CEA
1.9	18	18	21	19	18	18
2.1	15	16	19	17	17	16
2.3	14	14	18	16	15	15
2.5	12	13	16	14	14	13
2.7	11	12	14	13	12	12
2.9	10	11	13	12	11	11
3.1	10	10	12	11	10	10
3.3	9	9	11	10	10	10
3.5	9	9	10	10	10	10
3.7	9	9	10	10	10	10
Burnup	50 GWD/MTU	Minimum Cool Time [y] for				
Enrichment	No CEA (Class 1)	No CEA (Class 2)	5 Yr CEA	10 Yr CEA	15 Yr CEA	20 Yr CEA
1.9	27	27	29	27	27	27
2.1	24	24	27	25	24	24
2.3	22	22	25	23	22	22
2.5	19	19	23	21	20	20
2.7	17	17	21	19	18	18
2.9	15	16	19	18	18	18
3.1	15	15	18	17	17	17
3.3	15	15	17	17	17	17
3.5	14	14	15	15	15	15
3.7	14	14	15	15	15	15

Table 1.3.1-4 Loading Table for Maine Yankee GE14x14 Fuel Containing IGI Thimbles

Enrichment	Burnup (B) [GWD/MTU]				
[wt %]	B ≤ 30	30 < B ≤ 35	35 < B ≤ 40	40 < B ≤ 45	45 < B ≤ 50
1.9	6 years	8 years	11 years	18 years	27 years
2.1	6 years	7 years	10 years	16 years	24 years
2.3	6 years	7 years	9 years	14 years	22 years
2.5	6 years	7 years	9 years	13 years	19 years
2.7	6 years	6 years	8 years	11 years	17 years
2.9	5 years	6 years	8 years	10 years	15 years
3.1	5 years	6 years	7 years	10 years	15 years
3.3	5 years	6 years	7 years	9 years	15 years
3.5	5 years	6 years	7 years	9 years	14 years
3.7	5 years	6 years	7 years	9 years	14 years

Table 1.3.1-5 Required Cool Time for Maine Yankee Fuel Assemblies with Activated Stainless Steel Replacement Rods

Assy Number	Burnup [GWD/MTU]	Enrichment [wt %]	SSR Source [g/s/assy]	Cool Time [y]	Earliest Loadable
N420	45	3.3	2.1602E+13	10	Jan 2001
N842	35	3.3	3.1396E+12	6	Jan 2001
N868	40	3.3	5.2444E+12	7	Jan 2001
R032	45	3.5	1.4550E+13	9	Jan 2005
R439	50	3.5	1.3998E+13	14	Jan 2010
R444	50	3.5	5.5993E+13	19	Jan 2015

Table 1.3.1-6 Loading Table for Maine Yankee CE 14x14 Damaged Fuel

Enrichment wt % ^{235}U	Burnup (B) [GWD/MTU]				
	B ≤ 30	30 < B ≤ 35	35 < B ≤ 40	40 < B ≤ 45	45 < B ≤ 50
1.9	7 years	11 years	19 years	28 years	37 years
2.1	6 years	9 years	16 years	26 years	34 years
2.3	6 years	8 years	14 years	23 years	32 years
2.5	6 years	8 years	12 years	21 years	30 years
2.7	6 years	7 years	11 years	19 years	27 years
2.9	6 years	7 years	10 years	17 years	25 years
3.1	5 years	7 years	9 years	15 years	23 years
3.3	5 years	6 years	8 years	13 years	21 years
3.5	5 years	6 years	8 years	12 years	19 years
3.7	5 years	6 years	7 years	11 years	17 years

1.3.1.1.2 Maine Yankee Greater Than Class C Waste

The disposal of Greater Than Class C (GTCC) waste is controlled by 10 CFR 61 [7]. GTCC is defined in 10 CFR 61.55(a)(3) and (4) by the concentration of long-lived radionuclides, i.e., ^{14}C, ^{59}Ni, and ^{94}Nb, and/or short-lived radionuclides, i.e., ^{3}H, ^{60}Co, and ^{63}Ni.

GTCC waste consists of radiation activated and surface contaminated steel. Stainless steel core baffle structure, which is located adjacent to the reactor vessel in a high neutron flux field, is the major component of GTCC waste. The core baffle structure is cut underwater into pieces that are loaded into a GTCC basket. The GTCC basket is installed in a GTCC canister that has the same external dimensions as a Class 1 fuel canister.

The principal isotopic constituents of typical GTCC waste are presented in Table 1.3.1-7. The radionuclide composition of the waste was determined based on radiochemical assay of samples and dose rate measurements of the waste containers. The isotopes that primarily contribute to the radiological source term are ^{54}Mn, ^{55}Fe, ^{60}Co, and ^{63}Ni. The source terms applied in the evaluation of the GTCC waste are presented in Table 5.5.1.2-1. There is no combustible gas generation from the GTCC waste and there are no chemical or galvanic corrosion reactions with the stainless steel canister.

The design of the GTCC canister and basket is shown in Drawings 790-612 and 790-611, respectively. This basket is designed to fit the Class 1 Transportable Storage Canister. The structural evaluation of the basket for Maine Yankee waste is shown in Section 2.11.2. The thermal evaluation is shown in Section 3.6.1. The containment and shielding evaluations are shown in Sections 4.5.1.1 and 5.5.1.2, respectively. Since the GTCC waste does not contain any significant fissionable material, no criticality analysis is required.

The calculated weight of the loaded and sealed GTCC waste canister is:

	Pounds
GTCC waste canister (with both lids)	18,140
Weight of GTCC basket	32,320
Weight of GTCC waste	20,000
Total	70,460

This weight is less than the weight of the Class 1 Transportable Storage Canister containing spent fuel.

The GTCC waste canister is essentially identical to the UMS® Class 1 Transportable Storage Canister, except for the placement of lifting lugs and the placement of a keyway within the canister. Consequently, the interior and exterior dimensions and the materials of fabrication of the GTCC waste canister and lids are the same as those for the Class 1 canister. The GTCC basket is constructed of Type 304 stainless steel and consists primarily of a cylinder with a ⅜-inch thick wall closed at the bottom end with a ⅜-inch thick stainless steel plate. The cylinder is centered in the GTCC waste canister by 14 Type 304 stainless steel support plates along its length. The support plates are 1-inch thick and 65⅜ inches in diameter. The interior diameter of the basket cavity is 48⅜ inches and its interior length is 157 inches. A ⅜-inch thick stainless steel separator fixture divides the cylinder into two vertically stacked compartments, each 77 inches deep. The separator fixture restricts the diameter of the upper compartment to 47⅜ inches.

Since the GTCC waste canister has the same external dimensions as the UMS® Class 1 Transportable Storage Canister, one 16.75-inch canister spacer is required during transport of the GTCC waste canister. Transport spacers are described in Section 1.2.1.2.9.

Table 1.3.1-7 Isotopic Constituents of the Design Basis GTCC Waste

Radionuclide	Curie Inventory (Ci)/Canister
^{3}H	3.00E+02
^{14}C	1.50E+02
^{54}Mn	3.50E+02
^{55}Fe	2.00E+05
^{58}Co	1.00E+01
^{60}Co	2.90E+05
^{59}Ni	8.20E+02
^{63}Ni	9.00E+04
^{94}Nb	1.00E+01
^{99}Tc	1.00E+01
Total	5.82E+05

1.3.4 License Drawings

This section contains the License Drawings pertinent to the Universal Transport Cask. The dimensions indicated on the drawings are generally limited to one significant digit past the decimal point. Note that analysis of systems or components may present dimensions with additional significant digits based on more detailed engineering drawings.

Drawing No.	Rev. No.	Title
790-209	1	Impact Limiter Assembly-Upper, Cask, NAC-UMS®
790-210	1	Impact Limiter Assembly-Lower, Cask, NAC-UMS®
790-500	2	Assembly, Universal Transport Cask, Overpack, NAC-UMS®
790-501	5	Canister/Basket Assembly Table, NAC-UMS®
790-502	5	Cask Body, Transport Cask, NAC-UMS®
790-503	2	Lid Assembly, NAC-UMS® Cask
790-504	2	Port Coverplate Assembly, NAC-UMS®
790-505	1	Lifting Trunnion, NAC-UMS®
790-508	2	Misc. Details, Transport Cask, NAC-UMS®
790-509	2	Nameplates - NAC-UMS®
790-516	2	Package Assembly, Universal Transport Cask (UTC), NAC-UMS®
790-519	1	Package Assembly, Transport, Universal Transport Cask (UTC), NAC-UMS®
790-520	2	Spacers, Universal Transport Cask, NAC-UMS®
790-570	4	Fuel Basket Assembly, 56 Element BWR NAC-UMS®
790-571	2	Bottom Weldment, Fuel Basket, 56 Element BWR NAC-UMS®

Licensed Drawings (Continued)

Drawing No.	Rev. No.	Title
790-572	4	Top Weldment, Fuel Basket, 56 Element BWR, NAC-UMS®
790-573	7	Support Disk and Misc. Basket Details, 56 Element BWR, NAC-UMS®
790-574	3	Heat Transfer Disk, Fuel Basket, 56 Element BWR, NAC-UMS®
790-575	7	BWR Fuel Tube, NAC-UMS®
790-581	5	PWR Fuel Tube, NAC-UMS®
790-582	7	Shell Weldment, Canister, NAC-UMS®
790-583	4	Assembly, Drain Tube, Canister, NAC-UMS®
790-584	11	Details, Canister, NAC-UMS®
790-585	8	Transportable Storage Canister (TSC), NAC-UMS®
790-591	2	Bottom Weldment, Fuel Basket, 24 Element PWR, NAC-UMS®
790-592	5	Top Weldment, Fuel Basket, 24 Element PWR, NAC-UMS®
790-593	4	Support Disk and Misc. Basket Details, 24 Element PWR, NAC-UMS®
790-594	2	Heat Transfer Disk, Fuel Basket, 24 Element PWR, NAC-UMS®
790-595	5	Fuel Basket Assembly, 24 Element PWR, NAC-UMS®
790-605	8	BWR Fuel Tube, Over-Sized Fuel, NAC-UMS®
790-611	3	GTCC Waste Basket, Maine Yankee, NAC-UMS®
790-612	3	GTCC Waste Canister, Maine Yankee, NAC-UMS®
412-501	2	Spent Fuel Can Assembly, Maine Yankee (MY), NAC-UMS®
412-502	2	Fuel Can Details, Maine Yankee (MY), NAC-UMS®

FIGURE WITHHELD UNDER 10 CFR 2.390

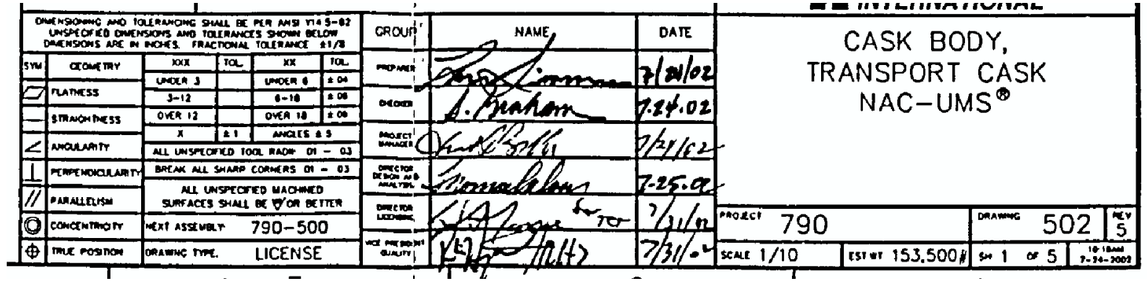


FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

CASK BODY,
TRANSPORT CASK
NAC-UMS®

PROJECT 790		DRAWING 502	REV 5
SCALE 1/6	EST WT	SH 2 OF 5	7-18-2009

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

CASK BODY,
TRANSPORT CASK
NAC-UMS®

PROJECT		DRAWING	REV
790		502	5
SCALE 1/12	EST WT	SH 3 OF 5	2:40PM 7-10-2009

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

CASK BODY,
TRANSPORT CASK
NAC-UMS®

PROJECT 790		DRAWING 502	REV 5
SCALE NOTED	EST WT	SH 4 OF 5	2:30PM 7-24-2002

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

CASK BODY,
TRANSPORT CASK
NAC-UMS®

PROJECT 790		DRAWING 502	REV 5
SCALE 1/6	EST WT	SH 5 OF 5	3:23PM 7-10-2003

FIGURE WITHHELD UNDER 10 CFR 2.390

DIMENSIONING AND TOLERANCING SHALL BE PER ASME Y14.5-94 UNSPECIFIED DIMENSIONS AND TOLERANCES SHOWN BELOW DIMENSIONS ARE IN INCHES. FRACTIONAL TOLERANCE ±1/8						GROUP	NAME	DATE	LID ASSEMBLY, NAC-UMS®
SYM	GEOMETRY	XXX	TOL.	XX	TOL.	PREPARER		7/16/02	
	FLATNESS	UNDER 3	± .001	UNDER 6	± .02	CHECKER		7.19.02	
		3-12	± .005	6-18	± .03	PROJECT MANAGER		7/18/02	
	STRAIGHTNESS	OVER 12	± .010	OVER 18	± .06	DIRECTOR DESIGN AND ANALYSIS		7-24-02	
		X	± .1	ANGLES ±0.5		DIRECTOR LICENSING		7/23/02	
	ANGULARITY	ALL UNSPECIFIED TOOL RADII .015 - .030				VICE PRESIDENT QUALITY		7/31/02	
	PERPENDICULARITY	BREAK ALL SHARP CORNERS .015 - .030							
	PARALLELISM	ALL UNSPECIFIED MACHINED SURFACES SHALL BE 125 OR BETTER							
	CONCENTRICITY	NEXT ASSEMBLY 790-500							
	TRUE POSITION	DRAWING TYPE LICENSE							

PROJECT	790	DRAWING	503	REV 2
SCALE 1/6	EST WT 8200#	SH 1 OF 3	12 3/16 X 9-1/4 PAPER	

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

LID ASSEMBLY,
NAC-UMS®

PROJECT 790		DRAWING 503	REV 2
SCALE 1/6	EST WT	SH 2 OF 3	1-3-APR 7-15-1998

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

LID ASSEMBLY
NAC-UMS®

PROJECT 790		DRAWING 503	REV 2
SCALE 1/6	EST WT	SH 3 OF 3	1 SHEET 7-10-2009

A

1

FIGURE WITHHELD UNDER 10 CFR 2.390

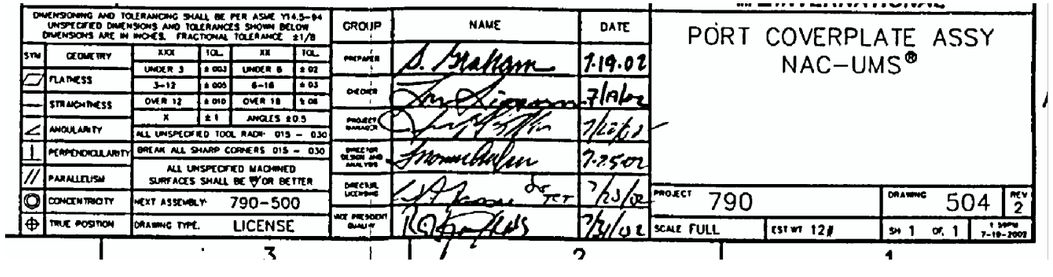


FIGURE WITHHELD UNDER 10 CFR 2.390

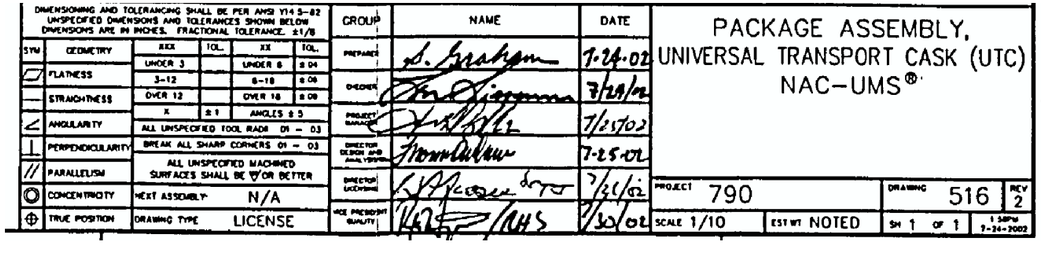


FIGURE WITHHELD UNDER 10 CFR 2.390

DIMENSIONING AND TOLERANCING SHALL BE PER ASME Y14.5-94
UNSPECIFIED DIMENSIONS AND TOLERANCES SHOWN BELOW
DIMENSIONS ARE IN INCHES. FRACTIONAL TOLERANCE ±1/8

SYM	GEOMETRY	.XXX	TOL.	.XX	TOL.
		UNDER 3	±.003	UNDER 6	±.02
⏥	FLATNESS	3-12	±.005	6-18	±.03
—	STRAIGHTNESS	OVER 12	±.010	OVER 18	±.06
		.X	±.1	ANGLES ±0.5	
∠	ANGULARITY	ALL UNSPECIFIED TOOL RADII .015 - .030			
⊥	PERPENDICULARITY	BREAK ALL SHARP CORNERS .015 - .030			
//	PARALLELISM	ALL UNSPECIFIED MACHINED SURFACES SHALL BE ▽ OR BETTER			
◎	CONCENTRICITY	NEXT ASSEMBLY: N/A			
⊕	TRUE POSITION	DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARER	S. Graham	7-24-02
CHECKER	[illegible]	7/24/02
PROJECT MANAGER	[illegible]	7/24/02
DIRECTOR DESIGN AND ANALYSIS	[illegible]	7-25-02
DIRECTOR LICENSING	[illegible]	7/26/02
VICE PRESIDENT QUALITY	[illegible]	7/30/02

PACKAGE ASSEMBLY,
TRANSPORT,
UNIVERSAL TRANSPORT CASK (UTC)
NAC-UMS®

PROJECT 790	DRAWING 519	REV 1
SCALE 1/10	EST WT NOTED	SH 1 OF 1

FIGURE WITHHELD UNDER 10 CFR 2.390

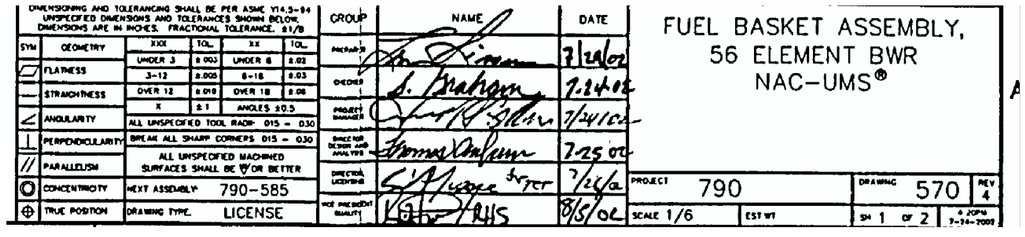


FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

FUEL BASKET ASSEMBLY,
56 ELEMENT BWR
NAC-UMS®

PROJECT 790		DRAWING 570	REV 4
SCALE 1/6	EST WT	SH 2 OF 2	12:32PM 7-10-2007

Chapter 2

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forging when redundant lifts are performed. The purpose of the trunnions is to enable lifting and handling of the cask. Two types of lifting systems may be used: redundant (four trunnions) or nonredundant (two trunnions). The lifting trunnions are designed to satisfy the heavy lifting requirements of NUREG-0612 [3] and attendant standard ANSI N14.6 [4] for a nonredundant lift using the two primary lifting trunnions or a redundant lift using all four of the lifting trunnions, as well as the requirements of 10 CFR 71.45(a) and Paragraph 506 of IAEA Safety Series No. 6. Analyses show that overload failure of the trunnions will not impair the ability of the cask body to continue to perform its function.

Two rotation pockets are welded to the outer shell near the bottom of the cask. Neutron shield material is displaced to accommodate the placement of the rotation pockets, which are used to support the bottom of the cask on the shipping frame and also, as a pivot point to rotate the cask from the vertical lifting position to the horizontal position and vice versa. The rotation pocket design prevents lateral and rearward movement of the cask. The pocket welds are designed to fail in shear before the outer shell fails, thereby enabling the cask to continue to perform its primary function.

Forward movement of the cask is prevented by the shear ring welded to the top forging of the cask. In the transport configuration, forward axial loads from the cask are passed through to the support frame where the shear ring contacts the frame. The shear ring welds are designed to fail in shear before the top forging, minimizing the damage to the cask, enabling the cask body to perform its primary function.

2.1.1.2 Transportable Storage Canister

The Transportable Storage Canister Assembly consists of a stainless steel canister shell assembly, a shield lid, and a structural lid. The shell assembly is a cylindrical shell welded to a bottom plate and a shield lid support ring welded to the interior of the canister shell. The shell assembly with both the shield and structural lid welded in place provides a double welded canister closure system for the fuel assemblies loaded in the basket. The canister assembly provides confinement for the spent fuel during storage and meets the requirements of 10 CFR 71.63(b) as a separate inner container for the transport of damaged fuel. The canister is evaluated for normal conditions of transport and hypothetical accident conditions for PWR fuel in Sections 2.6.12 and 2.7.7, respectively, and for BWR fuel in Sections 2.6.14 and 2.7.9. These analyses show that the canister maintains its leaktight containment function in all of the evaluated conditions.

A basket assembly, as described in Section 2.1.1.3, is positioned inside the shell assembly. The basket structure locates and supports the basket contents. There are two basket designs, each of which is designed to accommodate either intact PWR or BWR fuel assemblies. The transportable storage canister assembly is moved in a transfer cask during fuel-loading operations. The shield and structural lids are welded to the canister shell while the loaded canister is in the transfer cask.

In the spent fuel pool, the fuel is loaded into the basket/canister assembly positioned in the transfer cask. Upon completion of fuel loading, the shield lid is lowered into the top of the canister. The shield lid assembly is a 7-in.-thick Type 304 stainless steel disk positioned on the shield lid support ring above the basket assembly. Then the loaded canister assembly is moved to a decontamination pit for the remaining canister closure operations, including installation of the drain pipe.

Two penetrations through the shield lid are provided for draining, vacuum drying, and backfilling the canister with helium. The drain penetration is threaded on the top to accept the drain pipe. The pipe extends to within 1/8 in. of the bottom of the canister to facilitate draining water from the inside of the canister.

The vent port is used to pressurize the canister or as a vent/discharge port during cask operations. Both the drain and vent ports have a cover welded over the quick disconnect prior to installation of the structural lid.

The structural lid is a 3-in. thick Type 304L stainless steel disk positioned on top of the shield lid and welded to the shell after the shield lid is welded in place and the canister is drained, dried, and backfilled with helium. The structural lid is designed with removable hoist rings so that the loaded canister can be lifted. The canister design parameters for the transport of different classes of PWR and BWR fuel are provided in Chapter 1.0.

2.1.1.3 Fuel Basket

The fuel basket assembly structure is located inside the canister shell assembly. The basket and canister shell assemblies are handled as one unit. The basket provides the fuel assemblies with lateral support, decay heat removal capability, and criticality control during all storage and

The outside diameter of the Universal Transport Cask upper and lower impact limiters is 124.0 inches and the height is 43.0 inches. The overlap between the cask body and the impact limiters is 11.0 inches. Sixteen 1.25-inch diameter retaining rods, attach each impact limiter to the end of the cask. The attachments are described in detail in Section 2.6.7.5.7. The height of the redwood in the end section of the impact limiter is 30.0 inches. A ring of balsa wood forms part of the end section of the impact limiter. The balsa wood ring dimensions are: inside diameter = 99.2 inches, outside diameter = 123.75 inches, and height = 21.6 inches. The bottom region of the impact limiter is a 1.5-inch thick layer of balsa wood that absorbs most of the kinetic energy in a 1-ft end-drop impact and limits the impact force for normal conditions of transport (1-ft drop). The low crush strength balsa wood is necessary because the impact area is considerably greater in a flat end impact than in any other drop orientation. The redwood and the balsa wood side ring absorb most of the energy in a corner impact and all of the energy in a side impact.

The different segments and sections comprising each limiter are bonded to each other with DAP-Weldwood resorcinol adhesive.

For each of the impact load conditions in this analysis, the impact limiters remain in position on the cask and absorb the energy of the impact; thus, they limit the impact loads to the calculated values shown in Table 2.6.7.5-6

2.6.7.5.2 Load Conditions

The specific loading conditions for the impact limiters are defined by 10 CFR 71.71(c)(7), 10 CFR 71.73(c)(1) and Regulatory Guide 7.8, as follows:

1. 1-ft drop of the cask impacting at any angle from vertical (flat end) to corner (cask center of gravity directly above point of impact).
2. 1-ft drop of the cask in a horizontal orientation (side impact).
3. 30-ft drop of the cask in an end, side, corner, or oblique orientation.

On the basis of these loading conditions, the Universal Transport Cask impact limiters are designed for the 30-ft cask drops but with consideration of the effects of the 1-ft drops. The maximum impact forces and the maximum crush depth for the 1-ft and 30-ft cask drops are obtained from the LS-DYNA [33] analyses of the cask drops. LS-DYNA is an explicit finite element program capable of performing three-dimensional nonlinear analysis of structures containing nonlinear material behavior such as plastic deformation of steel or crushing of wood. LS-DYNA is described in Section 2.10.1.2.

2.6.7.5.3 Properties of Balsa Wood and Redwood

To adequately specify the balsa crush strength, NAC conducted dynamic compression tests of specimens taken from balsa obtained from a commercial supplier. The average density of the balsa wood tested was 8.5 lbs/ft³ (8.5 ± 1.5 lbs/ft³). To ensure an adequate sampling, the following matrix was developed to test a series of specimens at various strain rates.

Grain Direction	Temp (°F)	Strain Rate (s⁻¹)	Number of Tests
Perpendicular	70	25	8
Perpendicular	70	75	8
Perpendicular	70	175	8
Perpendicular	70	275	10
Perpendicular	70	375	9
Perpendicular	-40	25 175 375	8 8 8
Perpendicular	200	25 175 375	8 8 8
Perpendicular (Stack Configuration)	70	25 175 375	8 8 8
Parallel	70	25	8
Parallel	70	75	8
Parallel	70	175	8
Parallel	70	275	9
Parallel	70	375	10
Parallel	-40	25 175 375	8 8 8
Parallel	200	25 175 375	8 8 8
Parallel (Stack Configuration)	70	25 175 375	8 8 8

To adequately specify the redwood crush strength, NAC conducted dynamic compression tests of specimens taken from redwood obtained from a commercial supplier. The average density of the redwood tested was 23.5 lbs/ft³ (23.5 ± 3.5 lbs/ft³). To ensure an adequate sampling, the following matrix was developed to test a series of specimens at various strain rates, with each specimen in a test series taken from a different board.

Grain Direction	Temp (°F)	Strain Rate (s⁻¹)	Number of Tests
Perpendicular	70 ± 10	Static	10
Perpendicular	-40 ± 10	Static	10
Perpendicular	200 ± 10	Static	10
Parallel	70 ± 10	Static	10
Parallel	-40 ± 10	Static	10
Parallel	200 ± 10	Static	10
Perpendicular	70 ± 10	25	10
Perpendicular	-40 ± 10	25	10
Perpendicular	200 ± 10	25	10
Parallel	70 ± 10	25	10
Parallel	-40 ± 10	25	10
Parallel	200 ± 10	25	10
Perpendicular	70 ± 10	100	10
Parallel	70 ± 10	100	10
15° from Parallel	70 ± 10	Static	10
30° from Parallel	70 ± 10	Static	10

The tests included both parallel-to-the-grain (parallel) and perpendicular-to-the-grain (perpendicular) directions for hot, cold, and ambient temperature conditions. Test specimens were fabricated from larger wood boards and cut in accordance with the specified grain direction. Compression testing of the wood specimen was performed using a servohydraulic test machine. The test machine consists primarily of a load frame, actuator for applying the dynamic load, a load cell, and associated voltage transducer. The maximum actuator speed is 200 inches/second with a load capacity of 20 kips. Fixturing is used to position the test specimen for the application of the load and to hold instrumentation used to record test results. Test specimens are sized to conform to the geometry of the test machine and to allow the establishment of empirical relationships between actuator speed, actuator and specimen impact area, and total displacement including crush. Test specimens are fabricated from larger wood boards having specified material properties for moisture content and density. Wood test specimen size was based on test machine requirements.

For each strain rate and temperature condition, a data set was created that consists of 10 to 15 individual test specimens. To reduce this data, individual files of a data set were averaged together. These average curves were then simplified using minimal (30) data points. To produce simplified curves, the peak acceleration was retained and the area under the curve that represents

the energy absorption capacity was maintained. Stress-strain curves are developed in the parallel and perpendicular-to-the-grain directions for hot (200°F) and cold (-40°F) conditions. Table 2.6.7.5-1 through Table 2.6.7.5-4 provide a summary of the data used in the LS-DYNA analyses.

2.6.7.5.4 Specification for Universal Transport Cask Impact Limiters

The redwood material used for the Universal Transport Cask impact limiters must satisfy density and moisture content specifications. The density of any single redwood board shall be 23.5 ± 3.5 lb/ft^3. [redacted] The average moisture content for the lot of redwood shall be less than 12%.

The balsa wood to be used in the Universal Transport Cask impact limiter is specified to have a density between 7 and 10 pounds per cubic foot and to have a moisture content between 5 and 15 percent for any one piece with an average moisture content of not more than 12 percent for any lot. A density limit of 7 to 10 pounds/cubic foot is applied to be consistent with dynamic wood test density criteria [38].

2.6.7.5.5 [redacted] Impact Limiter Analysis

The primary areas of analytical evaluation required in an impact limiter analysis are (1) crush depth, (2) maximum acceleration, and (3) attachment to the cask. The crush depth and maximum acceleration are dependent on the crush strength of the crushable material, the area engaged in crushing, the geometry of the impact limiter, and the energy to be dissipated.

[redacted]

The LS-DYNA general purpose explicit finite element computer program is used to analyze an impact limiter for an impact event to determine the dynamics of the event, the acceleration generated during that event, and the depth of crush. A detailed description of this program is provided in Section 2.10.1.2.

The impact limiter finite element model was built using the ANSYS pre-processor and LS-DYNA's Finite Element Model Builder. The impact analyses were performed using LS-DYNA. The model is constructed of 8-node brick and 4-node shell elements. Using the symmetry planes that exist for the various drop orientations, the model was simplified so that only a half model was necessary for the analyses. The finite element model used in the analyses corresponds to the full-scale cask body and impact limiters. The complete finite element model is shown in Figure 2.6.7.5-3. Figure 2.6.7.5-4 shows only the steel shells and gussets that contain

the wood. The cask body section of the model consists of a single shell using an elastic material. The properties of the elastic modulus of the shell section of the cask body were adjusted so that the cross-sectional properties of the finite element model were equal to those of the full-scale design of the transport cask. As shown in Figure 2.6.7.5-3, the model contains a detailed representation of the trunnion and the cut out in the top impact limiter. The impact limiters are attached to the cask ends by beam elements corresponding to the attachment bolts for the impact limiter. The redwood and the balsa wood are modeled as an isotropic foam material. The stress-strain curves used as input into the LS-DYNA model were obtained by dynamic crush testing of the wood specimens.

Material Properties

To account for the deformation of the Type 304 stainless steel shells and gussets, these components were modeled with an elasto-plastic material—LS-DYNA material Type 24 ("Piecewise Linear Plasticity"). The required input data for the stainless steel consists of the stress-strain data presented in Table 2.6.7.5-5.

The transport cask body model consists of a single shell using an elastic material. The elastic modulus of the cask body was adjusted to allow the cross-sectional modulus of the finite element model to be equal to that of the full-scale cask. The total kinetic energy is accounted for by adjusting the mass density of the cask. Therefore, the mass density varies slightly depending on the drop orientation.

To account for the strain-rate sensitivity of the wood, the LS-DYNA analyses use material 163 (modified crushable foam). The modified crushable foam material model allows for the input of several stress-strain curves of various strain-rates. Up to two stress-strain curves are used ranging from 0 ε/sec to 25 ε/sec. For each time step during an analysis, LS-DYNA calculates the strain-rate of an individual element and uses the stress-strain data from the inputted stress-strain curves. For a strain rate between the inputted curves, LS-DYNA interpolated between the given curves. For low velocity impacts such as the 1-ft side drop, strain rates are essentially static. Therefore, LS-DYNA interpolates between the static stress-strain curve and the second stress-strain curve in the series. To account for crush strength fabrication tolerances, the -40°F cold case comparison stresses are factored by 1.10 and the +200°F hot case compression stresses are factored by 0.90.

The wood impact limiter surrounding the cask consists of 24 equally spaced angular wedges separated by radial gussets fabricated from steel plates. Since a half-symmetry finite element

model is used to represent the impact limiters, only 12 of the wood wedges are modeled. Out of the 12 modeled wood wedges, only 3 wedges are loaded during a 30-foot side drop. The first wedge is loaded in the parallel to grain direction. The second and third wedges are loaded between the parallel and perpendicular to grain directions. For the wedges where the impact force is applied between the parallel and perpendicular to grain directions, Hankinson's formula [56] is used to determine the strength properties of wood as it varies with the orthotropic axes of the wood grain.

$$N = \frac{PQ}{P\sin^2\theta + Q\cos^2\theta}$$

Where:

N = stress induced by a load acting at an angle to the grain direction
P = compression strength parallel to the grain direction
Q = compression strength perpendicular to the grain direction
θ = angle between the direction of the load and the direction parallel-to-the-grain

Using Hankinson's formula, stress-strain curves are generated for the second and third wedges at 15 and 30 degrees, respectively; therefore, in the LS-DYNA input files, unique stress-strain curves are applied to the 0, 15, and 30 degree wood wedges depending upon the loading angle, strain rate and temperature.

Boundary Conditions and Initial Conditions

LS-DYNA "Surface to Surface" contact interfaces are employed between the cask body and the impact limiter shells. The unyielding surface is modeled as being flat using the "Rigidwall Geometric Flat" option in LS-DYNA. Symmetry boundary conditions are imposed on the nodes in the X-Z plane. Initial velocities of 96.3 in./sec and 527.4 in/sec were applied to the entire model to represent the 1-foot and 30-foot drops, respectively. A uniform gravitational field corresponding to 386.4 in/sec^2 is also applied in the direction of the drop.

There are three orientations considered in the evaluation of the 1-foot and the 30-foot drops: end drop, center of gravity (CG) over corner and side drop. The end drop results in the maximum axial accelerations. To establish the bounding axial accelerations as well as the maximum axial crush depth, two end drop conditions are analyzed. To obtain the maximum acceleration, the top end drop is performed using -40°F material properties. This condition corresponds to the wood having maximum crush strength in conjunction with the largest backed area. To obtain the

maximum crush depth for the end drop orientation, the bottom end drop is performed using the material properties at 200°F. The bottom end of the transport cask has a smaller area than the top end and the use of 200°F material properties corresponds to the minimum crush strength.

The corner drop (CG over corner) results in the largest crush depth of the limiter. The side drop results in the maximum acceleration in the lateral direction on the cask.

Based on the validation study provided in Section 2.6.7.5.8, the side drop condition bounds any slap down for cask designs in which $L/r < 2$. Therefore, only the side drop analysis is performed to determine the bounding lateral accelerations and crush depths. The bounding side drop accelerations are determined using the cold material properties (–40°F). The bounding side drop crush depths are determined using the 200°F material properties.

2.6.7.5.6 Analysis Results

To obtain results from LS-DYNA, nodes of interest are used to record output data. These nodes are located at the plane of symmetry on the outer surface of the cylinder at the end of the cask cavity. For the side drop, the nodes record the lateral acceleration, and for the end drop, the nodes record the axial acceleration. For the CG over corner orientation, the recorded acceleration corresponds to the direction of drop. The nodal output is in the form of displacement and acceleration time histories. However, the acceleration time histories contain high frequency components, which do not represent the response of the cask to the external impact. Therefore, the time histories are filtered to obtain the true accelerations corresponding to the impact. For this evaluation, the Butterworth low-pass filter in LS-DYNA's post-processor is used with a filter frequency of 120 Hz. This filter frequency was used to filter the time histories of the impact tests for a steel billet in the side drop and end drop orientation (NUREG/CR-6608). The filter frequency was established by performing a modal analysis of the cask finite element model. The side drop modal analysis applied a simply supported condition in the direction of the drop at each of the cask ends, which resulted in a fundamental mode at 61 Hz. For the end drop modal analysis, an axial restraint is applied to the nodes at the end of the cask, which results in a fundamental mode at 129 Hz. A filter frequency of 120 Hz is used in the acceleration calculation.

The maximum accelerations for the 1-foot and the 30-foot drops are presented in Table 2.6.7.5-6. The filtered acceleration time histories for the conditions providing the maximum accelerations

for the end drop, CG over corner and side drop are shown in Figure 2.6.7.5-5, Figure 2.6.7.5-6 and Figure 2.6.7.5-7, respectively.

2.6.7.5.7 Impact Limiter Attachment Analysis

The following design criteria apply to the method of attaching the impact limiters to the cask body.

1. The impact limiters must remain attached to the cask body during normal handling and transport. Satisfaction of this criterion ensures that the limiters will be in a proper position to perform their impact-limiting function in the event of a free drop (normal or accident).

2. In a free drop (normal or accident), the limiter (or limiters) making initial contact with the unyielding surface must remain in position on the cask for the full duration of the initial impact. Satisfaction of this criterion ensures that the limiter(s) will be able to properly perform the impact-limiting function.

3. In a free drop (normal or accident) involving an initial impact on a single impact limiter, the limiter on the opposite end of the cask must remain attached to the cask during the initial impact. Satisfaction of this criterion ensures that the limiter will be in a proper position to perform its impact-limiting function in a subsequent secondary impact following the initial impact.

Sections 2.6.7.5.7.1 through 2.6.7.5.7.3 demonstrate that each of these criteria is satisfied.

2.6.7.5.7.1 Impact Limiter Attachment During Normal Handling and Transport

Attachment of the impact limiters to the cask body during normal handling and transport operations is ensured by demonstrating that the attachment hardware does not yield under normal handling and transport conditions. The worst-case loading associated with normal handling and transport is a 7.5 g-load corresponding to the peak longitudinal shock loading expected as the result of rail transport (as specified by the Field Manual of the AAR [31]).

The design load, P, on the attachment is P = (7.5)(8,846) = 66,345 lb, where 8,846 lb is the weight of each impact limiter.

Analysis of Retaining Rods

Sixteen 1.25-in. diameter retaining rods are equally spaced on a bolt circle diameter of 81.8 inches for the upper limiter and 71.1 inches for the lower limiter. The attachment geometry of the impact limiters is shown in Figure 2.6.7.5-8. The retaining rods are SA-193, Grade B8S stainless steel with a yield strength of 89.8 ksi and a design stress intensity (S_m) of 13.0 ksi at 200°F (Table 2.3.5-3).

The load on each retaining rod resulting from a longitudinal shock load of 7.5 g is given as

$$P = 66{,}345/16 = 4{,}147 \text{ lb per retaining rod.}$$

The retaining rod tensile area is 0.969 in^2 in the threaded region, resulting in a tensile stress of:

$$S_t = 4{,}147/0.969 = 4{,}275 \text{ psi}$$

Each retaining rod nut is torqued to 75 ± 5 ft-lbs, resulting in a preload of 2,560 lbs. Therefore, the preload stress is (2,560 lb/0.969 in^2 =) 2,642 psi. The total stress for the longitudinal shock load of 7.5g is, therefore, 4,275 + 2,642 = 6,920 psi (6.9 ksi). For the retaining rods, the allowable stress is twice S_m, or 2 x 13.0 = 26.0 ksi. The Margin of Safety (MS) is:

$$MS = (26/6.92) - 1 = +2.76$$

Analysis of Retaining Rod Anchorage

The nut of the retaining rod is bearing on a washer that has a diameter of 5.0 in. and a thickness of 0.50 in. The washer is bearing on the bearing plate portion of the impact limiter shell, which bears on the redwood material.

The load on each of the 16 retaining rods resulting during the normal transportation condition is 4,147 + 2,560 = 6,707 lb. The bearing area between the bearing plate and the redwood material is:

$$A = (\pi/4)(5.0^2 - 3.0^2) = 12.57 \text{ in}^2.$$

The bearing pressure is:

$$p = 6{,}707/12.57 = 534 \text{ psi}$$

The perpendicular-to-the-grain compressive stress in the redwood at 2.5% strain is 750 psi. The margin of safety for compression of the redwood is:

$$MS = (750/534) - 1 = +0.41.$$

The washer is made of Type 304 stainless steel and has a 1.51-inch diameter hole in the center. It is analyzed by assuming that it is simply supported along a circle having a diameter equal to the edge of the hole in the bearing plate (i.e. 3.00 in.). The total load of 6,707 lb is distributed along the edge of the nut, which has an average diameter of 1.939 in. From Roark, Table 24, Case 1a, [28], the stress on the washer is:

$$S_{max} = \left[\frac{12Wa^2}{\left(a-\frac{b^2}{a}\right)t^2}\right]\left[\frac{r_o}{a}\left\{\frac{1+\nu}{2}\ln\left(\frac{a}{r_o}\right)+\frac{1-\nu}{4}\left[1-\left(\frac{r_o}{a}\right)^2\right]\right\}\right] = 24.4 \text{ ksi}$$

where:

a = 1.50 in. b = 0.655 in.
t = 0.50 in. ν = 0.31
r_o = 0.9695 in W = (6,707/(2π x 0.9695)) = 1,101 lb/in

The yield strength of Type 304 stainless steel is 25.0 ksi at 200°F. The margin of safety is calculated MS = 25.0/24.4 - 1 = + 0.02. The positive margins of safety show that the attachment of the impact limiters is adequate during normal conditions of transport.

Evaluation of Impact Limiter Attachment for Vibration

During normal conditions of transport, the impact limiter attachment may be subjected to vibration induced from the combination of component natural frequency and a dynamic load forcing function dependent on the transport media. Design of the impact limiter attachment eliminates the potential for the postulated vibration loading to loosen the impact limiter attachment. Lock nuts are installed in back of each of the retaining rod attachment nuts to prevent them from becoming loose. Locking wires installed between sets of two retaining rods eliminate rotation of the impact limiter retaining rods relative to their anchorage. The combination of these two design features eliminates the potential for the impact limiter attachment to become loose as a result of postulated vibration loading during transport.

2.6.7.5.7.2 Response of Impacted Limiters During Initial Impact of Package with Ground

The second criterion applicable to the impact limiter attachments requires that the impact limiter making initial contact with the unyielding surface must remain in position on the cask for the full duration of the initial impact. To satisfy this criterion, the impact limiter(s) being crushed must not separate from the cask, although the attachment hardware (mounting plate and bolts) may fail during the impact event.

The ability of the NAC-STC impact limiter to remain in position during an impact was demonstrated with reference to several static compression tests of the NAC-STC, during which the only attachment mechanism was a strip of duct tape. All of the compression tests were performed by using eighth-scale models of the impact limiters. The results of these tests are applicable to the Universal Transport Cask.

Analytic evaluations are performed to further justify that the initially impacted Universal Transport Cask impact limiter remains in position during an impact event and properly performs its function. Results of evaluations indicate that the attachment hardware is not expected to fail and that the cask and impact limiter do not separate even if the attachment does fail. A significant resistance to the applied separation moment exists as a result of a combination of crushing of the limiter at the cask interface and also as a result of frictional resistance that exists at the interface. This total resistance is calculated to be greater than the applied separation moment.

2.6.7.5.7.3 Response of Secondary Impact Limiter During Initial Impact of Package

The final criterion to be satisfied is that for a free drop (normal or accident) involving an initial impact on a single impact limiter. The limiter on the opposite end of the cask (secondary limiter) must remain attached to the cask during the initial impact, thus ensuring that the secondary limiter is in position to absorb the secondary impact. The secondary limiter remains in position for the full duration of the secondary impact and performs its impact-limiting function. Attachment is ensured by demonstrating that the attachment hardware (mounting plate and retaining rods) does not fail during the initial impact.

During a free drop of the cask (normal or accident) involving an initial impact on a single impact limiter, i.e., flat end, center of gravity over corner, or any oblique drop, the ground exerts an upward force on the impact limiter that strikes it. The impact limiter in turn exerts an upward force on the cask body, thus decelerating the cask body. The cask body exerts an upward force on the secondary impact limiter and decelerates it. This scenario is repeated during a rebound of the whole package: the ground exerts an upward force on the impact limiter that strikes it; the impact limiter that strikes the ground exerts an upward force on the cask body and the cask body exerts an upward force on the secondary impact limiter, thereby accelerating the whole package upwards. When the entire package is in the air, its components (the impact limiter, the cask body, and the secondary impact limiter) move with the same acceleration and velocity; no other force acts among them. Thus, it is evident that during a free-drop impact on the first impact

limiter, no separation force exists between the cask body and the second impact limiter. The absence of separation forces ensures that the second impact limiter stays in position to absorb the second impact.

Analysis of the impact limiter mounting plate and retaining rods demonstrates that the impact limiter attachments provide significant resistance to any unspecified separation force on the impact limiter. This analysis provides further evidence that the secondary impact limiter will stay attached to the cask body to absorb the second impact.

2.6.7.5.8 Verification of LS-DYNA for Cask Drop Impact Limiter Evaluation

To confirm the adequacy of LS-DYNA for cask drop impact limiter analyses, a series of analyses were performed to compare analytical results to quarter-scale model tests for the NAC-STC transport cask. From the series of drop tests performed using the NAC-STC, four tests are compared to analytical calculations using LS-DYNA. The four drop tests are: end drop; CG over corner drop, side drop and a 75° oblique drop (measured from the vertical). The modeling procedure and material properties described in Section 2.6.7.5.5 for the full-scale cask model was employed in this evaluation to develop a quarter-scaled model of the NAC-STC cask. The filter frequencies for the lateral drops and the end drops were selected to be 450 Hz and 550 Hz, respectively. These were established by performing a modal analysis of the cask model. The results for the three drops are shown in Table 2.6.7.5-7. This table compares the LS-DYNA results and the NAC-STC results and shows that LS-DYNA adequately predicts the response of the wood impact limiters.

An additional analysis was performed using this model to determine the maximum accelerations for an 85° oblique drop orientation. The maximum accelerations were 201g and 195g for the cask top and cask bottom, respectively. The 75°, 85° and 90° results indicate that the side drop is bounding for this cask design in which the L/r (length to radius of gyration) is less than 2.

The oblique drop analyses for the 75° and 85° orientations used a coefficient of friction of 0.2 which is less than a typical value of 0.27 for steel-steel interface with an oxide film (Marks). An additional parametric study using the model described above showed that the bounding condition is the zero friction condition, which remains bounded by the side drop orientation.

2.10.1.2.1 LS-DYNA Computer Code Verification

Two separate cases are used to verify the LS-DYNA program as a tool to predict the deceleration of the cask body during normal and accident conditions. LS-DYNA provides two strain rate dependent material models that adequately simulate the behavior of wood crushing during a dynamic impact event. Benchmarking of the two material properties and the method of analysis are presented in the following sections. The first verification problem is designed to determine the accuracy of the modeling methodology when compared to closed form solutions. The second verification problem shows that strain rate dependent material models properly interpolate between inputted stress-strain curves at a given strain rate.

2.10.1.2.2 Predicting Impact Deceleration Using Strain Rate Sensitive Properties

The validation of the use of LS-DYNA to represent the behavior of the balsa wood impact limiters was accomplished by using the balsa stress-strain curve for a simple geometry for which the crushing and acceleration could be determined. The geometry used is shown in Figure 2.10.1-1, which corresponds to a right circular cylinder 50 inches in diameter and 50 inches in length. The model employed symmetry boundary conditions for the quarter-symmetry model. The stress-strain curve representative of balsa material is shown in Figure 2.10.1-2. The material model used in this evaluation is the FU_CHANG_FOAM (material 83), which is the material model employed in the balsa wood impact limiter evaluation. The impacting object is a quarter symmetry circular plate of the same diameter with an assigned weight of 257 kips. The interface between the balsa cylinder and the plate is modeled using automatic surface-to-surface, while the unyielding surface was modeled using the RIGIDWALL_GEOMETRIC_FLAT option. The system has an initial velocity of 150 in/sec. To compute the crush, an energy balance is used.

$$\frac{mv_o^2}{2} = AL\int_0^{\varepsilon_i}\sigma_i\,d\varepsilon$$

where:

A = area of the block being crushed
L = total original height of the block
$d\varepsilon_i$ = the incremental strain as the block crushes
σ_i = the stress at the given incremental strain value

The acceleration is computed by $\sigma \cdot A/W_t(g)$, where W_t is the weight of the modeled plate. The peak crush strength is 2,090 psi obtained from Figure 2.10.1-2. The results of the calculation are:

Item	LS-DYNA	Calculation	% Difference
Crush (in)	12.9	12.6	2
Acceleration (maximum) (g)	4.04	3.99	1

This demonstrates that the material model and numerical methodology employed in LS-DYNA for the balsa wood impact limiters is acceptable.

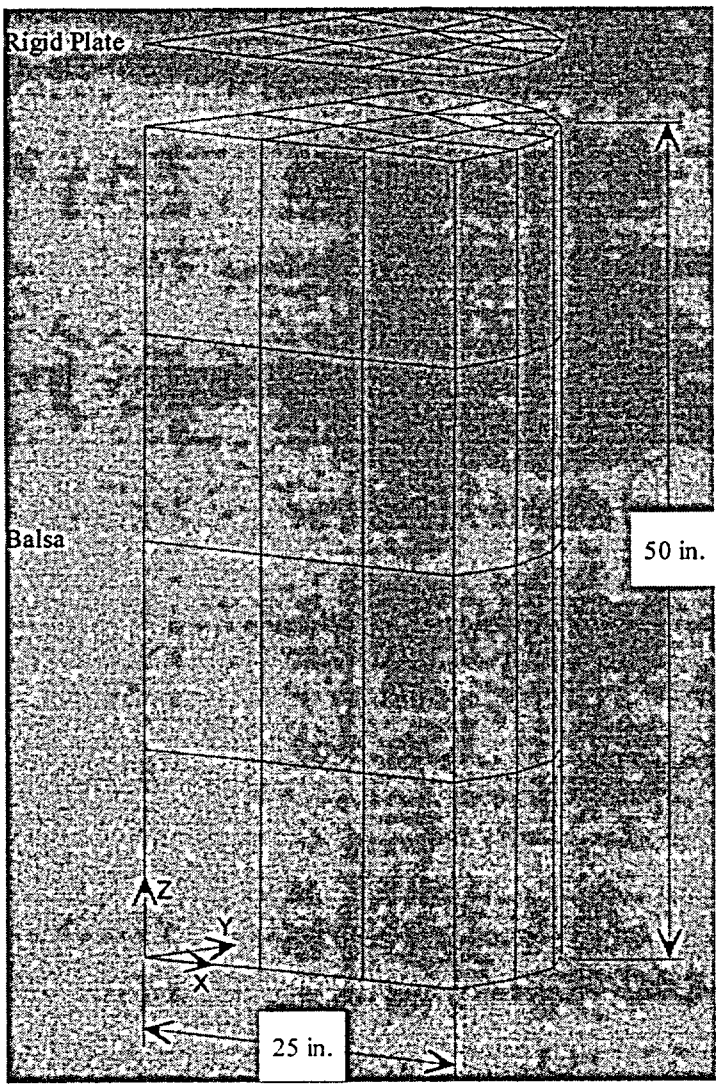
2.10.1.2.3 Accounting for Strain Rate Sensitivity by Interpolation

The strain rate sensitive foam/wood is modeled using the LS-DYNA finite element model builder (FEMB). The model is comprised of a steel block and a wooden cube. The model, as shown in Figure 2.10.1-3, is constructed of solid brick elements. The wooden cube measures 5 inches by 5 inches. The impacting steel plate is 5 inches tall and 7.5 inches across. Surface-to-surface contact interfaces are employed between the steel block and the wooden cube. The wooden cube sits on a rigid plane.

The Piecewise Linear Plasticity material model is used to represent the steel block. The wooden cube is represented as a homogeneous isotropic material, type number 163 in LS-DYNA (Modified Crushable Foam). For this example, three strain rates are inputted into the material model: 0 ε/sec, 20 ε/sec, 60 ε/sec, with corresponding constant stress values of 2000 psi, 7000 psi and 10,000 psi, respectively. A prescribed motion is applied to the steel block to apply a constant strain rate to the wood cube after 0.01 seconds.

To demonstrate that the correct strain rate curve is used during the crushing of the wood cube, two cases are considered. The first case uses 20 ε/sec, and the second case uses 40 ε/sec. The stress in the wood block should compare to the applied stress-strain curve at the strain rate of interest. For the 20 ε/sec case, the compressive stress in the cube is approximately 7,000 psi, which agrees with the LS-DYNA result in Figure 2.10.1-4. For the 40 ε/sec case, the compressive stress in the cube is a value of 8,000 psi, due to logarithmetic interpolation, that agrees with the LS-DYNA result in Figure 2.10.1-5. Therefore, the Modified Crushable Foam material model is an acceptable method of accounting for the strain rate variability of foam and wood crushable materials.

Figure 2.10.1-1 LS-DYNA Model Used to Verify the Material Model



Note: XZ and YZ planes are planes of symmetry

Figure 2.10.1-2 Stress-Strain Curve Used for the Balsa Material

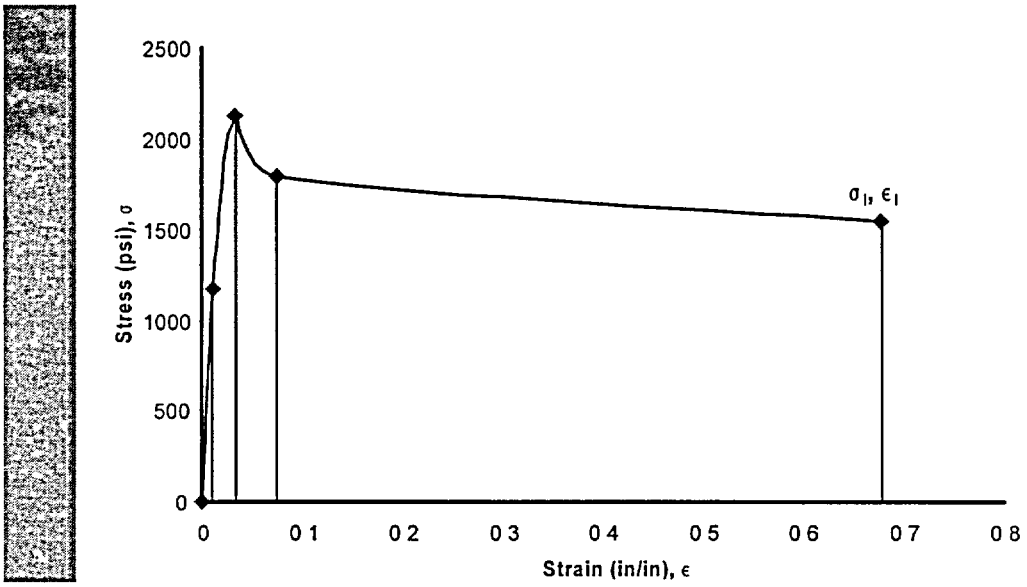


Figure 2.10.1-3 Finite Element Model for Strain-Rate Dependent Crushable Foam/Wood Block Impact

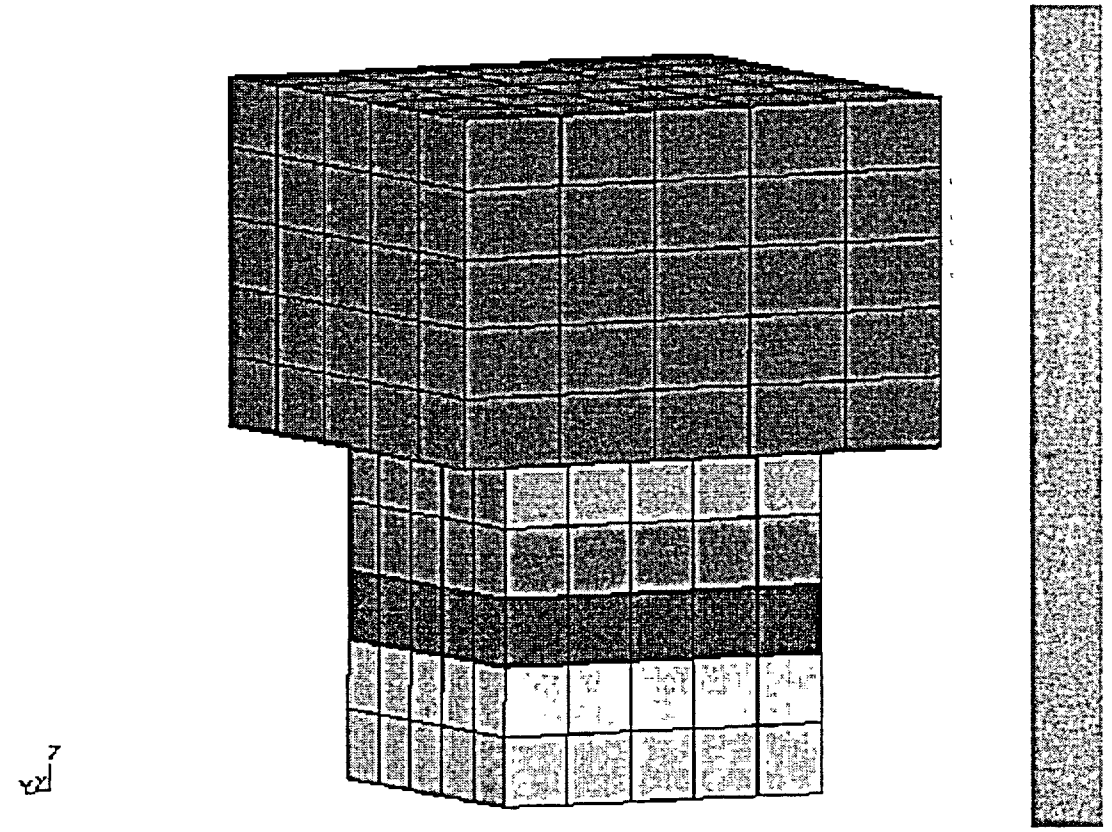


Figure 2.10.1-4 Stress Time History at 20 ε/sec

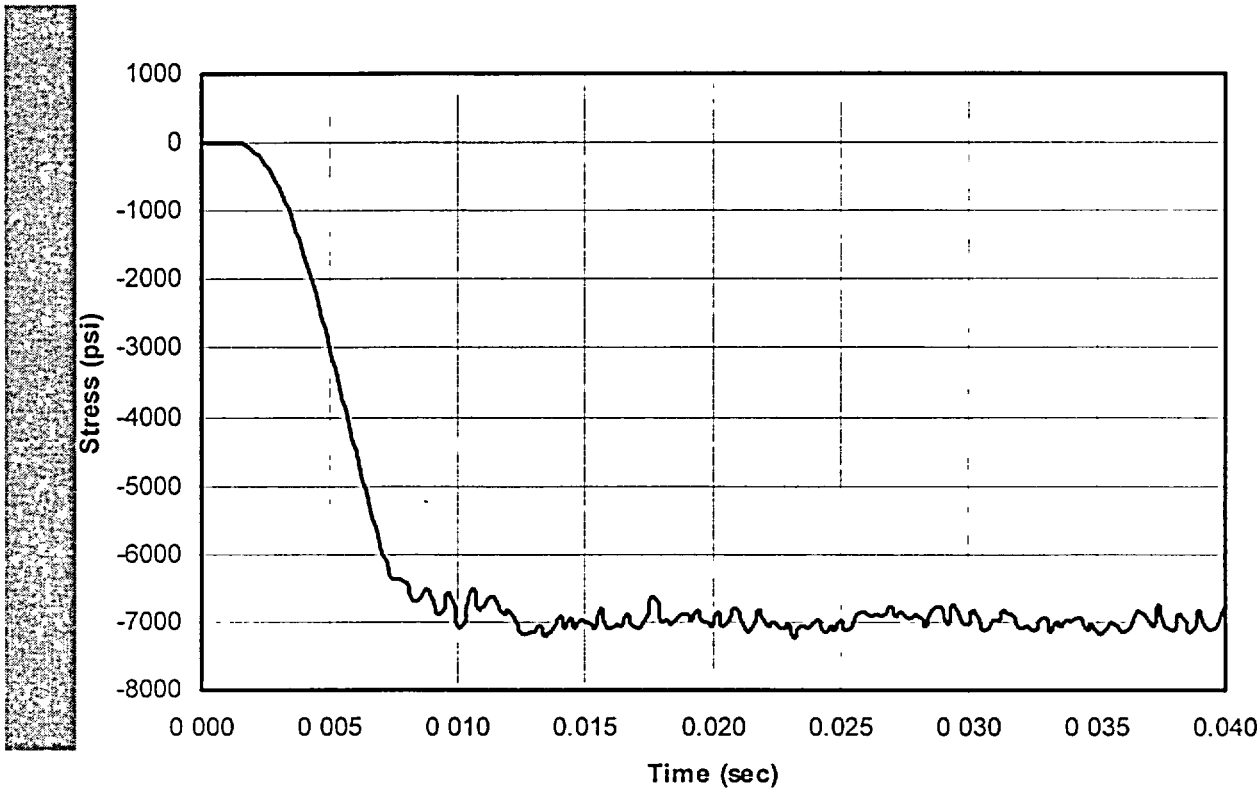
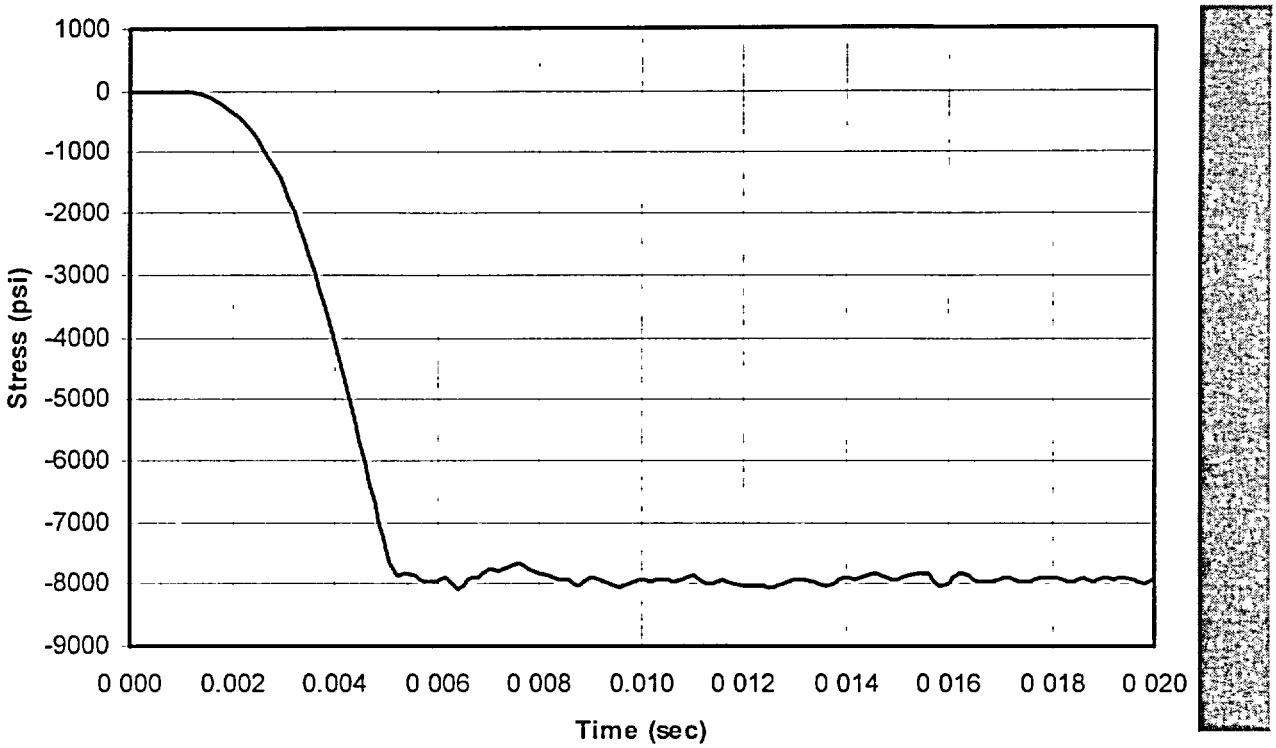


Figure 2.10.1-5 Stress Time History at 40 ε/sec



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UMS® Cask Model Drop Orientation	Quarter-Scale Drop Test Results (inch)			LS-DYNA Prediction (inch)		
	Original Thickness	Final Thickness	Measured Crush Depth	Original Thickness	Final Thickness	Total Crush Depth
Top End Drop	[redacted]	[redacted]	2.04	[redacted]	[redacted]	2.21
Top Corner Drop	[redacted]	[redacted]	2.95	[redacted]	[redacted]	3.36
Side Drop - Under the trunnion	3.50	0.63	2.87	3.47	0.38	3.09
Side Drop - Bottom impact limiter	5.13	2.38	2.75	5.13	2.39	2.74

These results of the UMS® Drop Test Program confirm the design-basis accelerations and crush depths used for the evaluation of the transport cask.

2.10.3.2 Acceptance Criteria for Model Performance

Acceptance criteria were established only for the scale model impact limiters and their attachment components, since the purpose of the scale model test program was to confirm their performance capabilities. The function of the scale model impact limiters is to limit the deceleration of the scale model package during the 30-foot drop event, while remaining firmly attached to the cask body. The impact limiter acceptance criteria requires that:

1. The crush depth be limited to prevent an impact of the cask body on the impact surface.
2. The accelerations be limited to be less than or equal to those used in the design analysis.
3. The impact limiters remain attached to the cask body and in position after the impact event.

The results of the UMS® Drop Test Program confirm:

1. The scale model body did not impact the pad surface confirming that the UMS® transport cask possesses a sufficient depth of wood to absorb all of the energy of a 30-foot drop in any orientation.
2. The maximum accelerations determined from the scale model tests are less than the design-basis values used to evaluate the UMS® transport cask components for a 30-foot drop accident.
3. The impact limiters remain attached to the transport cask body.

2.10.3.3 30-Foot Top End Drop and 30-Foot Top Corner Drop Tests Performed at ORNL

A quarter-scale model was used for the confirmatory testing of the UMS® impact limiters and attachments for the top end drop and top corner drop. These drop tests were performed at the Oak Ridge National Laboratory (ORNL) in April 1999. The quarter-scale model was only required to represent the appropriate cask body weight, center of gravity, and attachment interface materials and dimensions of the impact limiters and their attachments to the cask body. For this reason, a 20-inch diameter Schedule 160S stainless steel pipe was used to represent the cask body. To properly represent the weight and the location of the center of gravity of the cask and the mass moment of inertia, a series of weight disks (circular steel plates) were positioned inside the pipe. Three of the weight disks were 4 inches thick while a fourth was 4.5 inches thick. The actual location of the plates and the corresponding axial location of the center of gravity are shown in the model drawing 790-301, Sheets 1 through 3.

The total weight of the quarter-scale model including the impact limiters was 4,033 pounds, which closely approximates $(1/4)^3 = 1/64$ of the full-scale transport cask weight of 260,000 pounds.

The overall length of the model (without the impact limiters) is 52.31 inches, which is comprised of a 41.31-inch length of 20-inch diameter pipe welded to a 6-inch thick plate at the top end and a 5-inch thick plate at the bottom end. Both plates are Type 304 stainless steel. The top end plate was machined to represent the scaled outside diameters and axial dimensions of the upper forging and the neutron shield top plate. A 16.06-inch diameter through hole was machined in the center of the top end plate of the model body. Also, a recess was machined into the top end plate to accommodate the placement of the bolted lid. Two steel bars, scaled to represent the diameter and length of the cask lifting trunnions, were welded in the appropriate locations on the outside diameter of the top end plate.

The model lid outer diameter and the lid bolt recess diameter are quarter-scale dimensions, but the lid thickness and the number of lid bolts were not scaled. Scaling of the lid thickness and the bolts was not necessary because the purpose of the lid and bolts was only to back the upper impact limiter and to retain the dummy weights in the cavity of the model cask.

The 5-inch thick bottom end plate of the model was machined to represent the scaled outside diameters and the axial dimensions of the bottom end of the UMS® cask, including the neutron shield bottom end plate. The bottom plate thickness is not scaled, since it is only required to

A_{flow} = (π)(18.7)(.06)(52,500)/3,945 = 46.9 (g)

Where:

d = Thickness of the scale model impact limiter shell is 0.06 inch

σ_d = (75+30)/2 = 52.5 ksi (the average of the tensile and yield strengths at 70°F for Type 304 stainless steel)

W = model weight = 3,945 pounds (3,811 pounds for the model body and 134 pounds for the test weight representing the bottom impact limiter)

5. If the entire area of the redwood in the scale model impact limiter (outside diameter = 31 inches) would instantly initiate crushing, the force applied to the model for deceleration would be the ratio of the product of the cross-section area of the impact limiter and the intial crush strength of the redwood to the weight of the scale model package.

A_{flow} = (π/4)(31)2(640)/4,078 = 118 (g)

Where:

d = Outer diameter of the model impact limiter shell = 31 inches

σ_d = The initial crush strength of the redwood in the direction perpendicular to the grain = 640 psi

W = model weight acting on the top impact limiter bolts = 4,078 pounds (3,811 pounds for the model body, 133 pounds for the top impact limiter and 134 pounds for the test weight representing the bottom impact limiter)

4. If the redwood in the backed area of the model impact limiter (area directly under the model cask body) is considered as an elastic component only, the minimum immediate response time can be computed using the fundamental mode of the mass of the model acting on the redwood.

The total weight (W) of these components is W = 3,945 pounds (3,811 pounds for the model body and 134 pounds for the test weight representing the bottom impact limiter). The corresponding mass (m) is computed as 3,945/386.4 or 10.21 lb-sec^2/inch. The equivalent axial stiffness (K) of the system is:

$K = A \times E/L = 48.1$ E6 pounds/ inch

Where:

A = cross sectional area (backed area) of the redwood = $(\pi/4)(18.7)^2 = 274.6$ in^2

E = modulus of elasticity of redwood = 1.4 E6 psi

L = 8 inches (10.75 - 2.75)

The corresponding natural frequency is:

$f = (1/2\pi)\sqrt{(K/m)}$ (Hz)

f = 345 Hz

Based on this natural frequency, the accelerometer trace should indicate that for the initial peak the acceleration varies from a positive maximum value to a negative one, corresponding to the signal period/2 or (1/345)/2 = 1,449 micro-seconds. Since the time points on the acceleration trace are 30.5 micro-seconds, there should be approximately 48 (1,449/30.5) acceleration points showing the motion from zero to the initial maximum negative value. The accelerometer traces do not demonstrate this hypothesis. Thus, the use of the elastic properties for the redwood is significantly over-conservative.

It is concluded from the foregoing four considerations, that these conservative calculations confirm that the initial acceleration values are a result of high frequency effects in the accelerometer and, therefore, filtering the acceleration data is appropriate. The filtered results do not show the steep rise time nor the associated level of accelerations that are present in the unfiltered trace. The filtered result is superimposed on the unfiltered trace in Figure 2.10.3-1. The filtered data was integrated to obtain the velocity of the model body and was computed to be 529 in/sec compared to the 527.4 in/sec initial velocity. The peak acceleration is shown to be 55.0 g for the full-scale UMS® package.

2.10.3.3.4 Static Crush Test for the End Drop Orientation

To further confirm the design of the UMS® impact limiters, a static crush test in a top end drop orientation was conducted. The purpose of the static test was to: 1) identify any potential initial stiffness in the impact limiter, which would corroborate the large accelerations observed on the accelerometer traces during the early part of the 30-foot top end drop impact; and, 2) indicate

The force applied in the static crush test was increased until the energy absorbed by the model impact limiter section ($E_{limiter}$) was equivalent to, or greater than, the total potential energy (E_{total}) of the quarter-scale model for a 30-foot drop.

2.10.3.3.4.1 Static Test Results

1. The lateral displacements of the sides of the test fixture were measured to be less than 0.001 inch and the outward radial displacement of the test article was less than 0.1 inch. These values indicate that the boundary conditions were satisfied.

2. No malfunctions of the equipment or instrumentation were experienced.

3. The force-deflection curves for the model impact limiter sections used in Static Test 1 and Static Test 2 are shown in Figures 2.10.3-2 and 2.10.3-3, respectively. These curves include the previously discussed geometry and multiplier of 8 and 1.058, respectively.

4. The following crush and accelerations were determined based on Static Test 1 and Static Test 2. These values correspond to the conditions at the end of the test in which the energy absorbed by the model limiter section equals or exceeds the total potential energy of the scale model for a 30-foot drop. The force values include the geometry and dynamic load factors of 8 and 1.058, respectively.

Static Test	Crush Depth (in) (δ)	Force (kips) (F_{total})	Acceleration (g) (F_{total}/W)
1 (base line case)	5.24	701.7	174
2 (without the screw tube)	5.70	680.0	168.6

2.10.3.3.4.2 Static Test Observations

1. No initial peaks in the loading were observed for either Static Test 1 or Static Test 2. The crush forces developed in a monotonic manner increasing from zero to the maximum force reported above. During the static tests, there were no mechanical shocks observed in the equipment nor in the floor on which the testing machine was supported.

2. While the screw tubes are a source of significant strength, the initial deformation of the impact limiter does not occur in the region of the screw tubes. The calculated final accelerations for the model impact limiter design with the screw tube was only 3 percent larger than the design without the screw tubes.

3. The axial section of the model impact limiter shell at the 18.7-inch diameter next to the model lid buckled in the same general shape in the static test as in the 30-foot top end drop. Since the crush force developed in a monotonic manner and the mode of deformation between the static and dynamic drops are the same, it indicated that this section of the model impact limiter shell does not deform by plastic flow of the metal and does not contribute to large initial accelerations.

4. The crush and the accelerations reported above for the section of a model impact limiter is compared to the LS-DYNA results presented in Section 2.10.3.7. The static crush test results are compared to the LS-DYNA results in the following table:

Quarter-Scale End-Impact Static Test	Quarter-Scale Crush Depth (in)	Quarter-Scale Acceleration (g)	LS-DYNA Calculated Crush Depth (in)	LS-DYNA Calculated Acceleration (g)
Test 1	3.3	174	2.21	226
Test 2	3.7	169		

For the maximum acceleration case, the Static Test results are enveloped by the LS-DYNA analyses.

2.10.3.3.4.3 Summary of the Static Tests

The results of the static tests indicate that the initial high accelerations observed in the drop tests are a result of accelerometer high frequency effects. The filtered acceleration data more accurately reflects the response of the impact limiter in an end drop impact. Additionally, the static tests confirm that the impact limiter for the end drop has sufficient energy absorption capacity.

2.10.3.4 30-Foot Side Drop Test Performed at SNL

A quarter-scale model was used for the confirmatory testing of the UMS® impact limiters and attachments for a 30-foot side drop. The drop test was performed at Sandia National Laboratory (SNL) in March 2001. The quarter-scale model represents the materials and physical dimensions of the impact limiters and their attachments to the cask body in conjunction with the appropriate cask body weight, center of gravity, and attachment interface dimensions. Details of the test model are shown in the model drawing 790-308, Sheets 1 and 2.

The cask body is constructed of carbon steel. The 52.31-inch overall length of the cask body is comprised of a 38.64-inch length of 20-inch diameter schedule 120 pipe welded to an 8.36-inch thick plate at the top end. A 5.57-inch thick end plug welded to the inner shell seals the top end. At the bottom end, the 20-inch pipe outer shell is welded to a 3.3-inch thick lower end ring and 2-inch thick lower cap plate.

The top end plate is machined to represent the scaled outside diameters and axial dimensions of the upper forging and the neutron shield top plate. Two steel bars, scaled to represent the diameter and length of the cask lifting trunnions, are welded in the appropriate locations on the outside diameter of the top end plate. The 3.3-inch thick lower end ring and 2-inch thick lower cap plate are machined to represent the scaled outside diameters and the axial dimensions of the bottom end of the UMS® cask, including the neutron shield bottom end plate. The lower cap plate thickness is not scaled, since it is only required to provide backing area for the bottom impact limiter and to contribute to the weight and CG location of the scale model.

The inner shell of the cask body is constructed of a 14-inch diameter Schedule 80 pipe. The inner shell extends the length of the cask body and is flush with the top surface of the top end plate. At the lower end, the inner shell is welded to the inside surface of the lower cap plate. To properly represent the uniform axial weight distribution of the fuel and basket, the space between the inner and outer shells is filled with a uniform thickness of lead. The thicknesses of the inner and outer shells were selected to allow the cross sectional moment of inertia of the cask body cross section to correspond to (¼) of the full-scale design. The thickness of the top and bottom plates was adjusted to allow the model CG and moment of inertia of the cask body about the axis of rotation to be scaled to the full-scale design. This ensures that the load distribution to the model impact limiters for the drop test is representative of the loading that would occur on the full-scale UMS® transport cask.

The total weight of the quarter-scale model, including the impact limiters, was 4,062 pounds, which closely approximates $(1/4)^3 = 1/64$ of the full-scale transport cask weight of 260,000 pounds.

The model impact limiters are quarter-scale representations of the full-scale impact limiters. The redwood and balsa wood used in the model limiters meets the same specifications that are defined for the full-scale UMS® transport cask limiters in this SAR. The wood section shapes, joints, and bonds of the scale model impact limiters duplicate those of the full-scale impact limiters. The grain orientation of the redwood and balsa wood in the scale model impact limiters is identical to that as designed in the full-scale impact limiters. The scale model impact limiter shells were fabricated from 16 gauge (0.0625-inch thick) Type 304 stainless steel sheets, and the screw tubes, which serve as the penetrations for the impact limiter retaining rods, were fabricated from 0.035-inch thick, 0.75-inch diameter tubes. Each model impact limiter is attached to the cask by sixteen quarter-scale retaining rods fabricated from ASME SA-193 Grade B8S stainless steel.

The model impact limiter shells – i.e., material thickness, geometry, and welds – are appropriately quarter-scale. The diameter of the screw tubes is quarter-scale, but the tube wall thickness is full-scale due to fabricability and material availability limitations. The use of the thicker tube is considered to be conservative, since it tends to increase the stiffness of the limiter, if it has any effect at all. The effect of the tube thickness on the drop test results is insignificant, since the tubes are not located in the primary crush regions of the impact limiter.

2.10.3.4.1 Equipment and Instrumentation for the Tests Conducted at SNL

The pad for the side drop test at the SNL functions as the essentially unyielding impact surface. The surface of the target consists of armor plate measuring 34 feet by 16 feet and has a varying thickness from 8 inches to 4 inches. The plate is attached to reinforced concrete that allows the total mass of the system to be 1,000 tons. The total mass of the target is approximately 500 times that of the quarter-scale test model, which is large compared to the ratio of 30 recommended by IAEA. The pad at SNL is considered to meet the IAEA requirements for a drop test pad.

Lifting and dropping the model was performed with a system of cables to provide sufficient restraint from lateral motion of the cask, as well as limit the motion of the cables upon release of the cask model. The cask model was attached to the cable system via a single point, and an explosive bolt mechanism was used to release the cask from the cables. This mechanism

to obtain true accelerations corresponding to the impact. For this evaluation, the Butterworth low-pass filter in LS-DYNA's post-processor is used with a filter frequency of 450 Hz for the lateral direction and 550 Hz for the axial direction (refer to Sections 2.10.3.4.2 and 2.10.3.3.2, respectively). The Butterworth filter is used in NUREG/CR-6608 to filter the acceleration of the impact tests for a steel billet in the side drop and end drop orientation.

The following table shows the maximum accelerations for the three 30-foot drop cases:

UMS® Cask Model Drop Orientation	Model Acceleration Results [g]		LS-DYNA Acceleration Prediction [g]		Design Basis Acceleration [g]
	Top Accelerometer	Bottom Accelerometer	Top Accelerometer	Bottom Accelerometer	
Top Corner	121	N/A	143	N/A	240
Top End	220	N/A	226	N/A	240
Side	190	198	193	210	240

As the table shows, the maximum predicted acceleration of 226g occurs during the top end drop. Acceleration time-history plots are provided in Figures 2.10.3-8 and 2.10.3-9 for the side drop and Figures 2.10.3-12 and 2.10.3-13 for the top end and top corner drops, respectively. In all cases, the LS-DYNA prediction is greater than the quarter-scale drop test results.

A comparison of the predicted crush depth to the actual crush depth is provided in the following table:

Location	Model Drop Test Crush Depth [inch]			LS-DYNA Crush Depth Prediction [inch]		
	Original Thickness	Final Thickness	Measured Crush	Original Thickness	Final Thickness	Total Crush
Top End Drop	[redacted]	[redacted]	2.04	[redacted]	[redacted]	2.21
Top Corner Drop	[redacted]	[redacted]	2.95	[redacted]	[redacted]	3.36
Side Drop–under the trunnion	5.50	0.63	2.87	5.47	1.11	2.36
Side Drop–bottom impact limiter	5.13	2.38	2.75	5.13	2.42	2.71

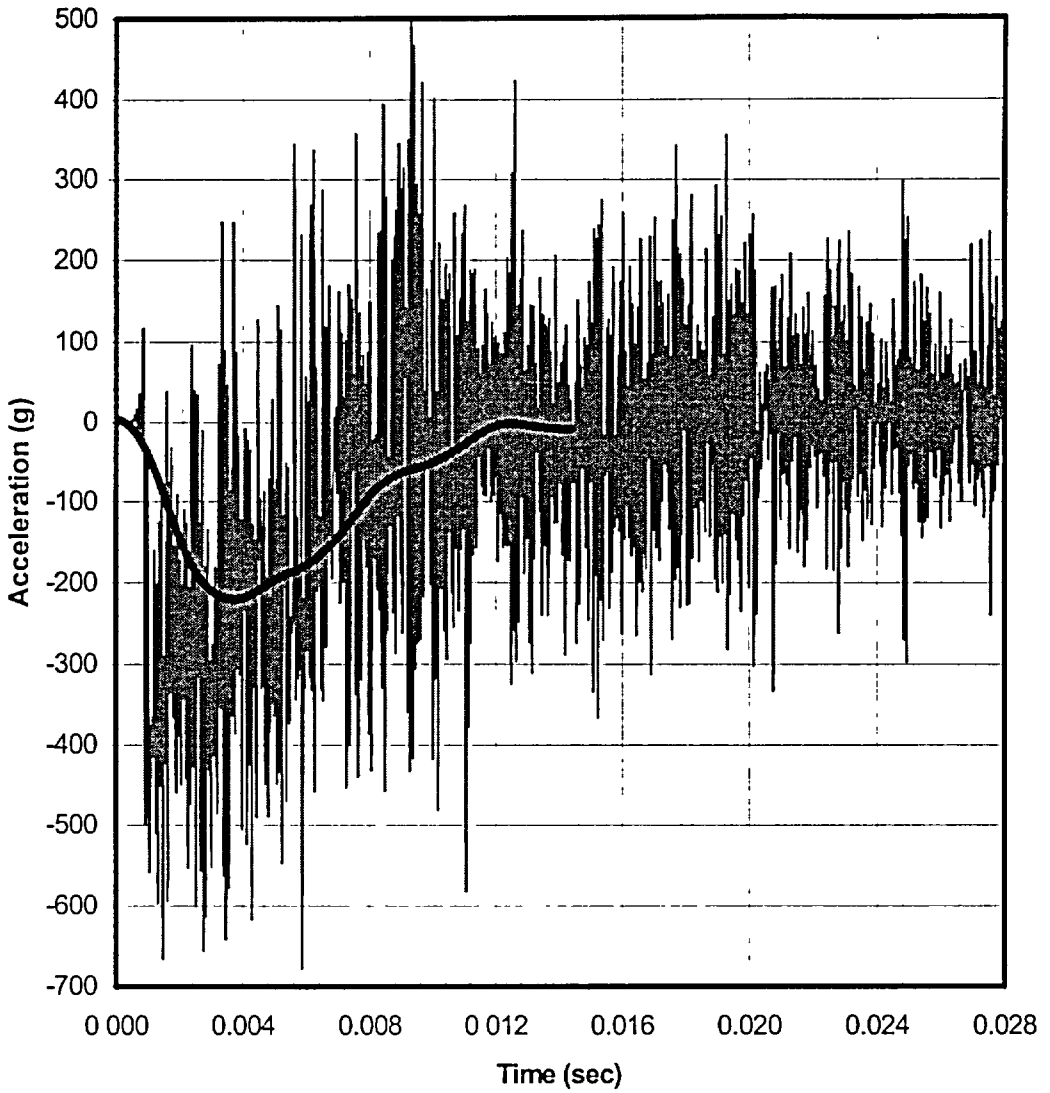
The table shows that LS-DYNA accurately predicts the amount of crush experienced during the drop tests except in regions where extreme irregular deformation occur (i.e. directly below the trunnion and corner). Figure 2.10.3-14 shows a direct comparison between the side drop test and the LS-DYNA analysis. As the figure shows, LS-DYNA provides a reasonable prediction of the crush depth that occurs in the drop accident.

The force-displacement curves for the end, corner and side drops are plotted in Figures 2.10.3-15 through 2.10.3-18. The corresponding energy dissipated by the impact limiter is computed by determining the area under the force-displacement curve. The following table summarizes the peak load, maximum deflection and the energy dissipated during the drop event.

Description	Drop Configuration			
	End	Corner	Side (Top Limiter)	Side (Bottom Limiter)
Peak Load, lbf	850,777	687,759	376,209	406,470
Maximum Deflection, in	2.68	4.98	3.20	3.31
Energy Dissipated in-lb ($\times 10^6$)	1.48	1.46	0.73	0.73

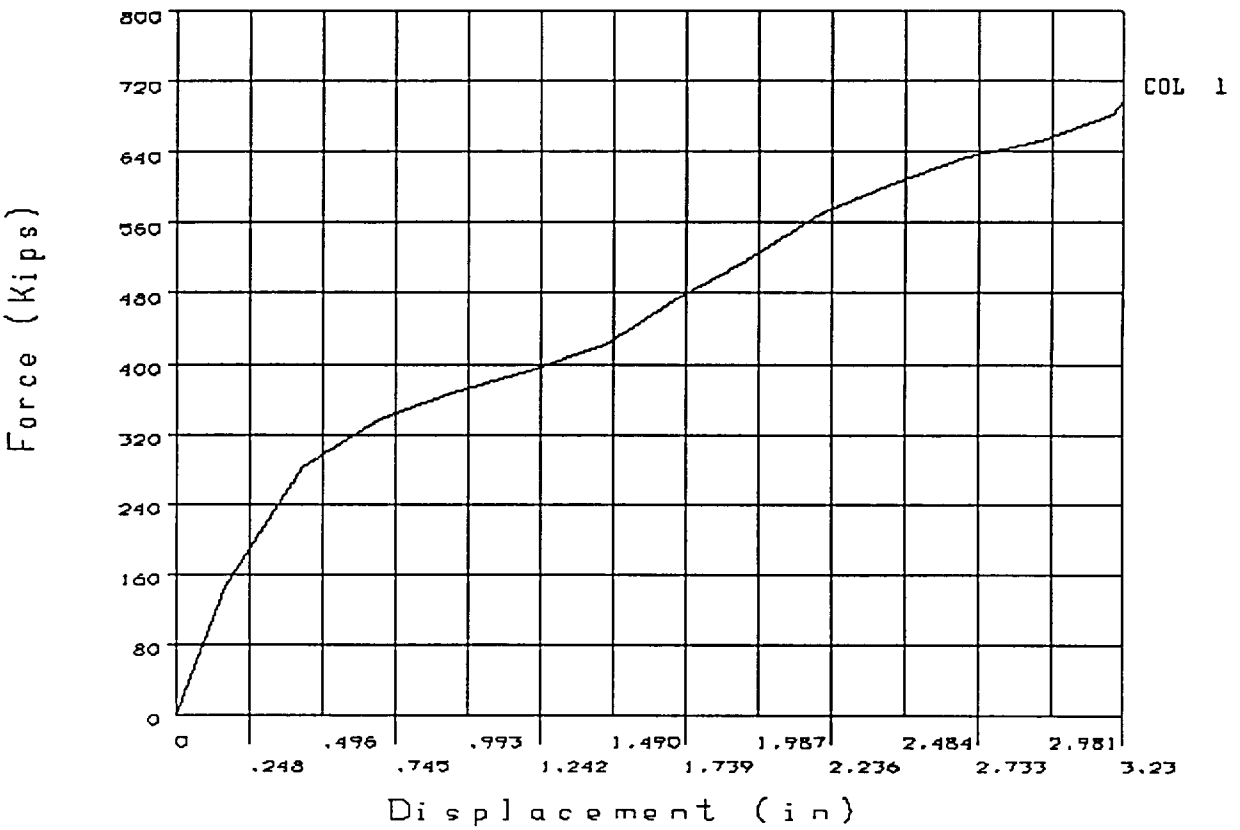
The energy associated with the 30-foot drop for a scaled model design weight of 4,060 pounds is 1.46×10^6 in-lb. The table shows that the energy dissipated by the impact limiters matches the energy associated with the 30-foot drop analyses.

Figure 2.10.3-1 Acceleration Time History for the Quarter-Scale Model Top End Drop Overlaid with the Filtered Data



Note: Negative accelerations correspond to deceleration of the quarter-scale model.

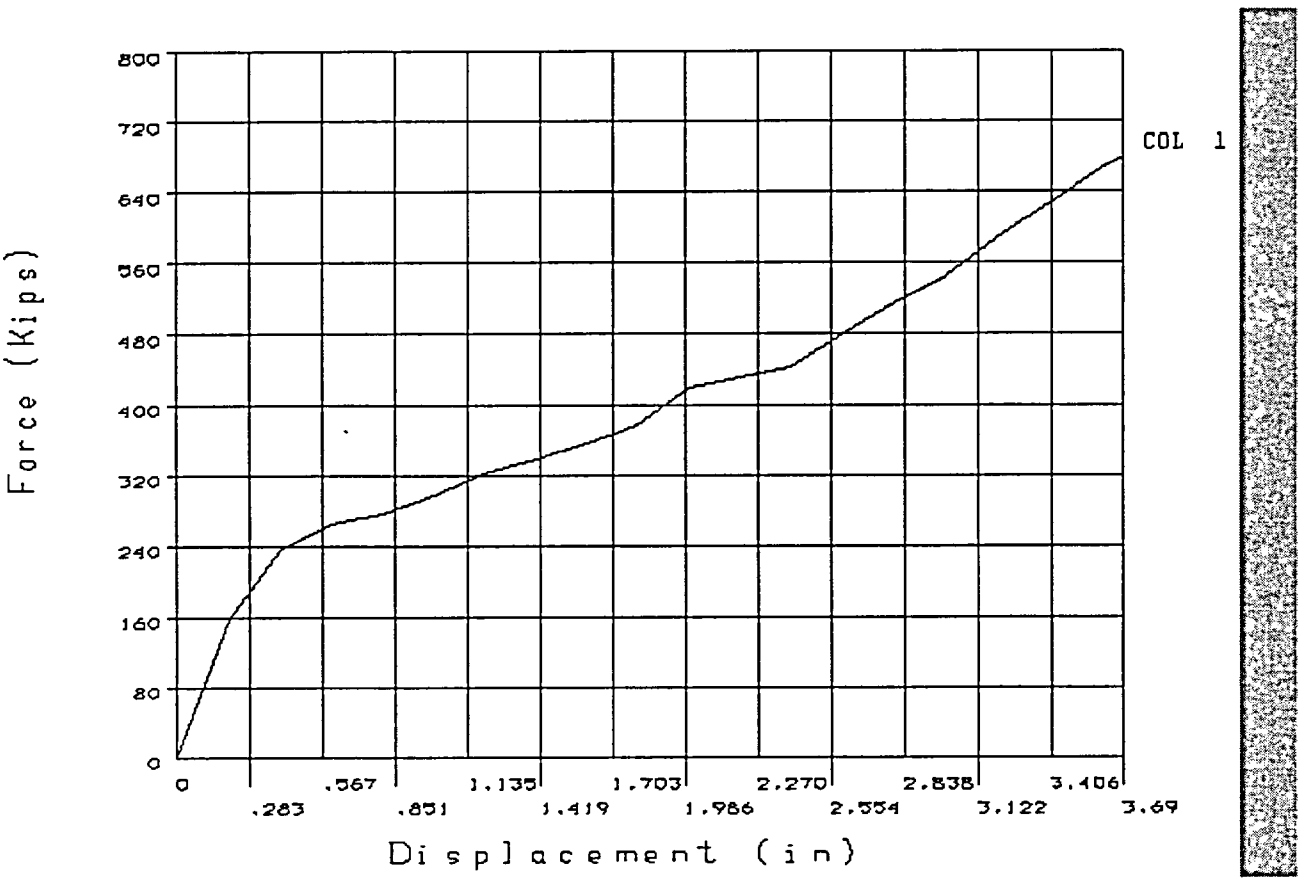
Figure 2.10.3-2 Force-Displacement Curve for Static Test 1 (End Drop Orientation) for a 45° Section of the Quarter-Scale Model Upper Impact Limiter



Note:

Forces correspond to a full quarter-scale model of the UMS® upper impact limiter. The forces have been multiplied by 1.058 to account for the dynamic crush strength of redwood.

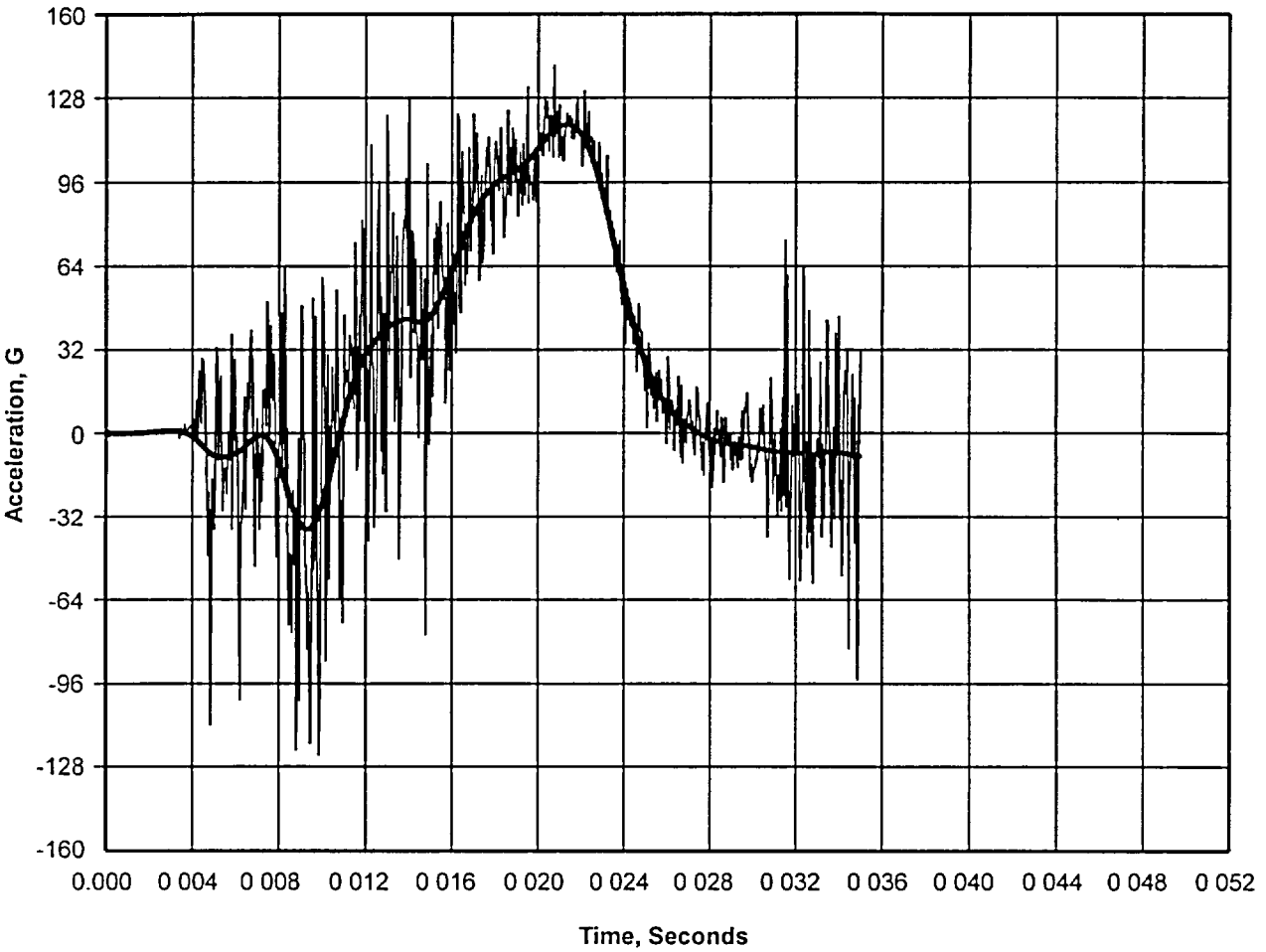
Figure 2.10.3-3 Force-Displacement Curve for Static Test 2 (End Drop Orientation) for a 45° Section of the Quarter-Scale Model Upper Impact Limiter



Note:

Forces correspond to a full quarter-scale model of the UMS® upper impact limiter. The forces have been multiplied by 1.058 to account for the dynamic crush strength of redwood.

Figure 2.10.3-4 Typical Filtered Acceleration Time History for the Quarter-Scale Model Top Corner Drop, Overlayed with the Unfiltered Data



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UMS®

UNIVERSAL MPC SYSTEM®

SAFETY ANALYSIS REPORT

for the

UMS® Universal Transport Cask

JULY 2002 UMST-02C

VOLUME 2 OF 2

NAC INTERNATIONAL

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