71-9297

Westinghouse

Westinghouse Electric Company
Nuclear Fuel
Columbia Fuel Site
P.O. Drawer R
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USA

U. S. Nuclear Regulatory Commission
Attn: Mr. Stewart Brown
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Our ref: NMS-NRC-05-002
Your Ref:

Mr. Brown:

February 16, 2005

Subject: CERTIFICATE OF COMPLIANCE NO. 9297 FOR THE MODEL NO. TRAVELLER PACKAGE, RESPONSE TO SECOND NRC REQUEST FOR ADDITIONAL INFORMATION (RAI)

Attached please find Westinghouse Electric Company's response to follow-on questions and comments NRC had with regard to the Traveller License Application. Westinghouse appreciates the thorough review given to the Safety Analysis Report, and is confident that all issues are resolved with this submittal.

The majority of changes involved correcting typographical, formatting, and cross-reference errors. Technical changes included such things as removing all reference to borated aluminum as a neutron poison, reporting on the sensitivity study for moving the clamshell around inside the outerpack, and updating the rod container analysis using the current HAC model.

Enclosed are the change pages that make up revision 2 to the Traveller SAR. A summary description of the major revision items is presented for each section.

Instructions for inserting the change pages is included. Also included is a list of effective pages for the SAR. Please place these after the table of contents. Please direct any questions to the undersigned at (803) 647-3552.

Sincerely,

WESTINGHOUSE ELECTRIC COMPANY, LLC

Norman A. Kent

Norman A. Kent
Manager Transport Licensing and Regulatory Compliance
Nuclear Material Supply

Enclosure: Rev 2 Change pages

Information in this record was deleted
in accordance with the Freedom of Information
Act, exemptions 4
FOIA- 2007-213

NMSS01

License Drawings

10004E58 (8 sheets)	Rev 3	Revision 3 removes all reference to borated aluminum
10006E58 (1 sheet)	Rev 1	Inadvertently omitted when Rev 1 to SAR was distributed.
10006E59 (2 sheets)	Rev 1	Inadvertently omitted when Rev 1 to SAR was distributed.

Section 1

- Removed reference to borated aluminum.

Section 2

- Removed reference to borated aluminum.
- Corrected grammatical and typographical errors.
- Corrected cross-reference errors.
- Revised Section 2.12.3 to place appropriate emphasis on FEA results.
- Replaced Figures 2-89 and 2-119 with correct annotations for axial and vertical response quantities
- Reconciled the peak acceleration values listed in Table 2-30 with those displayed in Figure 2-91.
- Provided reference or justification for the use of bolt interaction equations
- Provided justification for assertion that temperature and variation in form density due to manufacturing tolerances have only minor effect on the drop performance of the Traveller package.

Section 3

- Revised Table 3-1 to include information on shock mounts.

Section 5

- Revised section on shielding evaluation.

Section 6

- Removed reference to borated aluminum.
- Corrected grammatical and typographical errors.
- Corrected cross-reference errors.
- Removed references to specific regulatory requirements.

- Corrected inconsistency with regard to moderation configuration for array and individual package.
- Performed sensitivity study to evaluate effect on system k_{eff} if shock mounts were to fail and the clamshell were to relocate inside the outerpack.
- Revised fuel assembly parameter tables to include requested information such as nominal GT OD and thickness.
- Revised rod container section as follows:
    - Re-ran models using actual HAC model rather than earlier version.
    - The actual HAC model included replacement of borated aluminum with BORAL
    - Changing areal density from 0.0188 g/cm^2 to 0.0180 g/cm^2.
    - Included precise modeling of moderator blocks.
    - Included input decks which were inadvertently omitted in Rev 1.
    - Performed sensitivity analysis for varying water density for interspersed moderation for infinite array cases.
- Corrected mass quantities for actual package versus model.

Section 8

- Removed reference to borated aluminum.
- Revised section on neutronics testing requirements.

TRAVELLER SAFETY ANALYSIS REPORT
INSTRUCTIONS FOR INSERTING REVISION 2 CHANGE PAGES

Section 1

After Tab 1 "General Information," remove the following pages within this tab and insert the Revision 2 pages as follows:

Remove Pages	Insert Pages
1-3 (Rev. 0)/1-4 (Rev. 0)	1-3 (Rev. 0)/1-4 (Rev. 2)

Section 2

After Tab 2 "Structural Evaluation," remove the following pages within this tab and insert the Revision 2 pages as follows:

Remove Pages	Insert Pages
i (Rev. 1)/ii (Rev. 1)	i (Rev. 1)/ii (Rev. 2)
vii (Rev. 1)/viii (Rev. 1) <u>and</u> ix (Rev. 1)/x (Rev. 1)	vii (Rev. 2)/viii (Rev. 1) <u>and</u> ix (Rev. 1)/x (Rev. 2)
2-5 (Rev. 0)/2-6 (Rev. 0)	2-5 (Rev. 2)/2-6 (Rev. 2)
2-17 (Rev. 0)/2-18 (Rev. 0)	2-17 (Rev. 2)/2-18 (Rev. 2)
2-21 (Rev. 0)/2-22 (Rev. 0)	2-21 (Rev. 0)/2-22 (Rev. 1)
2-23 (Rev. 0)/2-24 (Rev. 0) <u>and</u> 2-25 (Rev. 0)/2-26 (Rev. 0)	2-23 (Rev. 2)/2-24 (Rev. 0) <u>and</u> 2-25 (Rev. 2)/2-26 (Rev. 0)
2-37 (Rev. 0)/2-38 (Rev. 1)	2-37 (Rev. 0)/2-38 (Rev. 2)
2-67 (Rev. 1)/2-67A (Rev. 1) <u>and</u> 2-67B (Rev. 1)/2-68 (Rev. 0)	2-67 (Rev. 2)/2-67A (Rev. 2) <u>and</u> 2-67B (Rev. 2)/2-68 (Rev. 2)
2-105 (Rev. 0)/2-106 (Rev. 1)	2-105 (Rev. 2)/2-106 (Rev. 1)
2-125 (Rev. 0)/2-126 (Rev. 0)	2-125 (Rev. 0)/2-126 (Rev. 2)
2-133 (Rev. 0)/2-134 (Rev. 1)	2-133 (Rev. 0)/2-134 (Rev. 2)
2-155B (Rev. 1)/2-156 (Rev. 0) <u>and</u> 2-157 (Rev. 0)/2-158 (Rev. 1)	2-155B (Rev. 1)/2-156 (Rev. 2) <u>and</u> 2-157 (Rev. 2)/2-158 (Rev. 1)
2-171 (Rev. 0)/2-172 (Rev. 0)	2-171 (Rev. 0)/2-172 (Rev. 2)
2-183 (Rev. 0)/2-184 (Rev. 0)	2-183 (Rev. 2)/2-184 (Rev. 0)
2-191 (Rev. 0)/2-192 (Rev. 0)	2-191 (Rev. 0)/2-192 (Rev. 2)

TRAVELLER SAFETY ANALYSIS REPORT
INSTRUCTIONS FOR INSERTING REVISION 2 CHANGE PAGES (cont.)

Section 3

After Tab 3 "Thermal Evaluation," remove the following pages within this tab and insert the Revision 2 pages as follows:

Remove Pages	Insert Pages
3-1 (Rev. 0)/3-2 (Rev. 1)	3-1 (Rev. 0)/3-2 (Rev. 2)

Section 5

After Tab 5 "Shielding Evaluation," remove the following pages within this tab and insert the Revision 2 pages as follows:

Remove Pages	Insert Pages
5-1 (Rev. 0)/Blank	5-1 (Rev. 2)/Blank

Section 6

After Tab 6 "Criticality," remove the following pages within this tab and insert the Revision 2 pages as follows:

Remove Pages	Insert Pages
i (Rev. 1)/ii (Rev. 1) <u>through</u> vii (Rev. 1)/Blank	i (Rev. 1)/ii (Rev. 2) <u>through</u> vii (Rev. 2)/Blank
6-1 (Rev. 0)/6-2 (Rev. 0) <u>and</u> 6-3 (Rev. 0)/6-4 (Rev. 0)	6-1 (Rev. 2)/6-2 (Rev. 0) <u>and</u> 6-3 (Rev. 2)/6-4 (Rev. 2)
6-9 (Rev. 1)/6-10 (Rev. 1)	6-9 (Rev. 1)/6-10 (Rev. 2)
6-15 (Rev. 0)/6-16 (Rev. 1)	6-15 (Rev. 2)/6-16 (Rev. 1)
6-19 (Rev. 1)/6-20 (Rev. 1) <u>through</u> 6-23 (Rev. 1)/6-24 (Rev. 1)	6-19 (Rev. 2)/6-20 (Rev. 2) <u>through</u> 6-23 (Rev. 2)/6-24 (Rev. 1)
6-27 (Rev. 1)/6-27A (Rev. 1)	6-27 (Rev. 1)/6-27A (Rev. 2)
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6-39 (Rev. 1)/6-40 (Rev. 1)	6-39 (Rev. 1)/6-40 (Rev. 2)
6-47 (Rev. 1)/6-47A (Rev. 1) and 6-47B (Rev. 1)/6-48 (Rev. 1)	6-47 (Rev. 1)/6-47A (Rev. 2) and 6-47B (Rev. 1)/6-48 (Rev. 2)

Then, after page 6-48A (Rev. 1)/6-48B (Rev. 1) add pages 6-48C (Rev. 2)/6-48D (Rev. 2).

Remove Pages	Insert Pages
6-49 (Rev. 0)/6-50 (Rev. 0)	6-49 (Rev. 0)/6-50 (Rev. 2)
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6-55 (Rev. 0)/6-56 (Rev. 0)	6-55 (Rev. 2)/6-56 (Rev. 2)
6-65 (Rev.1)/6-66 (Rev. 1)	6-65 (Rev. 2)/6-66 (Rev. 1)
6-99 – 6-103 (Rev. 1)/6-104 (Rev. 1) through 6-107L (Rev. 1)/6-108 (Rev. 1)	6-99 – 6-103 (Rev. 1)/6-104 (Rev. 2) through 6-107HH (Rev. 2)/6-108 (Rev. 1)

Then, after page 6-159 (Rev. 1)/6-160 (Rev. 1) add pages 6-160A (Rev. 2)/6-160B (Rev. 2) through 6-160I (Rev. 2)/6-160J (Rev. 2).

Section 8

After Tab 8 "Acceptance Tests & Maintenance Programs," remove the following pages within this tab and insert the Revision 2 pages as follows:

Remove Pages	Insert Pages
8-5 (Rev. 1)/8-5A (Rev. 1) through 8-7 (Rev. 1)/8-8 (Rev. 1)	8-5 (Rev. 2)/8-5A (Rev. 2) through 8-7 (Rev. 2)/8-8 (Rev. 1)

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1-1	0	2-16	0	2-53	0	2-94	0
1-2	1	2-17	2	2-54	0	2-95	0
1-3	0	2-18	2	2-55	0	2-96	0
1-4	2	2-19	0	2-56	1	2-97	0
1-5	0	2-20	0	2-57	0	2-98	0
1-6	0	2-21	0	2-58	0	2-99	1
1-6A	1	2-22	1	2-59	0	2-100	0
1-6B	1	2-22A	1	2-60	0	2-101	1
1-7	0	2-22B	1	2-61	0	2-102	0
1-8	0	2-22C	1	2-62	0	2-103	1
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		2-23	2	2-64	0	2-105	2
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iii	0	2-26	0	2-67	2	2-106B	1
iv	0	2-27	0	2-67A	2	2-107	0
v	1	2-28	0	2-67B	2	2-108	0
vi	1	2-29	0	2-68	2	2-109	0
vii	2	2-30	0	2-69	0	2-110	0
viii	1	2-31	0	2-70	0	2-111	0
ix	1	2-32	1	2-71	0	2-112	0
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xi	1	2-32B	1	2-73	0	2-114	0
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2-12	0	2-47	0	2-88	0	2-129	0
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iv	2
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6-9	1	6-46B	1	6-82A	1	6-107S	2
6-10	2	6-47	1	6-82B	1	6-107T	2
6-11	0	6-47A	2	6-82C	1	6-107U	2
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6-36	1	6-65	2	6-107E	2	6-121	1
6-37	1	6-66	1	6-107F	2	6-122	1
6-38	1	6-67	1	6-107G	2	6-123	1
6-39	1	6-68	0	6-107H	2	6-124	1
6-40	2	6-69	1	6-107I	2	6-125	1
6-41	1	6-70	1	6-107J	2	6-126	1
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6-42A	1	6-72 – 6-76	1	6-107L	2	6-128	1
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6-43	1	6-78	1	6-107N	2	6-13	1
6-44	1	6-79	1	6-107O	2	6-131	1
6-45	1	6-80	1	6-107P	2	6-132	1
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6-134	1	i	0				
6-135	1						
6-136	1	7-1	1				
6-137	1	7-2	1				
6-138	1	7-3	1				
6-139	1	7-4	1				
6-140	1						
6-141	1						
6-142	1	i	1				
6-143	1						
6-144	1	8-1	1				
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6-160D	2						
6-160E	2						
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6-160G	2						
6-160H	2						
6-160I	2						
6-160J	2						
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6-162	1						
6-163	1						
6-164	1						
6-165	1						

Westinghouse Electric Company, LLC
Columbia Fuel Fabrication Plant
Columbia, SC

Application for Certificate of Compliance for the Traveller PWR Fuel Shipping Package

NRC Certificate of Compliance

USA/9297/AF-96

Docket 71-9297

Initial Submittal: March 2004

Revision 1: November 2004

Revision 2: February 2005

Westinghouse

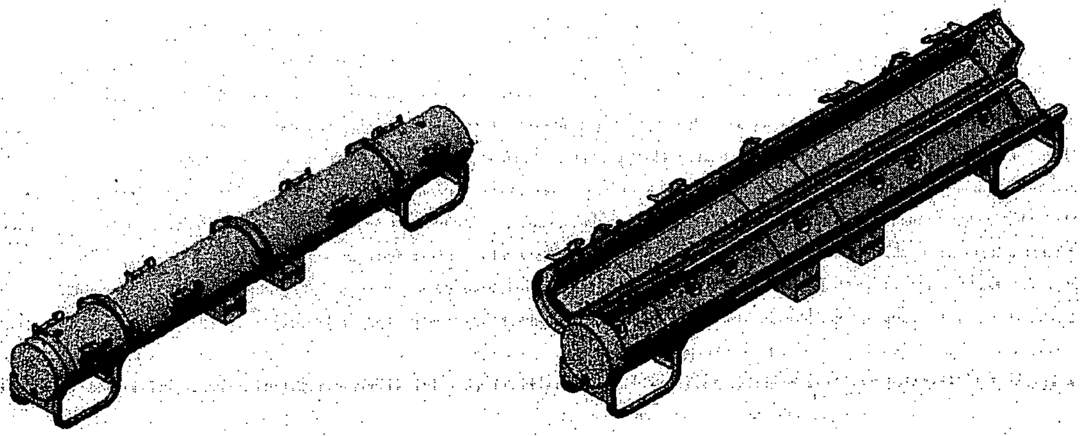

Figure 1-1 Outerpack Closed Position (left) and Opened Position (right)

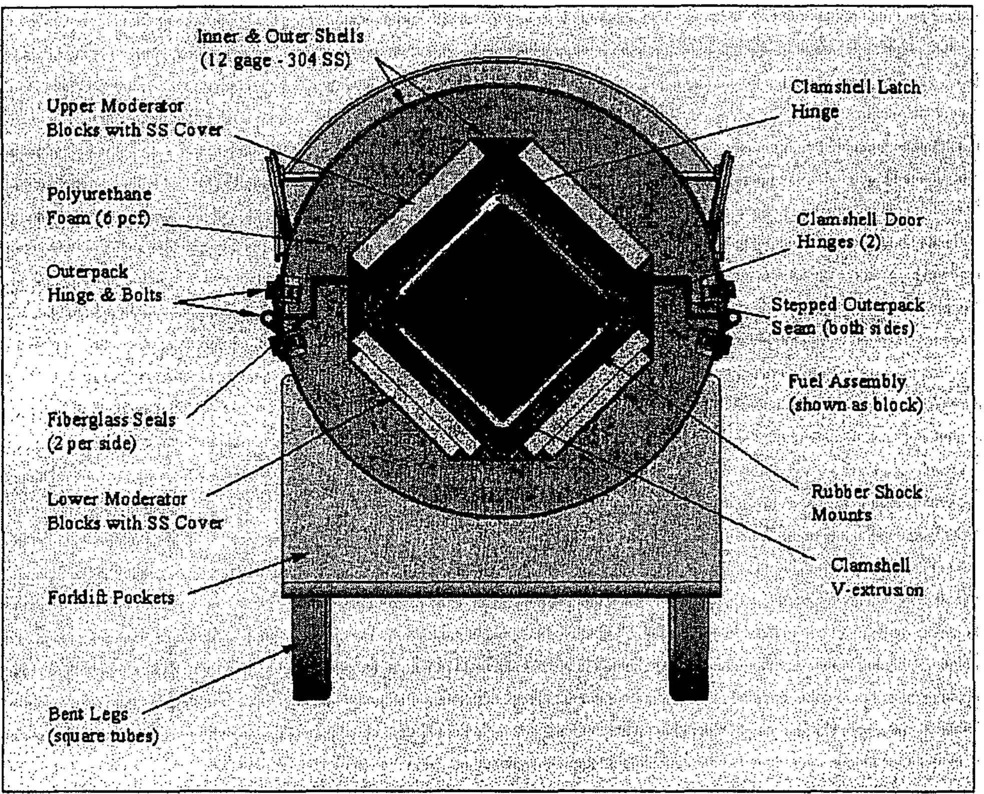

Figure 1-2 Outerpack Cross-Section View (typical)

1.2.1.3 Clamshell

The Clamshell is a structural component consisting of a lower aluminum "v" extrusion, two aluminum door extrusions, and a small top access door. Piano type hinges (continuous hinges) connect each door to the "v" extrusion. The doors are then held closed with a latch mechanism and eleven quarter-turn bolts (9 for the Traveller STD). At the bottom nozzle end, a base plate is bolted to the "v" extrusion. At the top nozzle end, the top plate and small v-shaped door are bolted together. These form the top door which is hinged at one side to allow it to swing open, leaving access to the top nozzle from above. The top door is secured with a short hinge pin which is inserted along the length of the top door. The Clamshell assembly is shown closed, and opened in Figure 1-3. A more detailed schematic showing key Clamshell components of the top end is depicted in Figure 1-4.

The quarter-turn Clamshell fasteners are shown in Figure 1-5. By rotating the nut plus or minus 90 degrees opens or closes the latch. Spring- loaded plungers on both sides of the nuts positively restrain each nut during shipping and handling, and precludes inadvertent opening of the latch.

The Fuel Assembly or Rod Tube is secured inside the Clamshell at three locations down the length. At the top end, two jackscrews with neoprene pads clamp the fuel assembly axially against the bottom plate. Adjustable spring-loaded pads are positioned at any axial location between end locations to secure the fuel assembly along its length. These pads will be located at mid-grid locations.

The "v" extrusion is lined with a cork rubber pad to cushion the contents and prevent damage during normal handling and transport conditions. The bottom plate is similarly lined with cork rubber.

Neutron absorber plates are installed in each leg of the "v" extrusion and in each of the doors. The absorber plate *is* inserted in pocket in each extrusion and attached with screws. The plates are solely for neutron absorption and do not provide any structural support. More details are described in Section 6, Criticality Evaluation and Section 8, Acceptance Tests and Maintenance Program.

The purpose of the Clamshell is to protect the contents during routine handling and in the event of an accident. During routine handling, the Clamshell doors are closed immediately after the contents are loaded. This provides a physical barrier to debris or accidental damage. During accident conditions, the Clamshell provides a physical barrier to rod bowing, lattice expansion, and loss of rods. It also provides neutron absorption.

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2.2 MATERIALS

2.2.1 Material Properties and Specifications

Mechanical properties for the materials used for the structural components of the Traveller packages are provided in this section. Temperature-dependent material properties for structural components are primarily obtained from Section II, Part D, of the ASME Boiler and Pressure Vessel (B&PV) Code. The analytic evaluation of the Traveller packages is via computer simulation (ANSYS/LS-DYNA®), only the material properties specific to the analysis portion and computer simulation portion of the evaluation are given. Table 2-2 lists the materials used in the Traveller packages and summarized key properties and specifications. More detailed material properties can be found in Appendix 2.12.2, Mechanical Design Calculations for the Traveller XL Shipping Package Traveller XL, and Appendix 2.12.3, Drop Analysis for the Traveller XL Shipping Package.

All materials used in the fabrication of the Certification Test Unit (CTU) meet 10 CFR 71 and TS-R-1 requirements. However, simulated neutron absorber plates were affixed to the inner faces of the Clamshell. These were fabricated from 1100-T0 aluminum ("dead soft" aluminum). These component plates did not contain boron, and were used to simulate the mechanical and thermal properties of *the neutron absorber plates*. The 1100-T0 aluminum was used due to its low mechanical properties. In production units, the actual *neutron absorber* plates will have insignificant differences in the material properties compared to the material used in the prototypes and CTU package.

2.2.2 Chemical, Galvanic, or Other Reactions

The Traveller series of packages are fabricated from ASTM A240 Type 304 stainless steel, 6000-series aluminum, borated 1100-series aluminum, polyurethane foam, and polyethylene sheeting. The stainless steel Outerpack does not have significant chemical or galvanic reactions with the interfacing components, air, or water.

The aluminum Clamshell is physically isolated, and environmentally protected, by the Outerpack and therefore will have negligible chemical or galvanic reactions with the interfacing components, air, or water. In addition, the Type 304 stainless steel fasteners which attach various Clamshell components represent a very small area ratio (cathode-to-anode ratio), which will render the reaction insignificant. Therefore, the requirements of 10 CFR §71.43(d), TS-R-1 (613) are met.

The Outerpack hinge bolts are zinc plated for the purpose of improving galling resistance which can be a significant problem when stainless steel fasteners are inserted in stainless steel threaded holes. The plating is not required for chemical or galvanic protection.

2.2.3 Effects of Radiation on Materials

There are no materials used in the Traveller packages which will be adversely affected by radiation under normal handling and transport conditions.

Table 2-2 Safety-Related Materials Used in the Traveller Packages

Material	Critical Properties	Reference Specifications/Codes	Comments
304 Stainless Steel	UTS: 75 ksi (517 MPa) YLD: 30 ksi (206 MPa) τ_{allow}: 18 ksi (124 MPa) E: 29.4 E6 psi (203 GPa)	ASTM A240 ASTM A276	Fully annealed material and not subject to brittle fracture.
6005-T6 Aluminum	UTS: 38 ksi (262 MPa) YLD: 35 ksi (241 MPa) τ_{allow}: 21 ksi (145 MPa) E: 10 E6 psi (69 GPa)	ASTM B221 ASTM B209	Reference standard UNS A96005
6061-T6 Aluminum	UTS: 45 ksi (310 MPa) YLD: 40 ksi (276 MPa) τ_{allow}: 24 ksi (165 MPa) E: 10 E6 psi (69 GPa)	ASTM B221 ASTM B209	Reference standard UNS A96061
Polyurethane Closed Cell Foam	Densities: 6 ± 1 pcf (0.096 ± 0.016 gm/cm^3), 10 ± 1 pcf (0.16 ± 0.016 gm/cm^3), 20 ± 2 pcf (0.32 ± 0.016 gm/cm^3) Crush Strengths: See Appendix 2.12.2	Westinghouse Specification PDSHIP02 ASTM D1621-94 ASTM D1622-93 ASTM D2842	Burn Characteristics verified by ASTM F-501, with exceptions noted in PDSHIP02.
UHMW Polyethylene	Specific Gravity: > 0.93 Molecular Wt: >3 million	ASTM D4020	N/A
Borated Aluminum Laminate Composite	Minimum areal densities: Borated Al Composite: 0.024 g/cm^2	Westinghouse Specification PDSHIP04 ASTM E748	The minimum areal densities are defined for the finished plate or laminate final thickness of 0.125" ± 0.006" (3.175 mm ± 0.153 mm). No structural credit is taken for the neutron poison plates.
Ceramic Insulation (Paper and Felt)	Max. use temp: >1800°F (982°C) Conductivity: ≤ 1.2 Btu-in/hr-ft^2 @ 500°F, (0.173 W/m-K @ 260°C)	N/A	The paper thickness is 0.0625" (1.59 mm), and the blanket thickness is 0.25" (6.35 mm)

<table>
<tr><th colspan="4">Table 2-5 Summary of the Development of the Traveller</th></tr>
<tr><th>Traveller XL</th><th>Test Sequence(s)</th><th>Structural Performance</th><th>Fire/Thermal Performance</th></tr>
<tr><td>Prototype-1
Drop testing: Jan 27-28, 2003
Burn Testing: Feb 28, 2003</td><td>Objective: FEA validation
- 9 m low angle slap down (14.5 degrees)
- 9 m high angle (71 degrees)
- 1 m pin puncture (through CG, low angle)
- 35 minute pool fire burn test.</td><td>- Outerpack – Satisfied requirements. Minor, local damage only.
- Clamshell – Satisfied requirements for 9 m low angle test. Failed requirements for 9 m high angle test. Satisfied 1 m pin puncture test.</td><td>Outerpack failed to prevent ignition of polyethylene sheets in one location.
Clamshell temperature away from interior combustion satisfied fire requirements.</td></tr>
<tr><td colspan="4">Comments:
The Traveller XL Prototype-1 demonstrated robust structural performance, except for the Clamshell head(s) attachment which was not adequate. The most probable root cause of ignition of polyethylene sheeting was polyurethane foam combustion products entering the inside of the Outerpack as a result of holes drilled into inner Outerpack shell for thermocouples. No seals were used in the Outerpack for conservatism.
Fire testing failed to prevent ignition of the combustible materials in the Outerpack. However, the components not adjacent to the internal fire remained well within thermal limitations, thus, demonstrating that the Outerpack had sufficient thermal resistance to external heat flow into package.
Design Changes as a Result of Testing:
Additional bolts were added to secure the top Clamshell head for Prototype-2 testing (see below).
The package was subjected to the applicable tests for Normal and Hypothetical Accident conditions as described below. Following this series, the package was modified again to assess the robustness of the design. The center Outerpack hinge bolts were removed (1 of 3 bolts) from each hinge section. The number of locking pins on the Clamshell latches was also reduced, from 18 to 12.</td></tr>
<tr><td>Prototype-2
Drop Testing: Jan 30, 2003
Burn Testing: N/A</td><td>- 1.2 m low angle slapdown (20 degrees)
- 1 m pin puncture (through CG, low angle)
- 9 m high angle (72 degrees)
Bolts and locking pins removed (described above)
- 9 m end drop (bottom end down)
- 9 m horizontal (feet down)
- 9 m horizontal (side down)</td><td>- Outerpack – Satisfied requirements for all 9 m drops and pin puncture tests. Minor, local damage only.
- Clamshell – Satisfied requirements for first 9 m drop. Bottom head separated in second 9 m drop (bottom end drop) because the fuel assembly was not properly seated against bottom Clamshell head as a result of prior drop. No other significant damage.</td><td>- Prototype 2 was not subjected to HAC fire testing.</td></tr>
</table>

Table 2-5 (cont.) Summary of the Development of the Traveller

Traveller XL	Test Sequence(s)	Structural Performance	Fire/Thermal Performance

Comments:

The performance of the Prototypes (1 & 2) associated with the first testing campaign clearly demonstrated the robustness of the Overpack and Clamshell (except for the Clamshell head attachments). In all, six (6) drops were performed on 2 full-scale prototypes from 9 m. The Outerpack retained its overall integrity and functionality. Most importantly, all design features important to criticality safety performed as intended. Moderator blocks and simulated *neutron absorber* plates remained intact and attached to their respective structural components.

Design Changes as a Result of Testing:

Based on the robust structural performance of the Prototype units, several design changes were made to the Traveller XL for subsequent testing in the second test campaign. The Traveller units fabricated for the second campaign were called the Qualification Test Units, or QTUs. A total of two units were fabricated and tested. The significant changes to the QTUs were as follows:

1. The Outerpack stainless steel shells were reduced from 11 gauge (0.1196 in., 3.04 mm) to 12 gauge (0.1046 in., 2.66 mm). This change was made primarily to lower weight and reduce excessive structural margin.
2. The hinge bolts were reduced in both number and size, from ten 7/8" (2.22 cm) diameter bolts to ten ¾" (1.91 cm) bolts. This change was made to reduce excessive design margin.
3. A total of 2 seal materials were added to the design to act as: 1) an environmental seal, and 2) to minimize hot gases from entering the Outerpack seams.
4. The Outerpack leg structure, circumferential stiffeners, stacking brackets, and forklift pocket structures were changed. These changes were made for simplified manufacturing purposes and to reduce excessive design margin.
5. The polyurethane foam density of the center section of the package was reduced from 11 pcf to 10 pcf. The axial limiter foam sections of the package were also reduced from 16 pcf to 14 pcf. This change was made to lower the impact deceleration, and therefore loads experienced by the Clamshell.
6. The Clamshell extrusions were made thicker, from a nominal 0.375" (0.95 cm) to 0.438" (1.11 cm). This change was made primarily to eliminate welding of the heads to the extrusions. Bolted connections were utilized to attach the heads.
7. The welded simulated poison plates were redesigned for a bolted connection. This change was made to reduce the distortion of the aluminum Clamshell extrusions due to welding.
8. The Clamshell door locking latches were redesigned for quarter-turn nuts. This change was made for manufacturing and aesthetic purposes.
9. The Clamshell axial restraint system for restraint of the fuel assembly was redesigned. This change was made to simplify the fuel handling.

Table 2-5 (cont.) Summary of the Development of the Traveller

<table>
<tr><th>Traveller XL</th><th>Test Sequence(s)</th><th>Structural Performance</th><th>Fire/Thermal Performance</th></tr>
<tr><td colspan="4">4. The four (4) long Outerpack hinge sections were lengthened to cover all of the Outerpack seams. There existed a nominal 3 inch (7.6 cm) uncovered section at the bottom end.
5. The bottom limiter cover which curves around the bottom impact limiter was extended an additional 1.5 inches axially. Ribs (or lips) were added to this cover, and to the bottom limiter, to further reduce the ingress of hot gases.
6. The foam density in the outer sections of impact limiters was increased from 14 pcf to 20 pcf to reduce the heat flow through these sections.
7. The polyethylene moderator sheets were redesigned for manufacturing purposes.
8. The silicone rubber Omega seal, was replaced with acrylic impregnated fiberglass braided tubing. This change was made to eliminate a potential source of combustion inside the Outerpack.
The design changes listed above were retrofitted onto the QTU-1 unit (which had already been burned). The QTU-1 unit was then instrumented and taken through a series of fire tests in an effort to quantify the thermal design margins associated with these design changes. This testing was considered necessary to quantify the thermal design margins before the final Certification Test Unit (CTU) test article was tested. The modified unit was tested twice. It was first burned for 40 minutes, then it was re-burned for another 30 minutes the following day. The results of the tests were excellent. The impact limiter pillow temperature never exceeded 120°C, and the data confirms the primary heating to the inside of the Outerpack is by conduction.
Based on the successful testing of the modified QTU-1 article, the design changes were incorporated in the manufacturing of the Traveller XL CTU package</td></tr>
<tr><td>CTU
Drop Testing:
Feb 5, 2004
Burn Testing:
Feb 10, 2004</td><td>- 1.2 m low angle slapdown (9 degrees)
- 9 m end drop (bottom end down)
- 1 m pin puncture (21 degrees through CG, directly onto Outerpack hinge)
- 32 minute pool-fire burn test.</td><td>- Outerpack – <u>Satisfied</u> requirements for both drops and pin puncture tests. Minor, local damage only.
- Clamshell – <u>Satisfied</u> requirements for both drop tests and thermal tests. The Clamshell retained its shape and remained closed and latched after drop testing.</td><td>Clamshell – <u>Satisfied</u> requirements for fuel containment and criticality safety. The Clamshell and its contents remained below a maximum of 150°C.</td></tr>
<tr><td colspan="4">The Traveller XL CTU demonstrated robust structural performance. No Outerpack bolts failed and the Outerpack retained its circular pre-test shape. The Outerpack did not separate, and the pin puncture did not perforate the inner or outer shells nor did it affect the Clamshell in any detrimental way. Minor weld failures on the Outerpack, in the region near the impact, were observed in post-test examinations. These failures had negligible effect on the performance of the CTU. The two (2) quick release pins on the cover lips detached during the drop test, therefore, they could not be used where they were intended, in the burn test (as such, they were not re-installed for the burn testing).</td></tr>
</table>

Table 2-5 (cont.) Summary of the Development of the Traveller

Traveller XL	Test Sequence(s)	Structural Performance	Fire/Thermal Performance

The impact limiter pillows performed as intended, however, they did not crush as much as intended due to the inherent axial flexibility of the 17x17 XL fuel assembly. The moderator sheeting remained completely contained within the sheet metal covering. A small brown spot was observed on the back side of one moderator sheet attached to the Outerpack top half. A very small amount of flow occurred away from the hot spot. This melt spot was small, affecting only a few cubic centimeters of material.

The Clamshell was found intact and closed, and the simulated poison plates maintained their attached position with very little distortion. Minor damage was observed at the location of the impact with the pillow, however, the damage had negligible effect on the performance of the Clamshell. All closure nuts remained intact with no signs of distortion or stress.

The most significant observation from the post-test examinations were 20 cracked fuel rod bottom end plug welds. These cracks occurred in the regions corresponding to the corners of the bottom nozzle. At these corners, the buckled bottom nozzle has steep faces (in excess of 45 degrees), which was exacerbated by the characteristically long legs of the 17XL assembly. The angled faces apply a side force to the local fuel rods as they are decelerated in the impact. The largest crack occurred in a fuel rod located in the outermost row within the assembly. The crack in the rod had a maximum width of approximately 0.075" (1.91 mm). This width is not sufficiently large enough for loss of fuel from the rod. Further, in all cases of cracked rods, the bottom end plugs did not separate. Therefore, fuel pellets are prevented from exiting any of the cracked rods.

Design Changes as a Result of Testing:

The CTU satisfied the HAC drop-test and burn-test requirements in all aspects. However, as with any development program, improvements can be envisioned after every series of tests. Based on the results of the CTU tests, several minor changes shall be incorporated into production units to enhance the performance of the package. There changes do not change the performance or characteristics of the package, but merely improve the safety margin of the package by incorporating rather obvious improvements as listed below. The basis for the change is also listed below:

1. The studs which hold the moderator blocks to the upper Outerpack half failed during the drop testing. The moderator remained contained within the sheet metal covering. However, the number of 3/8" (0.95 cm) diameter studs shall be increased by 50% on the top Outerpack assembly only.
2. The bottom impact limiter pillow is welded at the top plate to the Outerpack inner plate. This weld is design to break in a high angle impact. It performed well in the drop test, however, it did not completely break. This joint shall be redesigned with a small groove cut into the inner plate to form a weakened break point. The break shall therefore not necessarily occur at the weld location.
3. The quick release pins used to secure the bottom end seam flange cover failed during drop testing but had negligible effect on the performance (intended for thermal performance only). Therefore, they were not used in the thermal test and will not be used in production units.

The figure below (Figure 2-1B) shows the impact limiter, or Pillow, assembly (shown without insulation). This assembly is shown installed in the Traveller package bottom (the configurations are the same for STD and XL packages) in Figure 2-1C. The weld between the bottom plate (yellow) and the puncture plate (red) is also shown. During testing this weld failed as expected, however, it did not completely allow the components to separate. This design change weakens the bottom plate by reducing its thickness to a nominal 0.025" thickness, as shown in Figures 2-1D and 2-1E. A .25 inch wide channel was added to weaken the part.

2.7.1 Free Drop

Subpart F of 10 CFR 71, TS-R-1 (727) requires that a 9-meter (30 foot) free drop be considered for the Traveller series of packages. The free drop is to occur onto a flat, essentially unyielding, horizontal surface, and the package is to strike the surface in an orientation for which the maximum damage is expected. The free drop is addressed by test, in which the most severe orientation is used. The free drop precedes both the puncture and fire tests. The ability of the Traveller packages to adequately withstand this specified drop condition is demonstrated via drop testing of the full-scale Traveller XL Certification Test Unit (CTU). The Traveller XL variant bounds the shorter and lighter Traveller STD design.

2.7.1.1 Technical Basis for the Free Drop Tests

To properly select a worst case package orientation for the 9 m (30 feet) free drop event, the foremost item that could potentially compromise the criticality control integrity of the Traveller series of packages must be clearly identified.

The criticality control integrity may be compromised by four methods: 1) excessive movement of the fuel rods such that they form a critical geometry, 2) damage/destruction of the *neutron absorber* and polyethylene sheeting, 3) degradation of the *neutron absorber*/polyethylene sheeting and/or 4) other structural damage that could affect the nuclear reactivity of an array of packages.

For the above considerations, testing and FEA predictive methodology must include orientations that affect the Clamshell geometry and integrity. Throughout the development of the Traveller XL, minor design changes were made to optimize the structural and thermal performance of the package.

A total of nine (9) 30 foot (9 m) free drops were performed using full-scale prototypes at a variety of orientations to determine the most severe orientation and to assist in benchmarking the computer simulation model. Based on these tests, and the predictions of the analytic analyses, it was determined that the most severe 9 m free drop orientation was a bottom-end down drop due to; 1) the relatively high deceleration, 2) the greatest opportunity for lattice expansion of the fuel, and 3) the greatest opportunity for fire damage as a result of the subsequent pool-fire thermal testing.

The bottom-down end drop causes the greatest damage to the axial impact limiters, or "pillows." These pillows were incorporated as a re-design from QTU-2 testing whereby the Clamshell punched through the plate covering the inner section of the axial impact limiter. This exposed foam later burned within the interior of the Outerpack and ignited the moderator panels. The concept of a puncture plate was redesigned to incorporate a "puncture resistant" plate. The inner foam limiter was therefore protected by the puncture resistant plate (1/4" thk, 0.64 cm), and was enclosed by a spun metal "can" welded to the plate to completely seal the pillow assembly. CTU test results confirmed that no polyurethane foam was exposed as a result of the bottom-down end impact.

The long bottom nozzle "legs" associated with the Westinghouse 17x17 XL fuel assembly are considered the most severe because they allow considerable strain of the bottom nozzle (particularly the flow plate, or adapter plate) during a bottom-down end drop. The bowed adapter plate offers the greatest opportunity to damage fuel rods during the impact.

The top-down end drop produces significantly lower deceleration due to buckling of the axial clamp bolts. As these buckle, considerable energy is absorbed, thus lower the buckling of the top nozzle. By comparison, the bottom-down end drop is more severe.

2.7.1.2 Test Sequence for the Selected Tests

Based on the above discussions, the Traveller XL CTU was tested for one specific, HAC 9 m (30 foot) free drop conditions: 1) End drop onto the bottom of the container. This single "worst case" 9 m drop is required. Numerous 9 m drops using full-scale prototypes were tested prior to CTU testing to determine the most severe orientation. The specific conditions for all full-scale prototype and CTU tests are summarized in Table 2-2 above.

2.7.1.3 Summary of Results from the Free Drop Tests

Successful HAC free drop testing of the Traveller XL CTU certification unit indicates that the various structural features are adequately designed to withstand the 9 m (30 foot) free drop event. The most important result of the testing program was the demonstrated ability of the bounding Traveller XL package to maintain its criticality safety integrity.

Significant results of the free drop tests, including the thermal test, are as follows:

1. There was no breach or distortion of the Clamshell aluminum container.
2. There was no evidence of melting or material degradation on the polyethylene sheeting.
3. The Outerpack remained closed and structurally intact.
4. A small number of rods (20) were cracked during drop testing (only seen in bottom-end drops).
5. Rod damage has been at the end of the rods only. No damage anywhere else.
6. None of the end plugs have separated from the rods.
7. No pellet material is lost from the cracked rods.

Further details of the free drop test results are provided in Appendix 2.12.4, Traveller Drop Test Results.

2.7.2 Crush

The crush test specified in 10 CFR §71.73(c)(2), TS-R-1 (727) is required only when the specimen has mass not greater than 500 kg (1,100 pounds), an overall density not greater than 1,000 kg/m^3 (62.4 lb/ft^3), and radioactive contents greater than 1,000 A2, not as special form. The gross weights of the Traveller packages are greater than 500 kg (1,100 pounds). Therefore, the dynamic crush test of 10 CFR §71.73(c)(2), TS-R-1 (727) is not applicable to the Traveller series of packages.

2.7.3 Puncture

Subpart F of 10 CFR 71 requires performing a puncture test in accordance with the requirements of 10 CFR §71.71(c)(3), TS-R-1 (727). The puncture test involves a 1 m (40 inch) drop onto the upper end of a solid, vertical, cylindrical, mild steel bar mounting on an essentially unyielding, horizontal surface. The bar must be 15 cm (6 inches) in diameter, with the top surface horizontal and its edge rounded to a radius of not more than 6 mm (1/4 inch). The minimum length of the bar is to be 20 cm (8 inches). The ability of the bounding Traveller XL packages to adequately withstand this specified drop condition is demonstrated via testing of numerous full-scale Traveller XL prototypes and the Certification Test Unit (CTU).

2.7.3.1 Technical Basis for the Puncture Drop Tests

To properly select a worst case package orientation for the puncture drop test, items that could potentially compromise criticality integrity of the Traveller package must be clearly identified. For the Traveller XL package design, the foremost item to be addressed is the integrity of the Clamshell and the neutron moderation and absorption materials (i.e., *neutron absorber plate* and polyethylene sheeting).

The integrity of the Clamshell and the criticality control features may be compromised by two methods: 1) breach of the Clamshell boundary, and 2) degradation of the neutron moderation/control materials due to fire.

For the above reasons, testing must consider orientations that attack the Outerpack closure assembly, which may result in an excessive opening into the interior for subsequent fire event, and/or the Clamshell which contains the fuel assembly. Based on prototype testing and computer simulations of the pin puncture event, the pin puncture has insufficient energy to cause significant damage to the Outerpack hinge closure system nor to the Clamshell (including components within the Clamshell).

The greatest possibility of cumulative damage to the package occurs when the pin puncture is located in within the area of impact of the 9m drop. These locations further attack the welded joints adjacent to the crushed area between the Outerpack outer shell and the end cap. Many pin puncture locations were tested in prototype testing, and all had insignificant impact on the structural and thermal performance of the package. See Table 2-2 above, and Appendix 2.12.4, Traveller Drop Test Results, for more information regarding pin puncture testing.

Based on the above discussion, the Traveller XL CTU was specifically evaluated at a "new" location. The pin puncture was located such that the pin impacted directly on an Outerpack hinge at a low impact angle. This test had not previously been performed, and it was desired to test the hinge's ability to take a pin impact and still perform its important function of thermally protecting the seam between Outerpack bottom and top assemblies. Section 3 describes how the hinge protects the seam in more detail.

2.7.3.2 Summary of Results from the Puncture Drop Tests

Successful HAC puncture drop testing of the CTU indicates that the various Traveller XL packaging features are adequately designed to withstand the HAC puncture drop event. The most important result of the testing program was the demonstrated ability of the bounding Traveller XL to maintain its structural integrity. Significant results of the puncture drop testing are as follows:

1. Minor damage to the Outerpack and Outerpack hinge
2. No affect on the structural or thermal performance of the package.
3. There was no evidence of separation of the Outerpack seam which would allow hot gases to enter the Outerpack.
4. No evidence of movement occurred that would have significantly affected the geometry or structural integrity of the Clamshell.
5. There was no evidence of loss of contents from the Clamshell due to the puncture events.
6. There was no evidence of deterioration of the polyethylene sheeting in the subsequent fire event.
7. There was no evidence of deterioration of the borated-aluminum sheeting (simulated) in the subsequent fire event.

Further details of the puncture drop test results are provided in Appendix 2.12.4, Traveller Drop Test Results.

2.7.4 Thermal

Subpart F of 10 CFR 71, TS-R-1 requires performing a thermal test in accordance with the requirements of 10 CFR §71.71(c)(4), TS-R-1 (728). To demonstrate the performance capabilities of the Traveller packaging when subjected to the HAC thermal test specified in 10 CFR §71.71(c)(4), TS-R-1 (727), a full-scale CTU was burned in a fully engulfing pool fire. The test unit was subjected to a 9 m (30 foot) free drop, and a 1.2 m (4 foot) puncture drop, prior to being burned, as discussed above. Further details of the thermal performance of the Traveller XL CTU are provided in Section 3, Thermal Evaluation.

Type K thermocouples were installed on the exterior surface of the packaging (each side, top, and bottom) to monitor the package's temperature during the test. In addition, passive, non-reversible temperature indicating labels were installed on the Clamshell, fuel assembly, and inner surfaces of the Outerpack.

The CTU was exposed to a minimum 800°C (1,475°F), 30-minute pool fire. As discussed in Appendix 2.12.4, Traveller Drop Test Results, the package was orientated such that the Outerpack was on its side. This orientation offered the greatest opportunity for formation of a chimney and thus result in maximum combustion of the Outerpack foam and degradation of the polyethylene sheeting.

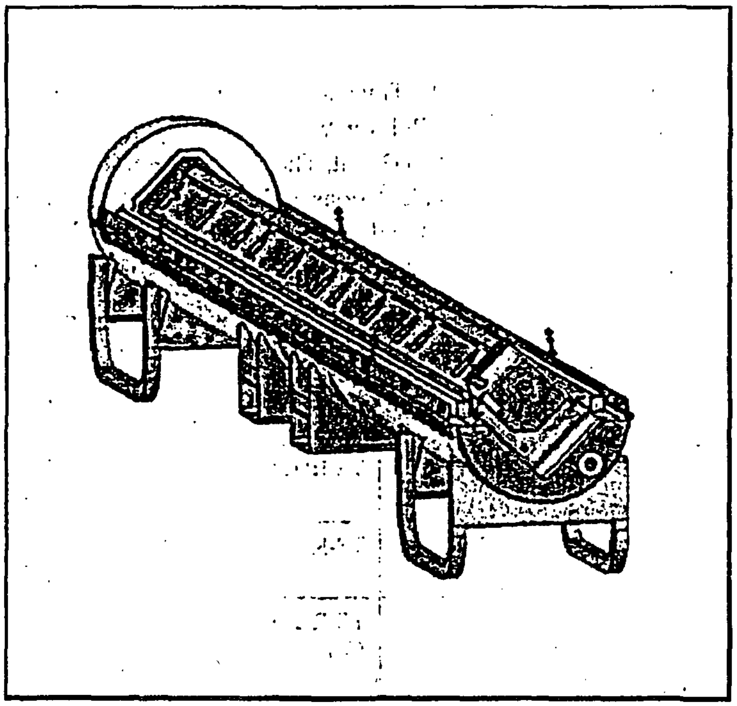


Figure 2-4 Internal View of the Traveller Shipping Package

2.12.2.1 Analysis Results and Conclusions

These analyses were performed to demonstrate Traveller XL package compliance to the mechanical requirements described in 10 CFR 71 and TS-R-1 for which no formal testing was conducted. These calculations bound the lighter, shorter Traveller STD unit. The applicable requirements are summarized in Table 2-7 below. The results of the design calculations (where applicable), acceptance criteria, and conditional acceptance are shown in Table 2-8. Based on the results in Table 2-8, the Traveller package is shown to be compliant to mechanical requirements described in 10 CFR 71 and TS-R-1.

Table 2-7 Summary of Regulatory Requirements for Mechanical Analysis

Requirement Description	US NRC Requirement	1996 IAEA Requirement	Applicable Condition
Lifting attachments	10 CFR 71.45(a)	TS-R-1, Paragraph 607	General Package Standard
Tie-Down devices	10 CFR 71.45(b)(1)	TS-R-1, Paragraph 636	General Package Standard
Design temperatures between –40°F (-40°C) and 158°F (70°C)	10 CFR 71.71(c)(1,2)	TS-R-1, Paragraphs 637 and 676	General Package Standard
Internal/External Pressure	10 CFR 71.71(c)(3,4)	TS-R-1, Paragraph 615	Normal transport condition
Vibration	10 CFR 71.71(c)(5)	TS-R-1, Paragraph 612	Normal transport condition
Water spray	10 CFR 71.71(c)(6)	TS-R-1, Paragraph 721	Normal transport condition
Compression/Stacking test	10 CFR 71.71(c)(9)	TS-R-1, Paragraph 723	Normal transport condition
Penetration	10 CFR 71.71(c)(10)	TS-R-1, Paragraph 724	Normal transport condition
Immersion	10 CFR 71.73(c)(6)	TS-R-1, Paragraph 729	Accident transport condition

The results of the design calculations (where applicable), acceptance criteria, and conditional acceptance are shown in Table 2-8. Based on the results in Table 2-8, the Traveller package is shown to be compliant to mechanical requirements described in 10 CFR 71 and TS-R-1. Where the design features of the Traveller eliminate design concerns (i.e., package tie-downs, internal pressure, etc.) detailed stress calculations were not performed.

2.12.3 DROP ANALYSIS FOR THE TRAVELLER XL SHIPPING PACKAGE

The primary method for evaluating the performance of the Traveller under hypothetical accident condition scenarios was actual testing of full-scale prototype packages. During the development program eighteen drop tests were conducted using a variety of orientations. Most of the drops were from greater than 9m. The drop tests are summarized in Table 2-5 and reported in detail in Section 2.12.4.

To supplement the actual test data, a finite element *analysis (FEA) study was conducted using two* models *that* were developed for the Traveller XL package. The first *FEA* model *was based on the design of the two prototypes that were tested* in January 2003. The second *FEA* model *was based on the design of the two* Qualification Test Units *that were* tested in September 2003. *The QTU (actual package and FEA model) incorporated the* modifications *that were made to the design as a result of the* prototype test results.

The objectives of *the drop analysis* effort *were:*

- *Demonstrate that the first model acceptably predicted actual test results. This was accomplished by comparing the permanent mechanical deformations that resulted from the actual prototype drops with those predicted by the FEA model.*
- *Assist in the evaluation of test results. Because the FEA prototype model acceptably predicted actual test results, it could be used with confidence as a tool to evaluate possible changes to the packaging design in order to finalize a design that would pass the hypothetical drop tests.*
- *Assist in planning final tests. The FEA results, combined with the data obtained by prototype drop testing, were used to establish drop orientations for the qualification test unit (QTU) and certification test unit (CTU) tests.*

Limitations were observed in the FEA process. For example, mesh density limitations meant that actual stress and strain predicted values could not be considered highly accurate. The models could identify regions of high stress and strain but could not accurately predict component failure unless predicted values were significantly above or below failure points. Instead, the models were developed to evaluate relative deformations, decelerations and energy absorption between drop orientations. The analyses provided a qualitative means for comparing predicted stresses and strains for different drop orientations to allow intelligent selection of drop orientations for testing. The Traveller program utilized extensive full-scale tests to prove the acceptability of the Traveller design. These tests results are described in sections 2.12.4 below and the results are compared with the FEA in this section.

2.12.3.1 *Conclusion and Summary of* Results

2.12.3.1.1 Conclusion

Analysis indicates that the Traveller XL shipping package complies with 10 CFR 71 and TS-R-1 requirements, respectively for all drop orientations. Test orientations which are most challenging are a

9 meter vertical drop with the bottom end of the package hitting first as shown in Figure 2-52A and a 9 meter CG-forward-of-corner drop onto the TN end of package with an 18° forward rotation, Figures 2-44 and Figure 2-45. The former has the greatest potential to damage the fuel assembly and the latter is most damaging to the shipping package itself. *Based on this analysis,* successful drop tests in these two orientations are adequate *to* demonstrate that the Traveller XL design meets/exceeds the HAC drop test requirements.

2.12.3.1.2 Summary of Results

Analyses were conducted for horizontal side drops, center-of-gravity-over-corner onto the top nozzle drops, and vertical drops onto the top nozzle and bottom nozzle. A significant amount of analytical data is presented in the following sections. Below is an summary of the major points in the order presented:

Determination of Most Damaging Orientations

- *The most damaging orientation for the outerpack may not be most damaging for the fuel assembly. Because of the robust design of the packaging, drop orientations that were most damaging to the fuel assembly took precedence.*
- *Analysis of drop orientations most damaging to the outerpack focused on three orientations: horizontal drop onto the side, vertical end drop (top and bottom nozzle end), and near-vertical drop (center-of-gravity over corner).*
- *Analysis of drop orientations most damaging to the fuel assembly focused on the vertical end drop (top and bottom nozzle end).*

Most Damaging Orientations to Outerpack

- *Horizontal drop onto the side gave highest predicted outerpack loads.*
- *CG forward of corner onto top predicted to be most damaging to outerpack because of potential damage that might compromise package ability to survive the thermal test.*
- *Damage to the Traveller XL shipping package from the HAC drop tests is predicted to be minor and primarily involves localized deformations in the region of impact. Both the Outerpack and Clamshell structures remain intact and closed.*

Most Damaging Orientations to Fuel Assembly

- *Bottom nozzle end drop predicted to be more damaging than top nozzle end drop.*
- *Fuel assembly damage is predicted to be confined to the top or bottom region depending on drop orientation. This damage primarily involves localized buckling and deformation of the nozzles.*

Temperature and Foam Density Effects

- *Temperature and foam density have a minor effect on drop performance of the Traveller XL package.*

- *For the orientation predicted most damaging to the Outerpack, a package with nominal foam density and dropped at "normal temperature" (75°F) experiences 8.5 and 13.7% higher loads than, respectively, one containing low density foam and dropped at 160°F or one containing high density foam and dropped at -40°F, Figure 2-62.*

- *Fuel assemblies in packages containing the highest allowable density foam and dropped at the lowest temperature extreme will experience accelerations that are very similar to those in packages with lowest allowable density foam and dropped at the highest temperature extreme, Figure 2-63. However, the accelerations at these extremes are only 5% greater than for a package dropped at 75°F containing nominal density foam.*

- *Bottom nozzle end drop predicted to be more damaging than top nozzle end drop.*

Pin Puncture

- *Analysis indicates that the Traveller XL is capable of withstanding the 1 m pin puncture test. The steel outer skin should not be ruptured.*

- *A maximum indentation of 67 mm is predicted for the 1 m pin puncture test when the package is impacted from underneath and dropped horizontally with its CG directly above the pin. during this test.*

Comparison of Prototype Test Results to Analysis Predicted Results.

- *There was good overall agreement between predicted and actual drop performance. This is evident by comparisons of predicted and actual permanent deformations, failed parts, and measured and predicted accelerations at specific positions on the Outerpack and Clamshell.*

Bolt Factor-of-Safety Calculations.

- The Traveller XL shipping package will survive the HAC drop tests in any orientation with few or no closure bolt failures. Horizontal side drops onto the hinges or latches, Figures 26A and B, result in the highest hinge/latch bolt loads. The analyses indicate ten ¾-10 stainless steel bolts/side are sufficient to ensure the Outerpack remains closed during such drops. The miminum predicted factor of safety for the Outerpack latch and hinge bolts is 1.12

[Rev 2 redistributed this information in Section 2.12.3.1 above.]

2.12.3.2 Predicted Performance of the Traveller Qualification Test Unit

2.12.3.2.1 Most Damaging Drop Orientations

A primary objective of this study was to determine the worst case drop orientation(s) for the HAC drop tests. This requirement is to drop test the shipping package in orientations that most damage: a) the shipping package, and b) the fuel assembly. It was quickly realized that the most damaging orientation for the shipping package, would not necessarily be the same for the fuel assembly. Based on the robust performance of the Traveller XL drop units during testing, orientations that were most severe to the fuel assembly became more significant.

Determination of the worst case orientation for the shipping package was facilitated by the Traveller XL computer analysis and results of the prototype tests. Many orientations can be eliminated from consideration due to inherent design features of the Traveller. For example, the circumferential stiffeners on the upper Outerpack, and the legs/forklift pocket structure, Figure 2-21, greatly reduce the crushing of the Outerpack since they crush prior to impact of the main body of the Outerpack. Drop orientations where one or the other of these structures directly contacts the drop pad, Outerpack damage is reduced in

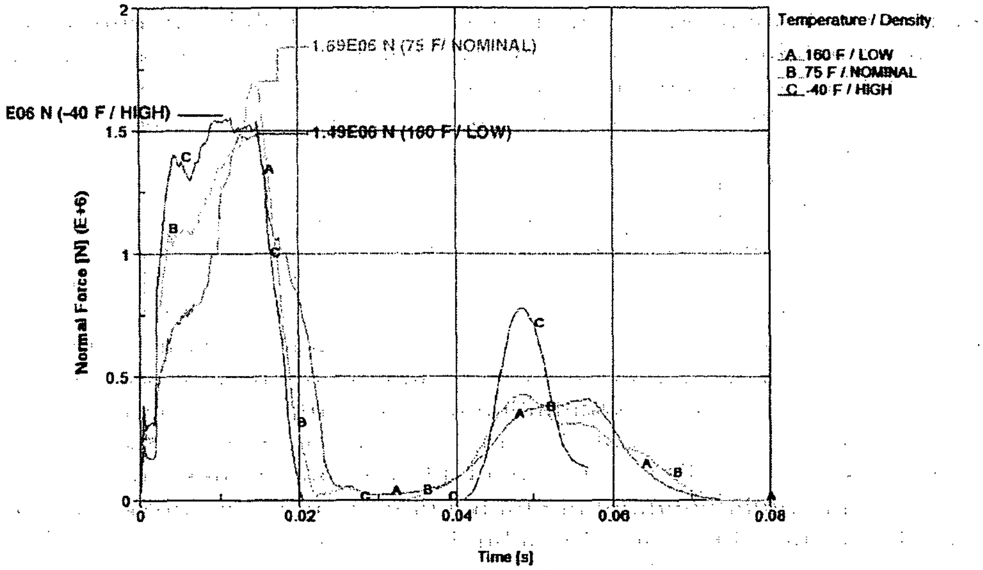


Figure 2-62 Predicted Temperature and Foam Density Effect on Outerpack/Drop Pad Interface Forces (9m CG-Forward-of-Corner with 18° Rotation Drop onto the Top End of the Package)

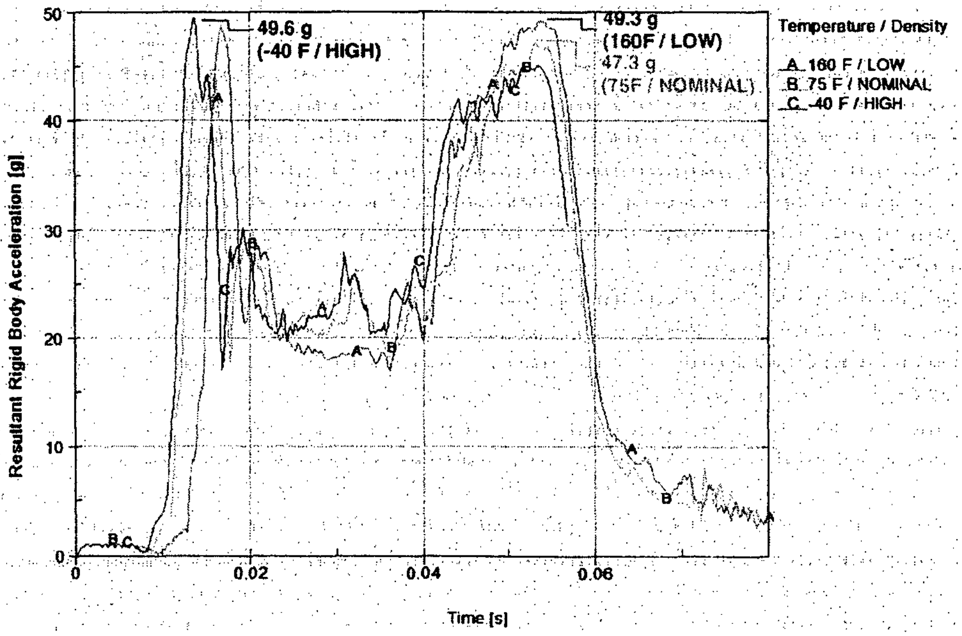


Figure 2-63 Predicted Temperature and Foam Density Effect on Outerpack/Drop Pad *Accelerations* (9m CG-Forward-of-Corner with 18° Rotation Drop onto the Top End of the Package) |

C02

In addition, the 9 meter vertical bottom-end down drop was analyzed using material properties for -40°C (-40°F) with foam density at the upper end of the tolerance band and 71°C (160°F) with foam density at the lower end of the tolerance band. The predicted results were compared with each other and with those at 24°C (75°F) and nominal foam density previously reported in Section 2.12.3.2.5. The results support the conclusions obtained from analysis of the 9 meter CG-forward-of-corner drops: temperature and variation in foam density due to manufacturing tolerances have only a minor effect on the drop performance of the Traveller package.

Temperature/foam tolerance effects for the 9 meter vertical drop onto the bottom nozzle end of the package were evaluated for the three previously noted conditions. Both predicted outerpack/drop pad force histories and fuel assembly accelerations were compared as shown in Figures 2-63A and 2-63B.

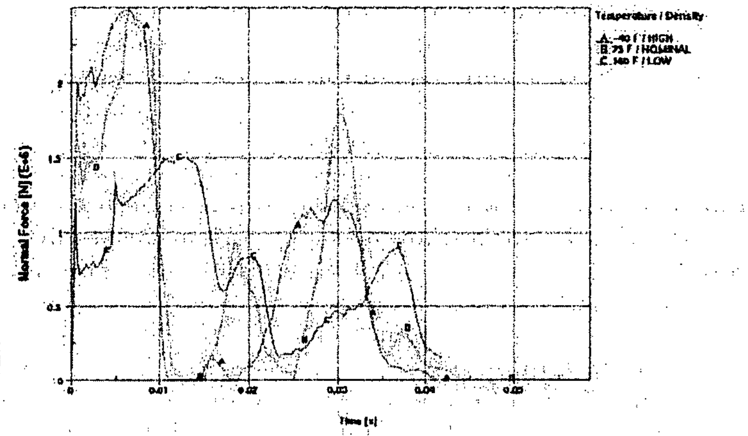


Figure 2-63A ***Predicted Temperature and Foam Density Effect on Outerpack/Drop Pad Interface Forces (9m Vertical Drop onto the Bottom End of the Package)***

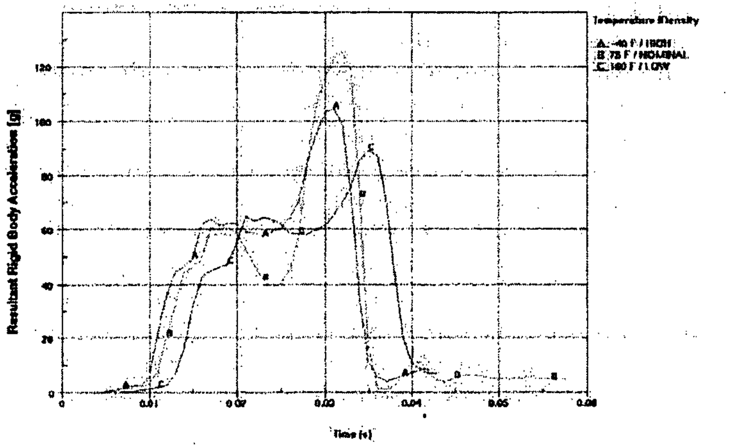
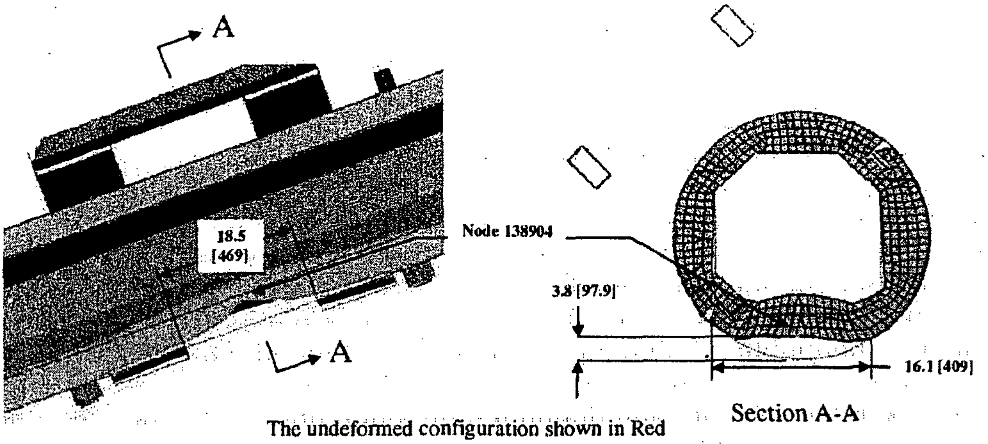


Figure 2-63B ***Predicted Temperature and Foam Density Effect on Fuel Assembly Acceleration (9m Vertical Drop onto the Bottom End of the Package)***

CO3



The undeformed configuration shown in Red
was based on deformed positions of Nodes 134236,
220381 and 94784.

Figure 2-87 Outerpack Predicted Deformations of Pin Drop

2.12.3.3.2 Accelerations

Vertical accelerations (Y-direction) measured during test 1.1 are compared with the FE-based predictions in Figures 2-88 through 2-92. Agreement was good. Indeed, discrepancies between the two could easily be attributed to the inherent error associated with obtaining such data.

For the Outerpack, both measured and predicted traces contained two peaks, Figure 2-88. These corresponded to the two impacts associated with this test as illustrated in Figure 2-78. (Note: the larger acceleration with the secondary impact should not be interpreted as meaning larger forces were associated with the second impact. Rather, the larger magnitude simply reflects that the accelerometer was much nearer the secondary impact end.) While there were two visible peaks, the measured response was very small for the primary impact. For the secondary impact, the predicted acceleration was 1270 g's. This was in accordance with the measured peak acceleration which indicated accelerations were greater than 950 g's.

For unknown reasons, the accelerometers on both the Clamshell top and bottom plates gave erroneous readings late into the drop. This is clearly evident from accelerometer data in Appendix 2.12.4 that the accelerometers "saturate" for over 0.025 seconds and provide no meaningful response afterwards. Thus, only the first 0.05 seconds of the Clamshell data was compared in this report. For the accelerometer on the Clamshell top plate, measured and predicted accelerations corresponding to the first impact (at time 0.01 seconds in Figure 2-90) were 555 g's. This was also in accordance with measurements which indicated a peak acceleration greater than 525 g's was experienced. As shown in Figure 2-91, peak accelerations of 205 g's were measured on the Clamshell bottom plate. The corresponding predicted acceleration is also shown. Note the peak predicted acceleration was 155 g's.

C04

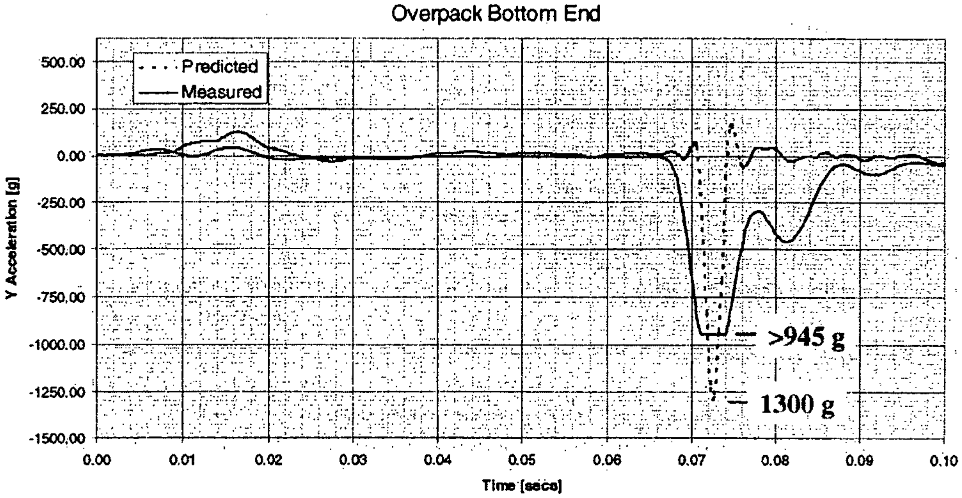


Figure 2-88 Predicted and Measured Y Accelerations

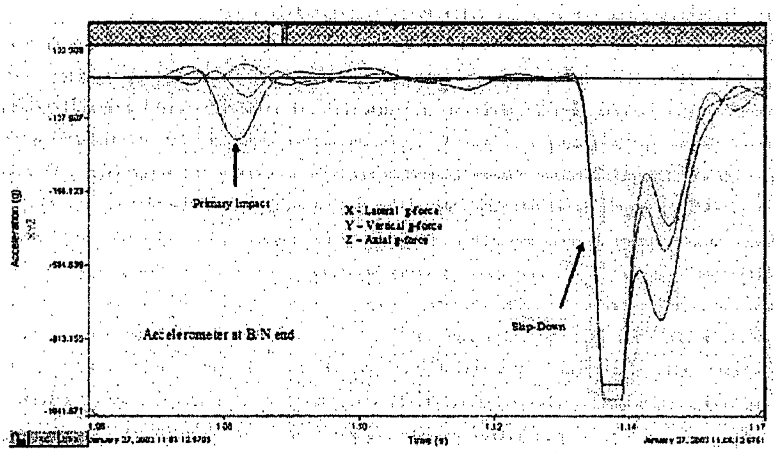


Figure 2-89 Three Axis Measured Accelerations

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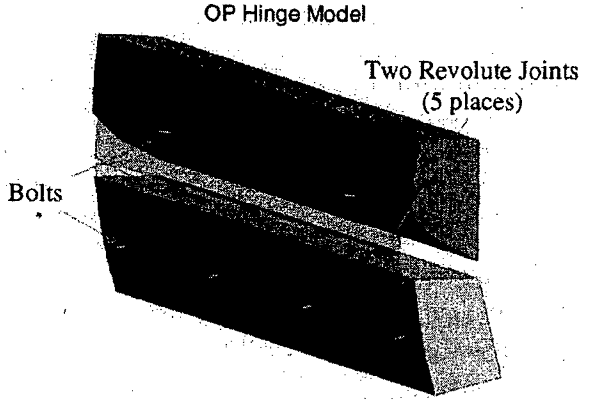


Qualification unit had two bolts in upper hinge block and the prototype unit had three. Both models had four bolts in bottom hinge block.

Figure 2-98 Outerpack Hinge Model

2.12.3.5.3 Qualification Unit Models (QTUs)

As with the Prototype units, the QTUs were constructed from many input files, see Figure 2-99. These files defined various details of the model and were included with, or without, transformations of coordinates and renumbering of identities as the model was assembled.

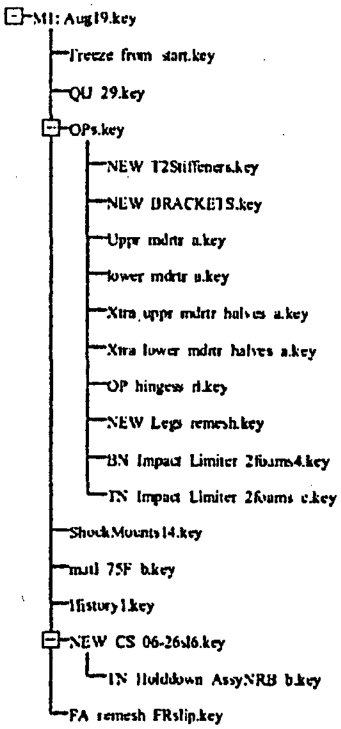
The main file, Aug19.key, contains the control cards, specifies outputs, contact definitions, and many attributes common to more than one subassembly. The major subassemblies were the Outerpack, Clamshell, and fuel assembly. These were defined in the OPs.key, CS_06_26sl6.key, and FA_remesh_FRslip.key files, respectively. The Outerpack and Clamshell subassemblies are detailed in Figures 2-101, 2-102 and 2-103 (The fuel assembly model was very similar to the one depicted previously in Figure 2-97. A total of 361,333 elements were used in the model (185985 shells, 157031 solids and 18317 beams).

The orientation for each run was defined in individual load case files. Likewise, the material property date was defined in three files which represented three different temperatures and foam densities. Obviously, only one load case file and one material file was invoked per run.

The Clamshell, Figure 2-102 is mounted to the Outerpack, Figure 2-100, with 14 rubber shock mounts. These shock mounts were modeled as discrete elements (springs). Outerpack hinge details were described in the previous section, see Figure 2-98.

Predicted model weight was 2.27 tonnes (4994 lbs). This matched the qualification unit's 4786 lb. average weight within 4.4%.

C06



```
⊟─MI: Aug19.key
  ├─Freeze from start.key
  ├─QU 29.key
  ⊟─OPs.key
  │   ├─NEW T2Stiffeners.key
  │   ├─NEW BRACKETS.key
  │   ├─Uppr mdrtr a.key
  │   ├─lower mdrtr a.key
  │   ├─Xtra uppr mdrtr halves a.key
  │   ├─Xtra lower mdrtr halves a.key
  │   ├─OP hinges d.key
  │   ├─NEW Legs remesh.key
  │   ├─BN Impact Limiter 2foams4.key
  │   └─TN Impact Limiter 2foams c.key
  ├─ShockMounts14.key
  ├─matl 75F b.key
  ├─History1.key
  ⊟─NEW CS 06-26sl6.key
  │   └─TN Holddown AssyNRB b.key
  └─FA remesh FRslip.key
```

Figure 2-99 FEA Input Files

2.12.3.5.4 Qualification Unit – Outerpack Model Details

The FE model of the outerpack is shown in Figures 2-100 through 2-101A. Key features of the outerpack include the combination circumferential stiffeners/legs, the forklift pockets, the upper and lower outerpack halves, the hinges/latches on the sides, the stacking brackets, and the circumferential stiffeners on the upper outerpack. These features were included in the FE model as described below.

The circumferential stiffeners/legs and forklift pockets (Figure 2-100A) were modeled using 4-node Belytschko-Tsay shell elements (LS-DYNA elform = 2). These elements were integrated at three locations through the thickness using Gaussian quadrature. 1,008 of these elements were used to model the forklift pockets and 4,436 were used modeling the legs.

| Both the circumferential stiffeners/legs and forklift pockets are welded to the lower *outer*pack outer casing. In the model, these parts were attached to one another using a penalty based tied contact algorithm (LS-DYNA's TIED_NODES_TO_SURFACE_OFFSET contact algorithm).

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QTU-1 was not opened until after the fire test. The Clamshell and fuel assembly were examined for damage at that time. The fuel assembly of QTU-1 was essentially undamaged, Figure 2-133. The most damage occurred at the top nozzle section where an area of approximately 2-3" in length increased from 8.375" nominal to 8.625". Grid 10 was torn, and all other grids were buckled but intact. The nozzles were essentially undamaged. The impact resulted in buckling of the core line-up pins attached to the top nozzle. The fuel rods appeared visibly undamaged.

The fuel assembly in QTU-1 was measured before the test and after the burn test at locations shown in Figure 2-134. Table 2-36 provides the pretest dimensions. Tables 2-37 and 2-38 provide the post test dimensions.

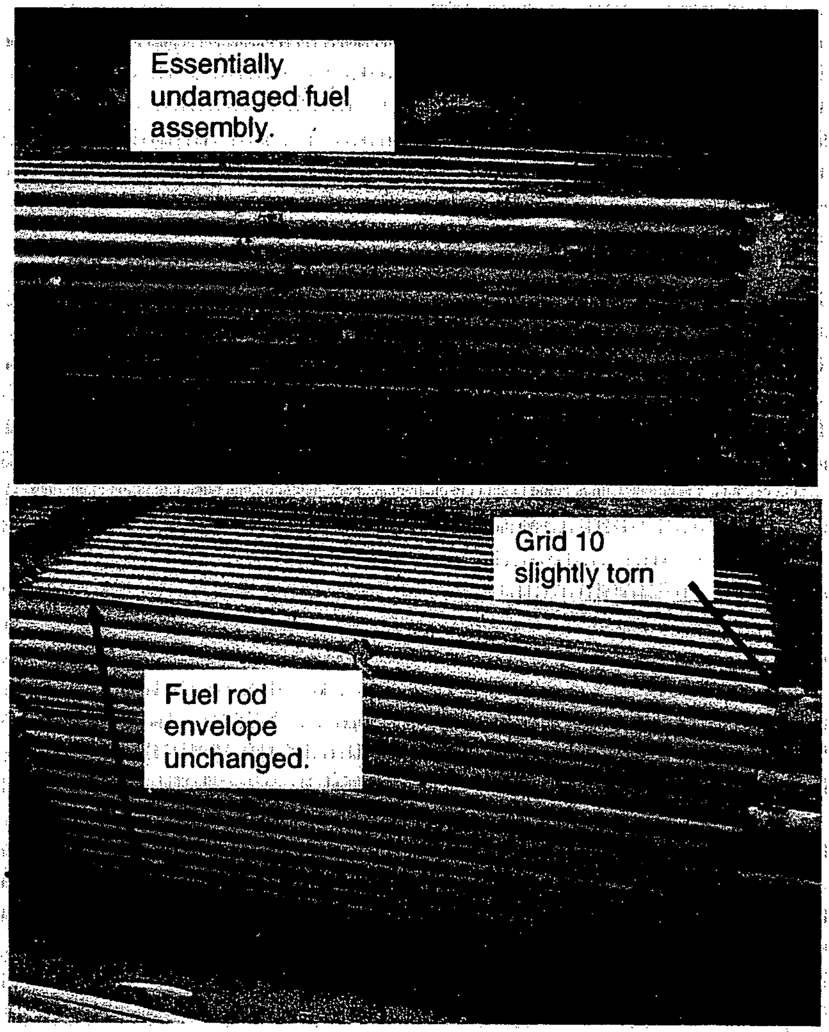

Figure 2-133 QTU-1 Fuel Assembly After Drop and Burn Tests

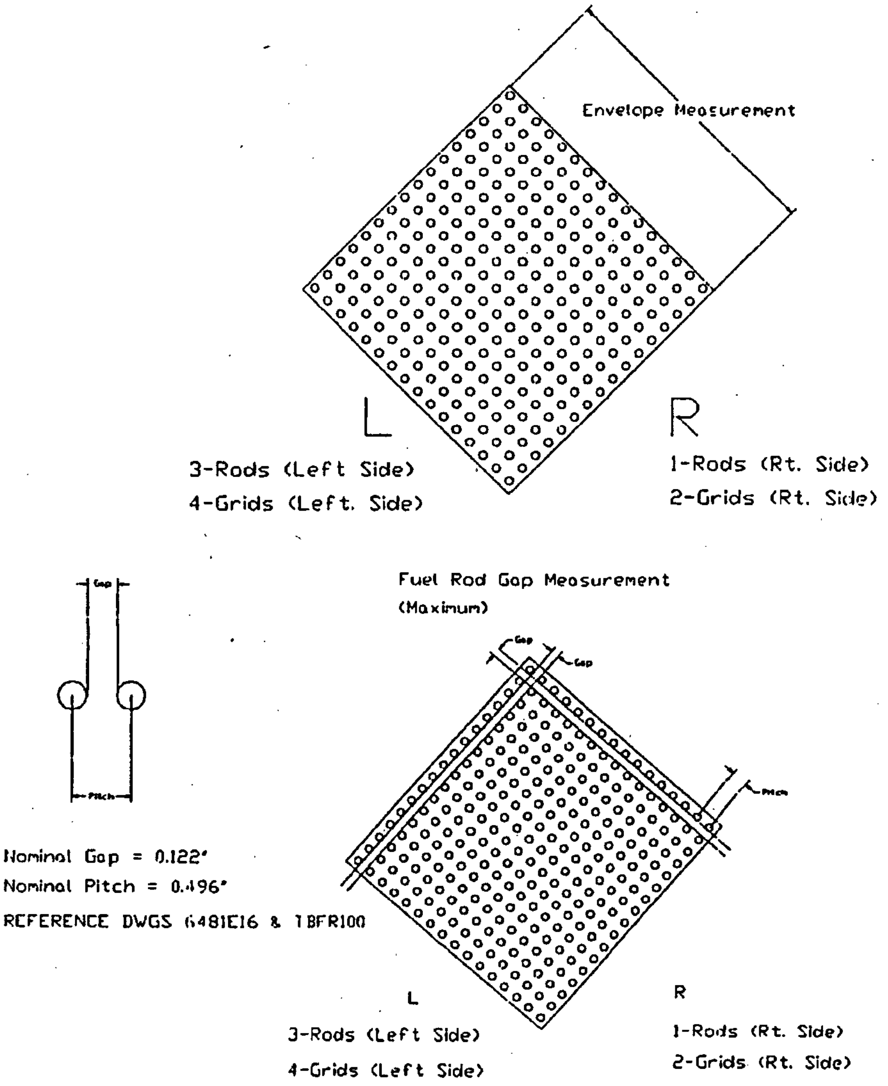

Figure 2-134 Measurements Made on QTU-*1* Fuel Assemblies Before and After Drop Tests

Table 2-43 QTU-2 Fuel Rod Pitch Data After Testing			
Fuel Rod Pitch Inspection Table			
Location	Maximum Gap, Inches		Maximum Pitch, Inches
	Left Side, LS	Right Side, RS	
Between B/N and Grid 1	0.722	0.501	1.097
Between Grids 1 and 2	0.539	0.501	0.914
Between Grids 2 and 3	0.250	0.316	0.691
Between Grids 3 and 4	0.137	0.125	0.512
Between Grids 4 and 5	0.153	0.132	0.528
Between Grids 5 and 6	0.142	0.143	0.518
Between Grids 6 and 7	0.145	0.146	0.521
Between Grids 7 and 8	0.141	0.138	0.516
Between Grids 8 and 9	0.162	0.122	0.537
Between Grids 9 and 10	0.139	0.141	0.516
Between Grid 10 and T/N	0.127	0.123	0.502
MAXIMUM VALUE	0.722	0.501	1.097

2.12.4.3 Certification Test Unit Drop Tests

A Traveller XL package was fabricated by Columbiana High Tech to serve as the certification test unit (CTU), Figures 2-140 and 2-141 and Table 2-44. This unit was subjected to a regulatory drop test performed February 5, 2004 in Columbiana, Ohio. The test included a 50 inch (1.27 m) slap down, a 32.8 feet (10.0 m) free drop test impacting the bottom nozzle, and a 42 inch (1.07 m) pin-puncture test, Figure 2-142 and Table 2-45. The CTU package was thermally saturated for approximately 15 hours prior to testing at a temperature of about 17°F (-8.3°C). At the time of testing the temperature was approximately 24°F (-4.4°C). The package's test weight was 4863 pounds.

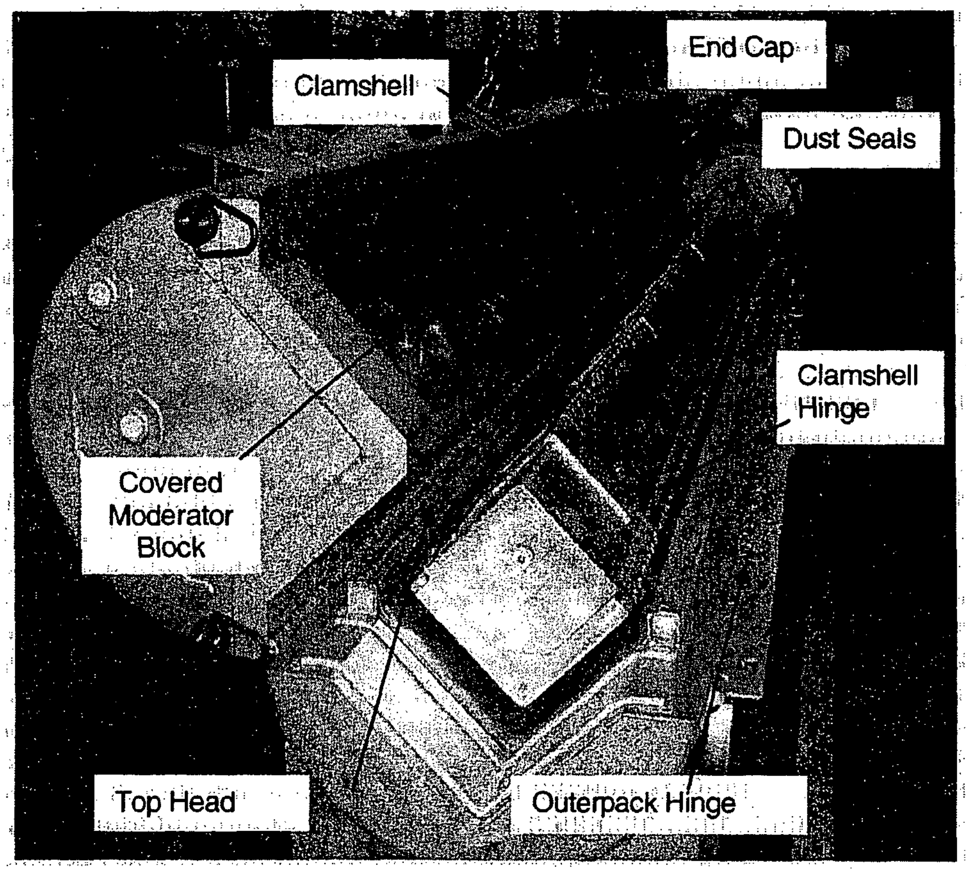

Figure 2-140 Traveller CTU Test Article Internal View

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approximately 1/2". Otherwise, the typical pitch pattern consisted of 2 rod rows touching and the remaining 14 rows at nominal pitch, Figure 2-152.

Figure 2-149 CTU Clamshell After Drop and Fire Tests

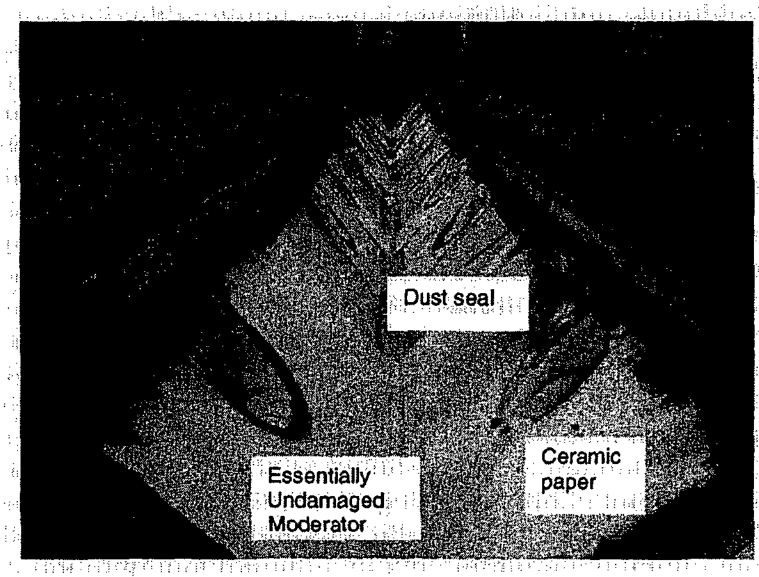

Figure 2-150 Outerpack Lid Moderator After Testing

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For a length of 10" above Grid 2, the fuel rod envelope compressed from 8-3/8" nominal to 8-1/4". This slight compression is due to the single top rod slightly compressed inward. Above this 10" region, the single rod bent outward about 1/2" for a length of approximately 25".

For the 25" length from between Grids 2 and 3 and up to Grid 4, the single rod resulted in a measured envelope of 8-7/8", but the remaining envelope of 16 rows was slightly compressed (about 1/16"). The maximum pitch caused by the single rod was 0.740" compared to 0.496" nominal. Otherwise, the average pitch was nominal.

For the remainder of the fuel assembly from Grid 4 to the top nozzle, the fuel rod envelope compressed about 0.15" and the grid envelope compressed about 1/4". The average pitch decreased from 0.496" to 0.459" in this region.

Grid 1 was severely buckled, and the ovality was measured to be 120° for a length of about 20", Figure 2-153. Grids 2 and 3 were broken at the top corner, but otherwise intact. Grids 4-10 were relatively undamaged. The fuel inspection also indicated that 7.5% (20 of 265 rods) were cracked at the end plug locations (Figure 2-154). The average crack width measured was approximately 0.030" (30 mils) and the average length was 50% of the rod diameter. The cracked rods were located at the four corners, indicating the vertical impact created symmetrical impact forces to be transmitted through the bottom nozzle and fuel rods (Figure 2-155).

The fuel assembly in QTU-1 was measured before the test and after the burn test at locations shown in Figure 2-134 above. Table 2-46 provides the pretest dimensions. Tables 2-47 through 2-50 provide the post test dimensions.

2.12.4.4 Conclusions

Three series of drop tests were performed during the development and certification of the Traveller shipping package. This included two prototype units, two qualification test units and one certification test unit. Design improvements were made at each step based on the results of the drop tests and subsequent fire tests. The drop test series included a regulatory normal free drop of 1.2 meters, a 9-meter end drop onto the bottom nozzle, and a 1-meter pin-puncture test on the hinge. Minor structural Outerpack damage indicated that the Traveller Outerpack design satisfied the hypothetical accident condition defined in 10 CFR 71 and TS-R-1. Furthermore, the Clamshell was found to meet the acceptance criteria of the test by maintaining closure and its pre-test shape. The post-test geometry of the fuel assembly was determined to meet the acceptance criteria since only local expansion was noted in the lower 20" of the bottom nozzle region and the cracked rod gaps were all measured less than a pellet diameter.

In summary, testing demonstrated the Traveller package is suitable for compliance to normal and hypothetical mechanical drop test conditions described in 10 CFR 71 and TS-R-1.

3 THERMAL EVALUATION

The Traveller series packages are limited to use for transporting unirradiated, low enriched uranium, nuclear reactor core assemblies. Because there is no heat generation within the package, thermal design for normal conditions is not necessary. The use of polyethylene as a moderator requires controlled heat-up during accident conditions, to prevent loss of hydrogen within the moderator.

3.1 DESCRIPTION OF THERMAL DESIGN

3.1.1 Design Features

The Traveller series packages, as described in section 2, utilize an aluminum Clamshell to contain a single unirradiated nuclear fuel assembly. The Clamshell is mounted within a cylindrical Outerpack fabricated from 304 stainless steel and flame retardant polyurethane foam. The stainless steel/foam sandwich provides thermal insulation during hypothetical fire conditions. Most of the heat capacity is within the Outerpack, provided by the polyethylene moderator, the aluminum Clamshell and the fuel assembly itself reducing the peak temperatures within the package.

The fuel rods, that contain the radioactive material, are designed to withstand temperatures of 1204°C (2200°F) without substantial damage. The primary temperature limitation is the polyethylene moderator located on the inside surface of the Outerpack. Polyethylene was selected because it retains it chemical composition and therefore its hydrogen content past melt temperature (between 120° and 137°C). Because of its very high viscosity, it will not flow significantly and will not change chemical composition unless significant amounts of high temperature oxygen are present (320-360°C).

The design and test strategy employed for the Traveller was to utilize design approaches that had previously passed the thermal test requirements. A review of previous designs and associated test results led to the selection of a stainless steel/polyurethane sandwich for the Outerpack. Based on this design approach, scoping tests and thermal analysis were performed to size the Outerpack structure. These analyses showed that sufficient polyurethane was incorporated to effectively insulate the interior of the Outerpack. As described in section 3.3.1 below, anticipated heat transfer due to conduction and radiation was so low that peak temperatures within the Outerpack would be below the melt temperature of the polyethylene and well below its ignition temperature. The primary concern was hot gas flow into the interior of the Outerpack. If both inner and outer skins of the Outerpack are ripped or if the seam between the Outerpack door and base are opened during the drop tests, hot gas from the fire could flow through the Outerpack significantly increasing its temperature. The Outerpack was made sufficiently robust that the defined drops did not create air infiltration paths within the Outerpack.

During the development process, three Traveller test articles were built. All were subjected to drop testing. Afterwards, these units were subjected to multiple burn tests. The information obtained during tests was incorporated into the final design of the Traveller Certification Test Unit (CTU). The CTU was subjected to drop testing as described above (Section 2.12.4). The CTU was then transported to Columbia, SC where it was burned in accordance with 10CFR71.73(c)(4) and TS-R-1, paragraph 728(a).

The package survived the test with maximum internal temperatures less than 180°C. The results of this test are described in section 3.5 and appendix 3.6.4.

3.1.2 Contents Decay Heat

Decay heat and radioactivity of the contents are not applicable for this package type.

3.1.3 Summary Tables of Temperatures

The maximum temperatures that affect structural integrity, containment, and criticality for both normal conditions of transport and hypothetical accident conditions are provided in Table 3-1. The table also includes the maximum measured temperature of the package components. All measured temperatures are within the limits specified. These results show that hypothetical accident thermal conditions will not materially affect the fuel assembly, the neutron poison plates, clamshell or the polyethylene moderator

During hypothetical accident conditions, the polyurethane insulation in the Outerpack protects the interior from excessive heat up. The Clamshell and its contents will not experience temperature increases significantly greater than 100°C. Therefore, room temperature material properties adequately describe the Clamshell and fuel assembly. The polyurethane foam will experience significant temperatures during the hypothetical accident. Because the lack of data at higher temperatures, the thermal analysis assumed foam properties above 340°C were equivalent to dry air. As shown by tests described in section 3.5 below, this approximation reasonably bounded actual properties.

Table 3-1 Summary Table of Temperatures for Traveller Materials

Material	Temperature Limit and Rational (C)	Measured Temperature in CTU Fire Test (C)$^{(1)}$
Uranium oxide	2750 (melt) 1300 (compatibility with zirconium)	104
Zircalloy	1850 (melt)	104
Aluminum	660 (melt)	104
Stainless steel	1480-1530 (melt)	177$^{(2)}$
UHMW Polyethylene	349 (boiling/ignition)	177$^{(2)}$
Fiberglass seals (Thermojecket S)	1000°F (long term)	Temperature not measured/Seals present after fire test
Shock Mounts (fully cross-linked natural rubber)	*greater than 300 (combustion)*	*177*$^{(2)}$
Refractory fiber felt insulation	2300°F (melt)	177$^{(2)}$

Notes:

(1) Temperature measurements made by non-reversible temperature strips. Exact time of peak temperature can be inferred from analysis. See section 3.3-1.

(2) One location was unreadable on inside Outerpack shell. See section 3.6-4.

5 SHIELDING EVALUATION

The radiation from low enriched uranium in fresh fuel assemblies that affects external dose includes alpha, beta, and gamma radiation. Because of the relatively short range of alpha particles in dense matter, alpha radiation poses little external dose hazard. The most energetic alphas produced by naturally occurring radionuclides will not penetrate the packaging materials.

Several uranium radioactive decay products are beta emitters. A primary radionuclide of concern is protactinium-234 in its metastable state (^{234m}Pa), a daughter of ^{238}U which produces a very high energy beta particle that can travel up to 20 feet in air. Significant beta radiation is also emitted from ^{234}Th (also a daughter of ^{238}U) and ^{231}Th (a daughter of ^{235}U). Typically, these are shielded with ½ inch of plastic, and therefore will be shielded by the packaging materials.

Storage of large quantities of uranium can create low-level gamma radiation fields (less than 0.05 mSv/hr [5 mrem/hr]). In addition to gamma emissions from the uranium decay chains (^{238}U and ^{235}U), recycled fuel materials introduced back into the enrichment process will result in higher gamma radiation fields because of ^{228}Th, a gamma-emitting daughter of ^{232}U with a relatively short half-life (1.9 yr).

The packaging materials of the Traveller effectively limit radiation levels on the external surface of the package. Under conditions of transport normally incident to transportation, the radiation level does not exceed 2 mSv/*hour* (200 mrem/*hour*) at any point on the external surface of the package.

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6 CRTICALITY

The following analyses demonstrate that the Traveller complies fully with the requirements of 10CFR71[1] and TS-R-1[2]. The nuclear criticality safety requirements for Type A fissile packages are satisfied for a single package and array configurations under normal conditions of transport and hypothetical accident conditions. A comprehensive description of the Traveller packaging is provided in Section 1. This section provides a description of the package (i.e., packaging and contents) that is sufficient for understanding the features of the Traveller that maintain criticality safety.

Specifically, this criticality evaluation presents the following information[3]:

1. Description of the contents and packaging, including maximum and minimum mass of materials, maximum ^{235}U enrichment, physical parameters, type, form, and composition.

2. Description of the calculational models, including sketches with dimensions and materials, pointing out the differences between the models and actual package design, with explanation of how the differences affect the calculations.

3. Justification for the credit assumed for the fixed neutron absorber content, including reference to the acceptance tests that are implemented which verify the presence and uniformity of the absorber.

4. Justification for assuming 90% credit for fixed moderating material.

5. Description of the most reactive content loading and the most reactive configuration of the contents, the packaging, and the package array in the criticality evaluation.

6. Description of the codes and cross-section data used, together with references that provide complete information.

7. Discussion of software capabilities and limitations of importance to the criticality safety evaluations.

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[1] Title 10, Code of Federal Regulations, Part 71 (10CFR71), Packaging and Transportation of Radioactive Material, edition effective Oct 2004.

[2] TS-R-1 1996 (Revised), Regulations for the Safe Transport of Radioactive Material.

[3] NUREG/CR-5661, Recommendations for Preparing the Criticality Safety Evaluation of Transport Packages.

8. Description of validation procedures to justify the bias and uncertainties associated with the calculational method, including use of the administrative subcritical margin of 0.05 delta k to set an upper safety limit (USL) of 0.94.

9. Demonstration that the effective neutron multiplication factor (k_{eff}) calculated in the safety analysis is less than the USL after consideration of appropriate bias and uncertainties for the following.

    a. A single package with optimum moderation within the containment (i.e., confinement) system, close water reflection, and the most reactive packaging and content configuration consistent with the effects of either normal conditions of transport or hypothetical accident conditions, whichever is more reactive.

    b. An array of 5N undamaged packages (packages subject to normal conditions of transport) with nothing between the packages and close water reflection of the array.

    c. An array of 2N damaged packages (packages subject to hypothetical accident conditions) if each package were subjected to the tests specified in §71.73, with optimum interspersed moderation and close water reflection of the array.

10. Calculation of the Criticality Safety Index (CSI) based on the value of N determined in the array analyses.

11. Description of the Traveller's Confinement System.

6.1 DESCRIPTION OF CRITICALITY DESIGN

6.1.1 Design Features

This section describes the design features of the Traveller that are important for criticality. The Traveller shipping package carries either a single PWR fuel assembly or a single rod container that holds either PWR or BWR rods. The Traveller is divided into two major systems, Outerpack and Clamshell. The Outerpack consists of a polyurethane foam material sandwiched between concentric stainless steel shells. The Outerpack is a split-shell design with the two halves hinged together. Neutron-moderating high-density polyethylene blocks are affixed to the upper and lower halves of the Outerpack.

The Clamshell is a rectangular aluminum box that completely encloses the contents. It is rotated 45° and mounted in the Outerpack with rubber shock mounts. Neutron absorber panels are slotted into the inner face of each Clamshell side. The Clamshell is designed such that it retains its original dimensions when subjected to the HAC tests. See Figure 6-1 for an exploded view of the Traveller.

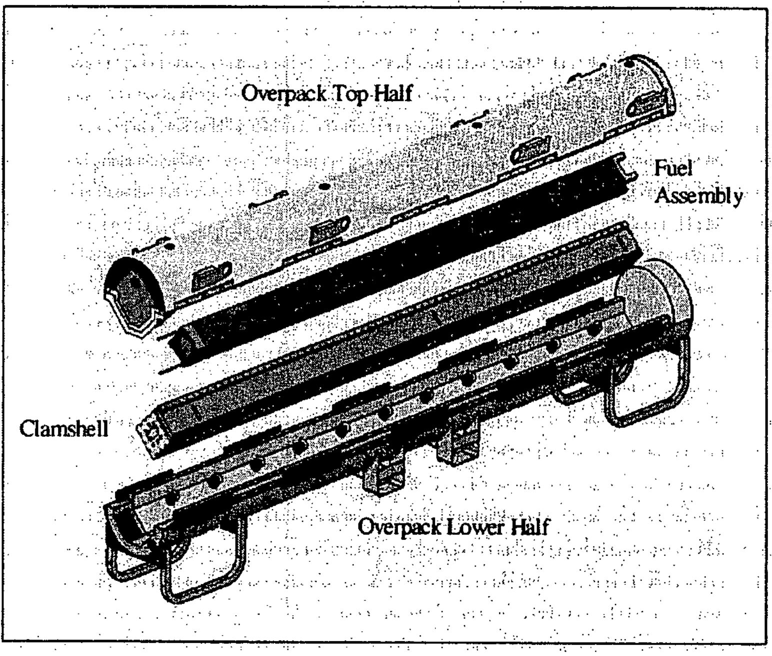

Figure 6-1 Traveller Exploded View

6.1.1.1 Containment System

The Containment System is described in both TSR-1 and 10CFR71 as, "the assembly of components of the packaging intended to retain the radioactive material during transport." The

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Containment System for the Traveller consists of the fuel rods, regardless of whether the Traveller is carrying a fuel assembly or rods in a rod container.

6.1.1.2 Confinement System

The Confinement System is defined in TS-R-1 as "the assembly of fissile material and packaging components specified by the designer and agreed to by the competent authority as intended to preserve criticality safety." Note that TS-G-1.1[1] further describes the confinement system as "that part of a package necessary to maintain the fissile material in the configuration that was assumed in the criticality safety assessment for an individual package." NUREG 1609[2] recommends that the analysis include a discussion of the "structural components that maintain the fissile material or neutron poisons in a fixed position within the package or in a fixed position relative to each other." These structural components are intended to maintain criticality safety of the package. These structural components of the packaging actually comprise part of the Confinement System.

The Confinement System for the Traveller consists of those assembly and packaging components that preserve criticality safety of a single package in isolation. Hence, it consists of the fuel rods, the fuel assembly (or rod container), and the Clamshell assembly, including the neutron absorber panels. The Confinement System is shown in Figure 6-2.

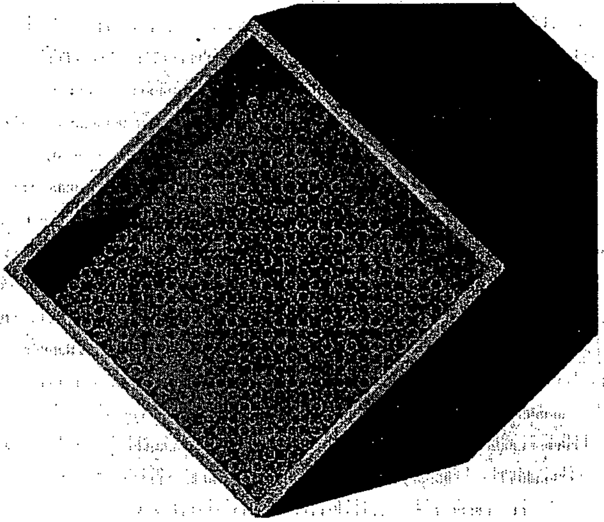

Figure 6-2 Traveller Confinement System

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[1] IAEA TS-G-1.1, Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material.

[2] NUREG 1609, Standard Review Plan for Transportation Packages for Radioactive Material.

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6.1.1.6.5 Region 5 – Polyurethane Foam Region

The polyurethane foam region is the floodable space that is formed when the polyurethane foam burns away. As mentioned above, since it is difficult to predict how much foam will actually burn away, the entire foam region is modeled as *water* for the *individual package cases* and *as a void for the array cases. These are* the most conservative configurations.

6.1.1.6.6 Region 6 – Outside Outerpack Region

This is the volume outside the Outerpack. It has been modeled both flooded and dry to determine which configuration is most conservative for single package and array.

6.1.1.7 Array Spacing Significant Components

The single component that affects the physical separation of the fissile material contents in package arrays is the Outerpack. The Outerpack outer radius is 12.50 inches ± 1.0 inch (317.50 mm ±25.40 mm). It is a cylindrical annular shell split along the longitudinal axis to form two separate halves. The inner and outer shells are fabricated from 12-gauge [0.104 in. 0.264 cm)] stainless steel sheet, and the space between the shells is filled with polyurethane foam. The foam has a nominal 3.0 in. (7.62 cm) radial thickness and axial thickness of approximately 8.0 in. (20.32 cm). The foam material limits impact forces on the fuel assembly and insulates the fuel assembly from heat generated by a fire. Circumferential stiffeners mounted outside provide significant impact protection to the Outerpack diameter. The Outerpack diameter is not reduced at all following hypothetical accident tests. *A sensitivity study was performed to evaluate k_{eff} as a function of Outerpack diameter. This evaluation is described in Section 6.7.11.*

6.1.2 Summary Tables of Criticality Evaluation

Sensitivity studies were performed using the Traveller XL to determine the most conservative *configurations for the normal and hypothetical accident conditions for an individual package and package arrays. These* results, rounded to three decimal places, *are shown in Table 6-1. Calculations were also made to show that* the Traveller *STD is bounded by the* Traveller XL. *Results for the Traveller STD are given in Table 6-2. Finally,* Table 6-3 *shows* results for the two types of rod containers, the Rod Box and Rod Pipe, *in the Traveller XL.*

Table 6-1 Summary Table for Traveller XL with PWR Fuel Assembly

Traveller XL	K_{eff}
Single Package	
Normal	0.201
HAC	0.885
Package Array	
Normal	0.272
HAC	0.939

Table 6-2 Summary Table for Traveller STD with PWR Fuel Assembly

Traveller STD	K_{eff}
Single Package	
Normal	n/a
HAC	0.865
Package Array	
Normal	0.256
HAC	0.897

Table 6-3 Summary Table for Traveller XL with the Rod Box and Rod Pipe

	K_{eff}
Single Package	
Rod Box	0.710
Rod Pipe	0.750
Package Array	
Rod Box	0.560
Rod Pipe	0.670

6.3 GENERAL CONSIDERATIONS

The models developed for these calculations are not exact representations of the package, but they do explicitly include all of the physical features that are important to criticality safety. Modeling approximations will be shown to be either conservative or neutral with respect to the criticality safety case. This section describes the packaging and the contents models.

6.3.1 Model Configuration

Geometry input dimensions are taken directly from design drawings and are derived by stacking dimensions from design drawings or calculated using geometric relationships and dimensions shown on design drawings. Longitudinal dimensions in the model are oriented along the z-axis, and latitudinal dimensions are oriented in the x-y plane. The origin of the individual package unit is near the bottom of the package along the z-axis and at the center of the package in the x-y plane. The positive direction is from bottom to top of the package along the z-axis, the positive direction is from left to right along the x-axis when viewed from the top of the package and the positive direction is from lower to upper along the y-axis.

6.3.1.1 Contents Models

The contents models used in support of this analysis include the PWR fuel assembly model, the BWR fuel rod model, and two rod container models, namely the Rod Pipe and Rod Box.

6.3.1.1.1 PWR Fuel Assembly Model: 17OFA-XL

Section 6.2.1 established that the 17x17OFA would be the fuel assembly used in all calculations. In order to incorporate the maximum fuel assembly length, the 17x17STD-XL, an imaginary fuel assembly, the 17OFA-XL, was modeled in the calculations. The 17OFA-XL model is described in detail in Appendix 6.10.3. It basically consists of concentric cuboids to model the top nozzle assembly, skeleton, and fuel regions. The fuel assembly origin is at the bottom left hand corner of the fuel assembly lower nozzle. The fuel assembly is placed inside the fuel confinement with no translation of the origin. Table 6-6 shows the parameters of the 17OFA-XL and how they compare to the 17x17OFA and 17x17STD.

Table 6-6 17OFA-XL Parameters

Fuel Assembly Type	W-STD/XL	W-OFA	W-OFA/XL
Nominal Pellet Diameter	0.3225 (8.192)	0.3088 (7.843)	0.3088 (7.843)
Annular Pellet Inner Diameter	0.155 (3.937)	0.155 (3.937)	0.155 (3.937)
Nominal Clad Thickness	0.0225 (0.572)	0.0225 (0.572)	0.0225 (0.572)
Clad Material	Zirconium alloy	Zirconium alloy	Zirconium alloy
Nominal Clad Outer Diameter	0.374 (9.499)	0.360 (9.144)	0.360 (9.144)
Maximum Stack Length	169 (4292.6)	145 (3683)	169 (4292.6)
Nominal Assembly Envelope	8.418 (213.817)	8.418 (213.817)	8.418 (213.817)
Kg's ^{235}U Assembly	28	22	28
Nominal Lattice Pitch	0.496 (12.598)	0.496 (12.598)	0.496 (12.598)
GT Diameter	0.482 (12.243)	0.474 (12.040)	0.474 (12.040)
GT Thickness	0.016 (0.406)	0.016 (0.406)	0.016 (0.406)
GT Material	ZIRC	ZIRC	ZIRC
IT Diameter	0.482 (12.243)	0.474 (12.040)	0.474 (12.040)
IT Thickness	0.016 (0.406)	0.016 (0.406)	0.016 (0.406)
IT Material	ZIRC	ZIRC	ZIRC

6.3.1.1.2 Fuel Rod Model

The fuel rods for the rod containers are conservatively modeled in order to bound all PWR and BWR fuel rods that will be transported. The rods are modeled as pellet stacks with no consideration given to cladding or other non-fuel characteristics or properties. The rod container analysis consists of evaluating arrays of pellet stacks inside each container type (Rod Box and Rod Pipe), varying the pellet diameter and pitch to determine the optimum configuration. *Actual* pellet diameters *of fuel to be transported* ranges from 0.20 inches to 0.60 inches [0.508 cm to 1.524 cm]. *The evaluation modeled the pellets over the range from 0.05 inches to 1.0 inch [0.127 cm to 2.54 cm]* at 0.05 inch increments. Pellet pitch *in the model* ranged from close-packed to 4.0 cm in order to find the optimum water-to-fuel ratios for each pellet diameter.

6.3.1.2.2 Clamshell Model

The Clamshell model is described in greater detail in Appendix 6.10.4. It consists of two concentric cuboids to model the outer wall and two intersecting cuboids to model the fixed neutron absorber panels, which are inset into the walls. The Clamshell origin is at the bottom left hand corner of the inside surface. The Clamshell is rotated 45 degrees in the positive direction and the origin is translated in the positive z direction to position the Clamshell inside the Outerpack. The Clamshell can be seen in Figure 6-2 and Figure 6-4.

6.3.2 Material Properties

The Standard Composition Library was used to specify material and mixtures. Those not found in the library are specified using the procedures for arbitrary mixtures described in the SCALE manual. Table 6-8 shows an excerpt from an input deck showing how the material properties are described. The technique used for modeling certain materials as a void (e.g. arbmfoam, arbmrubber) was to change the density by taking it to the 10^{-20} power).

Table 6-8 Sample Input Showing Material Properties

```
 TRAVELLER XL,17WOFA,ENV=24.384   cm,L=100    cm,B10=0.018  g/cm2
 44groupndf5  latticecell
  uo2 1 1 293 92235 5 92238 95 end
  h2o 2 1 293 end
  zirc4 3 1 293 end
  h2o 4 1 293 end
  h2o 5 1 293 end
  arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4  6 1 293
  end
  al 7 1 293 end
  ss304 8 1 293 end
  polyethylene 9 DEN=0.828 1.0 293 end
  arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4 11  1 293
  end
  b-10 12 0 0.0047781    end
  b-11 12 0 0.019398    end
  c   12 0 0.0060439    end
  al  12 0 0.043223    end
  arbmrubber 1.59e-20  7  0  0  0 8016 46.94 13000 19.92 14000 17.54 6012
  10.79 1001 4.73 11000 0.06 26000 0.02  14 1 293 end
  h2o 15 1 293 end
  uo2 16 1 293 92235 5 92238 95 end
  h2o 17 1 293 end
  zirc4 18 1 293 end
  h2o 19 1 293 end
 end comp
 squarepitch 1.4669      0.78435      16 19 0.9144       18 0.8001      17 end
 more data
 res=1  cylinder 0.39218      dan(1)=0.22632      end
```

To more fully document the composition of each compound and/or document the assumptions used in producing the associated cross-section data, a brief description of each material is given in Table 6-9 below:

Table 6-9 Material Descriptions

ZIRC4: Zircaloy - 6.56 g/cc • 98.23 wt % zirconium • 1.45 wt % tin • 0.1 wt % chromium • 0.210 wt % iron • 0.01 wt % hafnium	**SS304:** Stainless steel - 304 - 7.94 g/cc • 68.375 wt % iron • 19 wt % chromium • 9.5 wt % nickel • 2 wt % manganese • 1 wt % silicon • 0.08 wt % carbon • 0.045 wt % phosphorus
UO_2: Uranium dioxide: UO_2 - 10.96 g/cc	**POLYETHYLENE:** Polyethylene: $[C_2H_2]_n$, 0.92 g/cc
H2O: Water: cross sections developed using 1/E weighting everywhere, 0.9982 g/cc	**ARBMFOAM:** • C 50-70 wt % • O14-34 wt % • N 4-12 wt % • H 4-10 wt % • P 0-2 wt % • Si, <1 wt % • Cl <1800 ppm • Other <1 wt %
ARBMRUBBER: Rubber • O 49.94 wt% • Al 19.92 wt% • Si 17.54 wt% • H 4.73 wt% • Na 0.060 wt% • Fe 0.020 wt%	
ARBMBORAL: BORAL • B_4C • ^{10}B loading – 0.024 g/cm^2 • BORAL core thickness – 0.3175cm	

Multiple sets of iron, nickel, and chromium nuclides are available in the Standard Composition Library (FESS, NISS, CRSS). These sets correspond to different weighting functions used in generating the multigroup cross sections. For the 44- and 238-group libraries generated from ENDF/B-V data, there are two special weighting functions. One special weighting function corresponds to $1/E\ \sigma_t\ (E)$, where $\sigma_t\ (E)$ is the total cross section of stainless steel 304. In the other special weighting, $\sigma_t\ (E)$ is the cross section for the referenced nuclide.

Table 6-10 Material Compositions

Compound	Density (g/cm^3)	Elt.	Atomic density (atoms/b-cm)	Compound	Density (g/cm^3)	Elt.	Atomic density (atoms/b-cm)
Uranium dioxide	10.9600	U-235	1.23767E-03	BORAL	2.5891	B-10	0.0047781
		U-238	2.32186E-02			B-11	0.019398
		O	4.89126E-02			C	0.0060439
Water	0.9982	O	3.33846E-02			AL-27	0.043223
		H	6.67692E-02	Aluminum	2.7020	AL	6.03066E-02
Zirc 4	6.5600	ZR	4.25413E-02	Stainless steel	7.9400	C	3.18772E-04
		SN-112	4.68065E-06			SI	1.70252E-03
		SN-114	3.13652E-06			P	6.94680E-05
		SN-115	1.73715E-06			CRSS	1.74726E-02
		SN-116	7.01133E-05			MN	1.74071E-03
		SN-117	3.70592E-05			FESS	5.85446E-02
		SN-118	1.16872E-04			NISS	7.74020E-03
		SN-119	4.14021E-05	Polyethylene	0.9200	C	3.95300E-02
		SN-120	1.57260E-04			H	7.90600E-02
		SN-122	2.23417E-05	Silicone Rubber	1.5900	O	2.81077E-02
		SN-124	2.79391E-05			H	4.49402E-02
		FE	1.48557E-04			Fe	3.42922E-06
		CR	7.59779E-05			C	8.60970E-03
		HF	2.21333E-06			Al	7.06913E-03
Foam 11 PCF	0.1602	O	9.65313E-04			Si	5.97996E-03
		H	9.57279E-03			Na	2.49902E-05
		C	5.62769E-03				
		N	2.75581E-04				

6.3.2.1 Package to Model Comparison

A comparison of the mass of materials in the package model to the actual package provides an overall assessment of differences in geometry and material composition. The mass of the materials in the package model is calculated using the volume option in KENO-VI that calculates volumes of each material using the random method. The model volume is multiplied by the material density to obtain the model mass for each material. There are some materials in the actual package that are not included in the package model. Tables 6-11 through Table 6-13 compares the model mass quantities to the actual.

The actual mass of materials is obtained from design drawings for the package. A small quantity of plastic in the Outerpack vent plugs and steel in the shock mount bolts are not included. Also, some of the stainless steel structure in the Outerpack is not included in the model. Over 100 kg (220 lb.) of stainless steel in the components of the package were not included in the model. The cork rubber used as spacer material in the Clamshell, and the stainless steel in the Clamshell hinge pins are not included in the model.

Table 6-11 Actual Mass Versus Modeled Mass – Outerpack

Material No.	Material	Density	Model Mass	Approx. Mass
8	ASTM A240 type 304 SS	7.94 g/cm^3 [494.38 lb/ft^3]	408.7 kg [901 lb.]	488 kg [*1866* lb.]
6, 11	Foam	*0.10–0.32 g/cm^3* *[6.20 lb/ft^3]*	130.5 kg [287.7 lb.]	153 kg [*339* lb.]
14	Rubber	1.59 g/cm^3 [68.7 lb/ft^3]	3.8 kg [8.3 lb.]	4.5 kg [*14* lb.]
9	Polyethylene	0.92 g/cm^3 [57.43 lb/ft^3]	161.5 kg [356 lb.]	187 kg [*340* lb.]

Table 6-12 Actual Mass Versus Modeled Mass – Clamshell

Material No.	Material	Density	Model mass	Actual mass
7	6061 Aluminum	2.64 g/cm^3 [164.98 lb/ft^3]	118 kg [260 lb.]	162 kg [357 lb.]
12	BORAL	2.71 g/cm^3 [169.16 lb/ft^3]	25 kg [55 lb.]	25 kg [55 lb.]
NA	Cork/natural rubber	[0.56 g/cm^3] [34.73 lb/ft^3]	0	4.5 kg [9.9 lb.]
NA	Stainless steel	7.94 g/cm^3 [495.68 lb/ft^3]	0	3.72 kg [7.6 lb.]

None of the stainless steel in the bottom and top nozzle is included in the fuel assembly. The uranium dioxide actual mass is less than the model mass because theoretical density is used in the model, but actual density is 96.5 percent the theoretical density. The zirconium mass is less in the model because the spacer grids are not included. Neither the model mass nor the actual mass for the contents includes the mass of the fuel rod bottom and top end plugs, plenum spring. Also, the skeleton stainless steel lock tube and top nozzle insert mass are not included in the comparison.

Table 6-13 Material Specifications for Contents

Material No.	Material	Density	Model mass	Actual mass
1	Uranium dioxide	10.96 g/cm^3 [494.38 lb/ft^3]	575 kg [1268 lb.]	560 kg [1234 lb.]
2, 4	Water	0.9982 g/cm^3 [62.31 lb/ft^3]	Variable	Variable
3	Zircaloy	6.56 g/cm^3 [409.48 lb/ft^3]	126 kg [278 lb.]	148 kg [326 lb.]
NA	Stainless steel	7.94 g/cm^3 [795.63 lb/ft^3]	0 kg [0 lb.]	17 kg [37 lb.]
NA	Inconel		0 kg [0 lb.]	2.60 kg [5.7 lb.]

6.3.3 Computer Codes and Cross-Section Libraries

The 44-group ENDF/B-V library has been developed for use in the analysis of fresh and spent fuel and radioactive waste systems. The library was initially released in version 4.3 of SCALE. Collapsed from the finegroup 238-group ENDF/B-V cross-section library, this broad-group library contains all nuclides (more than 300) from the ENDF/B-V data files. Broad-group boundaries were chosen as a subset of the parent 238-group ENDF/B-V boundaries, emphasizing the key spectral aspects of a typical LWR fuel package. Specifically, the broad-group structure was designed to accommodate the following features: two windows (where the cross section drops significantly at a particular energy, allowing neutrons at that energy to pass through the material) in the oxygen cross-section spectrum; a window in the cross section of iron; the Maxwellian peak in the thermal range; and the 0.3-eV resonance in 239Pu (which, due to its low energy, cannot be properly modeled via the SCALE Nordheim Integral Treatment module NITAWL-II). The resulting boundaries represent 22 fast and 22 thermal energy groups; the full-group structure is compared with that of the 238-group library. The finegroup 238-group ENDF/B-V cross sections were collapsed into this broad-group structure using a fuel-cell spectrum calculated based on a 17 × 17 Westinghouse pressurized-water reactor (PWR) assembly. Thus, the 44-group library performs well for LWR lattices, but not as well for other types of systems. The 44-group ENDF/B-V library has been tested against its parent library, using a set of 33 benchmark problems in order to demonstrate that the collapsed set was an acceptable representation of 238-group ENDF/B-V, except for intermediate-energy systems.

6.3.4 Demonstration of Maximum Reactivity

This section demonstrates the most reactive configuration of each case presented in sections 6.4, 6.5, and 6.6. Assumptions and approximations are identified and justified. The optimum combinations of internal and interspersed moderation for the different cases are also explained.

6.3.4.1 Evaluation Strategy

It is important to understand *the* significant *differences that* exist between the routine transport configuration, the normal condition of transport case, the as-found configuration *after hypothetical accident (HAC) testing, and* the license-basis case. The Traveller CTU was tested in accordance with U.S. and IAEA regulatory requirements. Mechanical design calculations, finite element analysis calculations, actual drop test data, reasoned engineering analysis, and sound engineering judgment were used to determine worst-case orientations for the mechanical and thermal tests. This is explained in Section 2. The as-found condition of the package represents the most damaging configuration following actual testing. Therefore, it follows that the as-found package configuration combined with the worst-case flooding configuration, conservative material assumptions, and conservative fuel assembly assumptions should form the license-basis case *for the* safety analysis. (The worst-case flooding condition must be assumed because the Traveller was not actually subjected to an immersion test). The evaluation strategy used to arrive at the license-basis case is presented below. A flow chart showing the evaluation strategy is given in Figure 6-8.

Using the license-basis case as a frame of reference, a series of sensitivity studies were then performed to evaluate certain hypothetical conditions and scenarios. They are listed in Section 6.3.4.9 and discussed in Section 6.7.

6.3.4.2 Baseline Case for Packaging (Routine Condition of Transport)

The baseline case is *the* routine condition of transport. See Table 6-15. *Note that the Routine case was not modeled. It is presented in order to show the conservative differences that exist between it, the normal condition of transport, the as-found condition after testing, and the license-basis case, which are modeled.*

Table 6-14 has been deleted.

6.3.4.5 Conservative *Material* Assumptions

The following conservative material assumptions are incorporated:

- *The Traveller XL clamshell is conservatively modeled at 9.60-inches (23.384 cm), neglecting the presence of the cork liner and the manufacturing tolerance. This is a difference of 0.24 inches (0.61 cm).*
- *The Traveller STD clamshell is conservatively modeled at 9.1 inches (23.114 cm).*
- *Cork liner in clamshell not considered.*
- The polyethylene moderator blocks *are* modele*d* 90% actual density, or 0.828g/cc.
- The ^{10}B content *is modeled at 75% areal density for BORAL (0.0180 g/cm^2).*
- *The shock mounts are modeled as a void.*
- *Shock mount placement is important to criticality because the shock mounts penetrate the moderator through a 6 inch (15.24 cm) cutout. The shock mount configuration for the Traveller STD is modeled according to drawing, relative to either end of the outerpack. The Traveller XL is modeled conservatively in order to maximize the extent to which the 100-cm section of expanded lattice of the fuel assembly is placed over the shock mounts. Hence, the shock mounts are not placed at either end as shown in the license drawing and described in section 6.1.1.5. The first pair is locted 15 inches from the end. The second pair is 18 inches (45.7cm) from the first, and the third is 36 inches from the second. The gap between the first two pair of shock mounts is eliminated in order to maximize the interaction between the expanded sections of fuel.*

6.3.4.6 Normal Condition of Transport

The Traveller model under normal condition of transport is described as follows:

- Outerpack dimensions are modeled as in section 6.3.4.2.
- Clamshell is modeled as in section 6.3.4.5.
- Fuel assembly is modeled as in secton 6.3.4.2.
- The polyurethane foam and shock mounts are modeled at nominal density. Neither is altered under normal conditions of transport.
- The moderator blocks are modeled as in section 6.3.4.5.
- The neutron absorber is modeled as in section 6.3.4.5.
- All floodable void spaces of the Outerpack are modeled dry.
- The package is close reflected by 20 cm water.

As required by 10CFR71 *and TS-R-1*, the Traveller shipping package has been designed and constructed such that under the tests specified *for* normal conditions of transport, the following pertains:

- The contents are subcritical.
- The geometric forms of the package contents are not altered.
- There is no inleakage of water.

Table 6-15 Parameters for the *Different* Traveller Conditions

Parameter	Routine Condition *(Not Modeled)*	*Conservative* Material *Assumptions* *(Not Modeled)*	Normal Condition *of Transport* *(Modeled)*	*HAC* License-basis Case *(Modeled)*
SAR Section	*6.3.4.2*	*6.3.4.5*	*6.3.4.6*	*6.3.4.8*
Outerpack dimension	25.0 inches (63.5 cm)		25.0 inches (63.5 cm)	25.0 inches (63.5 cm)
Polyurethane foam density	Nominal Density		Nominal Density	*Water*/Void
Shock mount density	Nominal Density		Nominal Density	Void
Clamshell dimension: Traveller	9.0± 0.05 inches (22.86±0.127 cm)			
Clamshell dimension: Traveller XL	9.5±0.05 inches (24.13±0.127 cm)			
Cork liner in place on bottom faces	0.188 inches (0.476 cm)	Not in place	Not in place	Not in place
Effective Clamshell dimension: Traveller	8.86 inches (22.51 cm)	9.1 inches (23.114 cm)	9.1 inches (23.114 cm)	9.1 inches (23.114 cm)
Effective Clamshell dimension: Traveller XL	9.36 inches (23.78 cm)	9.6 inches (24.384 cm)	9.6 inches (24.384 cm)	9.6 inches (24.384 cm)
Neutron absorber density (B-Al/BORAL)	Nominal Density	75%	75%	75%
Moderator density	Nominal Density	90%	90%	90%
Flooding condition (single/array)				
Region 1 – Pin Gap	Dry/Dry		Dry/Dry	Flooded/Flooded
Region 2 – Fuel Assembly Envelope	Dry/Dry		Dry/Dry	Flooded/Flooded
Region 3 - Clamshell	Dry/Dry		Dry/Dry	Flooded/Dry
Region 4 - Outerpack	Dry/Dry		Dry/Dry	Flooded/Dry
Region 5 - Polyurethane Foam	Dry/Dry		Foam/Foam	H_2O/Void
Region 6 - Outside Outerpack	Dry/Dry		H_2O Reflected/Dry	H_2O Reflected/Dry
Fuel Assembly Lattice Pitch Expansion	None	None	None	100 cm

6.4 SINGLE PACKAGE EVALUATION

Calculations were performed to determine the most reactive configuration for a single package in isolation under normal and hypothetical accident conditions of transport. The configurations are described below. These descriptions hold for the Traveller STD and Traveller XL. Discussion for the rod containers is included in section 6.10.7.

6.4.1 Configuration for Fuel Assemblies

6.4.1.1 Configuration Under Normal Conditions of Transport

10CFR71 and TS-R-1 require that the contents be subcritical under normal conditions of transport. TS-R-1 indicates that when it can be demonstrated that the confinement system remains within the packaging following the prescribed tests, close reflection of the package by at least 20-cm water may be assumed. Since this is the case for the Traveller, the individual package evaluation includes the close-reflection around the Outerpack.

The parameters for the normal condition of transport are described in section 6.3.4.6 and shown in Table 6-15.

6.4.1.2 Configuration Under Hypothetical Accident Conditions

The hypothetical accident condition requires that the most reactive flooding configuration be considered. It is generally true that the most reactive configuration for an individual package would be that in which the neutrons are moderated as close to the fuel as possible and reflected back into the fuel assembly region. They should not be allowed to escape or to reach the neutron poison where they would be absorbed.

Calculations have shown that this is the case for the Traveller. Therefore, all floodable void spaces in the package are modeled as fully flooded, and the package is close reflected by 20-cm full density water.

The remaining parameters for the hypothetical accident condition (i.e., the license-basis case) for the Traveller are described in section 6.3.4.8 and shown in Table 6-15.

6.6.3 Results for Rod Containers

The discussion on the rod container results is found in appendix 6.10.7.

Table 6-19 Hypothetical Accident Condition Results for Rod Container – *Package Array*

Configuration	*Run No.*	k_s	Uncert.	Calculated k_{eff}
Rod Box	*B-ARR-12-5*	*0.5367*	*0.0013*	*0.5393*
Rod Pipe	*P-ARR-15-6*	*0.6518*	*0.0016*	*0.6550*

6.7 SENSITIVITY STUDIES

6.7.1 Flooding

During transport the package may be subjected to moderation provided by immersion of the package in naturally occurring sources of water (lakes, rivers, ocean, snow, rain) or fire extinguishing agents (water, foams, dry chemicals). Moderator ingress provides varying degrees of moderation inside and outside of the package. The analysis of variance for moderation that is provided by packaging components is evaluated assuming the fuel assembly is moderated with full density water. The greatest interaction between packages, that results in the highest k_{eff} for a package array, occurs when the transport condition causes moderation of the pin-cladding gap and the fuel region, and keeps all other void spaces inside and between the packages dry.

The criticality evaluation considered the Traveller under various flooding schemes to determine the most reactive flooding combination for both the individual package and the array. Note that because the Traveller was not subjected to the immersion test, it is necessary to consider all plausible flooding combinations.

6.7.1.1 Pin-Cladding Gap Flooding

Test results demonstrated that it is possible that rods will crack. Therefore, the evaluation assumes that the pin-gap is flooded for accident conditions. Therefore, the criticality evaluation modeled region 1 as full density water.

6.7.1.2 Most Reactive For Individual Package – Fully Flooded

It is generally true from a criticality perspective that the most reactive configuration for an individual package would be that in which the neutrons are moderated and reflected back into the fuel region before they escape or are absorbed by the neutron poison. Therefore, the most reactive flooding scenario for the individual package assumes that all floodable regions are fully flooded.

6.7.1.3 Most Reactive For Package Array – Preferential Flooding

Preferential flooding (also called differential or sequential flooding) is defined as that scenario in which one cavity of the package remains flooded while one or more of the other cavities drain completely. Referring to section 6.1.1.6 (Floodable Void Spaces) and Figure 6-4, the most reactive configuration for a package array is one in which the neutrons are fully moderated within the fuel region (regions #1 and #2) but where the remaining floodable spaces are modeled as a void to allow neutrons that escape one fuel assembly to have maximum interaction with surrounding packages. Modeling region #3 (Clamshell region) as a void maximizes the probability that neutrons escaping the fuel assembly region will pass out of the Clamshell through the neutron poison. Modeling regions #4 – #6 as voids gives the highest probability of neutron interaction among packages. The array is fully reflected by 20 cm full density water.

Calculations were run to determine the effect of removing the foam from the package. *The configuration evaluated is an infinite array of packages with the fuel assembly moderated and the remainder of the package regions dry. This configuration results in the maximum interaction between individual packages in a package array and emphasizes the effect of eliminating the moderating effect of the foam. Removal of the foam to a lesser extent may be considered equivalent evaluation of interspersed moderation discussed in Section 6.7.1.5.* Results showed that eliminating the foam *for the configuration that* results in *maximum interaction results in* an increase in k_{eff} of 0.025.

6.7.6 *Deleted*

6.7.7 Polyethylene Density

Moderator blocks *are a packaging component that* provide moderation control by maintaining a fixed amount of moderation between the contents in the individual packages. The polyethylene moderator blocks provide moderation that in combination with a neutron poison effectively reduces the interaction between packages. The fixed moderator and a neutron poison are arranged to function as a neutron flux trap.

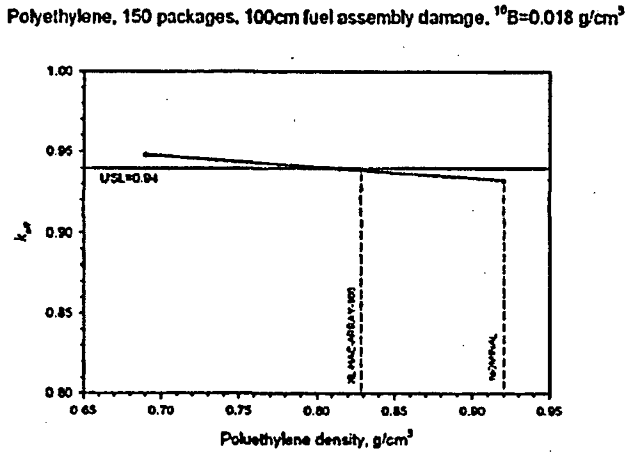

Figure 6-17 Effect of Varying Polyethylene Density

The *HAC License-Basis case for the* polyethylene was evaluated at densities equating to 100% ($\rho = 0.92$ gm/cc), 90% ($\rho = 0.83$ gm/cc), and 75% ($\rho = 0.69$ gm/cm^3) to determine effect. *The configuration is an infinite array of packages with the fuel assembly moderated and the remainder of the package regions dry results in the maximum interaction between individual packages in a package array. The polyurethane foam in the outer pack shell is eliminated and replaced with void to maximize the interaction and emphasize the effect of changes in the polyethylene moderator.* Figure 6-17 shows the *effect of reducing the polyethylene density for a range of boron content from 2.0 wt% boron to 4.5 wt% boron in the poison plates. The average effect of* reducing polyethylene density by 10% increased k_{eff} approximately 1%, and reducing density to 75% increases k_{eff} approximately 2%. *This effect* of reducing the polyethylene density blocks is not strongly dependent on the neutron poison content within the range of parameters evaluated. Results are given in Table 6-*39B*. A sample input deck is provided in Table 6-38.

6.7.8 Reduction of Boron Content in Neutron Absorber

The analysis included a sensitivity study of boron content in the neutron absorber. The sensitivity to ^{10}B areal density is evaluated for a package array with 100 cm fuel lattice expansion. Figure 6-18 shows k_{eff} versus ^{10}B content for BORAL. The ^{10}B effectiveness does not diminish significantly until the areal density decreases to approximately 0.010 gm/cm^2. As can be seen in

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the curves, the boron content in the Traveller neutron absorbers is well beyond the "knee" on the curve. Results are given in Table 6-39. *Number densities used in the boron content analysis are given* in Table 6-39A.

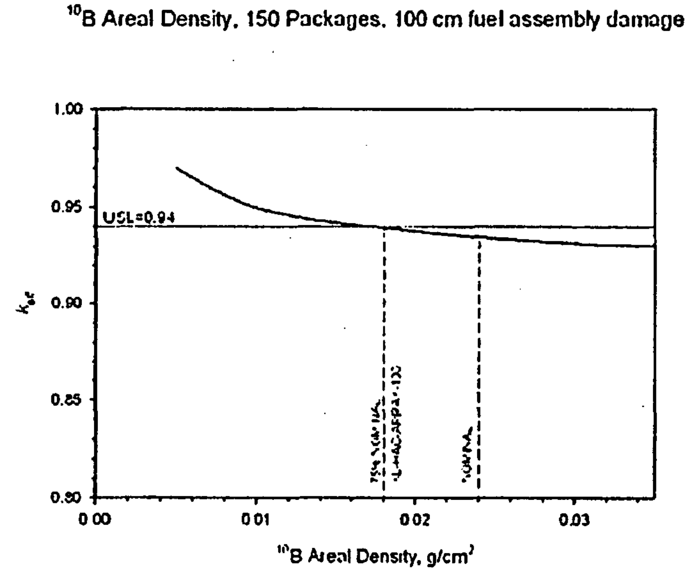

Figure 6-18 Sensitivity Study of Boron Content for Traveller XL Package Array

6.7.9 Elimination of Structural Stainless Steel

Neutron absorption occurs in the stainless steel of the package due to its chromium content. Note that the model takes credit for only about 60% of the stainless steel in the package. Calculations were performed to determine the effect on k_{eff} of variations in stainless steel thickness due to manufacturing tolerances. Figure 6-18A shows the effect. Results are given in Table 6-39C.

6.7.14 Clamshell Position Inside Outerpack

An analysis was performed to evaluate the effect of the clamshell coming loose from the shock mounts and coming to rest on the moderator blocks. The study assumes that all of the shock mounts burn away. The two calculations consider the license basis case (XL-HAC-ARRAY-100 model) with the clamshell resting on the moderator blocks either in the lower half of the outerpack (clamshell down model) or, assuming the packages were upside down, with the clamshell resting on the moderator blocks in the upper half of the outerpack. For the clamshell-up model, the clamshell is rotated 180 degrees so the fuel assembly makes contact with the clamshell at the outerpack edge.

The likelihood of this event occurring is very small for numerous reasons. First, even though the shock mounts are not safety related items, actual testing showed that all of the shock mounts survived the drop and fire tests, and remain connected to the clamshell. Second, engineering scoping analysis estimates that if only one pair of shock mounts at each end survives the drop and fire, they are sufficient to hold the clamshell suspended in the outerpack. If all the shock mounts at one end were to be destroyed, then the clamshell may come into contact with the outerpack at that end only.

Nevertheless, calculations were performed to show the effect on keff if all shock mounts were destroyed. The results show no change in keff for the clamshell down model, and a slight increase for the clamshell up and rotated model. Table 6-19A below gives the results. Figure 6-18C shows the clamshell up and rotated model. Table 6-39F gives the input deck for the clamshell up and rotated model.

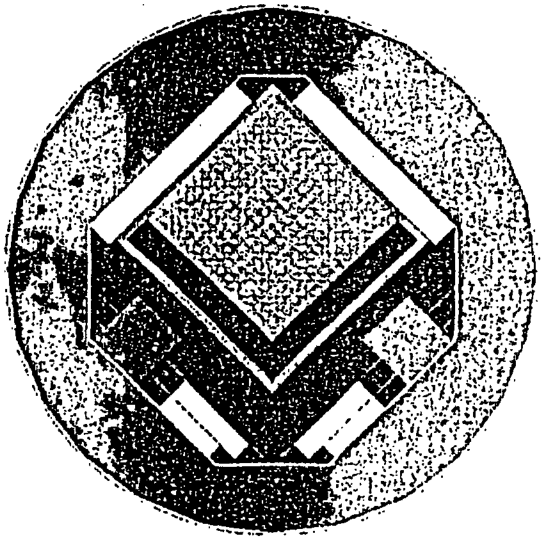

Figure 6-18C Clamshell Up and Rotated Model

Table 6-19A Clamshell Position Inside Outerpack

Configuration	*ks*	*Uncert.*	*Calculated keff*
Clamshell Up-Rotated	*0.9392*	*0.0009*	*0.9410*
Clamshell Down	*0.9377*	*0.0008*	*0.9393*

6.8 FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT

Application for air transport for the Traveller will be made at a later date.

6.9 BENCHMARK EVALUATIONS

The computer code used for these criticality calculations has been benchmarked against applicable criticality experiments.

6.9.1 Applicability of Benchmark Experiments

There are approximately 180 experiments that are applicable to transport.[1] Of these, 55 were selected based on their structural, material, poison, geometry, and spectral similarities to the Traveller. Table 6-40 in appendix 6.10.9 gives a summary of available LWR critical experiments and indicates how many of each type were selected. The selected experiments were grouped into four classifications: Simple Lattice, Separator Plate, Flux Trap, and Water Hole experiments. Table 6-41 shows the breakdown of the experiments into the four classifications. In general, there were 15 Simple Lattice experiments, 26 Separator Plate experiments, 8 Flux Trap experiments, and 6 Water Hole experiments.

In determining which experiments were not applicable, criteria were established by which experiments would be rejected. These criteria include:

- No separator plates made of hafnium, copper, cadmium, zirconium, or depleted uranium (include only separator plates made of stainless steel, aluminum or boron),
- No thick wall lead, steel, or uranium reflector material,
- No hexagonal fuel rod lattices,
- No burnable poison rods (Ag-In-Cd rods, B_4C rods, UO_2-Gd_2O_3 rods)
- No soluble boron

The 55 experiments were analyzed for their applicability to the Traveller package. Table 6-25 shows a summary comparison of the benchmark critical experiment properties to the Traveller package. The range of properties for the critical experiment includes range of values for the Traveller package.

In addition, a qualitative evaluation of the neutron event probabilities is also done to compare the importance of the contents and packaging materials relative to neutron absorption. Comparing the absorption probabilities for the critical experiments and package indicates that the importance of neutron absorption is similar between the critical experiments and package model.

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[1] NUREG/CR-6361 (ORNL/TM-13211): Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages.

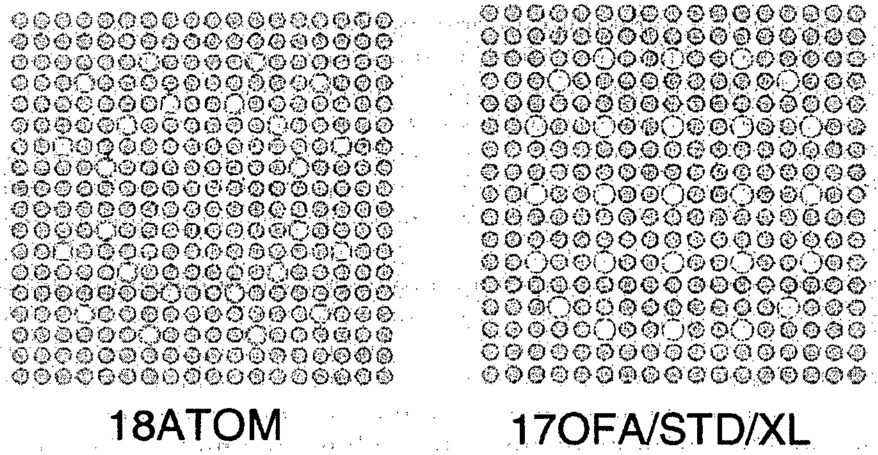

Figure 6-20 Cross Section for 18x18 and 17x17 Assemblies

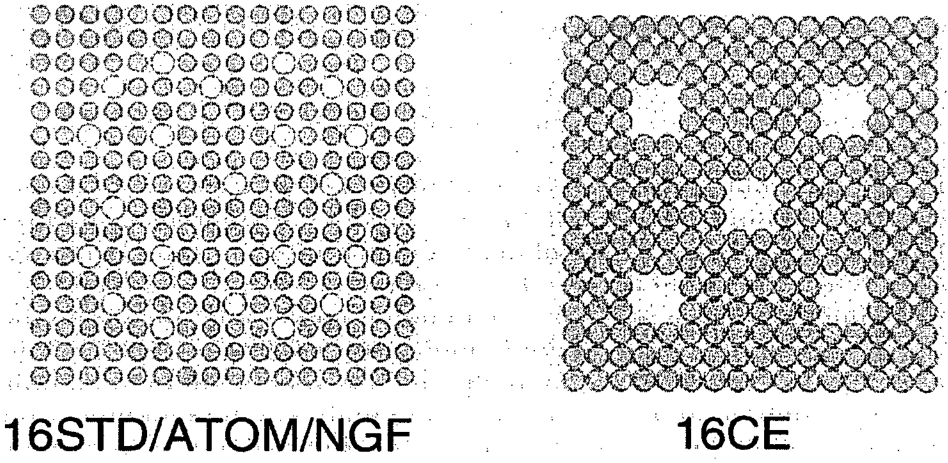

Figure 6-21 Cross Sections for 16x16 Assemblies

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Table 6-20 Parameters for 14x14 Fuel Assemblies

Fuel Assembly Description	14 X 14	14 X 14	14 X 14
Fuel Assembly Type	W-STD	W-OFA	CE-1/CE-2
Rods per assembly	179	179	176
No. Non-Fuel Rods	17	17	20
Nominal Pellet Diameter	0.3659	0.3444	0.3765/0.3805
Nominal Clad Outer Diameter	0.4220	0.4000	0.4400
Nominal Clad Thickness	0.0243	0.0243	0.0280/0.0260
Clad Material	Zirconium alloy	Zirconium alloy	Zirconium alloy
Nominal GT Outer Diameter	*0.5390*	*0.5260*	*1.1110*
Nominal GT Thickness	*0.0170*	*0.0170*	*0.038*
Nominal Assembly Envelope	7.756	7.756	8.110
Nominal Lattice Pitch	0.5560	0.5560	0.5800
Nominal G ^{235}U/cm length	*57*	*52*	60/62
Fuel Rod Arrangement	Fig 6-22	Fig 6-22	Fig 6-22

Table 6-21 Parameters for 15x15 Fuel Assemblies

Fuel Assembly Description	15 X 15	15 X 15
Fuel Assembly Type	STD/OFA	B&W
Rods per Assembly	205	*208*
No. Non-Fuel Rods	20	*17*
Nominal Pellet Diameter	0.3659	0.3659
Nominal Clad Outer Diameter	0.4220	0.4220
Nominal Clad Thickness	0.0243	0.0243
Clad Material	Zirconium alloy	Zirconium alloy
Nominal GT Outer Diameter	*0.5460/0.5330*	*0.5330*
Nominal GT Thickness	*0.0170*	*0.0170*
Nominal Assembly Envelope	8.418	8.528
Nominal Lattice Pitch	0.5630	0.5680
Nominal G ^{235}U/cm length	*65*	*65*
Fuel Rod Arrangement	Fig 6-22	Fig 6-22

Table 6-22 Parameters for 16x16 Fuel Assemblies

Fuel Assembly Description	16 X 16	16 X 16	16 X 16	16 X 16
Fuel Assembly Type	W-STD	CE	NGF	ATOM
Rods per Assembly	235	236	235	235
No. Non-Fuel Rods	21	20	21	21
Nominal Pellet Diameter	0.3225	0.3250	0.3088	0.3590
Nominal Clad Outer Diameter	0.3740	0.3820	0.3600	0.4232
Nominal Clad Thickness	0.0225	0.0250	0.0225	0.0285
Clad Material	Zirconium alloy	Zirconium alloy	Zirconium alloy	Zirconium alloy
Nominal GT Outer Diameter	*0.4710*	*0.9800*	*0.4740*	*0.5331*
Nominal GT Thickness	*0.0180*	*0.040*	*0.0160*	*0.0449*
Nominal Assembly Envelope	7.763	8.122	7.763	9.0354
Nominal Lattice Pitch	0.4850	0.5060	0.4850	0.5630
Nominal G ^{235}U/cm length	*60*	*60*	*60*	*79*
Fuel Rod Arrangement	Figure 6-21	Figure 6-21	Figure 6-21	Figure 6-21

Table 6-23 Parameters for 17x17 and 18x18 Fuel Assemblies

Fuel Assembly Description	17 X 17	17 X 17	18 X 18
Fuel Assembly Type	W-STD/XL	W-OFA	ATOM
Rods per Assembly	264	264	300
No. Non-Fuel Rods	25	25	24
Nominal Pellet Diameter	0.3225	0.3088	0.3169
Nominal Clad Outer Diameter	0.3740	0.3600	0.3740
Nominal Clad Thickness	0.0225	0.0225	0.0252
Clad Material	Zirconium alloy	Zirconium alloy	Zirconium alloy
Nominal GT Outer Diameter	*0.4820*	*0.4740*	*0.4803*
Nominal GT Thickness	*0.0160*	*0.0160*	*0.0433*
Nominal Assembly Envelope	8.418	8.418	9.031
Nominal Lattice Pitch	0.4960	0.4960	0.500
Nominal G ^{235}U/cm length	*65*	*60*	*71*
Fuel Rod Arrangement	Figure 6-20	Figure 6-20	Figure 6-20

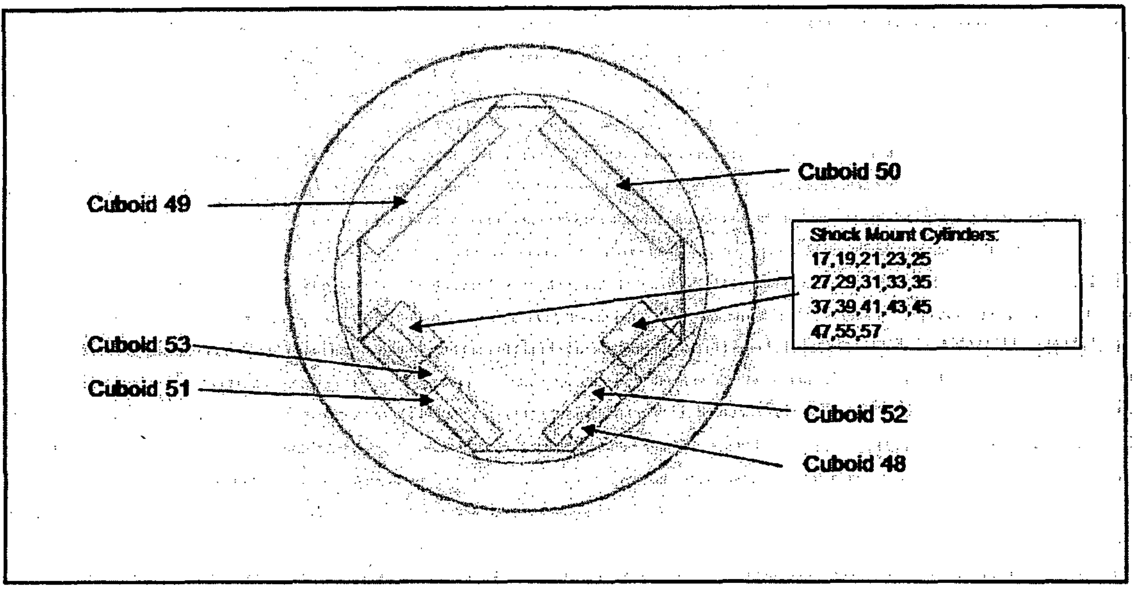

Figure 6-30 Keno 3d Line Schematic of Outerpack Cuboids

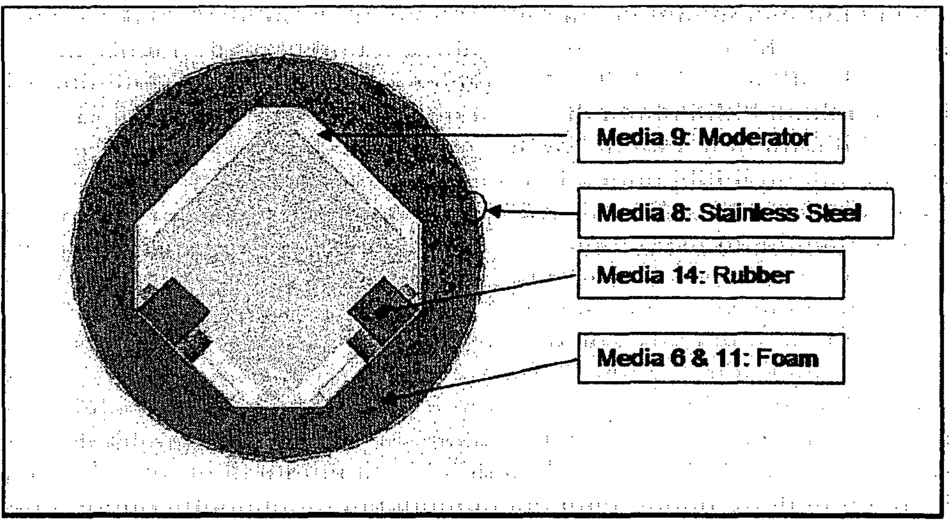

Figure 6-31 Keno 3d Rendering of Outerpack

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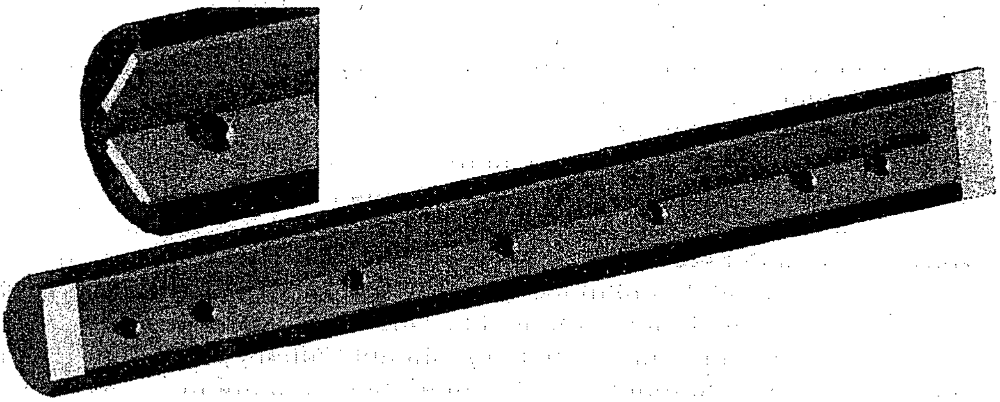

Figure 6-32 Keno 3d *Rendering* of *XL* Outerpack

6.10.4.3 Clamshell Model

The Clamshell is *defined in* unit 11. Figure 6-33 shows a sample of the unit 11 input lines for the Clamshell. Figure 6-34 is a schematic drawing of the Clamshell model.

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6.10.7 ROD CONTAINER CALCULATIONS

6.10.7.1 Introduction

The calculations involved two separate analyses, one for the Rod Pipe, and another for the Rod Box. The approach used was the same for both. *First, each container* was modeled *using* the Traveller XL *outerpack model for the* hypothetical accident conditions for individual package and package array cases. *Second,* the analyses consisted of modeling pellet stacks inside the container and varying the pitch to determine the optimum pellet pitch-to-diameter ratio. *The following pellet diameters were used with corresponding pitches in order to find the optimum values. Note that not all pitch/diameter runs were completed. However, sufficient data were obtained to define curves.*

Pitch Value (cm)	*Pellet Diameters (cm)*
Close Packed (pitch = diameter)	*0.25/ 0.30/0.35/0.40/0.45/0.50/0.60/0.80/0.90/1.00*
1.2	*0.05/0.10/0.15/0.20/0.25/0.30/0.35/0.40/0.45/0.50*
1.5	*0.05/0.10/0.15/0.20/0.25/0.30/0.35/0.40/0.45/0.50*
1.8	*0.05/0.10/0.15/0.20/0.25/0.30/0.35/0.40/0.45/0.50*
2.0	*0.05/0.10/0.15/0.20/0.25/0.30/0.35/0.40/0.45/0.50*
2.5	*0.25/ 0.30/0.35/0.40/0.45/0.50/0.60/0.80/0.90/1.00*
3.0	*0.25/ 0.30/0.35/0.40/0.45/0.50/0.60/0.80/0.90/1.00*
4.0	*0.25/ 0.30/0.35/0.40/0.45/0.50/0.60/0.80/0.90/1.00*

After plotting curves to find approximate maximum k_{eff} values for the pitch/diameter combinations, two array cases were selected, one each for the rod box and rod pipe. These were analyzed to determine the effect on k_{eff} of varying the interspersed moderation water density. These results are shown in Figure 6-39.

6.10.7.2 Models

The fuel rod model is described in Section 6.3.1.1.2. The container models, which consist of a simple cylinder and cube, are described in Section 6.3.1.1.3 and Section 6.3.1.1.4. The box and pipe materials were not included in the models. The dimensions equate to the outside dimensions of the particular container. Figure 6-40 shows the *rod* box and *rod* pipe models inside the Traveller XL.

6.10.7.3 Individual Package Configuration

The analysis assumes the most conservative flooding configuration for the individual package, which is the fully flooded condition. This is discussed in Section 6.7.1.

6.10.7.4 Package Array Configuration

The analysis *uses the same* flooding configuration for the package array *case under hypothetical accident conditions, namely the XL-HAC-ARRAY-100 model.* This is discussed in Section 6.7.1.

6.10.7.5 Results

The *results indicate* that both rod container types are geometry limiting with respect to criticality. Calculated k_{eff} results were found to be *less than 0.75* for all cases. The rod pipe *appears to be* the bounding container, and that the individual case *results were higher* than the array cases *modeled. Scoping calculations on interspersed moderation water density show that there is no intermediate peak between the vacuum condition and full-water density. The individual package cases (isolated) are the most limiting.*

Plots *are provided that* show k_{eff} versus pellet diameter *for the pitch values, for each of the four general groups (i.e., pipe individual, pipe array, box individual, and box array). These are presented as Figures 6-35, 6-36, 6-37, and 6-38.*

Results are provided for the pitch/pellet diameter combinations for the individual and array cases. These are presented as Tables 6-36, 6-36A, 6-36B, and 6-36C. *The results generally show that the maxima for the different groups (i.e., pipe and box, individual package and array) fall in the same area, P/D= 1.97, pellet diameter = 0.762 cm (0.30 inch), pitch = 1.50 cm (0.591 inch).*

Run #	*Table*	*ks*	*sigma*	*Ks+2s*	*Pell. Diam. (inch)*	*Pell. Diam. (cm)*	*Rod Pitch (inch)*	*Rod Pitch (cm)*	*p/d*
P-IP-15-6	*6-36*	*0.7425*	*0.0015*	*0.7455*	*0.30*	*0.762*	*0.591*	*1.50*	*1.97*
P-ARR-15-6	*6-36A*	*0.6622*	*0.0016*	*0.6654*	*0.30*	*0.762*	*0.591*	*1.50*	*1.97*
B-IP-15-6	*6-36B*	*0.7008*	*0.0015*	*0.7038*	*0.30*	*0.762*	*0.591*	*1.50*	*1.97*
B-ARR-15-6	*6-36C*	*0.5512*	*0.0014*	*0.5540*	*0.30*	*0.762*	*0.591*	*1.50*	*1.97*

Results are provided for scoping calculations on the interspersed moderation cases in Table 6-36D. The array and individual package results are also listed for the corresponding cases. It can be seen that there is good agreement between the vacuum and full-water density cases. The data are plotted in Figure 6-39.

Sample input decks are provided in Tables 6-36E (Rod Box Individual Package), 6-36F (Rod Pipe Package Array, and 6-36G (Rod Pipe Interspersed Moderation). In the models, unit 13 is the rod box/pipe unit. Unit 67 is the fuel rod, and unit 55 is the global unit, and as such contains the outerpack, unit 10. The model is run as an infinite array by setting mirror boundaries for the +/-x and +/-y axes (H_2O on +/- z axes), and as an individual package by setting vacuum boundaries all around. For the individual package cases, the global unit #55 includes a 20cm H_2O cylinder around the outerpack.

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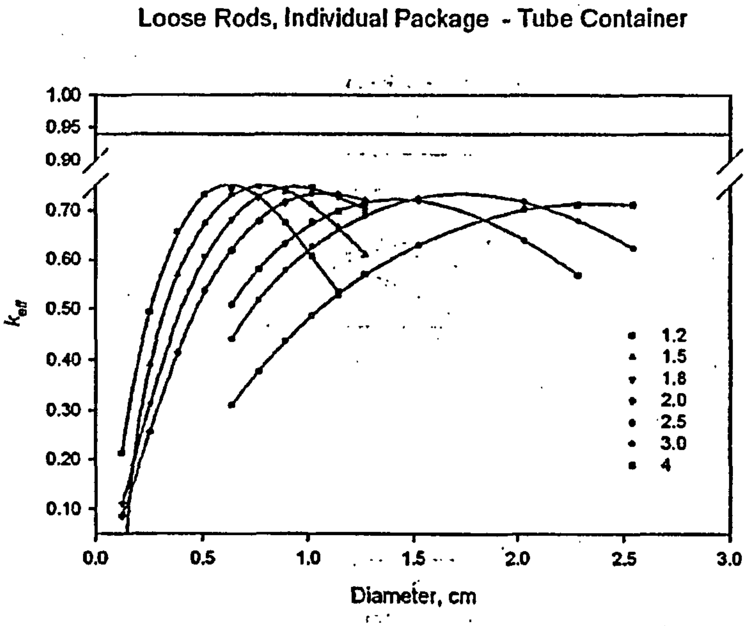

Figure 6-35 Rod Pipe – k_{eff} vs. Pellet *Diameter* for Individual Package

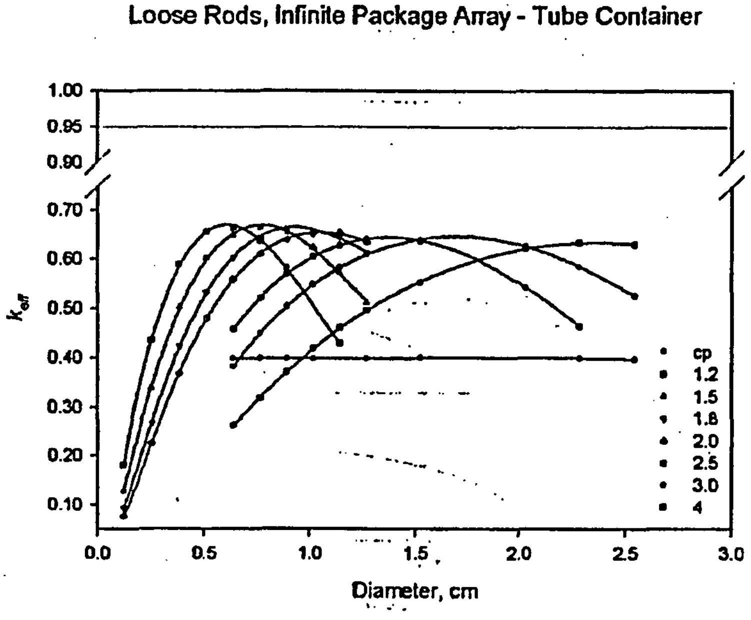

Figure 6-36 Rod Pipe – k_{eff} vs. Pellet Diameter for *Infinite Array*

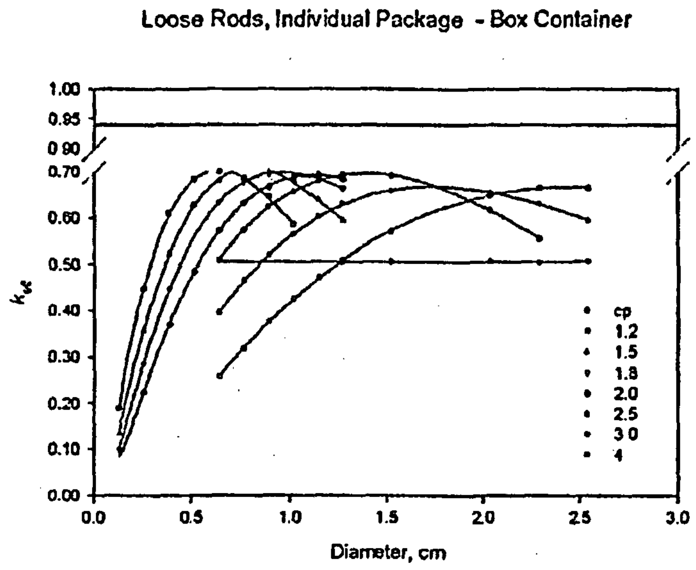

Figure 6-37 Rod *Box* – k_{eff} vs. Pellet Diameter for Individual Package

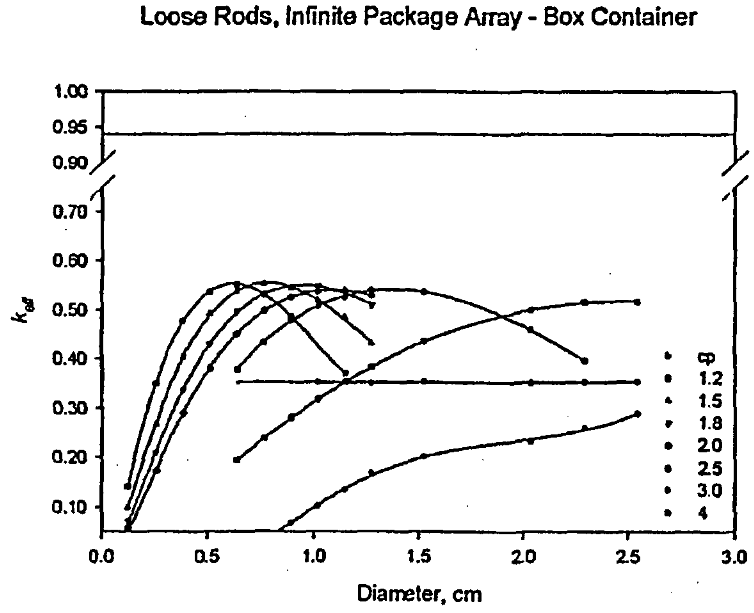

Figure 6-38 Rod Box – k_{eff} vs. Pellet *Diameter* for Package Array

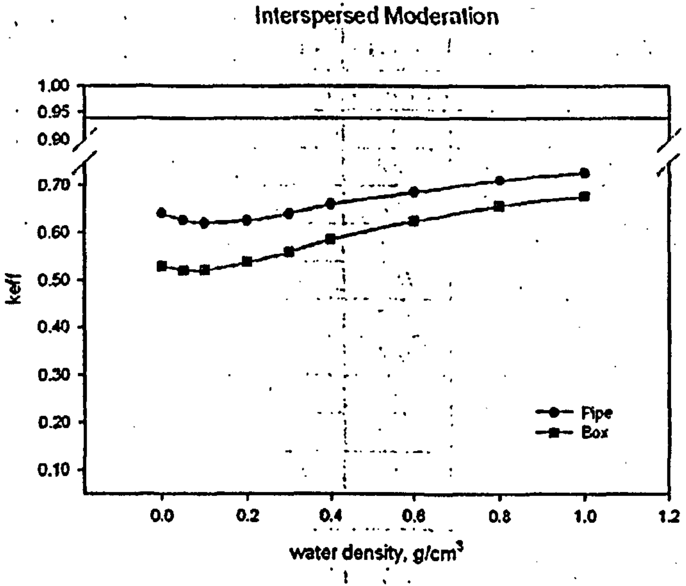

Figure 6-39 *Interspersed Moderation Curves for Rod Box and Rod Pipe*

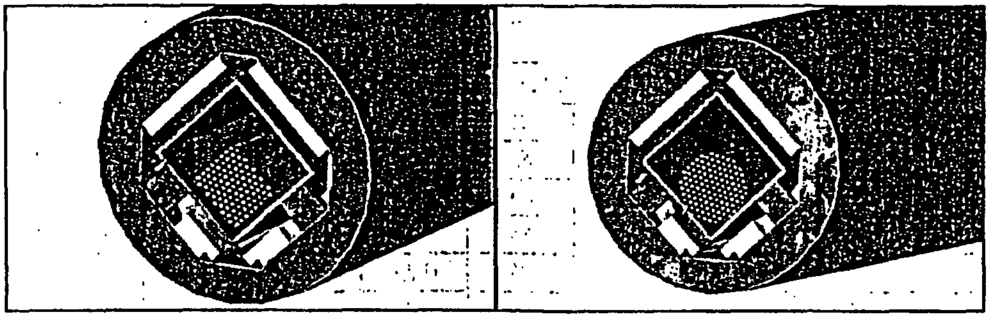

Figure 6-40 Rod *Box and Rod* Pipe in Traveller XL

Table 6-36 Results for Rod Pipe Individual Package HAC

Run #	ks	sigma	Ks+2s	No. Fuel Rods	Pell. Diam. (inch)	Pell. Diam. (cm)	Rod Pitch (inch)	Rod Pitch (cm)	p/d
1.2 cm Pitch									
P-IP-12-1	0.2118	0.0008	0.2134	187	0.05	0.127	0.472	1.20	9.45
P-IP-12-2	0.4917	0.0012	0.4941	187	0.10	0.254	0.472	1.20	4.72
P-IP-12-3	0.6545	0.0013	0.6571	187	0.15	0.381	0.472	1.20	3.15
P-IP-12-4	0.7281	0.0014	0.7309	187	0.20	0.508	0.472	1.20	2.36
P-IP-12-5	0.7416	0.0013	0.7442	187	0.25	0.635	0.472	1.20	1.89
P-IP-12-6	0.7233	0.0014	0.7261	187	0.30	0.762	0.472	1.20	1.57
P-IP-12-7	0.6731	0.0014	0.6759	187	0.35	0.889	0.472	1.20	1.35
P-IP-12-8	0.6049	0.0011	0.6071	187	0.40	1.016	0.472	1.20	1.18
P-IP-12-9	0.5329	0.0011	0.6071	187	0.45	1.143	0.472	1.20	1.05
P-IP-12-10				187	0.50	1.270	0.472	1.20	0.94
1.5 cm Pitch									
P-IP-15-1	0.3893	0.0011	0.3915	121	0.05	0.127	0.591	1.50	11.81
P-IP-15-2	0.5654	0.0013	0.5680	121	0.10	0.254	0.591	1.50	5.91
P-IP-15-3	0.6706	0.0015	0.6736	121	0.15	0.381	0.591	1.50	3.94
P-IP-15-4	0.7285	0.0015	0.7315	121	0.20	0.508	0.591	1.50	2.95
P-IP-15-5	0.7425	0.0015	0.7455	121	0.25	0.635	0.591	1.50	2.36
P-IP-15-6	0.7339	0.0014	0.7367	121	0.30	0.762	0.591	1.50	1.97
P-IP-15-7	0.7073	0.0015	0.7103	121	0.35	0.889	0.591	1.50	1.69
P-IP-15-8	0.6639	0.0013	0.6665	121	0.40	1.016	0.591	1.50	1.48
P-IP-15-9	0.6081	0.0014	0.6109	121	0.45	1.143	0.591	1.50	1.31
P-IP-15-10	0.3893	0.0011	0.3915	121	0.50	1.270	0.591	1.50	1.18
1.8 cm Pitch									
P-IP-18-1	0.1097	0.0005	0.1107	85	0.05	0.127	0.709	1.80	14.17
P-IP-18-2	0.3104	0.0009	0.3122	85	0.10	0.254	0.709	1.80	7.09
P-IP-18-3				85	0.15	0.381	0.709	1.80	4.72
P-IP-18-4	0.6039	0.0015	0.6069	85	0.20	0.508	0.709	1.80	3.54
P-IP-18-5	0.6776	0.0016	0.6808	85	0.25	0.635	0.709	1.80	2.83
P-IP-18-6	0.7225	0.0013	0.7251	85	0.30	0.762	0.709	1.80	2.36
P-IP-18-7	0.7384	0.0015	0.7414	85	0.35	0.889	0.709	1.80	2.02
P-IP-18-8	0.7425	0.0015	0.7455	85	0.40	1.016	0.709	1.80	1.77
P-IP-18-9	0.7246	0.0015	0.7276	85	0.45	1.143	0.709	1.80	1.57
P-IP-18-10	0.6977	0.0013	0.7003	85	0.50	1.270	0.709	1.80	1.42

Table 6-36 (cont.) **Results for Rod Pipe Individual Package HAC**

Run #	ks	sigma	Ks+2s	No. Fuel Rods	Pell. Diam. (inch)	Pell. Diam. (cm)	Rod Pitch (inch)	Rod Pitch (cm)	p/d
				2.0 cm Pitch					
P-IP-20-1	*0.0858*	*0.0005*	*0.0868*	*61*	*0.05*	*0.127*	*0.787*	2.00	*15.75*
P-IP-20-2	*0.2548*	*0.0008*	*0.2564*	*61*	*0.10*	*0.254*	*0.787*	2.00	*7.87*
P-IP-20-3	*0.4130*	*0.0010*	*0.4150*	*61*	*0.15*	*0.381*	*0.787*	2.00	*5.25*
P-IP-20-4	*0.5349*	*0.0012*	*0.5373*	*61*	*0.20*	*0.508*	*0.787*	2.00	*3.94*
P-IP-20-5	*0.6165*	*0.0013*	*0.6191*	*61*	*0.25*	*0.635*	*0.787*	2.00	*3.15*
P-IP-20-6	*0.6754*	*0.0015*	*0.6784*	*61*	*0.30*	*0.762*	*0.787*	2.00	*2.62*
P-IP-20-7	*0.7118*	*0.0014*	*0.7146*	*61*	*0.35*	*0.889*	*0.787*	2.00	*2.25*
P-IP-20-8	*0.7310*	*0.0014*	*0.7338*	*61*	*0.40*	*1.016*	*0.787*	2.00	*1.97*
P-IP-20-9	*0.7274*	*0.0015*	*0.7304*	*61*	*0.45*	*1.143*	*0.787*	2.00	*1.75*
P-IP-20-10	*0.7159*	*0.0014*	*0.7187*	*61*	*0.50*	*1.270*	*0.787*	2.00	*1.57*
				2.5 cm Pitch					
P-IP-25-1	*0.5069*	*0.0014*	*0.5097*	*37*	*0.25*	*0.635*	*0.984*	2.50	*3.94*
P-IP-25-2	*0.5780*	*0.0013*	*0.5806*	*37*	*0.30*	*0.762*	*0.984*	2.50	*3.28*
P-IP-25-3	*0.6304*	*0.0015*	*0.6334*	*37*	*0.35*	*0.889*	*0.984*	2.50	*2.81*
P-IP-25-4	*0.6730*	*0.0015*	*0.6760*	*37*	*0.40*	*1.016*	*0.984*	2.50	*2.46*
P-IP-25-5	*0.6953*	*0.0014*	*0.6981*	*37*	*0.45*	*1.143*	*0.984*	2.50	*2.19*
P-IP-25-6	*0.7094*	*0.0015*	*0.7124*	*37*	*0.50*	*1.270*	*0.984*	2.50	*1.97*
P-IP-25-7	*0.7169*	*0.0015*	*0.7199*	*37*	*0.60*	*1.524*	*0.984*	2.50	*1.64*
P-IP-25-8	*0.6371*	*0.0014*	*0.6399*	*37*	*0.80*	*2.032*	*0.984*	2.50	*1.23*
P-IP-25-9				*37*	*0.90*	*2.286*	*0.984*	2.50	*1.09*
P-IP-25-10				*37*	*1.00*	*2.540*	*0.984*	2.50	*0.98*
				3.0 cm Pitch					
P-IP-30-1				*31*	*0.25*	*0.635*	*1.181*	3.00	*4.72*
P-IP-30-2				*31*	*0.30*	*0.762*	*1.181*	3.00	*3.94*
P-IP-30-3	*0.5740*	*0.0014*	*0.5768*	*31*	*0.35*	*0.889*	*1.181*	3.00	*3.37*
P-IP-30-4	*0.6234*	*0.0013*	*0.6260*	*31*	*0.40*	*1.016*	*1.181*	3.00	*2.95*
P-IP-30-5	*0.6578*	*0.0015*	*0.6608*	*31*	*0.45*	*1.143*	*1.181*	3.00	*2.62*
P-IP-30-6	*0.6873*	*0.0014*	*0.6901*	*31*	*0.50*	*1.270*	*1.181*	3.00	*2.36*
P-IP-30-7	*0.7198*	*0.0014*	*0.7226*	*31*	*0.60*	*1.524*	*1.181*	3.00	*1.97*
P-IP-30-8	*0.7132*	*0.0018*	*0.7168*	*31*	*0.80*	*2.032*	*1.181*	3.00	*1.48*
P-IP-30-9	*0.6765*	*0.0016*	*0.6797*	*31*	*0.90*	*2.286*	*1.181*	3.00	*1.31*
P-IP-30-10	*0.6212*	*0.0013*	*0.6238*	*31*	*1.00*	*2.540*	*1.181*	3.00	*1.18*

Table 6-36 (cont.) Results for Rod Pipe Individual Package HAC

Run #	ks	sigma	Ks+2s	No. Fuel Rods	Pell. Diam. (inch)	Pell. Diam. (cm)	Rod Pitch (inch)	Rod Pitch (cm)	p/d
4.0 cm Pitch									
P-IP-40-1	0.3085	0.0010	0.3105	19	0.25	0.635	1.575	4.00	6.30
P-IP-40-2	0.3754	0.0011	0.3776	19	0.30	0.762	1.575	4.00	5.25
P-IP-40-3	0.4356	0.0012	0.4380	19	0.35	0.889	1.575	4.00	4.50
P-IP-40-4	0.4837	0.0013	0.4863	19	0.40	1.016	1.575	4.00	3.94
P-IP-40-5	0.5266	0.0013	0.5292	19	0.45	1.143	1.575	4.00	3.50
P-IP-40-6	0.5676	0.0013	0.5702	19	0.50	1.270	1.575	4.00	3.15
P-IP-40-7	0.6280	0.0013	0.6306	19	0.60	1.524	1.575	4.00	2.62
P-IP-40-8	0.6999	0.0014	0.7027	19	0.80	2.032	1.575	4.00	1.97
P-IP-40-9				19	0.90	2.286	1.575	4.00	1.75
P-IP-40-10	0.7081	0.0015	0.7111	19	1.00	2.540	1.575	4.00	1.57

Table 6-36A Results for Rod Pipe Package Array HAC

Run #	ks	sigma	Ks+2s	No. Fuel Rods	Pell. Diam. (inch)	Pell. Diam. (cm)	Rod Pitch (inch)	Rod Pitch (cm)	p/d
Close Packed									
P-ARR-CP-1	*0.3961*	*0.0009*	*0.3979*		*0.25*	*0.635*	*0.25*	*0.64*	*1.0*
P-ARR-CP-2	*0.3972*	*0.0009*	*0.3990*		*0.30*	*0.762*	*0.30*	*0.76*	*1.0*
P-ARR-CP-3	*0.3962*	*0.0009*	*0.3980*		*0.35*	*0.889*	*0.35*	*0.89*	*1.0*
P-ARR-CP-4	*0.3967*	*0.0008*	*0.3983*	*253*	*0.40*	*1.016*	*0.40*	*1.02*	*1.0*
P-ARR-CP-5				*200*	*0.45*	*1.143*	*0.45*	*1.14*	*1.0*
P-ARR-CP-6	*0.3967*	*0.0009*	*0.3985*	*163*	*0.50*	*1.270*	*0.50*	*1.27*	*1.0*
P-ARR-CP-7	*0.3981*	*0.0008*	*0.3997*	*109*	*0.60*	*1.524*	*0.60*	*1.52*	*1.0*
P-ARR-CP-8				*64*	*0.80*	*2.032*	*0.80*	*2.03*	*1.0*
P-ARR-CP-9	*0.3975*	*0.0008*	*0.3991*	*54*	*0.90*	*2.286*	*0.90*	*2.29*	*1.0*
P-ARR-CP-10	*0.3950*	*0.0009*	*0.3968*	*41*	*1.00*	*2.540*	*1.00*	*2.54*	*1.0*
1.2 cm Pitch									
P-ARR-12-1	*0.1800*	*0.0007*	*0.1814*	*187*	*0.05*	*0.127*	*0.472*	*1.20*	*9.45*
P-ARR-12-2	*0.4332*	*0.0012*	*0.4356*	*187*	*0.10*	*0.254*	*0.472*	*1.20*	*4.72*
P-ARR-12-3	*0.5860*	*0.0013*	*0.5886*	*187*	*0.15*	*0.381*	*0.472*	*1.20*	*3.15*
P-ARR-12-4	*0.6532*	*0.0014*	*0.6560*	*187*	*0.20*	*0.508*	*0.472*	*1.20*	*2.36*
P-ARR-12-5	*0.6604*	*0.0017*	*0.6638*	*187*	*0.25*	*0.635*	*0.472*	*1.20*	*1.89*
P-ARR-12-6	*0.6351*	*0.0014*	*0.6379*	*187*	*0.30*	*0.762*	*0.472*	*1.20*	*1.57*
P-ARR-12-7	*0.5792*	*0.0016*	*0.5824*	*187*	*0.35*	*0.889*	*0.472*	*1.20*	*1.35*
P-ARR-12-8				*187*	*0.40*	*1.016*	*0.472*	*1.20*	*1.18*
P-ARR-12-9	*0.4271*	*0.0010*	*0.4291*		*0.45*	*1.143*	*0.472*	*1.20*	*1.05*
P-ARR-12-10					*0.50*	*1.270*	*0.472*	*1.20*	*0.94*
1.5 cm Pitch									
P-ARR-15-1	*0.1271*	*0.0006*	*0.1283*	*121*	*0.05*	*0.127*	*0.591*	*1.50*	*11.81*
P-ARR-15-2	*0.3364*	*0.0011*	*0.3386*	*121*	*0.10*	*0.254*	*0.591*	*1.50*	*5.91*
P-ARR-15-3	*0.4993*	*0.0013*	*0.5019*	*121*	*0.15*	*0.381*	*0.591*	*1.50*	*3.94*
P-ARR-15-4	*0.5984*	*0.0014*	*0.6012*	*121*	*0.20*	*0.508*	*0.591*	*1.50*	*2.95*
P-ARR-15-5	*0.6463*	*0.0015*	*0.6493*	*121*	*0.25*	*0.635*	*0.591*	*1.50*	*2.36*
P-ARR-15-6	*0.6622*	*0.0016*	*0.6654*	*121*	*0.30*	*0.762*	*0.591*	*1.50*	*1.97*
P-ARR-15-7	*0.6511*	*0.0016*	*0.6543*	*121*	*0.35*	*0.889*	*0.591*	*1.50*	*1.69*
P-ARR-15-8	*0.6218*	*0.0014*	*0.6246*	*121*	*0.40*	*1.016*	*0.591*	*1.50*	*1.48*
P-ARR-15-9	*0.5706*	*0.0013*	*0.5732*	*121*	*0.45*	*1.143*	*0.591*	*1.50*	*1.31*
P-ARR-15-10	*0.5090*	*0.0011*	*0.5112*	*121*	*0.50*	*1.270*	*0.591*	*1.50*	*1.18*

Table 6-36A Results for Rod Pipe Package Array HAC (cont.)

Run #	ks	sigma	Ks+2s	No. Fuel Rods	Pell. Diam. (inch)	Pell. Diam. (cm)	Rod Pitch (inch)	Rod Pitch (cm)	p/d
1.8 cm Pitch									
P-ARR-18-1	0.0919	0.0005	0.0929	85	0.05	0.127	0.709	1.80	14.17
P-ARR-18-2	0.2645	0.0009	0.2663	85	0.10	0.254	0.709	1.80	7.09
P-ARR-18-3	0.4208	0.0012	0.4232	85	0.15	0.381	0.709	1.80	4.72
P-ARR-18-4	0.5298	0.0013	0.5324	85	0.20	0.508	0.709	1.80	3.54
P-ARR-18-5	0.6002	0.0014	0.6030	85	0.25	0.635	0.709	1.80	2.83
P-ARR-18-6	0.6426	0.0014	0.6454	85	0.30	0.762	0.709	1.80	2.36
P-ARR-18-7	0.6598	0.0015	0.6628	85	0.35	0.889	0.709	1.80	2.02
P-ARR-18-8				85	0.40	1.016	0.709	1.80	1.77
P-ARR-18-9	0.6430	0.0014	0.6458	85	0.45	1.143	0.709	1.80	1.57
P-ARR-18-10	0.6098	0.0010	0.6118	85	0.50	1.270	0.709	1.80	1.42
2.0 cm Pitch									
P-ARR-20-1	0.0751	0.0004	0.0759	61	0.05	0.127	0.787	2.00	15.75
P-ARR-20-2	0.2248	0.0009	0.2266	61	0.10	0.254	0.787	2.00	7.87
P-ARR-20-3	0.3662	0.0010	0.3682	61	0.15	0.381	0.787	2.00	5.25
P-ARR-20-4	0.4765	0.0012	0.4789	61	0.20	0.508	0.787	2.00	3.94
P-ARR-20-5	0.5565	0.0014	0.5593	61	0.25	0.635	0.787	2.00	3.15
P-ARR-20-6	0.6077	0.0016	0.6109	61	0.30	0.762	0.787	2.00	2.62
P-ARR-20-7	0.6371	0.0014	0.6399	61	0.35	0.889	0.787	2.00	2.25
P-ARR-20-8	0.6505	0.0015	0.6535	61	0.40	1.016	0.787	2.00	1.97
P-ARR-20-9	0.6497	0.0017	0.6531	61	0.45	1.143	0.787	2.00	1.75
P-ARR-20-10	0.6317	0.0010	0.6337	61	0.50	1.270	0.787	2.00	1.57
2.5 cm Pitch									
P-ARR-25-1	0.4558	0.0013	0.4584	37	0.25	0.635	0.984	2.50	3.94
P-ARR-25-2	0.5188	0.0013	0.5214	37	0.30	0.762	0.984	2.50	3.28
P-ARR-25-3	0.5679	0.0013	0.5705	37	0.35	0.889	0.984	2.50	2.81
P-ARR-25-4	0.6022	0.0014	0.6050	37	0.40	1.016	0.984	2.50	2.46
P-ARR-25-5	0.6257	0.0013	0.6283	37	0.45	1.143	0.984	2.50	2.19
P-ARR-25-6	0.6373	0.0015	0.6403	37	0.50	1.270	0.984	2.50	1.97
P-ARR-25-7	0.6351	0.0014	0.6379	37	0.60	1.524	0.984	2.50	1.64
P-ARR-25-8	0.5410	0.0012	0.5434	37	0.80	2.032	0.984	2.50	1.23
P-ARR-25-9	0.4619	0.0011	0.4641	37	0.90	2.286	0.984	2.50	1.09
P-ARR-25-10					1.00	2.540	0.984	2.50	0.98

Table 6-36A Results for Rod Pipe Package Array HAC (cont.)

Run #	ks	sigma	Ks+2s	No. Fuel Rods	Pell. Diam. (inch)	Pell. Diam. (cm)	Rod Pitch (inch)	Rod Pitch (cm)	p/d
3.0 cm Pitch									
P-ARR-30-1	*0.3806*	*0.0012*	*0.3830*	*31*	*0.25*	*0.635*	*1.181*	*3.00*	*4.72*
P-ARR-30-2	*0.4473*	*0.0012*	*0.4497*	*31*	*0.30*	*0.762*	*1.181*	*3.00*	*3.94*
P-ARR-30-3	*0.5012*	*0.0012*	*0.5036*	*31*	*0.35*	*0.889*	*1.181*	*3.00*	*3.37*
P-ARR-30-4	*0.5451*	*0.0015*	*0.5481*	*31*	*0.40*	*1.016*	*1.181*	*3.00*	*2.95*
P-ARR-30-5	*0.5806*	*0.0013*	*0.5832*	*31*	*0.45*	*1.143*	*1.181*	*3.00*	*2.62*
P-ARR-30-6	*0.6066*	*0.0013*	*0.6092*	*31*	*0.50*	*1.270*	*1.181*	*3.00*	*2.36*
P-ARR-30-7	*0.6367*	*0.0015*	*0.6397*	*31*	*0.60*	*1.524*	*1.181*	*3.00*	*1.97*
P-ARR-30-8	*0.6246*	*0.0015*	*0.6276*	*31*	*0.80*	*2.032*	*1.181*	*3.00*	*1.48*
P-ARR-30-9	*0.5822*	*0.0014*	*0.5850*	*31*	*0.90*	*2.286*	*1.181*	*3.00*	*1.31*
P-ARR-30-10	*0.5232*	*0.0013*	*0.5258*	*31*	*1.00*	*2.540*	*1.181*	*3.00*	*1.18*
4.0 cm Pitch									
P-ARR-40-1	*0.2606*	*0.0009*	*0.2624*	*19*	*0.25*	*0.635*	*1.575*	*4.00*	*6.30*
P-ARR-40-2	*0.3157*	*0.0011*	*0.3179*	*19*	*0.30*	*0.762*	*1.575*	*4.00*	*5.25*
P-ARR-40-3	*0.3690*	*0.0011*	*0.3712*	*19*	*0.35*	*0.889*	*1.575*	*4.00*	*4.50*
P-ARR-40-4	*0.4158*	*0.0011*	*0.4180*	*19*	*0.40*	*1.016*	*1.575*	*4.00*	*3.94*
P-ARR-40-5	*0.4577*	*0.0012*	*0.4601*	*19*	*0.45*	*1.143*	*1.575*	*4.00*	*3.50*
P-ARR-40-6	*0.4942*	*0.0013*	*0.4968*	*19*	*0.50*	*1.270*	*1.575*	*4.00*	*3.15*
P-ARR-40-7	*0.5506*	*0.0013*	*0.5532*	*19*	*0.60*	*1.524*	*1.575*	*4.00*	*2.62*
P-ARR-40-8	*0.6191*	*0.0014*	*0.6219*	*19*	*0.80*	*2.032*	*1.575*	*4.00*	*1.97*
P-ARR-40-9	*0.6309*	*0.0015*	*0.6339*	*19*	*0.90*	*2.286*	*1.575*	*4.00*	*1.75*
P-ARR-40-10	*0.6280*	*0.0014*	*0.6308*	*19*	*1.00*	*2.540*	*1.575*	*4.00*	*1.57*

Table 6-36B Results for Rod Box Individual Package HAC

Run #	ks	sigma	Ks+2s	No. Fuel Rods	Pell. Diam. (inch)	Pell. Diam. (cm)	Rod Pitch (inch)	Rod Pitch (cm)	p/d
Close Packed									
B-IP-CP-1					*0.25*	*0.635*	*0.25*	*0.64*	*1.0*
B-IP-CP-2					*0.30*	*0.762*	*0.30*	*0.76*	*1.0*
B-IP-CP-3					*0.35*	*0.889*	*0.35*	*0.89*	*1.0*
B-IP-CP-4				*196*	*0.40*	*1.016*	*0.40*	*1.02*	*1.0*
B-IP-CP-5	*0.5025*	*0.0011*	*0.5047*	*155*	*0.45*	*1.143*	*0.45*	*1.14*	*1.0*
B-IP-CP-6	*0.5044*	*0.0011*	*0.5066*	*120*	*0.50*	*1.270*	*0.50*	*1.27*	*1.0*
B-IP-CP-7				*85*	*0.60*	*1.524*	*0.60*	*1.52*	*1.0*
B-IP-CP-8	*0.5048*	*0.0011*	*0.5070*	*51*	*0.80*	*2.032*	*0.80*	*2.03*	*1.0*
B-IP-CP-9	*0.5028*	*0.0010*	*0.5048*	*42*	*0.90*	*2.286*	*0.90*	*2.29*	*1.0*
B-IP-CP-10	*0.5044*	*0.0012*	*0.5068*	*32*	*1.00*	*2.540*	*1.00*	*2.54*	*1.0*
1.2 cm Pitch									
B-IP-12-1	*0.188*	*0.0007*	*0.1894*	*143*	*0.05*	*0.127*	*0.472*	*1.20*	*9.45*
B-IP-12-2	*0.4459*	*0.0012*	*0.4483*	*143*	*0.10*	*0.254*	*0.472*	*1.20*	*4.72*
B-IP-12-3	*0.6061*	*0.0015*	*0.6091*	*143*	*0.15*	*0.381*	*0.472*	*1.20*	*3.15*
B-IP-12-4	*0.6798*	*0.0015*	*0.6828*	*143*	*0.20*	*0.508*	*0.472*	*1.20*	*2.36*
B-IP-12-5	*0.6967*	*0.0014*	*0.6995*	*143*	*0.25*	*0.635*	*0.472*	*1.20*	*1.89*
B-IP-12-6	*0.6819*	*0.0014*	*0.6847*	*143*	*0.30*	*0.762*	*0.472*	*1.20*	*1.57*
B-IP-12-7	*0.6430*	*0.0013*	*0.6456*	*143*	*0.35*	*0.889*	*0.472*	*1.20*	*1.35*
B-IP-12-8	*0.5829*	*0.0012*	*0.5853*		*0.40*	*1.016*	*0.472*	*1.20*	*1.18*
B-IP-12-9					*0.45*	*1.143*	*0.472*	*1.20*	*1.05*
B-IP-12-10				*143*	*0.50*	*1.270*	*0.472*	*1.20*	*0.94*
1.5 cm Pitch									
B-IP-15-1	*0.1333*	*0.0006*	*0.1345*	*93*	*0.05*	*0.127*	*0.591*	*1.50*	*11.81*
B-IP-15-2	*0.3543*	*0.0010*	*0.3563*	*93*	*0.10*	*0.254*	*0.591*	*1.50*	*5.91*
B-IP-15-3	*0.5198*	*0.0012*	*0.5222*	*93*	*0.15*	*0.381*	*0.591*	*1.50*	*3.94*
B-IP-15-4	*0.6254*	*0.0013*	*0.6280*	*93*	*0.20*	*0.508*	*0.591*	*1.50*	*2.95*
B-IP-15-5	*0.6774*	*0.0015*	*0.6804*	*93*	*0.25*	*0.635*	*0.591*	*1.50*	*2.36*
B-IP-15-6	*0.7008*	*0.0015*	*0.7038*	*93*	*0.30*	*0.762*	*0.591*	*1.50*	*1.97*
B-IP-15-7	*0.6964*	*0.0016*	*0.6996*	*93*	*0.35*	*0.889*	*0.591*	*1.50*	*1.69*
B-IP-15-8	*0.6780*	*0.0014*	*0.6808*	*93*	*0.40*	*1.016*	*0.591*	*1.50*	*1.48*
B-IP-15-9	*0.6363*	*0.0014*	*0.6391*	*93*	*0.45*	*1.143*	*0.591*	*1.50*	*1.31*
B-IP-15-10	*0.5906*	*0.0014*	*0.5934*	*93*	*0.50*	*1.270*	*0.591*	*1.50*	*1.18*