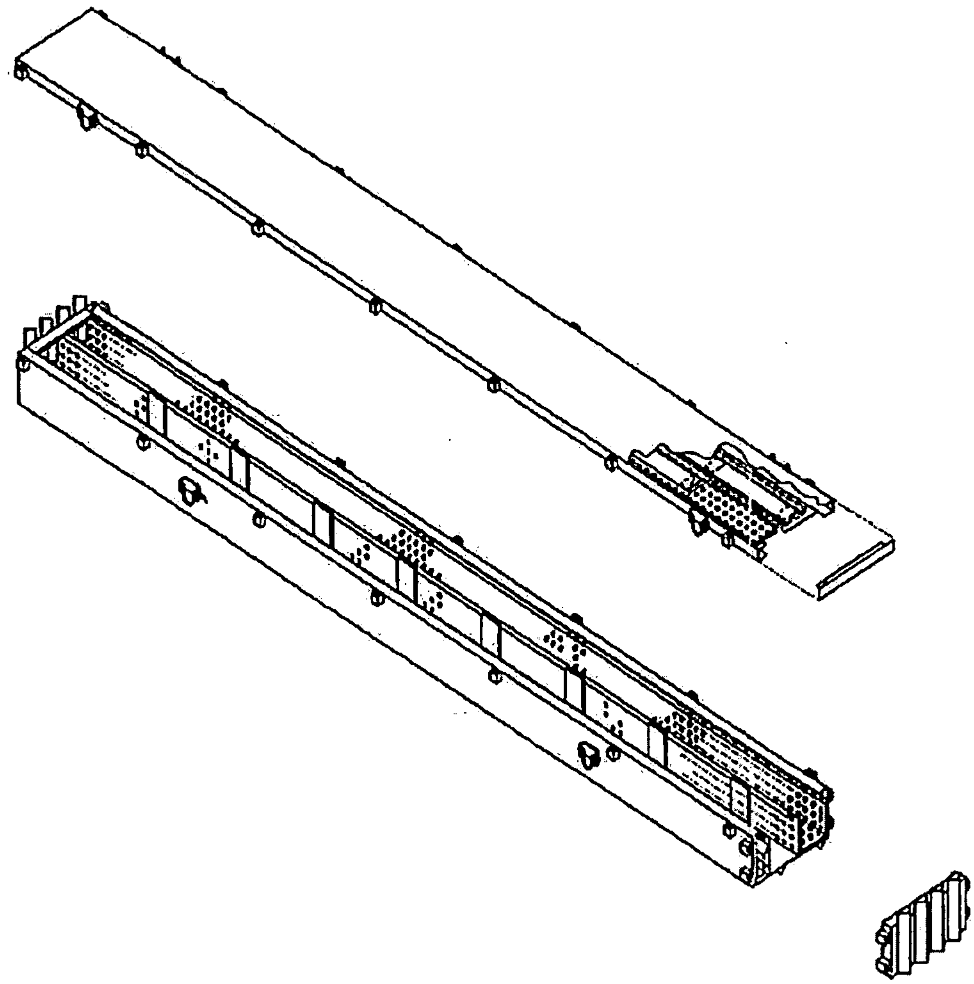
NON-PROPRIETARY



EMF-1563
Revision *16*

Safety Analysis Report (SAR) for
Transnuclear, Inc. Model SP-1, SP-2, and
SP-3 Shipping Containers
Certificate of Compliance No. 9248
Docket Number 71-9248

November 2016

Nature of Changes

Item	Section	Description and Justification
1.	*NA*	*Added the Proprietary Information Notice page. A Proprietary Information Notice page was not previously included in the safety analysis report (SAR).*
2.	*Chapter 1, Section 1.2*	*Revised Section 1.2, "This Revision" to discuss the change to Revision 15 of the SAR. Revision 16 of the SAR is due to superseding Drawing EMF-304,416 with AREVA drawing no. 02-9264132-000 Rev. 0.*
3.	*Chapter 1, Table 1.1*	*For the entry for Figure Number 1.1 the drawing, EMF-304,416, is superseded by AREVA drawing no. 02-9264132-000 Rev. 0 and Note 5 on this drawing is revised.*
4.	*Chapter 1, Drawing EMF-304,416*	*This drawing is superseded by AREVA drawing no. 02-9264132-000 Rev. 0. and revised to change Note 5. The changed note is to provide clarification to the licensees on the use of closed cell polyethylene (CCP) foam that is used for packing material in the SP-1, SP-2, and SP-3 inner containers.*

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2C	Design and Test Information of the Previously Designated RA-1 Inner and Outer Containers Used for Shipping BWR Fuels
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1. Introduction

1.1 History

On April 7, 1992 the NRC notified AREVA NP that NRC Certificate of Compliance 4986 for the RA-2 and RA-3 shipping containers, under which AREVA NP had been a registered user, was being revised for General Electric's use exclusively and that AREVA NP should submit an interim application for a one-year certificate. The notice further stated that a consolidated application would have to be submitted by the expiration date of the one-year certificate. In response to that notice, AREVA NP submitted an abbreviated application for the SP-1 container on May 15, 1992. Subsequently, on December 15, 1992, AREVA NP submitted an amendment application to add the SP-2 container. The SP-1 and SP-2 containers are virtually identical to General Electric's RA-3 and RA-2 containers, respectively.

Revision 0 of Certificate of Compliance 9248 for the SP-1 container was issued June 17, 1992 with an expiration date of June 30, 1993. Subsequent revisions have added the SP-2 and SP-3 container.

1.2 *Revision 16 Changes*

The purpose of this revision to the Safety Analysis Report (SAR) is *for the issuance of Drawing 02-9264132-000 Rev. 0 to supersede drawing EMF 304,416 Rev. 14 and revise Note 5. This note refers to the closed cell polyethylene (CCP) foam that is used for packing material in the SP-1, SP-2, and SP-3 inner containers.*

1.3 General Package Description

The SP-series package consists of a right rectangular metal inner container transported in a wooden outer container. The wooden outer container includes cushioning material. The inner metal container has two internal channel sections which may contain one fuel assembly each or group of unassembled rods each. Descriptions of the containers which comprise the SP-series package and the structural evaluations thereof are included in the subsequent chapters of this consolidated application.

The original GE-designed RA-1 inner container was modified to accommodate a longer bundle. This was accomplished by adding a larger end cap to the existing RA-1 body and identifying this design version as the RA-2 (Transnuclear's SP-2) inner container. Subsequently, out of consideration for fabrication and handling, the longer bodied (short end cap) RA-3 (Transnuclear's SP-1) was introduced. Currently in use are three models of the SP series inner containers, SP-1, SP-2 and SP-3. These models are presently being used with the SP-1 wooden outer container. In addition, loose rods containing gadolinia may be shipped in place of fuel assemblies if they are contained in the "Gadolinia Rod Container" or the 5 inch schedule 40 product container.

1.4 **Compliance**

This section generally describes the tests and evaluations carried out on the RA series of containers by General Electric. The results of such tests and evaluations are applicable also to the SP series of containers. The tests and evaluations are further described in Appendices 2A, 2B, 2C, 2D, and 2E.

The General Electric Model RA series fuel shipping container has been subjected to normal transport condition tests and evaluations specified in Appendix A of 10 CFR *Part* 71 and the hypothetical accident condition tests and evaluations, in the sequence specified in Appendix 2B.

It is concluded that the RA series packaging has successfully passed the acceptance criteria demonstrated as follows:

1.4.1 Normal Transport Condition Tests

1.4.1.1 Heat and Cold

None of the components of the fuel assemblies or the inner metal container on which containment integrity and nuclear safety depend are significantly affected by temperatures within the range of -40 °F to 130 °F.

1.4.1.2 Pressure

A standard breather relief valve installed on the outer shell of the end cap is set to re-seat at a 0.5 psi pressure difference between the inside and outside of the inner container and is capable of airflow adequate for surface or air transport. Therefore, there is no effect on the packaging from an environmental difference of 0.5 *atmospheres*. Note: The functional description of the breather valve by GE in Appendix 2B Section 1.3, third paragraph, is in error and shall be disregarded.

1.4.1.3 Vibration

A 3 inch thick layer of honeycomb cushioning material surrounds the inner metal container at the sides, top and bottom with an additional 9 inch thickness at the ends. Alternatively, there are 3 inches of honeycomb on top and bottom of the inner container and 2 inches on the sides. The inner container is not free to shift during transport since the ethafoam cushioning is slightly compressed during final closure, and the wooden outer container is bolted shut. Since the bolted assemblies in the metal container are held either by clips on the nuts or by lock washers, they cannot loosen during normal transport vibration or shock even if all vibration is not eliminated by the cushioning material.

1.4.1.4 Water Spray

Since the package is designed to remain subcritical assuming any degree of credible in-leakage, water inside the outer container would have no effect on criticality safety considerations. In addition, the effectiveness of the impact limiters and the wooden box structure was not substantially reduced as a result of the water spray test conducted on September 25, 1981. Results of the water spray test showed a maximum reduction of honeycomb compressive strength of 1-1/2% for one side, 3% for the other side, 5% for the bottom, and an undetectable amount for the ends since no wetting of the end honeycomb could be observed.

1.4.1.5 Drop Test

The complete package is designed to protect the fuel assemblies within the inner metal container from loss of containment integrity or change in nuclear safety reliability by virtue of thick cushioning material surrounding it. The shock absorption to the corners, edges and at all joints in the plywood, supplemented by the inherent elasticity of bolts and nails used in final closure of the outer package, constitutes a more than adequate buffer against the subject tests. Additionally, the RA outer container provides added protection to the end cap and cover of the inner RA container during an accident.

1.4.1.6 Corner Drop

Test not required since the package weight exceeds 110 pounds.

1.4.1.7 Penetration

Tests were conducted in which the flat circular end of a vertical steel cylinder 1-1/4 inches in diameter weighing 13 pounds was dropped four feet onto the center of the ½ inch plywood outer container. No damage resulted after four drop tests.

1.4.1.8 Compression

Tests were conducted in which six loaded packages (15,750 lb.) were stacked for 24 hours. There was no visible or measurable damage to the container on the bottom of the stack. The test weight was greater than either of the conditions specified in 10 CFR *Part* 71 Appendix A.

1.4.2 Hypothetical Accident Conditions

1.4.2.1 Free Drop

Four individual drop tests through a distance of 30 feet have been conducted on the RA containers in 1966, 1974, 1978, and 1980. The test packages contained two dummy fuel assemblies to simulate the actual weight of a loaded RA inner container (1,865 lb.). In all tests, the cover and end caps remained intact. The inside angle spacers maintained the *required* annulus so that criticality safety considerations were not affected. The maximum annular reduction of approximately 1% was produced by the test in 1966.

There were no ruptured fuel rods in any of the tests. Therefore, the fuel pellets would remain contained inside the fuel rods.

1.4.2.2 Puncture

A puncture test on the inner metal container conducted in 1980 produced an indentation, but no puncture. There were no ruptured fuel rods, and even though the container was bowed approximately 2 inches, the angle spacers maintained the spacing required so that criticality safety considerations were not affected. This test was conducted on an inner container only, without the protection of the outer wooden box. It easily can be seen that the damage would be considerably less with both the outer and inner container packages. Furthermore, the inner package is designed to remain subcritical with water in-leakage such as that which could result from puncture.

1.4.2.3 Thermal

A thermal test was conducted in 1980 that produced a maximum temperature of 1640 °F flame temperature. An actual gasoline fire test was selected to be most representative of the accident considered. The gasket and other combustible materials inside the container, including foamed polyethylene cushioning and plastic rod spacers, completely burned away during the thirty minute test.

Five hundred gallons of gasoline were consumed during the test, and no abnormal thermal distortion was observed. The pressure relief valve and the burnt gasket permitted the pressure inside to be vented away and prevented rupture of the container.

1.4.2.4 Water Immersion

After the fire test mentioned above, a water immersion test was performed. Water leaked into the container since the gasket was consumed during the fire. Residue and debris remaining did not restrict the free flow of water into and out of the container. The presence of water for 8 hours caused no damage to the fuel rods.

There was no significant deformation or distortion of the container that reduced the effectiveness of the annulus to flooding by water entering through the closure joints since the gasket had burnt away.

These conditions were considered in the criticality calculations which showed the reactivity of such an array when flooded to be subcritical.

1.5 *SP Series Shipping Packages*

1.5.1 SP-1 Inner Container

1.5.1.1 Description

The SP-1 inner container is a right rectangular metal box used inside an SP-1 outer wooden container for shipping fuel assemblies (maximum of two per inner container) or groups of fuel rods in specified containers.

The inner container consists of an outer shell and perforated inner basket separated by structural angle iron. The outer shell is formed of minimum 16-gauge carbon steel plate with an integral welded end of the same material. Four angle stiffeners made of 11-gauge carbon steel are welded on approximately *4* inch centers to the outer end surface of the container. Approximate dimensions of this inner container are 11-1/2 inches high, 18 inches *wide* and 179 inches long.

The inner basket is constructed of 16-gauge carbon steel plate with 3/4 inch perforations on 1-3/4 inch centers. It is welded to the upper edge of the outer shell to form two U-shaped channels approximately 6-7/8 $in.^2$ in cross-section. The channels may be lined with low-density ethafoam cushioning cemented in place with perforations matching the size and location of those in the inner basket as described on Figure 1.1. To support the inner basket within the outer shell, four angle iron spacers made of 1/8 inch thick carbon steel are positioned longitudinally along the entire length of the body. Two similar angle iron spacers are positioned longitudinally in the cover.

The SP-1 inner metal container is designed with a longer body and shorter end cap than the SP-2 inner container. The SP-3 inner metal container, like the SP-1, is designed with a longer body and shorter end cap than the SP-2 inner container. The SP-1 and SP-2 inner containers are used interchangeably for shipping assemblies and rods while the SP-3 is limited to two types of assemblies. All may be used in the SP-1 wooden outer container.

The cover and end cap of the inner container are of similar construction to the box to provide an approximately 2 inch annulus around the fuel, except at the ends, when the box is closed. A gasket of approximately 1/2 inch thick hollow rubber (isoprene or neoprene) provides a completed seal with the cover in place. Closure of the box is effected by bolted assemblies.

The SP-1 inner container may be welded, riveted and/or screwed, or all welded construction. In the welded, riveted and/or screwed inner container, the cover liner is removable and the cavity is of riveted and welded construction.

1.5.1.2 Containment Vessel Penetrations

A standard breather relief valve installed on the outer shell of the end cap is set to re-seat at a 0.5 psi pressure difference between the inside and outside of the inner container and is capable of airflow adequate for surface or air transport.

1.5.1.3 Safety

The SP-1 inner container's safety was demonstrated to be acceptable based on a hypothetical accident condition test conducted in 1980 in accordance with criteria for compliance with 10 CFR *Part* 71.36. See Appendix 2B for the test report.

1.5.2 SP-2 Inner Container

1.5.2.1 Description

The SP-2 inner container is a right rectangular metal box used inside an SP-1 outer wooden container for shipping fuel assemblies (maximum of two per inner) or groups of fuel rods strapped together (sometimes referred to as bundles).

The inner container consists of an outer shell and perforated inner basket separated by structural angle iron. The outer shell is formed of minimum 16-gauge carbon steel plate with an integral welded end of the same material. Four angle stiffeners made of 11-gauge carbon steel are welded on approximately 4 inch centers to the outer end surface of the container.

Approximate dimensions of this inner container are 11-1/2 inches high, 18 inches wide and 179 inches long.

The inner basket is constructed of 16-gauge carbon steel plate with 3/4 inch perforations on 1-3/4 inch centers. It is welded or riveted to the upper edge of the outer shell to form two U-shaped channels approximately 6-7/8 $in.^2$ in cross-section. The channels may be lined with low-density ethafoam cushioning cemented in place with perforations matching the size and locations of those in the inner basket. To support the inner basket within the outer shell, four angle iron spacers made of 1/8 inch thick carbon steel are positioned longitudinally along the entire length of the body. Two similar angle iron spacers are positioned longitudinally in the cover.

The cover and end cap of the inner container are constructed similar to the body to provide an approximately 2 inch annulus around the fuel, except at the ends, when the body is closed. The end cap of the SP-2 container is approximately 7 inches long. A gasket of approximately 1/2 inch thick hollow rubber (isoprene or neoprene) provides a completed seal with the cover in place. Closure of the box is effected by bolted assemblies.

The SP-3 inner metal container, like the SP-1, is designed with a longer body and shorter end cap than the SP-2 inner container. The SP-1 and SP-2 inner containers are used interchangeably for shipping assemblies and rods while the SP-3 is limited to two types of assemblies. All may be used in the SP-1 wooden outer container.

1.5.2.2 Containment Vessel Penetrations

A standard breather relief valve installed on the outer shell of the end cap is set to re-seat at a 0.5 psi pressure difference between the inside and outside of the inner container and is capable of airflow adequate for surface or air transport.

1.5.2.3 Safety

The SP-2 inner container's safety was demonstrated to be acceptable based on tests performed on the GE RA-1 inner container as described in Appendix 2 and according to the current engineering evaluation performed on the RA series containers as discussed in Appendix 2A.

1.5.3 SP-3 Inner Container

1.5.3.1 Description

The SP-3 inner container is a right rectangular metal box used inside an SP-1 outer wooden container for shipping fuel assemblies (maximum of two per inner container) or groups of fuel rods in specified containers.

The inner container consists of an outer shell and perforated inner basket separated by structural angle iron. The outer shell is formed of minimum 16-gauge carbon steel plate with an integral welded end of the same material. Four angle stiffeners made of 11-gauge carbon steel are welded on approximately *4* inch centers to the outer end surface of the container. Approximate dimensions of this inner container are 11-1/2 inches high, 18 inches wide, and 179 inches long.

The inner basket is constructed of 16-gauge carbon steel plate with 3/4 inch perforations on 1-3/4 inch centers. It is welded to the upper edge of the outer shell to form two U-shaped channels approximately 6-7/8 $in.^2$ in cross-section. The channels may be lined with low-density ethafoam cushioning cemented in place with perforations matching the size and location of those in the inner basket as described on Figure 1.1. To support the inner basket within the outer shell, four angle iron spacers made of 1/8 inch thick carbon steel are positioned longitudinally along the entire length of the body. Two similar angle iron spacers are positioned longitudinally in the cover. The body and cover angle iron spacers create a minimum spacing of 1-5/8 inches between the inner basket and the outer shell compared to 1-15/16 in the SP-1 and SP-2 containers. This is the only difference between the SP-1 and SP-3.

The SP-3 inner metal container, like the SP-1, is designed with a longer body and shorter end cap than the SP-2 inner container. The SP-1 and SP-2 inner containers are used interchangeably for shipping assemblies and rods while the SP-3 is limited to two types of assemblies. All may be used in the SP-1 wooden outer container.

The cover and end cap of the inner container are of similar construction to the box to provide an approximately 1-5/8 inch annulus around the fuel, except at the ends, when the box is closed. A gasket of approximately 1/2 inch thick hollow rubber (isoprene or neoprene) provides a completed seal with the cover in place. Closure of the box is *effected* by bolted assemblies.

The SP-3 inner container may be welded, riveted and/or screwed, or all welded construction. In the welded, riveted and/or screwed inner container, the cover liner is removable and the cavity is of riveted and welded construction.

1.5.3.2 Containment Vessel Penetrations

A standard breather relief valve installed on the outer shell of the end cap is set to re-seat at a 0.5 psi pressure difference between the inside and outside of the inner container and is capable of airflow adequate for surface or air transport.

1.5.3.3 Safety

The SP-3 inner container's safety was demonstrated to be acceptable based on a hypothetical accident condition test conducted in 1980 in accordance with criteria for compliance with 10 CFR *Part* 71.36. See Appendix 2B for the test report.

1.5.4 SP-1 Outer Container

1.5.4.1 Description

The all-wood outer container is a right rectangular box with nominal dimensions of between 31 inches and 33 inches high, 30 inches and 32 inches wide, and up to 207 inches long. It is fabricated of 1/2 inch plywood, cleated with nominal 2 inch x 4 inch studs, and mounted on a 30 to 32 inch wide platform constructed of nominal 2 inch x 10 inch planks and with bolted-on skids of nominal 4 inch x 4 inch wood.

Internal cushioning consists of kraft fiber honeycomb impregnated with phenolic resin. Cushioning nominally 8-1/2 inches to 9 inches thick is used to line the inside of the box at the ends, while one layer of between 2 inches and 3 inches thick material is used for the top, bottom, and sides.

Additional cushioning consists of pads of expanded polyethylene material. Five pads 3 inches thick x 18 inches x 20-1/2 inches are located over the transverse skids at the bottom and at the top, while five pads of material 1/2 inch thick x 18 inches x 12 inches are located at related positions on each side of the box. The SP-1 outer container has a 1/2 inch plywood sheet faced with 1/8 inch steel sheet at each end of the box.

The box has no attached lifting or tiedown devices.

The SP-1 outer container is used primarily to reduce shocks and vibrations to the packaged fuel assemblies which are encountered in normal material handling, warehousing, and transportation. The SP-1 outer container also provides a degree of impact reduction capability for protecting the packaged assemblies against damage in rough material handling, dropping while loading or unloading and in impacts due to low speed accidents. In addition, the outer container provides added protection to the end cap and cover of the SP-1, SP-2 and SP-3 inner containers during an accident.

1.5.4.2 Safety

The SP-1 outer container's safety has been determined as the result of a drop test to be acceptable for the purpose it was designed. See Appendix 2A of this section for the test report.

1.6 ***Contents of Shipping Containers***

The contents allowed to be shipped in the SP-1, SP-2 and SP-3 containers include BWR fuel assemblies with a maximum enrichment of 5 wt. % U-235 and individual fuel rods enriched to a maximum of 5.0 wt. % U-235 and containing a minimum gadolinia content of 1.0 *wt. %*. The payload of the SP-3 is limited to category 8 and 9 fuel assemblies as discussed in Chapter 6 and Appendices 6H and 6I.

Each fuel assembly is enclosed in an unsealed polyethylene sheath. The ends of the sheath are neither taped nor folded in any manner that would prevent the flow of liquids into or out of the ends of sheathed fuel assemblies.

Individual rods are shipped either in a product container or the gadolinia rod shipping container. The product container consists of a 5 inch schedule 40 stainless steel pipe fitted with either a screw type or flanged closure. The gadolinia rod shipping container is shown in Figure 1.3.

Specific descriptions of fuel assemblies and rods to be shipped in the SP-1, SP-2 and SP-3 containers are given in Chapter 6.

TABLE 1.1	
Summary Listing of Applicable Licensing Drawings	
Reference Figure No.	**Drawing No. and Description**
1.1	*02-9264132-000 Rev. 0* SP-1, 2, & 3 Inner Shipping Container Assembly
1.2	EMF-306, 272, Sh. 1, Rev. 10 SP-1 Outer Shipping Container
1.3	EMF-309, 141, Rev. 1 Gadolinia Rod Shipping Container

Controlled Document

PROPRIETARY AND SECURITY RELATED INFORMATION WITHHELD UNDER 10 CFR 2.390

DWG. NO.	REFERENCE DRAWING TITLE

APP'D	DRAWN	REVISION DESCRIPTION	REV

APPROVALS	NAME	DATE
DRAWN BY	BRD	11-16
CHECKED BY		
APP'D BY		

AREVA

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TITLE: SP-1, -2, & -3 INNER SHIPPING CONTAINER ASSEMBLY

BLDG/RM	CSA	PIN

DRAWING NO. 02-9264132-000 REV 000

DO NOT SCALE DRAWING SHEET 001 OF 001

PROPRIETARY AND SECURITY RELATED INFORMATION WITHHELD UNDER 10 CFR 2.390

Framatome ANP

SP-1 OUTER SHIPPING CONTAINER

EMF-306,272 R-10

PROPRIETARY AND SECURITY RELATED INFORMATION WITHHELD UNDER 10 CFR 2.390

Siemens Power Corporation

SCALE: .15" = 1"			
	DATE	NAME	TITLE
DRAWN BY	5-11-95	DLP	GADOLINIA ROD SHIPPING CONTAINER
CHECKED BY	5-12-95	TGH	
APPROVED	5-15-95	JCC	
APPROVED	5-15-95	JBE	
APPROVED	5-19-95	TMH	

DRAWING NO. EMF-309,141 R-1

SH NO. 1 SHEETS 1

2. **Structural Evaluation**

The structural evaluations of the SP-1, SP-2 and SP-3 containers under normal transport and hypothetical accident conditions are described in Appendices 2A, 2B, 2C, 2D, and 2E. These appendices are comprised of the appendices of Section 2 of General Electric's March 17, 1992 Consolidated Application for the RA-Series Shipping Package. The SP-1 and SP-2 are virtually identical to the RA-3 and RA-2, respectively. The SP-3 is identical to the SP-1 except for the spacing differences described in 1.5.3.1. Appendices 2A, 2B, 2C, 2D and 2E cover structural, thermal, and containment evaluations of these containers.

3. Thermal Evaluation

The thermal evaluations of the SP-1, SP-2 and SP-3 containers under normal transport and hypothetical accident conditions are described in Appendices 2A, 2B, 2C, 2D, and 2E. These appendices are comprised of the appendices of Section 2 of General Electric's March 17, 1992 Consolidated Application for the RA-Series Shipping Package. The SP-1 and SP-2 are virtually identical to the RA-3 and RA-2, respectively. The SP-3 is identical to the SP-1 except for the spacing differences described in 1.5.3.1. Appendices 2A, 2B, 2C, 2D, and 2E cover structural, thermal, and containment evaluations of these containers.

4. Containment Evaluation

The evaluations of containment of contents under normal transport and hypothetical accident conditions of the SP-1, SP-2 and SP-3 containers are described in Appendices 2A, 2B, 2C, 2D, and 2E. These appendices are comprised of the appendices of Section 2 of General Electric's March 17, 1992 Consolidated Application for the RA-Series Shipping Package. The SP-1 and SP-2 are virtually identical to the RA-3 and RA-2, respectively. The SP-3 is identical to the SP-1 except for the spacing differences described in 1.5.3.1. Appendices 2A, 2B, 2C, 2D, and 2E cover structural, thermal, and containment evaluations of these containers.

5. Shielding Evaluation

Because the SP-1, SP-2 and SP-3 shipping containers are designed to carry low enriched unirradiated fuel, there is no need for shielding to reduce radiation. Typical dose rates at the outer surface of a loaded container are 0.05-0.1 mSv/hr (5-10 mr/hr).

6. Criticality Evaluation

6.1 *Introduction*

The evaluations of the SP-1, SP-2 and SP-3 containers to retain their contents under both normal transport and hypothetical accident conditions are documented in Appendices 2A-2E.

6.2 *Description of Contents*

There are eight fuel assembly types, plus fuel rods outside of assemblies which constitute the contents to be shipped under this *report*. They are described below.

6.2.1 Type G1 (Category 1) Fuel Assemblies

UO_2 fuel assemblies in a 7 x 7, an 8 x 8, or a 9 x 9 square array with a maximum fuel cross-section area of 25.0 $in.^2$, maximum fuel length of 174 inches and maximum average enrichment of 3.3 wt. % U-235. Minimum Zircaloy clad thickness is 0.025 inches; maximum pellet diameter is 0.555 inches. Any number of water rods in any arrangement are permitted.

6.2.2 Type G2 (Category 2) Fuel Assemblies

UO_2 fuel assemblies in a 7 x 7, an 8 x 8, or a 9 x 9 square array with a maximum fuel length of 174 inches, and a maximum average enrichment between 3.3 wt. % to 4.0 wt. % U-235. Pellet and cladding dimensions and nuclear poison specifications are to be in accordance with the limits specified in Appendix 6A.

6.2.3 10 x 10 (Category 3) Fuel

UO_2 fuel assemblies with a maximum enrichment of 5.0 *wt. %* U-235, and a maximum average *planar* enrichment of 4.0 *wt. %* U-235. Each fuel assembly is made up of fuel rods in a 10 x 10 square array, with a maximum fuel cross-section *area* of 25.221 $in.^2$, a nominal pitch of 0.511 inch, and a maximum fuel length of 174 inches. The maximum pellet diameter is 0.3356 inch, the minimum clad thickness is 0.0225 inch, and the maximum U-235 enrichment in any edge rod is 4.0 percent by weight. Each assembly contains at least 6 rods with minimum nominal 2.0 *wt. %* Gd_2O_3, which are symmetric about the diagonal, and each assembly contains at least 4 water rods in the 4 central rod positions.

6.2.4 Fuel Rods (Category 4)

UO_2 fuel rods with a maximum U-235 enrichment of 5.0 wt. % and a minimum gadolinia content of 1.0 *wt. %*. The maximum pellet diameter is 0.5 inch and the maximum rod length is 169 inches. The rods may be clad with Zircaloy, steel, or aluminum. Rods meeting the above requirements may be placed into the "Gadolinia Rod Container" or the 5 inch schedule 40 stainless steel pipe product container and shipped in the SP-1, SP-2 or SP-3 in lieu of one or two fuel assemblies.

6.2.5 10x10 (Category 5) ATRIUM Fuel Assemblies

UO_2 fuel assemblies with maximum U-235 enrichment (wt.%) constraints as follows: perimeter rods: 4.0%; UO_2-Gd_2O_3 ("gadolinia") Rods: 5.0%; All other interior rods: 4.0% average and no rod shall exceed 5.0%. Each assembly is composed of a 10x10 array of fuel rods and water rods. A water channel is required in the central 3x3 rod positions. Any number of additional water rods in any arrangement is permitted including part length rods. The maximum fuel *cross-section area is 25.0 in.^{2} and the maximum fuel length is* 174 inches. The maximum pellet diameter is 0.35 inches and the minimum clad thickness is 0.018 inches. Each assembly shall include at least twelve rods with at least 2.0 wt.% gadolinia in all axial regions with enriched pellets in a pattern symmetric about one of the assembly diagonals. At least eight of the twelve gadolinia rods shall be located in rows 2 and 9 and columns 2 and 9. The nominal diameter of the gadolinia pellets shall be no less than that of the UO_2 (non-gadolinia) pellets.

6.2.6 Additional 10x10 (Category 6) ATRIUM Fuel Assemblies

UO_2 fuel assemblies with a maximum U-235 enrichment of 5.0 wt. %. Each assembly is composed of a 10x10 array of fuel rods with a water channel or water rods located in a central 3x3 array of rods location. Any number of additional water rods or water channels in any arrangement is permitted including part length rods. The maximum fuel *cross-section area is 25.0 in.^{2} and the maximum fuel length is* 174 inches. The maximum pellet diameter is 0.35 inches and the minimum clad thickness is 0.018 inches. Each assembly shall contain at least eight rods with at least 2.0 wt. % gadolinia in all axial regions with enriched pellets. Additional gadolinia rod specifications are given in Appendix 6G.

6.2.7 9x9 (Category 7) ATRIUM Fuel Assemblies

UO_2 fuel assemblies with a maximum U-235 enrichment of 5.0 wt. %. Each assembly is composed of a 9x9 array of fuel rods with a water channel or water rods in the center 3x3 rod locations. Any number of additional water rods or water channels in any arrangement is permitted. The maximum fuel *cross-section area is 25.0 in.^{2} and the maximum fuel length is* 174 inches. The maximum pellet diameter is 0.40 inches and the minimum clad thickness is 0.015 inches. Each assembly shall contain at least eight rods with at least 2.0 wt. % gadolinia in all axial regions with enriched pellets. Additional gadolinia rod specifications are given in Appendix 6G.

6.2.8 Additional 9x9 (Category 8) ATRIUM Fuel Assemblies

UO_2 fuel assemblies in a 9x9 square array with a maximum fuel cross-section *area* of 25.*0 in.^{2}*, maximum fuel length of 174 inches, and a maximum average enrichment of 4.0 *wt. %* U-235. The nominal pellet diameter is 0.370 inch. At least the center 3x3 rod locations shall be a water channel. Each assembly must include at least eight rods with a minimum nominal gadolinia (Gd_2O_3) content of 2.0 *wt. %* in all axial regions with enriched pellets. Additional gadolinia rod specifications are given in Appendix 6H.

6.2.9 Additional 10x10 (Category 9) ATRIUM Fuel Assemblies

UO_2 fuel assemblies in a 10x10 square array with a maximum fuel cross-section *area* of 25.0 *in.^{2}* and a maximum fuel length of 174 inches. The maximum U-235 enrichment is 5.0 *wt. %*, the maximum U-235 enrichment for all edge rods is 4.75 *wt. %*, the maximum enrichment for the *4* corner edge rods is 3.05 *wt.%*, and the maximum U-235 enrichment for the *8* edge rods immediately adjacent to the *4* corner edge rods is 3.55 *wt. %*. The pellet diameter is between 0.30 and 0.3957 inch and a nominal pitch of 0.510 inch. Each assembly must have a water channel in a central 3x3 position. Each assembly must include at least *10* rods with a minimum nominal content of 2.0 *wt. %* gadolinia (Gd_2O_3) in all axial regions with enriched pellets and in a pattern symmetric about one of the assembly diagonals. Polyethylene shipping shims may be inserted between the fuel rods and between the upper tie plate and the fueled region. Additional gadolinia rod specifications are given in Appendix 6I.

6.2.10 Low Enriched Gadolinia Free 10x10 (Category 10) ATRIUM Fuel Assemblies

UO_2 fuel assemblies composed of fuel rods in a 10x10 square array with a maximum fuel cross-section *area* of 25.0 *in.*^{2} and a maximum fuel length of 174 inches. The maximum U-235 enrichment is 2.3 w. %. The pellet diameter is between 0.30 and 0.3957 inch. Each assembly must have a water channel in a central 3x3 position. Any number of additional water rods in any arrangement is permitted, including part length rods. Polyethylene shipping shims may be inserted between the fuel rods. An additional upper tie plate (UTP) shipping shim may be added between the UTP and the fueled region. This UTP shim may consist of a maximum of 345 g plastic or plastic composite.

6.3 ***Criticality Evaluation of Individual Fuel Types***

6.3.1 Type G1 (Category 1) Fuel Assemblies

Parameter	Value
Assembly size	5.0 inch x 5.0 inch (maximum)
Assembly array	7 x 7, 8 x 8, 9 x 9
Average water/fuel volume ratio (Vw/Vf)	1.0 (minimum)
Pellet to clad radial gap	0.003 inch (minimum)
Clad thickness	0.025 inch (minimum)
Pellet diameter	0.555 inch (maximum)
Water rods	Any number/any arrangement
Assembly-average enrichment[1]	3.3 *wt. %* U-235 (maximum)
Gd_2O_3 requirement	None

Appendix 6A, as modified by 6F, describes the criticality analyses of the type G1 fuel assembly to be shipped in SP-1 or SP-2 containers.

6.3.2 Type G2 (Category 2) Fuel Assemblies

Parameter	Value
Assembly size	5.0 inch x 5.0 inch (maximum)

[1] UO_2 rods and UO_2-Gd_2O_3 rods may contain several inches of natural enrichment UO_2 pellets at either or both ends of the pellet stack. The assembly-average enrichment limits are for the enriched zone only *(*i.e., the assembly-average enrichment does not include the natural uranium at the ends of the pellet stack*)*.

Assembly array	7 x 7, 8 x 8, 9 x 9
Average water/fuel volume ratio (Vw/Vf)	1.0 (minimum)
Pellet to clad radial gap	0.003 inch (minimum)
Clad thickness	0.025 inch (minimum)
Pellet diameter	0.555 inch (maximum)
Water rods	Any number/any arrangement
Assembly-average enrichment[1]	3.3-4.0 *wt.* % U-235 (maximum)
Gd_2O_3 requirement	None

- Minimum number of UO_2-Gd_2O_3 rods is four in non-perimeter locations symmetric about the assembly diagonal.
- UO_2-Gd_2O_3 rods may contain various Gd_2O_3 concentrations in the enriched fuel zone but the minimum Gd_2O_3 concentration in the enriched zone to qualify as one of the four UO_2-Gd_2O_3 rods is 2.0 *wt.* %.
- The nominal length of the UO_2-Gd_2O_3 region shall be equal to or greater than the nominal length of the enriched region in the UO_2 fuel rods.
- Gd_2O_3 is not required in the end regions with natural uranium.

Appendix 6A, as modified by 6F, describes the criticality analyses of the type G2 fuel assembly to be shipped in SP-1 or SP-2 containers. Attached Appendix 6H describes the criticality analysis of the Category 2 fuel to be shipped in the SP-3 container.

6.3.3 <u>10x10 (Category 3) Fuel Assemblies</u>

Parameter	Value
Assembly size	5.022 inch *by 5.022* (maximum)
Enrichment of any pellet in assembly	5.0 *wt.* % U-235 (maximum)
Enrichment of any pellet in an edge rod	4.0 *wt.* % U-235 (maximum)
Maximum average planar enrichment[2]	4.0 *wt.* % U-235 (maximum)
Clad thickness	0.0225 inch (maximum)
Pellet diameter	0.3356 inch (maximum)
Fuel density	98.0% TD (maximum)
Rod pitch	0.511 inch (nominal)
UO_2-Gd_2O_3 rods	6 (minimum)
Gd_2O_3 content	2.0± 0.08 *wt.* % (minimum)
Water rods	Center 4 rods (minimum)
Poison rod arrangement	Symmetrical across the diagonal
Fuel rod array in bundle	10 x 10

[2] Maximum average planar enrichment: The average enrichment at the axial location yielding the highest planar average.

Appendix 6B, as modified by 6F, describes the criticality analyses for 10 x 10 fuel assemblies to be shipped in SP-1 or SP-2 containers.

6.3.4 Fuel Rods (Category 4)

UO_2 fuel rods with a maximum U-235 enrichment of 5.0 wt. % and a minimum gadolinia content of 1.0 *wt. %*. The maximum pellet diameter is 0.5 inch and the maximum rod length is 169 inches. The rods may be clad with Zircaloy, steel, or aluminum. Rods meeting the above requirements may placed into the "Gadolinia Rod Container" or the *5* inch schedule 40 stainless steel pipe product container and shipped in the SP-1 or SP-2 in lieu of *1* or *2* fuel assemblies.

Appendix 6C, as modified by 6F, describes the criticality analyses for gadolinia-bearing rods to be shipped in the gadolinia rod container in SP-1 and SP-2 containers.

6.3.5 10x10 (Category 5)ATRIUM Fuel Assemblies

Parameter	Value
Assembly size	5.0 inch *by 5.0 inch* (maximum)
Enrichment of any pellet in assembly	5.0 *wt.* % U-235 (maximum)
Enrichment of any pellet in an edge rod	4.0 *wt.* % U-235 (maximum)
Maximum average planar enrichment[2] excluding Gd rods and edge rods	4.0 *wt.* % U-235 (maximum)
Clad thickness	0.018 inch (minimum)
Pellet diameter	0.35 inch (maximum)
Fuel density	98.0% TD (maximum)
Rod pitch	0.510 inch (nominal)
UO_2-Gd_2O_3 rods	12 (minimum)
Gd_2O_3 content	2.0± 0.08 *wt. %* (minimum)
Water rods	Center 3 x 3 rods (minimum)
Poison rod arrangement	Symmetrical across the diagonal
Fuel rod array in bundle	10 x 10

Appendix 6D, as modified by 6F, describes the criticality analyses for 10 x 10 fuel assemblies to be shipped in SP-1 or SP-2 containers.

6.3.6 Additional 10x10 (Category 6) ATRIUM Fuel Assemblies

Parameter	Value
Assembly size	5.0 inch *by 5.0 inch* (maximum)
Enrichment of any pellet in assembly	5.0 *wt.* % U-235 (maximum)
Clad thickness	0.018 inch (minimum)
Pellet diameter	0.35 inch (maximum)
Fuel density	98.0% TD (maximum)
Rod pitch	0.510 inch (nominal)
UO_2-Gd_2O_3 rods	8 (minimum)
Gd_2O_3 content	2.0± 0.08 *wt.* % (minimum)
Water rods	Center 3 x 3 rods (minimum)
Fuel rod array in bundle	10 x 10

Appendix 6E, as modified by 6F, describes the criticality analyses for 10 x 10 fuel assemblies to be shipped in SP-1 or SP-2 containers.

6.3.7 9x9 (Category 7) ATRIUM Fuel Assemblies

Parameter	Value
Assembly size	5.0 inch *by 5.0 inch* (maximum)
Enrichment of any pellet in assembly	5.0 *wt.* % U-235 (maximum)
Enrichment of any pellet in an edge rod	4.0 *wt.* % U-235 (maximum)
Maximum average planar enrichment[3]	4.0 *wt.* % U-235 (maximum)
Clad thickness	0.015 inch (minimum)
Pellet diameter	0.40 inch (maximum)
Fuel density	98.0% TD (maximum)
Rod pitch	0.569 inch (nominal)
UO_2-Gd_2O_3 rods	8 (minimum)
Gd_2O_3 content	2.0± 0.08 *wt.* % (minimum)
Water rods	Center 3 x 3 rods (minimum)
Fuel rod array in bundle	9 x 9

Appendix 6E, as modified by 6F, describes the criticality analyses for 9 x 9 fuel assemblies to be shipped in SP-1 or SP-2 containers.

[3] Maximum average planar enrichment: The average enrichment at the axial location yielding the highest planar average.

6.3.8 Additional 9x9 (Category 8) ATRIUM Fuel Assemblies

Parameter	Value
Assembly size	5.0 inch x 5.0 inch (maximum)
Assembly array	9x9
Average water/fuel volume ratio (Vw/Vf)	1.0 (minimum)
Pellet to clad radial gap	0.003 inch (minimum)
Clad thickness	0.025 inch (minimum)
Pellet diameter	0.555 inch (maximum)
Water rods	Center 3x3 rods
Assembly-average enrichment	4.0 *wt. %* U-235 (maximum)
Gd_2O_3 requirement	

- Minimum number of UO_2-Gd_2O_3 rods is four in non-perimeter locations symmetric about the assembly diagonal.
- UO_2-Gd_2O_3 rods may contain various Gd_2O_3 concentrations in the enriched fuel zone but the minimum Gd2O3 concentration in the enriched zone to qualify as one of the four UO_2-Gd_2O_3 rods is 2.0 *wt. %*.
- The nominal length of the UO_2-Gd_2O_3 region shall be equal to or greater than the nominal length of the enriched region in the UO_2 fuel rods.
- Gd_2O_3 is not required in the end regions with natural uranium.

Attached Appendix 6H describes the criticality analysis of the Category 8 fuel to be shipped in the SP-1, SP-2 and SP-3 containers.

6.3.9 Additional 10x10 (Category 9) ATRIUM Fuel Assemblies

Parameter	Value
Assembly size	5.0 inch x 5.0 inch (maximum)
Fuel rod array in bundle	10x10
Fuel length	174 inches (maximum)
Enrichment of any pellet in the assembly	5.0 *wt. %* U-235 (maximum)
Enrichment of any pellet in an edge rod	4.75 *wt. %* U-235 (maximum)
Enrichment of any pellet in one of the four corner edge rods	3.05 *wt. %* U-235 (maximum)
Enrichment of any pellet in one of the eight edge rods immediately adjacent to the four corner rods	3.55 *wt. %* U-235 (maximum)
Clad thickness	Not restricted

Pellet diameter	0.30 inch (minimum); 0.3957 inch (maximum)
Rod pitch	0.510 inch (nominal)
Fuel density	98.0% TD (maximum)
UO_2 - Gd_2O_3 rods	10 (minimum)
Gd_2O_3 content	2.0 *wt.* % nominal (minimum)
Water rods	Center 3x3 rods (minimum)

- Each assembly must include a minimum of 10 rods with a minimum 2.0 *wt.* % gadolinia (Gd_2O_3) in all axial regions with enriched pellets.
- The gadolinia rods must be in a pattern symmetric about one of the assembly diagonals.
- At least *10* gadolinia rods must be located in rows 2 and 9 and in columns 2 and 9 of the assembly and cannot be immediately adjacent to another one of the *10* gadolinia rods, however diagonally adjacent is permitted.
- Polyethylene shipping shims may be inserted between the fuel rods up to a maximum volume fraction of 0.14 averaged over the void volume of the assembly.
- An additional upper tie plate shipping shim may be added between the upper tie plate and the fueled region. This upper tie plate shim may consist of a maximum of 345 g plastic or plastic composite.

Appendix 6I describes the criticality analyses for Category 9, 10x10 fuel assemblies to be shipped in SP-1, SP-2 or SP-3 packagings.

6.3.10 Low Enriched Gadolinia Free 10x10 (Category 10) ATRIUM™ Fuel Assemblies

Parameter	Value
Assembly size	5.0 inch x 5.0 inch (maximum)
Fuel rod array in bundle	10x10
Fuel length	174 inches (maximum)
Enrichment of any pellet in the assembly	2.3 *wt.* % U-235 (maximum)
Clad thickness	Not restricted
Pellet diameter	0.30 inch (minimum); 0.3957 inch (maximum)
Rod pitch	0.510 inch (nominal)
Fuel density	98.0% TD (maximum)
UO_2 - Gd_2O_3 rods	0 (minimum)
Gd_2O_3 content	0.0 *wt.* % nominal (minimum)
Water rods	Center 3x3 rods (minimum)

- Polyethylene shipping shims may be inserted between the fuel rods up to a maximum volume fraction of 0.14 averaged over the void volume of the assembly.

- An additional upper tie plate shipping shim may be added between the upper tie plate and the fueled region. This upper tie plate shim may consist of a maximum of 345 g plastic or plastic composite.

Appendix 6J describes the criticality analyses for Category 10, 10x10 fuel assemblies to be shipped in SP-1, SP-2 or SP-3 packagings.

7. Operating Procedures for Loading and Unloading SP-1, SP-2 and SP-3 Containers

7.1 *Container Handling*

Fuel assemblies and individual fuel rods are loaded for shipment into the SP-1, SP-2 and SP-3 containers in the UO2 Building in accordance with standard operating procedures. The following describes the portions of the applicable procedures pertinent to safety.

- Verify that the fuel assemblies have been completed in compliance with applicable acceptance criteria.
- Inspect fuel assemblies for cleanliness.
- Assure that the polyethylene sheath which is placed over the assembly prior to loading into containers, is open at both ends and is no longer than the assembly.
- If loose (not part of a fuel assembly) rods are to be shipped in an SP container, they must be prepared as described below.
  - Only rods containing at least 1.0 wt. % gadolinia, sheathed or unsheathed, may be shipped in the SP-1, SP-2 and SP-3 containers.
  - The rods may be shipped either in the gadolinia rod shipping container, shown in Figure 1-4 or in a product container consisting of a 5 inch schedule 40 stainless steel pipe with a screw type or flange closure. The product container must be vented if it contains material that decomposes at less than 1475 °F.
- Prior to placing fuel assemblies or fuel rods into the SP inner container, visually inspect SP inner container for overall condition including:
  - Proper container preparation (presence of a “release” sticker)
  - Handles and brackets
  - Exterior welds
  - Foam padding
  - Gasket condition
  - Cleanliness
- For fuel assemblies, raise the SP inner container to the vertical position and insert the fuel assembly with the lower tie plate inserted into the thrust block to assure proper orientation. Lower the inner container to horizontal and add shimming to prevent fuel assembly movement.
- For fuel rods, the gadolinia rod shipping container and the product container are loaded into the SP inner container while it is in the horizontal position.

- Complete an inspection to assure compliance with loading procedures for the inner SP container.
- Bolt the end cap and lid of the inner container into place.
- Inspect the outer SP-1 container for structural integrity, cleanliness, and loose material.
- Load the inner container into the outer container and shim as necessary to prevent differential movement between the containers.
- Complete a second inspection to assure compliance with the procedures for loading the inner container into the outer SP container.
- Install and bolt the outer lid into place.
- Install tamper indicating seals at each end of the outer container.
- Radioactively survey for compliance with DOT regulations and release the loaded SP container for shipment.

7.2 *Shipment Procedures*

- Affix proper warning labels to each container.
- Overcheck fuel assembly or fuel rod parameters for compliance with the shipping container NRC Certificate of Compliance requirements.
- Load, tie down, and/or shore the SP containers onto a truck and radioactively survey the truck for compliance with DOT regulations.

8. Acceptance Tests and Maintenance Program

Transnuclear's radioactive material shipping containers, including the SP-1, SP-2 and SP-3 containers, are covered by its NRC-approved quality assurance program for shipping containers. The scope of this QA program includes design, procurement, fabrication, assembly, maintenance, modification and repair of such shipping containers.

8.1 *Acceptance Tests*

Transnuclear, Inc. conducts quality inspections of SP-1 outer containers and SP inner containers prior to first use. The following steps are included in such inspections.

8.1.1 SP Inner Containers

Typical Characteristic Inspected	Typical Inspection Method
• Proper marking, general cleanliness, rust, cracks, and dents	Visual
• Cover and end pieces for fit and function	Visual
• Container dimensions	Measurements, based on approved drawings, to assure that minimum dimensions for criticality safety are met. Assure that overall length, width and height are within tolerance.
• Weld integrity, including closure lugs and lifting handle placement and attachment	Visual
• Gasket condition	Visual
• Pressure relief valve	Check for presence and proper operation
• Vendor's certificate of compliance	Review for completeness
• Vendor's facility and QC program	*Transnuclear, Inc.* QA representative inspection

8.1.2 SP-1 Outer Containers

Typical Characteristic Inspected	Typical Inspection Method
• Proper marking, general cleanliness	Visual
• Cover/base for fit and function	Visual
• Container dimensions	Measurements, based on approved drawings, to assure minimum thickness of honeycomb material.
• Shipping damage	Visual
• Cover drain holes	Probe to make sure holes are not plugged
• Fit of inner container in outer container	Visual
• Vendor's certificate of compliance	Review for completeness

8.2 ***Maintenance Program***

The SP inner containers and SP-1 outer containers are maintained and repaired at AREVA NP. The following steps are included in the maintenance and repair done at AREVA NP.

8.2.1 SP Inner Containers

- Repair any holes.
- Replace parts or work out dents greater that ½ inch deep.
- Replace parts or do weld repair on broken welds, seams, damaged lugs, or damaged lifting handles.
- Replace pressure relief valves which don't pass test or have been damaged.
- Replace or repair gaskets which are damaged, brittle, or flat from overcompression.
- Replace ethafoam if greater that 10% of a piece is missing.
- Replace damaged or missing fasteners.
- Repaint if needed.
- Make sure container is clean and free of loose debris.

8.2.2 SP-1 Outer Container

- Replace 2x4's if cracks exceed 25% of width or are over 6 inches long.
- Replace 2x10's and 2x12's, if cracks exceed 25% of width or length of lumber.
- Replace plywood with punctures, separating laminations, or more than a square foot of missing lamination.
- Replace damaged skids.
- Replace honeycomb if greater than 10% of a piece is missing or damaged.

- Replace damaged, heavily corroded, or missing nuts, bolts, nails, and screws. Superficial surface rust is allowed on all carbon steel fasteners.
- Make sure interior is clean and dry.
- Repaint and remark as necessary.

Appendix 2A

CURRENT ENGINEERING EVALUATION OF THE RA-SERIES FUEL SHIPPING CONTAINERS

(From Appendix A to Section 2.0 of General Electric's March 17, 1992 Consolidated Application for Certificate of Compliance 4986)

APPENDIX A TO SECTION 2.0

CURRENT ENGINEERING EVALUATION OF THE RA-SERIES FUEL SHIPPING CONTAINERS

1.0 INTRODUCTION

The RA-3 all-wood outer container is a right rectangular box with nominal dimensions of 207 inches long, by 30 inches wide, by 31 inches high. It is fabricated of 1/2 inch plywood, cleated with nominal 2 inch x 4 inch studs, and mounted on a 30 inch wide base constructed of nominal 2 inch x 10 inch planks and with bolted-on skids of nominal 4 inch x 4 inch wood. The cover is secured with thirty 3/8 inch mild steel bolts. Cushioning material is provided on the sides and ends of the container to reduce vibrations and to centrally locate the inner container inside the outer wooden box. Cushioning material is Ethafoam brand closed cell foamed polyethylene, which is impervious to water, and phenolic resin impregnated paper honeycomb.

The RA outer container is used primarily to reduce shocks and vibrations to the packaged fuel assemblies encountered during normal material handling, warehousing, and transportation. In addition, the outer container provides added protection to the inner RA container if accident conditions occur.

The wood box is neither designed to survive hypothetical accident conditions without significant damage nor to prevent all damage to the inner metal container. The inner metal container, itself, is relied on to maintain containment, integrity and nuclear safety in hypothetical accident conditions, and its capability has been demonstrated.

2.0 PRIOR TEST DROPS

2.1 RA-1 Container

The General Electric RA-series fuel assembly shipping container combination of inner and outer containers has been in service since 1966 and designs have evolved to present configurations shown in Section 3.0 of this application on GE Drawings 769E229, 769E231, and 769E232.

2.1.1 RA-1 Drop Test

The initial outer wood container design (RA-1) did not have the ends bolted in place, and relied on the honeycomb material only as a filler to position the metal inner container. The RA-1 container combination was drop tested in 1966 with two simulated fuel assemblies inside the inner container.

Results of the test indicate that the end of the outer wood container completely separated from the box upon impact (see Appendix A, Photograph 1), thus subjecting the inner metal container to most of the impact energy produced. Although there was some damage to the inner container, its closure fasteners, and the simulated fuel assemblies, the test was concluded a success because the assemblies were wholly contained, fuel rods were not ruptured, and there was no significant deformation in the metal container.

2.2 RA-2 Container

The RA-2 inner and RA-3 outer container design revisions strengthened both inner and outer containers. The RA-2 inner containers used higher strength bolts (ASTM A-354-BD) to secure the end cap and the end cap was lengthened by 4 inches. Conservative engineering calculations were used to justify the need for strong bolts in the end cap. The RA-3 outer container changes included:

- The use of 3/8 inch diameter bolts and nuts to secure the end panels to the wood box, in addition to the nailed construction used in the RA-1 design, to improve the impact strength of the box.
- Replacing the honeycomb in the ends of the container with a honeycomb having a compressive strength of 290 psi, which engineering calculations showed to reduce the impact velocity to zero.

2.2.1 RA-2 Drop Test

The RA-2 inner/RA-3 outer container was drop tested on March 24, 1974, (see Appendix A, Photograph 2) with the

RA-2 inner container modifications mentioned above and the outer container with the 110 psi honeycomb, and nailed and bolted end panels.

Results of the test showed that the bolted end of the box did not separate completely from the outer wooden container (see Appendix A, Photograph 3). There was some damage to the end cap and fuel assembly tie plate handles (see Appendix A, Photographs 4 and 5). This was also concluded to demonstrate a successful test.

2.3 RA-3 Container

The RA-3 outer container was the same as the container described above. The RA-3 inner container utilized a longer body, and an end cap the same depth as the RA-1. ASTM A-354-BD bolts were used to secure the end cap. These were subsequently changed to mild steel bolts.

2.3.1 RA-3 Drop Test

2.3.1.1 RA-3 Inner Container With a Fiberglass Outer Container

This test was conducted in 1978. The inner container was constructed in accordance with GE Drawing No. 731E674, Revision 6, which used ASTM A-354-BD bolts for the end cap. The outer container was an experimental fiberglass design. Its contents were dummy fuel assemblies simulating the 8x8 BWR fuel assembly.

At impact, the end of the fiberglass container, a piece approximately two feet long, completely separated from the outer container allowing the inner container to impact the unyielding surface, thus absorbing nearly all the impact energy (see Appendix A, Photographs 6 and 7).

Post test inspection showed that damage to the simulated fuel assemblies or the inner container was not significantly large. Therefore, it was concluded that the test passed the acceptance criteria of 10 CFR 71.36(b), which was the regulation in effect at that time.

2.3.1.2 RA-3 Inner Container Drop Test With No Outer Container

This test was conducted in 1980. The RA-3 inner container used mild steel, plated bolts to secure the cover and the end cap. Other features were identical to those previously mentioned in this report. It was constructed in accordance with GE Drawing No. 769E231, Revision 0.

It was free dropped 30 feet, impacting at approximately the same altitude as all other tests described. The major difference with this test was that it had no outer container. The full impact on the unyielding concrete surface was absorbed by the metal inner container, the end cap and the mild steel bolts that secured the end cap and cover.

This was was concluded to have met all acceptance criteria of 10 CFR 71.36(b) which was the regulation in effect at that time.

A comprehensive report of this test, along with the other three hypothetical accident condition tests, and photographs of the entire test program was prepared, is identified and maintained in GE Packaging Engineering, Design Record File No. DRF A-00-01362, Test No. 2.

3.0 CONCLUSIONS

3.1 The bolted construction of the RA-3 outer container has improved the impact resistance of the design. This was evident by the 1974 RA-2/RA-3 test.

3.2 The RA-3 outer container does not need to maintain complete integrity in the drop test. The RA-2/RA-3 test in 1974 shows that RA-3 outer with 110 psi cushioning is satisfactory.

3.3 The 1980 RA-3 inner container test also demonstrates that for the RA-3 inner, no overpack is required. Engineering calculations on the impact limiting capabilities of the honeycomb show that the honeycomb can never reduce the impact velocity of the inner container to zero since the wooden end of the box will not dissipate this amount of energy without damage. It was demonstrated by the tests that the honeycomb used in the RA outer containers is stronger than the wood box. As a result, the minimum honeycomb compressive strength required must be consistent with the load carrying capabilities of the outer wood container.

3.4 Strong bolts are not required in the RA-3 inner container since the 1980 tests verified that RA-3 inners with normal mild steel bolts will meet the container requirements.

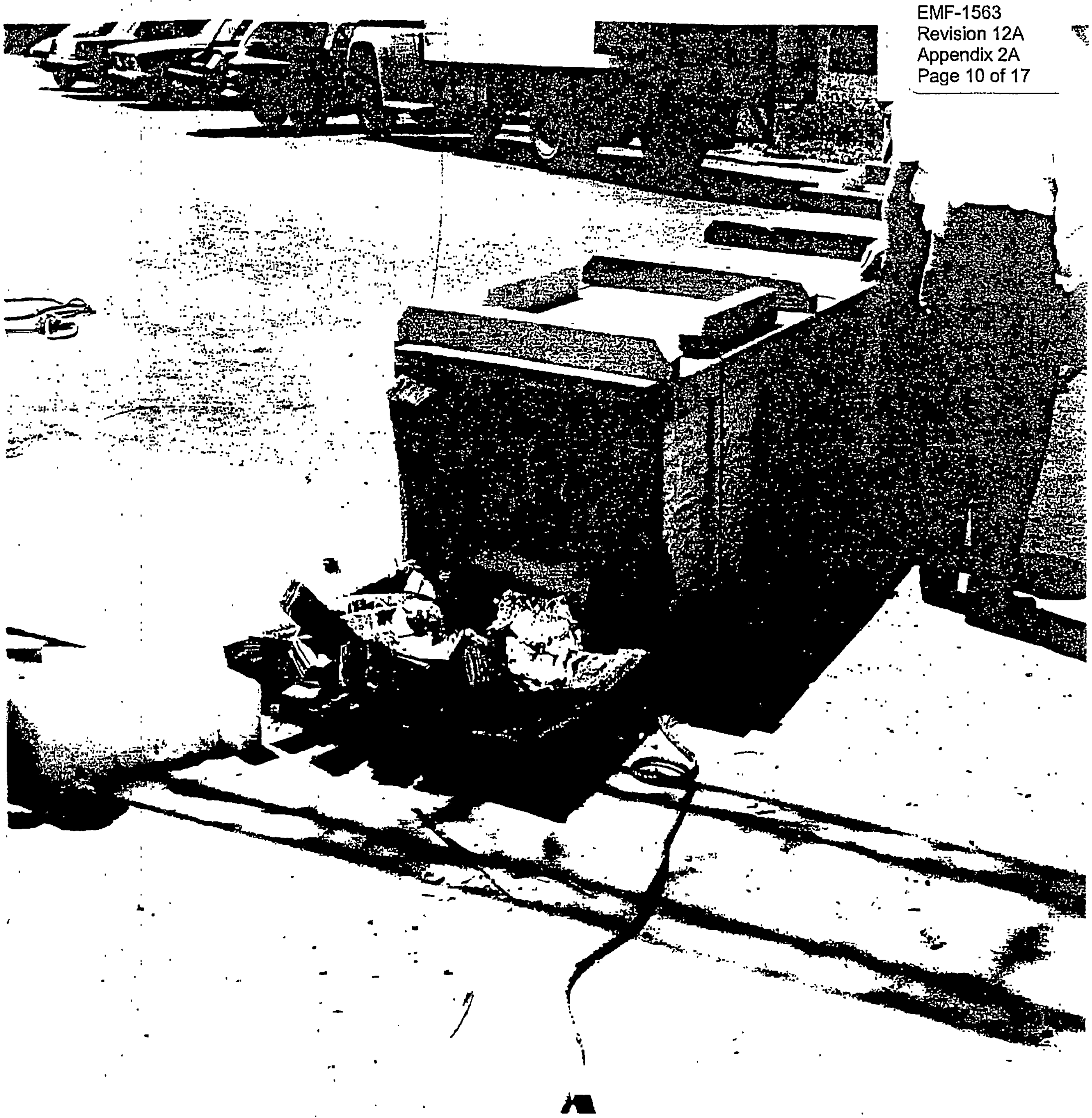
3.5 The 1974 RA-2 inner/RA-3 outer test showed that the improved outer container, having the bolted end panel and 110 psi honeycomb, provided adequate strength to contain the honeycomb and permit it to dissipate the impact energy. In addition, the damage done to the end cap was minimal (see Appendix A, Photographs 4 and 8) and not of sufficient magnitude to justify the conservative design assumptions used in earlier calculations. Based on this data, it is concluded that the high strength AT A-354-BD bolts are not required in the RA-2 end cap attachment.

SUMMARY

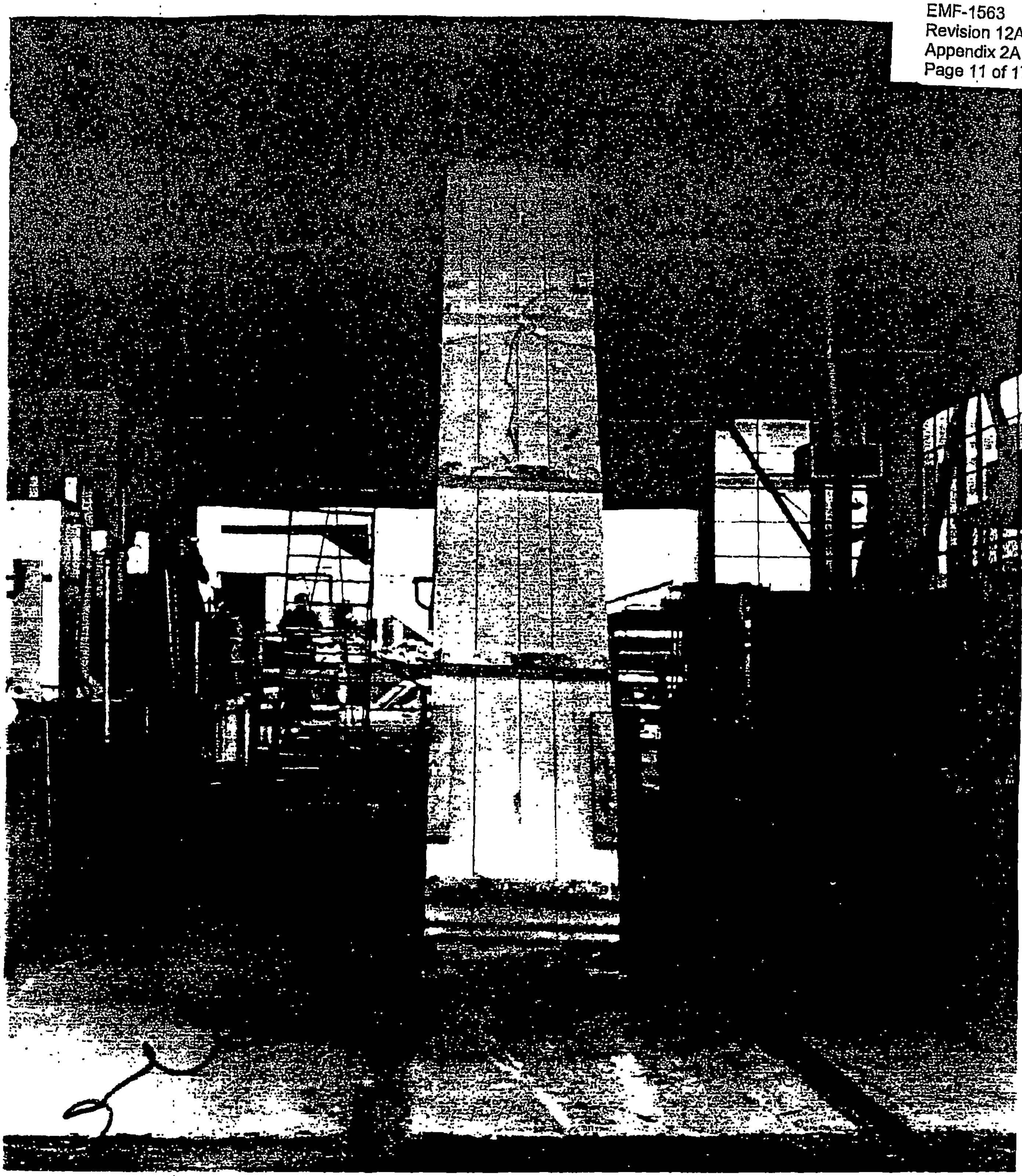
RA CONTAINER DROP TEST

Year	Outer Container	Inner Container	Honeycomb Compressive Strength	Cover Bolts	End Cap Bolts
1966	RA-1	RA-1	75 psi	Latches	Latches
1974	RA-3	RA-2	110 psi	Latches	ASTM A-354
1978	Experimental Fiberglass	RA-3	110 psi	ASTM A-307	ASTM A-354
1980	N/A See Note (1)	RA-3	N/A See Note (1)	Mild Steel	Mild Steel

Note: (1) Drop test conducted in 1980 was an RA-3 inner container only, with no outer container overpack



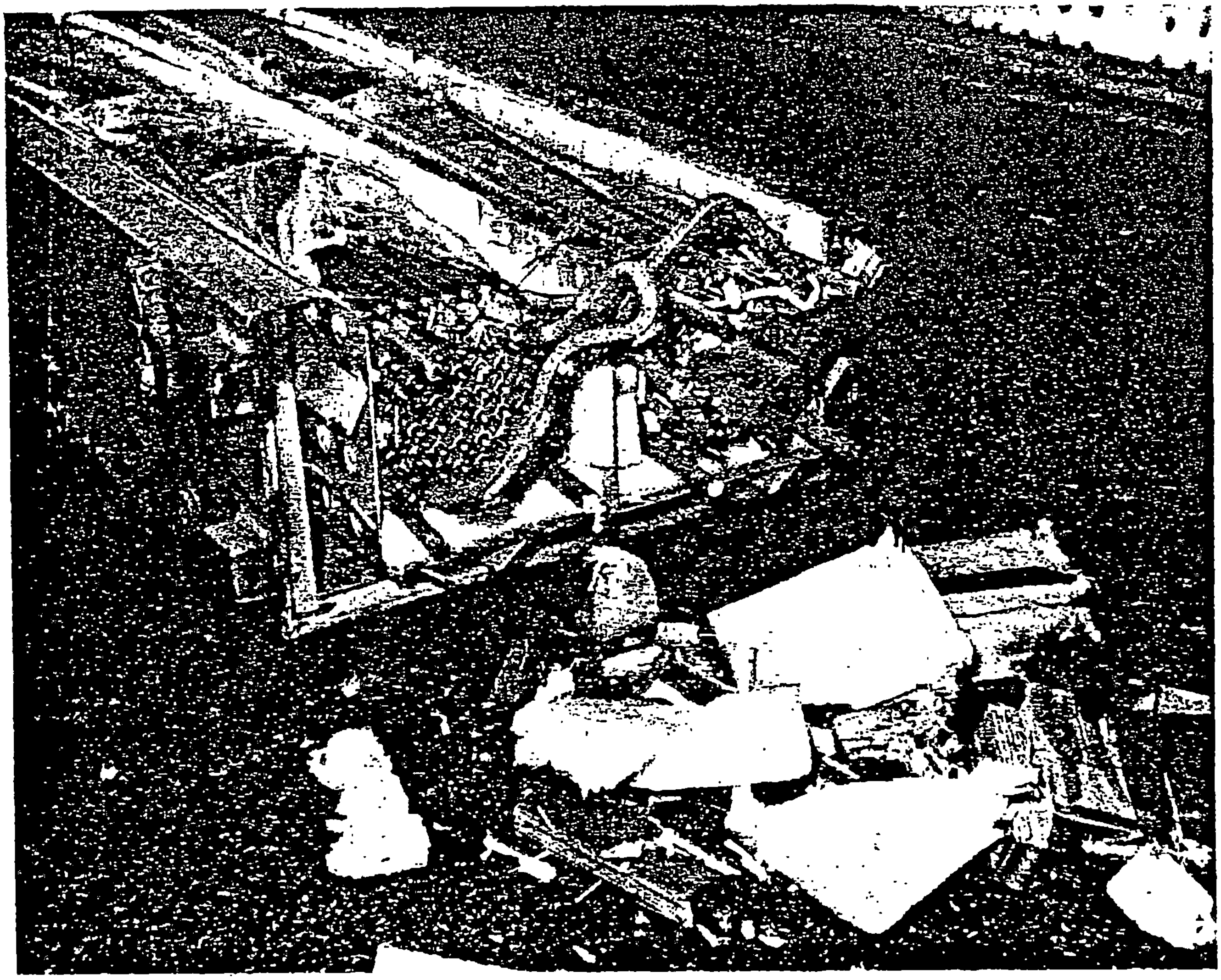
Photograph No. 1, 1966 RA-1 Drop Test Results



Photograph No. 2, 1974 RA-2/RA-3 Drop Test

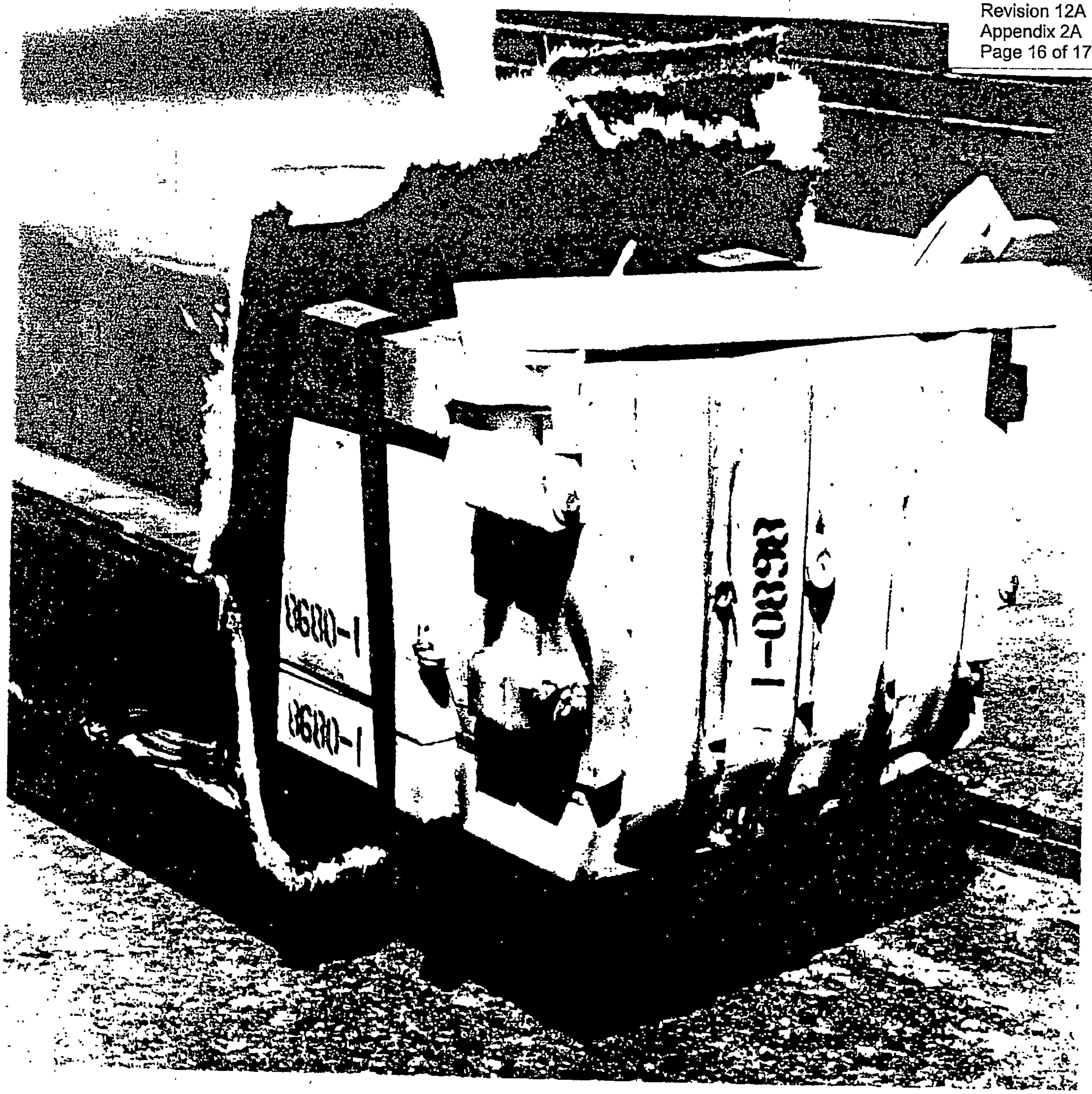
Photograph No. 3, 1974 RA-2/RA-3 Drop Test

Photograph No. 4, 1974 RA-2/RA-3 Drop Test (End Cap Damage)

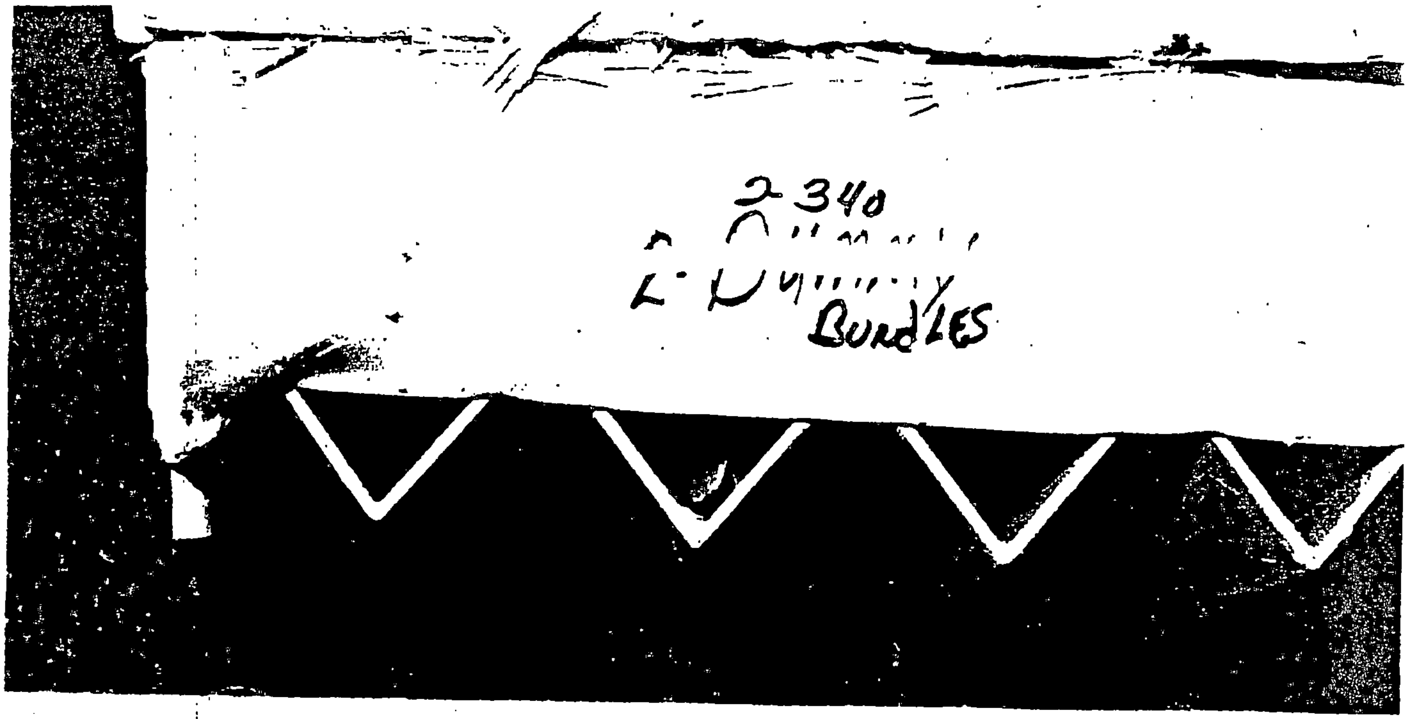


Photograph No. 5 1974 RA-2/RA-3 Drop Test (Tie Plate Damage)

Photograph No. 6, 1978 Drop Test RA-3 Inner/Fiberglass Outer



Photograph No. 7, 1978 Drop Test (End Cap Damage)



Photograph No. 8 1974 RA-2/RA-3 Drop Test (end cap)

Photograph No. 8, 1974 RA-1/RA-3 Drop Test (End Cap)

Appendix 2B

TEST REPORT FOR HYPOTHETICAL ACCIDENT CONDITION TESTS OF AN RA-3 INNER FUEL SHIPPING CONTAINER

(From Appendix B to Section 2.0 of General Electric's March 17, 1992 Consolidated Application for Certificate of Compliance 4986)

APPENDIX B TO SECTION 2.0

TEST REPORT FOR

HYPOTHETICAL ACCIDENT

CONDITION TESTS OF AN

RA-3 INNER FUEL

SHIPPING CONTAINER

DRF No. A00-01362
Test No. 2

TEST REPORT

FOR

HYPOTHETICAL ACCIDENT CONDITION TESTS OF AN

RA-3 INNER FUEL SHIPPING CONTAINER

In accordance with criteria for compliance with 10 CFR 71.36

BY

JOHN A. ZIDAK

Packaging Engineering

General Electric Company
Nuclear Energy Traffic Operation
San Jose, California

TEST REPORT

FOR

HYPOTHETICAL ACCIDENT CONDITION TESTS OF AN

RA-3 INNER FUEL SHIPPING CONTAINER

1.0 INTRODUCTION

1.1 Purpose

The purpose of the tests described was to demonstrate that the RA inner container loaded with two simulated fuel assemblies could pass the hypothetical accident condition tests described in 10 CFR 71, Appendix B, without the additional protection of the wooden RA outer container.

1.2 Test Summary

Hypothetical accident condition tests were conducted on a General Electric Model RA-3 fuel shipping container (inner container only), in accordance with 10 CFR 71 "Packaging of Radioactive Materials for Transport and Transportation of Radioactive Materials Under Certain Conditions". The tests consisted of a free drop test, puncture test, thermal test and water immersion test. The tests were conducted at General Electric Company's Wilmington Manufacturing Department facility on January 29, 1980 and June 18, 1980.

1.3 Packaging Description

The inner container of the RA-3 model packaging is a right rectangular metal box consisting of an outer shell and perforated inner basket separated by structural angle iron.

The outer shell is formed of minimum 16-gauge carbon steel plate with an integral welded end of the same material. Four angle stiffeners made of 11-gauge carbon steel, are welded on approximately four inch centers to the outer surface of the end plate. Approximate dimensions of this inner container are 11-1/4 inches high, 18-1/8 inches wide, and 182-7/8 inches long.

The inner basket is constructed of 16-gauge carbon steel plate with 3/4 inch perforations on 1-3/4 inch centers. It is riveted to the upper edge of the outer shell with 3/16 dia. blind steel rivets to form two U-shaped channels approximately 6-7/8 inch in cross-section. The channels are lined with low-density ethafoam cushioning cemented in place with perforations matching the size and locations of those in the inner basket. To support the inner basket within the outer shell, four 2.66 inch x 2.66 inch angle iron spacers made of 1/8 inch thick carbon steel are positioned longitudinally along the entire length of the body. The cover and end cap of the inner container are constructed similar to the box to provide a 2-inch annulus around the fuel, except at the ends, when the box is closed. A pressure relief valve is installed on the end cap, capable of passing

2-cfm air automatically to a 0.5-psi pressure difference between the outside and the inside of the box. A rectangular gasket of 30 to 55 durometer hollow rubber (isoprene or neoprene) provides a completed seal with the cover and end cap in place. Closure of the box is effected by 18 commercial grade, plated, 3/8 dia. mild steel bolts.

The inner container for the RA-3 packaging was constructed in accordance with the following General Electric drawings:

731E674 - Revision 7
769E231 - Revision 0

1.3.1 Test Containers

RA-3 inner container serial number I-2004 was selected from inventory for the tests. It was manufactured by Precision Metal Products, Wilmington, North Carolina in January 1980.

1.3.2 Test Load

The container was loaded with two dummy fuel assemblies that were manufactured in accordance with General Electric Company's Fuel Fabrication Operation procedures. They were essentially identical in all respects to production bundles except their rods contained lead filler rather than UO_2 pellets. The test bundles were fabricated in accordance with G.E. Fuel Production procedures.

1.3.3 Container Packing

The two dummy bundles were packed into the inner container, serial number I-2004 per Packaging Data Sheet No. PD-016H, except the paragraphs pertaining to the outer wooden container were not applicable.

2.0 ACCEPTANCE CRITERIA

The applicable criteria for acceptance are specified in 10 CFR 71.36(b).

10CFR 71.36(b): A package used for the shipment of fissile material shall be so designed and constructed and its contents so limited that if subjected to the hypothetical accident conditions specified in Appendix B of this part as the Free Drop, Puncture, Thermal, and Water Immersion conditions, in the sequence listed in Appendix B, the package would be subcritical. In determining whether this standard is satisfied, it shall be assumed that:

10CFR 71.36(b)(1): The fissile material is in the most reactive credible configuration consistent with the damaged condition of the package and the chemical and physical form of the contents;

10CFR 71.36(b)(2): Water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents; and

10CFR 71.36(b)(3): There is reflection by water on all sides and as close as is consistent with the damaged condition of the package.

3.0 TESTING

The hypothetical accident condition tests were conducted in the sequence specified in Appendix B to 10CFR71, to evaluate the ability of the package to withstand cumulative damage of the four tests. The tests, as specified in above mentioned regulation are as follows:

a) Free Drop - A free drop through a distance of 30 feet onto a flat essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected.

b) Puncture - A free drop through a distance of 40 inches striking, in a position for which maximum damage is expected, the top end of a vertical cylindrical mild steel bar mounted on an essentially unyielding horizontal surface. The bar shall be 6 inches in diameter, with the top horizontal and its edge rounded to a radius of not more than one-quarter inch, and of such a length as to cause maximum damage to the package, but not less than 8 inches long. The long axis of the bar shall be perpendicular to the unyielding horizontal surface.

c) Thermal - Exposure to a thermal test in which the heat input to the package is not less than that which would result from exposure of the whole package to a radiaiton environment of 1,475°F. for 30 minutes with an emissivity coefficient of 0.9, assuming the surfaces of the package have an absorption coefficient of 0.8. The package shall not be cooled artificially until 3 hours after the test period unless it can be shown that the temperature on the inside of the package has begun to fall in less than 3 hours.

d) Water Immersion (fissile material packages only) - Immersion in water to the extent that all portions of the package to be tested are under at least 3 feet of water for a period of not less than 8 hours.

3.1 Test Procedure

3.1.1 Free Drop

The top edge of end which has the bolted end cap was established to be the surface most vulnerable to produce a failure of the closure. The container was oriented such that its attitude at impact was about 25° from vertical and would impact at the cover/end cap interface; this attitude was maintained through the use of guying lines attached to the containers.

The container was raised by a crane to a 30 foot height at approximately 25° angle as shown in Photograph No. 1. The height was determined by a measure weighted cord attached to the container. The quick release mechanism was activated and the container fell free 30 feet (Photograph No. 2) impacting at the predetermined angle and point of impact (see Photographs No. 3 and 4), onto a flat reinforced concrete pad.

Results

Damage was confined to the impacted area. End of the container was damaged and one of the 14 cover bolts broke loose (Photographs No. 5 and 6): however, the remaining 13 cover bolts and the 4 on the end cap held the cover and end cap securely in place as evidenced by Photographs No. 3, 4 and 5.

3.1.2 Puncture Test

The container was free dropped through a distance of 40 inches, striking the top end of a vertical steel bar mounted on a reinforced concrete pad. (See Photograph No. 9). The bar was fabricated per the requirements of 10CFR71 (Appendix B).

A vertical drop with the package impacting on the 16-gauge container bottom equidistant from both ends was considered the most vulnerable orientation to puncture.

Results

The container was indented as seen in Photographs No. 8, 9 and 10, but there was no puncture. These photographs, as well as No.'s 13 and 14 indicate that the container was bowed several inches and still remained intact.

After completion of the puncture test, the cover and end cap were removed and a visual inspection of the fuel bundles revealed one broken fuel spacer and deformation of the upper tie plate handle, Photographs 11 and 12. There was no indication of fuel rod rupture as was substantiated by the Fuel Quality Control Engineering report dated August 11, 1980 (see Appendix 1).

3.1.3 Thermal Test

A Thermal Test of Container No. I-2004 followed the 30 foot free drop and puncture tests. The thermal test conducted required exposure to an environment of 1,475° minimum for a period of 30 minutes. Since an actual gasoline fire with open flames provides the most realistic means of satisfying the requirements of 10CFR71 thermal test, this method was chosen for the RA-3 inner container test.

Test set-up as shown in Fig. 1 was used. The gasoline and water supplies were located 100 feet from the fire pan. A thermocouple mounted on the closure adjacent to the slight opening of the container lid monitored the flame temperature using a Honeywell Model R7353A Dail-O-Troll, Serial No. 7812-3849, which was calibrated using a West millivolt pot that has traceability to the National Bureau of Standards.

A rectangular, steel fire pit with the container mounted 2 feet above the surface allowed for approximately 2 feet of flames around all sides of the container. By using the open gasoline fire, the emissivity and absorbtion coefficients were in accordance with those specified in 10CFR71, Appendix B.

3.1.3.1 Test Procedure

Approximately 400 gallons of water were fed into the pit resulting in a water level of 5 inches. Approximately 50 gallons of gasoline were then fed into the steel fire pit to form a layer of fuel about one inch deep on top of the water surface.

After ignition, (see Photograph No. 15) the fuel and water supplies were turned on and manually controlled to one gallon per minute of water and 15 GPM of fuel to maintain a fire that completely enveloped the RA-3 inner container. Photographs No. 16 through 23 are random photographs taken during the test. The temperature measured on the surface of the test container increased rapidly to 1,475°F. (Photographs 24, 25 and 26) and exceeded that throughout the test with a maximum temperature of 1,640°F. being reached. The full fire test continued for 30 minutes, burning 500 gallons of fuel during that period.

Results

Preliminary visual inspection after the thermal test showed no significant damage to the container, its cover or end cap that would affect criticality safety considerations. It was also noted that the intense heat of the fire and the weight of the dummy bundles straightened the RA container that was bowed several inches after the puncture test. (Compare Photographs 13 and 14 with Photographs 27 and 28.)

3.1.4 Water Immersion Test

After the fire test, container no. I-2004 with the two dummy bundles was allowed to cool down for the prescribed period of time, and then placed in the water immersion pit (see Photographs 29 and 30) under 3-1/2 feet of water. It remained submerged for 8 hours.

Results

Water leaked into the container since the gasket was consumed during the fire test. The presence of water in the container for 8 hours caused no undue affect on safety since criticality analysis took this into account. And finally, the presence of water for 8 hours caused no damage to the fuel rods, as evidenced by the Quality Control report.

3.1.5 Post Test Inspection

Following immersion as described, the container was opened and inspected. There was no physical damage to the rods in the dummy bundles, as was reported in the Fuel Quality Control Engineering report dated August 11, 1980 (Appendix 1).

4.0 CONCLUSION

Hypothetical accident condition test specified in 10CFR71, Appendix B, have been conducted, witnessed by Quality Control Engineering and have passed the acceptance criteria.

The General Electric Model No. RA-3 metal inner fuel shipping container with two dummy fuel bundles has been subjected to the hypothetical accident conditions specified in Appendix B of 10CFR71: the Free Drop, Puncture, Thermal, and Water Immersion tests, in the sequence specified by the regulation.

It is concluded that the RA-3 inner container has successfully passed the acceptance criteria due to the following:

4.1 The cover and end cap remained intact. There was one bolt failure in the cover, but 13 bolts are more than adequate to secure the cover. All four end cap bolts remained intact. Therefore, the contents would be contained inside the package.

4.2 There were no ruptured fuel rods. Therefore, the fuel pellets would be contained inside the rods.

4.3 There was no significant deformation to the container externally, the end cap or the inside angle spacers, and the basket that supports the fuel. Even though the container was bowed after the Puncture test, the angle spacers in the container maintained the spacing required so that criticality safety considerations were not affected.

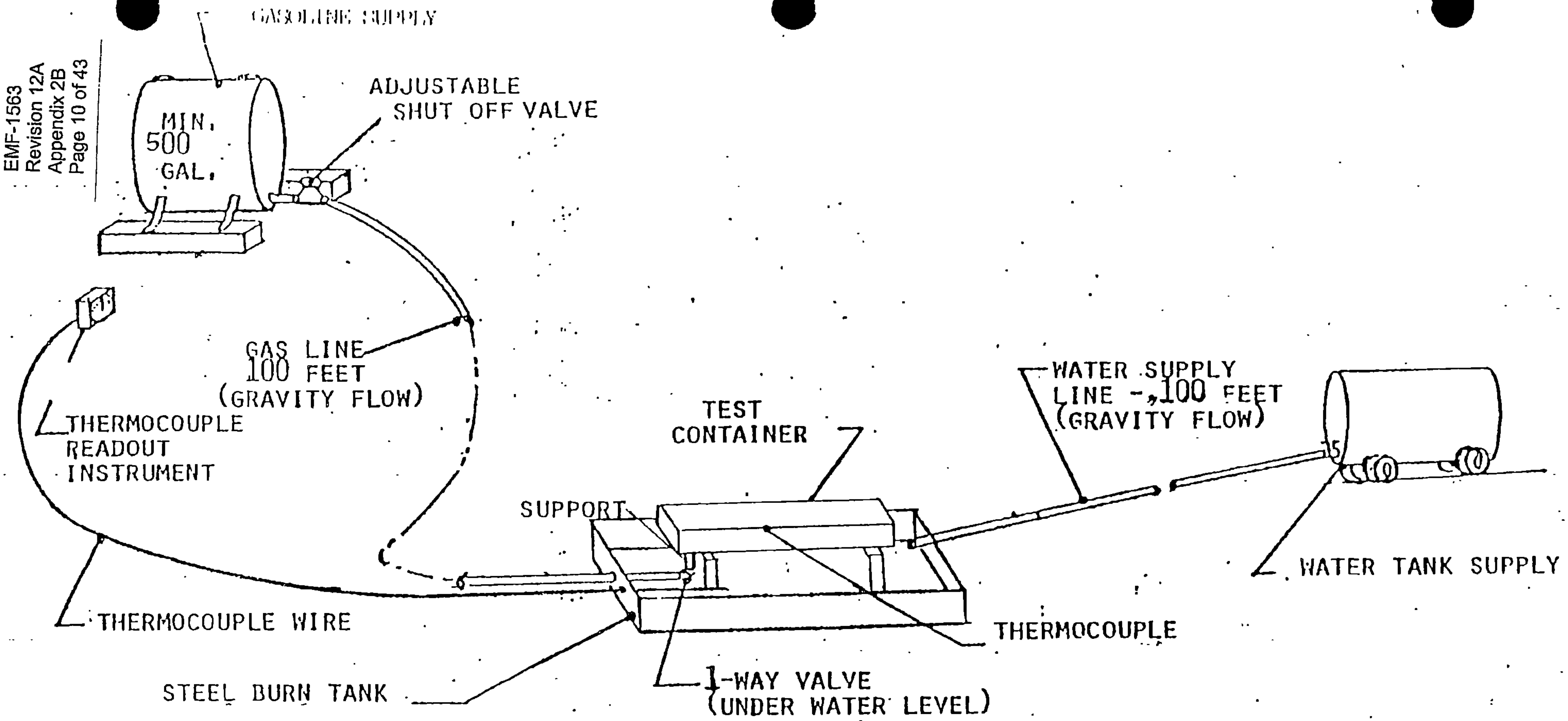


FIGURE 1
THERMAL TEST SETUP

DRF No. A00-01362
Test No. 2

TEST REPORT

FOR

HYPOTHETICAL ACCIDENT CONDITION TESTS OF AN

RA-3 INNER FUEL SHIPPING CONTAINER

In accordance with criteria for compliance with 10 CFR 71.36.

BY

JOHN A. ZIDAK

Packaging Engineering

General Electric Company
Nuclear Energy Traffic Operation
San Jose, California

TEST REPORT
FOR
HYPOTHETICAL ACCIDENT CONDITION TESTS OF AN
RA-3 INNER FUEL SHIPPING CONTAINER

1.0 INTRODUCTION

1.1 Purpose

The purpose of the tests described was to demonstrate that the RA inner container loaded with two simulated fuel assemblies could pass the hypothetical accident condition tests described in 10 CFR 71, Appendix B, without the additional protection of the wooden RA outer container.

1.2 Test Summary

Hypothetical accident condition tests were conducted on a General Electric Model RA-3 fuel shipping container (inner container only), in accordance with 10 CFR 71 "Packaging of Radioactive Materials for Transport and Transportation of Radioactive Materials Under Certain Conditions". The tests consisted of: a free drop test, puncture test, thermal test and water immersion test. The tests were conducted at General Electric Company's Wilmington Manufacturing Department facility on January 29, 1980 and June 18, 1980.

1.3 Packaging Description

The inner container of the RA-3 model packaging is a right rectangular metal box consisting of an outer shell and perforated inner basket separated by structural angle iron.

The outer shell is formed of minimum 16-gauge carbon steel plate with an integral welded end of the same material. Four angle stiffeners made of 11-gauge carbon steel, are welded on approximately four inch centers to the outer surface of the end plate. Approximate dimensions of this inner container are 11-1/4 inches high, 18-1/8 inches wide, and 182-7/8 inches long.

The inner basket is constructed of 16-gauge carbon steel plate with 3/4 inch perforations on 1-3/4 inch centers. It is riveted to the upper edge of the outer shell with 3/16 dia. blind steel rivets to form two U-shaped channels approximately 6-7/8 inch in cross-section. The channels are lined with low-density ethafoam cushioning cemented in place with perforations matching the size and locations of those in the inner basket. To support the inner basket within the outer shell, four 2.66 inch x 2.66 inch angle iron spacers made of 1/8 inch thick carbon steel are positioned longitudinally along the entire length of the body. The cover and end cap of the inner container are constructed similar to the box to provide a 2-inch annulus around the fuel, except at the ends, when the box is closed. A pressure relief valve is installed on the end cap, capable of passing

2-cfm air automatically to a 0.5-psi pressure difference between the outside and the inside of the box. A rectangular gasket of 30 to 55 durometer hollow rubber (isoprene or neoprene) provides a completed seal with the cover and end cap in place. Closure of the box is effected by 1S commercial grade, plated, 3/8 dia. mild steel bolts.

The inner container for the RA-3 packaging was constructed in accordance with the following General Electric drawings:

731E674 - Revision 7
769E231 - Revision 0

1.3.1 Test Containers

RA-3 inner container serial number I-2004 was selected from inventory for the tests. It was manufactured by Precision Metal Products, Wilmington, North Carolina in January 1980.

1.3.2 Test Load

The container was loaded with two dummy fuel assemblies that were manufactured in accordance with General Electric Company's Fuel Fabrication Operation procedures. They were essentially identical in all respects to production bundles except their rods contained lead filler rather than UO_2 pellets. The test bundles were fabricated in accordance with G.E. Fuel Production procedures.

1.3.3 Container Packing

The two dummy bundles were packed into the inner container, serial number I-2004 per Packaging Data Sheet No. PD-016H, except the paragraphs pertaining to the outer wooden container were not applicable.

2.0 ACCEPTANCE CRITERIA

The applicable criteria for acceptance are specified in 10 CFR 71.36(b).

10CFR 71.36(b): A package used for the shipment of fissile material shall be so designed and constructed and its contents so limited that if subjected to the hypothetical accident conditions specified in Appendix B of this part as the Free Drop, Puncture, Thermal, and Water Immersion conditions, in the sequence listed in Appendix B, the package would be subcritical. In determining whether this standard is satisfied, it shall be assumed that:

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b) Puncture - A free drop through a distance of 40 inches striking in a position for which maximum damage is expected, the top end of a vertical cylindrical mild steel bar mounted on an essentially unyielding horizontal surface. The bar shall be 6 inches in diameter, with the top horizontal and its edge rounded to a radius of not more than one-quarter inch, and of such a length as to cause maximum damage to the package, but not less than 8 inches long. The long axis of the bar shall be perpendicular to the unyielding horizontal surface.

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d) Water Immersion (fissile material packages only) - Immersion in water to the extent that all portions of the package to be tested are under at least 3 feet of water for a period of not less than 8 hours.

3.1 Test Procedure

3.1.1 Free Drop

The top edge of end which has the bolted end cap was established to be the surface most vulnerable to produce a failure of the closure. The container was oriented such that its attitude at impact was about 25° from vertical and would impact at the cover end cap interface; this attitude was maintained through the use of guying lines attached to the containers.

The container was raised by a crane to a 30 foot height at approximately 25° angle as shown in Photograph No. 1. The height was determined by a measure weighted cord attached to the container. The quick release mechanism was activated and the container fell free 30 feet (Photograph No. 2) impacting at the predetermined angle and point of impact (see Photographs No. 3 and 4), onto a flat reinforced concrete pad.

Results

Damage was confined to the impacted area. End of the container was damaged and one of the 14 cover bolts broke loose (Photographs No. 5 and 6); however, the remaining 13 cover bolts and the 4 on the end cap held the cover and end cap securely in place as evidenced by Photographs No. 3, 4 and 5.

3.1.2 Puncture Test

The container was free dropped through a distance of 40 inches, striking the top end of a vertical steel bar mounted on a reinforced concrete pad. (See Photograph No. 9). The bar was fabricated per the requirements of 10CFR71 (Appendix B).

A vertical drop with the package impacting on the 16-gauge container bottom equidistant from both ends was considered the most vulnerable orientation to puncture.

Results

The container was indented as seen in Photographs No. 8, 9 and 10, but there was no puncture. These photographs, as well as No.'s 13 and 14 indicate that the container was bowed several inches and still remained intact.

After completion of the puncture test, the cover and end cap were removed and a visual inspection of the fuel bundles revealed one broken fuel spacer and deformation of the upper tie plate handle. Photographs 11 and 12. There was no indication of fuel rod rupture as was substantiated by the Fuel Quality Control Engineering report dated August 11, 1980 (see Appendix 1).

3.1.3 Thermal Test

A Thermal Test of Container No. I-2004 followed the 30 foot free drop and puncture tests. The thermal test conducted required exposure to an environment of 1,475^{O} minimum for a period of 30 minutes. Since an actual gasoline fire with open flames provides the most realistic means of satisfying the requirements of 10CFR71 thermal test, this method was chosen for the RA-3 inner container test.

Test set-up as shown in Fig. 1 was used. The gasoline and water supplies were located 100 feet from the fire pan. A thermocouple mounted on the closure adjacent to the slight opening of the container lid monitored the flame temperature using a Honeywell Model R7353A Dail-O-Troll, Serial No. 7812-3849, which was calibrated using a West millivolt pot that has traceability to the National Bureau of Standards.

A rectangular, steel fire pit with the container mounted 2 feet above the surface allowed for approximately 2 feet of flames around all sides of the container. By using the open gasoline fire, the emissivity and absorbtion coefficients were in accordance with those specified in 10CFR71, Appendix B.

3.1.3.1 Test Procedure

Approximately 400 gallons of water were fed into the pit resulting in a water level of 5 inches. Approximately 50 gallons of gasoline were then fed into the steel fire pit to form a layer of fuel about one inch deep on top of the water surface.

After ignition, (see Photograph No. 15) the fuel and water supplies were turned on and manually controlled to one gallon per minute of water and 15 GPM of fuel to maintain a fire that completely enveloped the RA-3 inner container. Photographs No. 16 through 23 are random photographs taken during the test. The temperature measured on the surface of the test container increased rapidly to 1,475°F. (Photographs 24, 25 and 26) and exceeded that throughout the test with a maximum temperature of 1,640°F. being reached. The full fire test continued for 30 minutes, burning 500 gallons of fuel during that period.

Results

Preliminary visual inspection after the thermal test showed no significant damage to the container, its cover or end cap that would affect criticality safety considerations. It was also noted that the intense heat of the fire and the weight of the dummy bundles straightened the RA container that was bowed several inches after the puncture test. (Compare Photographs 13 and 14 with Photographs 27 and 28.)

3.1.4 Water Immersion Test

After the fire test, container no. I-2004 with the two dummy bundles was allowed to cool down for the prescribed period of time, and then placed in the water immersion pit (see Photographs 29 and 30) under 3-1/2 feet of water. It remained submerged for 8 hours.

Results

Water leaked into the container since the gasket was consumed during the fire test. The presence of water in the container for 8 hours caused no undue affect on safety since criticality analysis took this into account. And finally, the presence of water for 8 hours caused no damage to the fuel rods, as evidenced by the Quality Control report

3.1.5 Post Test Inspection

Following immersion as described, the container was opened and inspected. There was no physical damage to the rods in the dummy bundles, as was reported in the Fuel Quality Control Engineering report dated August 11, 1980 (Appendix 1).

4.0 CONCLUSION

Hypothetical accident condition test specified in 10CFR71, Appendix B, have been conducted, witnessed by Quality Control Engineering and have passed the acceptance criteria.

The General Electric Model No. RA-3 metal inner fuel shipping container with two dummy fuel bundles has been subjected to the hypothetical accident conditions specified in Appendix B of 10CFR71: the Free Drop, Puncture, Thermal, and Water Immersion tests, in the sequence specified by the regulation.

It is concluded that the RA-3 inner container has successfully passed the acceptance criteria due to the following:

4.1 The cover and end cap remained intact. There was one bolt failure in the cover, but 13 bolts are more than adequate to secure the cover. All four end cap bolts remained intact. Therefore, the contents would be contained inside the package.

4.2 There were no ruptured fuel rods. Therefore, the fuel pellets would be contained inside the rods.

4.3 There was no significant deformation to the container externally, the end cap or the inside angle spacers, and the basket that supports the fuel. Even though the container was bowed after the Puncture test, the angle spacers in the container maintained the spacing required so that criticality safety considerations were not affected.

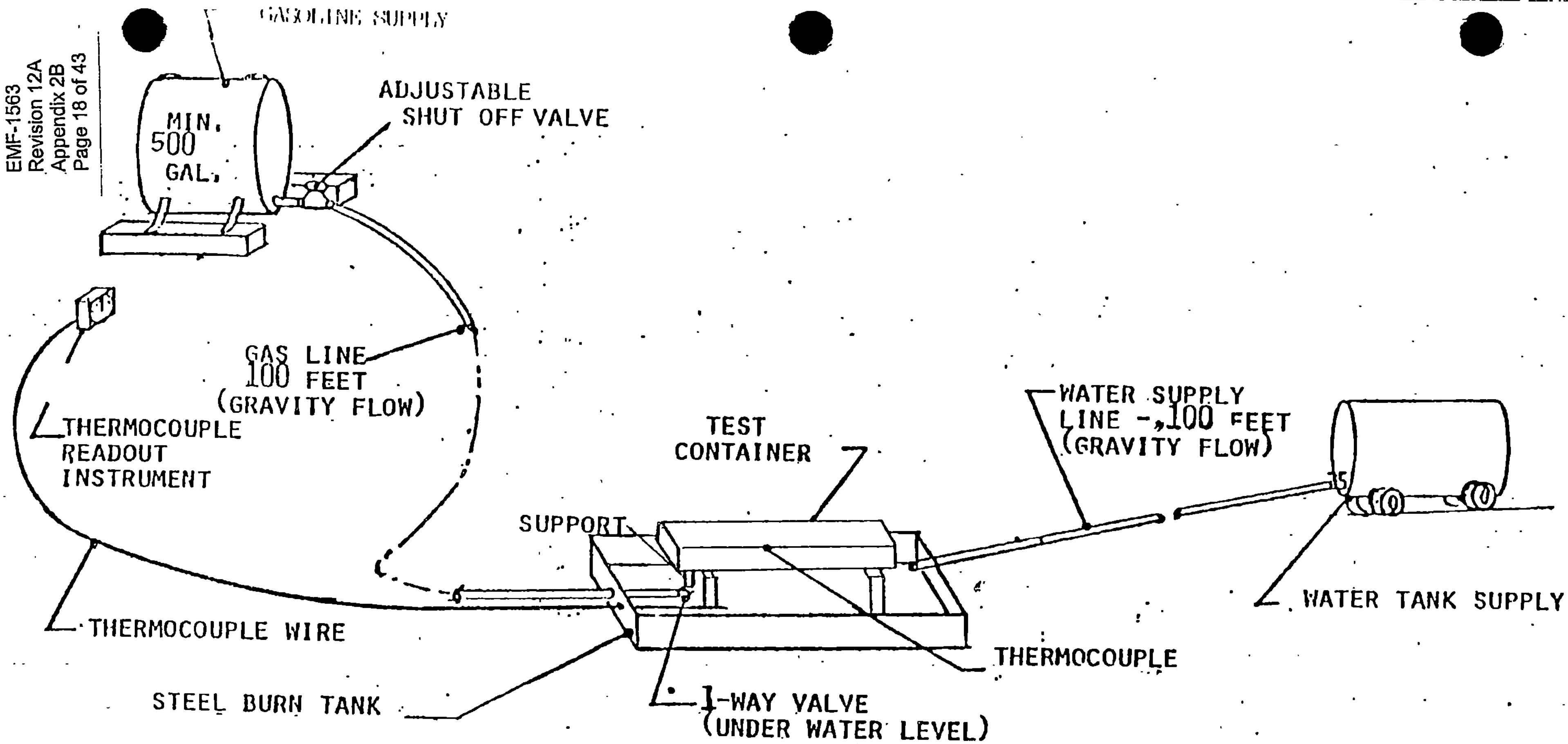


FIGURE 1

THERMAL TEST SETUP

GENERAL ELECTRIC

DIAL COMM. 8*292-6072 DATE. August 11, 1980 COPIES.

DEPT. WMD-FQCE

ADDRESS. M/C H-39 Wilmington, N.C.

SUBJECT. RA CONTAINER BURN TEST INSPECTION

[redacted]
Packaging Engineer
M/C 512, San Jose

Per your request, the RA container and dummy bundles used in the burn test on 6/18/80 were visually evaluated. Container and bundles were steam cleaned prior to inspection. Listed are my observations and comments.

A) RA container had some wrapage of metal, but no rupturing occurred.

B) All ethafoam and lid gaskets were completely destroyed.

C) Residue from plastic fuel rod separators was accumulated on lower tie plates and the lower eighteen inches of rods. (This probably occurred during lifting of RA after test.)

D) Dummy bundles show no signs of heat releated damage. (End plug welds and cladding show no signs of rupturing or heat damage.)

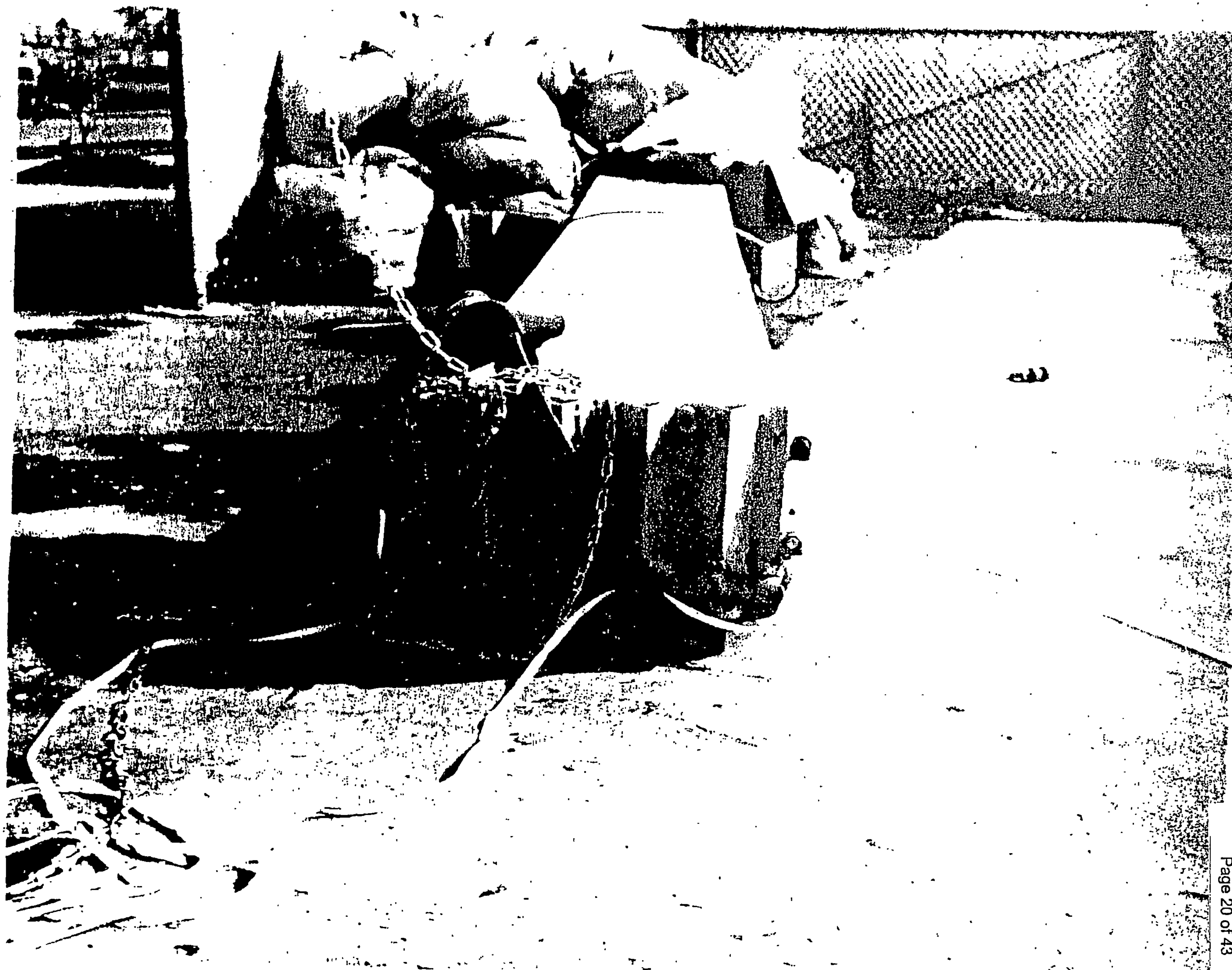
E) Cladding had smoke and carbon residue which should be cleanable, no heat deformities noted.

My observation is that there was no physical damage to rods in dummy bundles, only surface damage (residue, smoke) to bundle components as a result of ethafoam and plastic separators residue.

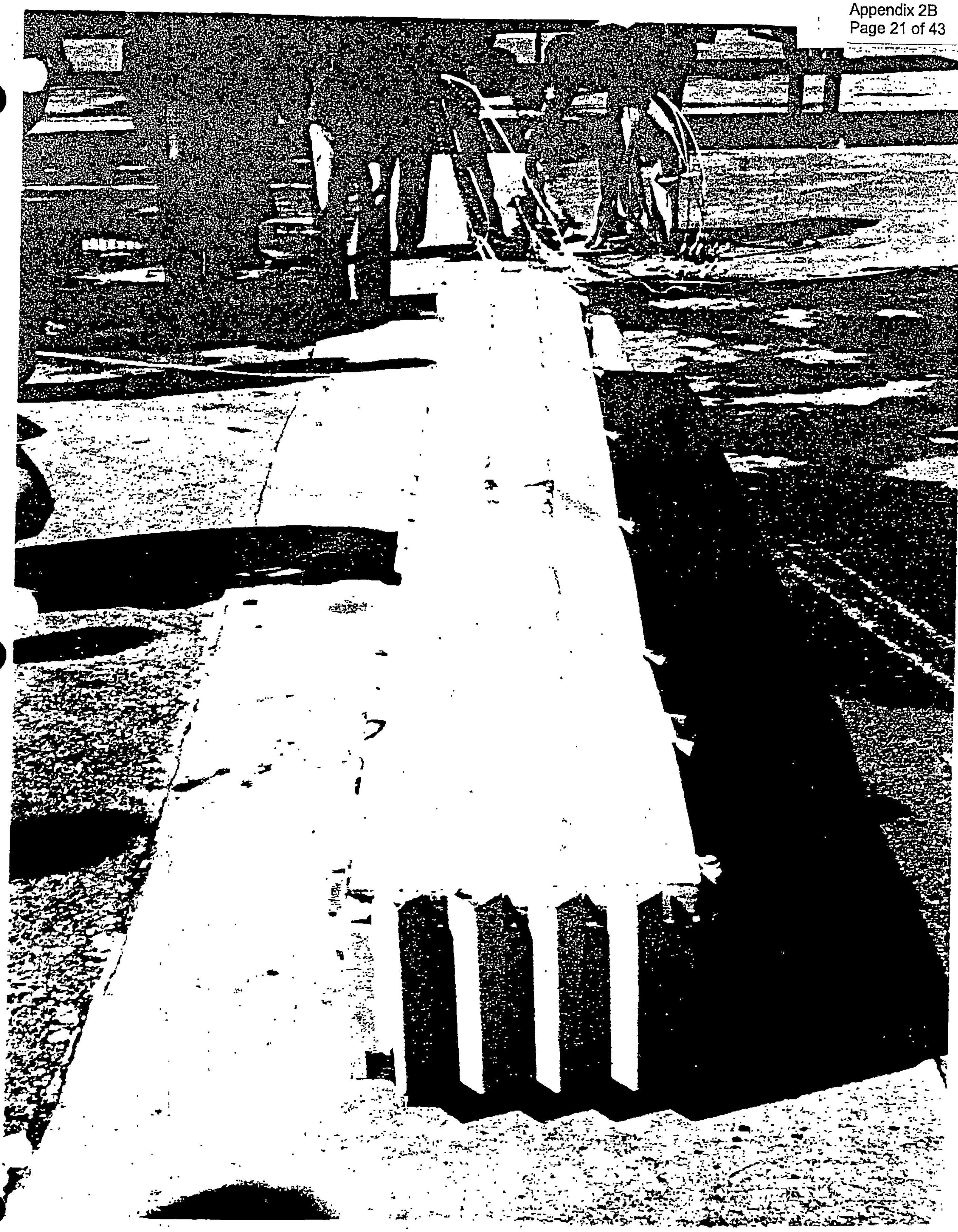
John Ragins, Specialist
Fuel Quality Control Engineering

lb

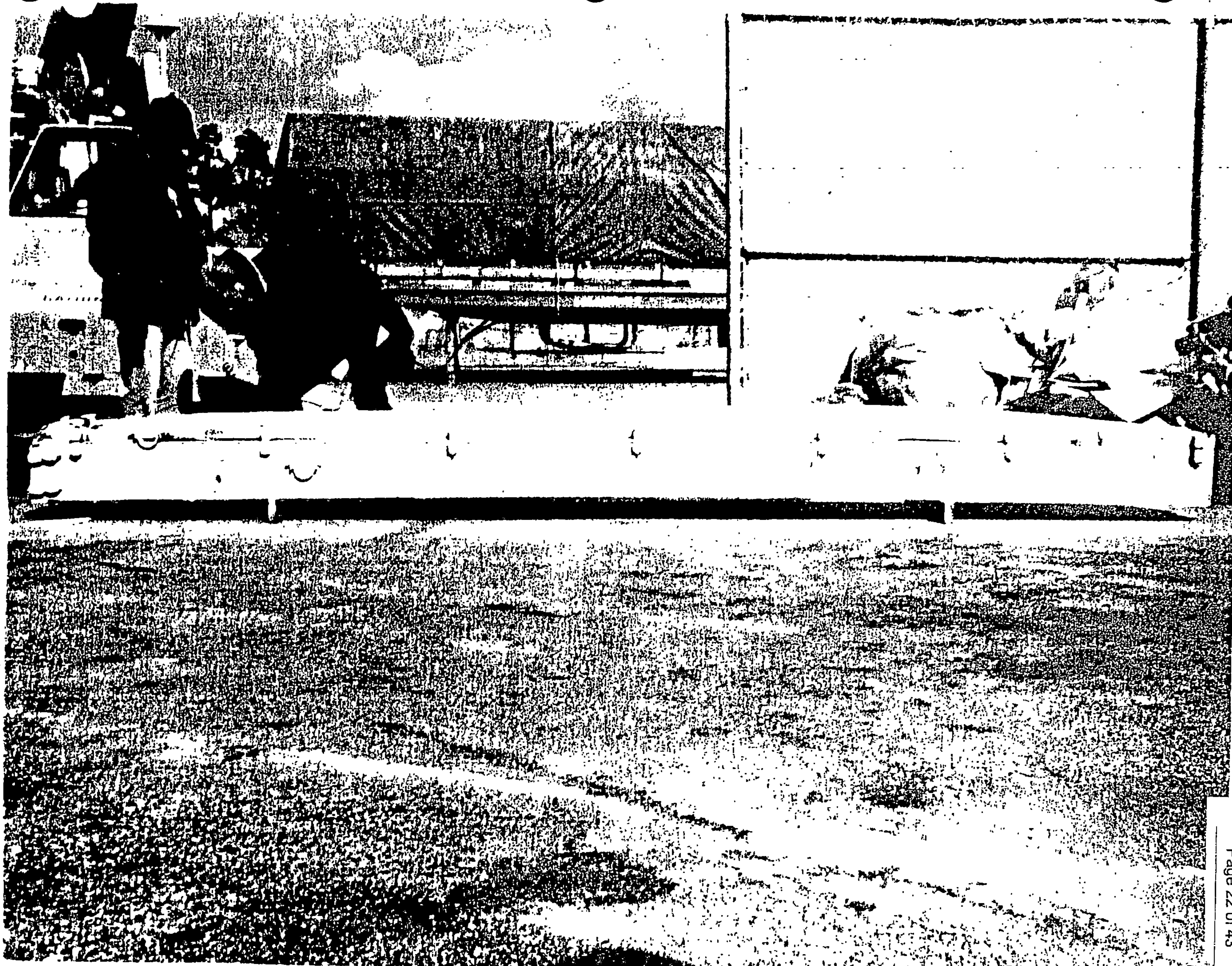
PHOTOGRAPH NO. 1: RA INNER CONTAINER RAISED TO 30 FOOT HEIGHT.



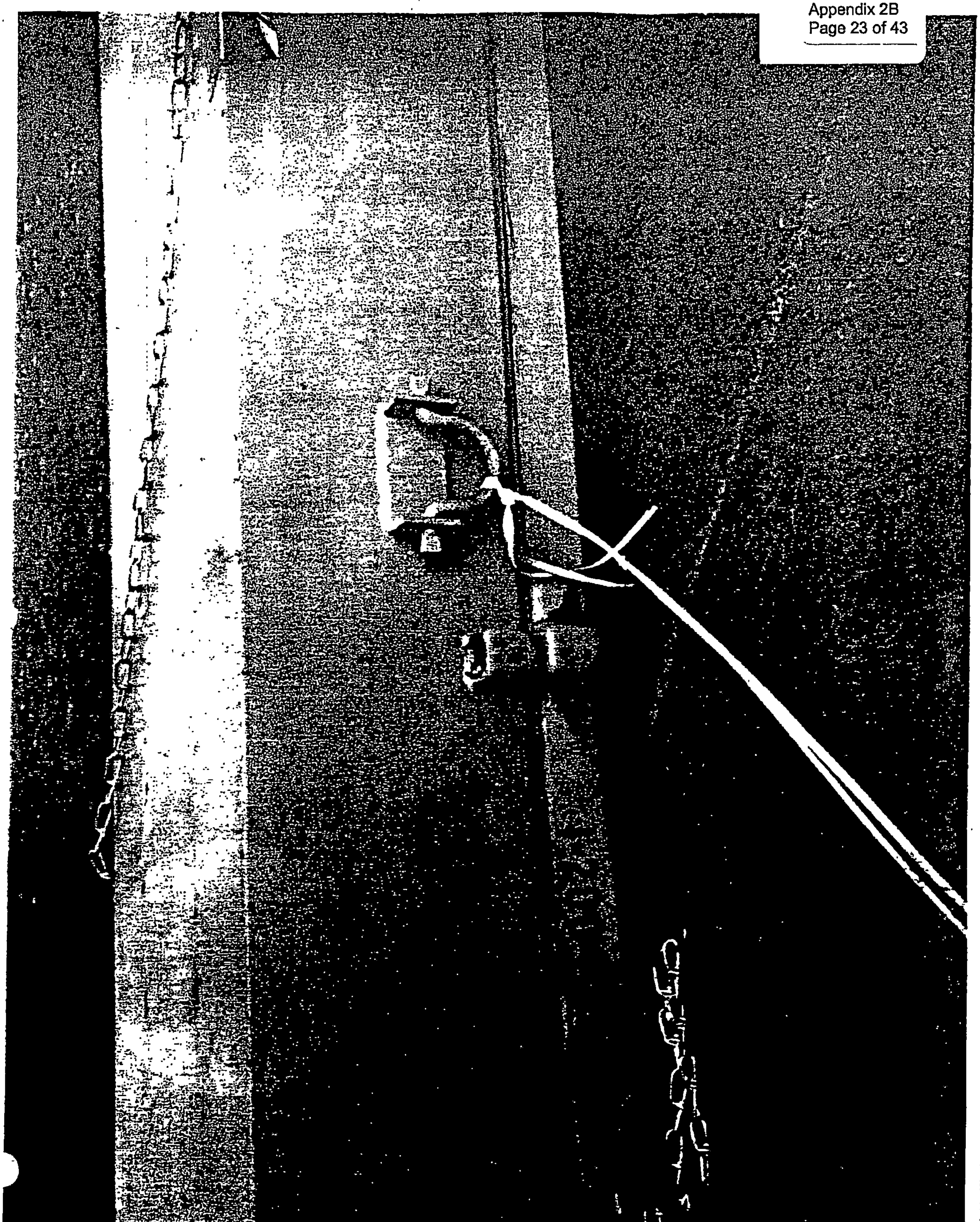
PHOTOGRAPH NO. 3: RA INNER CONTAINER AFTER 30 FOOT DROP



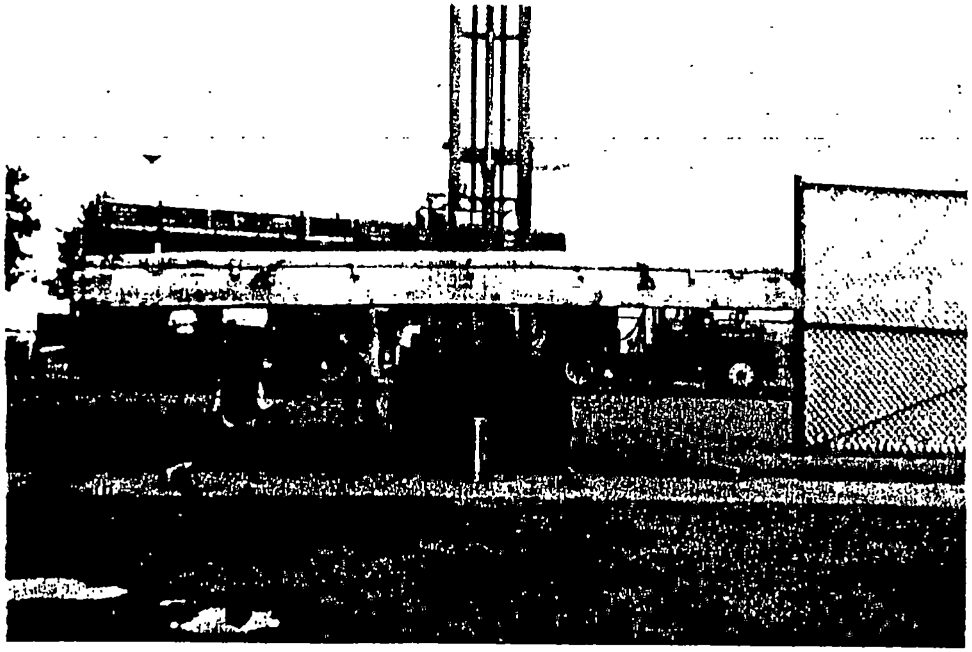
PHOTOGRAPH NO. 4: RA INNER CONTAINER AFTER 30 FOOT DROP

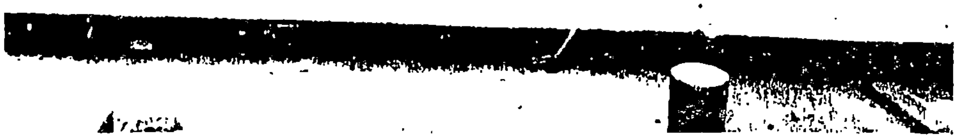


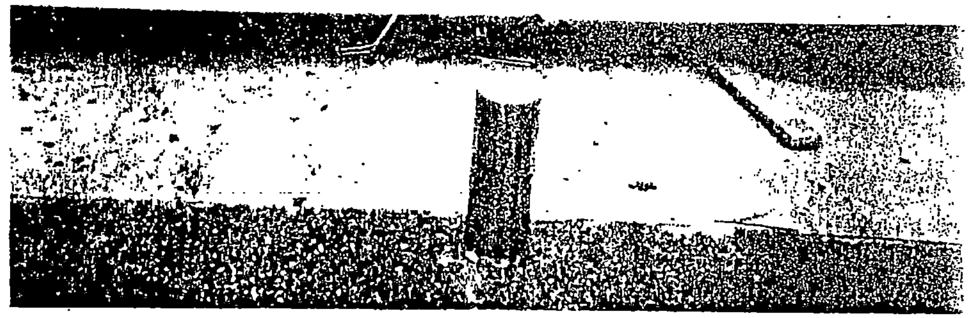
PHOTOGRAPH NO. 5: RA INNER CONTAINER AFTER 30 FOOT DROP

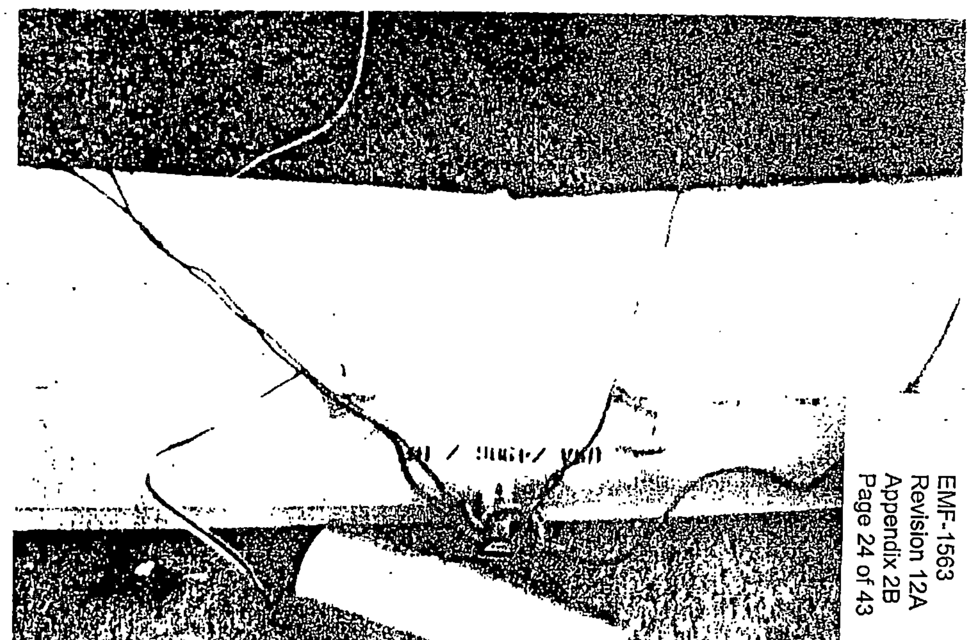


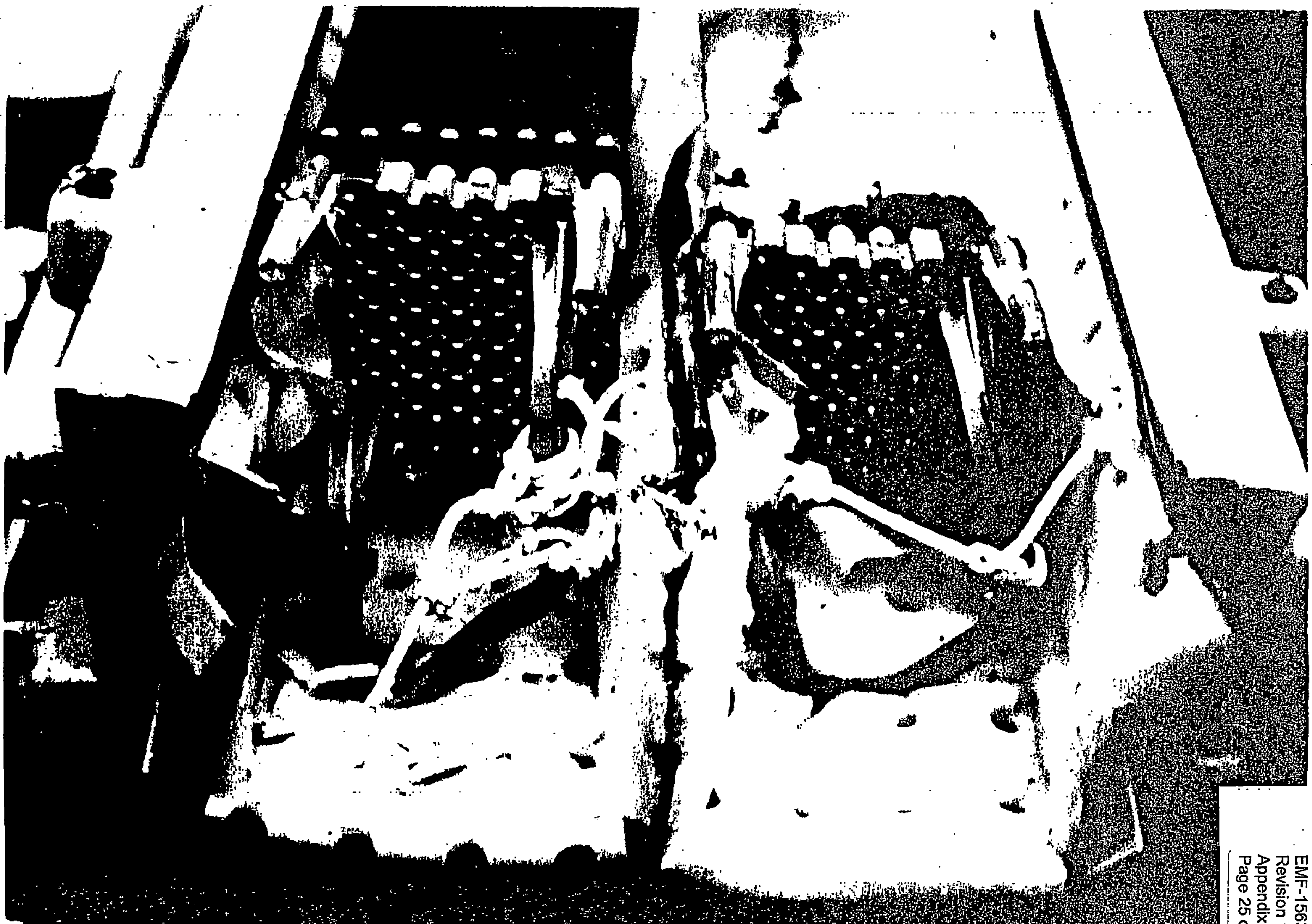
PHOTOGRAPH NO. 6: FAILED COVER BOLT



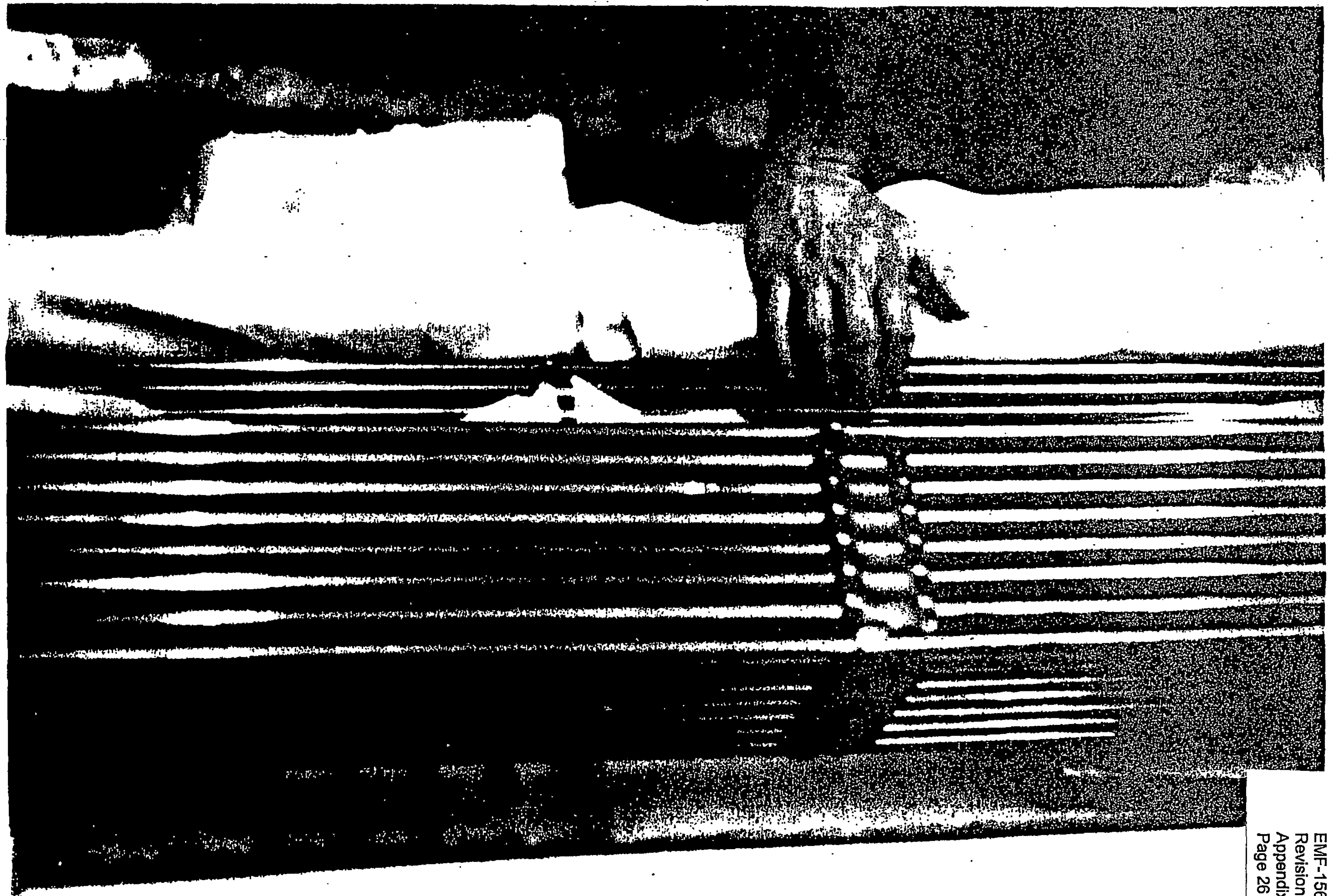




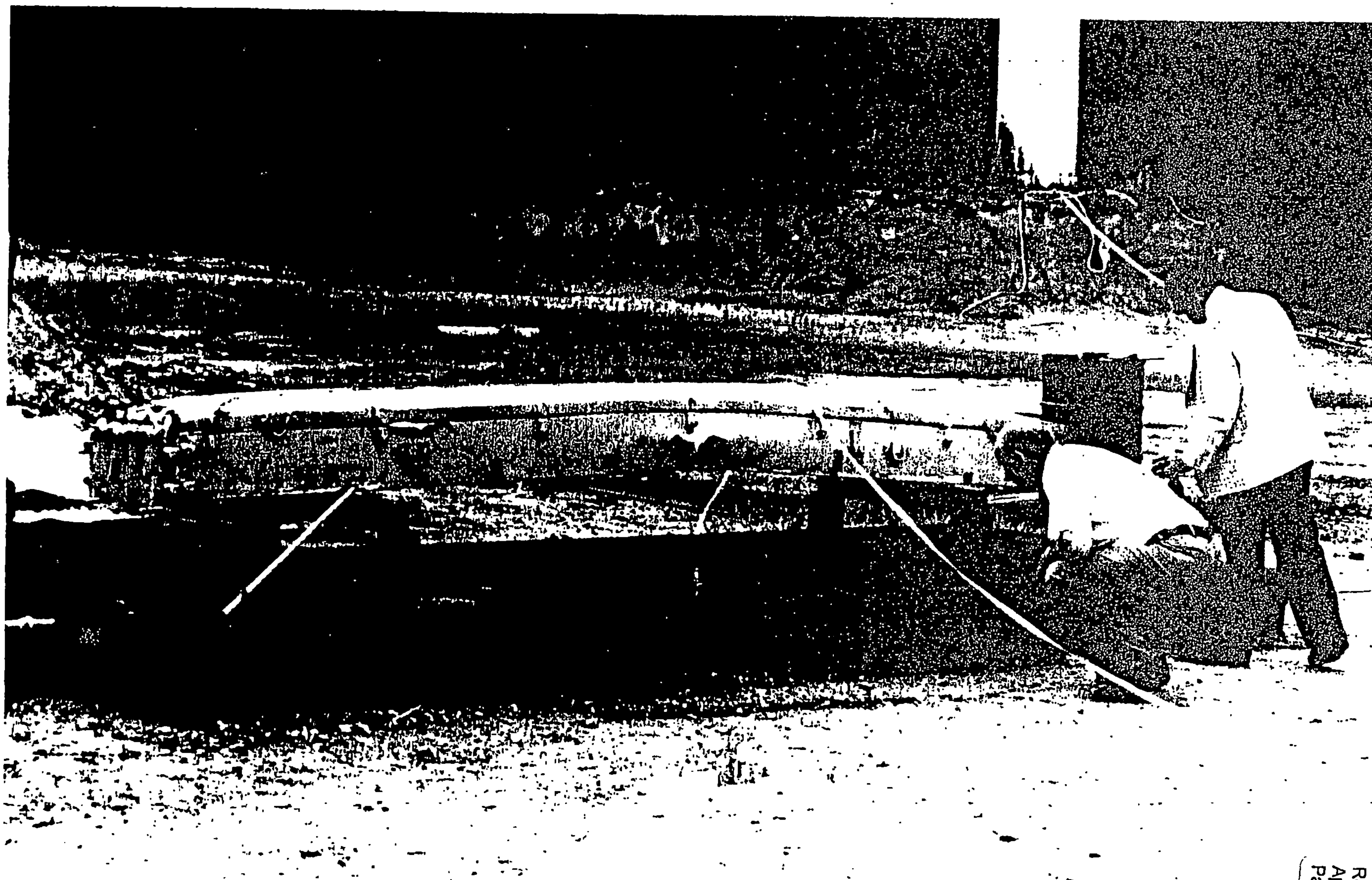




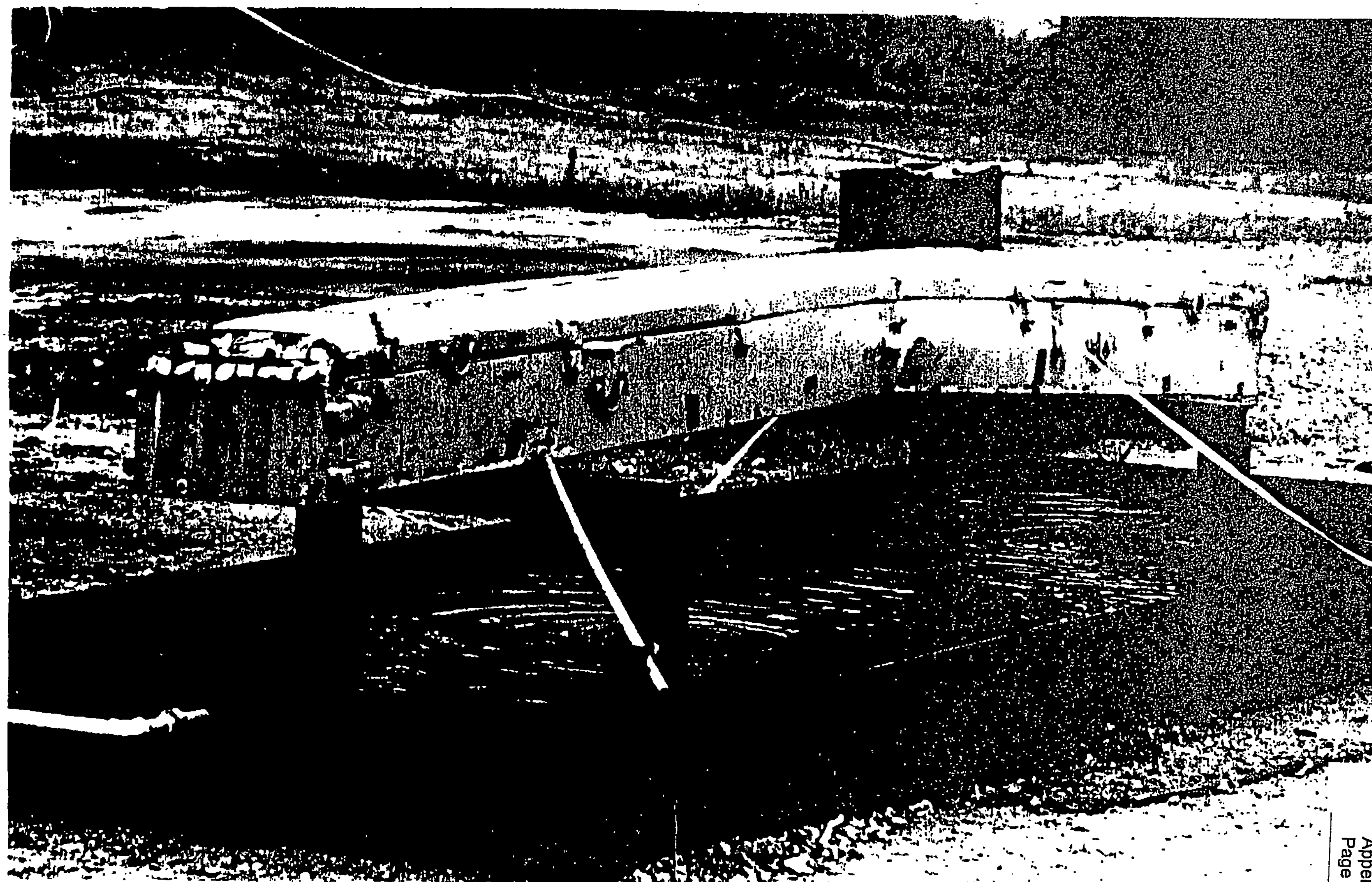
PHOTOGRAPH NO. 11 – DUMMY FUEL [illegible]



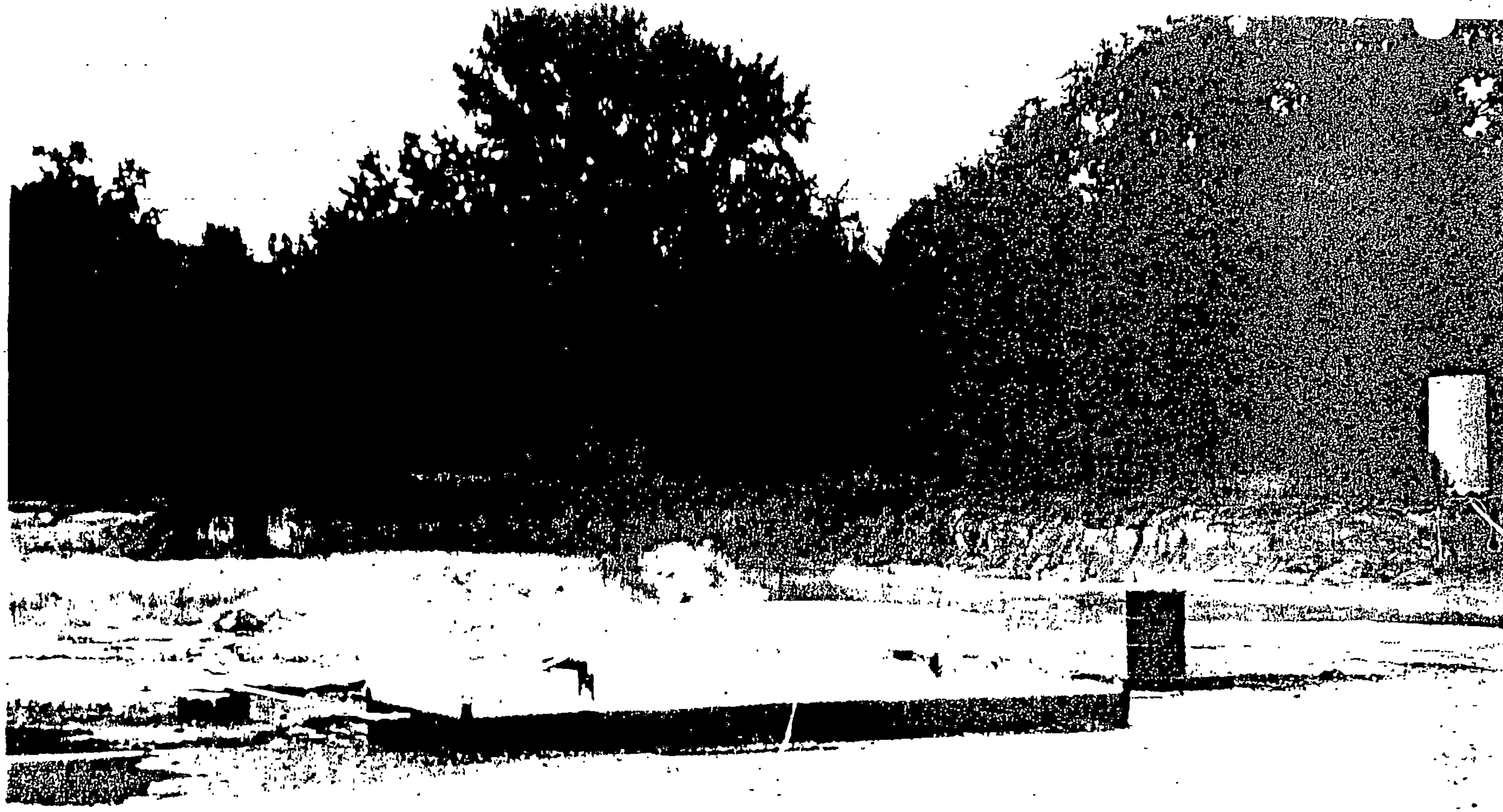
PHOTOGRAPH NO. 12: BROKEN FUEL SPACER



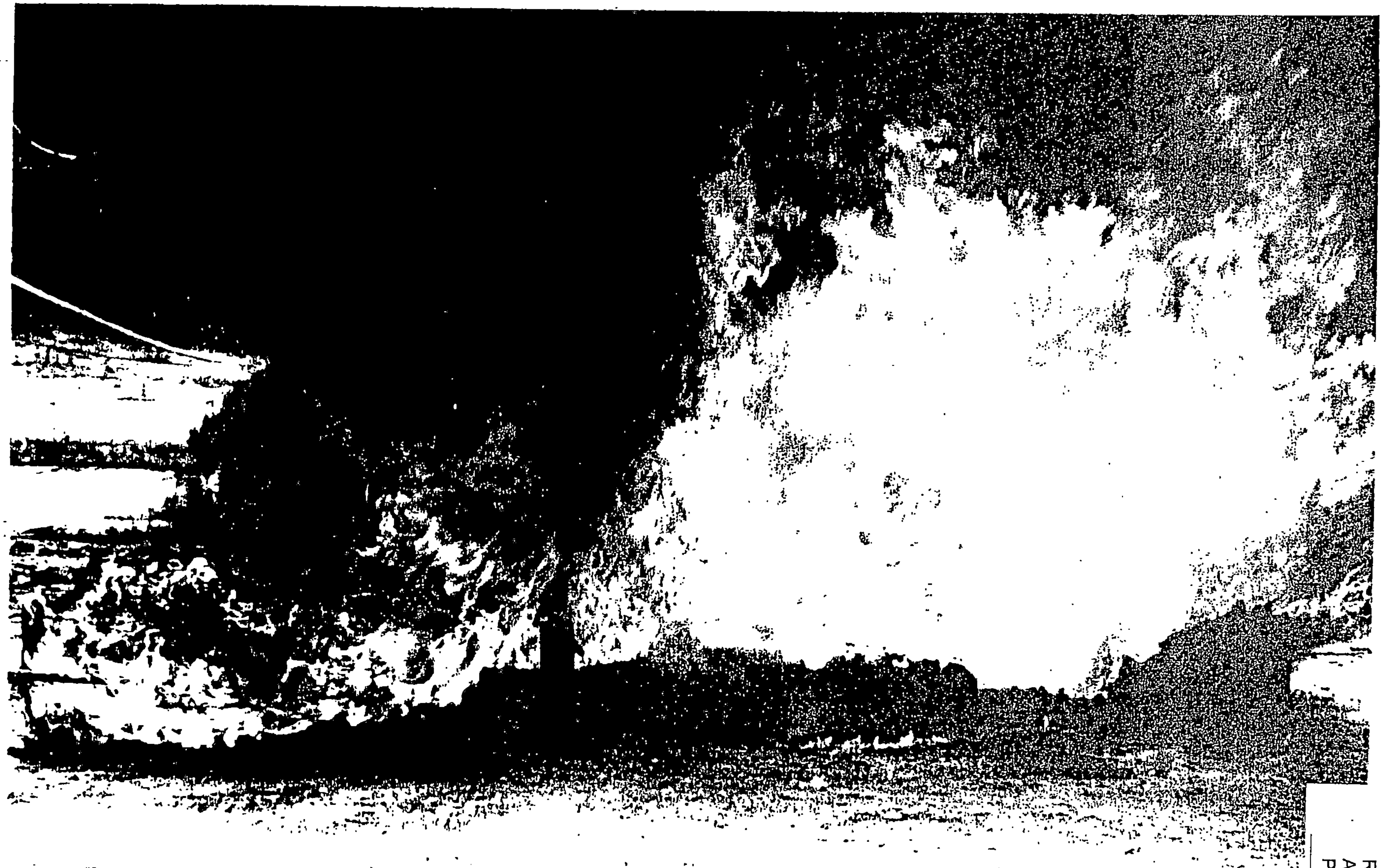
PHOTOGRAPH NO. 13: RA INNER CONTAINER PRIOR TO FIRE TEST



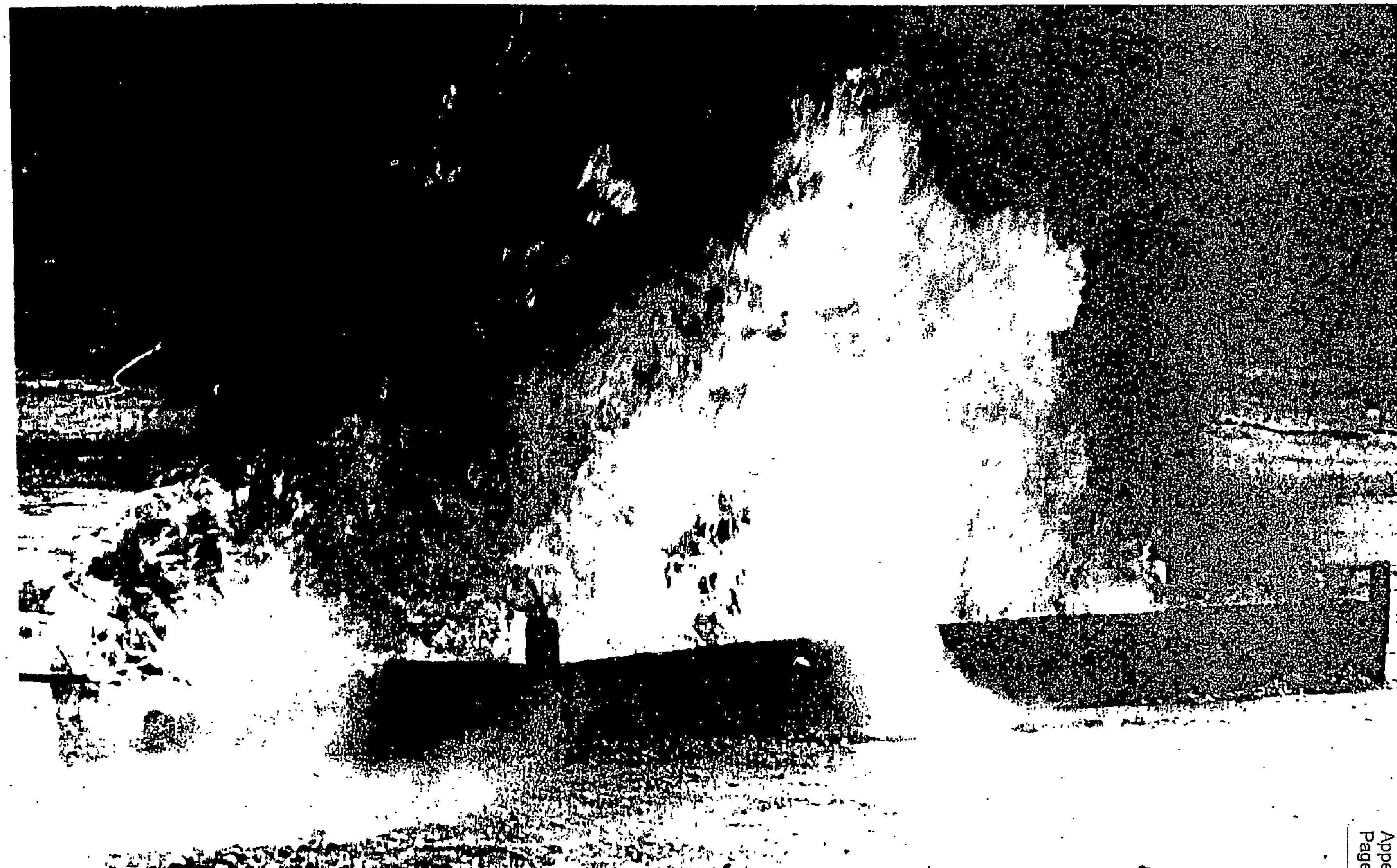
PHOTOGRAPH NO. 11: RA INNER CONTAINER PRIOR TO FIRE TEST



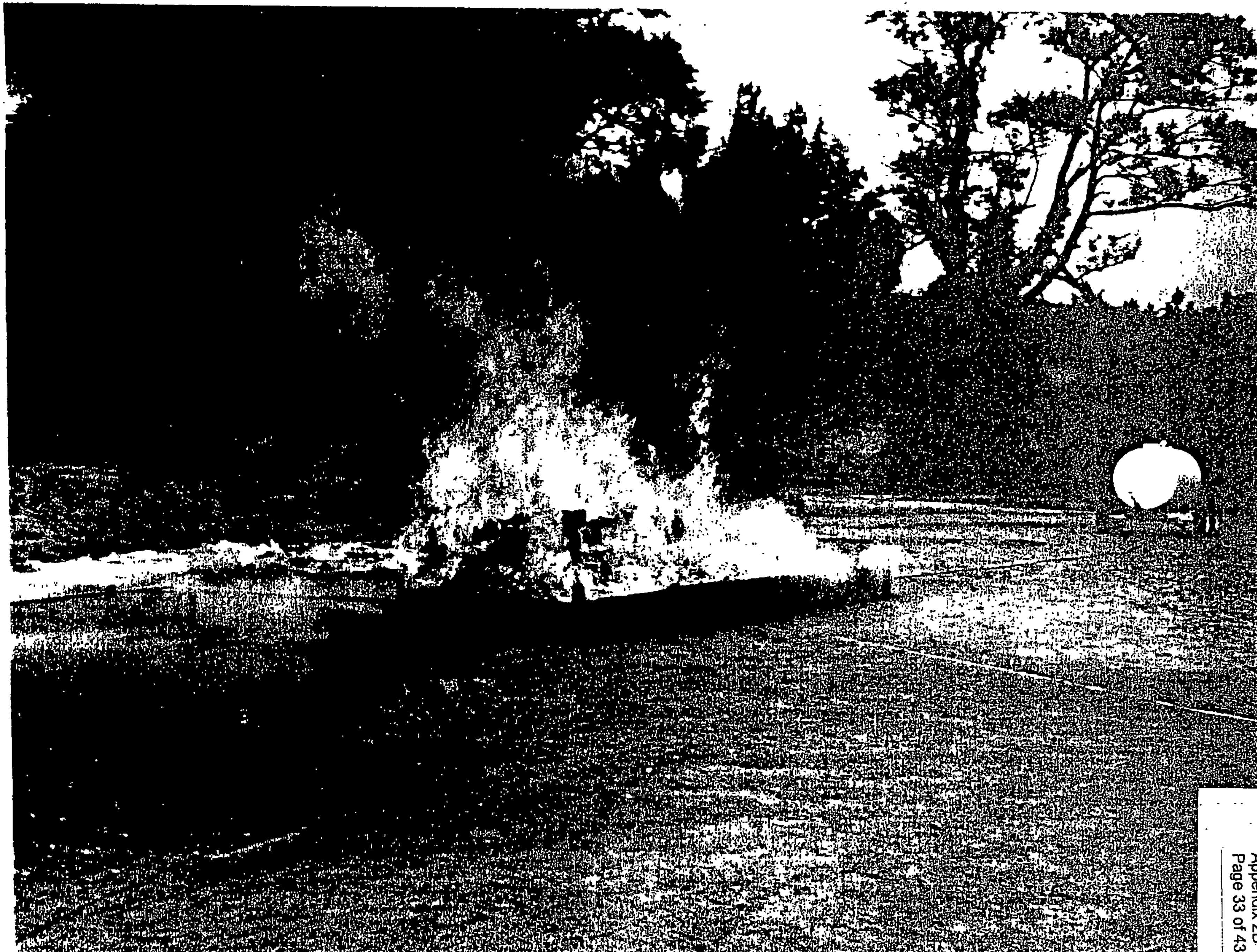
PHOTOGRAPH NO. 15 - INSPECTION OF PIPE



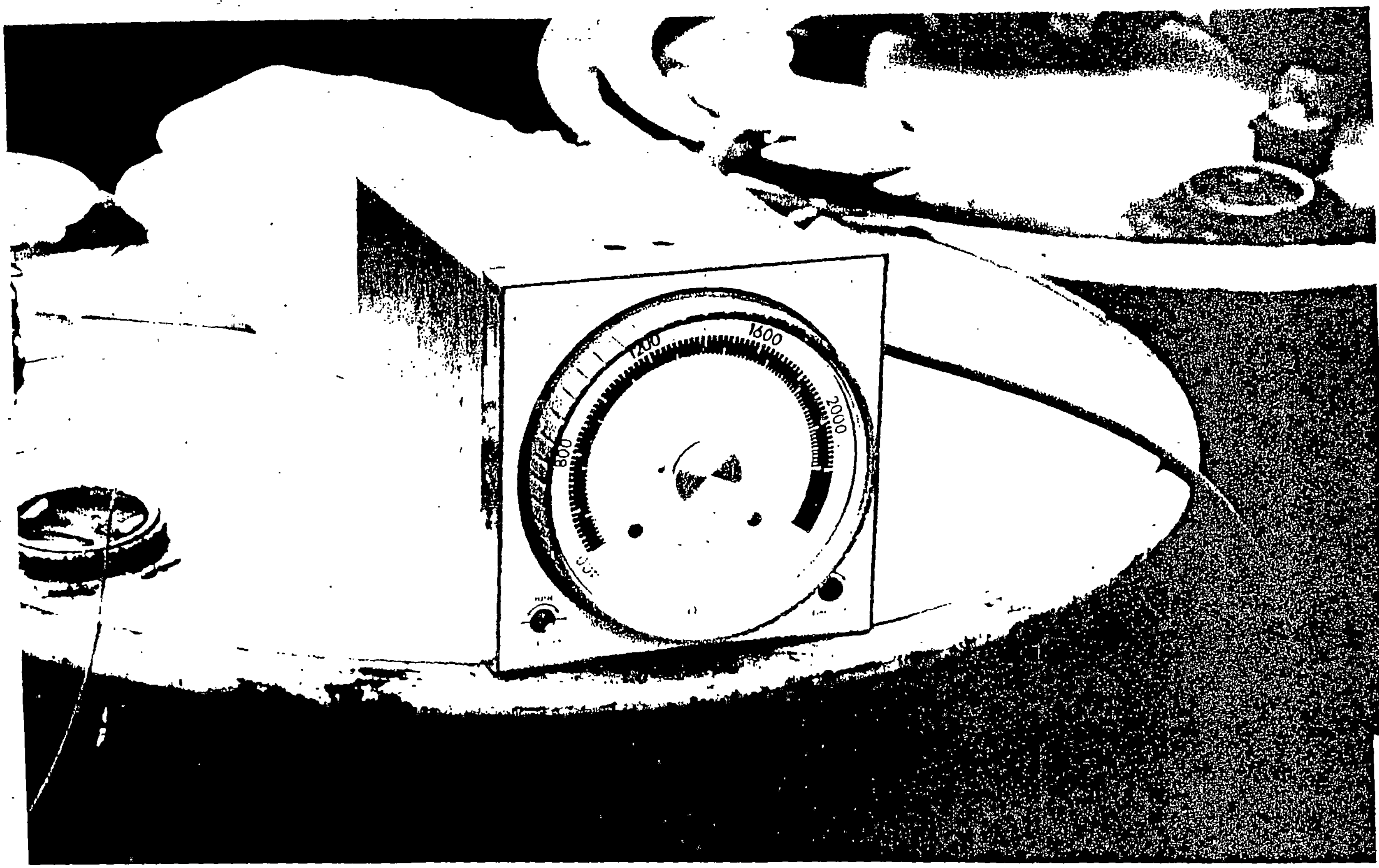
PHOTOGRAPH NO. 1C: FIRE TEST



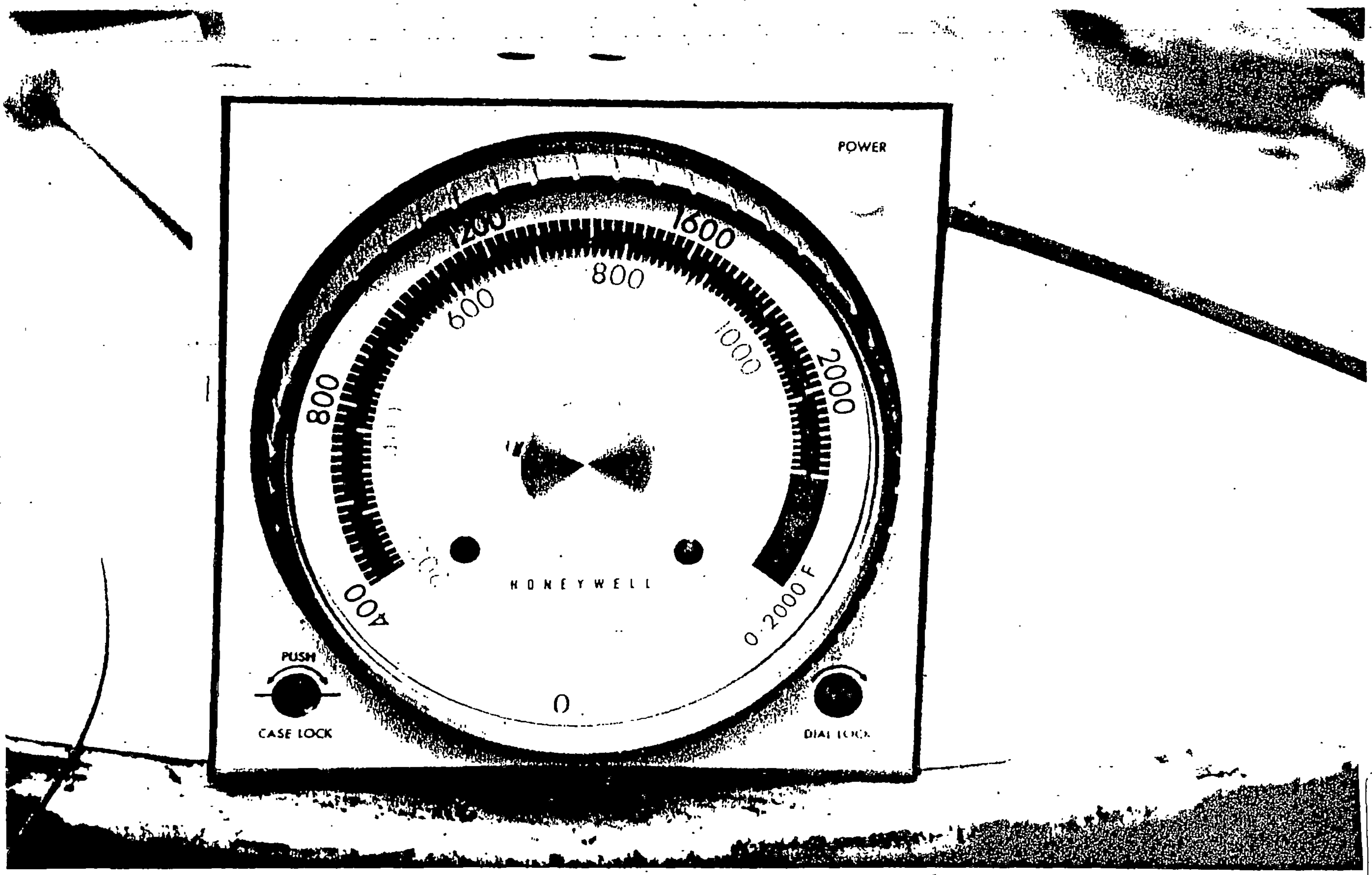
PHOTOGRAPH NO. 18: FIRE TEST



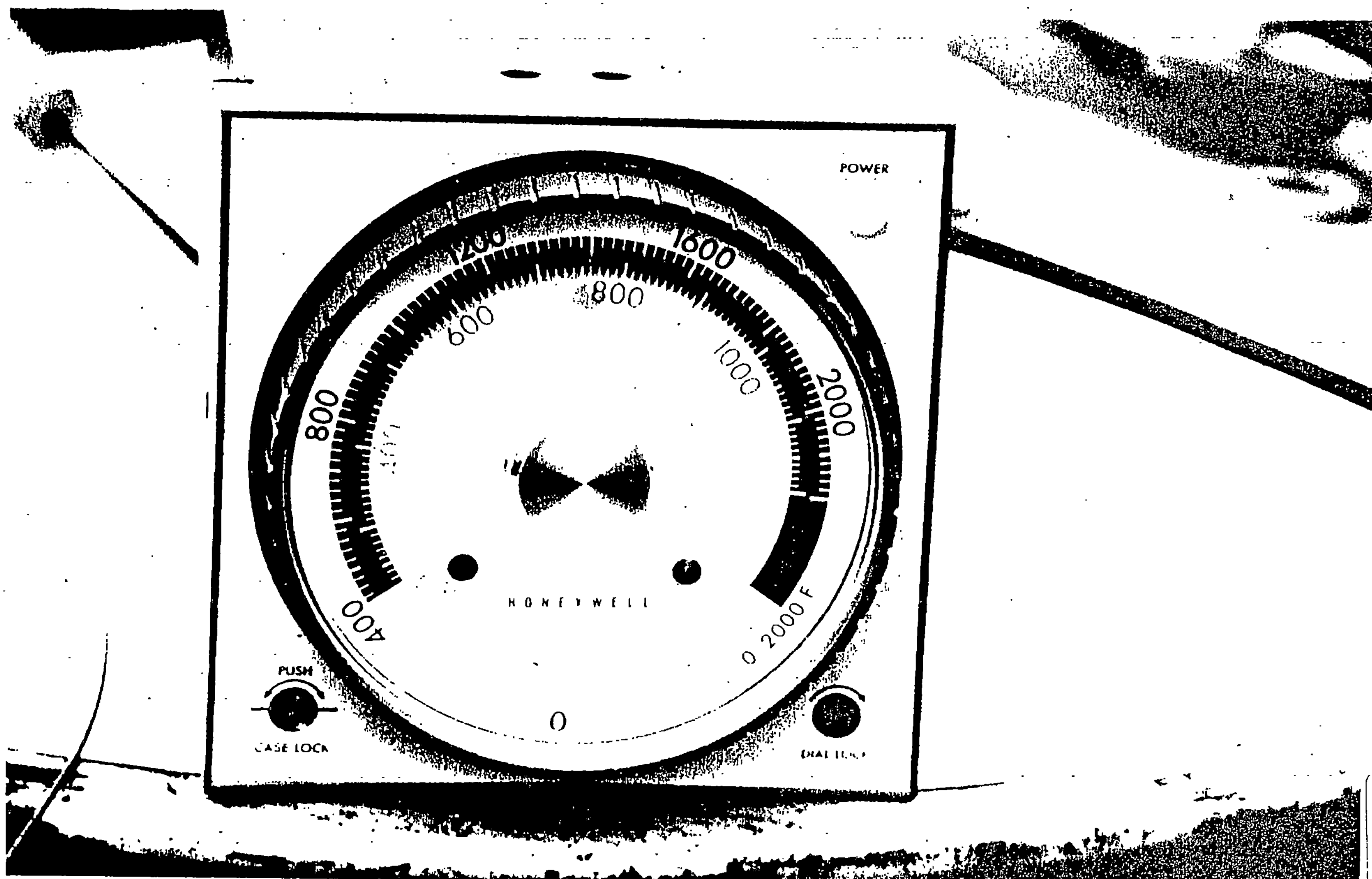
PHOTOGRAPH NO. FIRE TEST



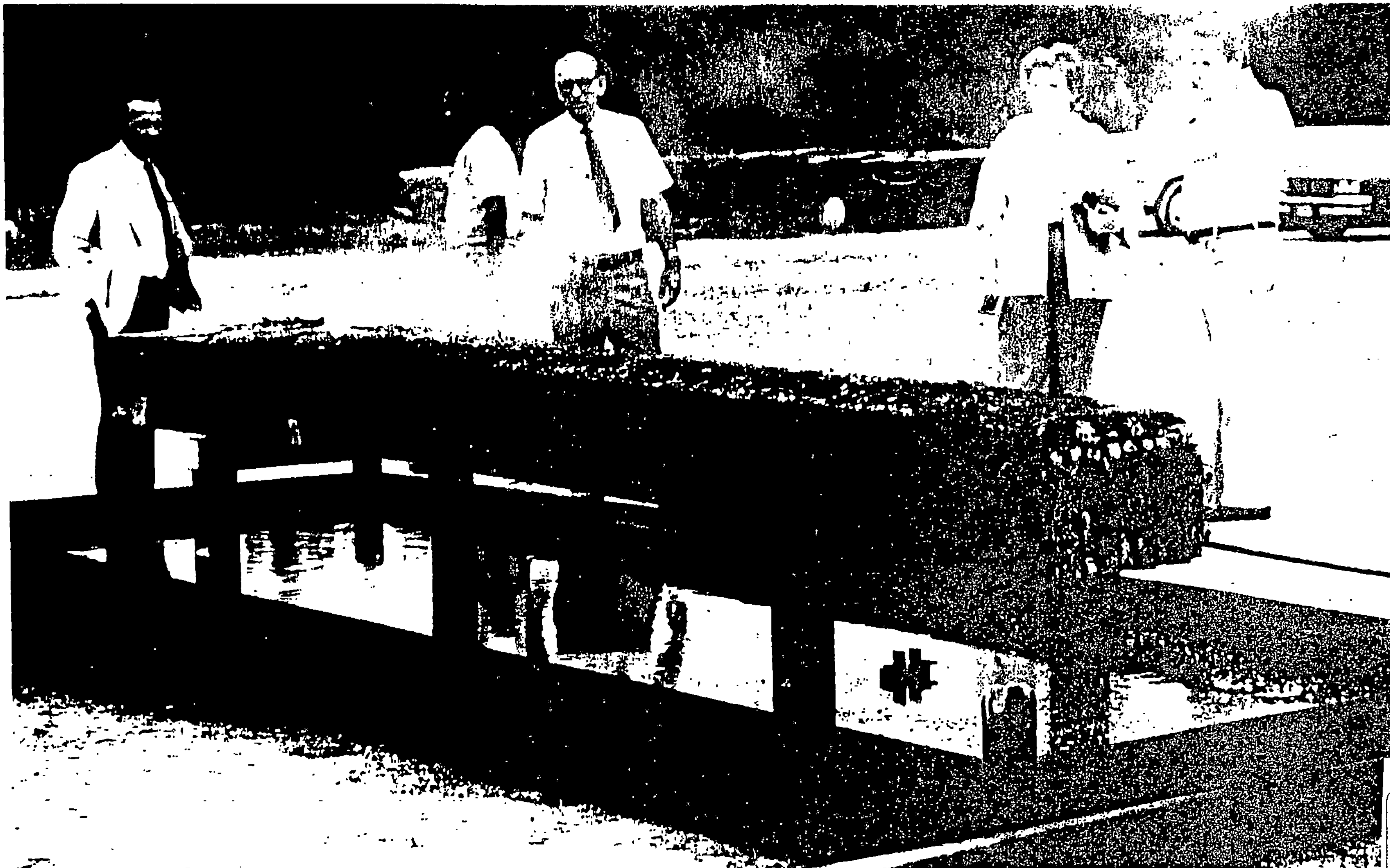
PHOTOGRAPH NO. 21: HONEYWELL DIAL-O-TROLL TEMPERATURE READ OUT



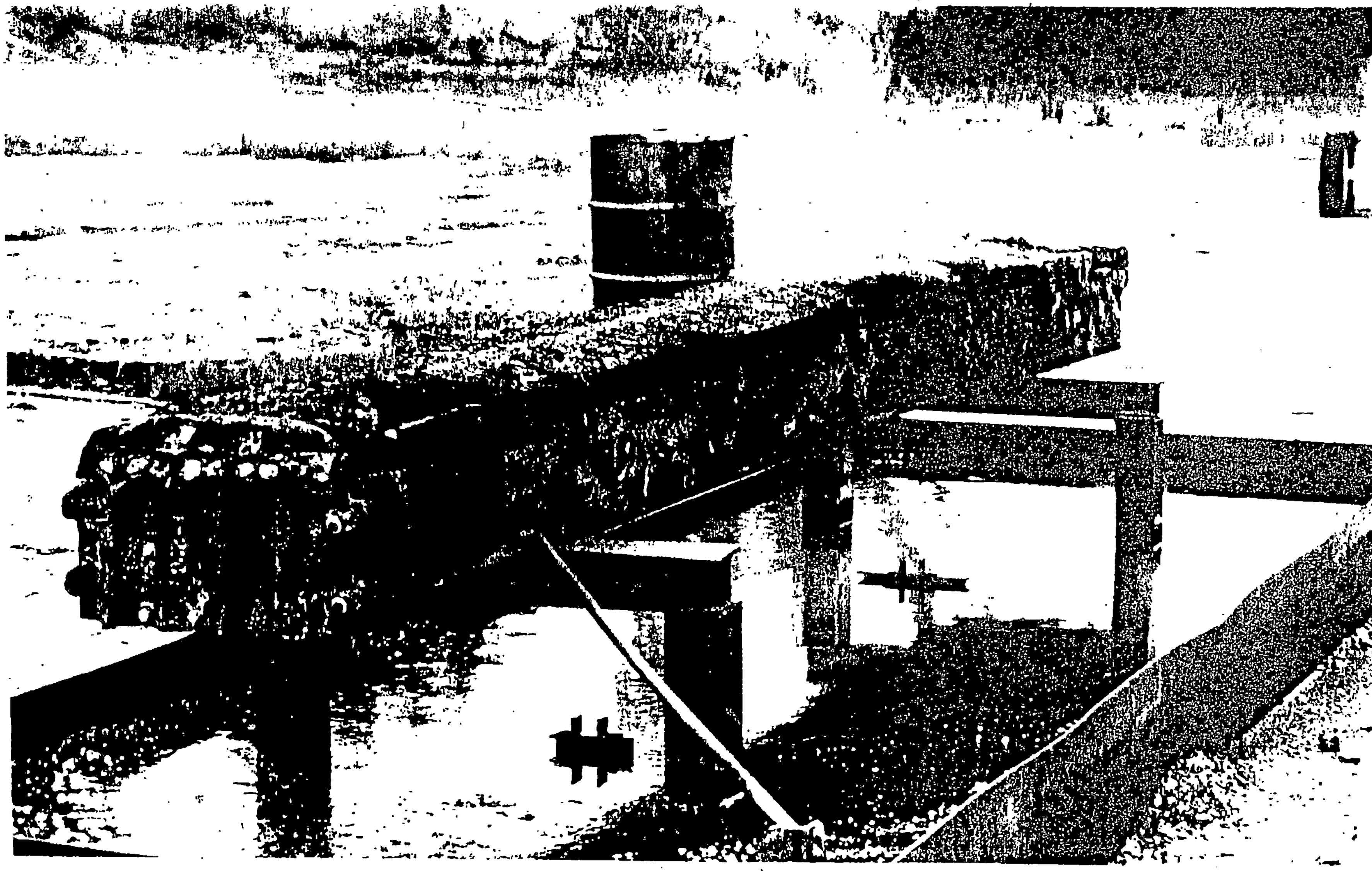
PHOTOGRAPH NO. [illegible]. HONEYWELL DIAL-O-TROLL TEMPERATURE READ OUT



PHOTOGRAPH NO. [illegible] HONEYWELL DIAL [illegible]



PHOTOGRAPH NO. 27 GA INNER CONTAINER AFTER FIRE TEST



PHOTOGRAPH NO. 28: RA INNER CONTAINER AFTER FIRE TEST

PHOTOGRAPH NO. 20: WATER IMMERSION TEST

PHOTOGRAPH NO. 30: WATER IMMERSION TEST

Appendix 2C

DESIGN AND TEST INFORMATION OF THE PREVIOUSLY DESIGNATED RA-1 INNER AND OUTER CONTAINERS USED FOR SHIPPING BWR FUELS

(From Appendix C to Section 2.0 of General Electric's March 17, 1992 Consolidated Application for Certificate of Compliance 4986)

APPENDIX C TO SECTION 2.0

DESIGN AND TEST INFORMATION OF THE PREVIOUSLY DESIGNATED RA-1 INNER AND OUTER CONTAINERS USED FOR SHIPPING BWR FUELS

NOTE: The RA-1 package was the first licensed shipping container for the transport of BWR fuel. While once incorporated in the authorization of certificate USA/4986/B()F, it is no longer in use.

1.0 MODEL RA-1 PACKAGE*

The Model RA-1 package consists of a right rectangular metal inner container within a wooden outer container and separated from the outer container by cushioning material. Descriptions of these containers and of the structural evaluation thereof are given below.

1.1 Description of RA-1 Inner Container

The inner container of the RA-1 model package is a metal box consisting of an outer shell and perforated inner basket separated by structural angle iron.

The outer shell is formed of minimum 16-gauge carbon steel plate with an integral welded end of the same material. Four angle stiffeners made of 11-gauge carbon steel, are welded on approximately four inch centers to the outer surface of the end plate. Approximate dimensions of this inner container are 11 inches high, 18 inches wide, and 174 inches long.

The inner basket is constructed of 16-gauge carbon steel plate with 3/4 inch perforations on 1 3/4 inch centers. It is welded to the upper edge of the outer shell to form two U-shaped channels approximately 6 7/8 inch square in cross-section. The channels may be lined with low-density ethafoam cushioning cemented in place with perforations matching the size and locations of those in the inner basket. To support the inner basket within the outer shell, four 3 inch x 3 inch angle iron spacers made of 1/8 inch thick carbon steel are positioned longitudinally along the entire length of the body.

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*No longer in use. Description included because of references in other sections of this consolidated application to analyses performed on this inner container.

The cover and end cap of the inner container are constructed similar to the box to provide a 2 inch annulus around the fuel, except at the ends, when the box is closed. A manually operable pressure relief valve is installed on the outer shell. capable of passing 2-cfm air automatically to a 0.5-psi pressure difference between the outside and the inside of the box. A gasket of 1/2 inch thick hollow rubber (isoprene or neoprene) provides a completed seal with the cover in place. Closure of the box is effected by bolted assemblies, latches ("Camloc," 3711 series) or equivalent which are inaccessible during transport.

1.2 Description of RA-1 All-Wood Outer Container*

The all-wood outer container is a box with dimensions of 33 inches high, 32 inches wide, and up to 207 inches long. It is fabricated of 1/2 inch plywood, cleated with nominal 2 inch x 4 inch studs, and mounted on a 32 inch platform constructed with nominal 2 inch x 10 inch planks with bolted 4 inch x 4 inch skids. Internal cushioning consists of 3 inch layers of 3/8 inch cell kraft fiber honeycomb impregnated with phenolic resin. Three such 3-inch layers are used to line the inside of the box at the ends, while one such layer is used for the top, bottom, and sides. The remaining inner space at the ends is filled with expanded polyethylene cushioning. Five pads of expanded polyethylene cushioning, three inch in thickness and 12 inches wide, are placed

*No longer in use. Description included because of references in other sections of this consolidated application to analyses performed on this outer container.

inside the box centered over the transverse skids at the sides, top and bottom of the box. The box has no attached lifting or tiedown devices.

1.3 Structural Analysis of RA-1 All-Wood Outer Container

A complete structural analysis was performed for the all wood outer container described on page 2-C3. This analysis was reviewed and approved by registered professional engineers in the State of California, GE #17022 and MET. E. #301. The analysis demonstrates that the container performs very well with respect to the tests described in 10 CFR 71.34(a). Detailed data of the analyses are given in Table 1, page 2-C6.

1.4 Structural Evaluation of RA-1 Package with All-Wood Outer Container

A sample RA-1 package, consisting of the inner container described on page 2-C2 and the outer wood container described on page 2-C3, was subjected to the tests and assessments set forth in Subpart C of 10 CFR 71.

1.4.1 Normal Transport Conditions

A. General: There are no components of the packaging or its contents which are subject to chemical reaction in normal transportation environment. The package cannot be opened inadvertently, uses no coolant, and has no lifting devices or tiedown attachments.

B. Thermal: None of the components of the fuel assemblies or the inner metal container on which containment integrity and nuclear safety depend are significantly affected by temperatures within the range of -40° F to 130° F.

C. Pressure: The breather valve opens automatically when the inner container is subjected to ± 0.5 psi pressure differential. Therefore, there is no effect on the packaging from an environment of 0.5 atmosphere.

D. Vibration: A 3" thick layer of honeycomb cushioning material surrounds the inner metal container at the sides, top and bottom with an additional 9" thickness at the ends. The ethafoam cushioning is slightly compressed in final closure and banding of the outer container and is therefore not free to shift during transport. Since the bolted assemblies* or latches on the metal container are pinned, they cannot loosen during normal transport vibration or shock even were such vibration able to penetrate the cushioning material.

E. Water Spray & Drop Tests: The complete package is designed to protect the fuel assemblies within the inner metal container from loss of containment integrity or change in nuclear safety reliability by virtue of thick cushioning material surrounding it. The shock absorbing qualities of this material and of the heavy wooden cleats at the corners, edges and at all joints in the plywood, supplemented by the inherent resiliency of nails and steel bands used in final closure of the outer package constitute a more than adequate buffer against the subject tests. This conclusion is further supported by analysis of high speed motion pictures recorded during the 30-feet drop test, described on page 2-C9, in

*Bolted (lug) assemblies are features on both the RA-2 and RA-3 inner metal containers.

TABLE 1

RA-1 ALL WOOD OUTER CONTAINER

Property	
CONSTRUCTED MATERIALS	
1) Frame	2" x 4" Wood[3]
- Ultimate Strength	1,750 psi
- Compressive Strength	1,400 psi
- Shear Strength	125 psi
- Ductility (%)	No value
- Modulus of Elasticity	1,760,000 psi
2) Panel	CDX Plywood[4]
- Ultimate Strength	2,000 psi
- Compressive Strength	1,600 psi
- Shear, Normal to Face	250 psi
LOAD CARRYING ABILITY[2]	
1) Frame	
- Tension	10,500 lbs
- Compression	8,750 lbs
- Shear	750 lbs
2) Panels	
- Tension	1,000 lbs
- Compression	800 lbs
- Shear	125 lbs
FASTENINGS	20 Penny Nails Spaces 9" Apart
1) Lateral Allowance Load[5]	94 lbs

[1] "Consolidated Application for an NRC Certificate of Compliance for the General Electric RA-Series Packages," General Electric Company, January 28, 1975.

[2] Engineering Report #6-9004-1, "Comparison of GE Outer Shipping Container 731E283 with ECC Outer Container 200001," C. H. Martin and J. G. Hill, Environmental Container Corporation, November 11. 1969

[3] Timber Construction Manual, Table 2.13, page 2-44, Industrial Douglas Fir

[4] Timber Construction Manual, Table 4.10, page 4-98, Exterior Grade Plywood

[5] The Wood Handbook, U. S. Department of Agriculture, =72, pages 173 and 182.

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which the flexibility of the package under impact is clearly evident.

Since the package is designed to remain subcritical assuming any degree or credible mode of inleakage, it was not necessary to subject the package to a water spray test. However, as a result of a specific request made on 4/13/81 by the NRC, a water spray test was conducted on 9/25/81. The test is documented in the 1/14/82 report contained in Section 7.0.

F. Penetration: Tests were conducted in which the flat circular end of a vertical steel cylinder 1 1/4" in diameter weighing 13 pounds was dropped four feet onto the center of the 1/2" plywood outer container. No damage resulted after four drop tests.

G. Compression: Tests were conducted in which six loaded packages were stacked. There was no visible or measurable damage to the container on the bottom of the stack.

1.4.2 Hypothetical Accident Conditions

A. Free Drop: 1) Table 2, page 2-C9, contains details of the 30-feet free drop test conducted with the RA-1 package consisting of the inner metal container described on page 2-C2 and the all-wood outer container described on page 2-C3.

The inner metal container of the RA-1 package which was subjected to 30-feet drop tests, is closed with the "Camloc" latches.* Minor damage occurred to several latches but there was no container lid separation. The metal bolt closure is structurally equivalent to the latch. A comparison of the latch and bolt closure indicates that both are welded directly to the metal RA-1 container with approximately the same surface area of weld.

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*These latches have been replaced on the RA-2 and RA-3 inner containers, with bolted (lug) assemblies as illustrated in Sections 6.1 and 6.2 and on drawings 769E231 and 769E232, location L-2.

TABLE 2

DETAILS OF 30-FT FREE DROP TEST CONDUCTED ON RA-1 PACKAGE

Height

30-ft measured by weighed string hung from bottom of package

Attitude of Impact

Long axis about 25° from vertical

Impact Surface of Package

Top edge of end which has the clamped end cap on the inner package. (From a series of drop tests of an earlier prototype, it was clearly established that the end cap and cover edge was the most vulnerable impact attitude. Previous drops also included flat on the cover surface and flat on the bottom.)

Surface Struck

18" thick concrete pad. Pad not damaged by test drop.

Contents

Two simulated fuel assemblies each fabricated of 3/4" diameter steel rods 157" long over a wood core and welded to typical reactor fuel assembly hardware at both ends. Dummy dimensions - 6" x 6" x 174" long, weight - 632-lbs each.

Results

Damage confined to impacted area. End of outer box separated from body exposing inner container but inner container still in position in outer container. End cap of inner container was still latched but gasketed surface not in contact with shell flange along one end of end cap. Subsequent immersion would have permitted water leakage into inner container. End cap had to be unlatched and pried off with a tool in order to permit subsequent removal of cover and fuel assemblies. Two-inch annulus remained intact except in a 5" long area at one end of the cover where resulting space averaged about one inch: an insignificant (1%) portion of the total container surface.

1.4.2 A. 2) The structural support of the latch is a 5/16" steel bolt. The structural support of the bolted closure is a 3/8" steel bolt.

3) The lugs will be welded on the PA-1 container in the same number and location as the latches.

The bolted closure has a Tinnerman, No. C7957-3816-24 threated cage nut securely fastened to the bottom of the bolt assembly. This bolted closure is secured or released by using a hand wrench.

It is General Electric's view that the bolted closure assembly represents the same degree of safety as the latched assembly.

B. Puncture: In view of the fact that the inner metal container remained firmly within the outer packaging, and since the inner package was properly designed to remain subcritical with water inleakage such as that which could result from a puncture, an actual puncture test was not conducted.

C. Thermal: An actual thermal test was not conducted but the outer packaging and cushioning material was assumed to be completely consumed under thermal test conditions. However, the remaining inner package is constructed of noncombustible material and the minimum melting point of the fuel material is 4360° F. The pressure relief valve permits escape of heated air from the metal container. Therefore, this device would prevent rupture of the container even if the gasket did not melt to allow pressure relief. The 18-gauge steel container is internally braced with lengthwise angle iron on both sides and bottom; the cover is similarly braced. Previous tests of an 18 gauge 55-gallon drum in a jet fuel fire which exceeded an exposure temperature of 1475° F for more than 30 minutes produced no melting or distortion of the outer surfaces. It is, therefore, concluded that a similar thermal test at 1475° F for 30 minutes would result in no damage to the Model RA-1 inner container or its contents more severe that the assumed conditions considered in the criticality analysis presented in Section 8.

D. Water Immersion: Since the package is designed to remain subcritical assuming any degree or credible mode of water inleakage, it was not necessary to subject the package to an immersion test.

ISSUED IN FRA-ANP ON-LINE DOCUMENT SYSTEM
DATE: 2-5-04

Appendix 2D

DESIGN AND TEST INFORMATION FOR EARLIER VERSIONS OF THE RA-2 INNER AND OUTER CONTAINERS USED FOR SHIPPING BWR FUELS

(From Appendix D to Section 2.0 of General Electric's March 17, 1992 Consolidated Application for Certificate of Compliance 4986)

APPENDIX D TO SECTION 2.0

DESIGN AND TEST INFORMATION FOR EARLIER VERSIONS OF THE RA-2 INNER AND OUTER CONTAINERS USED FOR SHIPPING BWR FUELS

NOTE: The RA-2 outer container has been replaced by the RA-3 outer container. The RA-2 inner container has been modified and re-evaluated.

1.0 MODEL RA-2 PACKAGE

The model RA-2 package consists of a right rectangular metal inner container within a wooden outer container and separated from the outer container by cushioning material. Descriptions of these containers and of the structural evaluation thereof are given below.

1.1 Description of the RA-2 Inner Container

The inner container for the model RA-2 package is identical to that described on page 2-C2 for the model RA-1 package. with the following exceptions:

- The RA-2 inner container is longer (179 1/8 inches in length) to accommodate fuel assemblies, by redesigning the end cap.
- ASTM A-307-A bolts used to fasten the RA-1 end cap are replaced by stronger ASTM A-354-BD bolts for the RA-2.

The inner container is constructed in accordance with the following General Electric Drawing:

- 769E232 - Revision 3

Section 6.1 contains a copy of this drawing.

1.2 Description of RA-2 All-Wood Outer Container*

The RA-2 outer container has a 1/2 inch plywood sheet faced with 1/8 inch steel sheet replacing the 3 inch thick ethafoam pad at each end of the box.
The purpose of the change is to elongate the cavity of the outer container to accommodate the longer inner container.

*No longer in use. Description included because of references in other sections of this consolidated application to analyses performed on this outer container.

1.3 Structural Evaluation

The RA-2 package evaluation is based on assessment of the effect of differences from the Sub-Model RA-1 design on the results of the 30-ft free fall to which an RA-1 prototype was subjected in 1966. In that test, described on page 2-C9, the end of the outer box separated from the body, exposing the end of the inner container, but with the inner container still in position in the outer container. The end cap, although not undamaged, was in place and latched such that the fuel assemblies remained securely retained in the as-shipped configuration.

Several design changes are made in the RA-2 design to maintain the same impact resistance characteristics of the package system with the new longer inner package. These are described below.

1.3.1 Cushioning

The outer container of the RA-1 package has three 3" layers of 3/8" cell phenolic resin impregnated kraft fiber honeycomb with an impact resistance of 75-psi and a 3" layer of ethafoam at each end. In the outer container for the RA-2 package, the honeycomb impact resistance is increased to *290-psi by the use of heavier weight paper. For the outer container, the ethafoam (3" thick pads at each end) used in the RA-1 is replaced by a sheet of 1/2" plywood faced with a 1/8" steel sheet. Calculations of the impact resistance inherent in the RA-1 end cushioning brought to

*This evaluation has been reassessed. See Appendix A to this Chapter, especially sections 2.2, 2.2.1, and 3.3.

light the fact that the ethafoam pad has only minor energy absorption strength in the hypothetical accident condition, and was designed primarily to minimize shock and vibration in normal transport. Further, it was discovered that only the area of honeycomb cushioning equivalent to the end cap area was utilized in the RA-1 arrangement.

To correct this deficiency* a load spreading steel plate 1/8" x 15" x 20" held in position by a 1/2" plywood sheet, is substituted for the ethafoam pad. By this arrangement, the inner metal container weighing a total of 1865 pounds, and contents, as loaded with two assemblies, would result in a 300 square inch impact area on the 290-psi honeycomb and reduce the impact velocity of the metal container to zero* in the 30-ft free fall with a 8.4" thickness of honeycomb.

It is, therefore, concluded that the 9" thick honeycomb pad more than adequately protects the inner container against loss of the fuel assemblies even without the further box strengthening described below.

1.3.2 Joint Strength for Inner Containers

ASTM A-307 Grade A-type bolts are authorized as an alternative to the latching mechanism used on the RA-1 drop-tested prototype. The RA-2 inner container is equipped with stronger bolts - ASTM A-345-BD - at the end cap lug positions.

Stress calculations for the RA-2 with the longer end cap closed by these 90,000-psi yield strength bolts indicated there will be no bolt bending, bolt direction shear, weld shear or box bending forces in excess of that strength.

*This evaluation has been reassessed. See Appendix A to this Chapter, expecially sections 2.2, 2.2.1, and 3.3.

Appendix 2E

TEST REPORT FOR WATER SPRAY OF RA-2/RA-3 FUEL SHIPPING CONTAINER

(From Appendix E to Section 2.0 of General Electric's March 17, 1992 Consolidated Application for Certificate of Compliance 4986)

APPENDIX E TO SECTION 2.0

TEST REPORT FOR

WATER SPRAY OF RA-2/RA-3

FUEL SHIPPING CONTAINER

TEST REPORT

FOR

WATER SPRAY OF RA-2/RA-3 FUEL SHIPPING CONTAINER

In accordance with criteria for compliance with 10 CFR 71.35

BY

JOHN A. ZIDAK

MANAGER

Packaging Engineering

General Electric Co.
Nuclear Energy Traffic Operation
San Jose, California

DATE ISSUED January 14, 1982

TEST REPORT

FOR

WATER SPRAY OF RA-2/RA-3 FUEL SHIPPING CONTAINER

1.0 INTRODUCTION

1.1 PURPOSE

The purpose of the test described, was to determine the effects of, and take into account for NRC Certificate of Compliance application, the water spray test specified in 10 CFR Part 71, Appendix A - Normal conditions of Transport.

Test was requested in a letter from NRC dated April 13, 1981, relative to application for renewal of NRC Certificate of Compliance No. 4986.

1.2 TEST DESCRIPTION

A representative RA-2/RA-3 outer wood container was selected from inventory, and was to be tested to the requirements of 10 CFR 71, Appendix A, Paragraph 5, which reads as follows:

> A water spray sufficiently heavy to keep the entire exposed surface of the package except the bottom continuously wet, during a period of 30 minutes.

However, the test conditions used, which are more demanding, were those specified in proposed revised 10 CFR 71, Appendix A, paragraph 6, which reads as follows:[1]

> A water spray that simulates exposure to rainfall of approximately 5 cm (2 in.) per hour for at least one hour.

Since both model RA-2 and RA-3 containers are essentially the same with respect to their wood construction, phenolic impregnated paper honeycomb and foamed polyethylene impact limiters, testing one representative container is considered to have satisfied the requirement for both the RA-2 and RA-3 containers.

1.2.1 TEST PLAN

The test was conducted in accordance with the test plan dated September 21, 1981 that was approved by Packaging Engineering, Traffic and Materials Distribution, Fuel Quality Engineering, Nuclear Safety Engineering and Licensing and Compliance Audits.

[1] Proposed requirements were published in the Federal Register, on 8/17/79, at FR 44 48234.

1.2.2 CONTAINERS USED

Inner container model RA-2, serial number I-0888 and Outer container model RA-3, serial No. R2251 were selected from inventory for the test (see figure 1).

1.2.3 TIME, LOCATION AND ENVIRONMENT

The test was conducted on September 25, 1981 at Container Products Corporation, 23rd Street, Wilmington N.C. between the hours of 1:00 p.m. and 4:00 p.m. It was held outdoors, the weather was sunny, temperature approximately 80°F with a slight breeze, about 5 miles per hour.

1.3 PACKAGING DESCRIPTION

The RA-2 and RA-3 packagings are right rectangular boxes consisting of a wooden outer container approximately 207" long by 30" wide by 31" high, and a smaller steel inner container. The outer box is lined with cushioning material that supports and locates the inner container. The cushioning material is closed cell foamed polyethylene (2.2 lb per cubic foot density) which is impervious to water, and, water-resistant phenolic resin-impregnated, paper honeycomb. Closure of outer container is accomplished by thirty 3/8" diameter bolts. The metal inner container has water tight, gasketed closures that are secured by 3/8" diameter bolts. Total packaging weight is approximately 1400 pounds.

1.4 TEST SET-UP

Spray test equipment consisted of a rectangular manifold pipe 21 feet long and 6 feet wide. 24 nozzles were utilized, 10 nozzles on each side, and 2 on each end (see figure 2). The nozzles were mounted 4 feet above the ground and were angled downward at 45°. Three receptacles were used to collect the spray water for measurement at the end of the spray period.

1.5 PRE-TEST INSPECTION

Prior to testing, the containers were open and inspected by a Fuel Fabrication Quality Control inspector to verify they were dry inside and all component parts were present and undamaged. Criteria same as for production packaging (see appendix 1).

2.0 TEST PROCEDURE

The dry package was centered under the spray fixture and the water turned on (see figure 3). The outer container was sprayed with water for one hour. (This is double the time duration of one half hour, currently required by 10CFR 71.) Spray water collected in the three cylindrical receptacles was measured to be 2-3/8 inches, 3 inches, and 4-7/8 inches, depending on location during the spray period. The measured water level exceeded the proposed requirement of 2 inches per hour. (Reference proposed rule published 8/17/79, 44 Federal Register 48234.) The entire exposed surface of the package except the bottom was kept wet during the one hour test period, as required by 10CFR 71 Appendix A.

2.1 OBSERVATIONS

During the test it was noted that the water spray impinging on the container was heavier than on the three cylindrical receptacles. Also, water pooled on the cover between the cleats, to a depth of 1/4 inch, and drained away through slots in the cleats provided for this purpose see (figure 4).

3.0 POST TEST INSPECTION

Upon completion of the test, the bolts and steel straps were removed from the outer container and the cover removed. A small amount of water (less than 2.0 fluid ounces) was scattered on the length of the polyethylene shroud that covers the inner container (see figure 5 and 6). The inner container was removed and the following observations were recorded:

(a) The phenolic-impregnated paper honeycomb and polyethylene foam impact limiting material was dry in both ends (see figure 7).

(b) The metal and wood plates at both ends were dry.

(c) The north side (as oriented during test) showed water inleakage. However, less than 3% of the visible honeycomb was damp (see figure 8). Damp area pattern was essentially vertical. Foamed polyethylene parts were not damp to touch.

(d) The south side showed water leakage, with about 6% of the visible honeycomb being damp to touch (see figure 9, 10, and 11). Again, damp area pattern was vertical. Plastic parts were not damp to touch.

(e) On the bottom, 2 of 5 plastic cushioning pads had drops of standing water, estimated in total to be less than 1 ounce. The other 3 were dry.

(f) On the bottom, about 10% of the visible phenolic honeycomb was damp to touch (see figure 11). Damp areas corresponded generally to damp areas on adjacent sides of container, described earlier. In crevices at edges of honeycomb, some moisture was observed on the wood bottom. Visible water was limited to a few drops. All pieces of plastic and honeycomb cushioning were checked and it was determined that none had come loose, indicating that adhesives had not functionally weakened where water had touched them.

(g) After removal of the inner container, its cover and end cap were removed, and inner container parts oriented so that any trapped water would drain in a manner to be visible. No water was found in the inner container, and touch inspection of accessible areas also indicated no moisture. It was concluded no water entered the inner container.

4.0 ACCEPTANCE CRITERIA

The applicable acceptance criteria for meeting the requirements of 10 CFR 71.35:

(a) 10 CFR 71.35(a)(1) requires that there will be no release of radioactive material from the containment vessel under normal conditions of transport.

(b) 10 CFR 71.35(a)(2) requires the effectiveness of the package will not be substantially reduced under normal conditions of transport.

(c) 10 CFR 71.35(b)(2) requires the geometric form of the package contents would not be substantially altered under normal conditions of transport.

In addition the effectiveness of the impact limiters will not be substantially reduced over the short or long term, due to the effects water spray test.

5.0 CONCLUSIONS

The General Electric fuel shipping container model No. RA-2/RA-3 has successfully passed a water spray test that is more severe than that required by 10 CFR 71 paragraph 35. In addition, there was no substantial reduction in the effectiveness of the plastic and paper honeycomb impact limiters. As concluded from the following:

5.1 Reliance is placed on the inner metal container to prevent release of radioactive material. Wetting the wood outer container does not contribute significantly to any weakening of the inner container.

5.2 The impact limiting plastic cushions (foamed polyethylene) are closed cell and waterproof. This same material is used as floatation cushions on commercial aircraft.

5.3 The phenolic resin-impregnated, paper honeycomb is resistant to water. Vendor test have shown that it retains 50% of its compressive strength after a 24 hour water soak test. (Per Hexcel Corporation report No. LSR932114 dated January 11, 1980, appendix 2.) After the water spray test period of 1 hour, the wet areas of the phenolic-impregnated paper honeycomb were 0% for ends, about 3% for one side and 6% for the other, and about 10% in the bottom. This is a relatively insignificant percentage of the total, considering that after even 24 hours of soaking in water, the material retains good compression qualities. Therefore, the maximum reduction in strength is 1-1/2% for one side, 3% for the other, and 5% for the bottom. It is, therefore, concluded that the wetting encountered in the water spray test has no detrimental long-term effect on impactlimiting capabilities.

5.4 Reliance is placed on the inner metal container to protect the geometric form of the package contents. Since the wood container would not be substantially weakened by being wet, it would not contribute substantially to any weakening of the inner container.

5.5 Packaging is designed to be water-resistant, not water-proof. The outer container, made of nailed and bolted wood and plywood, is strong and resilient. It is water-resistant, due to its covering of paint and sealant, but is not impervious to water. No gasket is used, and some inleakage of water is possible, and even anticipated, on occasion. Water accumulation on the top of the container is quickly drained off through slots in the cleats provided for this purpose.

5.6 Maintenance inspections assure that only undamaged containers are used. Moreover, as required in NRC regulations 10 CFR 71.54, routine determinations prior to each use of a package, each container is inspected to ascertain that it (including, specifically, the paper and plastic parts) has not been significantly damaged, either by possible long-term effects of water or by physical activity such as possible careless handling. All containers which are ascertained to have received significant damage are reworked and further inspected prior to use. Containers which do not meet the criteria after rework are removed from service.

5.7 Continued usage experience demonstrates that containers may become wet when stored empty at either reactor sites or the WMD site, or when transported empty without tarpaulin protection. However while the design life of the outer container is considered to be five years, actual life is longer.

5.8 Empty containers are inspected prior to use, as described earlier. After containers have been packed with fuel bundles, they are stored only under cover and are transported either in covered vehicles or under tarpaulin protection. Therefore, the bundles are delivered to reactor sites in containers whose quality is undiminished from the condition existing when inspected both before and after packing.

APPENDIX 1

WILMINGTON MANUFACTURING DEPARTMENT
FUEL FABRICATION QUALITY CONTROL - FMO

ATTACHMENT 6

PROJECT For Outer RA Water Spray Test

BUNDLE SERIAL NOS. (A) ______ (B) ______

INNER SHIPPING CONTAINER NO. I-0888

OUTER SHIPPING CONTAINER NO. R-2251

NOTE: This sheet forms part of the permanent quality record for the project. When completed, forward to Certification & Release - FMO.

2nd

PACKAGE INSPECTION FORM

PRIOR TO LOADING BUNDLES INTO INNER CONTAINER, CHECK INNER CONTAINER FOR THE FOLLOWING:

5.1 Completed traveler present, no damage to container.

5.2 No visible indications of water in the container. Check with hand for dampness. ok

5.3 Container interior and cover for rust or other particles that would affect bundle cleanliness. All paint must be dry to the touch.

CHECK BUNDLES FOR THE FOLLOWING:

5.4 Packing spacers properly installed between rods in each direction and assembly properly bagged.

5.5 Finger spring protectors in place per PROD 50.70.

5.6 Visible portion of bundles free of finger marks, oil, rust, etc.

AFTER LOADING BUNDLE INTO INNER CONTAINER, CHECK FOR THE FOLLOWING:

6.1 ~~Bundle has an acceptable~~ final inspection ~~stamp on upper tie plate. All~~ characteristics of ~~stamp must be visible and complete.~~

6.2 ~~No visible damage.~~ Cor~~rect bundle~~ numbers. ~~Hold-down bar is secure.~~

6.3 ~~Assembly properly loaded into~~ inner container (pac~~king, tie-downs, ropes, upper and lower wooden blocks, etc.), no foreign~~ material.

6.3 ~~Plastic bag does not extend~~ beyond ends of ~~bundle and ends of bag are left open~~ (not taped or sealed).

6.4 ~~After end plate is secured,~~ no visible gap ~~between upper tie plate and wooden~~ block.

6.5 Check rubber gasket around lid and end cap for looseness and smoothness. ok

6.5 After the lid is secured, verify that all bolts are in place and tight. Cover and end cap gaskets tight (check with .015" feeler gage). ok

6.6 ~~Tamper-safe seals are affixed. Record~~ seal ~~serial numbers.~~

#________, #________, &
#________ Time ________

6.6 ~~Proper enrichment tape~~ is on the inner container.

6.7 ~~Proper bundle serial numbers~~ are marked on the ~~plastic cover~~. Inner container lid clean.

6.8 All other labeling except that required by this inspection has been removed.

6.9 Plastic cover secure. Breather valve not obstructed, verify valve is operational.

*INSPECTOR C. Foy DATE 9/24/81

BEFORE LOADING INNER CONTAINER INTO OUTER CONTAINER, CHECK FOR THE FOLLOWING:

7.1 Outer container is solid throughout all corners, lids, sides, etc. Completed traveler present. No water accumulation in the container. Packing absorbers (fillers) correct type, and in the proper position as required. No packing is missing. No accumulation of foreign material.

AFTER LOADING RA INTO WOODEN CONTAINER, CHECK FOR THE FOLLOWING:

8.1 Inner and outer container numbers match.

8.1 Plastic cover not damaged. ok

8.1 RA resting level on all supports in wooden container.

8.2 ~~Serial number of bundles and~~ inner container marked on outer container.

8.2 ~~Proper enrichment tape on outer container.~~

8.2 All other labeling except that required by this inspection has been removed.

AFTER WOODEN CONTAINER HAS BEEN BOLTED AND BANDED, CHECK FOR THE FOLLOWING:

9.1 Cover fastened securely with all metal straps and bolts in place as required. ok

9.1 ~~Verify that the tamper-safe seals were affixed. Record seal serial numbers.~~

#________ & #________

*INSPECTOR C. Foy DATE 9-24-81

Time ________

Time Share Entry ________

*After completion of the inspections required in each section, sign and date the checklist at the location provided to indicate that you have completed the required inspections and found no conditions outside of the quality limits.

QC-241
Rev. 18

KP-3/4-80(11) AND KP-3/4-80(18) WET COMPRESSION TESTS

OBJECTIVE: The main purpose of this test program was to compare the wet compressive strength and modulus retention of KP-3/4-80(11) and KP-3/4-80(18) Honeycomb.

REQUESTED BY: G. Smith

PROCEDURE: Dublin's R&D test laboratory received 1" thick slices of KP-3/4-80(11) and KP-3/4-80(18) honeycomb. KP-3/4-80(11) core appeared to have processed on edges. 4" x 4" stabilized compression specimens were prepared using 0.020" aluminum skins bonded to the core with a room temperature curing epoxy adhesive. One hole was drilled in the middle of each sample and then the specimens were submerged in water for 48 hours, and sets of specimens were also prepared for "dry" or as received testing.

Room temperature (63°F and 76% relative humidity) tests were accomplished on the 60,000 lb. Satec test machine at a 0.020 in/min loading rate. Load-deflection curves were obtained autographically by means of a transducer.

TEST RESULTS: Table I contains the test data in which all the specimens exhibited compressive mode failures. The average values are summarized below:

Core Type	Conditioned	DRY Density	Compression Strength	Compression Modulus
KP-3/4-80(11)	Dry	1.35 pcf	35.2 psi	7.54 ksi
	Wet	1.37	5.4	1.09
KP-3/4-80(18)	Dry	1.29	40.0	6.51
	Wet	1.32	20.0	6.25

CONCLUSIONS: The KP-3/4-80(18) core retained much more of its compressive strength (50%) and modulus (96%) than did the KP-3/4-80(11) product, 15% and 14% respectively.

T. N. B[illegible]
T. N. [illegible]

TNB/ec

LIST OF FIGURES

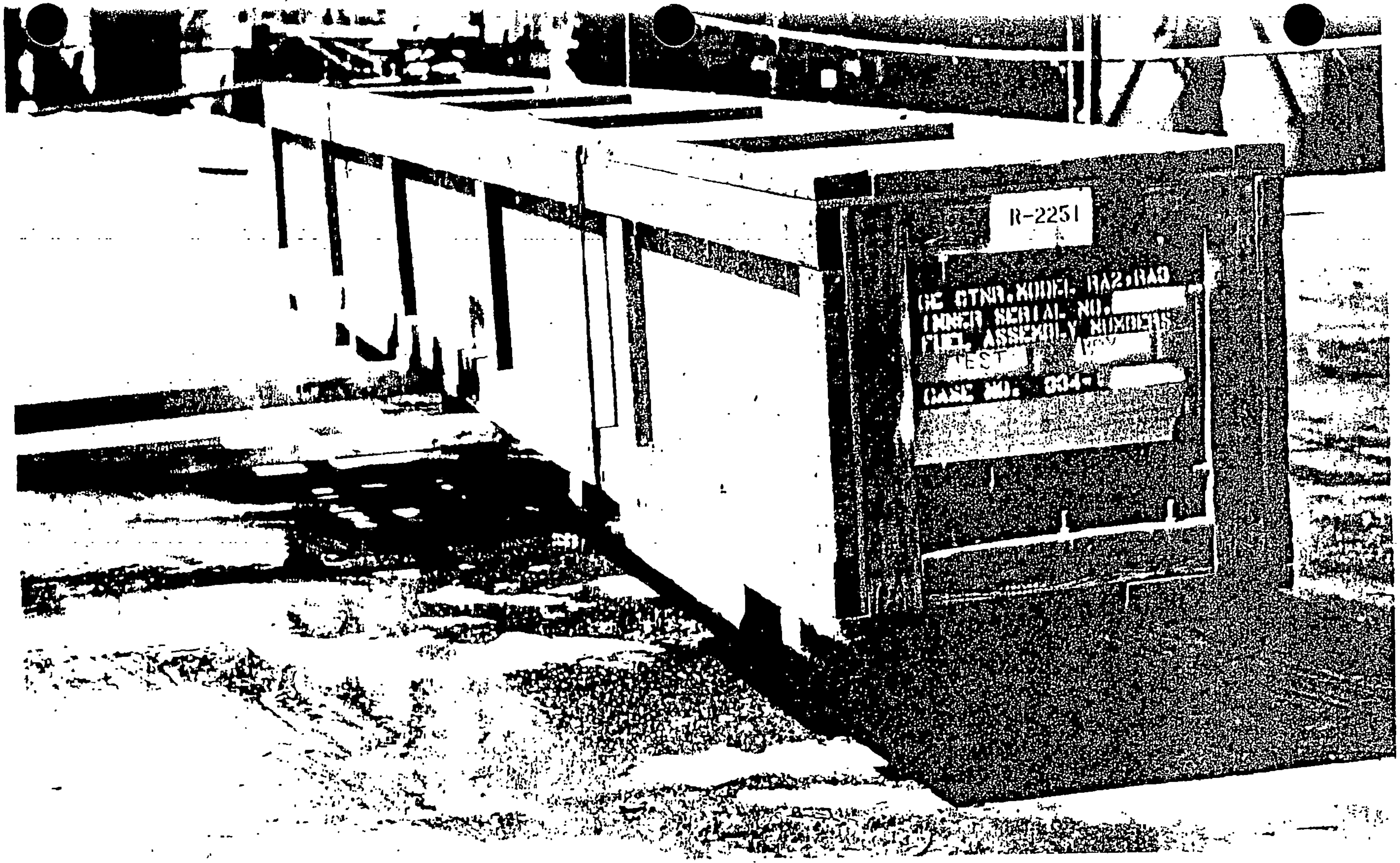


FIGURE 1. RA CONTAINERS - PRE-TEST PHOTO

FIGURE 2. TEST SETUP

FIGURE 3. WATER SPRAY TEST

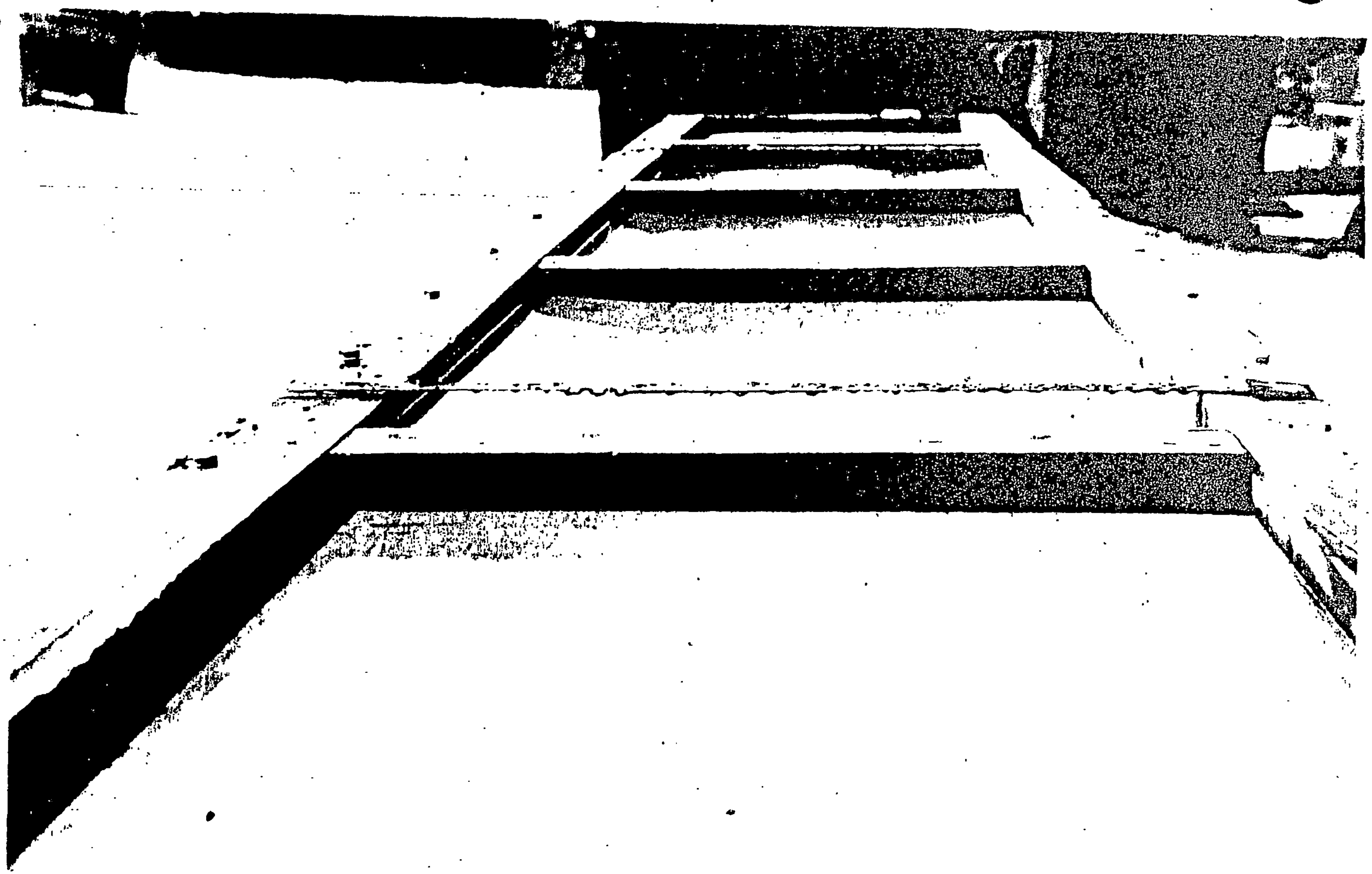
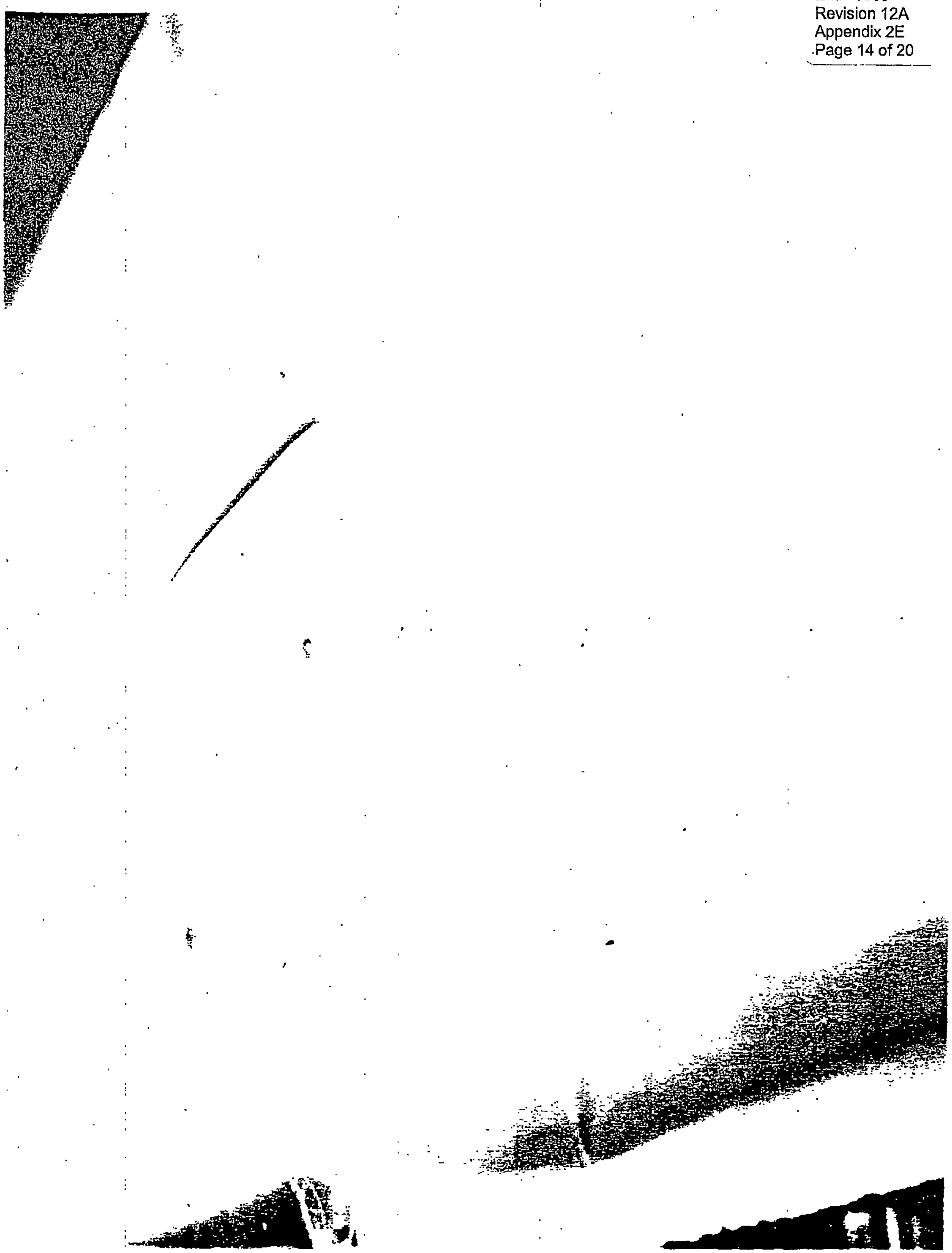


FIGURE 4, WATER ON SURFACE OF CONTAINER COVER



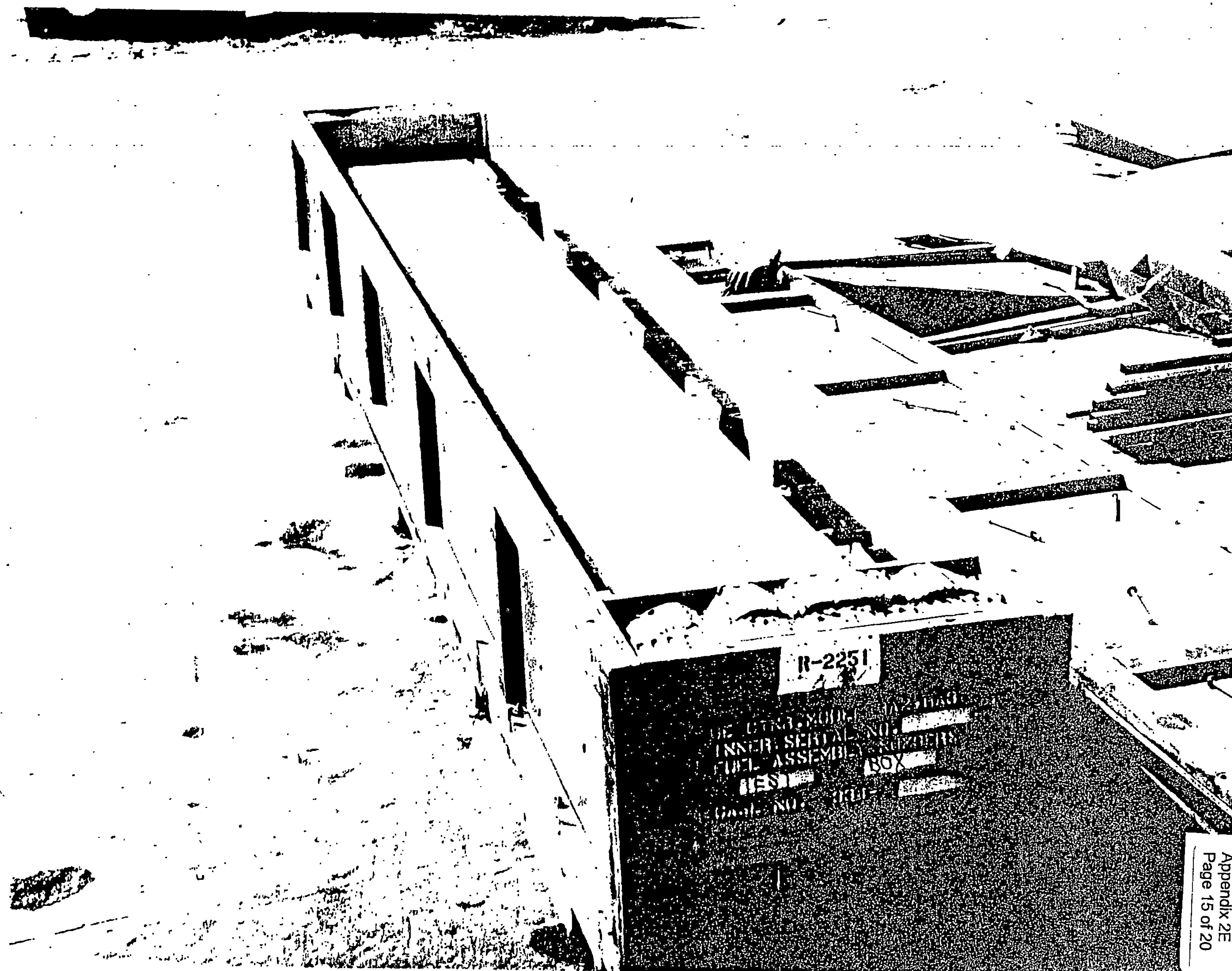


FIGURE 7. INSIDE OF CONTAINER WITH SHROUD REMOVED

FIGURE 8, DAMP AREA OF HONEYCOMB

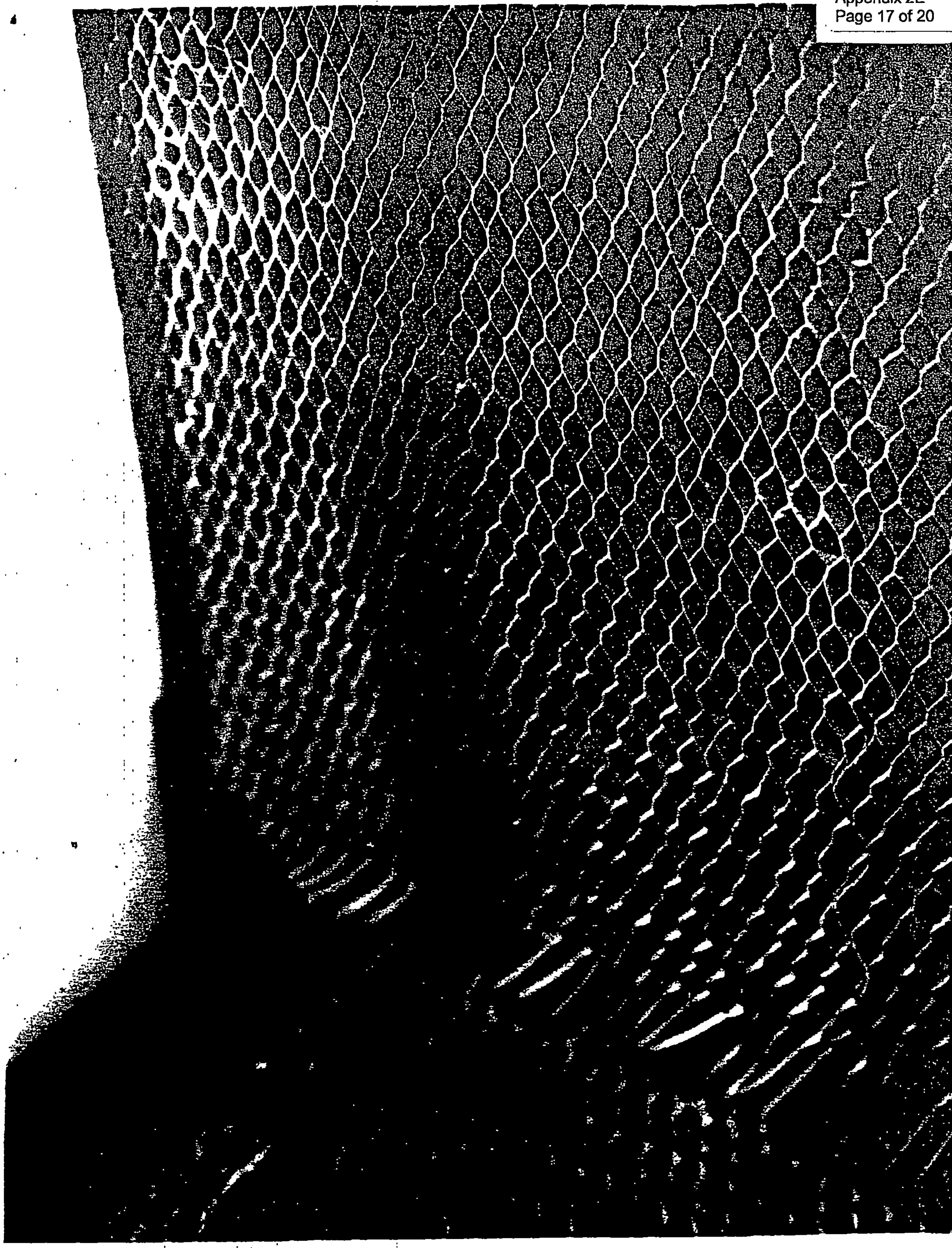


FIGURE 9. SOUTH SIDE OF CONTAINER

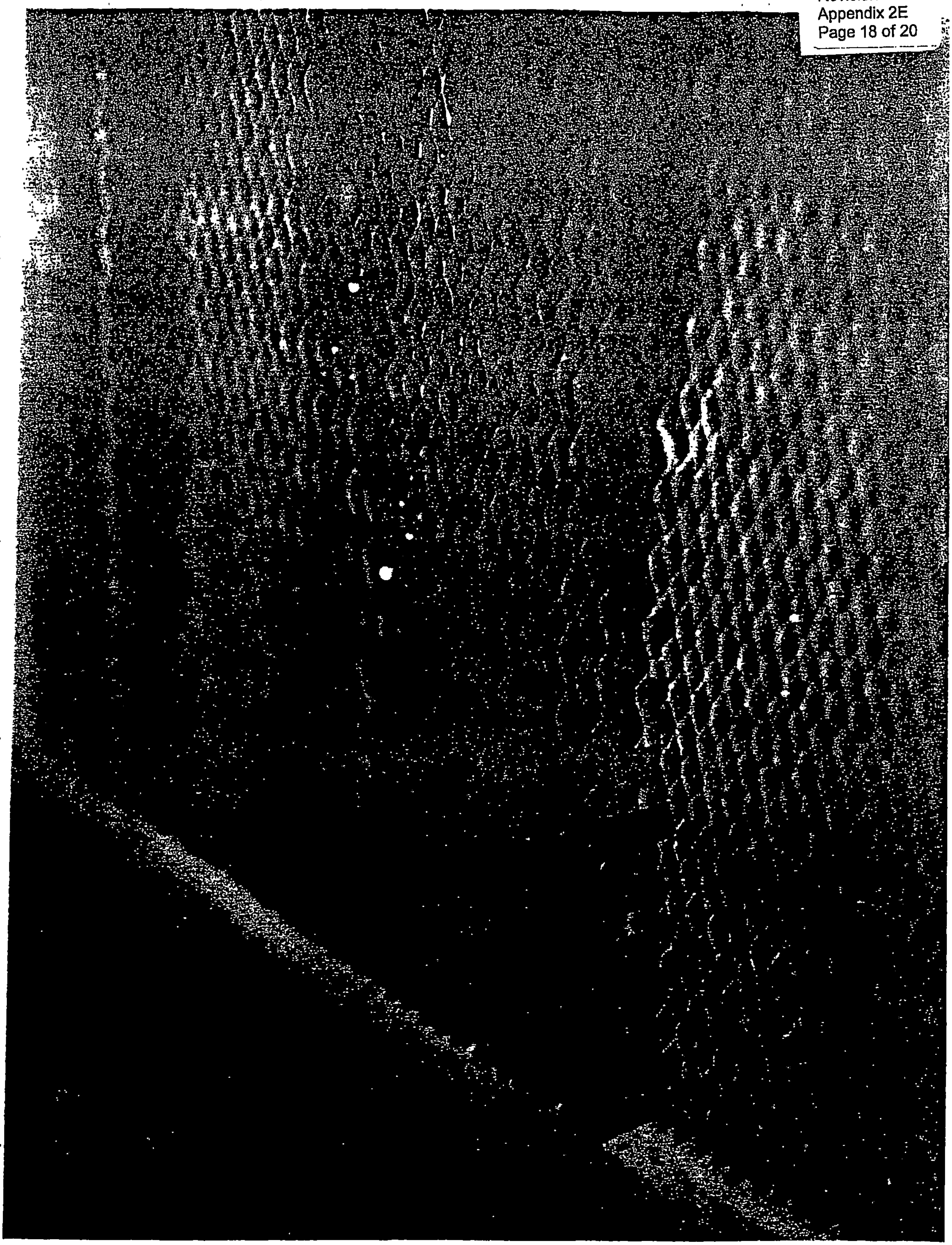


FIGURE 10, SOUTH SIDE OF CONTAINER

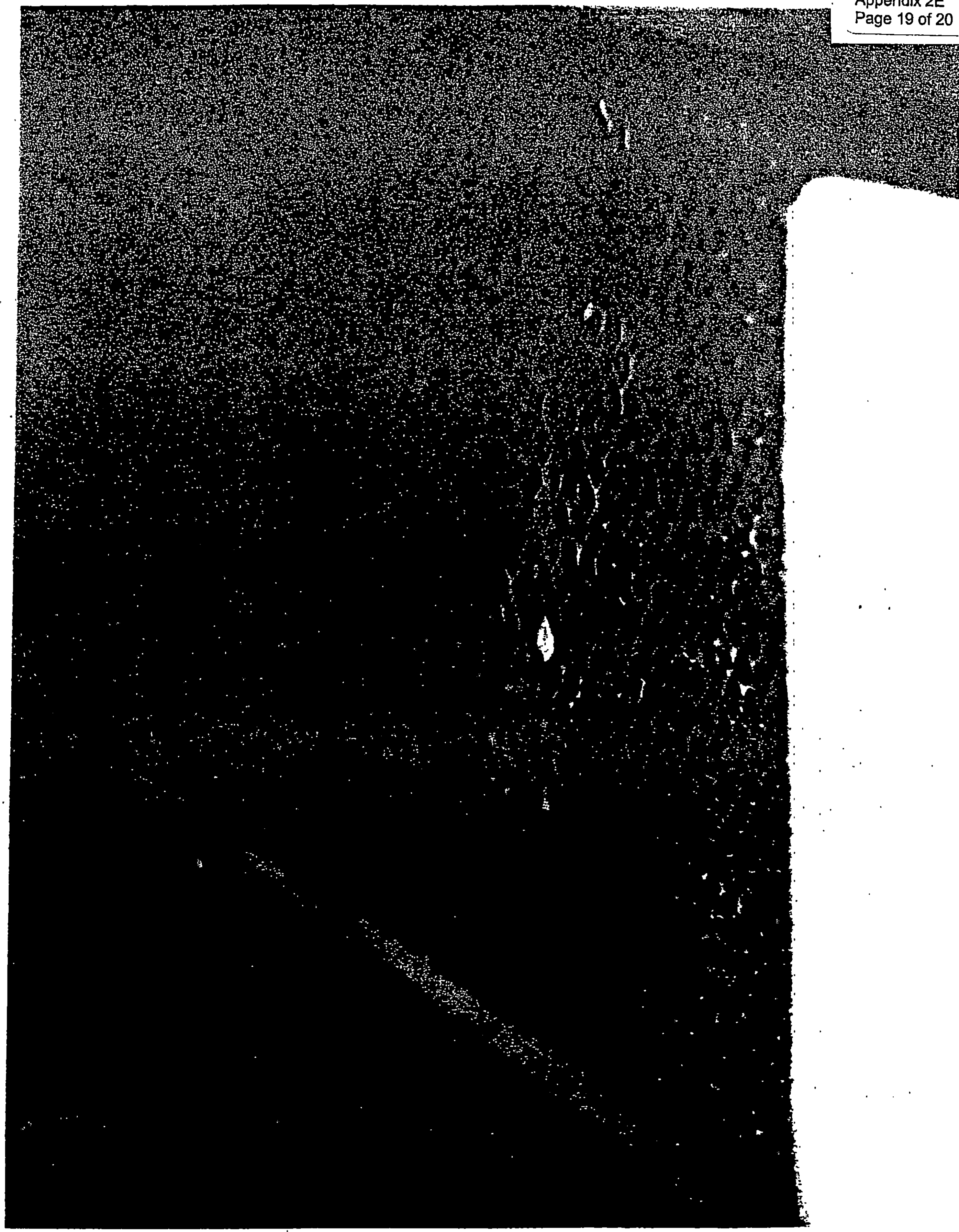


FIGURE 11, BOTTOM OF CONTAINER

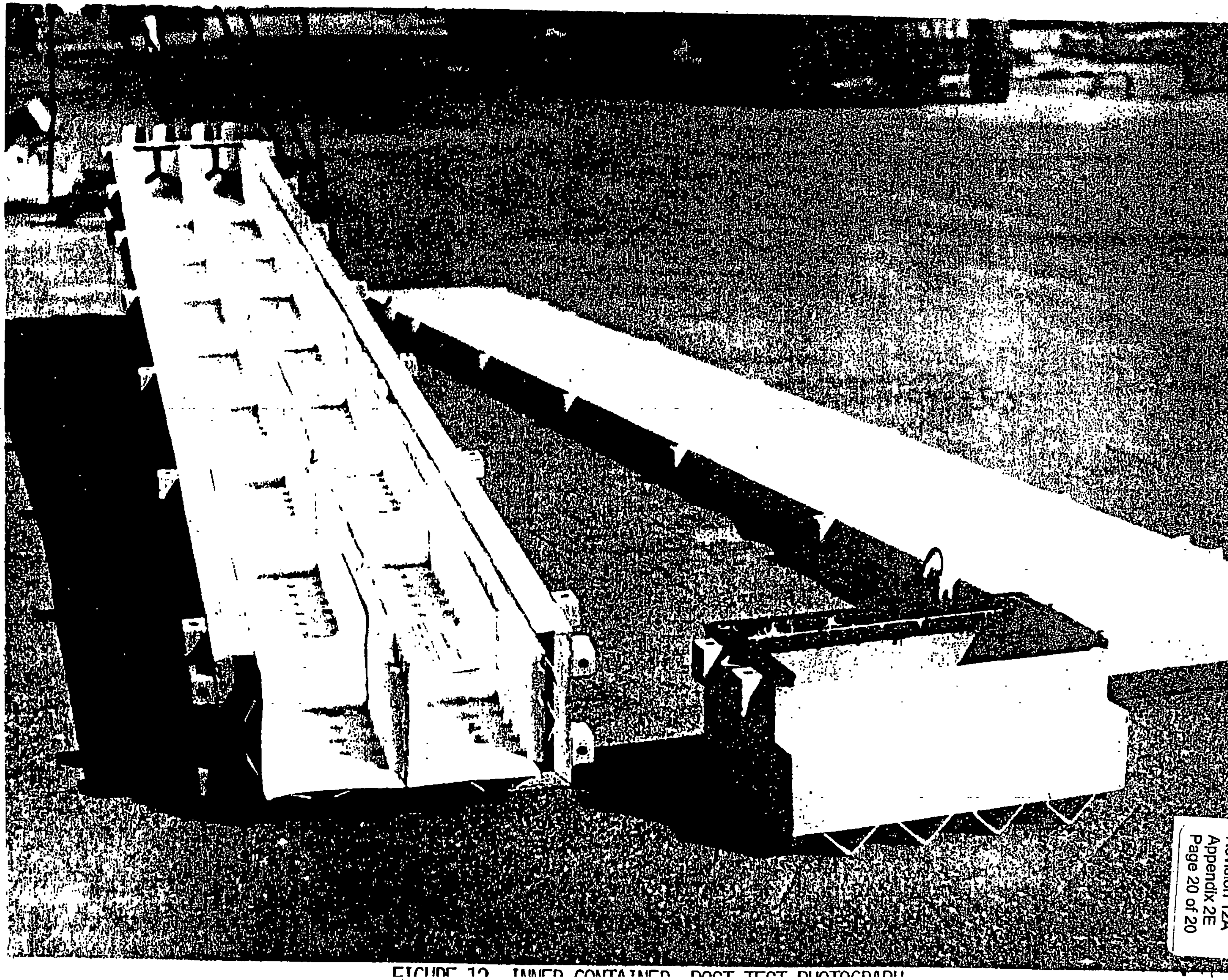


FIGURE 12 INNER CONTAINER - POST TEST PHOTOGRAPH

Appendix 6A

ATTACHMENT 2 OF ADVANCED NUCLEAR FUELS CORPORATION SUPPLEMENTAL APPLICATION TO CERTIFICATE OF COMPLIANCE NO. 4986

ANF-88-120, Re
Issue Date: 7/27/88

SUPPLEMENTAL APPLICATION
TO
CERTIFICATE OF COMPLIANCE NO. 4986

Prepared by

L. D. Gerrald

July 1988

CRITICALITY SAFETY ANALYSIS FOR FUEL TYPES G1 AND G2 AND FOR OUTER CONTAINER PADDING EFFECTS

INTRODUCTION

The objective is to conservatively demonstrate that the subject generic fuel types meet the criticality safety requirements of 10 CFR Part 71 for a Fissile Class I package. Criticality safety is also demonstrated for any honeycomb/ethafoam thickness in the outer container.

Fuel assemblies typically have one or more "water rods" in locations that could contain a fuel rod. The existing wording in Section 5(b)(1) of the Certificate of Compliance includes phrases such as "an 8x8 square array of fuel rods." This could be interpreted to mean that all lattice locations must be occupied by fuel rods. The generic fuel descriptions in the application include unlimited water rods and the criticality safety analysis demonstrates safety with these water rods.

Attachment 3 contains additional data on water rod effects.

METHODS

K-inf (k_{eff}) calculations were performed using transport theory codes XSDRNPM (1-D) and CASMO (2-D) and with the Monte Carlo code KENO-Va (3-D). CASMO was used for several calculations in a broad-based sensitivity study. SCALE codes (BONAMI, NITAWL, XSDRNPM and KENO-Va) were used to replicate selected CASMO cases.

MODEL DESCRIPTION

Package

An infinite array of infinite length inner containers was modeled to conservatively demonstrate criticality safety at normal conditions and at hypothetical accident conditions. Each package contained two identical assemblies with an infinite fuel length.

Since the package is symmetric about the plane midway between the two contained assemblies, models typically included only one of these symmetric halves (one assembly) to represent an infinite array of whole packages. An orientation with two assemblies side by side (left-right) was selected for the model. Only the left assembly was modeled in CASMO but both halves were modeled in KENO.

The steel parts modeled are:

- Two edge-to-edge "baskets" of 0.0598 inch thick carbon steel with 0.75 inch diameter holes in a 1.75 inch square pitch pattern. Accordingly, the basket was modeled as 85.57 vol% carbon steel and 14.43 vol% moderation.

- The outer shell of the inner container was modeled as 0.0598 inch thick carbon steel (100 vol%).
- The annulus between the basket and the shell contains six angles of 0.125 inch thick carbon steel. For the left half (CASMO) model, three angles were included: one each above, below, and to the left of the assembly. These angles were represented as "smeared" steel in the moderation occupying the annulus. Other calculations with a more explicit modeling of the geometry of the steel angles yielded results not significantly different from the "smeared steel" model. Since peak reactivity occurs with low density interspersed moderation, neutrons have relatively long mean-free path lengths and would be expected to interact with all steel in the system. Therefore, the smeared steel model is adequate.

The steel mass in the infinite length inner container model is about 525 pounds per 177.6 inch length. The measured weights of the three inner container components (lid, removable end, main body) are 197, 15 and 399 pounds, respectively. The total tare weight is about 611 pounds. A generous allowance for the weight of the ethafoam and wood in the samples is six pounds. Therefore, the estimated steel weight is 605 pounds. For the infinite length model, twice the mass of the removable end is subtracted to yield a 575 pound weight. Since the actual system contains considerably more steel than that modeled, the model results are conservative.

The basket outer dimensions were 7.0"x7.0" (x infinite length). The assembly was centered in the basket and the two baskets were edge-to-edge; i.e., the plane of symmetry was at the right edge of the left basket.

The annulus was 2.0 inches thick. Therefore, the inner dimensions of the shell of the inner container are 18 inches wide by 11 inches high. With the 0.0598 inch thick shell, the outer dimensions are about 18.12 inches wide by 11.12 inches high.

All volume not occupied by rods or steel was filled with uniform density water.

FUEL MODELS

Three assembly types (7x7, 8x8 and 9x9) were modeled with a fixed 5.0"x5.0" assembly size. To conservatively demonstrate safety for generic assemblies with various numbers of water rods and with various pellet diameters, pellet and clad dimensions were calculated for models with water/fuel volume ratios (Vw/Vf) in the range 1.0 to 4.0. typical Vw/Vf ratios for actual assemblies are in the range 1.5 to 2.5. for flooded conditions, the optimum Vw/Vf is typically 2.5 to 3.5. However, for arrays of edge-to-edge packages, the k-inf with low density interspersed moderation is much greater than that at flooded conditions. With low density interspersed moderation, the dominant effect is increasing k-inf with increasing pellet diameter. At these conditions, the between-assembly moderation is worth more than within-assembly moderation; i.e., the Vw/Vf effect is relatively small and the perimeter rods in an assembly are much better moderated and much more reactive than interior rods in the assembly.

The pellet diameters and the rod pitches used are listed in Table 1. In all cases, the clad ID/OD values are 0.006/0.056 inches larger than the pellet diameter.

TABLE 1

PELLET DIAMETERS/ROD PITCHES MODELED
FOR 5.0"x5.0" BUNDLE

Vw/Vf	7x7 Type Dia./Pitch (in)	8x8 Type Dia./Pitch (in)	9x9 Type Dia./Pitch (in)
1.0	0.5550/0.7315	0.4801/0.6377	0.4221/0.5652
1.5	0.5049/0.7399	0.4363/0.6440	0.3835/0.5701
2.0	0.4668/0.7462	0.4031/0.6487	0.3542/0.5737
2.5	0.4364/0.7513	0.3767/0.6525	0.3309/0.5766
3.0	0.4115/0.7554	0.3551/0.6556	0.3118/0.5790
3.5	0.3906/0.7589	0.3369/0.6582	0.2957/0.5810
4.0	0.3726/0.7619	0.3213/0.6604	0.2820/0.5828

For an NxN assembly with rod pitch "PIT" and with a clad outer diameter "COD", the assembly size is defined by:

$$\text{Assembly Size} = \text{PIT} * (\text{N}-1) + \text{COD}$$

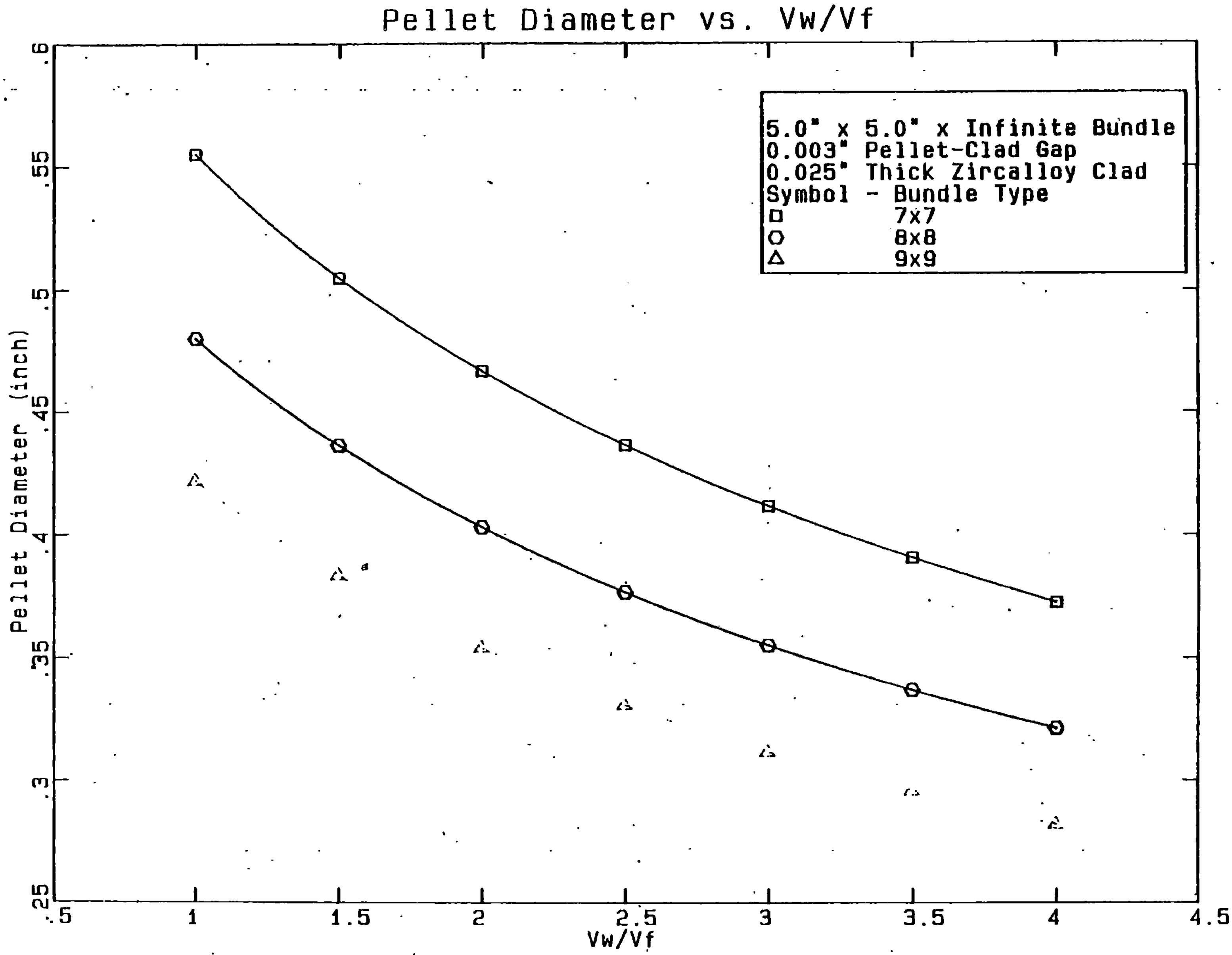
For the 7x7 assembly with a Vw/Vf of 1.0, the assembly size is:

$$0.7315 * 6 + (0.5550 + 0.056) = 5.0 \text{ inches}$$

Figure 1 shows the relation between pellet diameter and Vw/Vf for the three assembly types.

RESULTS FOR TYPE G1 FUEL

All rods were 3.3 percent enriched UO_2 at 95 percent TD (10.412 gm/cc). There was no Gd_2O_3 in the model. All locations in the 7x7, 8x8 or 9x9 assembly were occupied by fuel rods. The CASMO-3 results with various interspersed water densities are in Table 2.



FIGUR

4

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TABLE 2

K-INF DATA FOR EDGE-EDGE INNER CONTAINERS
TYPE G1 FUEL AT 3.3% ENRICHMENT
CASMO-3 RESULTS

Water Density Vol%	Vw/Vf 1.0	1.5	2.0	2.5	3.0	3.5	4.0
				7x7 Assembly			
8	0.9595	0.9593	0.9546	0.9473	0.9376	0.9269	0.9155
10	0.9623	0.9596	0.9529	0.9435	0.9327	0.9209	0.9086
12	0.9570	0.9526	0.9445	0.9341	0.9225	0.9101	0.8974
100	0.7370	0.7590	0.7670	0.7670	0.7624	0.7548	0.7455
				8x8 Assembly			
8	0.9554	0.9543	0.9490	0.9468	0.9307	0.9198	0.9080
10	0.9577	0.9542	0.9469	0.9368	0.9256	0.9134	0.9008
12	0.9521	0.9469	0.9380	0.9272	0.9151	0.9023	0.8895
100	0.7344	0.7560	0.7644	0.7646			
				9x9 Assembly			
8	0.9516	0.9499	0.9440	0.9352	0.9248	0.9134	0.9014
10	0.9539	0.9497	0.9417	0.9312	0.9196	0.9070	0.8941
12	0.9484	0.9424	0.9329	0.9216	0.9090	0.8960	0.8829
100	0.7264	0.7474	0.7554	0.7555	0.7510	0.7437	0.7348

The Table 2 results indicate:

- The optimum interspersed water density is about 10 percent.
- The peak reactivity is with the largest pellet diameter; i.e., the 7x7 assembly with the Vw/Vf ratio of 1.0.
- This fuel type is adequately subcritical in a Fissile Class I package.

Figures 2 and 3 show the Table 2 data at 8, 10 and 12 percent water densities. Figure 2 shows a decrease in k-inf with increasing Vw/Vf while Figure 3 shows an increasing k-inf with increasing pellet diameter.

Figure 4 shows water density effects for the 7x7 assembly.

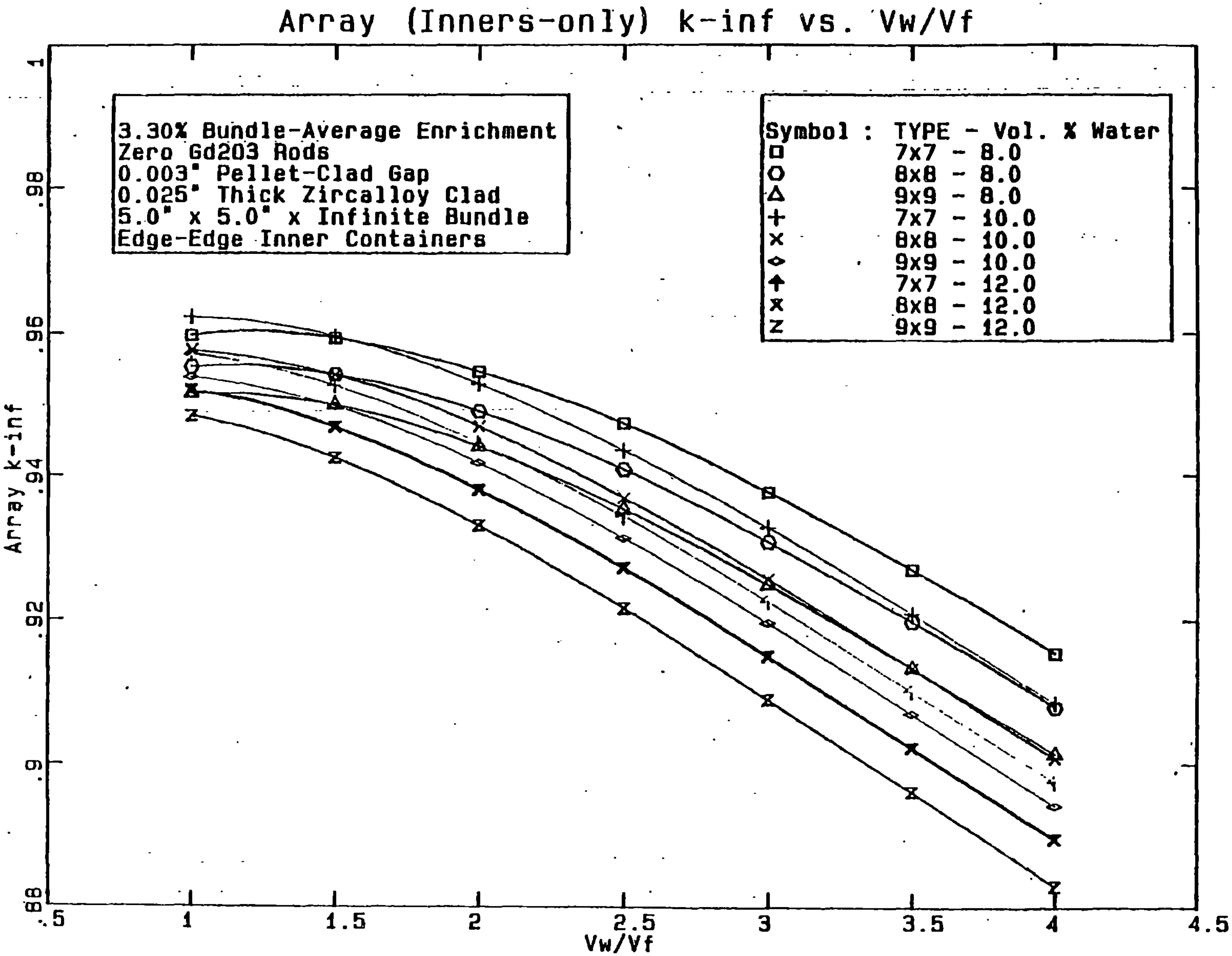
Array (Inners-only) k-inf vs. Vw/Vf
3.30% Bundle-Average Enrichment
Zero Gd203 Rods
0.003" Pellet-Clad Gap
0.025" Thick Zircalloy Clad
5.0" x 5.0" x Infinite Bundle
Edge-Edge Inner Containers
Symbol : TYPE - Vol. % Water
7x7 - 8.0
8x8 - 8.0
9x9 - 8.0
7x7 - 10.0
8x8 - 10.0
9x9 - 10.0
7x7 - 12.0
8x8 - 12.0
9x9 - 12.0
Array k-inf
Vw/Vf
1
.98
.96
.94
.92
.9
.88
.5
1
1.5
2
2.5
3
3.5
4
4.5

FIGURE 2

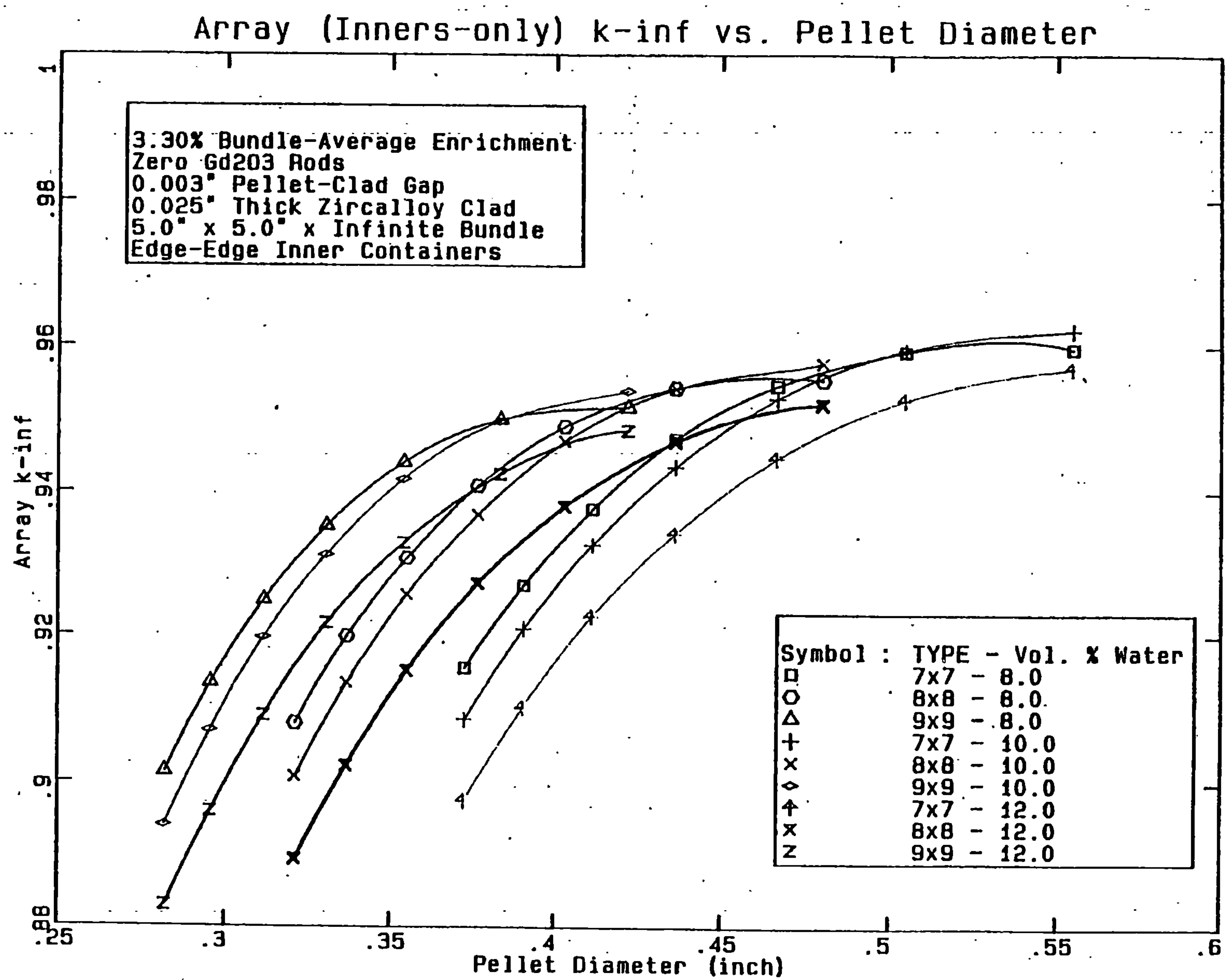

FIGURE 3

7

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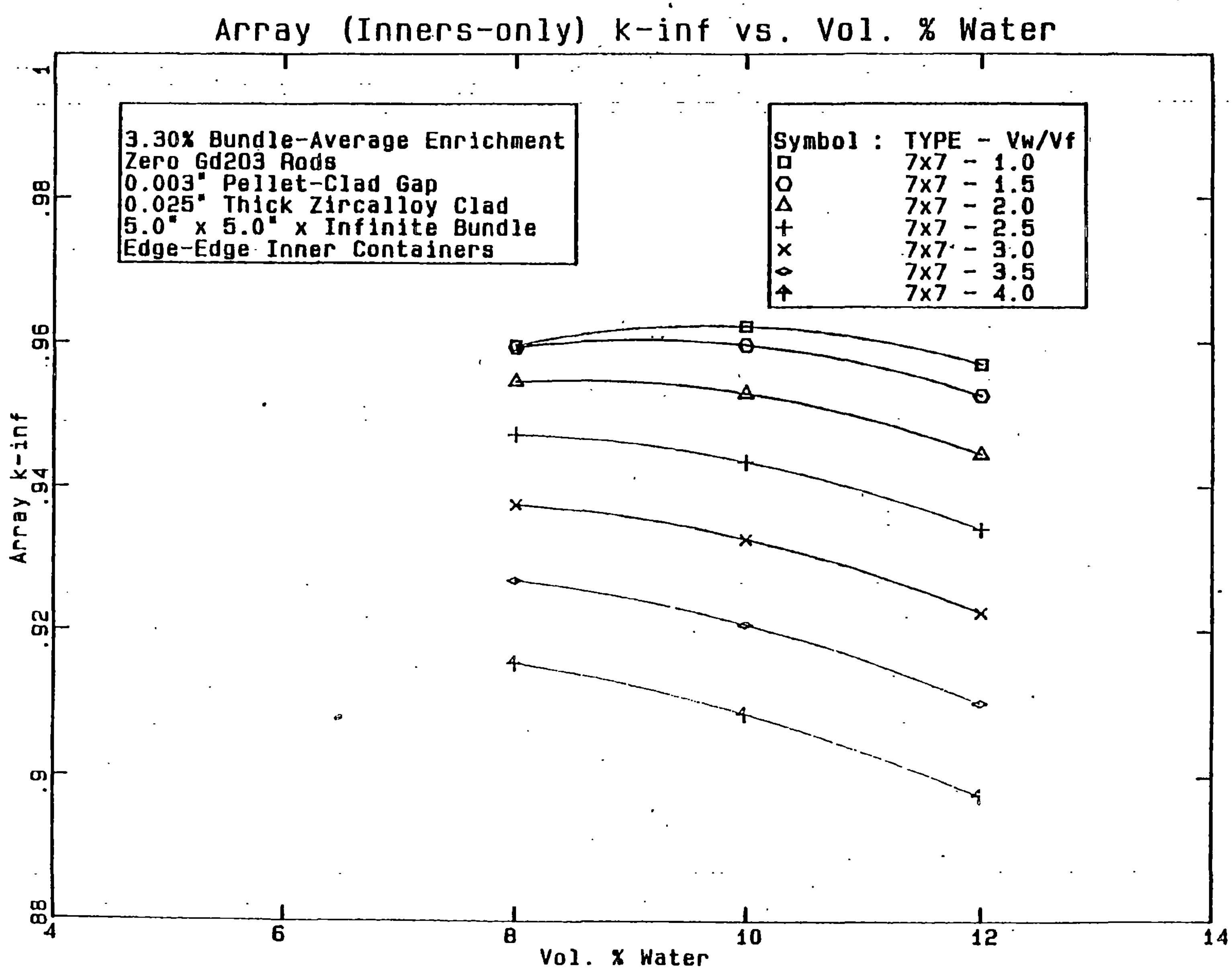

Array (Inners-only) k-inf vs. Vol. % Water
3.30% Bundle-Average Enrichment
Zero Gd2O3 Rods
0.003" Pellet-Clad Gap
0.025" Thick Zircalloy Clad
5.0" x 5.0" x Infinite Bundle
Edge-Edge Inner Containers
Symbol : TYPE - Vw/Vf
7x7 - 1.0
7x7 - 1.5
7x7 - 2.0
7x7 - 2.5
7x7 - 3.0
7x7 - 3.5
7x7 - 4.0
Array k-inf
1
.98
.96
.94
.92
.9
.88
4
6
8
10
12
14
Vol. % Water

FIGURE 4

RESULTS FOR TYPE G2 FUEL

The specified Gd_2O_3 requirement is at least four rods with at least 2.0 wt% Gd_2O_3. The four rods shall be symmetric about the assembly diagonal in non-perimeter locations. The cases modeled contained only four UO_2-Gd_2O_3 (poison) rods in the 7x7, 8x8 and 9x9 assemblies. The poison rod arrangements modeled are:

ARRANGEMENT A

7x7 Bundle

U	U	U	U	U	U	U
U	P	U	U	U	P	U
U	U	U	U	U	U	U
U	U	U	U	U	U	U
U	U	U	U	U	U	U
U	P	U	U	U	P	U
U	U	U	U	U	U	U

8x8 Bundle

U	U	U	U	U	U	U	U
U	P	U	U	U	U	P	U
U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U
U	P	U	U	U	U	P	U
U	U	U	U	U	U	U	U

9x9 Bundle

U	U	U	U	U	U	U	U	U
U	P	U	U	U	U	U	P	U
U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U
U	P	U	U	U	U	U	P	U
U	U	U	U	U	U	U	U	U

ARRANGEMENT B

7x7 Bundle

U	U	U	U	U	U	U
U	U	P	U	U	U	U
U	P	U	U	U	U	U
U	U	U	U	U	U	U
U	U	U	U	U	P	U
U	U	U	U	P	U	U
U	U	U	U	U	U	U

8x8 Bundle

U	U	U	U	U	U	U	U
U	U	P	U	U	U	U	U
U	P	U	U	U	U	U	U
U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U
U	U	U	U	U	U	P	U
U	U	U	U	U	P	U	U
U	U	U	U	U	U	U	U

9x9 Bundle

U	U	U	U	U	U	U	U	U
U	U	P	U	U	U	U	U	U
U	P	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	P	U
U	U	U	U	U	U	P	U	U
U	U	U	U	U	U	U	U	U

ARRANGEMENT C

7x7 Bundle

U	U	U	U	U	U	U
U	U	U	P	U	U	U
U	U	U	U	U	U	U
U	P	U	U	U	P	U
U	U	U	U	U	U	U
U	U	U	P	U	U	U
U	U	U	U	U	U	U

8x8 Bundle

U	U	U	U	U	U	U	U
U	U	U	P	U	U	U	U
U	U	U	U	U	U	U	U
U	P	U	U	U	U	U	U
U	U	U	U	U	U	P	U
U	U	U	U	U	U	U	U
U	U	U	U	P	U	U	U
U	U	U	U	U	U	U	U

9x9 Bundle

U	U	U	U	U	U	U	U	U
U	U	U	P	U	U	U	U	U
U	U	U	U	U	U	U	U	U
U	P	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	P	U
U	U	U	U	U	U	U	U	U
U	U	U	U	U	P	U	U	U
U	U	U	U	U	U	U	U	U

ARRANGEMENT D

9x9 Bundle

```
U U U U U U U U U
U U U U P U U U U
U U U U U U U U U
U U U U U U U U U
U P U U U U U P U
U U U U U U U U U
U U U U U U U U U
U U U U P U U U U
U U U U U U U U U
```

The CASMO results for type G2 fuel in various arrangements are in Table 3.

TABLE 3

K-INF DATA FOR EDGE-EDGE INNER CONTAINERS
TYPE G2 FUEL AT 4.0% ENRICHMENT
CASMO-3 RESULTS

Water Density (Vol%)	Vw/Vf 1.0	1.5	2.0	2.5	3.0	3.5	4.0
	7x7 Assembly, Poison Rod Arrangement B						
4	0.9019	0.9003	0.8954	0.8884	0.8802	0.8710	0.8612
6	0.9324	0.9259	0.9169	0.9063	0.8949	0.8827	0.8703
8	0.9417	0.9316	0.9198	0.9069	0.8932	0.8795	0.8659
10	0.9400	0.9274	0.9136	0.8988	0.8843	0.8697	0.8553
	7x7 Assembly, Poison Rod Arrangement C						
6	0.9331	0.9265	0.9174	0.9066	0.8950	0.8827	0.8701
8	0.9427	0.9324	0.9204	0.9073	0.8934	0.8795	0.8658
10	0.9411	0.9284	0.9143	0.8994	0.8846	0.8698	0.8552
100	0.7073	0.7206	0.7228	0.7191			
	8x8 Assembly, Poison Rod Arrangement A						
8	0.9328	0.9245	0.9142	0.9025	0.8901	0.8773	0.8650

TABLE 3 (Cont.d)

Water Density (Vol%)	Vw/Vf 1.0	1.5	2.0	2.5	3.0	3.5	4.0
			8x8 Assembly, Poison Rod Arrangement B				
6	0.9354	0.9301	0.9221	0.9122	0.9012	0.8894	0.8774
8	0.9446	0.9358	0.9248	0.9125	0.8994	0.8864	0.8731
10	0.9424	0.9312	0.9184	0.9043	0.8904	0.8763	0.8623
12	0.9338	0.9210	0.9068	0.8923	0.8776	0.8631	0.8490
			8x8 Assembly, Poison Rod Arrangement C				
6	0.9368	0.9312	0.9229	0.9127	0.9015	0.8895	0.8773
8	0.9463	0.9371	0.9259	0.9132	0.8998	0.8866	0.8730
10	0.9444	0.9328	0.9896	0.9052	0.8909	0.8765	0.8623
			9x9 Assembly, Poison Rod Arrangement B				
6	0.9370	0.9325	0.9250	0.9156	0.9049	0.8935	0.8818
8	0.9462	0.9382	0.9279	0.9160	0.9034	0.8906	0.8775
10	0.9440	0.9336	0.9213	0.9081	0.8944	0.8805	0.8652
			9x9 Assembly, Poison Rod Arrangement C				
6	0.9384						
8	0.9480	0.9397	0.9290	0.9168	0.9039	0.8909	0.8776
10	0.9461						
			9x9 Assembly, Poison Rod Arrangement D				
6	0.9389						
8	0.9486	0.9403	0.9296	0.9172	0.9043	0.8911	0.8778
10	0.9468						

The Table 2 results indicate that the peak reactivity condition for type G2 fuel with arrangements A-D is:

- A 9x9 assembly with a Vw/Vf of 1.0.
- Poison rod Arrangement D.
- About 8 volume percent interspersed water.

In contrast to the unpoisoned type G1 results which showed that the assembly with the largest pellet diameter (7x7, Vw/Vf=1.0) was most reactive, the poisoned assembly results indicate that the 9x9 assembly is most reactive. A probable reason is that, for a fixed number of poison rods (four here), the fractional poison rod content is decreasing in the sequence 7x7, 8x8 and 9x9; i.e., 4/49, 4/64 and 4/81. The peak reactivity for the three assembly arrays in all poison rod arrangements are nearly equal. The poison effect appears to slightly offset the pellet diameter effect.

Arrangement D is most reactive because the most reactive (best moderated) rods in the assemblies are the corner rods and because the Gd_2O_3 becomes a more effective poison with increasing moderation. As we move the poison rods away from the corner rods, we gain full benefit from corner moderation and decrease the poison effectiveness.

This is actually a very conservative model due to assuming that all rods are at the assembly-average enrichment. Actual assemblies will have multiple enrichments with the lower enrichments on the perimeter and the higher enrichments inside where less moderation is available. This is required to assure approximately equal powers for the rods in the operating assembly.

The models and the limits proposed are also very conservative because the reactivity of new fuel assemblies are approximately constant regardless of the assembly-average enrichment. The typical in-core k-inf values for new fuel will be in the range 1.10 to 1.20. As enrichments are increased, the new fuel reactivity is controlled by increased amounts of burnable poison (Gd_2O_3).

Based on the results in Table 3, additional poison rod arrangements were modeled. These arrangements were based on the premise that moving the poison rods toward the assembly interior would result in higher reactivities. The arrangements are:

```
7x7 Bundle               9x9 Bundle               9x9 Bundle
Arrangement C2           Arrangement D2           Arrangement D3

                         U U U U U U U U U        U U U U U U U U U
U U U U U U U            U U U U U U U U U        U U U U U U U U U
U U U U U U U            U U U U P U U U U        U U U U U U U U U
U U U P U U U            U U U U U U U U U        U U U U P U U U U
U U P U P U U            U U P U U U P U U        U U U P U P U U U
U U U P U U U            U U U U U U U U U        U U U U P U U U U
U U U U U U U            U U U U P U U U U        U U U U U U U U U
U U U U U U U            U U U U U U U U U        U U U U U U U U U
                         U U U U U U U U U        U U U U U U U U U
```

The k-inf results are in Table 4.

TABLE 4

K-INF DATA FOR EDGE-EDGE INNER CONTAINERS
TYPE G2 FUEL AT 4.0% ENRICHMENT
CASMO-3 RESULTS

Water Density (Vol%)	Vw/Vf 1.0	1.5	2.0	2.5	3.0	3.5	4.0
			7x7 Arrangement C2				
8	0.9588	0.9484	0.9359	0.9222	0.9076	0.8931	0.8787
			9x9 Arrangement D2				
8	0.9602	0.9512	0.9397	0.9266	0.9129	0.8991	0.8851
100	0.7201	0.7336	0.7370				
			9x9 Arrangement D3				
8	0.9676	0.9591	0.9477	0.9346	0.9208	0.9068	0.8926
100	0.7258	0.7393	0.7427				

The Table 4 results are consistent in showing the 9x9 assembly as most reactive and in showing that the most reactive poison rod arrangement has them removed from the corner/edge fuel rods. As described earlier, poison effectiveness is decreased in regions with depressed thermal flux. Having the poison rods in the center of the assembly and close together is expected and observed to be the most reactive arrangement.

An infinite array of edge-to-edge inner containers will be adequately subcritical with optimum interspersed moderation and with generic fuel types G1 and G2. An infinite array of edge-to-edge packages with the wooden outer container present will be bounded by the results for inner containers.

KENO-Va RESULTS

Selected CASMO cases were replicated using KENO-Va and other codes/cross sections from the SCALE-3 system. The Criticality Safety Analysis Sequence (CSAS) routines were used to calculate atom densities but the CSAS calculated escape cross section input into BONAMI array 9** was not used for the reasons detailed below.

The CSAS routines provide inputs for BONAMI and NITAWL. When 16-group cross sections are used, as they were here, the self-shielding corrections for U-235 and U-238 are done by BONAMI. The ISSOPT option in BONAMI set by CSAS is for a homogeneous system. Appropriate "extra" cross sections may be entered into

BONAMI array 9**. The sig-esc calculated by CSAS for a rod array is that for the center rod in a 3x3 array with the assumption that the center rod neutrons encounter only the other eight rods in the 3x3 array. For arrays flooded with water or other media with a similar total cross section, this is a good approximation.

For low density interspersed moderation, this 3x3 model can lead to non-conservative errors:

The Dancoff factor for the 3x3 array is too low because the central rod neutrons may actually encounter more than eight other rods.

The calculated sig-escape will be too high for the same reason.

If this sig-escape is used in BONAMI, the resulting cross sections will be non-conservative; i.e., the k-inf (k_{eff}) results obtained will tend to be lower than actual.

It is noted that the low Dancoff factor is entered by CSAS into the NITAWL input which could also yield non-conservative results when using the 27-group or the 123-group cross section libraries.

If the modeled rods are nearly edge-to-edge, the errors in the 3x3 CSAS model are reduced. Also, as the moderator (water) density is increased, the non-conservative errors are reduced/eliminated.

Others, including code custodians (Lester Petrie) at RSIC have been informed.

Notes on self-shielding calculations follow.

- Dancoff factors and sig-escapes were calculated using a Monte Carlo model of infinite and finite rod arrays.
- The results obtained with BONAMI using ISSOPT equal 2 (unclad) or 9 (clad) agree well with the infinite lattice Monte Carlo results.
- If self-shielding corrections are based on an infinite array of rods, the results will be very conservative because the perimeter rods are better moderated (they have higher sig-escapes) than the interior rods; i.e., the infinite lattice model contains only interior rods while the actual assembly is about 40 (9x9) to 49 (7x7) percent perimeter rods.
- KENO models used three UO_2 rod types and, as applicable, one UO_2-Gd_2O_3 rod type. The three UO_2 rod types are interior (non-perimeter) rods, edge rods facing the companion assembly, and the rods on the other three edges of the assembly. The Monte Carlo derived sig-esc was used in BONAMI array 9** with ISSOPT = 0.

RESULTS FOR TYPE G1 BUNDLES

7X7 Assembly, Vw/Vf = 1.0, 10% Water Density

k-inf = 0.9563 ± 0.0035 (KENO-Va)

k-inf = 0.9623 (CASMO) (From Table 2)

The macro sig-esc values used in BONAMI for the interior, edge-out and edge-in (facing other assembly) rods are 0.2321, 0.4059 and 0.3529.

8x8 Assembly, Vw/Vf = 1.0, 10% Water Density

k-inf = 0.9521 ± 0.0032 (KENO-Va)

k-inf = 0.9577 (CASMO)

The macro sig-esc values used in BONAMI for the interior, edge-out and edge-in (facing other assembly) rods are 0.2531, 0.4409 and 0.3680.

KENO-Va RESULTS FOR TYPE G2 BUNDLES 9X9 ASSEMBLY, POISON ROD ARRANGEMENT D3

Results with 10 percent water density:

- 16-group cross sections: 0.9640 ± 0.0032
- 123 group cross sections: 0.9610 ±0.0039
- 27 group cross sections: 0.9514 ± 0.0037

As is often observed, the 27-group cross section results are biased low by about 0.01.

The results with eight percent water density:

- 16-group cross sections: 0.9611 ± 0.0032
- CASMO: 0.9676 (Table 4)

The CASMO-KENO agreement is very good.

Typical inputs to BONAMI, NITAWL, KENO-Va and CASMO are in Attachment 4.

OUTER CONTAINER PADDING EFFECTS

Infinite arrays of undamaged packages were modeled to demonstrate that reduced amounts of honeycomb/ethafoam in the outer container cannot lead to criticality. The outer container cross sectional area is about 29.75 inches wide by about 27.25 inches tall without the spacing of the nominal 4x4 skids at the bottom.

With the skid spacing, the packages are on about 29.75"x30.75" centers.

KENO-Va calculations for inner containers on 29.75"x29.75" centers produced the results in Table 5. The outer container was represented by four 0.5 inch thick plywood walls. All volume not occupied by wood, fuel, or the steel of the inner container was filled with low density water. The most reactive unpoisoned fuel type (7x7, Vw/Vf=1.0) was modeled inside the package. According to the results presented, the most reactive type G2 fuel (9x9 arrangement D3) will yield very similar results. The KENO-Va model is identical to that cited earlier (inner container arrays) except for the addition of spacing filled with wood and moderation.

TABLE 5

INFINITE ARRAY OF UNDAMAGED PACKAGES
OUTER CONTAINER IS 0.5 INCH PLYWOOD PLUS LOW DENSITY WATER
KENO-Va RESULTS

Water Density (Vol%)	k-inf
0	0.9627 ± 0.0037
0.5	0.9555 ± 0.0030
1	0.9432 ± 0.0038
2	0.9125 ± 0.0034

All of the results are subcritical and they indicate that adding moderation such as honeycomb, ethafoam, and additional wood (2x4's, 4x4's) to the plywood-only model would result in reduced reactivities. Therefore, the honeycomb/ethafoam in the outer container is not needed for criticality safety nor for cushioning during the hypothetical accident conditions. Accordingly, there is no adverse safety effect by allowing any honeycomb/ethafoam thickness nor by allowing unlimited cutouts of these pads.

Additional KENO cases were run without plywood in the model; i.e., the entire volume between inner containers was filled with low density water. These results are useful for comparison to the k-inf results for edge-edge inner containers and also to determine the optimum interspersed water density.

TABLE 6

INNER CONTAINERS ON 29.75" X 29.75" CENTERS
WATER-ONLY BETWEEN CONTAINERS IN INFINITE ARRAY
KENO-Va RESULTS

Water Density (Vol%)	k-inf
1	0.9264 ± 0.0030
1.5	0.9563 ± 0.0033
2	0.9469 ± 0.0036
2.5	0.9425 ± 0.0035
3	0.9254 ± 0.0035

The above data indicate that the peak reactivity for the normal array is bounded by the k-inf for edge-edge inner containers. Also, the above data indicate that the package will be subcritical in any array with optimum interspersed moderation; i.e., the outer container is not needed for criticality safety for all fuel types bounded by the reactivities of generic types G1 and G2.

ATTACHMENT 3

WATER ROD EFFECTS

Additional data are presented supporting the allowance of any number of water rods in any arrangement. All results presented in Attachment 2 for fuel types G1 and G2 indicate a decrease in array k-inf with increasing Vw/Vf. The models in Attachment 2 had fuel rods only; water rods were not explicitly modeled but the moderation from water rods (if any) is averaged into the unit cell.

The Table 2 data at optimum interspersed moderation (10% water) are shown in Figure 5. If the three points at each Vw/Vf are connected by the best straight line, seven lines with potentially different slopes and intercepts will be formed. To establish a single function, the slope and intercept were assumed to be a linear function of Vw/Vf.

k-inf = Slope * (Pellet Diameter) + Intercept

Multiple linear regression yields the following for 10 percent water density.

Slope = -3.8614E-2 + 6.1499E-2 * Vw/Vf

Intercept = 0.98728 - 3.8088E-2 * Vw/Vf

The slope increases with Vw/Vf while the intercept decreases with increasing Vw/Vf. This is obvious from visual examination of Figure 5.

The desired function of pellet diameter (in inches) (POD) and Vw/Vf (VWVF) is:

k-inf = 0.9873 -3.8614E-2 * POD - 3.8088E-2 * VWVF + 6.1499E-2 * (POD * VWVF).

The above equation represents the type G1 k-inf data (10 percent water) with a standard error of 0.00207 in k-inf.

For a 0.555 inch pellet diameter, the regression equation becomes:

k-inf = 0.9658 - 3.9561E-3 * VWVF

The predicted k-inf results for a 0.555 inch diameter pellet with 10 percent dense water are listed in Table 7.

Array (Inners-only) k-inf vs. Pellet Diameter

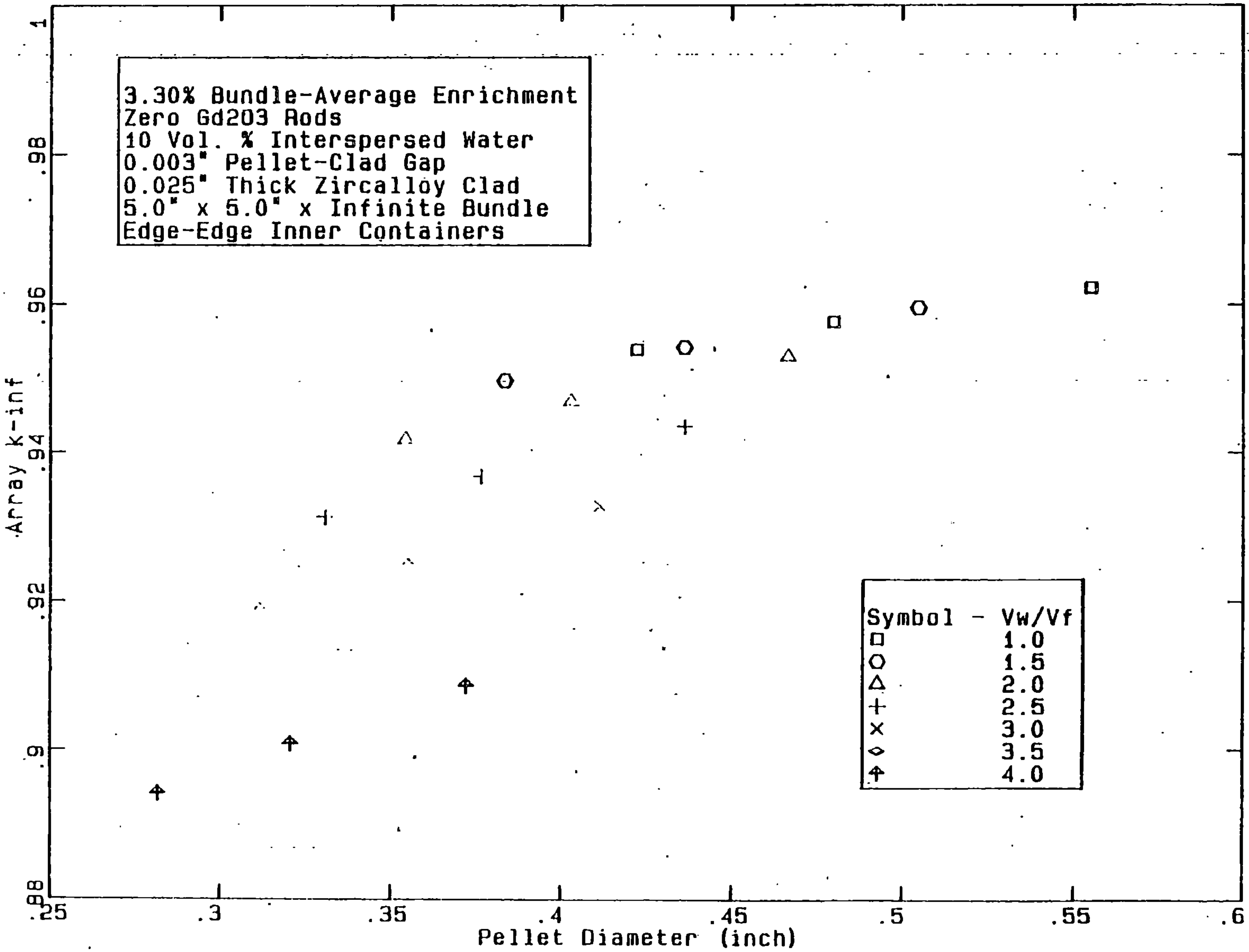


FIGURE 5

TABLE 7

INFINITE ARRAY (INNERS-ONLY) RESULTS
BASED ON REGRESSION EQUATION
0.555 INCH PELLET DIAMETER, 10 PERCENT DENSE WATER

Vw/Vf	k-inf
1.0	0.9619
2.0	0.9579
3.0	0.9540
4.0	0.9500

The above data at the maximum (most reactive) pellet diameter, the k-inf decreases with increasing Vw/Vf. This implies that any number of water rods may be present.

Additional cases were run for a 7x7 assembly (10 percent water) with a 0.555 inch pellet diameter but with explicit modeling of water rods as 100 vol% moderation (no clad).

The rods arrangements and the k-inf (CASMO) are given below. The arrangements for the left bundle in the package is shown. It is noted that the right edge of this assembly is less moderated than the other three sides because of the proximity of the companion assembly to the right. Accordingly, added moderation was preferentially added to the right half of the left assembly.

The arrangement of the right bundle is the mirror image of that of the left bundle.

ARRANGEMENT E1

```
F F F F F F F
F F F F F F F
F F F F F F F
F F F W F F F
F F F F F F F
F F F F F F F
F F F F F F F
```

Vw/Vf = 1.0461
k-inf = 0.9625

ARRANGEMENT E2

```
F F F F F F F
F F F F F F F
F F F F F F F
F F F F W F F
F F F F F F F
F F F F F F F
F F F F F F F
```

Vw/Vf = 1.0461
k-inf = 0.9626

ARRANGEMENT E3

```
F F F F F F F
F F F F F F F
F F F F F F F
F F F F F W F
F F F F F F F
F F F F F F F
F F F F F F F
```

Vw/Vf = 1.0461
k-inf = 0.9625

ARRANGEMENT E4

F	F	F	F	F	F	F
F	F	F	F	F	F	F
F	F	F	F	F	F	F
F	F	F	W	W	F	F
F	F	F	F	F	F	F
F	F	F	F	F	F	F
F	F	F	F	F	F	F

Vw/Vf = 1.0941
k-inf = 0.9628

ARRANGEMENT E5

F	F	F	F	F	F	F
F	F	F	F	F	F	F
F	F	F	F	F	F	F
F	F	F	W	F	F	F
F	F	F	F	W	F	F
F	F	F	F	F	F	F
F	F	F	F	F	F	F

Vw/Vf = 1.0941
k-inf = 0.9627

ARRANGEMENT E6

F	F	F	F	F	F	F
F	F	F	F	F	F	F
F	F	F	F	F	F	F
F	F	F	W	W	W	F
F	F	F	F	F	F	F
F	F	F	F	F	F	F
F	F	F	F	F	F	F

Vw/Vf = 1.1443
k-inf = 0.9628

ARRANGEMENT E7

F	F	F	F	F	F	F
F	F	F	F	F	F	F
F	F	W	F	W	F	F
F	F	F	F	F	F	F
F	F	W	F	W	F	F
F	F	F	F	F	F	F
F	F	F	F	F	F	F

Vw/Vf = 1.1966
k-inf = 0.9622

ARRANGEMENT E8

F	F	F	F	F	F	F
F	F	F	F	F	F	F
F	F	W	W	W	F	F
F	F	W	W	W	F	F
F	F	W	W	W	F	F
F	F	F	F	F	F	F
F	F	F	F	F	F	F

Vw/Vf = 1.4977
k-inf = 0.9610

ARRANGEMENT E9

F	F	F	F	F	F	F
F	F	F	F	F	F	F
F	F	F	W	W	W	F
F	F	F	W	W	W	F
F	F	F	W	W	W	F
F	F	F	F	F	F	F
F	F	F	F	F	F	F

Vw/Vf = 1.4977
k-inf = 0.9614

The highest k-inf value is 0.9628 as compared to the 0.9623 value with zero water rods (Vw/Vf = 1.0). This 0.0005 difference is trivial. For the first few water rods, moderation and fuel worths are nearly equal; i.e., replacing fuel rods with moderation (water rods) produces little or no change in k-inf. For the higher Vw/Vf cases, the k-inf is seen to be decreasing because fuel is worth more than moderation.

These data support the model with the moderation from water rods averaged over the entire assembly. Therefore, the Attachment 1 results for fuel types G1 and G2 are appropriate.

ATTACHMENT 4

BONAMI Input for Most Reactive Type G1 Assembly (7x7, Vw/Vf=1.0)

```
' RA-3 WITH 3.3
 0$$ 16 15 18 17
 1$$ 0 3 9 2R1 0
 2** 1.0-5 E
 T
 3$$ 3R1 3R2 3R3
 4$$ 92235 92238 8016 2Q3
 5** 7.76071E-04 2.24538E-02 R.64598E-02 2Q3
 6$$ 1 2 3
 7** 1 2 3
 8** F2.93E+02
 9** 0.2276 0.4095 0.3566
 10$$ 92501 92801 8016 92502 92802 801602 92503 92803 801603
 11$$ F0
 T
```

NITAWL Input for Most Reactive Type G1 Assembly (7x7, Vw/Vf=1.0)

```
' RA-3 WITH 3.3
0$$ 6 7 8 11 18 19 9 0 20
 1$$ 0 11 5R0 0 2R0 -1 0
 T
2$$ 1I92501 92503 1I92801 92803 8016
1001 40302 26000 6012
 4** F2.93E+02
 T
```

KENO-Va Input for Most Reactive Type G1 Assembly (7x7, Vw/Vf=1.0)

```
 7x7 BUNDLE IN RA-3, 3.3
READ PARAMETERS
TME=290.0 GEN=83 NPG=300 LIB=41 TBA=3.0
FLX=YES FDN=YES XS1=YES NUB=YES PWT=YES
PLT=YES
END PARAMETERS
READ MIXT  SCT=1
MIX= 1
'  UO2 PELLET, 3.3
    92501  7.760713E-04
    92801  2.245383E-02
     8016  4.645982E-02
MIX= 2
'  UO2 PELLET, 3.3
    92502 7.760713E-04
    92802 2.245383E-02
     8016  4.645982E-02
```

```
MIX=3
'  UO2 PELLET, 3.3
     92503  7.760713E-04
     92803  2.245383E-02
      8016  4.645982E-02
MIX=4
'  SMEARED ZR CLAD
'  POD,CID,COD= 0.555",0.561",0.611"
' VOL FRACT ZR = 0.8975
'  AT DENS = 0.8975 * 4.2518E-2 = 3.8157E-2
     40302  3.8157E-02
MIX=5
'  WATER, 10 VOL%
      8016  3.337967E-03
      1001  6.675933E-03
MIX=6
'  CARBON STEEL, 100
      6012  3.921682E-03
     26000  8.350009E-02
MIX=7
'  CARBON STEEL, 85.57
5 0.1443
6 0.8557
MIX=8
' CARBON STEEL, 8.64 VOL
' 2.75" X 0.125" THICK ANGLE IN 3.8891" X 2.0" AREA
5 0.9136
6 0.0864
RESM 3 3 1 2 3
END MIXT
READ GEOMETRY
UNIT  1
COM=" INTERIOR UO2 ROD      "
CYLI  1 1 0.70485 2P225.58
CYLI  4 1 0.77597 2P225.58
CUBO  5 1 4P0.929 2P225.58
UNIT  2
COM=" EDGE UO2 ROD      "
CYLI  2 1 0.70485 2P225.58
CYLI  4 1 0.77597 2P225.58
CUBO  5 1 4P0.929 2P225.58
UNIT  3
COM=" EDGE ROD FACING OTHER BUNDLE          "
CYLI  3 1 0.70485 2P225.58
CYLI  4 1 0.77597 2P225.58
CUBO  5 1 4P0.929 2P225.58
UNIT 4
COM="  7X7 BUNDLE IN LEFT BASKET     "
ARRAY 1 2R-6.503 -225.58
CUBO  5 1 4P8.7381 2P225.58
'  ADD 0.00598 INCH OF PERFORATED STEEL
CUBO  7 1 4P8.89 2P225.58
```

```
UNIT 5
COM="  7X7 BUNDLE IN RIGHT BASKET     "
ARRAY 2 2R-6.503 -225.58
CUBO  5 1 4P8.7381 2P225.58
'  ADD 0.00598 INCH OF PERFORATED STEEL
CUBO  7 1 4P8.89 2P225.58
UNIT 6
COM=" SPACING & STEEL ANGLE BESIDE BASKET          "
CUBO  8 1 2P2.54 2P4.9391 2P225.58
CUBO  5 1 2P2.54 2P8.89 2P225.58
UNIT 7
COM=" ANGLES & SPACING BENEATH & ABOVE BASKETS      "
'  ANGLE STEEL SMEARED IN 3.8891" X 2.0" VOLUME
CUBO  8 1 2P4.9392 2P2.54 2P225.58
CUBO  5 1 2P8.89 2P2.54 2P225.58
UNIT 8
COM=" 2X2 INCH MODERATION REGIONS AT CORNERS      "
CUBO  5 1 4P2.54 2P225.58
UNIT 9
COM=" 1 INNER CONTAINER          "
ARRAY 3 -22.86 -13.97 -225.58
' ADD 0.0598 INCH WALLS
REPL  6 1 6R0.1519 1
GLOBAL
UNIT 10
COM="ARRAY OF INNERS           "
'  THIS IS MULTI-UNIT ARRAY WITH SPECULAR REFLECTION
'  ATTEMPT TO REDUCE COLLISIONS WITH BOUNDARY
ARRAY 4 3R0.0
END GEOMETRY
READ ARRAY
ARA=1 NUX=7 NUY=7 NUZ=1
FILL
2 2 2 2 2 2 2
2 1 1 1 1 1 3
2 1 1 1 1 1 3
2 1 1 1 1 1 3
2 1 1 1 1 1 3
2 1 1 1 1 1 3
2 2 2 2 2 2 2
 END FILL
ARA=2 NUX=7 NUY=7 NUZ=1
FILL
2 2 2 2 2 2 2
3 1 1 1 1 1 2
3 1 1 1 1 1 2
3 1 1 1 1 1 2
3 1 1 1 1 1 2
3 1 1 1 1 1 2
2 2 2 2 2 2 2
 END FILL
ARA=3 NUX=4 NUY=3 NUZ=1
```

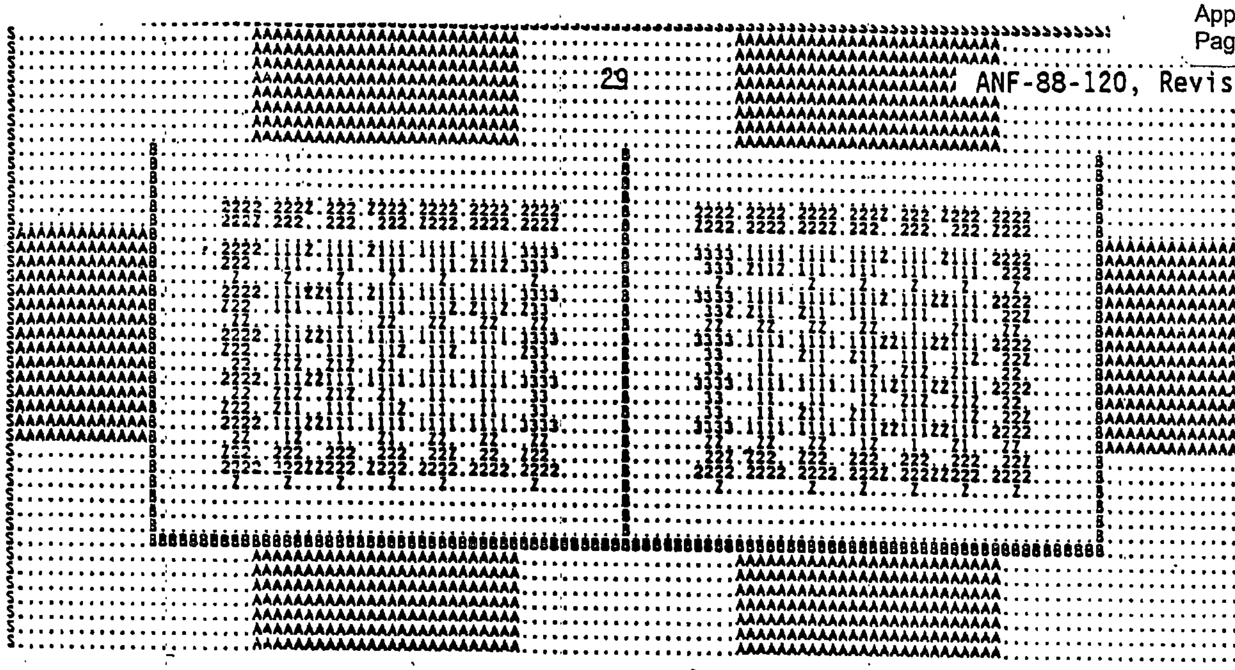
```
FILL
8 7 7 8
6 4 5 6
8 7 7 8
END FILL
ARA=4 NUX=5 NUY=5 NUZ=1
FILL F9 END FILL
END ARRAY
READ START
NST=1
END START
READ BOUNDS
ALL=SPECULAR
END BOUNDS
READ PLOT
TTL=" XY SECTION AT Z=10 CM                    "
NCH=" 123Z.SBA"
XUL=0.0 XLR=46.03 YUL=28.25 YLR=0.0 ZUL=10.0 ZLR=10.0
UAX=1.0 VDN=-1.0 NAX=120 LPI=6 END
TTL="  LEFT HALF       "
NCH=" 123Z.SBA"
XUL=0.0 XLR=23.02 YUL=28.25 YLR=0.0 ZUL=10.0 ZLR=10.0
UAX=1.0 VDN=-1.0 NAX=120 LPI=6 END
TTL=" LOWER RT QUADRANT OF LET HALF            "
NCH=" 123Z.SBA"
XUL=0.0 XLR=11.51 YUL=14.13 YLR=0.0 ZUL=10.0 ZLR=10.0
UAX=1.0 VDN=-1.0 NAX=120 LPI=6 END
TTL=" UPPER LEFT QUADRANT OF LET HALF              "
NCH=" 123Z.SBA"
XUL=0.0 XLR=11.51 YUL=28.25 YLR=14.13 ZUL=10.0 ZLR=10.0
UAX=1.0 VDN=-1.0 NAX=120 LPI=6 END
END PLOT
END DATA

KENO=Va Model for Most Reactive Type G2 Assembly
 9X9 BUNDLE IN RA-3, 4.0
READ PARAMETERS
TME=60.0 GEN=83 NPG=300 LIB=41 TBA=3.0
FLX=YES FDN=YES XS1=YES NUB=YES PWT=YES
PLT=NO
END PARAMETERS
READ MIXT  SCT=1
MIX= 1
'  U02 PELLET, 4.0
     92501 9.4068E-04
     92801  2.2291E-02
      8016  4.6464E-02
MIX= 2
'  U02 PELLET, 4.0
     92502 9.4068E-04
     92802 2.2291E-02
      8016  4.6464E-02
```

```
MIX=3
'  UO2 PELLET, 4.0
     92503 9.4068E-04
     92803  2.2291E-02
      8016  4.6464E-02
MIX=4
'  UO2-GD2O3 PELLET, 4.0 GD2O3, 10.331 GM/CC
     92504  9.147386E-04
     92804  2.167629E-02
      8016  4.621194E-02
     64000  6.865846E-04
MIX=5
'  SMEARED ZR CLAD
'  POD,CID,COD= 0.4221",0.4281",0.4781"
' VOL FRACT ZR = 0.8988
'  AT DENS = 0.8988 * 4.2518E-2 = 3.8215E-2
     40302  3.8215E-02
MIX=6
'  WATER, 8 VOL%
      8016 2.6704-3
      1001 5.3408-3
MIX=7
'  CARBON STEEL, 100
      6012  3.921682E-03
     26000  8.350009E-02
MIX=8
'  CARBON STEEL, 85.57
6 0.1443
7 0.8557
MIX=9
' CARBON STEEL, 8.64 VOL
' 2.75" X 0.125" THICK ANGLE IN 3.8891" X 2.0" AREA
6 0.9136
7 0.0864
END MIXT
READ GEOMETRY
UNIT  1
COM=" INTERIOR UO2 ROD      "
CYLI  1 1 0.5361 2P225.58
CYLI  5 1 0.6072 2P225.58
CUBO  6 1 4P0.71785 2P225.58
UNIT  2
COM=" EDGE UO2 ROD      "
CYLI  2 1 0.5361 2P225.58
CYLI  5 1 0.6072 2P225.58
CUBO  6 1 4P0.71785 2P225.58
UNIT  3
COM=" EDGE ROD FACING OTHER BUNDLE         "
CYLI  3 1 0.5361 2P225.58
CYLI  5 1 0.6072 2P225.58
CUBO  6 1 4P0.71785 2P225.58
```

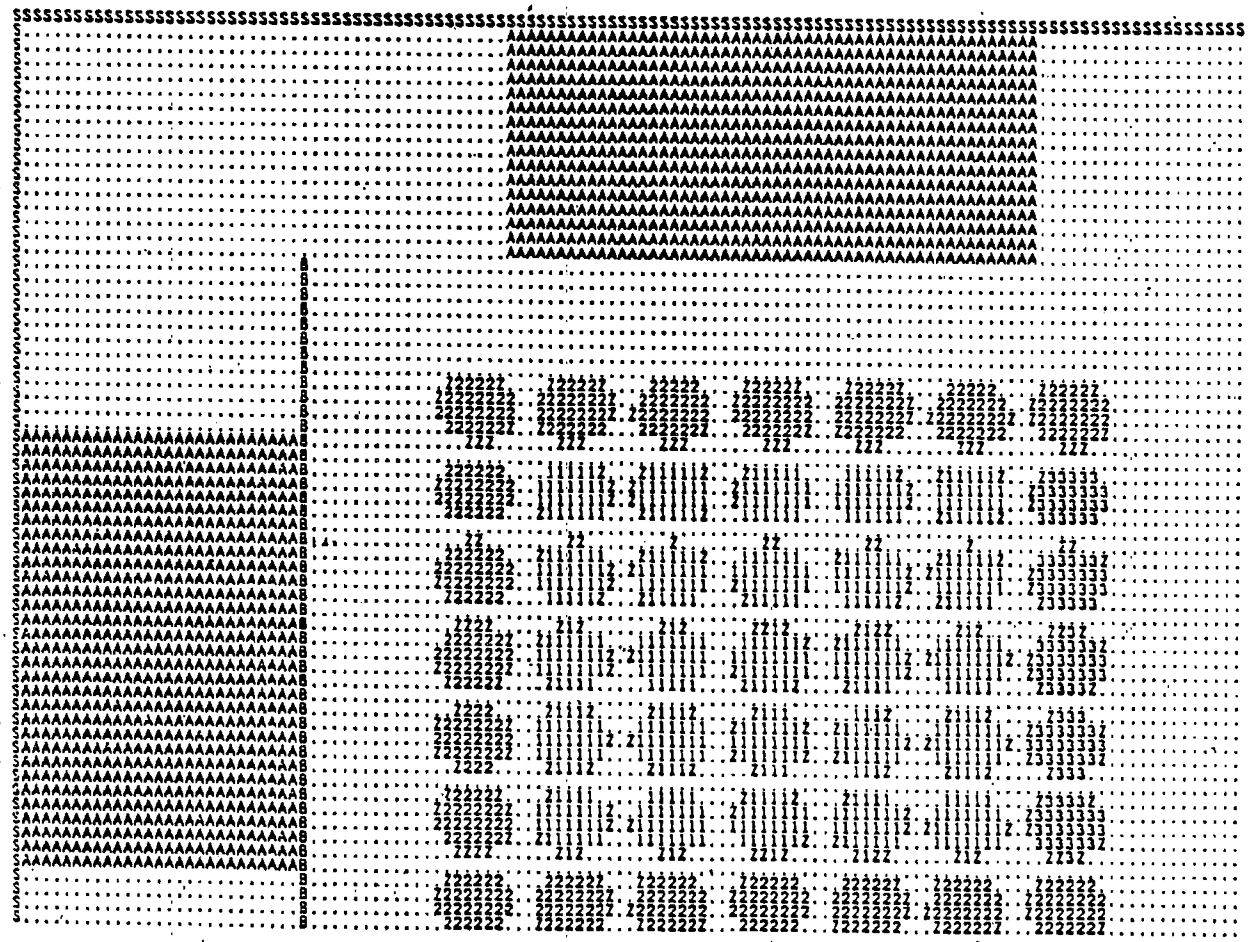
```
UNIT  4
COM=" UO2-GD2O3 ROD        "
CYLI  4 1 0.5361 2P225.58
CYLI  5 1 0.6072 2P225.58
CUBO  6 1 4P0.71785 2P225.58
UNIT 5
COM="  9X9 BUNDLE IN LEFT BASKET     "
ARRAY 1 2R-6.46065 -225.58
CUBO  6 1 4P8.7381 2P225.58
'  ADD 0.00598 INCH OF PERFORATED STEEL
CUBO 8 1 4P8.89 2P225.58
UNIT 6
COM="  9X9 BUNDLE IN RIGHT BASKET     "
ARRAY 2 2R-6.46-65 -225.58
CUBO  6 1 4P8.7381 2P225.58
'  ADD 0.00598 INCH OF PERFORATED STEEL
CUBO  8 1 4P8.89 2P225.58
UNIT 7
COM=" SPACING & STEEL ANGLE BESIDE BASKET          "
CUBO  9 1 2P2.54 2P4.9391 2P225.58
CUBO  6 1 2P2.54 2P8.89 2P225.58
UNIT 8
COM=" ANGLES & SPACING BENEATH & ABOVE BASKETS      "
CUBO  9 1 2P4.9392 2P2.54 2P225.58
CUBO  6 1 2P8.89 2P2.54 2P225.58
UNIT 9
COM="2X2 INCH MODERATION REGIONS AT CORNERS         "
CUBO  6 1 4P2.54 2P225.58
UNIT 10
COM=" 1 INNER CONTAINER        "
ARRAY 3 -22.86 -13.97 -225.58
' ADD 0.0598 INCH WALLS
REPL  7 1 6R0.1519 1
GLOBAL
UNIT 11
COM="ARRAY OF INNERS          "
ARRAY 4 3R0.0
END GEOMETRY
READ ARRAY
ARA=1 NUX=9 NUY=9 NUZ=1
FILL
2 2 2 2 2 2 2 2 2
2 1 1 1 1 1 1 1 3
2 1 1 1 1 1 1 1 3
2 1 1 1 4 1 1 1 3
2 1 1 4 1 4 1 1 3
2 1 1 1 4 1 1 1 3
2 1 1 1 1 1 1 1 3
2 1 1 1 1 1 1 1 3
2 2 2 2 2 2 2 2 2
 END FILL
ARA=2 NUX=9 NUY=9 NUZ=1
```

```
FILL
2 2 2 2 2 2 2 2 2
3 1 1 1 1 1 1 1 2
3 1 1 1 1 1 1 1 2
3 1 1 1 4 1 1 1 2
3 1 1 4 1 4 1 1 2
3 1 1 1 4 1 1 1 2
3 1 1 1 1 1 1 1 2
3 1 1 1 1 1 1 1 2
2 2 2 2 2 2 2 2 2
 END FILL
ARA=3 NUX=4 NUY=3 NUZ=1
FILL
9 8 8 9
7 5 6 7
9 8 8 9
END FILL
ARA=4 NUX=5 NUY=5 NUZ=1
FILL F10 END FILL
END ARRAY
READ START
NST=1
END START
READ BOUNDS
ALL=SPECULAR
END BOUNDS
END DATA
```



KENO-Va PLOT OF INNER CONTAINER MODEL
KEY: 1,2,3 = UO2 PELLET, Z = Zr CLAD, . = MODERATION,
S = STEEL SHELL, B = BASKET, A = SMEARED BASKET-MODERATION

DETAIL OF LEFT HALF OF MODEL
(FINNER DETAIL WOULD SHOW ENTIRE BASKET)



Appendix 6B

SIEMENS POWER CORPORATION - NUCLEAR DIVISION
CRITICALITY SAFETY ANALYSIS FOR SHIPMENT OF SPC 10X10 - 8B FUEL ASSEMBLIES IN THE SP-1 SHIPPING CONTAINER

Siemens Power Corporation

EMF-92-104
Revision 2
Issue Date: 2/2/93

CRITICALITY SAFETY ANALYSIS

FOR SHIPMENT OF SPC 10X10-8B

FUEL ASSEMBLIES IN THE SP-1 SHIPPING CONTAINER

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CRITICALITY SAFETY ANALYSIS
FOR SHIPMENT OF SPC 10X10-8B
FUEL ASSEMBLIES IN THE SP-1 SHIPPING CONTAINER

1.0 INTRODUCTION

The objective is to conservatively demonstrate that the subject generic fuel type meets the criticality safety requirements of 10 CFR Part 71 for a Fissile Class I package. Criticality safety is also demonstrated for any honeycomb/ethafoam thickness in the outer container. Shipping shims inside the fuel assembly are not allowed.

2.0 SUMMARY

The results of the calculations indicated that an unlimited number of SP-1 Shipping Containers containing two 10x10 assemblies side-by-side each subject to the constraints of Table 1 will not exceed 0.95 at the 95 percent confidence level.

TABLE 1 REFERENCE FUEL BUNDLE PARAMETERS

Parameter	Value
Edge of Outer Square Determined by Peripheral Fuel Rods (inch)	5.022 Maximum
Enrichment of Any Pellet in Assembly (wt. %)	5.0 Maximum
Enrichment of any Pellet in an Edge Rod (wt. %)	4.0 Maximum
Maximum Average Planar Enrichment (wt. %)*	4.0 Maximum
Clad Thickness (inch)	0.0225 Minimum
Pellet Diameter (inch)	0.3356 Maximum
Fuel Density (% TD)	98.0 Maximum
Rod Pitch (inch)	0.511 Nominal
UO_2-Gd_2O_3 Rods	6.0 Minimum
Gd_2O_3 Content (wt.%)	2.0± 0.08
Water Rods	Center 4 Rods Minimum
Poison Rod Arrangement	Symmetrical Across the Diagonal
Fuel Rod Array in Bundle	10x10

* Maximum Average Planar Enrichment: The average enrichment at the axial location yielding the highest planar average.

The analysis includes the effect of interspersed moderation, the placement of poison rods, the effect of the number of water rods and Uranium enrichment on the reactivity of the SP-1 Shipping Container. This analysis used CASMO, a two dimensional transport code, for parametric evaluations and KENO V.a for verification of the results, as appropriate. The reactivities calculated by both CASMO and KENO were in close agreement. The Keno results were slightly higher and more conservative.

3.0 METHODS

K-infinite calculations were performed using transport theory code CASMO-3D. K-effective calculations were performed using the Monte-Carlo code KENO-Va. CASMO was used for several calculations in a broad-based sensitivity study. SCALE codes (BONAMI, NITAWL, XSDRNPM, and KENO-Va) were used to replicate selected CASMO cases.

The Criticality Safety Analysis Sequence (CSAS) routines were used to calculate atom densities but the CSAS calculated escape cross section input into BONAMI 9** was not used for the reasons detailed below.

The CSAS routines provide inputs for BONAMI and NITAWL. When 16-group cross sections are used, as they were for most cases here, the self-shielding corrections for ^{235}U and ^{238}U are done by BONAMI. The ISSOPT option in BONAMI, set by CSAS, is for a homogeneous system. Appropriate "extra" cross sections may be entered into BONAMI array 9**. The sig-escape calculated by CSAS for a rod array is that for the center rod in a 3x3 array with the assumption that the center rod neutrons encounter only the other eight rods in the 3x3 array. For arrays flooded with water or other media with a similar total cross section, this is a good approximation.

For low density interspersed moderation, this 3x3 model can lead to non-conservative errors:.

- The Dancoff factor for the 3x3 array is too low because the central rod neutrons may actually encounter more than eight other rods.
- The calculated sig-escape will be too high for the same reason.

- If this sig-escape is used in BONAMI, the resulting cross sections will be non-conservative; i.e., the k-inf (k_{eff}) results obtained will tend to be lower than actual.
- It is noted that the low Dancoff factor is entered by CSAS into the NITAWL input which could also yield non-conservative results when using the 27-group or the 123-group cross section libraries.
- If the modeled rods are nearly edge-to-edge, the errors in the 3x3 CSAS model are reduced. Also, as the moderator (water) density is increased, the non-conservative errors are reduced/eliminated.

To avoid such non-conservatisms and to be consistent with the methods described in ANF-88-120, Rev. 0 "Supplemental Application to Certificate of Compliance No. 4986", self-shielding calculations were made as follows:

- Dancoff factors and sig-escapes were calculated using a Monte Carlo model of an infinite array of fuel assemblies in SP-1 inner containers.
- KENO models used three UO_2 rod types and, as applicable, one UO_2-Gd_2O_3 rod type. The three UO_2 rod types are interior (non-perimeter) rods, edge rods facing the companion assembly, and the rods on the other three edges of the assembly. The Monte Carlo derived sig-escape for each rod type was used in BONAMI array 9** with ISSOPT = 0.

4.0 MODEL DESCRIPTION

The model used for the SP-1 is identical to the model used in ANF-88-120 "Supplemental Application to Certificate of Compliance No. 4986." An infinite array of infinite length inner containers was modeled to conservatively demonstrate criticality safety at normal conditions and at hypothetical accident conditions. Each package contained two identical assemblies with an infinite fuel length.

Since the package is symmetric about the plane midway between the two contained assemblies, models typically included only one of these symmetric halves (one assembly) to represent an infinite array of whole packages. An orientation with two assemblies side-by-side (left-right) was selected for the model. Only the left assembly was modeled in CASMO but both halves were modeled in KENO. A plot of the KENO model is included on pg. 30.

The steel parts modeled are:

- Two edge-to-edge "baskets" of 0.0598 inch thick carbon steel with 0.75 inch diameter holes in a 1.75 inch square pitch pattern. Accordingly, the basket was modeled as 85.57 vol% carbon steel and 14.43 vol% moderation.
- The outer shell of the inner container was modeled as 0.0598 inch thick carbon steel (100 vol%).
- The annulus between the basket and the shell contains six angles of 0.125 inch thick carbon steel. For the left half, (CASMO) model, three angles were included: one each above, below, and to the left of the assembly. These angles were represented as "smeared" steel in the moderation occupying the annulus. Other calculations with a more explicit modeling of the geometry of the steel angles yielded results not significantly different from the "smeared steel" model. Since peak reactivity occurs with low density interspersed moderation, neutrons have relatively long mean-free path lengths and would be expected to interact with all steel in the system. Therefore, the smeared steel model is adequate.

The steel mass in the infinite length inner container model is about 525 pounds per 177.6 inch length. The measured weights of the three inner container components (lid, removable end, main body) are 197, 15 and 399 pounds, respectively. The total tare weight is about 611 pounds. A generous allowance for the weight of the ethafoam and wood in the samples is six pounds. Therefore, the estimated steel weight is 605 pounds. For the infinite length model, twice the mass of the removable end is subtracted to yield a 575 pound weight. Since the actual system contains considerably more steel than that modeled, the model results are conservative.

The basket outer dimensions were 7.0"x7.0" (x infinite length). The assembly was centered in the basket and the two baskets were edge-to-edge; i.e., the plane of symmetry was at the right edge of the left basket.

The annulus was 2.0 inches thick. Therefore, the inner dimensions of the shell of the inner container are 18 inches wide by 11 inches high. With the 0.0598 inch thick shell, the outer dimensions are about 18.12 inches wide by 11.12 inches high. All volume not occupied by rods or steel was filled with uniform density water.

5.0 ANALYSIS

The fuel bundle modeled is a 10x10-8B assembly. The center four rod positions of the bundle are occupied by a single large water rod. Reference Fuel Bundle Parameters for the models are listed in Table 2.

TABLE 2 REFERENCE FUEL BUNDLE PARAMETERS

Parameter	Value Used
Average Enrichment (%)	Varied
Clad Outer Diameter (inch)	0.387
Clad Inside Diameter (inch)	0.337
Pellet Diameter (inch)	0.335
Fuel Density (% TD)	98.0
Rod Pitch (inch)	0.511
UO_2-Gd_2O_3 Rods	Varied
Gd_2O_3 Content (wt.%)	2.0
Water Rods	Varied
Fuel Rod Array in Bundle	10x10

The major assumptions made in this analysis reflect the fuel composition typical of SNP 10x10-8B assemblies. They include:

- The fuel bundle is symmetrical across the diagonal and has the physical characteristics listed in Table 1.
- The system was at room temperature.

- Interspersed moderator (water) was uniformly dispersed in the system around the fuel rods and between fuel assemblies.
- The holes in the steel basket were homogenized into the basket.
- The ends of the fuel rods were not modeled.
- The fuel bundle arrays are spectrally reflected to represent an infinite system.
- The steel angles in the space between the basket and the shell was smeared into the interspersed moderation.
- The gadolinia content is at least 2.0 weight percent in at least six rods.

5.1 Effect of Interspersed Moderation

CASMO was used to determine the effect of various amounts of moderation on an infinite array of inner SP-1 shipping containers containing 10x10 fuel assemblies. The purpose of the calculations was to determine the density (volume percent) of interspersed moderation which resulted in the highest reactivity. A display of the rod arrangement is shown in Figure 1 and the calculational results are given in Table 3.

FIGURE 1 10X10 ASSEMBLY WITH 9 POISON RODS

```
1 1 1 1 1 1 1 1 1 1
1 1 1 2 1 1 2 1 1 1
1 1 1 1 1 1 1 1 1 1
1 2 1 1 1 0 1 1 2 1
1 1 1 0 W W 1 1 1 1
1 1 1 1 W W 0 1 1 1
1 2 1 1 0 1 2 1 2 1
1 1 1 1 1 1 1 1 1 1
1 1 1 2 1 1 2 1 1 1
1 1 1 1 1 1 1 1 1 1
```

Where

1 = fuel rod
2 = poison rod
0 = water rod
W = central water rod

**TABLE 3 K-INF OF 10X10 FUEL ASSEMBLIES
9 POISON RODS, 4.5 WT.% ^{235}U**

Case Identification	% Int. Mod.	k-inf
CASMO		
ra3-97	3	0.87229
ra3-95	5	0.90270
ra3-93	7	0.90821
ra3-90	10	0.89719
ra3-80	20	0.88208
KENO V.a		
k5oa-cask-b.10	10	0.9056±.0027

The results show that the highest reactivity was obtained when the interspersed moderation was at 7 volume percent. A confirmatory run made with the KENO V.a code was 0.9056 as compared with 0.8972 from the results of the CASMO calculations.

5.2 Effect of Poison Rod Positions

CASMO was also used to determine the effect of the positions of poison rods on an infinite array of 10x10 fuel assemblies in an SP-1 inner container. Five arrangements of six poison rods around a central water rod are shown in Figure 2. The results of the calculations are given in Table 4. These models assumed 4.5 weight percent ^{235}U and 3 volume percent water as interspersed moderator. A 7 volume percent water was repeated for arrangement PD which had indicated the highest calculated reactivity due to poison rod placement.

FIGURE 2 ARRANGEMENTS OF 6 POISON RODS

PA

U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	P	U	P	U
U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	P	U
U	U	U	U	W	W	U	U	U	U
U	P	U	U	W	W	U	U	U	U
U	U	U	U	U	U	U	U	U	U
U	P	U	P	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U

PB

U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	P	U	U	U
U	U	U	U	U	U	U	P	U	U
U	U	U	U	U	U	U	U	P	U
U	U	U	U	W	W	U	U	U	U
U	U	U	U	W	W	U	U	U	U
U	P	U	U	U	U	U	U	U	U
U	U	P	U	U	U	U	U	U	U
U	U	U	P	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U

PC

U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	P	U	U	U	U
U	U	U	U	U	U	P	U	U	U
U	U	U	U	W	W	U	P	U	U
U	U	P	U	W	W	U	U	U	U
U	U	U	P	U	U	U	U	U	U
U	U	U	U	P	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U

PD

U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	P	P	U	U	U
U	U	U	U	W	W	P	U	U	U
U	U	U	P	W	W	U	U	U	U
U	U	U	P	P	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U

PE

U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U
U	U	U	U	P	U	P	U	U	U
U	U	U	P	W	W	U	U	U	U
U	U	U	U	W	W	P	U	U	U
U	U	U	P	U	P	U	U	U	U
U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U

**TABLE 4 K-INF OF 10X10 ASSEMBLIES
6 POISON RODS, 4.5 WT.% ^{235}U**

Case Identification	% Int. Mod.	Arrangement	k-inf
ra3-t1	3	PA	0.89285
ra3-t3	3	PB	0.89598
ra3-t4	3	PC	0.90166
ra3-t5	3	PD	0.90526
ra3-t5.07	7	PD	0.96471
ra3-t6	3	PE	0.90370

These calculations indicate that the highest reactivity for low interspersed moderation occurs when the poison rods are near the center of the assembly (arrangement PD). This arrangement is most reactive because the most reactive (best moderated) rods in the assemblies are the corner rods and because the Gd_2O_3 becomes a more effective poison with increasing moderation. As we move the poison rods away from the corner rods, we gain full benefit from corner moderation and decrease the poison effectiveness. This result agrees with the results in ANF-88-120[2].

5.3 Effect of Interspersed Moderation, Cross Sections and Enrichment

The effects of interspersed moderation, enrichment and Cross Section Library selection were examined for arrangement PD. This is actually a very conservative model due to assuming that all rods are at the Maximum Planar Enrichment. Actual assemblies will have multiple enrichments with the lower enrichments on the perimeter and the higher enrichments inside where less moderation is available. This is required to assure approximately equal powers for the rods in the operating assembly.

The SCALE system of computer codes was used for this evaluation. Cross sections were prepared by BONAMI and NITAWL. KENO V.a was used to model system. The results of these calculations agreed well with the CASMO calculations and are listed in Table 5.

The KENO V.a calculations confirm the reactivity of an infinite array of assemblies placed in the inner SP-1 shipping container was highest at 7 volume percent interspersed moderator. The KENO V.a result was 0.9691 ± .0028 (1σ) as compared to 0.9647 obtained by CASMO.

TABLE 5 REACTIVITY OF ARRANGEMENT PD

Case Identification	^{235}U Enrichment	% Int. Mod.	Cross Sections	k-inf±1σ
a-cask-c.03	4.5	3	16 group	0.90124±.0023
a-cask-c.07	4.5	7	16 group	0.9691±.0028
a-cask-c.10	4.5	10	16 group	0.9651±.0030
a-cask-c.12	4.5	12	16 group	0.9554±.0035
a-cask-c1.0	4.5	100	16 group	0.7347±.0040
a-cask-d.07	4.0	7	16 group	0.9319±.0027
a-cask-c.07	4.5	7	16 group	0.9691±.0028
27-cas-c.07	4.5	7	27 group	0.9552±.0031

The calculated reactivity of the system using 27 group cross sections was less than the corresponding calculation using 16 group cross sections, 0.9552 and 0.9691, respectively. This agrees with previous results documented ANF-88-120.

The results also indicate that the k-inf for 4.5 weight percent enrichment is subcritical but exceeds .95. The reactivity is less than 0.95 for 4.0 weight percent enrichment. The effect of varying the uranium enrichment on k-inf is shown in Figure 3 and tabulated in Table 6.

FIGURE 3 EFFECT OF URANIUM ENRICHMENT ON REACTIVITY

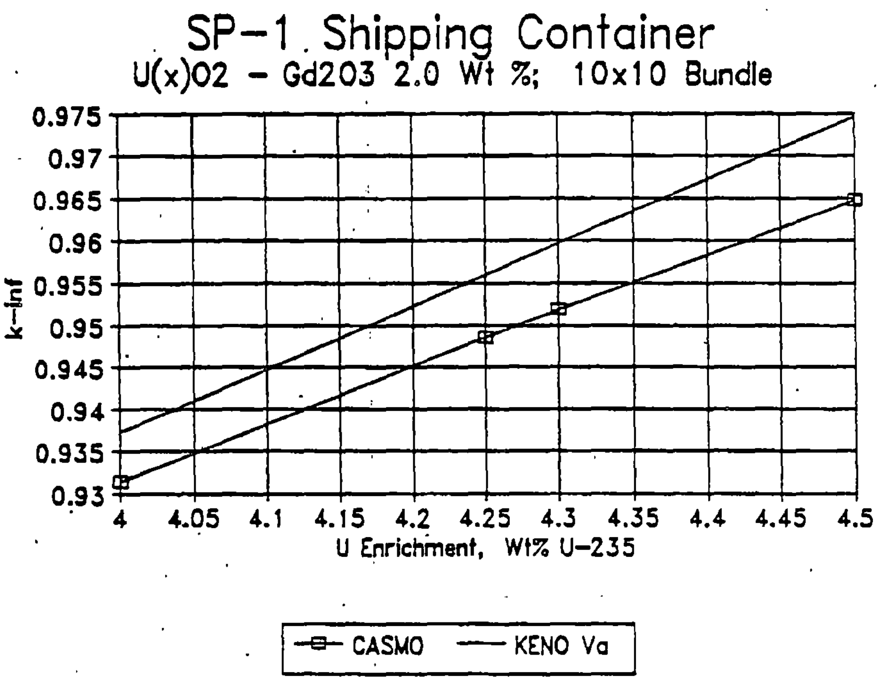

TABLE 6 K-INF OF 10X10 ASSEMBLIES AT VARIOUS URANIUM ENRICHMENTS 6 POISON RODS AND 7 VOL.% WATER

Case Identification	U Enrichment Wt. %	k-inf
400-t5.07	4.00	0.93145
425-t5.07	4.25	0.94862
430-t5.07	4.30	0.95192
ra3-t5.07	4.50	0.96471
KENO V.a k5oa-cask-d.07	4.00	k-inf+2σ 0.93734
k5oa-cask-c.07	4.50	0.97464

5.4 Effect of Water Rods

The effect of the presence of water rods on an infinite array 10x10 fuel assemblies placed in the inner SP-1 shipping container was determined by using CASMO. These cases assume 4.5 wt.% ^{235}-U, 10 Vol.% water, and no poison rods. The arrays are shown in Figure 3 and the results of the calculations are given in Table 7.

FIGURE 4 ARRANGEMENTS OF WATER RODS IN 10X10 ASSEMBLY

WA

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WB

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WC

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WD

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WE

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WF

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WG

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U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U
U	U	U	U	W	W	U	U	U	U
U	U	U	W	W	W	U	U	U	U
U	U	U	W	W	W	U	U	U	U
U	U	U	U	W	W	U	U	U	U
U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U

WH

U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U
U	U	U	W	W	W	U	U	U	U
U	U	U	W	W	W	U	U	U	U
U	U	U	W	W	W	U	U	U	U
U	U	U	W	W	W	U	U	U	U
U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U

WI

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U	U	U	W	W	W	W	U	U	U
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U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U

WJ

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U	U	U	W	W	W	W	U	U	U
U	U	U	W	W	W	W	U	U	U
U	U	U	W	W	W	W	U	U	U
U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U

TABLE 7 K-INF OF 10X10 ASSEMBLIES WITH VARIOUS WATER RODS 4.5 WT.% U, 10 VOL.% WATER AND NO POISON

Case Identification	Arrangement	k-inf
0gad	WA	1.00574
0gad-2w	WB	1.00530
0gad-4w	WC	1.00482
0gd-4wd	WD	1.00220
0gd-4wd1	WE	1.00404
0gad-4ws	WF	1.00507
0gad-6ws	WG	1.00457
0gad-8ws	WH	1.00392
0gd10ws	WI	1.00301
0gad12ws	WJ	1.00207

These results show that for low density interspersed moderator there is a reduction in reactivity when the number of water rods increases. Water rods placed nearer the perimeter of the assembly decreased the reactivity of the system more than those located near the center. The most reactive arrangement is when small water rods are not included in the assembly.

The results listed in Table 8 show that replacing fuel rods with water rods at full flooding causes a small change in reactivity, comparable to the differences between CASMO and KENO. In all cases, k-inf is well below 0.95. The removal of fuel rods at full density water causes a change in reactivity that is approximately equal to the change due to increased moderation in the water rods for two, four, and six water rods. The reduction in fuel appears to be dominant for eight water rods. This shows that the fully flooded containers are safely subcritical without any poison rods. However, poison rods are needed to remain subcritical at optimum moderation.

TABLE 8 K-INF OF 10X10 ASSEMBLIES WITH VARIOUS WATER RODS 4.5 WT.% U, 100 VOL.% WATER AND NO POISON

Case Identification	Arrangement	k-inf
0gadfw	WA	0.9238
0gad-2wfw	WB	0.9249
0gd-4wfw	WC	0.9254
0gd-4wsfw	WF	0.9246
0gad-6sf	WG	0.9226
0gad-8wsf	WH	0.9204

5.5 Effect of Fuel Assembly Spacing

The effect of moving the fuel assemblies normally centered in the SP-1 inner container toward and apart from one another was evaluated using KENO-V.a. The results in Table 9 show an increase in k-inf when the bundles are moved apart and a decrease when the bundles are brought closer together. An infinite array of 4.0 wt.% bundles under certain conditions exceeds a k-eff of 0.95. The results listed in Table 9 show that 260 SP-1 inner shipping containers in a 13 wide X 20 high array are not at optimum moderation at 7-8 vol.% as they are in an infinite array. The data in Table 9 for the finite array were interpolated and optimum moderation was found to be at 18 vol.% water. KENO-Va calculates k-eff for this condition to be 0.9120 ± .0023.

TABLE 9 EFFECT OF SPACING OF FUEL BUNDLES

Case Identification	Description	Moderation Vol.% Water	k-eff
An infinite array of containers			
e.07	Bundles inside the basket are as close as design permits. Bundle enrichment is 4.5 wt.% U-235. Pellet Diameter is 0.3356 inches	7	.9420 ± .0032
c.07	As above with the bundles centered (Standard)	7	.9691 ± .0028
f.07	As above with the bundles as far apart as design permits	7	.9802 ± .0026
g-apart	As above with Bundle enrichment 4.0 wt.% U-235	8	.9533 ± .0030
A 13 wide by 20 high array of containers			
a-13x20ap	Bundles inside the basket are as far apart as design permits. Bundle enrichment is 4.0 wt.% U-235. Pellet Diameter is 0.3356 inches. The array is reflected by 30 cm of full density water.	8	.8659 ± .0028
a-13x20ap15	As above	15	0.9006 ±.0028
a-13x20ap20	As above	20	0.9008 ±.0024
a-13x20ap30	As above	30	0.8722 ± .0026

5.6 Effect Of Outer Container and Spacing

KENO-V.a was used to model infinite arrays of undamaged packages to demonstrate that reduced amounts of honeycomb/ethafoam in the outer container cannot lead to criticality. The inner containers were placed on 29.75" by 27.75" centers to match the normal container spacing without 4"x4" skids at the bottom. The model assumed fuel assemblies with 4.5 wt% ^{235}U and arrangement PD.

Cases with and without the container wood are included. The wood was assumed to have a density of 0.75 g/cc and to be 0.5 inch thick on the top and two sides and 3 5/8 inch thick on the bottom. All volume not occupied by wood, fuel, or the steel of the inner container was filled with low density water. The results are given in Table 10.

TABLE 10 EFFECT OF OUTER CONTAINER PRESENCE AND SPACING

Run No. k5oa-cas-	Int. Mod %	k-inf±1σ	k-inf+2σ
Without Wood			
h.010	1.0	.9484±.0024	.9532
h.015	1.5	.9617±.0032	.9680
h.020	2.0	.9566±.0029	.9625
h.025	2.5	.9475±.0021	.9537
h.030	3.0	.9268±.0032	.9332
With Wood			
i.000	0.0	.8962±.0030	.9023
i.005	0.5	.8850±.0033	.8915
i.010	1.0	.8563±.0031	.8625
i.020	2.0	.8119±.0034	.8187

All of the results are subcritical and they indicate that adding moderation such as honeycomb, ethafoam, and additional wood to the plywood only model would result in reduced reactivities. Therefore, the honeycomb/ethafoam in the outer container is not needed for criticality safety nor for cushioning during the hypothetical accident conditions. Accordingly, there is not adverse safety effect by allowing any honeycomb/ethafoam thickness nor by allowing unlimited cutouts of these pads.

The data in Table 10 also indicate that the peak reactivity for the normal array is bounded by the k-inf for edge-edge inner containers. There is no statistically significant difference between k-inf for the close-packed array of inner containers and the outer containers without the wood. Both models are at optimum moderation with the H/U ratio essentially constant.

5.7 Effect of Poison Content in Poison Rods

Casmo was used to examine the sensitivity of reactivity on Gd_2O_3 content in the poison rods. When Gd_2O_3 was reduced from a nominal 2.0 wt.% to 1.95 wt.% for case 400-t5.07 reactivity increased from 0.93145 to .93186, an increase of .00041. When Gd_2O_3 was reduced to 1.5 wt.% for this case reactivity increased to .93596, an increase of .004510. These results indicate that assemblies with allowable variations in Gd_2O_3 will remain subcritical by a substantial margin.

5.8 The Effect of Fuel Pellet Diameter

CASMO was used to examine the sensitivity of k-inf to pellet diameter at various amounts of moderation in and between the fuel assemblies. The models used in this study use fuel arrangement PD, shown in figure 2. The U-235 enrichment was 4.5 wt.%. The results are listed in table 11 and clearly show that reducing pellet diameter causes a decrease in k-inf.

TABLE 11 K-INFINITY FOR VARIOUS PELLET DIAMETERS

Vol. % Water	K-inf for Pellet OD 0.3350"	K-inf for Pellet OD 0.3300"	K-inf for Pellet OD 0.3250"	K-inf for Pellet OD 0.3200"
6	0.9631	0.9589	0.9590	0.9567
7	0.9672	0.9628	0.9625	0.9599
8	0.9675	0.9629	0.9622	0.9594
9	0.9655	0.9608	0.9598	0.9566
10	0.9619	0.9571	0.9557	0.9524
100	0.7348	0.7322	0.7339	0.7331

The maximum pellet diameter including manufacturing tolerances will be less than 0.3356 inches. At optimum moderation CASMO calculates k-inf to be 0.9682 for 4.5 wt.% enriched bundles. Reducing enrichment to 4.0 wt.% reduces k-inf to 0.9352. Adding a .001 inch gap further reduces k-inf to 0.9350. A Keno-Va model of the no gap case at 4.0 wt.% U-235 produces a k-eff of 0.9341 ± .0023.

5.9 Discussion of Results

The greatest reactivity for the system occurred with interspersed moderation at about 7 volume percent. Calculations by both CASMO and KENO-V.a computer codes supported this conclusion. A variation in the position of the six poison rods showed that the most reactive configuration with low density interspersed moderator occurred when the poison rods were placed close to the large central water rod. This was due to the increased moderation of the neutrons near the outer rows of the assemblies which made the neutron poison more effective in those positions.

The CASMO calculations at optimum moderation indicated that the highest reactivity occurred with no small water rods. These calculations also indicate that the reactivity decreased when the water rods were placed nearer the perimeter of the assembly and when the number of water rods was increased.

KENO-V.a demonstrated that for the worst credible arrangement and an uranium enrichment of 4.0 Wt.% the calculated k-eff of an infinite system while the fuel assemblies are centered in the basket is 0.9341 ±.0023. The worst credible arrangement for 260 SP-1 inner containers is a 13x20 array with the fuel assemblies shifted to the outer region of the basket and 18 vol% water as an interspersed moderator. K-eff + 2 σ for this arrangement and condition is 0.9166. Therefore the requirements for a fissile class 1 package are met.

6.0 METHODS VALIDATION

Supplemental benchmarking was performed using experimental data from 15 critical mass experiments. The experiments selected are described in References 3 and 4. The data are included in table 11. The methods in reference 5 were used to calculate the weighted average k-eff and the standard deviation of the bias.

Weighted average k-eff: 1.0035

Bias Standard Deviation: 0.00368

The weight of each k-eff value is proportional to the reciprocal of its variance.

These results demonstrate the average k-effective reported by KENO + 2σyields a k-eff at a conservative 95% confidence level.

**TABLE 12 BENCHMARK CALCULATION RESULTS
KENO-Va WITH 16 GROUP CROSS SECTIONS**

Case Number	Calculated k-eff
	Reference 3 Experiments
2378	1.00395 ± 0.00376
2384	1.00037 ± 0.00306
2388	0.99886 ± 0.00341
2420	1.00038 ± 0.00367
2396	0.99443 ± 0.00360
2402	1.00694 ± 0.00283
2411	1.01223 ± 0.00286
2407	1.00647 ± 0.00332
2414	1.00967 ± 0.00327
	Reference 4 Experiments
9	1.00092 ± 0.00487
10	1.00181 ± 0.00412
11	0.99786 ± 0.00413
12	0.99885 ± 0.00487
31	1.00442 ± 0.00421

7.0 REFERENCES

1. Smith, M.H., "Principal Fuel Design Parameters Gundremmingen C, 10x10-8B Lead Assemblies," ANF-91-017(P), March 29, 1991.

2. Gerrald, L.D., "Supplemental Application to Certificate of Compliance No. 4986," ANF-88-120, July, 1988.

3. Baldwin, M.N., et.al., "Critical Experiments Supporting Close Proximity Water Storage of Power Reactor Fuel", BAW-1484-7, July 1979.

4. Bierman, S.R., Durst, B.M., and Clayton, E.D., "Critical Separation Between Subcritical Clusters of 4.31% Enriched UO_2 Rods in Water With Fixed Neutron Poisons", NUREG/CR-0073, May 1978.

5. Marshall, W., Clemson, P.D., Walker, G., "Criticality Safety Criteria", ANS Trans, 35, 278 (1980).

8.0 COMPUTER INPUT LISTINGS

The following is an example of typical computer input for the BONAMI, NITAWL AND KENO V.a computer codes.

BONAMI input for uranium enriched to 4.5 weight percent, gadolinia at 2.0 weight percent and 7 volume percent of interspersed water:

```
'SHIPPING CASK RA-3 10X10 6Gd RODS, 0.07 IM  U4.5  Gd2.0
'  Gd rods clustered around central water col
0$$ 16 15 18 17
 1$$ 0  9 26 2R1 0
2** 1.0E-03 1.35
T
3$$ 1 4 5 6 1 4 5 6 1 3 4 5 6 8 9 2 3 8 9 6 7 8 9 7 8
9
4$$ 4R92235 4R92238 7R-8016 -40302 3R-1001 -64000 3R-6012
3R-26000
5** 3R1.09163E-03 1.0596E-03 3R2.28741E-02 2.2203E-02
4.79315E-02 2.335903E-03 2R4.79315E-02 4.75857E-02 3.370708E-04
2.134081E-04 4.25181E-02 4.671806E-03 6.741416E-04 4.268162E-03
7.06997E-04 3.92168E-03 3.35578E-03 3.38833E-04 8.35001E-02
7.1451E-02 7.21441E-03
6$$ 1 2 3 4 5 6 7 8 9
8**  9R2.93E+02
'zone 1 is uo2 interior rods; zone 2 is zr; zone 3 is h2o;
'zone 4 is uo2 edge rods; zone 5 is uo2 facing rods;
'zone 6 is uo2-gd2o3 poison interior rods;
'zone 7 is c steel; zone 8 is mod c steel; zone 9 is dil c steel
9** .36749  2.2791 0.0  .59538  .50642  .34281  1.6657  2.4331  .13749
10$$ 9223501 9223504  9223505  9223506
9223801 9223804 9223805 9223806
8016 10 11 12 13 14 15 40302
1001 18 19 64000 6012 22 23 2600007 2600008 2600009
11$$  9R0
12** F293.0
T
```

NITAWL input for uranium enriched to 4.50 weight percent, 2.0 weight percent gadolinia and 7 volume percent of interspersed water:

```
'SHIPPING CASK RA-3 10X10 6Gd RODS, 0.07 IM  U4.5  Gd2.0
'  Gd rods clustered around central water  rod
0$$ 11 12 13 14 18 19 9 0 20
 1$$ 0 26 5R0 13 2R0 -1 0
T
2$$ 9223501 9223504  9223505  9223506
9223801 9223804 9223805 9223806
8016 10 11 12 13 14 15 40302
1001 18 19 64000 6012 22 23 2600007 2600008 2600009
```

```
3**
 9223501. 293.00 2.0  4.2550E-01 0.79449  1.4255E+03  1.0916E-03 1.0
  15.9994  1.6466E+02 1.0   238.0510  1.7392E+02 1.0   1.0
 9223504. 293.00 2.0  4.2550E-01 0.49179  3.4908E+02  1.0916E-03 1.0
 .15.9994  1.6466E+02 1.0   238.0510  1.7392E+02 1.0   1.0
 9223505. 293.00 2.0  4.2550E-01 0.58925  3.4908E+02  1.0916E-03 1.0
  15.9994  1.6466E+02 1.0   238.0510  1.7392E+02 1.0   1.0
 9223506. 293.00 2.0  4.2550E-01 0.78608  3.5476E+02  1.0596E-03 1.0
  15.9994  1.6841E+02 1.0   238.0510  1.7392E+02 1.0   1.0
 9223801. 293.00 2.0  4.2550E-01 0.79449  6.8031E+01  2.2874E-02 1.0
  15.9994  7.8579E+00 1.0   235.0440  5.0109E-01 1.0   1.0
 9223804. 293.00 2.0  4.2550E-01 0.49179  1.6659E+01  2.2874E-02 1.0
  15.9994  7.8579E+00 1.0   235.0440  5.0109E-01 1.0   1.0
 9223805. 293.00 2.0  4.2550E-01 0.58925  1.6659E+01  2.2874E-02 1.0
  15.9994  7.8579E+00 1.0   235.0440  5.0109E-01 1.0   1.0
 9223806. 293.00 2.0  4.2550E-01 0.78608  1.6930E+01  2.2203E-02 1.0
  15.9994  8.0370E+00 1.0   235.0440  5.0109E-01 1.0   1.0
 40302. 293.00 1.0  6.3510E-02 0.71227  1.9136E+02  4.2518E-02 1.0
  0.0000  0.0000E+00 0.0    0.0000  0.0000E+00 0.0   1.0
 64000. 293.00 0.0  0.0000E+00 0.78608  5.3170E+02  7.0700E-04 1.0
  15.9994  2.5240E+02 1.0   238.0510  2.6066E+02 1.0   1.0
 2600007. 293.00 1.0  2.5400E+00 0.14215  1.1551E+01  8.3500E-02 1.0
  12.0110  2.2074E-01 1.0    0.0000  0.0000E+00 0.0   1.0
 2600008. 293.00 1.0  2.5400E+00 0.18303  1.1851E+01  7.1451E-02 1.0
   1.0079  1.9247E-01 1.0   12.0110  2.2074E-01 1.0   1.0
 2600009. 293.00 1.0  2.5400E+00 0.27049  3.0377E+01  7.2144E-03 1.0
   1.0079  1.2069E+01 1.0    15.9994  1.5847E+00 1.0   1.0
4** 26R2.93E+02
T
```

An example folKENO V.a computer input for uranium enriched to 4.5 weight percent, 2.0 weight percent gadolinia and 7 volume percent of interspersed water:

```
SHIPPING CASK RA-3 10X10 0.07  IM;   U4.50   Gd2.00   6 Gd Rods
'  no small water cols _ Gd rods clustered near central water col
READ PARM  GEN=103  NPG=300  PLT=YES
  TME=570  TBA=2.0  LIB=41  FLX=YES  XS1=YES  NUB=YES  PWT=YES  RUN=YES
END PARM
'
READ MIXT
'KENO5-TYPE MIXING TABLE  XSLIB NUCLIDES
MIX= 1
' U(4.50)O2 AT 0.98 OF 10.96 = 10.7408  INTERIOR ROD
   9223501  1.091628E-03
   9223801  2.287414E-02
    8016   4.793154E-02
MIX= 2
' ZIRCALLOY AT 6.44 G/CC
   40302   4.251812E-02
MIX= 3
' WATER AT 0.9982 G/CC X 7.00E-02 VOL FRACT FOR INTERSPERSED MOD
```

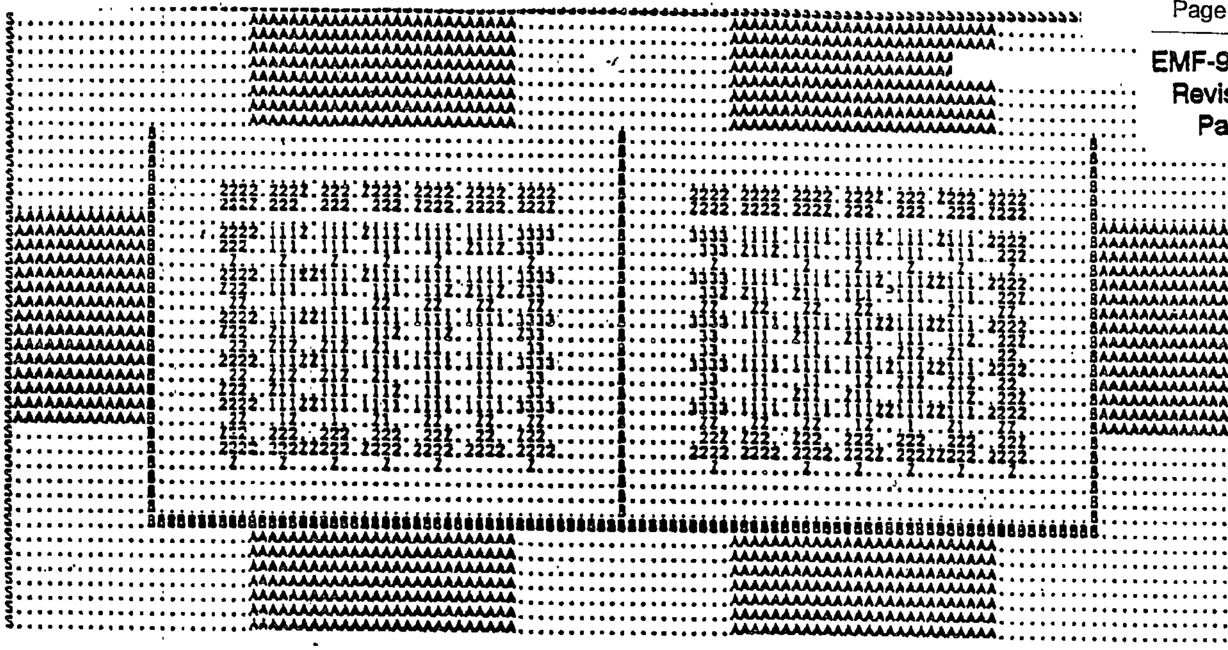
```
    8016    2.335903E-03
    1001    4.671806E-03
MIX= 4
' U(4.50)O2 AT 0.98 OF 10.96 = 10.7408  EDGE ROD
   9223504  1.091628E-03
   9223804  2.287414E-02
    8016    4.793154E-02
MIX= 5
' U(4.50)O2 AT 0.98 OF 10.96 = 10.7408  FACING ROD
   9223505  1.091628E-03
   9223805  2.287414E-02
    8016    4.793154E-02
MIX= 6
' U(4.50)O2 - Gd2O3(2.0) AT 0.98 THEO DENSITY ,POISON ROD
' UO2 AT (0.98)[(0.980/10.96)]/[(0.980/10.96)+(0.020/7.400)]=0.951247
   9223506  1.059600E-03
   9223806  2.220302E-02
    8016    4.758573E-02
' Gd2O3 AT (0.98)[(0.020/7.400)]/[(0.980/10.96)+(0.020/7.400)]=0.02875254
   64000    7.069965E-04
MIX= 7
' CARBON STEEL AT 7.8212 G/CC, 100%
    6012    3.921683E-03
   2600007  8.350010E-02
MIX= 8
' CARBON STEEL & WATER,  85.57% CS,  14.43% IM
' INTERSPERSED MODERATION VOL FR=(0.1443)(VF OF MATL 3=0.070)=0.010101
    8016    3.370708E-04
    1001    6.741416E-04
' CARBON STEEL AT 0.8557 VOL FR
    6012    3.355784E-03
   2600008  7.145103E-02
MIX= 9
' CARBON STEEL & WATER,  8.64% CS,  91.36% IM
' INTERSPERSED MODERATION VOL FR=(0.9136)(VF OF MATL 3=0.070)=0.063952
    8016    2.134081E-03
    1001    4.268162E-03
' CARBON STEEL AT 0.0864 VOL FR
    6012    3.388334E-04
   2600009  7.214409E-03

RESM 1 4 1 4 5 6
RESM 2 1 2
RESM 4 4 4 1 5 6
RESM 5 4 5 1 4 6
RESM 6 4 6 1 4 5
RESM 7 1 7
RESM 8 1 8
RESM 9 1 9
END MIXT
 READ GEOM
'
 UNIT 1
```

```
COM=' UO2 FUEL  XXX.XX ACTIVE FUEL LENGTH AS OXIDE  INTERIOR UO2 ROD'
'  FUEL LENGTH XXX.XX+0.355=XXX.XXX"; DIAM 0.33504 [na '+0.0005=0.33554']'
CYLI     1  1  0.42550   2P225.58
'  CLAD INSIDE DIAM 0.3370 [na '+0.0015=0.3385']'
CYLI     0  1  0.42799      2P225.58
'  CLAD OUTSIDE DIAM (ZRALLOY-2) 0.3870 [na '-0.002=0.3868']'
CYLI     2  1  0.49150      2P225.58
'  ADD MODERATION WATER AT 0.511024" PITCH
CUBO     3  1  4P0.64900   2P225.58

UNIT 2
COM=' UO2 FUEL  XXX.XX ACTIVE FUEL LENGTH AS OXIDE  EDGE UO2 ROD'
'  FUEL LENGTH XXX.XX+0.355=XXX.XXX"; DIAM 0.33504 [na '+0.0005=0.33554']'
CYLI     4  1  0.42550   2P225.58
'  CLAD INSIDE DIAM 0.3370 [na '+0.0015=0.3385']'
CYLI     0  1  0.42799      2P225.58
'  CLAD OUTSIDE DIAM (ZRALLOY-2) 0.3870 [na '-0.002=0.3868']'
CYLI     2  1  0.49150      2P225.58
'  ADD MODERATION WATER AT 0.511024" PITCH
CUBO     3  1  4P0.64900   2P225.58

UNIT 3
COM=' UO2 FUEL  XXX.XX ACT FUEL LNGTH AS OXIDE;EDGE UO2 ROD FACING OTHER UNIT'
'  FUEL LENGTH XXX.XX+0.355=XXX.XXX"; DIAM 0.33504 [na '+0.0005=0.33554']'
CYLI     5  1  0.42550   2P225.58
'  CLAD INSIDE DIAM 0.3370 [na '+0.0015=0.3385']'
CYLI     0  1  0.42799      2P225.58
'  CLAD OUTSIDE DIAM (ZRALLOY-2) 0.3870 [na '-0.002=0.3868']'
CYLI     2  1  0.49150      2P225.58
'  ADD MODERATION WATER AT 0.511024" PITCH
CUBO     3  1  4P0.64900   2P225.58

UNIT 4
COM='UO2-GD2O3 FUEL XXX.XX ACT FUEL LNGTH AS OX;INTERIOR POISON UO2-GD2O3 ROD'
'  FUEL LENGTH XXX.XX+0.355=XXX.XXX"; DIAM 0.33504 [na '+0.0005=0.33554']'
CYLI     6  1  0.42550   2P225.58
'  CLAD INSIDE DIAM 0.3370 [na '+0.0015=0.3385']'
CYLI     0  1  0.42799      2P225.58
'  CLAD OUTSIDE DIAM (ZRALLOY-2) 0.3870 [na '-0.002=0.3868']'
CYLI     2  1  0.49150      2P225.58
'  ADD MODERATION WATER AT 0.511024" PITCH
CUBO     3  1  4P0.64900   2P225.58

UNIT 5
COM=' 10X10 BUNDLE IN LEFT BASKET   '
''  [(PITCH)(N-1)+(CLAD OD)]/2 = [(1.298*9)+0.983]/2 = 6.3325 CM
'  USE (PITCH)(N)/2  =  [(1.298*10)/2] = 6.49
ARRAY    1  2R-6.49          -225.58
'  [(SHELL SIZE)-(2)(THICKNES)]/2 = {[(7)-(2*0.0598)]/2}*{2.54} = 8.7381 CM
CUBO     3  1   4P8.7381     2P225.5801
'  ADD 0.0598 INCH OF PERFORATED STEEL
CUBO     8  1   4P8.89       2P225.5801
```

```
UNIT 6
COM=' 10X10 BUNDLE IN RIGHT BASKET  '
'  [(PITCH)(N-1)+(CLAD OD)]/2 = [(1.298*9)+0.983]/2 = 6.3325 CM
'  USE (PITCH)(N)/2  =  [(1.298*10)/2] = 6.49
ARRAY    2  2R-6.49        -225.58
'  [(SHELL SIZE)-(2)(THICKNES)]/2 = {[(7)-(2*0.0598)]/2}*{2.54} = 8.7381 CM
CUBO     3  1  4P8.7381    2P225.5801
'  ADD 0.0598 INCH OF PERFORATED STEEL
CUBO     8  1  4P8.89      2P225.5801

UNIT 7
COM=' SPACING & STEEL ANGLE BESIDE BASKET  '
'  ANGLE STEEL SMEARED IN 2 INCHES X 3.8891 INCHES VOLUME
'  2 INCHES X (7-3.8891=3.111) INCHES OF WATER DIVIDED INTO 2 PARTS
CUBO     9  1  2P2.54      2P4.9391    2P225.58
'  2 INCHES X 7 INCHES TOTAL SIZE
CUBO     3  1  2P2.54      2P8.89      2P225.5801

UNIT 8
COM=' ANGLES & SPACING BENEATH & ABOVE BASKETS  '
'  ANGLE STEEL SMEARED IN 3.8891 INCHES  X 2 INCHES VOLUME
CUBO     9  1  2P4.9392    2P2.54      2P225.58
'  7 INCHES X 2 INCHES TOTAL SIZE
CUBO     3  1  2P8.89      2P2.54      2P225.5801

UNIT 9
COM=' 2X2 INCH MODERATION REGIONS AT CORNERS  '
CUBO     3  1  4P2.54      2P225.5801

UNIT 10
COM=' 1 INNER CONTAINER  '
'  18 X 11 X 177.622 INCHES
ARRAY    3  -22.86  -13.97  -225.58
'  ADD  0.0598 INCH WALLS OF CARBON STEEL
REPL     7  1  6R0.1519  1

UNIT 11
COM=' INTERSPERSED WATER 'WATER HOLE'  '
CUBO     3  1  4P0.64900   2P225.58

GLOBAL
UNIT 12
COM=' ARRAY OF INNERS  '
' THIS IS MULTI-UNIT ARRAY WITH SPECULAR REFLECTION
' ATTEMPT TO REDUCE COLLISIONS WITH BOUNDARY
ARRAY    4  3R0.0

END GEOM

READ ARRAY

ARA=1  NUX=10  NUY=10  NUZ=1
' 6 GD RODS IN COL-ROW 6-4 7-4 7-5 4-6 4-7 5-7
```

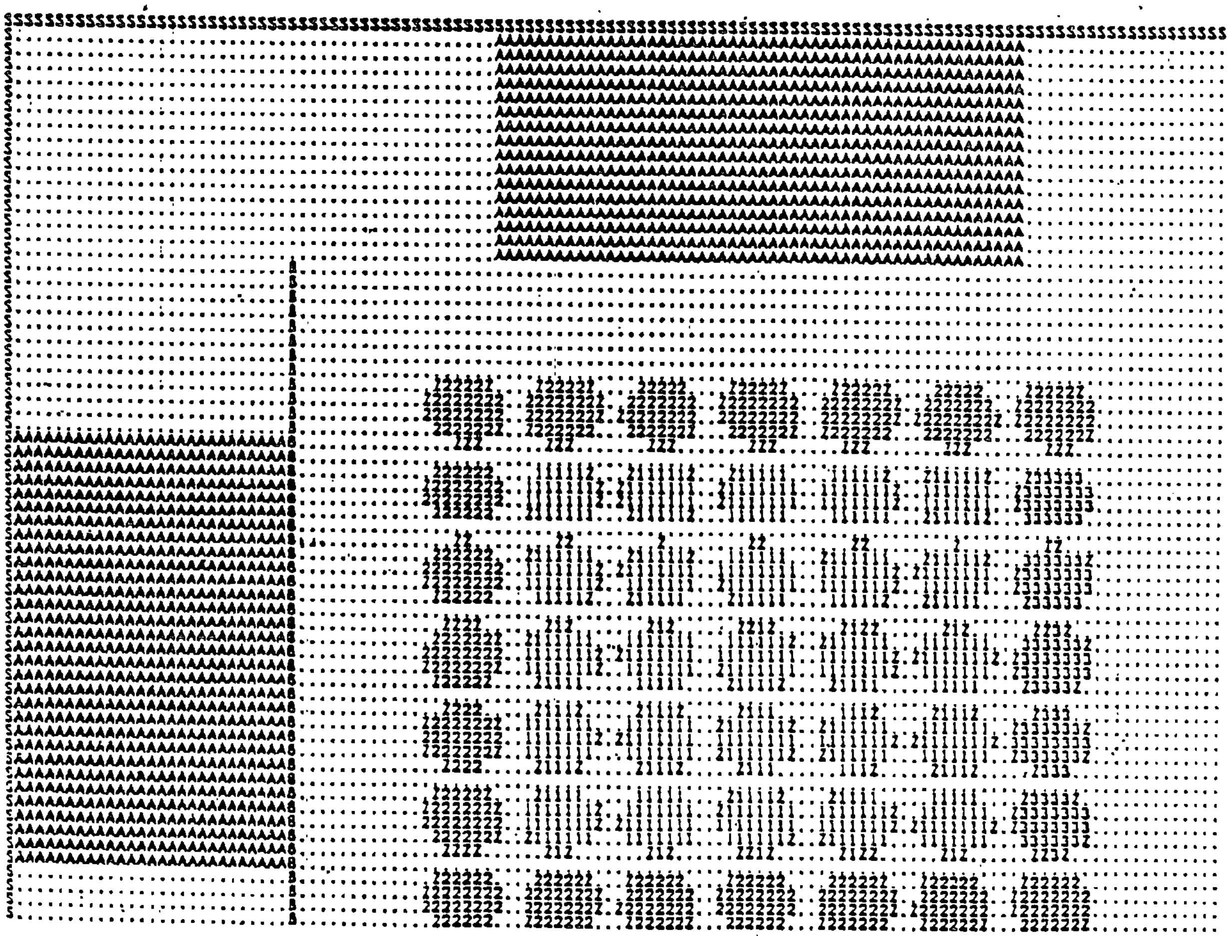
```
' no SMALL WATER RODS IN COL-ROW 6-4 4-5 7-6 5-7
FILL
'COL 1  2  3  4  5  6  7  8  9 10

    2  2  2  2  2  2  2  2  2  2
    2  1  1  1  1  1  1  1  1  3
    2  1  1  1  1  1  1  1  1  3
    2  1  1  1  1  4  4  1  1  3
    2  1  1  1 11 11  4  1  1  3
    2  1  1  4 11 11  1  1  1  3
    2  1  1  4  4  1  1  1  1  3
    2  1  1  1  1  1  1  1  1  3
    2  1  1  1  1  1  1  1  1  3
    2  2  2  2  2  2  2  2  2  2    END FILL

ARA=2  NUX=10  NUY=10  NUZ=1
' 6 GD RODS IN COL-ROW 6-4 7-4 7-5 4-6 4-7 5-7
' no SMALL WATER RODS IN COL-ROW 6-4 4-5 7-6 5-7
FILL
'COL 1  2  3  4  5  6  7  8  9 10

    2  2  2  2  2  2  2  2  2  2
    3  1  1  1  1  1  1  1  1  2
    3  1  1  1  1  1  1  1  1  2
    3  1  1  1  1  4  4  1  1  2
    3  1  1  1 11 11  4  1  1  2
    3  1  1  4 11 11  1  1  1  2
    3  1  1  4  4  1  1  1  1  2
    3  1  1  1  1  1  1  1  1  2
    3  1  1  1  1  1  1  1  1  2
    2  2  2  2  2  2  2  2  2  2    END FILL

ARA=3  NUX=4  NUY=3  NUZ=1
FILL
9 8 8 9
7 5 6 7
9 8 8 9   END FILL

ARA=4  NUX=5  NUY=5  NUZ=1
FILL  F10  END FILL

END ARRAY

READ START   NST=1   END START

READ BOUNDS   ALL=SPECULAR   END BOUNDS

READ PLOT
TTL='  FUEL CASK X-Y SECTION AT Z=10  '
NCH='.IZ+OFPSMD'
' VOID  INNER  ZR  IMOD  OUT  FACING  POISON  STEEL  MOD STEEL  DILUTE STEEL
 XUL= 0.0    YUL=28.25   ZUL=10.0
 XLR=46.03   YLR= 0.0    ZLR=10.0
```

```
UAX=1.0   VDN=-1.0   NAX=130  LPI=6   END

TTL=' LEFT HALF                 '
 XUL= 0.0    YUL=28.25   ZUL=10.0
 XLR=23.02   YLR= 0.0    ZLR=10.0   END

TTL=' LOWER RIGHT QUADRANT OF LEFT HALF   '
 XUL= 0.0    YUL=14.13   ZUL=10.0
 XLR=11.51   YLR= 0.0    ZLR=10.0   END

TTL=' UPPER LEFT QUADRANT OF LEFT HALF    '
 XUL= 0.0    YUL=28.25   ZUL=10.0
 XLR=11.51   YLR=14.13   ZLR=10.0
 END PLOT
 END DATA
 END KENO
END
```



KENO-Va PLOT OF INNER CONTAINER MODEL
KEY: 1,2,3 = UO2 PELLET, Z = Zr CLAD, . = MODERATION,
S = STEEL SHELL, B = BASKET, A = SMEARED BASKET-MODERATION

DETAIL OF LEFT HALF OF MODEL
(FINNER DETAIL WOULD SHOW ENTIRE BASKET)



EMF-92-104
Revision 2
Issue Date:

CRITICALITY SAFETY ANALYSIS FOR SHIPMENT OF SPC 10X10-8B FUEL ASSEMBLIES IN THE SP-1 SHIPPING CONTAINER

DISTRIBUTION

J. B. Edgar (7)
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T. C. Probasco
Document Control (5)

Appendix 6C

SIEMENS POWER CORPORATION SUPPLEMENTAL APPLICATION TO ADD GADOLINIA - BEARING LOOSE RODS TO CERTIFICATE OF COMPLIANCE 9248

EMF-1563
Supplement 3

Supplemental License Application for Siemens Power Corporation Model SP-1 and SP-2 Shipping Containers Certificate of Compliance No. 9248 Docket No. 71-9248

December 1994

Issue Date: 12/23/94

SUPPLEMENTAL LICENSE APPLICATION
FOR
SIEMENS POWER CORPORATION
MODEL SP-1 AND SP-2
SHIPPING CONTAINERS

Certificate of Compliance No. 9248
Docket No. 71-9248

Siemens Power Corporation
Nuclear Division
Richland, WA

**SUPPLEMENTAL LICENSE APPLICATION
FOR
SIEMENS POWER CORPORATION
MODEL SP-1 AND SP-2 SHIPPING CONTAINERS**

Certificate of Compliance No. 9248
Docket No. 71-9248

Prepared by: J. B. Edgar, Staff Engineer, Licensing, Regulatory Compliance — 12/22/94 Date

Accepted by: R. L. Feuerbacher, Manager, Materials and Scheduling — 12/22/94 Date

Concurred by: A. Reparaz, Manager, Fuel Design — 12/22/94 Date

Approved by: L. J. Maas, Manager, Regulatory Compliance — 12/22/94 Date

SUPPLEMENTAL LICENSE APPLICATION
FOR
SIEMENS POWER CORPORATION
MODEL SP-1 AND SP-2 SHIPPING CONTAINERS

Certificate of Compliance No. 9248
Docket No. 71-9248

TABLE OF CONTENTS

1.0 INTRODUCTION

This application is made as an additional supplement to document EMF-1563, "Consolidated License Application for Siemens Power Corporation Model SP-1 and SP-2 Shipping Containers,"originally submitted in May 1993, revised in December 1993, and supplemented in September and October 1994. The purpose of this application is to add gadolinia-bearing fuel rods to the allowable contents in Section 5(b)(1) of NRC Certificate of Compliance 9248 and to add a stainless steel box to house those rods inside the SP-1 and SP-2 shipping containers in Section 5(a).

2.0 SUMMARY

This document provides demonstration that the following additions to Section 5 of Certificate of Compliance No. 9248 meets the requirements in 10 CFR Part 71.

5(a)(5) Gadolinia Rod Container.

A 10 gauge stainless steel box with a flanged lid and end closure.

5(b)(1)(vi) UO_2 fuel rods with a maximum U-235 enrichment of 5.0 wt.% and a minimum gadolinia content of 1.0 wt%. The maximum pellet diameter is 0.5 inch and the maximum rod length is 169" inches. The rods may be clad with zircaloy, steel, or aluminum. Rods meeting the above requirements may placed into the "Gadolinia Rod Container" and shipped in the SP-1 or SP-2 in lieu of one or two fuel assemblies. Fissile Class I is authorized for shipping Gadolinia Rod Containers.

Criticality safety was demonstrated by modeling infinite arrays of unclad fuel rods. The fuel was 5.0% enriched UO_2 with 0.75 wt.% gadolinia (Gd_2O_3). The fuel density modeled was 100% of theoretical. The maximum k-inf calculated with 75% of the minimum specified gadolinia content is about 0.909. Finite arrays of packages with the spacings and structural materials actually in the packages would be less reactive.

3.0 FISSILE MATERIAL DESCRIPTION

The criticality safety calculations were based on the following very conservative set of conditions and property assumptions:

a. An infinite array of infinite-length fuel rods was modeled. The modeled rods were unclad and there was no steel in the model.

b. All rods were modeled at a 5.0% enrichment and with 75% of minimum 1.0 wt.% gadolinia specified.

c. The spacing and interspersed moderation within the infinite rod array were evaluated to determine the combination for peak k-inf.

d. The theoretical density of UO_2 is 10.96 grams per cc. The theoretical density of gadolinia is 8.31 grams per cc. When gadolinia is added to UO_2, the theoretical density of the two-phase mixture or of a solid solution is lower than 10.96 grams per cc. The density modeled in these calculations is 10.9305 grams per cc which is the estimated theoretical density for UO_2 with 0.75 wt.% Gd_2O_3.

4.0 PACKAGING DESCRIPTION

Each SP-1 and SP-2 can contain up to two BWR assemblies or two Gadolinia Rod Containers.

The SP-1 and SP-2 are composed of a steel "inner container" and a wooden "outer container". The inner containers contain two "baskets" made of 0.0598" thick carbon steel with 0.75" diameter holes in a 1.75" square pitch pattern. The baskets are nominally 7"x7" in cross section. The two baskets are placed edge-to-edge in the center of the nominally 18" wide by 11" high steel inner container (0.0598" carbon steel walls). There is a 2" thick annulus between the basket wall and the inner container wall. In this annulus are six carbon steel angles (2.8125"x2.8125"x0.125" nominal).

To demonstrate criticality safety of the package containing Gadolinia Rod Containers, infinite arrays of close-packed gadolinia rods were modeled. All structural members and rod cladding were omitted from the model.

5.0 CALCULATION METHODOLOGY AND VALIDATION

The codes, cross sections, and other data from SCALE 4.2 (1) were used. The "CSASIX" option was used with 16, 27, 123, and 218 group cross sections for most calculations. The codes executed, in sequence, are: DRIVER, CSAS25, BONAMI, NITAWL, and XSDRN.

5.1 Validation/Benchmarking

Additional critical experiments (Reference 3) with gadolinium were modeled. The experiments determined the critical number of UO_2 fuel rods with gadolinium dissolved in the water between the rods. The rods were in a triangular-pitched array in a cylindrical vessel with water reflection on all sides of the approximately cylindrical-shaped rod array. Three rod pitches were used for the 14.40 mm OD rods: 22.86mm, 27.94mm, and 33.02mm. The experiments were modeled using cell-weighted cross sections simulating the unit cell. A cylindrical fuel region with a cross sectional area equal to that of the reported critical number of rods was modeled with full water reflection. The cases were replicated with the 16, 27, 123, and 218 group cross section libraries in SCALE. The calculation results are tabulated and plotted below.

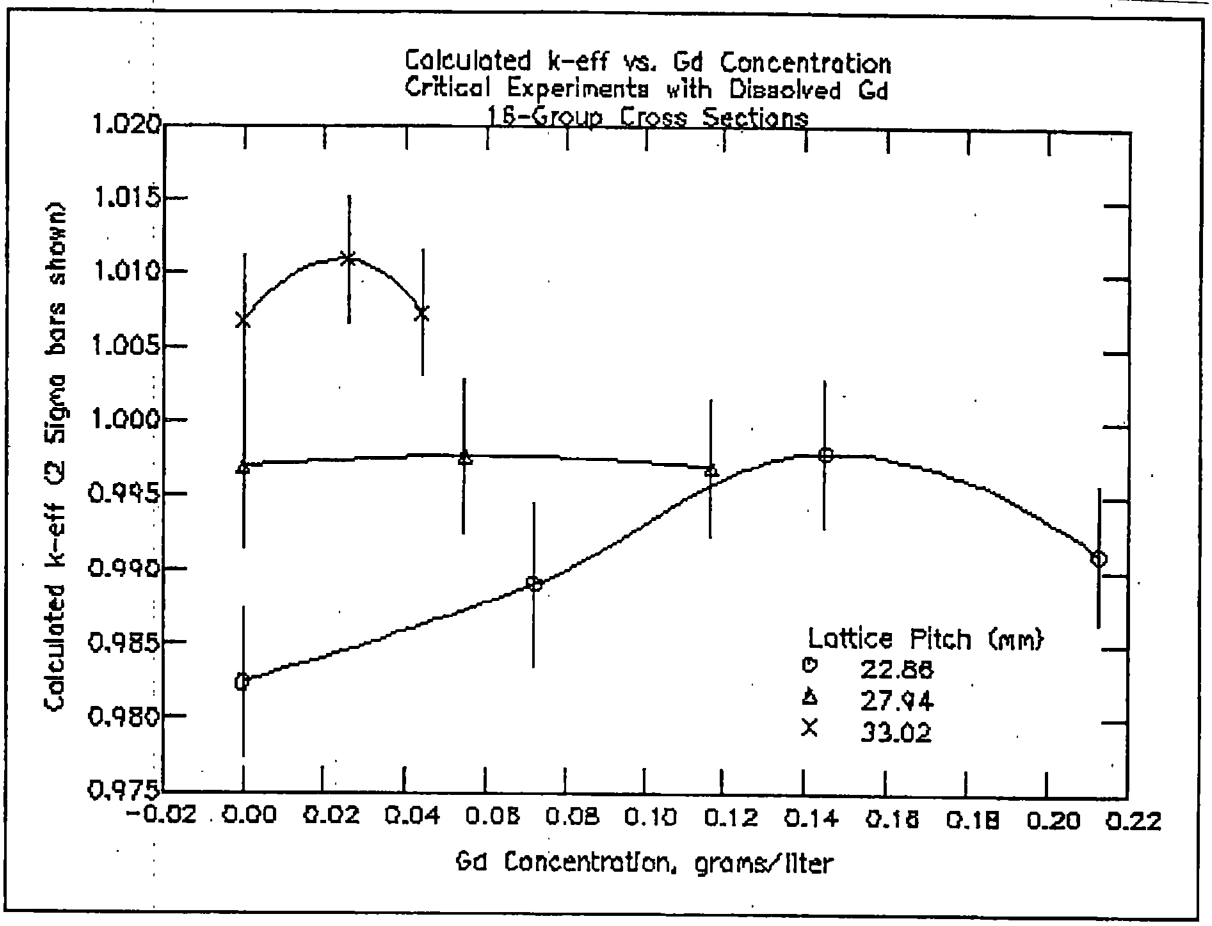
Ten experiments were modeled: seven contain gadolinium and three are water-only reference cases. The average and standard deviations of the calculation bias, based only on the seven cases with gadolinium, are in the following table. Bias corrections will not cause calculated k-inf values to exceed 0.95.

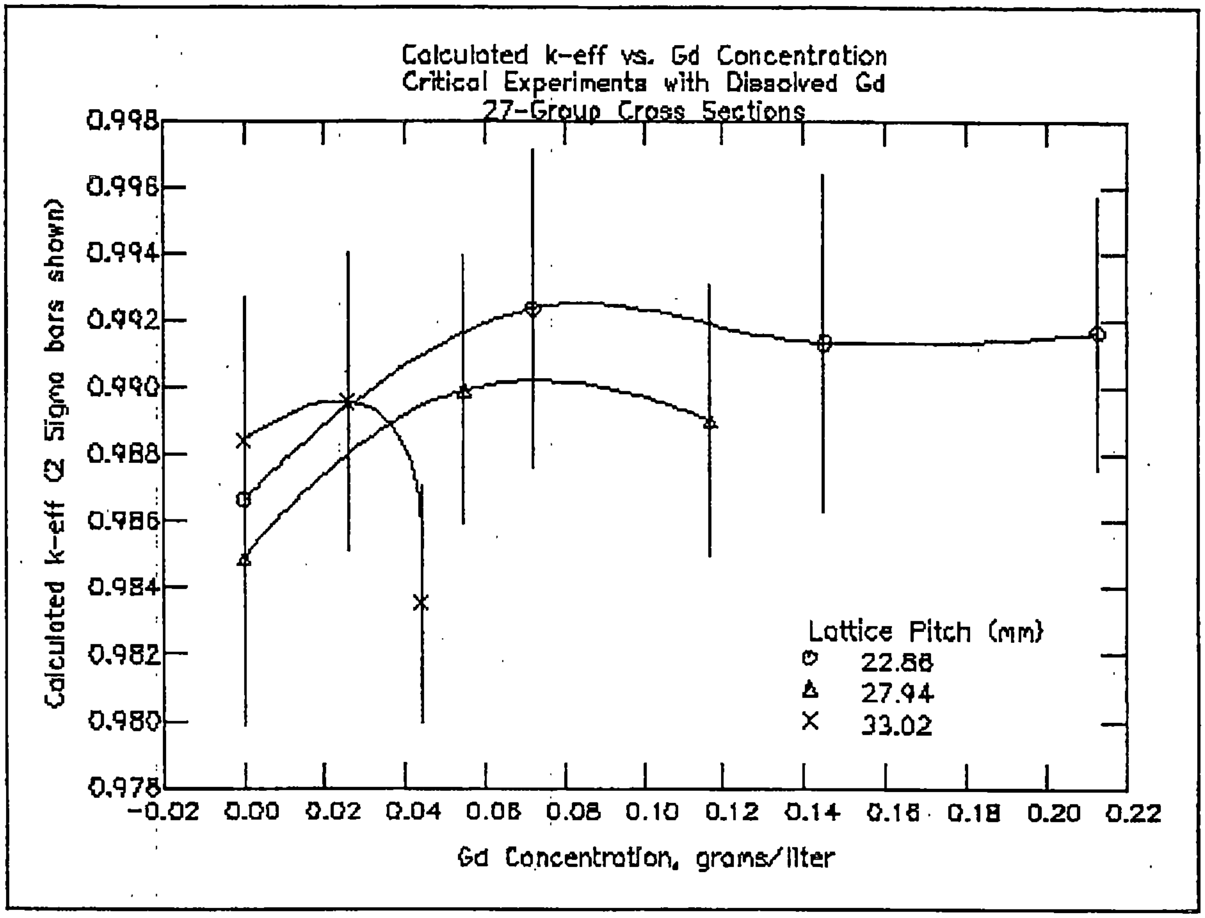
CALCULATION BIAS FOR CASES WITH GADOLINIUM

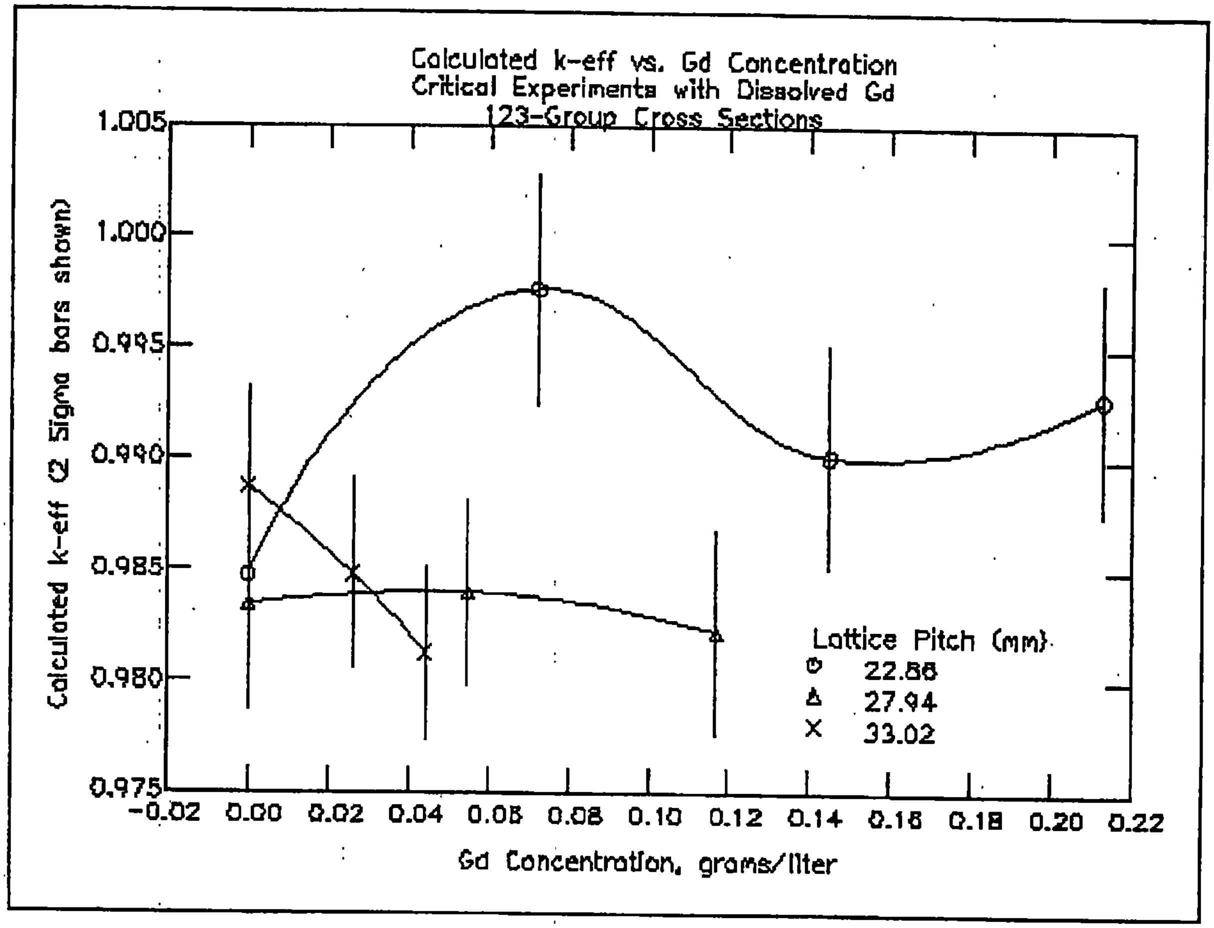
Cross Section Library (Energy Groups)	Calculation Bias Average	Calculation Bias Standard Deviation
16	0.0001875	0.00774
27	0.010864	0.002430
123	0.013481	0.005322
218	0.011443	0.001899

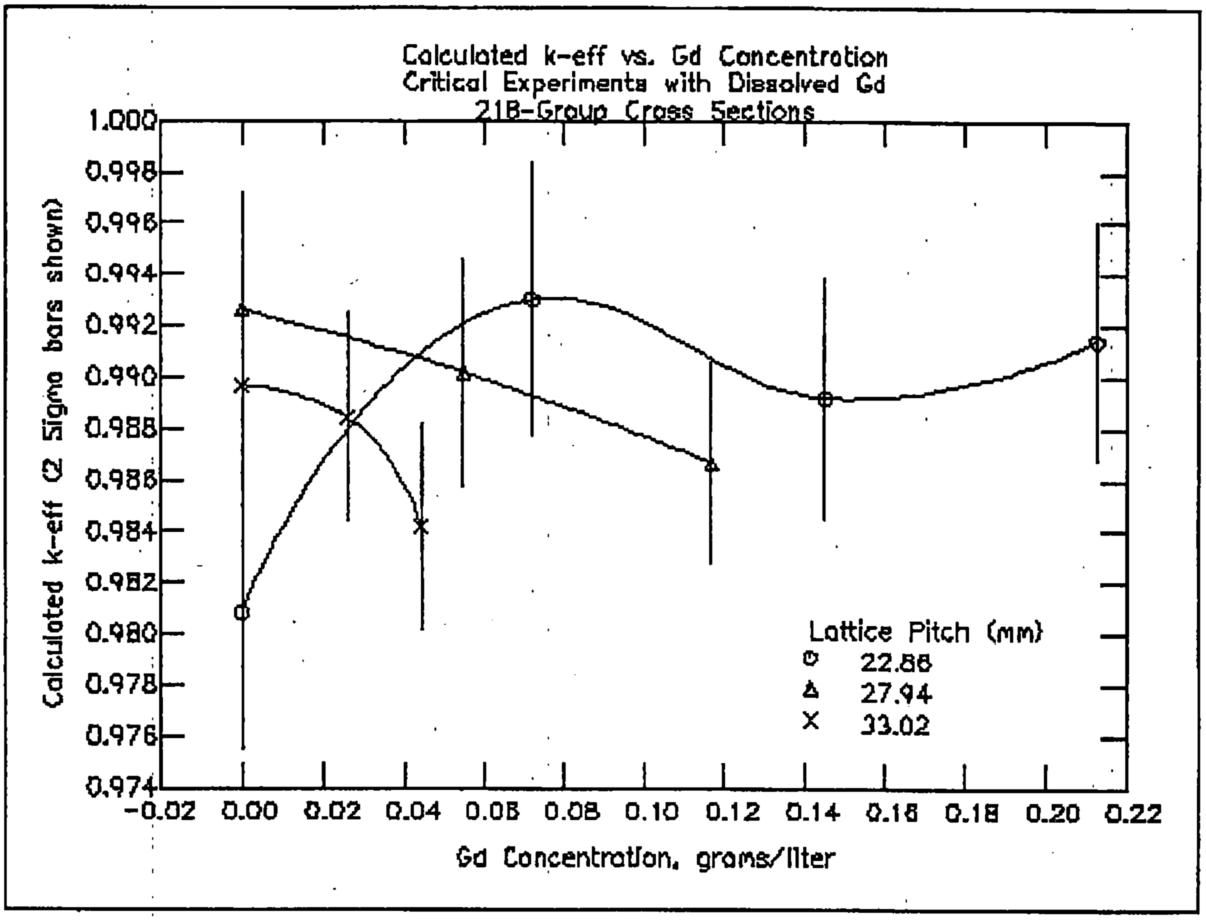
CRITICAL EXPERIMENTS WITH GADOLINIUM
CALCULATION RESULTS

Experiment No.	Triangular Lattice Pitch, mm	Gd Concentration, Grams/liter	16-Group k-eff		27-Group k-eff		123-Group k-eff		218 Group k-eff	
			Avg.	Std.Dev.	Avg.	Std.Dev.	Avg.	Std.Dev.	Avg.	Std.Dev.
001	22.86	0	0.98242	0.00251	0.98663	0.00291	0.98478	0.00283	0.98083	0.00267
009		0.0722	0.9891	0.00274	0.99236	0.00237	0.99762	0.00257	0.99304	0.00265
010		0.145	0.99793	0.00248	0.99134	0.00252	0.99013	0.0025	0.9892	0.00232
011		0.213	0.99121	0.00231	0.99164	0.00202	0.99279	0.00259	0.99142	0.00232
012	27.94	0	0.99701	0.00277	0.98487	0.0025	0.98348	0.00236	0.99262	0.00231
016		0.0547	0.99769	0.00254	0.98993	0.00198	0.98402	0.00207	0.99019	0.00219
017		0.1169	0.99698	0.00226	0.98901	0.00201	0.98224	0.0023	0.98669	0.00196
018	33.02	0	1.0068	0.00215	0.98841	0.00211	0.98877	0.00223	0.98967	0.00235
023		0.0257	1.01088	0.00211	0.98957	0.00223	0.98482	0.00213	0.98843	0.00201
024		0.044	1.00728	0.00207	0.98352	0.00177	0.98126	0.00192	0.98415	0.00199


Calculated k-eff vs. Gd Concentration
Critical Experiments with Dissolved Gd
16-Group Cross Sections
Calculated k-eff (2 Sigma bars shown)
1.020
1.015
1.010
1.005
1.000
0.995
0.990
0.985
0.980
0.975
-0.02
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
Gd Concentration, grams/liter
Lattice Pitch (mm)
22.86
27.94
33.02


Calculated k-eff vs. Gd Concentration
Critical Experiments with Dissolved Gd
27-Group Cross Sections
Calculated k-eff (2 Sigma bars shown)
0.998
0.996
0.994
0.992
0.990
0.988
0.986
0.984
0.982
0.980
0.978
-0.02
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
Gd Concentration, grams/liter
Lattice Pitch (mm)
22.86
27.94
33.02


Calculated k-eff vs. Gd Concentration
Critical Experiments with Dissolved Gd
123-Group Cross Sections
Calculated k-eff (2 Sigma bars shown)
1.005
1.000
0.995
0.990
0.985
0.980
0.975
-0.02
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
Gd Concentration, grams/liter
Lattice Pitch (mm)
22.86
27.94
33.02



6.0 CALCULATION RESULTS

6.1 Infinite Arrays of Edge-to-Edge Rods

Infinite arrays of unclad edge-to-edge rods in a triangular-pitched array were modeled with fuel diameters in the range 0.1" to 0.5" and with interspersed water densities in the range 0.1 to 100 volume %.

As shown in Table 6.1 and the following plots, the k-inf results with 16 and 123 group cross sections are higher than those with 27 or 218 group cross sections.

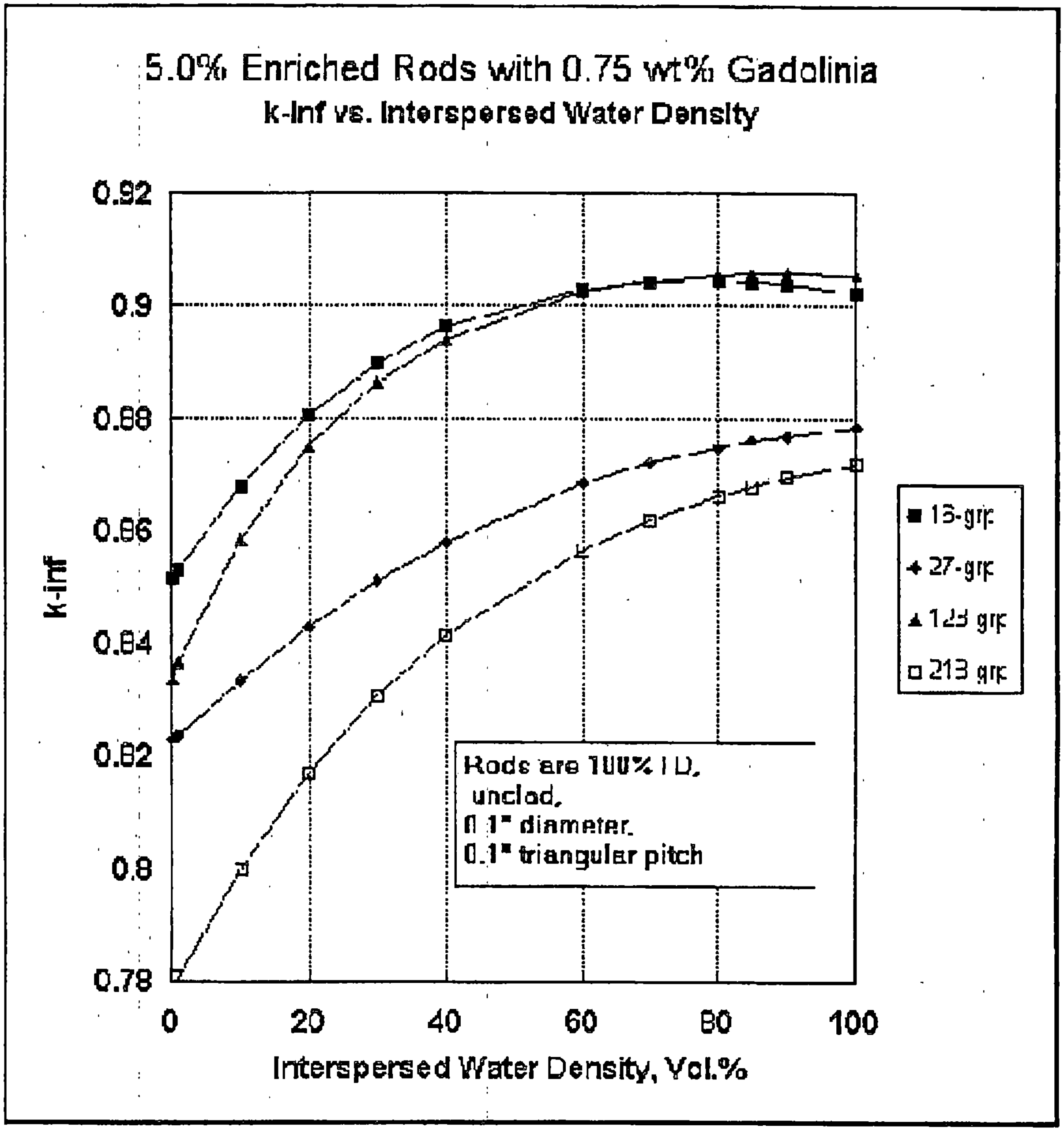
With 16 or 123 group cross sections, the peak k-inf was calculated with about 80 to 90 volume% water between the edge-to-edge rods, which indicates that increased spacings, including a square pitched arrangement, with full density water would result in a lower k-inf.

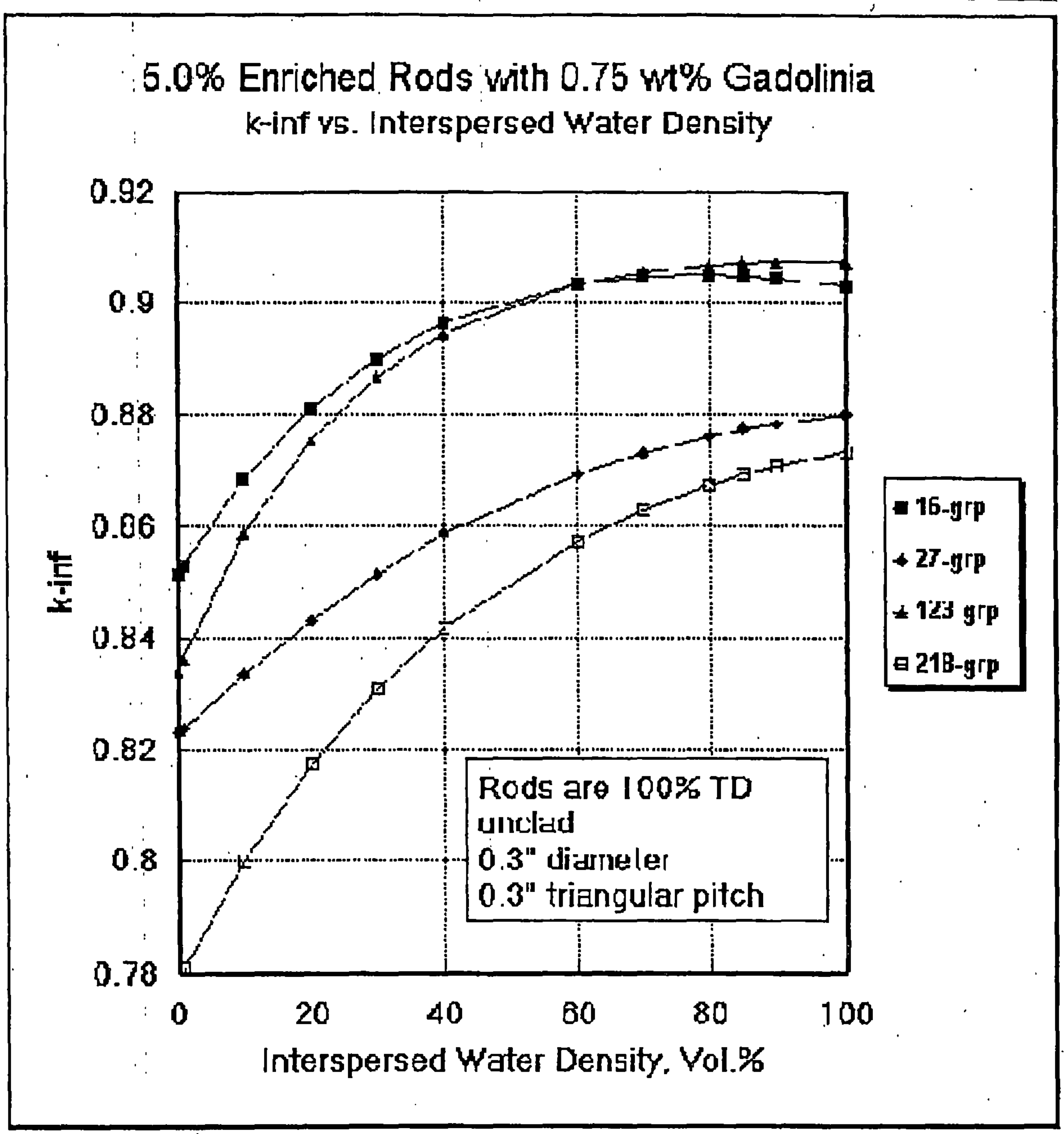
With 27 and 218 group cross sections, the highest k-inf was calculated with 100 volume % water between the edge-to-edge rods, which could mean that increased spacings between rods might result in slightly higher k-inf values. However, there appears to be little potential for exceeding the values calculated with 16/123 group cross sections. Spacing effects were evaluated in later sections.

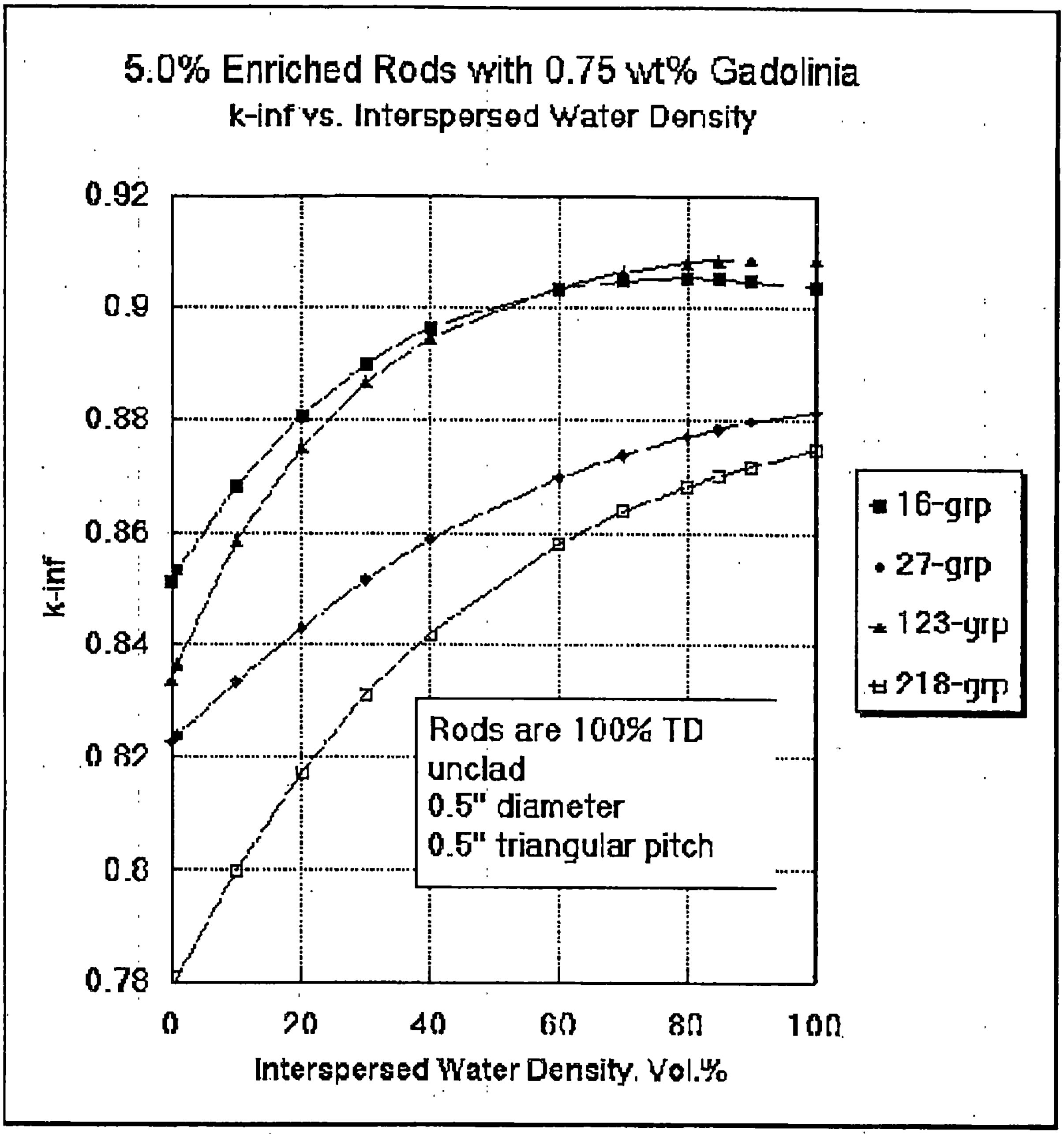
The diameter effect is seen to be small but the highest k-inf was calculated with the largest fuel diameter.

TABLE 6.1
Infinite Array of Unclad Rods
5.0% Enriched, 100% TD, 0.75 wt% Gadolinia
Edge-to-edge rods, Triangular Pitch

Rod Diameter, inch	Interspersed Water, Vol.%	k-inf			
		16-grp	27-grp	123-grp	218-grp
0.1	100	0.902341	0.87838	0.905532	0.871947
	90	0.90373	0.876979	0.905889	0.869572
	85	0.904165	0.876043	0.905845	0.868088
	80	0.904407	0.874934	0.905629	0.866382
	70	0.904221	0.872153	0.904588	0.862221
	60	0.902972	0.868531	0.902543	0.856882
	40	0.896149	0.858266	0.894008	0.841549
	30	0.889767	0.85135	0.886343	0.830759
	20	0.880665	0.843078	0.875085	0.817148
	10	0.868104	0.833419	0.858495	0.799998
	1	0.853174	0.823744	0.836611	0.780924
	0.1	0.851473	0.822747	0.833931	0.778812
0.3	100	0.903084	0.879937	0.907193	0.873265
	90	0.904322	0.878287	0.907278	0.870701
	85	0.904691	0.87723	0.907102	0.869123
	80	0.904869	0.876005	0.906756	0.867326
	70	0.904569	0.873	0.90547	0.862987
	60	0.903223	0.869174	0.903199	0.857482
	40	0.896257	0.858575	0.894297	0.841863
	30	0.88983	0.851533	0.886502	0.830957
	20	0.880696	0.843165	0.875154	0.817252
	10	0.868114	0.833443	0.858513	0.800031
	1	0.853174	0.823744	0.836611	0.780924
	0.1	0.851473	0.822747	0.833931	0.778812
0.5	100	0.903746	0.881439	0.908798	0.874614
	90	0.904865	0.879574	0.908643	0.871871
	85	0.905177	0.878409	0.908347	0.870205
	80	0.905302	0.877077	0.907883	0.868318
	70	0.904903	0.873865	0.906365	0.863803
	60	0.90347	0.869842	0.903876	0.858129
	40	0.896368	0.858904	0.894605	0.842207
	30	0.889895	0.851731	0.886674	0.831176
	20	0.88073	0.843261	0.87523	0.817367
	10	0.868125	0.833471	0.858532	0.800067
	1	0.853174	0.823745	0.836611	0.780925
	0.1	0.851473	0.822747	0.833931	0.778812


5.0% Enriched Rods with 0.75 wt% Gadolinia
k-Inf vs. Interspersed Water Density
0.92
0.9
0.88
0.86
0.84
0.82
0.8
0.78
k-inf
0
20
40
60
80
100
Interspersed Water Density, Vol.%
Rods are 100% TD,
unclad,
0.1" diameter,
0.1" triangular pitch
27-grp
213 grp


5.0% Enriched Rods with 0.75 wt% Gadolinia
k-inf vs. Interspersed Water Density
0.92
0.9
0.88
0.86
0.84
0.82
0.8
0.78
k-inf
0
20
40
60
80
100
Interspersed Water Density, Vol.%
16-grp
27-grp
123 grp
218-grp
Rods are 100% TD
unclad
0.3" diameter
0.3" triangular pitch


5.0% Enriched Rods with 0.75 wt% Gadolinia
k-inf vs. Interspersed Water Density
k-inf
0.92
0.9
0.88
0.86
0.84
0.82
0.8
0.78
0
20
40
60
80
100
Interspersed Water Density, Vol.%
16-grp
27-grp
123-grp
218-grp
Rods are 100% TD
unclad
0.5" diameter
0.5" triangular pitch

6.2 Infinite Arrays of Spaced Rods

Infinite arrays of unclad rods in a triangular-pitched array were modeled with various spacings (rod pitches). All cases were modeled with the most reactive fuel diameter (0.5") and with 10 volume % interspersed water. The low water density model was used to make the system less sensitive to changes in the rod pitch.

The calculation results are in Table 6.2. The peak k-inf in these cases is about 0.905-0.907 for 16 and 123 group cross sections, which agrees well with the peak in Table 6.1. The peak with 27 and 218 group cross sections is about 0.882 and 0.878, respectively, which is only slightly higher than the peaks in Table 6.1.

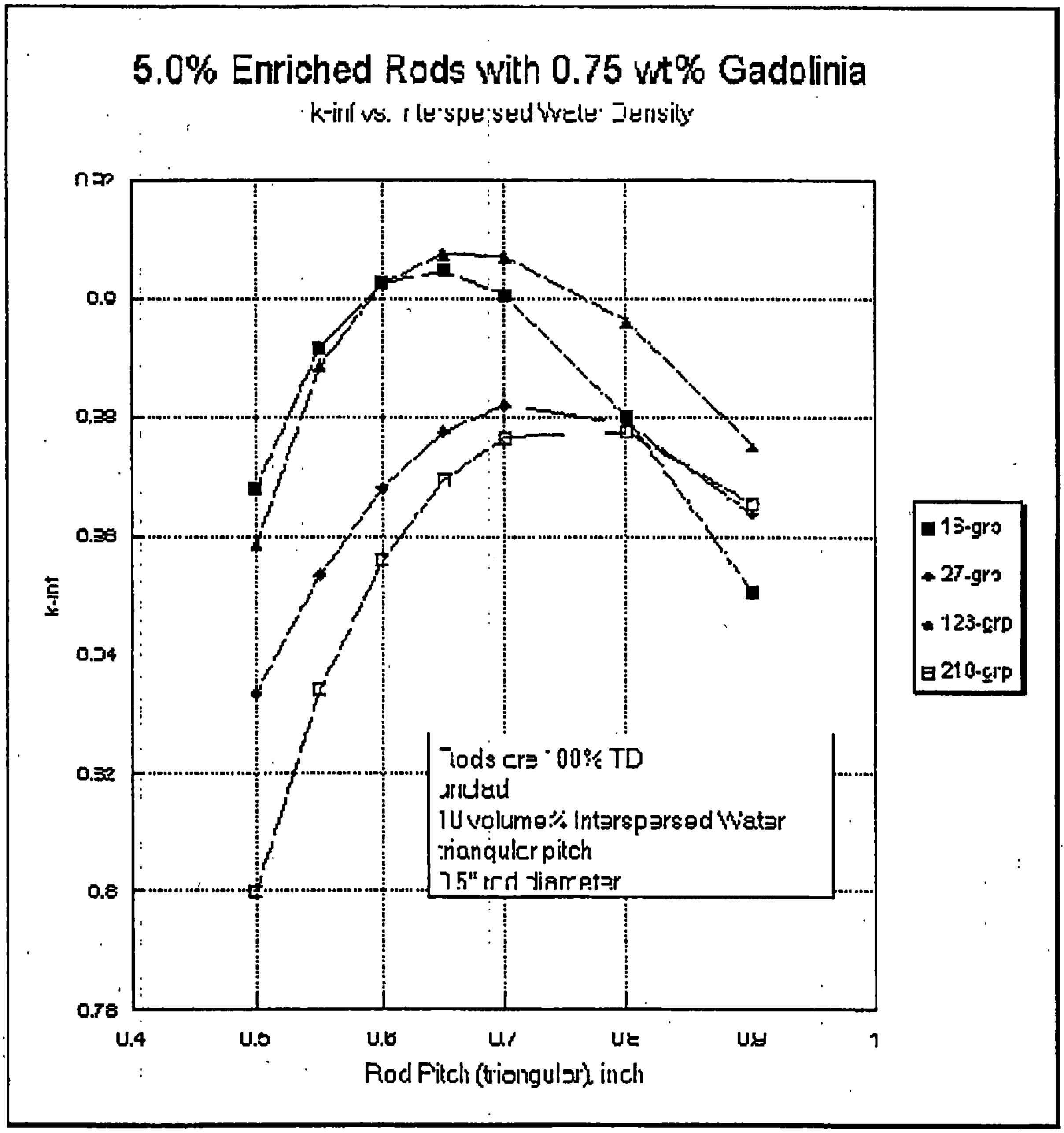
TABLE 6.2
Infinite Array of Unclad Rods
5.0% Enriched, 100% TD, 0.75 wt% Gadolinia
0.5" Diameter Rods, 10 Volume % Interspersed Water, Triangular Pitch

Rod Pitch, inch	k-inf			
	16-Grp	27-Grp	123-Grp	218-Grp
0.5	0.868125	0.833471	0.858532	0.800067
0.55	0.89167	0.853524	0.888732	0.834125
0.6	0.902541	0.868143	0.902394	0.856084
0.65	0.90466	0.877465	0.907404	0.869538
0.7	0.900607	0.882038	0.907127	0.876779
0.8	0.879988	0.879181	0.896181	0.87773
0.9	0.850797	0.863824	0.875447	0.865624

Additional cases with spaced rods with full density water were modeled to verify that the peak k-inf is as shown in Table 6.2. These additional calculation results are in Table 6.3.

TABLE 6.3
Infinite Array of Unclad Rods
5.0% Enriched, 100% TD, 0.75 wt% Gadolinia
0.5" Diameter Rods, 100 Volume % Interspersed Water, Triangular Pitch

Rod Pitch, Inch	k-inf			
	16-Grp	27-Grp	123-Grp	218-Grp
0.50	0.903746	0.881439	0.908798	0.874614
0.505	0.898959	0.882972	0.906804	0.877998
0.51	0.892340	0.882574	0.903356	0.879100
0.515	0.884383	0.880535	0.898719	0.878394
0.52	0.875667	0.877173	0.893161	0.876259
0.53	0.857389	0.867453	0.880011	0.868775



7.0 REFERENCES

1. NUREG/CR-0200: SCALE: A MODULAR CODE SYSTEM FOR PERFORMING STANDARDIZED COMPUTER ANALYSES FOR LICENSING EVALUATION

2. NUREG/CR-0073: "Critical Separation Between Subcritical Clusters of 4.31 wt% Enriched UO_2 Rods in Water with Fixed Neutron Poisons"

3. Lloyd, R.C., Durst, B.M., and Clayton, E.D.: "Effect of Soluble Neutron Absorbers on Criticality of Low U-235 Enriched UO_2 Lattices", Nuclear Science and Engineering: 71, 164-169 (1979)

8.0 INPUT LISTING

The data in Table 6.1 were calculated using inputs such as that listed below.

```
=csasix
inf array of gad rods
hans latt

uo2 1 den=10.9305 0.9925 293. 92235 5.0 92238 95.0 end
arbm-gd2o3 10.9305 2 0 1 0 64000 2 8016 3 1 0.0075 293 end

h2o  2 1.0 293 end

end comp
'  0.5" pellet diam, 0.5"pitch
tria 1.27 1.27 1 2 end
end
=csasix
inf array of gad rods
hans latt

uo2 1 den=10.9305 0.9925 293. 92235 5.0 92238 95.0 end
arbm-gd2o3 10.9305 2 0 1 0 64000 2 8016 3 1 0.0075 293 end

h2o  2 0.9 293 end

end comp
'  0.5" pellet diam, 0.5"pitch
tria 1.27 1.27 1 2 end
end
=csasix
inf array of gad rods
hans latt

uo2 1 den=10.9305 0.9925 293. 92235 5.0 92238 95.0 end
arbm-gd2o3 10.9305 2 0 1 0 64000 2 8016 3 1 0.0075 293 end

h2o  2 0.85 293 end

end comp
'  0.5" pellet diam, 0.5"pitch
tria 1.27 1.27 1 2 end
end
=csasix
inf array of gad rods
hans latt

uo2 1 den=10.9305 0.9925 293. 92235 5.0 92238 95.0 end
arbm-gd2o3 10.9305 2 0 1 0 64000 2 8016 3 1 0.0075 293 end

h2o  2 0.8 293 end
```

```
end comp
' 0.5" pellet diam, 0.5"pitch
tria 1.27 1.27 1 2 end
end
=csasix
inf array of gad rods
hans latt

uo2 1 den=10.9305 0.9925 293. 92235 5.0 92238 95.0 end
arbm-gd2o3 10.9305 2 0 1 0 64000 2 8016 3 1 0.0075 293 end

h2o  2 0.7 293 end

end comp
' 0.5" pellet diam, 0.5"pitch
tria 1.27 1.27 1 2 end
end
=csasix
inf array of gad rods
hans latt

uo2 1 den=10.9305 0.9925 293. 92235 5.0 92238 95.0 end
arbm-gd2o3 10.9305 2 0 1 0 64000 2 8016 3 1 0.0075 293 end

h2o  2 0.6 293 end

end comp
' 0.5" pellet diam, 0.5"pitch
tria 1.27 1.27 1 2 end
end
=csasix
inf array of gad rods
hans latt

uo2 1 den=10.9305 0.9925 293. 92235 5.0 92238 95.0 end
arbm-gd2o3 10.9305 2 0 1 0 64000 2 8016 3 1 0.0075 293 end

h2o  2 0.4 293 end

end comp
' 0.5" pellet diam, 0.5"pitch
tria 1.27 1.27 1 2 end
end
=csasix
inf array of gad rods
hans latt

uo2 1 den=10.9305 0.9925 293. 92235 5.0 92238 95.0 end
arbm-gd2o3 10.9305 2 0 1 0 64000 2 8016 3 1 0.0075 293 end

h2o  2 0.3 293 end
```

```
end comp
' 0.5" pellet diam, 0.5"pitch
tria 1.27 1.27 1 2 end
end
=csasix
inf array of gad rods
hans latt

uo2 1 den=10.9305 0.9925 293. 92235 5.0 92238 95.0 end
arbm-gd2o3 10.9305 2 0 1 0 64000 2 8016 3 1 0.0075 293 end

h2o  2 0.2 293 end

end comp
' 0.5" pellet diam, 0.5"pitch
tria 1.27 1.27 1 2 end
end
=csasix
inf array of gad rods
hans latt

uo2 1 den=10.9305 0.9925 293. 92235 5.0 92238 95.0 end
arbm-gd2o3 10.9305 2 0 1 0 64000 2 8016 3 1 0.0075 293 end

h2o  2 0.1 293 end

end comp
' 0.5" pellet diam, 0.5"pitch
tria 1.27 1.27 1 2 end
end
=csasix
inf array of gad rods
hans latt

uo2 1 den=10.9305 0.9925 293. 92235 5.0 92238 95.0 end
arbm-gd2o3 10.9305 2 0 1 0 64000 2 8016 3 1 0.0075 293 end

h2o  2 0.01 293 end

end comp
' 0.5" pellet diam, 0.5"pitch
tria 1.27 1.27 1 2 end
end
=csasix
inf array of gad rods
hans latt

uo2 1 den=10.9305 0.9925 293. 92235 5.0 92238 95.0 end
arbm-gd2o3 10.9305 2 0 1 0 64000 2 8016 3 1 0.0075 293 end

h2o  2 0.001 293 end
```

```
end comp
' 0.5" pellet diam, 0.5"pitch
tria 1.27 1.27 1 2 end
end
```

Appendix 6D

SIEMENS POWER CORPORATION SUPPLEMENTAL APPLICATION TO ADD 10X10 FUEL ASSEMBLIES TO CERTIFICATE OF COMPLIANCE 9248

EMF-1563, Sup. 1
Revision 1

Supplemental License Application For Siemens Power Corporation Model SP-1 and SP-2 Shipping Containers

Certification of Compliance No. 9248
Docket No. 71-9248

March 1995

SUPPLEMENTAL LICENSE APPLICATION
FOR
SIEMENS POWER CORPORATION
MODEL SP-1 AND SP-2
SHIPPING CONTAINERS

Certificate of Compliance No. 9248
Docket No. 71-9248

Siemens Power Corporation
Nuclear Division
Richland, WA

**SUPPLEMENTAL LICENSE APPLICATION
FOR
SIEMENS POWER CORPORATION
MODEL SP-1 AND SP-2 SHIPPING CONTAINERS**

Certificate of Compliance No. 9248
Docket No. 71-9248

Prepared by:	J. B. Edgar, Staff Engineer, Licensing Regulatory Compliance	3/10/95 Date
Accepted by:	R. L. Feuerbacher, Manager Materials and Scheduling	3/14/95 Date
Concurred by:	A. Reparaz, Manager Fuel Design	3/10/95 Date
Approved by:	CDM JBE for L. J. Maas, Manager Regulatory Compliance	3/10/95 Date

SUPPLEMENTAL LICENSE APPLICATION
FOR
SIEMENS POWER CORPORATION
MODEL SP-1 AND SP-2 SHIPPING CONTAINERS

Certificate of Compliance No. 9248
Docket No. 71-9248

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Purpose

This document is provided in support of the Revised Supplemental Application To Certificate of Compliance No. 9248 dated March 1995. In that application, an additional category was proposed for Section 5(b)(1) of the Certificate. Calculation descriptions and results are provided to demonstrate that the additional categories meet all criticality safety requirements in 10 CFR Part 71.

1.2 Scope of Analysis

The existing four categories in Section 5(b)(1) of the Certificate are unchanged. A new fuel shipment category is added to Section 5(b)(1) for 10x10 assemblies.

1.3 Summary of Conclusions

The following new category could be added to the Certificate of Compliance since it meets all requirements specified in 10 CFR Part 71. Shipping shims are authorized in the category described.

5(b)(1)(v) UO_2 fuel assemblies with maximum U-235 enrichment (wt.%) constraints as follows: Perimeter Rods: 4.0%; UO_2-Gd_2O_3 ("Gadolinia") Rods: 5.0%; All other Interior Rods: 4.0% average and no rod shall exceed 5.0%. Each assembly is composed of a 10x10 array of fuel rods and water rods. A water channel is required in the central 3x3 rod positions. Any number of water rods in any arrangement is permitted in addition to the 3x3 water channel. The maximum fuel dimensions are 5.0" by 5.0" by 174". The maximum pellet diameter is 0.35" and the minimum clad thickness is 0.018". Each assembly shall include at least twelve rods with at least 2.0 wt.% gadolinia in all axial regions with enriched pellets. At least eight of the twelve gadolinia rods shall be located in rows 2 and 9 and columns 2 and 9 in a pattern symmetric about one of the assembly diagonals. The nominal diameter of the gadolinia pellets shall be not less than that of the UO_2 (non-gadolinia) pellets. Fissile Class II is authorized with a Minimum Transport Index of 1.0. Polyethylene shims with a thickness up to 0.1267" may be placed between rows or columns of rods along the entire length of the assembly. Shims with a 0.1267 inch thickness are equivalent to a maximum allowable polyethylene volume of 33.93 cubic centimeters per centimeter length per assembly. (Note: This has the same hydrogen density as 40.04 cubic centimeters of water per centimeter length.)

2.0 PACKAGE AND MODEL DESCRIPTION

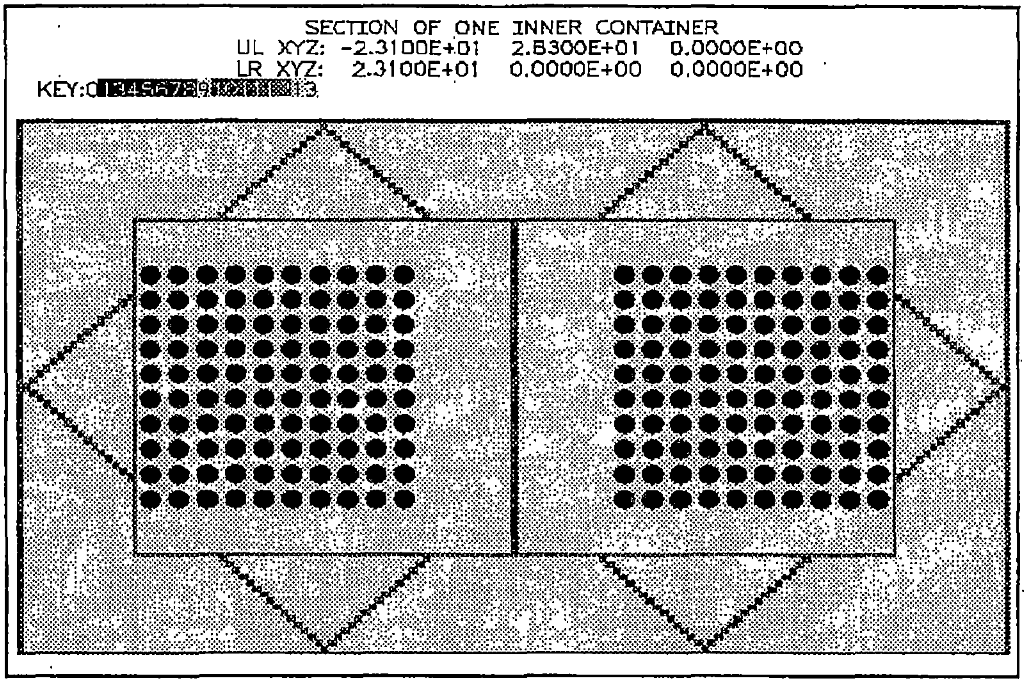
Each SP-1 can contain up to two BWR assemblies. The SP-1 is composed of a steel "inner container" and a wooden "outer container". Most criticality safety calculations are at "damaged" or "accident" conditions where the outer container is assumed to have burned away and the inner containers are stacked edge-to-edge in an array of at least 250 units (Fissile Class I) or at least 2N (Fissile Class II), where "N" is the maximum number of packages allowed per shipment. "N" is defined as 50 divided by the minimum Transport Index.

The inner containers contain two "baskets" made of 0.0598" thick carbon steel with 0.75" diameter holes in a 1.75" square pitch pattern. The baskets are nominal 7"x7" in cross section. The two baskets are placed edge-to-edge in the center of the nominal 18" wide by 11" high steel inner container (0.0598" carbon steel walls). A 2" thick annulus is between the basket wall and the inner container wall. In this annulus are six carbon steel angles (2.8125"x2.8125"x0.125" nominal).

All previous calculations for the SP-1 have demonstrated that peak reactivity with uniform interspersed moderation is with low density (typically 10 to 20 volume %) water. With low density interspersed water, the edge rods in the assemblies are best moderated. It has been found that the most reactive position for the assemblies is to have both at the outer edges of their baskets, which allows maximum moderation of the edge rods facing the other assembly in the same package. This is the arrangement modeled in these calculations, unless noted otherwise.

3.0 ANALYTICAL METHODOLOGY

The codes, cross sections, and other data from SCALE 4.2 (1) and CASMO-3G were used. All components were modeled as precisely as possible in KENO-Va.
The baskets were modeled as carbon steel with moderation-filled holes (not "smeared") and the angles were closely approximated in volume and geometry using 31 steel segments with a total steel volume slightly less than the minimum (nominal minus tolerances). Finite arrays with 30 cm of water reflection were modeled in KENO-Va. The following figure is a KENO-Va plot for a typical model.



CASMO-3G was also used to calculate k-inf for various fuel types. The steel and moderation were "smeared" together in the various regions of the CASMO model. The CASMO model also had the assemblies to the shifted to the outer edges of their baskets. The arrays modeled were either infinite or 8x13x1.

3.1 Benchmarking

The SCALE 4.2 system was developed for use by the USNRC and its licensees. Critical experiments were modeled using the same methodology used in these calculations. The benchmark calculations and the methodology for determining the calculation bias and its uncertainty and for determining the bias-corrected 95% upper limit on k-eff are described in this Section.

3.1.1 Calculation of bias and bias uncertainty

The bias and its standard deviation were calculated using the methods described in Reference 4. These methods use standard Analysis of Variance principles. The average over all cases of the KENO k-eff and its variance (square of standard deviation) are calculated. The average of the average k-eff (grand average) is weighted by the reciprocal of its variance. The average value of the variance is taken as the "within class" variance. The variance of the average k-eff data, weighted as for the grand average, is taken as the "between class" variance. The "within class" variance is subtracted from the "between class" variance to yield the variance of the class effect. Since the true value for all cases is assumed to be 1.0 (critical), the class effect (the change in average k-eff from case to case) is also the bias and the variance of the class effect is the variance of the bias. A zero variance of the bias would mean that the bias is constant from case to case. Standard statistical techniques test the ratio of the "between" and "within" variances. If this ratio does not exceed the "F" test, it is concluded that the class effect variance is not significant and it is assigned the value zero. The methods in Reference 4 do not include a test of significance. The calculated bias is the value to add to the calculation result. Therefore, a negative bias indicates conservative results. The bias uncertainty is pooled with the KENO uncertainty for a given case by taking the square root of the sum of squares. The pooled uncertainty is multiplied by a factor appropriate for the degrees of freedom (calculated as shown in Ref. 4) for a one-sided 95% confidence limit. The 95% upper limit is the sum of the KENO k-eff plus the bias plus the pooled uncertainty multiplied by the factor. The one-sided confidence limit factor is used because only the upper limit is of interest.

As will be shown in Sections 3.1.2 and 3.1.3, there is no significant difference between the bias for experiments with and without gadolinium. Therefore, all experiments were combined to calculate the bias to be applied to these calculation results.

The bias and bias uncertainty with 16-group cross sections is -2.4405E-3 ± 4.6889E-3 and with 27-group cross sections it is +6.3419E-3 ± 4.9757E-3.

3.1.2 PNL Critical Experiments (Reference 2)

The reference 2 experiments involve three flooded clusters of 4.31% enriched rods with variable spacings between the clusters and with various absorbers between the clusters. The case numbers referenced below were taken from Reference 2. Brief descriptions of the cases modeled follow. These experiments were selected because they were the closest available to the conditions being modeled. Experiments with stainless steel and zircaloy were selected because they are in the SP-1 model. Cases with boron were selected to include a strong neutron absorber; gadolinium was not available in these experiments. Separate experiments with gadolinium are reported in Section 3.1.3.

Cases 001,002, and 003 determine the critical size of one cluster. The critical size was interpolated based on experiments with integral numbers of rods per edge; the critical number had a fractional number of rods on one edge and either 8, 9, or 10 rods on the other edge. These three cases were modeled using cell-weighted cross sections. A suffix "x" on the case name was used to denote cases modeled with cell-weighted cross sections.

Case 004 involved three 15x8 clusters with no absorber plates.

Cases 007, 008, 013, and 014 involved three cluster with 304L steel absorber plates. Two plate thicknesses and different absorber spacings from the central cluster were tested.

Cases 009, 010R, 011, and 012 are similar to the previous four except that the 304L steel contained either 1.05 or 1.62% Boron.

Case 031 involved three clusters with BORAL absorber plates.

Cases 029 and 030 involved three clusters with Zircaloy-4 absorber plates.

The "x" suffix on the case name denotes cell-weighted cross-sections. Suffixes such as "a" are for explicitly-modeled rods.

The bias and bias uncertainty calculated for these benchmark cases are tabulated below.

REFERENCE 2 CASES
CALCULATION RESULTS
WITH 16-GROUP CROSS SECTIONS

Case ID	k-eff	
	Avg.	Std.Dev.
a-c001x	1.00355	0.00249
a-c002x	1.00905	0.00257
a-c003x	1.00845	0.00252
a-c004	1.00435	0.00265
a-c005a	1.00244	0.00265
a-c005b	1.00198	0.00252
a-c006a	1.00177	0.00253
a-c006b	1.00443	0.00270
a-c007a	1.00352	0.00252
a-c007x	1.00788	0.00253
a-c008a	0.99798	0.00241
a-c008x	1.00109	0.00242
a-c009a	1.00365	0.00221
a-c010a	0.99854	0.00246
a-c011a	1.00138	0.00255
a-c012aa	1.00329	0.00244
a-c013a	0.99712	0.00258
a-c013x	1.01149	0.00227
a-c014a	0.99991	0.00241
a-c014x	1.00732	0.00259
a-c029a	0.99894	0.00254
a-c030a	1.00278	0.00257
a-c031a	1.00582	0.00250

The bias an bias uncertainty calculated for these 16-group cases are -3.3617E-3 ± 2.8457E-3.

**REFERENCE 2 CASES
CALCULATION RESULTS
WITH 27-GROUP CROSS SECTIONS**

Case ID	k-eff	
	Avg.	Std.Dev.
b-c001x	1.00591	0.00264
b-c002x	0.99828	0.00274
b-c003x	1.00268	0.00234
b-c004	0.99853	0.00266
b-c005a	0.98845	0.00348
b-c006a	0.99000	0.00247
b-c007a	1.00394	0.00309
b-c007x	0.99789	0.00256
b-c008a	0.98856	0.00367
b-c008x	1.00177	0.00268
b-c009a	0.99293	0.00344
b-c010a	0.99237	0.00315
b-c011a	0.99493	0.00356
b-c012a	1.00104	0.00327
b-c013a	0.99779	0.00346
b-c013x	0.99306	0.0025
b-c014a	0.99177	0.00343
b-c014x	0.99708	0.0024
b-c029a	0.99366	0.0023
b-c030a	0.99241	0.00259

The bias an bias uncertainty calculated for these 27-group cases are 3.4601E-3 ± 4.0706E-3.

3.1.3 Experiments with Gadolinium (Ref. 3)

Additional critical experiments (Reference 3) with gadolinium were modeled. The experiments determined the critical number of UO_2 fuel rods with gadolinium dissolved in the water between the rods. The rods were in a triangular-pitched array in a cylindrical vessel with water reflection on all sides of the approximately cylindrical-shaped rod array. Three rod pitches were used for the 14.40 mm OD rods: 22.86mm, 27.94mm, and 33.02mm. The experiments were modeled using cell-weighted cross sections simulating the unit cell. A cylindrical fuel region with a cross sectional area equal to that of the reported critical number of rods was modeled with full water reflection. The cases were replicated with the 16 and 27 group cross section libraries in SCALE. The calculation results are tabulated and plotted below.

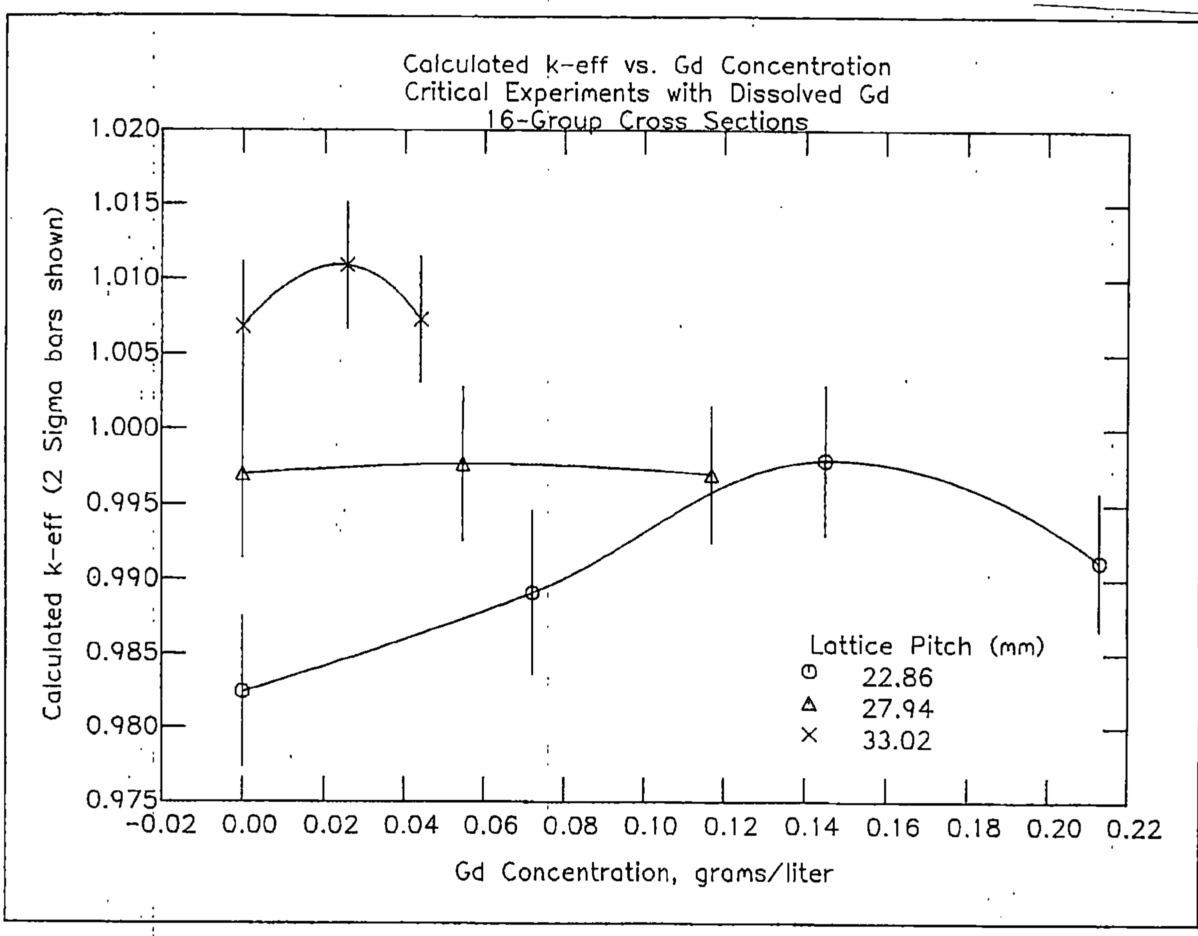
Ten experiments were modeled: seven contain gadolinium and three are water-only reference cases. The average and standard deviations of the calculation bias, based only on the seven cases with gadolinium, are in the following table. Comparing these results with those from the previous section indicates that there is no significant difference in the bias due to gadolinium. Therefore, the two sets of data will be combined for the final bias calculation.

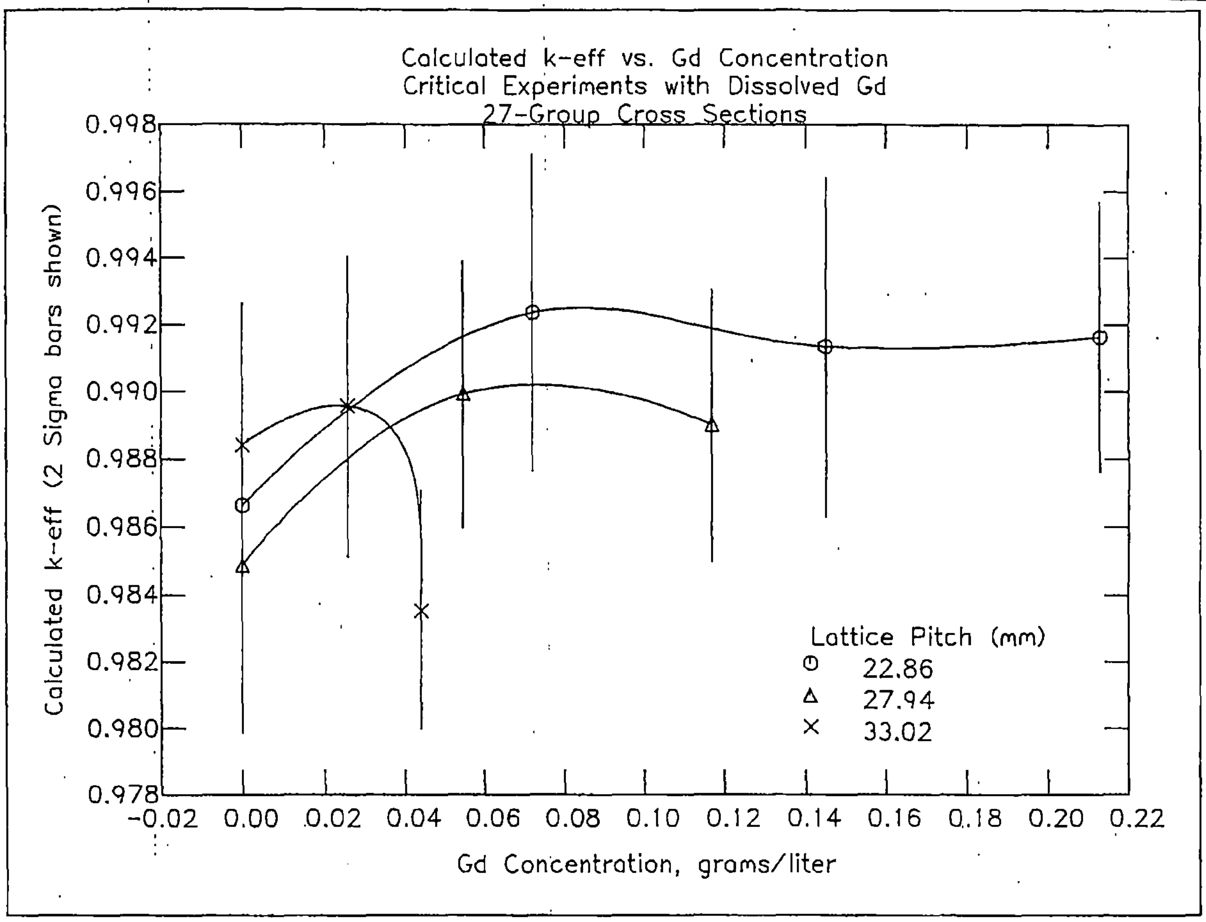
CALCULATION BIAS FOR CASES WITH GADOLINIUM

Cross Section Library (Energy Groups)	Calculation Bias Average	Calculation Bias Standard Deviation
16	0.0001875	0.00774
27	0.010864	0.002430

CRITICAL EXPERIMENTS WITH GADOLINIUM
CALCULATION RESULTS

Experiment No.	Triangular Lattice Pitch, mm	Gd Concentration, Grams/liter	16-Group k-eff		27-Group k-eff	
			Avg.	Std.Dev.	Avg.	Std.Dev.
001	22.86	0	0.98242	0.00251	0.98663	0.00291
009		0.0722	0.9891	0.00274	0.99236	0.00237
010		0.145	0.99793	0.00248	0.99134	0.00252
011		0.213	0.99121	0.00231	0.99164	0.00202
012	27.94	0	0.99701	0.00277	0.98487	0.0025
016		0.0547	0.99769	0.00254	0.98993	0.00198
017		0.1169	0.99698	0.00226	0.98901	0.00201
018	33.02	0	1.0068	0.00215	0.98841	0.00211
023		0.0257	1.01088	0.00211	0.98957	0.00223
024		0.044	1.00728	0.00207	0.98352	0.00177


Calculated k-eff vs. Gd Concentration
Critical Experiments with Dissolved Gd
16-Group Cross Sections
Calculated k-eff (2 Sigma bars shown)
1.020
1.015
1.010
1.005
1.000
0.995
0.990
0.985
0.980
0.975
-0.02 0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18 0.20 0.22
Gd Concentration, grams/liter
Lattice Pitch (mm)
22.86
27.94
33.02



4.0 ANALYSIS

The new Category proposed for Certificate Section 5(b)(1) is analyzed in this Section. Included in this Section are several sensitivity studies showing the effect of various parameters plus calculations with the most reactive combination of the various parameters.

The previous applications have demonstrated the key parameters affecting the peak k-eff for an array of SP-1 packages are:

1. The number of packages in the array. Larger arrays tend to produce higher k-eff values. In certain cases, Fissile Class II was specified to allow use of smaller arrays.

2. The fuel enrichment. Higher enrichments lead to higher k-eff values.

3. Assembly size ("Envelope"). Larger transverse dimensions tend to increase k-eff. The length of the assembly has relatively little effect. Assemblies were modeled with the

maximum allowable envelope.

4. Interspersed Moderation. For limiting conditions, low density interspersed moderation produces a higher k-eff than full flooding. Additional evidence of this fact is included in this application.

5. Number, Arrangement, and Composition of Gadolinia Rods. For a given number of Gadolinia rods, the most reactive arrangement is to have them clustered together in the central parts of the assembly. This was demonstrated in the previous two supplemental applications and it is also seen in comparing cases in this application. The gadolinia content was modeled at the 75% of the minimum specified value.

6. Water Rods and Water Channels. Fuel assemblies typically do not have all lattice locations occupied by fuel rods. The missing locations are called "Water Rods" or "Water Channels" in cases such as a 2x2 or 3x3 array of water rods at the assembly center. Water rods and water channels cause lower k-eff relative to assemblies with all locations occupied by fuel rods. This was demonstrated in the previous two supplemental applications and additional evidence is presented in this document.

7. Fuel (pellet) diameter: Larger pellet diameters, at least up to about 0.5", lead to higher k-eff values. This was demonstrated in previous supplemental applications and additional evidence is presented in this application.

The additional evidence discussed in items 4, 5, 6 and 7 above and additional factors affecting the k-eff of arrays of SP-1 packages and fuel types in general are discussed below.

4.1 Flooded Conditions

A single SP-1 has its maximum k-eff at flooded conditions and with the assemblies shifted toward the inner edges of their baskets. The assemblies are well coupled within the package but, for arrays of edge-to-edge inner containers, the assemblies are effectively decoupled between packages. Fully flooded arrays of packages (damaged) were modeled with 5.0% enriched 10x10 assemblies without gadolinia rods. Infinite arrays are acceptable with zero gadolinia.

In this section, it will be demonstrated that an infinite array of edge-to-edge inner containers is adequately subcritical at fully flooded conditions and with:

1. Any pellet diameter and any clad thickness ≥ 0.018". There was no gap between the pellet and clad in these models.

2. Any combination of water and polyethylene within the assemblies in any Moderator-to-Fuel Volume Ratio. This effectively bounds any number of water rods and/or channels in any arrangement and any number of polyethylene shims in any arrangement.

3. Any U-235 enrichment up to 5.0% in all rods.

4. No gadolinia is included in these calculations and none is required to assure safety at flooded conditions.

5. Any array of packages is acceptable.

4.1.1 CONSERVATIVE XSDRN MODEL (NO STEEL, FLOODED)

A series of calculations with a conservative 1-D model was performed to develop a family of curves without the "noise" in Monte Carlo (KENO) calculation results. This simple model was a cylindrical approximation of two infinite-length edge-to-edge assemblies (10" wide by 5" high fuel region) in a 18" wide by 11" high inner container. The within-assembly moderator was either water or 100% polyethylene (PE). The between-assembly moderator was always water. The boundary conditions in XSDRN were set for an infinite array. Pellet diameters in the range 0.20" to 0.50" were modeled with a 0.018" thick zircaloy clad. The assemblies were modeled as a cell-weighted mixture with a moderator-to-fuel volume ratio in the range 1.5 to 4.0. This set of calculations was replicated with the 16 and 27 group cross section libraries.

The conservative XSDRN calculation results are tabulated and plotted below. The results are summarized as follows:

1. Pure polyethylene yields a higher SP-1 k-inf than does water. KENO-Va calculation results with the steel in the model are presented later to demonstrate that worst-case polyethylene moderation is acceptable.

2. The optimum moderator-to-fuel volume ratio decreases with increasing pellet diameter.

3. The differences between the peak k-inf for most pellet diameters is relatively small. It is expected that Monte Carlo results would be unable to discern many of these differences without extremely large numbers of histories. The optimum pellet diameter at flooded conditions is about 0.35".

CONSERVATIVE XSDRN SP-1 MODEL (NO STEEL)
INFINITE ARRAY (3-D) OF EDGED-TO-EDGE INNER CONTAINERS
5.0% ENRICHED, 0.018" THICK CLAD, FULLY FLOODED
XSDRN RESULTS WITH 16-GROUP CROSS SECTIONS

Case ID	Within-Assembly Moderator	Pellet Diam, inch	Moderator to Fuel Volume Ratio	Unit Cell k-inf	SP-1 k-inf
a-h2020a	Water	0.20	2.0	1.47723	0.86495
a-h2020c	PE	0.20	2.0	1.50103	0.92599
a-h2025a	Water	0.20	2.5	1.50353	0.88202
a-h2025c	PE	0.20	2.5	1.51765	0.94303
a-h2030a	Water	0.20	3.0	1.51588	0.89042
a-h2030c	PE	0.20	3.0	1.52216	0.95055
a-h2035a	Water	0.20	3.5	1.51961	0.89317
a-h2035c	PE	0.20	3.5	1.52140	0.95303
a-h2040a	Water	0.20	4.0	1.51948	0.89288
a-h2040c	PE	0.20	4.0	1.51592	0.95145
a-h2520a	Water	0.25	2.0	1.48936	0.87607
a-h2520c	PE	0.25	2.0	1.50941	0.93645
a-h2525a	Water	0.25	2.5	1.51153	0.89051
a-h2525c	PE	0.25	2.5	1.52621	0.95253
a-h2530a	Water	0.25	3.0	1.52391	0.89805
a-h2530c	PE	0.25	3.0	1.53052	0.95900
a-h2535a	Water	0.25	3.5	1.52776	0.90004
a-h2535c	PE	0.25	3.5	1.52718	0.95929
a-h2540a	Water	0.25	4.0	1.52599	0.89829
a-h2540c	PE	0.25	4.0	1.51880	0.95542
a-h3020a	Water	0.30	2.0	1.49838	0.88332
a-h3020c	PE	0.30	2.0	1.51835	0.94439
a-h3025a	Water	0.30	2.5	1.51943	0.89653

Case ID	Within-Assembly Moderator	Pellet Diam, inch	Moderator to Fuel Volume Ratio	Unit Cell k-inf	SP-1 k-inf
a-h3025c	PE	0.30	2.5	1.53013	0.95718
a-h3030a	Water	0.30	3.0	1.52782	0.90160
a-h3030c	PE	0.30	3.0	1.53230	0.96174
a-h3035a	Water	0.30	3.5	1.52961	0.90197
a-h3035c	PE	0.30	3.5	1.52739	0.96046
a-h3040a	Water	0.30	4.0	1.52656	0.89899
a-h3040c	PE	0.30	4.0	1.51744	0.95509
a-h3520a	Water	0.35	2.0	1.50361	0.88743
a-h3520c	PE	0.35	2.0	1.52314	0.94867
a-h3525a	Water	0.35	2.5	1.52421	0.89976
a-h3525c	PE	0.35	2.5	1.53459	0.96051
a-h3530a	Water	0.35	3.0	1.53213	0.90393
a-h3530c	PE	0.35	3.0	1.53339	0.96263
a-h3535a	Water	0.35	3.5	1.53140	0.90254
a-h3535c	PE	0.35	3.5	1.52511	0.95894
a-h3540a	Water	0.35	4.0	1.52546	0.89766
a-h3540c	PE	0.35	4.0	1.51231	0.95147
a-h4010a	Water	0.40	1.0	1.39899	0.82438
a-h4010c	PE	0.40	1.0	1.43607	0.87738
a-h4015a	Water	0.40	1.5	1.47279	0.86825
a-h4015c	PE	0.40	1.5	1.49917	0.92698
a-h4020a	Water	0.40	2.0	1.50975	0.89093
a-h4020c	PE	0.40	2.0	1.52638	0.95111
a-h4025a	Water	0.40	2.5	1.52665	0.90098
a-h4025c	PE	0.40	2.5	1.53454	0.96056

Case ID	Within-Assembly Moderator	Pellet Diam, inch	Moderator to Fuel Volume Ratio	Unit Cell k-inf	SP-1 k-inf
a-h4030a	Water	0.40	3.0	1.53202	0.90337
a-h4030c	PE	0.40	3.0	1.53185	0.96121
a-h4035a	Water	0.40	3.5	1.53006	0.90081
a-h4035c	PE	0.40	3.5	1.52160	0.95585
a-h4040a	Water	0.40	4.0	1.52265	0.89468
a-h4040c	PE	0.40	4.0	1.50641	0.94653
a-h4510a	Water	0.45	1.0	1.40557	0.82846
a-h4510c	PE	0.45	1.0	1.44229	0.88175
a-h4515a	Water	0.45	1.5	1.47921	0.87176
a-h4515c	PE	0.45	1.5	1.50448	0.93034
a-h4520a	Water	0.45	2.0	1.51402	0.89290
a-h4520c	PE	0.45	2.0	1.52935	0.95265
a-h4525a	Water	0.45	2.5	1.52925	0.90158
a-h4525c	PE	0.45	2.5	1.53470	0.95998
a-h4530a	Water	0.45	3.0	1.53227	0.90229
a-h4530c	PE	0.45	3.0	1.52831	0.95806
a-h4535a	Water	0.45	3.5	1.52730	0.89778
a-h4535c	PE	0.45	3.5	1.51484	0.95040
a-h4540a	Water	0.45	4.0	1.51715	0.88985
a-h4540c	PE	0.45	4.0	1.49687	0.93905
a-h5010a	Water	0.50	1.0	1.41164	0.83179
a-h5010c	PE	0.50	1.0	1.44757	0.88513
a-h5015a	Water	0.50	1.5	1.48419	0.87414
a-h5015c	PE	0.50	1.5	1.50889	0.93270
a-h5020a	Water	0.50	2.0	1.51761	0.89406

Case ID	Within-Assembly Moderator	Pellet Diam, inch	Moderator to Fuel Volume Ratio	Unit Cell k-inf	SP-1 k-inf
a-h5020c	PE	0.50	2.0	1.53095	0.95294
a-h5025a	Water	0.50	2.5	1.53034	0.90099
a-h5025c	PE	0.50	2.5	1.53330	0.95806
a-h5030a	Water	0.50	3.0	1.53091	0.89999
a-h5030c	PE	0.50	3.0	1.52414	0.95405
a-h5035a	Water	0.50	3.5	1.52370	0.89387
a-h5035c	PE	0.50	3.5	1.50780	0.94429
a-h5040a	Water	0.50	4.0	1.51128	0.88435
a-h5040c	PE	0.50	4.0	1.48693	0.93087

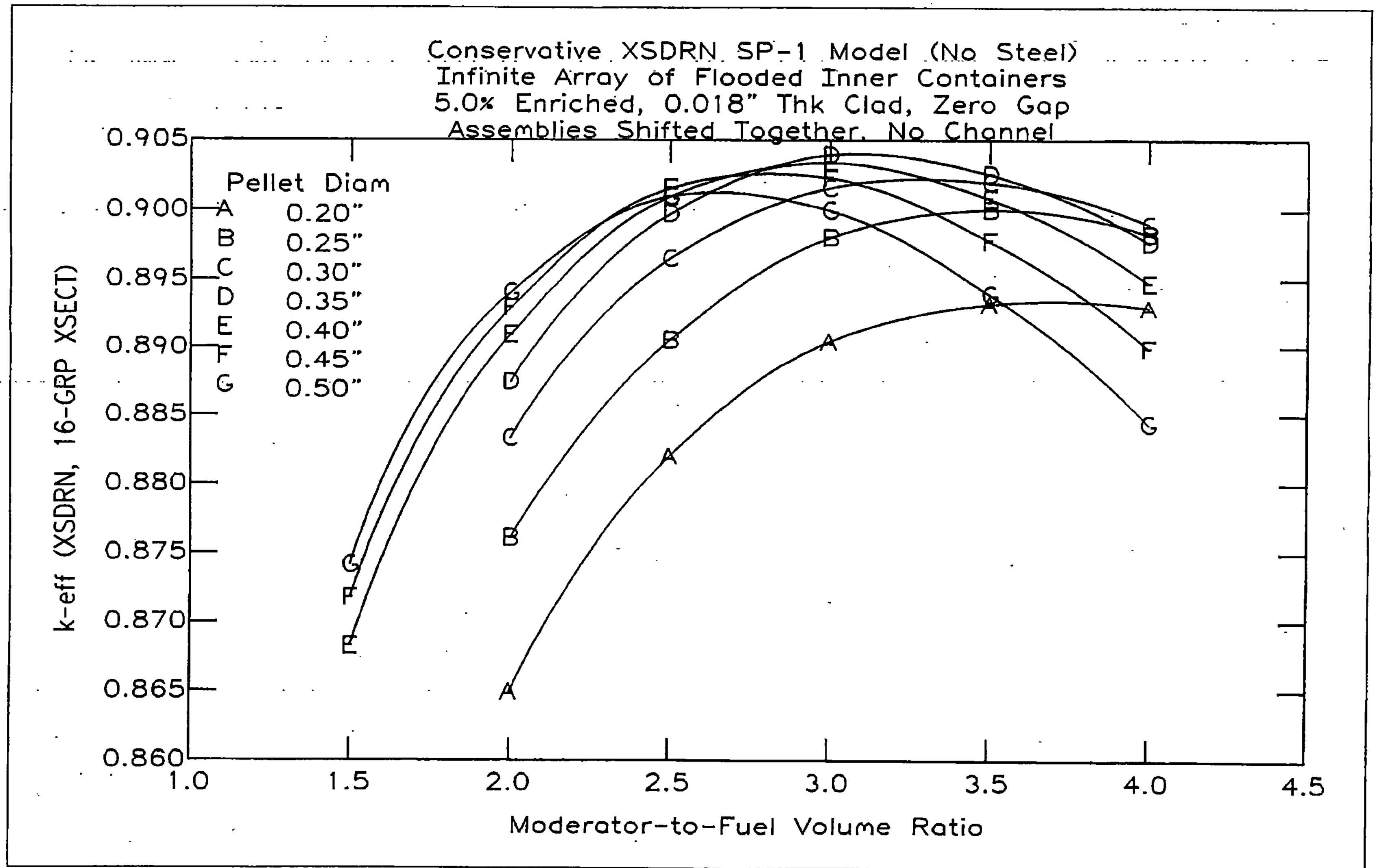
**CONSERVATIVE XSDRN SP-1 MODEL (NO STEEL)
INFINITE ARRAY (3-D) OF EDGED-TO-EDGE INNER CONTAINERS
5.0% ENRICHED, 0.018" THICK CLAD, FULLY FLOODED
XSDRN RESULTS WITH 27-GROUP CROSS SECTIONS**

Case ID	Within-Assembly Moderator	Pellet Diam, inch	Moderator to Fuel Volume Ratio	Unit Cell k-inf	SP-1 k-inf
b-h2020a	Water	0.20	2.0	1.47339	0.86610
b-h2020c	PE	0.20	2.0	1.49595	0.92761
b-h2025a	Water	0.20	2.5	1.49808	0.88290
b-h2025c	PE	0.20	2.5	1.51245	0.94482
b-h2030a	Water	0.20	3.0	1.51030	0.89140
b-h2030c	PE	0.20	3.0	1.51715	0.95246
b-h2035a	Water	0.20	3.5	1.51445	0.89435

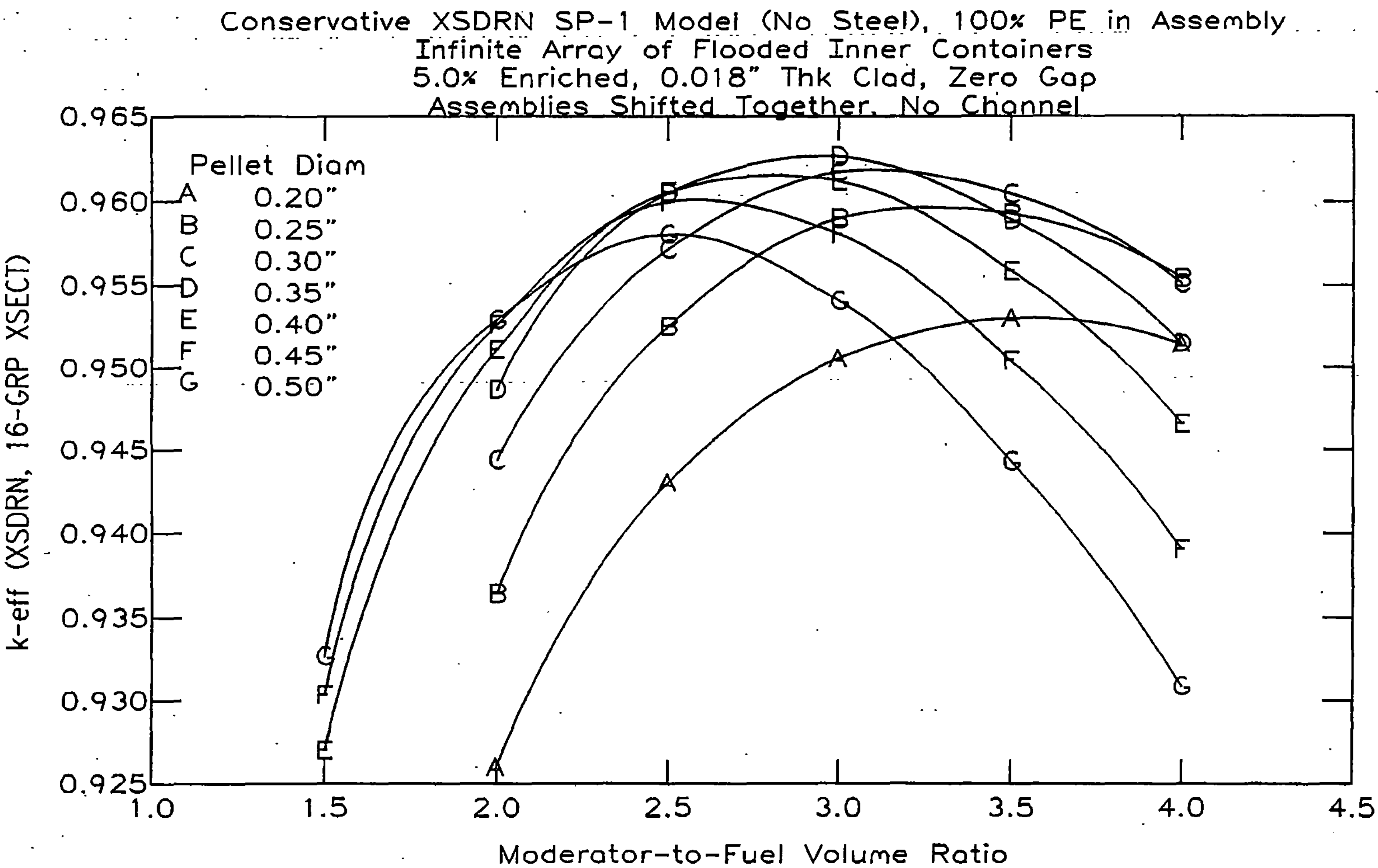
Case ID	Within-Assembly Moderator	Pellet Diam, inch	Moderator to Fuel Volume Ratio	Unit Cell k-inf	SP-1 k-inf
b-h2035c	PE	0.20	3.5	1.51441	0.95383
b-h2040a	Water	0.20	4.0	1.51311	0.89345
b-h2040c	PE	0.20	4.0	1.50675	0.95096
b-h2520a	Water	0.25	2.0	1.48533	0.87699
b-h2520c	PE	0.25	2.0	1.50630	0.93879
b-h2525a	Water	0.25	2.5	1.50769	0.89179
b-h2525c	PE	0.25	2.5	1.51989	0.95342
b-h2530a	Water	0.25	3.0	1.51751	0.89826
b-h2530c	PE	0.25	3.0	1.52167	0.95850
b-h2535a	Water	0.25	3.5	1.51926	0.89921
b-h2535c	PE	0.25	3.5	1.51604	0.95738
b-h2540a	Water	0.25	4.0	1.51556	0.89639
b-h2540c	PE	0.25	4.0	1.50558	0.95215
b-h3020a	Water	0.30	2.0	1.49413	0.88393
b-h3020c	PE	0.30	2.0	1.51335	0.94556
b-h3025a	Water	0.30	2.5	1.51414	0.89684
b-h3025c	PE	0.30	2.5	1.52400	0.95774
b-h3030a	Water	0.30	3.0	1.52153	0.90138
b-h3030c	PE	0.30	3.0	1.52278	0.96036
b-h3035a	Water	0.30	3.5	1.52082	0.90043
b-h3035c	PE	0.30	3.5	1.51420	0.95687
b-h3040a	Water	0.30	4.0	1.51470	0.89578
b-h3040c	PE	0.30	4.0	1.50087	0.94938
b-h3520a	Water	0.35	2.0	1.50068	0.88834
b-h3520c	PE	0.35	2.0	1.51803	0.94947

Case ID	Within-Assembly Moderator	Pellet Diam, inch	Moderator to Fuel Volume Ratio	Unit Cell k-inf	SP-1 k-inf
b-h3525a	Water	0.35	2.5	1.51827	0.89939
b-h3525c	PE	0.35	2.5	1.52561	0.95923
b-h3530a	Water	0.35	3.0	1.52313	0.90202
b-h3530c	PE	0.35	3.0	1.52130	0.95943
b-h3535a	Water	0.35	3.5	1.51989	0.89920
b-h3535c	PE	0.35	3.5	1.50968	0.95359
b-h3540a	Water	0.35	4.0	1.51129	0.89275
b-h3540c	PE	0.35	4.0	1.49342	0.94387
b-h4010a	Water	0.40	1.0	1.39258	0.82241
b-h4010c	PE	0.40	1.0	1.43084	0.87699
b-h4015a	Water	0.40	1.5	1.46895	0.86820
b-h4015c	PE	0.40	1.5	1.49574	0.92817
b-h4020a	Water	0.40	2.0	1.50552	0.89099
b-h4020c	PE	0.40	2.0	1.52087	0.95139
b-h4025a	Water	0.40	2.5	1.52057	0.90016
b-h4025c	PE	0.40	2.5	1.52527	0.95870
b-h4030a	Water	0.40	3.0	1.52282	0.90089
b-h4030c	PE	0.40	3.0	1.51777	0.95648
b-h4035a	Water	0.40	3.5	1.51699	0.89621
b-h4035c	PE	0.40	3.5	1.50304	0.94832
b-h4040a	Water	0.40	4.0	1.50586	0.88797
b-h4040c	PE	0.40	4.0	1.48379	0.93639
b-h4510a	Water	0.45	1.0	1.40009	0.82675
b-h4510c	PE	0.45	1.0	1.43780	0.88158
b-h4515a	Water	0.45	1.5	1.47477	0.87127

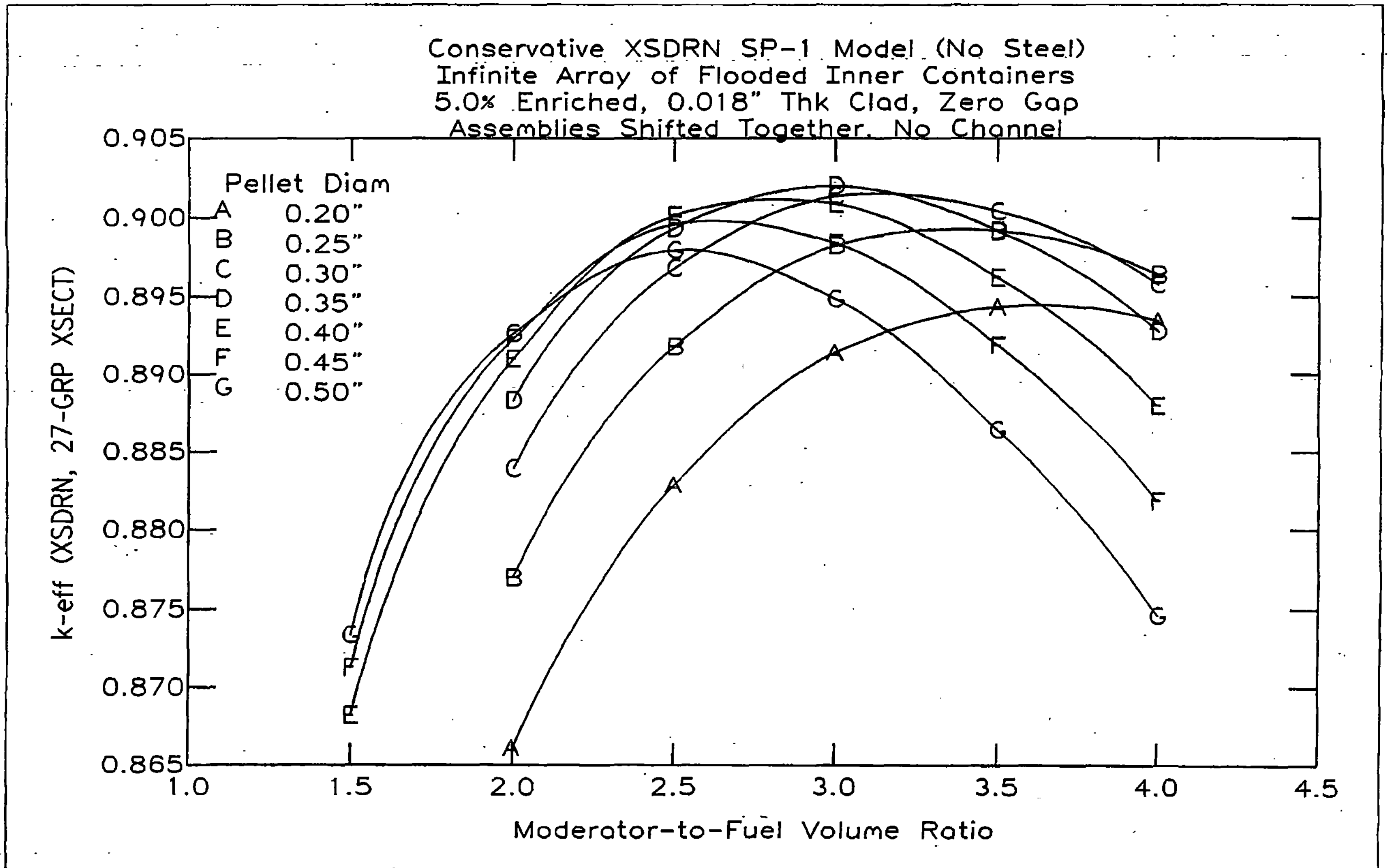
Case ID	Within-Assembly Moderator	Pellet Diam, inch	Moderator to Fuel Volume Ratio	Unit Cell k-inf	SP-1 k-inf
b-h4515c	PE	0.45	1.5	1.50020	0.93091
b-h4520a	Water	0.45	2.0	1.50896	0.89232
b-h4520c	PE	0.45	2.0	1.52221	0.95179
b-h4525a	Water	0.45	2.5	1.52138	0.89959
b-h4525c	PE	0.45	2.5	1.52331	0.95663
b-h4530a	Water	0.45	3.0	1.52094	0.89840
b-h4530c	PE	0.45	3.0	1.51253	0.95197
b-h4535a	Water	0.45	3.5	1.51244	0.89185
b-h4535c	PE	0.45	3.5	1.49461	0.94149
b-h4540a	Water	0.45	4.0	1.49872	0.88182
b-h4540c	PE	0.45	4.0	1.47232	0.92739
b-h5010a	Water	0.50	1.0	1.40671	0.83019
b-h5010c	PE	0.50	1.0	1.44381	0.88515
b-h5015a	Water	0.50	1.5	1.47954	0.87337
b-h5015c	PE	0.50	1.5	1.50353	0.93255
b-h5020a	Water	0.50	2.0	1.51124	0.89263
b-h5020c	PE	0.50	2.0	1.52229	0.95102
b-h5025a	Water	0.50	2.5	1.52094	0.89797
b-h5025c	PE	0.50	2.5	1.52000	0.95336
b-h5030a	Water	0.50	3.0	1.51773	0.89484
b-h5030c	PE	0.50	3.0	1.50585	0.94626
b-h5035a	Water	0.50	3.5	1.50652	0.88642
b-h5035c	PE	0.50	3.5	1.48470	0.93345
b-h5040a	Water	0.50	4.0	1.49017	0.87462
b-h5040c	PE	0.50	4.0	1.45934	0.91716



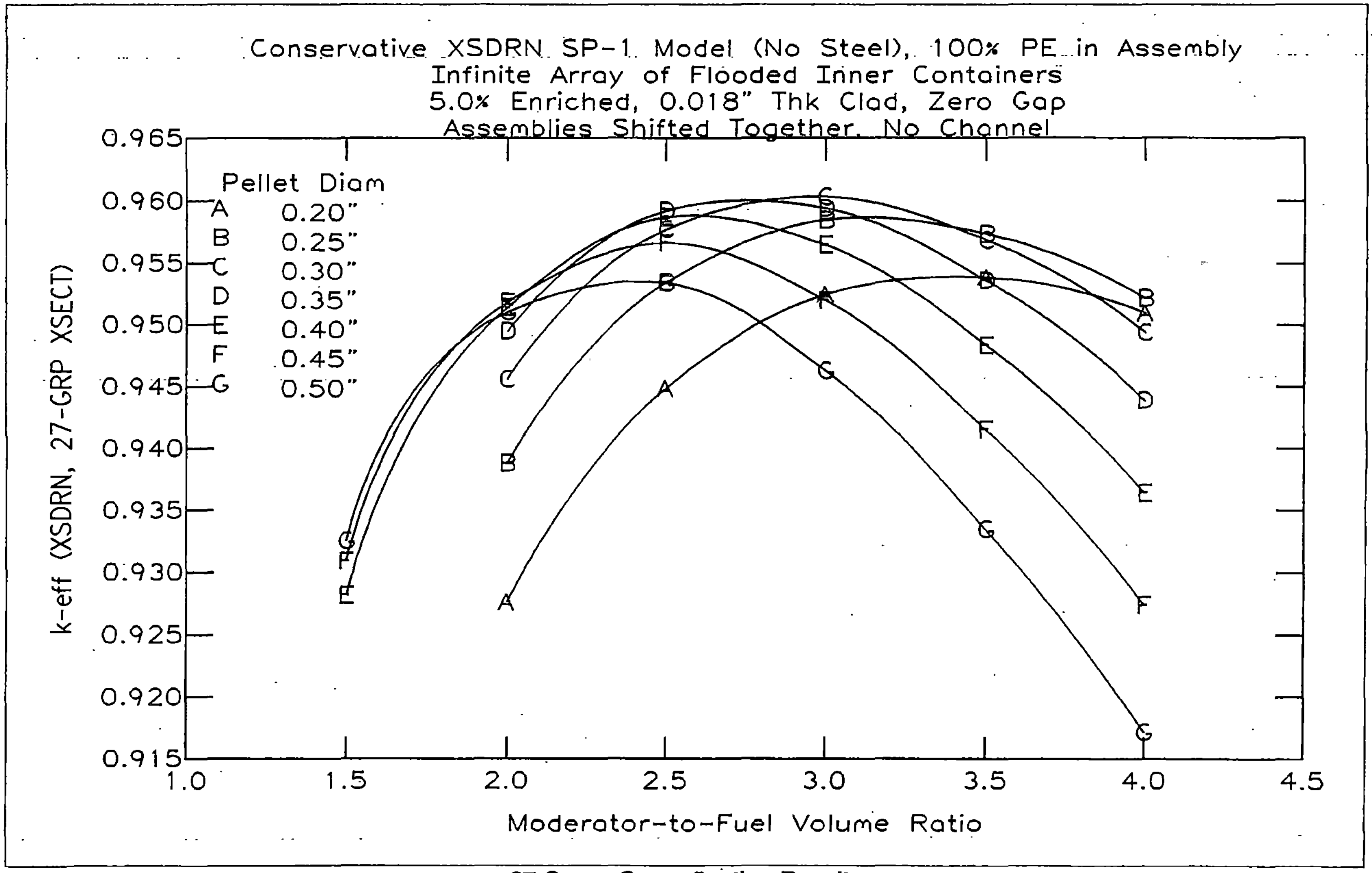
16-Group Cross Section Results



16-Group Cross Section Results



27-Group Cross Section Results



27-Group Cross Section Results

4.1.2 CONSERVATIVE KENO MODEL (NO STEEL, FLOODED)

Several of the XSDRN model cases were replicated with a conservative KENO model. The KENO model uses cuboidal geometry types (with cell-weighted cross sections) but no steel is in the model. Cases with a water-filled channel at the center of the assembly were included in the KENO cases. The channel was a 1.5" by 1.5" region (30% of assembly dimension). Additional cases with nine discrete 0.1267" thick polyethylene shims equally spaced across the assembly were also included. The calculation results are tabulated and plotted below.

The XSDRN-KENO agreement is judged to be good. Addition of a water-filled channel lowers the peak k-inf for the 100% polyethylene moderated assembly cases. Water-moderated assemblies are clearly acceptable even without steel in the model.

CONSERVATIVE KENO SP-1 MODEL (NO STEEL)
INFINITE ARRAY (3-D) OF EDGED-TO-EDGE INNER CONTAINERS
5.0% ENRICHED, 0.018" THICK CLAD, FULLY FLOODED
KENO-Va RESULTS WITH 16-GROUP CROSS SECTIONS

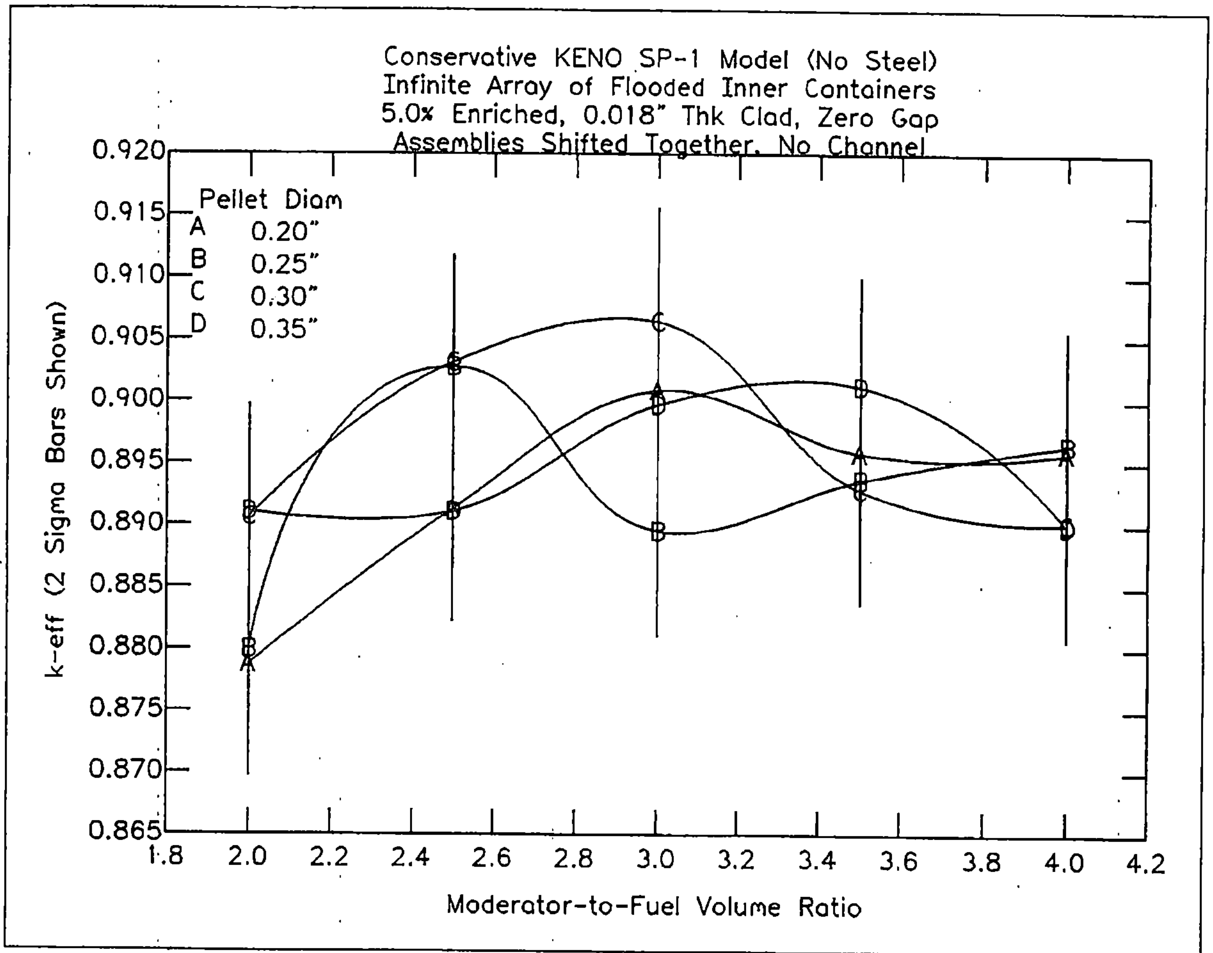
Case ID	Within-Assembly Moderator/ Channel?	Pellet Diam, inch	Mod. to Fuel Vol. Ratio	KENO k-inf	
				Avg.	Std.Dev.
a-f2020a	Water/No	0.20	2.0	0.87876	0.00453
a-f2020b	Water/Yes	0.20	2.0	0.88485	0.00479
a-f2020c	PE/No	0.20	2.0	0.93063	0.00390
a-f2020d	PE/Yes	0.20	2.0	0.93336	0.00449
a-f2020e	Water-Shims/No	0.20	2.0	0.92717	0.00426
a-f2025a	Water/No	0.20	2.5	0.89129	0.00451
a-f2025b	Water/Yes	0.20	2.5	0.89513	0.00385
a-f2025c	PE/No	0.20	2.5	0.94557	0.00407
a-f2025d	PE/Yes	0.20	2.5	0.93681	0.00398
a-f2030a	Water/No	0.20	3.0	0.90086	0.00411
a-f2030b	Water/Yes	0.20	3.0	0.89664	0.00424
a-f2030c	PE/No	0.20	3.0	0.94008	0.00414
a-f2030d	PE/Yes	0.20	3.0	0.93018	0.00476
a-f2030e	Water-Shims/No	0.20	3.0	0.91579	0.00458

Case ID	Within-Assembly Moderator/ Channel?	Pellet Diam, inch	Mod. to Fuel Vol. Ratio	KENO k-inf	
				Avg.	Std.Dev.
a-f2035a	Water/No	0.20	3.5	0.89583	0.00382
a-f2035b	Water/Yes	0.20	3.5	0.88990	0.00418
a-f2035c	PE/No	0.20	3.5	0.94763	0.00494
a-f2035d	PE/Yes	0.20	3.5	0.92924	0.00448
a-f2035e	Water-Shims/No	0.20	3.5	0.90497	0.00402
a-f2040a	Water/No	0.20	4.0	0.89580	0.00439
a-f2040b	Water/Yes	0.20	4.0	0.88763	0.00441
a-f2040c	PE/No	0.20	4.0	0.94291	0.00412
a-f2040d	PE/Yes	0.20	4.0	0.92183	0.00391
a-f2040e	Water-Shims/No	0.20	4.0	0.90523	0.00429
a-f2520a	Water/No	0.25	2.0	0.87997	0.00398
a-f2520b	Water/Yes	0.25	2.0	0.88920	0.00435
a-f2520c	PE/No	0.25	2.0	0.93842	0.00444
a-f2520d	PE/Yes	0.25	2.0	0.94057	0.00429
a-f2520e	Water-Shims/No	0.25	2.0	0.92728	0.00471
a-f2525a	Water/No	0.25	2.5	0.90276	0.00442
a-f2525b	Water/Yes	0.25	2.5	0.90054	0.00467
a-f2525c	PE/No	0.25	2.5	0.96030	0.00500
a-f2525d	PE/Yes	0.25	2.5	0.94144	0.00494
a-f2525e	Water-Shims/No	0.25	2.5	0.92663	0.00367
a-f2530a	Water/No	0.25	3.0	0.88953	0.00422
a-f2530b	Water/Yes	0.25	3.0	0.89933	0.00463
a-f2530c	PE/No	0.25	3.0	0.94879	0.00460
a-f2530d	PE/Yes	0.25	3.0	0.94276	0.00448
a-f2530e	Water-Shims/No	0.25	3.0	0.92537	0.00455

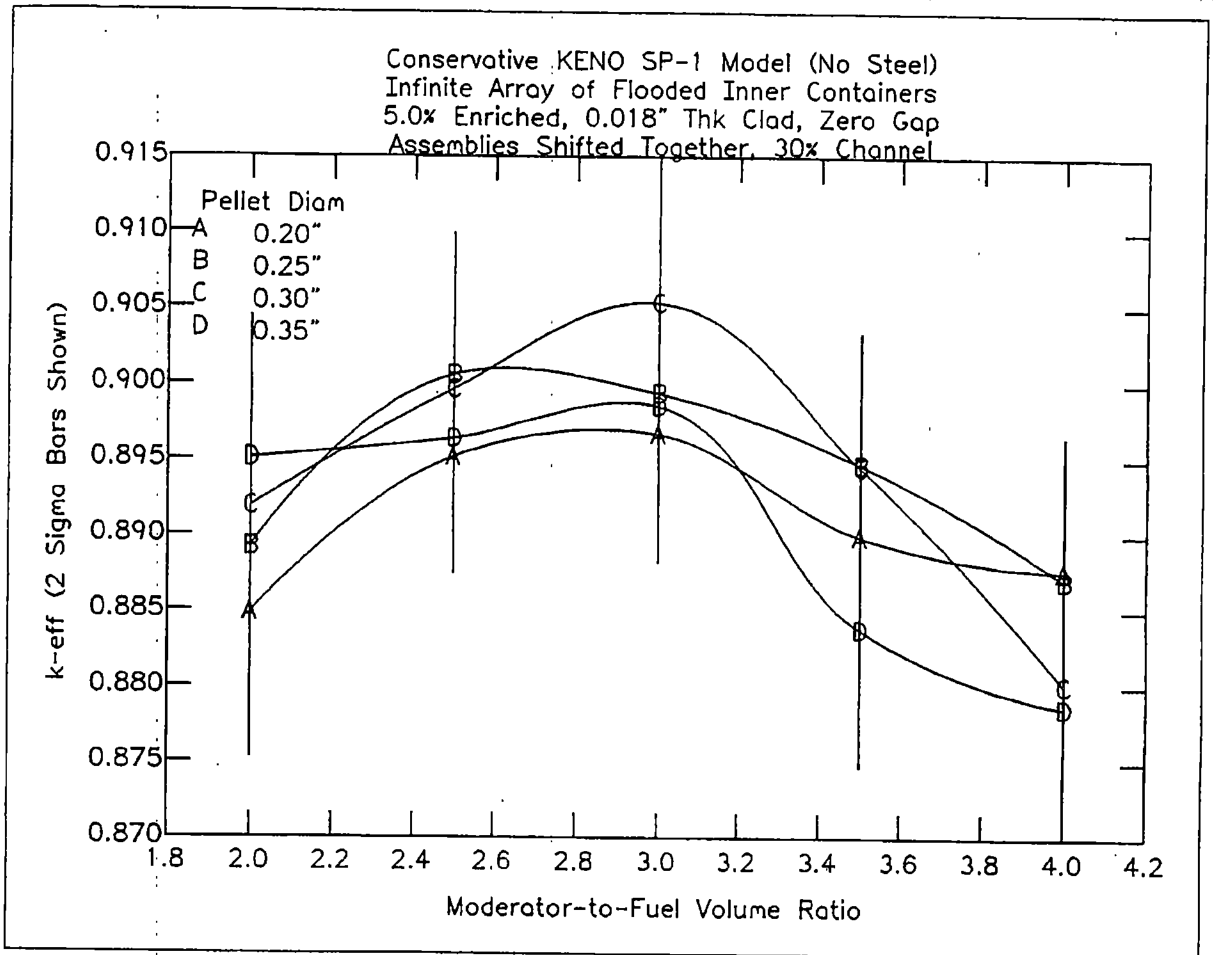
Case ID	Within-Assembly Moderator/ Channel?	Pellet Diam, inch	Mod. to Fuel Vol. Ratio	KENO k-inf	
				Avg.	Std.Dev.
a-f2535a	Water/No	0.25	3.5	0.89364	0.00444
a-f2535b	Water/Yes	0.25	3.5	0.89466	0.00433
a-f2535c	PE/No	0.25	3.5	0.95147	0.00451
a-f2535d	PE/Yes	0.25	3.5	0.93338	0.00452
a-f2535e	Water-Shims/No	0.25	3.5	0.91106	0.00420
a-f2540a	Water/No	0.25	4.0	0.89647	0.00459
a-f2540b	Water/Yes	0.25	4.0	0.88704	0.00474
a-f2540c	PE/No	0.25	4.0	0.94321	0.00496
a-f2540d	PE/Yes	0.25	4.0	0.91946	0.00479
a-f2540e	Water-Shims/No	0.25	4.0	0.90705	0.00476
a-f3020a	Water/No	0.30	2.0	0.89060	0.00420
a-f3020b	Water/Yes	0.30	2.0	0.89189	0.00443
a-f3020c	PE/No	0.30	2.0	0.93445	0.00356
a-f3020d	PE/Yes	0.30	2.0	0.93180	0.00473
a-f3020e	Water-Shims/No	0.30	2.0	0.93166	0.00455
a-f3025a	Water/No	0.30	2.5	0.90312	0.00431
a-f3025b	Water/Yes	0.30	2.5	0.89959	0.00467
a-f3025c	PE/No	0.30	2.5	0.95102	0.00407
a-f3025d	PE/Yes	0.30	2.5	0.94908	0.00445
a-f3025e	Water-Shims/No	0.30	2.5	0.92919	0.00492
a-f3030a	Water/No	0.30	3.0	0.90641	0.00460
a-f3030b	Water/Yes	0.30	3.0	0.90528	0.00447
a-f3030c	PE/No	0.30	3.0	0.94905	0.00421
a-f3030d	PE/Yes	0.30	3.0	0.94281	0.00450
a-f3030e	Water-Shims/No	0.30	3.0	0.93184	0.00433

Case ID	Within-Assembly Moderator/ Channel?	Pellet Diam, inch	Mod. to Fuel Vol. Ratio	KENO k-inf	
				Avg.	Std.Dev.
a-f3035a	Water/No	0.30	3.5	0.89289	0.00461
a-f3035b	Water/Yes	0.30	3.5	0.89449	0.00419
a-f3035c	PE/No	0.30	3.5	0.95040	0.00422
a-f3035d	PE/Yes	0.30	3.5	0.94390	0.00482
a-f3035e	Water-Shims/No	0.30	3.5	0.91050	0.00431
a-f3040a	Water/No	0.30	4.0	0.89012	0.00472
a-f3040b	Water/Yes	0.30	4.0	0.88006	0.00425
a-f3040c	PE/No	0.30	4.0	0.94030	0.00476
a-f3040d	PE/Yes	0.30	4.0	0.91684	0.00439
a-f3040e	Water-Shims/No	0.30	4.0	0.89556	0.00400
a-f3520a	Water/No	0.35	2.0	0.89106	0.00432
a-f3520b	Water/Yes	0.35	2.0	0.89507	0.00467
a-f3520c	PE/No	0.35	2.0	0.95105	0.00430
a-f3520d	PE/Yes	0.35	2.0	0.93813	0.00417
a-f3520e	Water-Shims/No	0.35	2.0	0.92565	0.00490
a-f3525a	Water/No	0.35	2.5	0.89108	0.00370
a-f3525b	Water/Yes	0.35	2.5	0.89634	0.00400
a-f3525c	PE/No	0.35	2.5	0.94660	0.00430
a-f3525d	PE/Yes	0.35	2.5	0.94669	0.00413
a-f3525e	Water-Shims/No	0.35	2.5	0.93796	0.00429
a-f3530a	Water/No	0.35	3.0	0.89969	0.00457
a-f3530b	Water/Yes	0.35	3.0	0.89847	0.00429
a-f3530c	PE/No	0.35	3.0	0.95890	0.00426
a-f3530d	PE/Yes	0.35	3.0	0.93678	0.00411
a-f3530e	Water-Shims/No	0.35	3.0	0.92420	0.00457

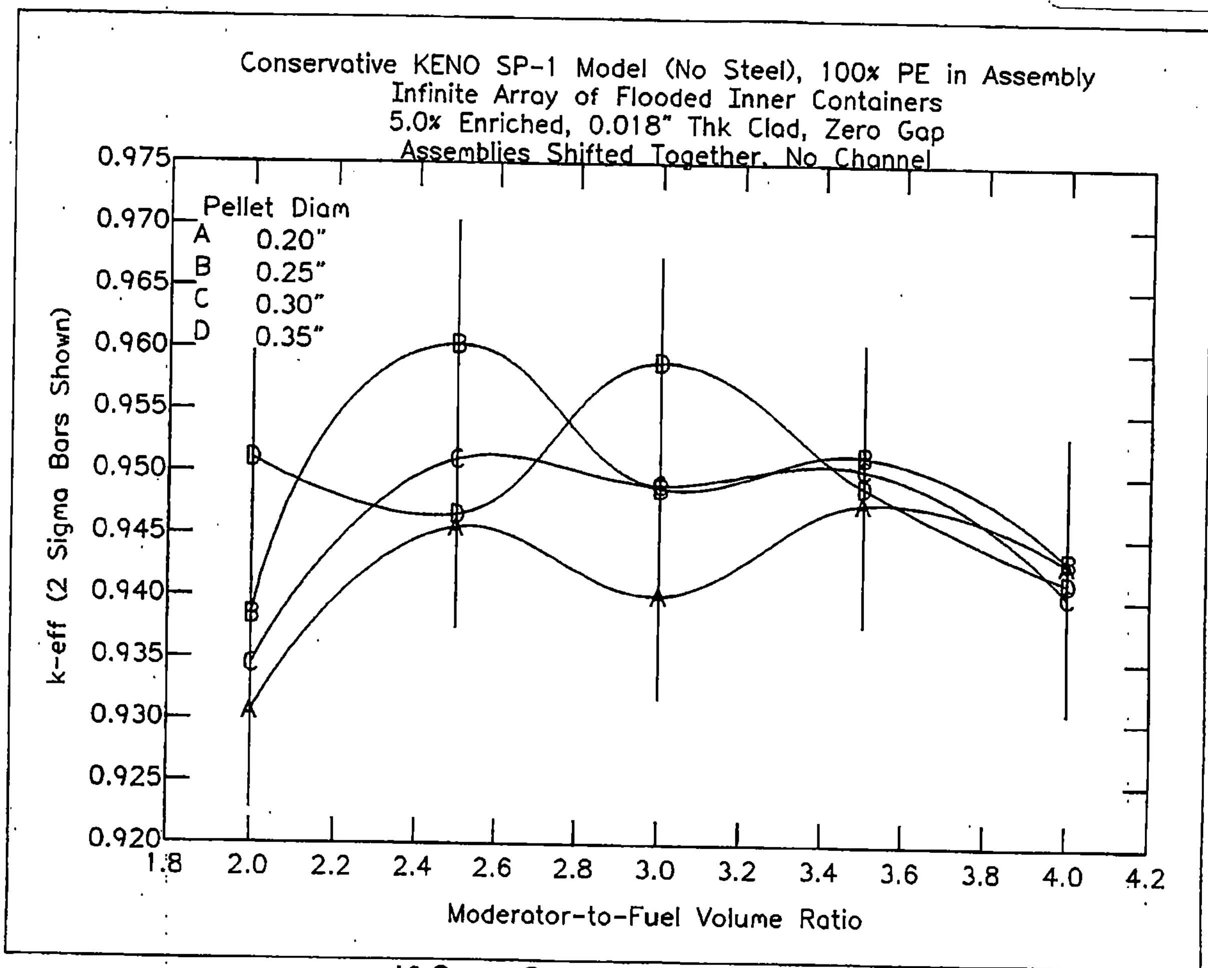
Case ID	Within-Assembly Moderator/ Channel?	Pellet Diam, inch	Mod. to Fuel Vol. Ratio	KENO k-inf	
				Avg.	Std.Dev.
a-f3535a	Water/No	0.35	3.5	0.90120	0.00441
a-f3535b	Water/Yes	0.35	3.5	0.88376	0.00453
a-f3535c	PE/No	0.35	3.5	0.94897	0.00433
a-f3535d	PE/Yes	0.35	3.5	0.92683	0.00427
a-f3535e	Water-Shims/No	0.35	3.5	0.90340	0.00417
a-f3540a	Water/No	0.35	4.0	0.88992	0.00429
a-f3540b	Water/Yes	0.35	4.0	0.87859	0.00406
a-f3540c	PE/No	0.35	4.0	0.94135	0.00433
a-f3540d	PE/Yes	0.35	4.0	0.91071	0.00428
a-f3540e	Water-Shims/No	0.35	4.0	0.88200	0.00450



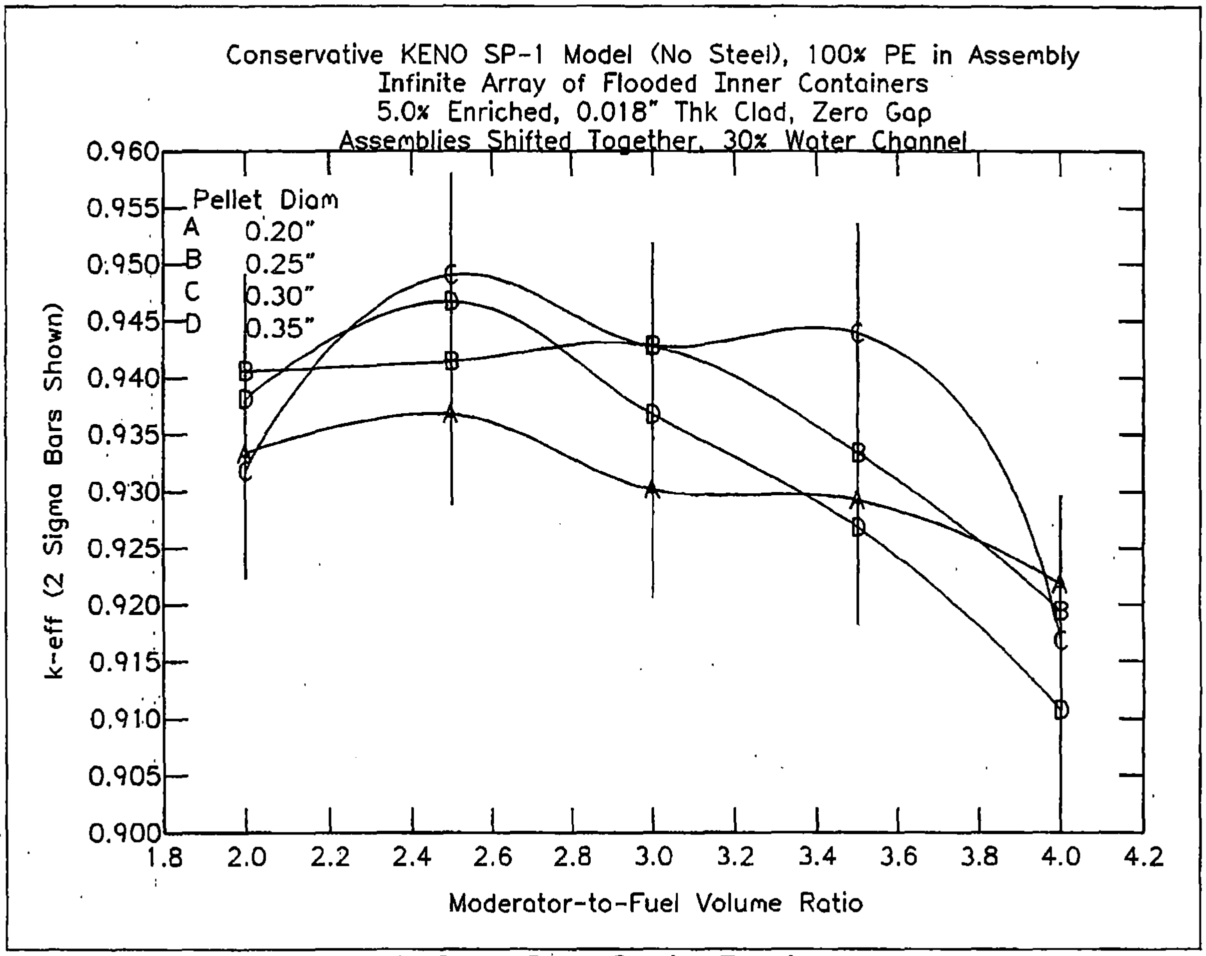
16-Group Cross Section Results



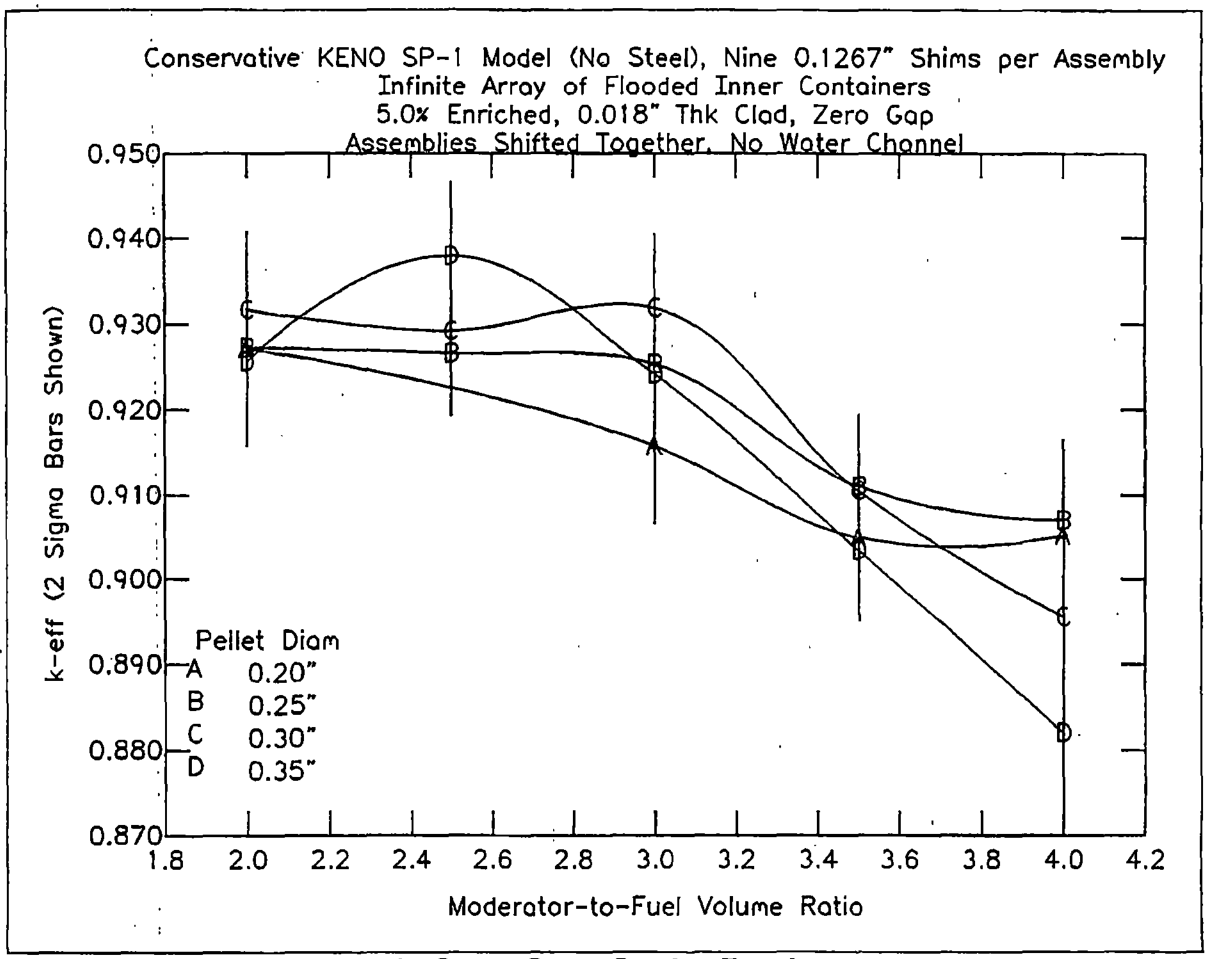
16-Group Cross Section Results



16-Group Cross Section Results



16-Group Cross Section Results



16-Group Cross Section Results

4.1.3 KENO MODEL (FLOODED) WITH STEEL INCLUDED

An infinite array (3-D) of flooded edge-to-edge inner containers was modeled with the steel basket, angles, and shell included. Each package contained two 5" by 5" assemblies shifted together as closely as possible. The assemblies were simulated by cell-weighted cross sections based on a unit cell with a pellet diameter in the range 0.2" to 0.5" and with a moderator-to-fuel ratio in the range 2.0 to 4.0. Cases with water and 100% polyethylene in the assembly were modeled. The available volume external to the assemblies was modeled as filled with water. The calculation results are tabulated and plotted below.

The limiting cases are:

16-Group: Case "a-g3530c", bias-corrected 95% UL: 0.93068

27-Group: Case "b-g2525c", bias-corrected 95% UL: 0.93306

It is concluded that the package is adequately subcritical in any array at flooded conditions with any pellet diameter, any number of water rods in any arrangement, with or without a water channel, with or without gadolinia rods, with any arrangement of rods with enrichments up to 5.0%, and with any number of polyethylene shims in any arrangement.

KENO SP-1 MODEL (WITH STEEL)
INFINITE ARRAY (3-D) OF EDGED-TO-EDGE INNER CONTAINERS
5.0% ENRICHED, 0.018" THICK CLAD, FULLY FLOODED
KENO RESULTS WITH 16-GROUP CROSS SECTIONS

Case ID	Within-Assembly Moderator	Pellet Diam, inch	Mod. to Fuel Vol. Ratio	k-eff	
				Avg.	Std.Dev.
a-g2020a	Water	0.20	2.0	0.83526	0.00452
a-g2020c	PE	0.20	2.0	0.88592	0.00415
a-g2025a	Water	0.20	2.5	0.84504	0.00451
a-g2030a	Water	0.20	3.0	0.84094	0.00485
a-g2030c	PE	0.20	3.0	0.90552	0.00392
a-g2035a	Water	0.20	3.5	0.85281	0.00426
a-g2035c	PE	0.20	3.5	0.90434	0.00398
a-g2040a	Water	0.20	4.0	0.84752	0.00446
a-g2040c	PE	0.20	4.0	0.90370	0.00440

Case ID	Within-Assembly Moderator	Pellet Diam, inch	Mod. to Fuel Vol. Ratio	k-eff	
				Avg.	Std.Dev.
a-g2520a	Water	0.25	2.0	0.84519	0.00465
a-g2520c	PE	0.25	2.0	0.90331	0.00439
a-g2525a	Water	0.25	2.5	0.85445	0.00415
a-g2525c	PE	0.25	2.5	0.90763	0.00455
a-g2530a	Water	0.25	3.0	0.85372	0.00484
a-g2530c	PE	0.25	3.0	0.91334	0.00403
a-g2535a	Water	0.25	3.5	0.85586	0.00446
a-g2535c	PE	0.25	3.5	0.91780	0.00428
a-g2540a	Water	0.25	4.0	0.85437	0.00498
a-g2540c	PE	0.25	4.0	0.90556	0.00436
a-g3020a	Water	0.30	2.0	0.84923	0.00458
a-g3020c	PE	0.30	2.0	0.90908	0.00410
a-g3025a	Water	0.30	2.5	0.85126	0.00451
a-g3025c	PE	0.30	2.5	0.90900	0.00378
a-g3030a	Water	0.30	3.0	0.86247	0.00433
a-g3030c	PE	0.30	3.0	0.91366	0.00432
a-g3035a	Water	0.30	3.5	0.85584	0.00465
a-g3035c	PE	0.30	3.5	0.90524	0.00389
a-g3040a	Water	0.30	4.0	0.85556	0.00428
a-g3040c	PE	0.30	4.0	0.90460	0.00375
a-g3520a	Water	0.35	2.0	0.85702	0.00452
a-g3520c	PE	0.35	2.0	0.91050	0.00459
a-g3525a	Water	0.35	2.5	0.85422	0.00431
a-g3525c	PE	0.35	2.5	0.91820	0.00521
a-g3530a	Water	0.35	3.0	0.85580	0.00397

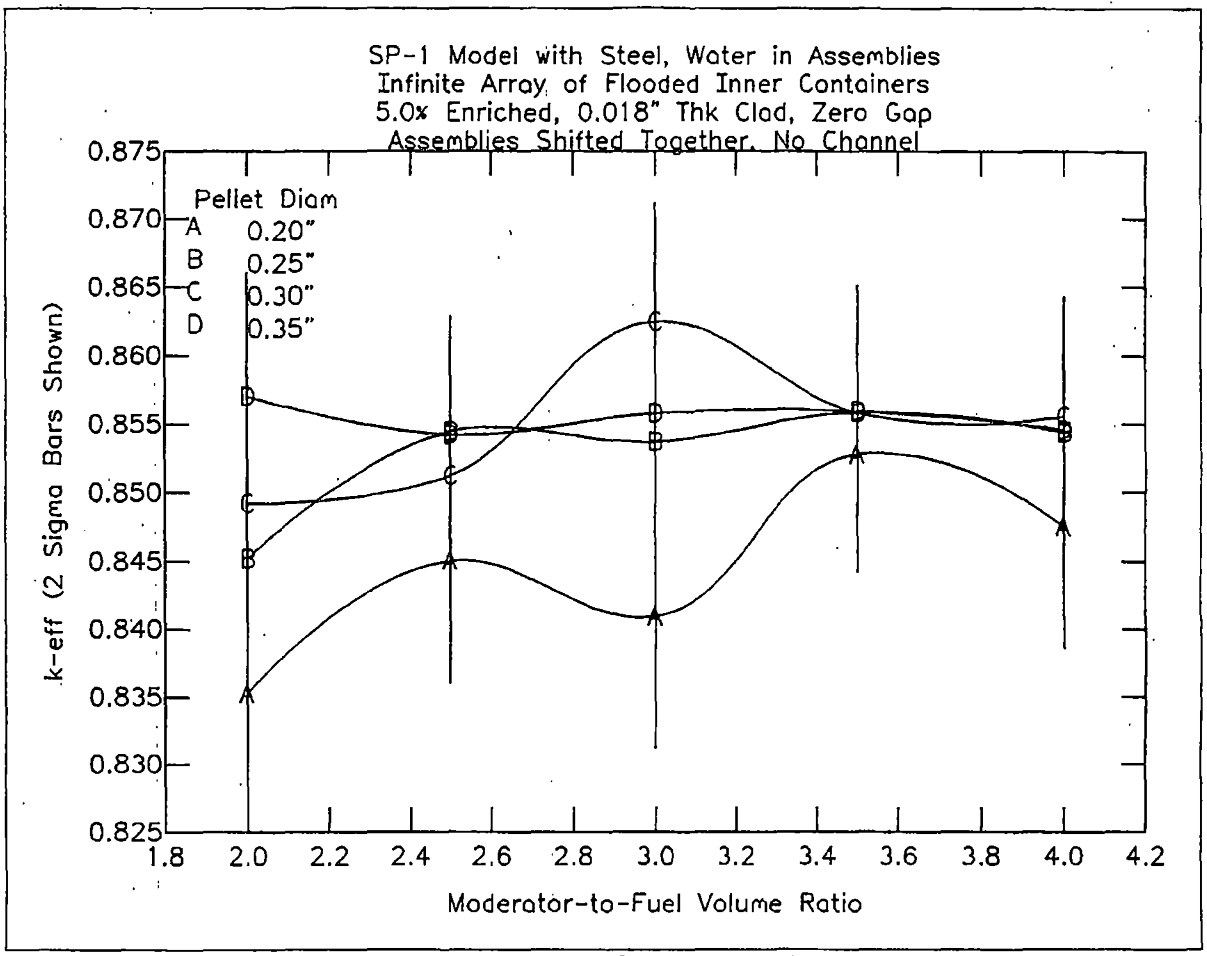
Case ID	Within-Assembly Moderator	Pellet Diam, inch	Mod. to Fuel Vol. Ratio	k-eff	
				Avg.	Std.Dev.
a-g3530c	PE	0.35	3.0	0.92188	0.00488
a-g3535a	Water	0.35	3.5	0.85595	0.00410
a-g3535c	PE	0.35	3.5	0.90628	0.00449
a-g3540a	Water	0.35	4.0	0.85456	0.00370
a-g3540c	PE	0.35	4.0	0.89620	0.00435

KENO SP-1 MODEL (WITH STEEL)
INFINITE ARRAY (3-D) OF EDGED-TO-EDGE INNER CONTAINERS
5.0% ENRICHED, 0.018" THICK CLAD, FULLY FLOODED
KENO RESULTS WITH 27-GROUP CROSS SECTIONS

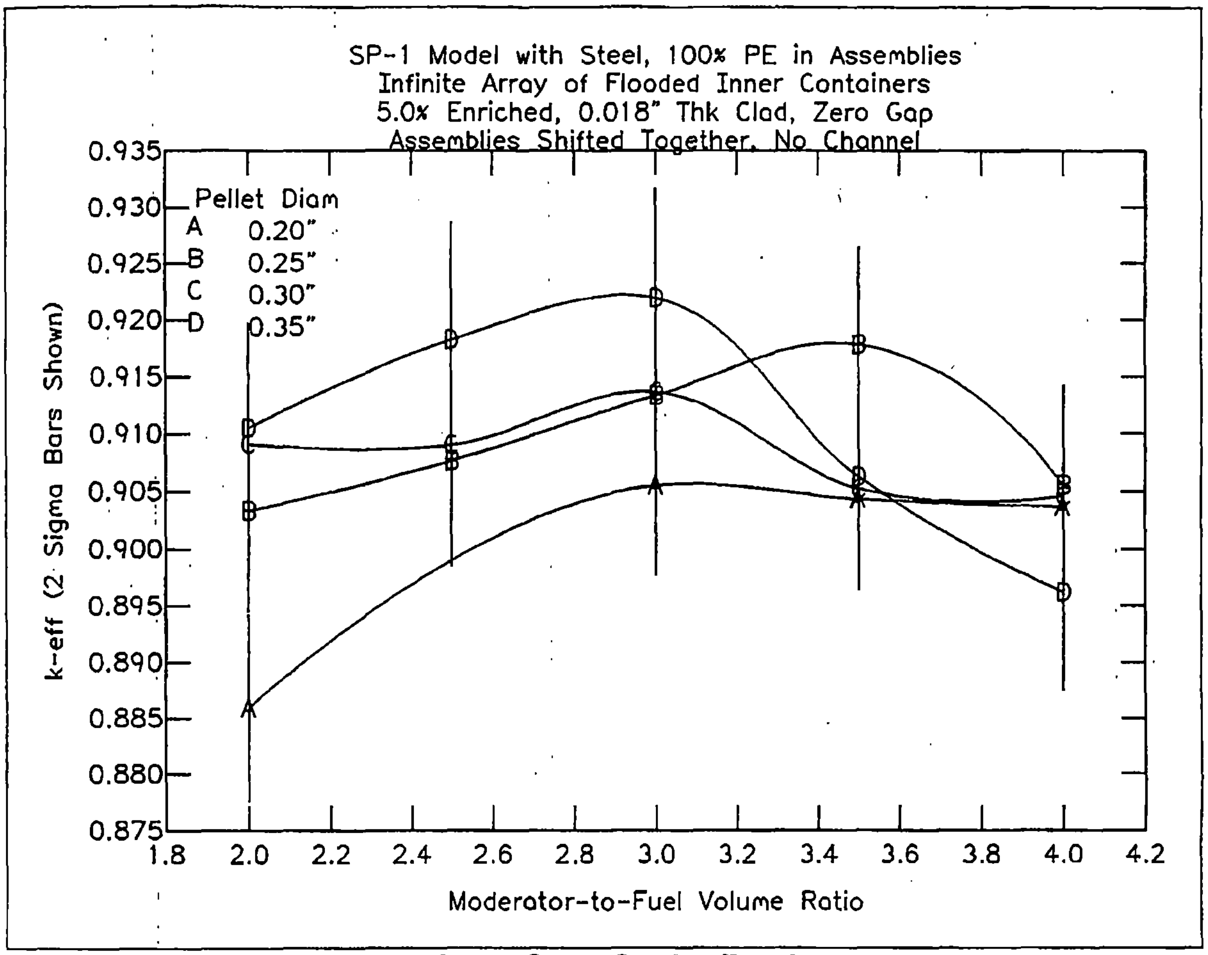
Case ID	Within Assembly Moderator	Pellet Diam, inch	Mod. to Fuel Vol. Ratio	k-eff	
				Avg.	Std.Dev.
b-g2020a	Water	0.20	2.0	0.84106	0.00456
b-g2020c	PE	0.20	2.0	0.89691	0.00544
b-g2025a	Water	0.20	2.5	0.84771	0.00418
b-g2025c	PE	0.20	2.5	0.90507	0.00451
b-g2030a	Water	0.20	3.0	0.85499	0.00387
b-g2030c	PE	0.20	3.0	0.91254	0.00483
b-g2035a	Water	0.20	3.5	0.86079	0.00418
b-g2035c	PE	0.20	3.5	0.91472	0.00437
b-g2040a	Water	0.20	4.0	0.85637	0.00409
b-g2040c	PE	0.20	4.0	0.90839	0.00469
b-g2520a	Water	0.25	2.0	0.85102	0.00399
b-g2520c	PE	0.25	2.0	0.89825	0.00376
b-g2525a	Water	0.25	2.5	0.86299	0.00505

Case ID	Within Assembly Moderator	Pellet Diam, inch	Mod. to Fuel Vol. Ratio	k-eff	
				Avg.	Std.Dev.
b-g2525c	PE	0.25	2.5	0.92508	0.00415
b-g2530a	Water	0.25	3.0	0.86711	0.00431
b-g2530c	PE	0.25	3.0	0.92091	0.00435
b-g2535a	Water	0.25	3.5	0.85632	0.00449
b-g2535c	PE	0.25	3.5	0.91707	0.00414
b-g2540a	Water	0.25	4.0	0.85102	0.00420
b-g2540c	PE	0.25	4.0	0.90408	0.00433
b-g3020a	Water	0.30	2.0	0.85156	0.00448
b-g3020c	PE	0.30	2.0	0.91182	0.00455
b-g3025a	Water	0.30	2.5	0.86442	0.00419
b-g3025c	PE	0.30	2.5	0.92380	0.00425
b-g3030a	Water	0.30	3.0	0.85735	0.00457
b-g3030c	PE	0.30	3.0	0.92194	0.00484
b-g3035a	Water	0.30	3.5	0.86472	0.00381
b-g3035c	PE	0.30	3.5	0.91602	0.00411
b-g3040a	Water	0.30	4.0	0.85676	0.00444
b-g3040c	PE	0.30	4.0	0.91409	0.00462
b-g3520a	Water	0.35	2.0	0.86583	0.00412
b-g3520c	PE	0.35	2.0	0.91006	0.00458
b-g3525a	Water	0.35	2.5	0.86063	0.00397
b-g3525c	PE	0.35	2.5	0.91983	0.00497
b-g3530a	Water	0.35	3.0	0.86350	0.00443
b-g3530c	PE	0.35	3.0	0.91868	0.00423
b-g3535a	Water	0.35	3.5	0.85684	0.00402
b-g3535c	PE	0.35	3.5	0.90675	0.00440

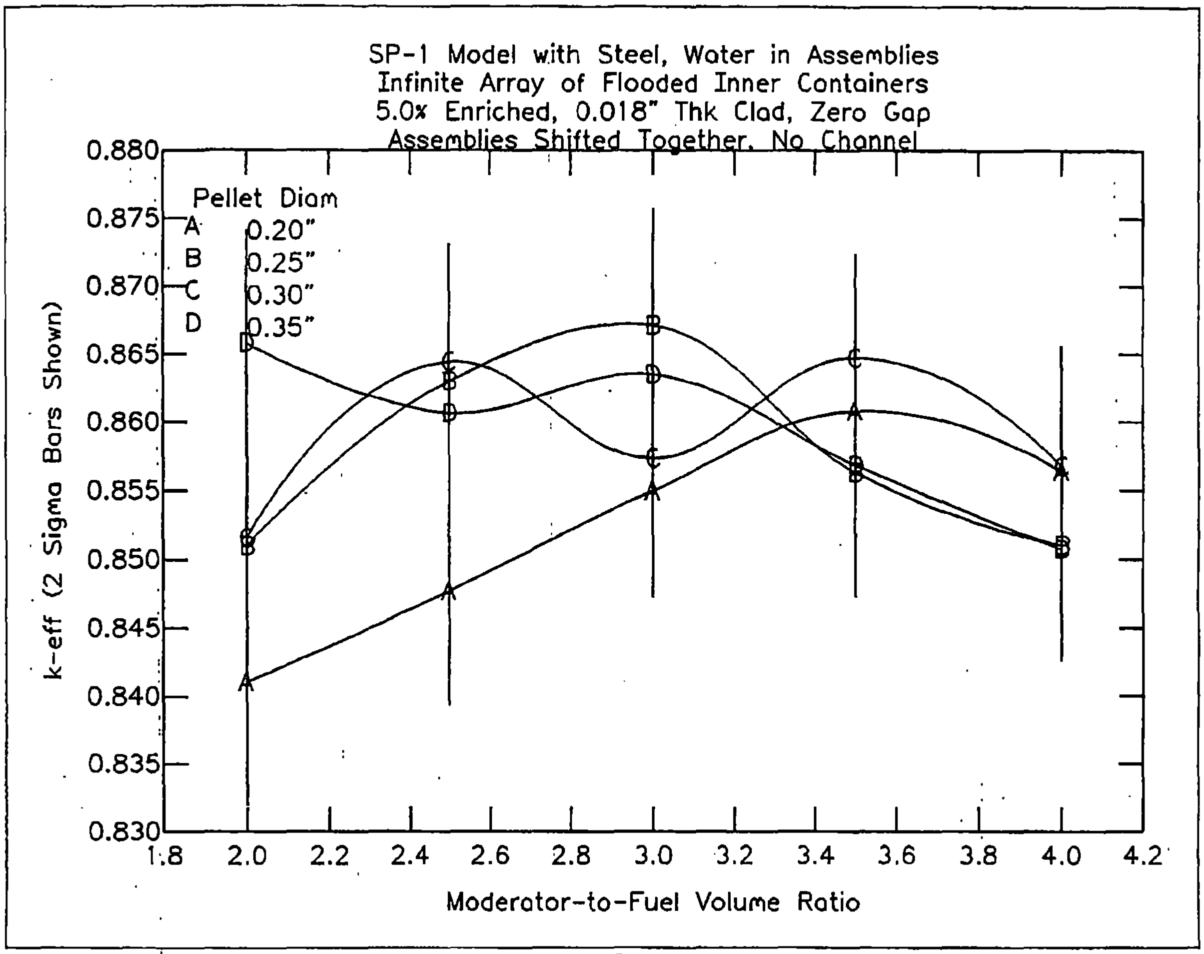
Case ID	Within Assembly Moderator	Pellet Diam, inch	Mod. to Fuel Vol. Ratio	k-eff	
				Avg.	Std.Dev.
b-g3540a	Water	0.35	4.0	0.85076	0.00397
b-g3540c	PE	0.35	4.0	0.90292	0.00423



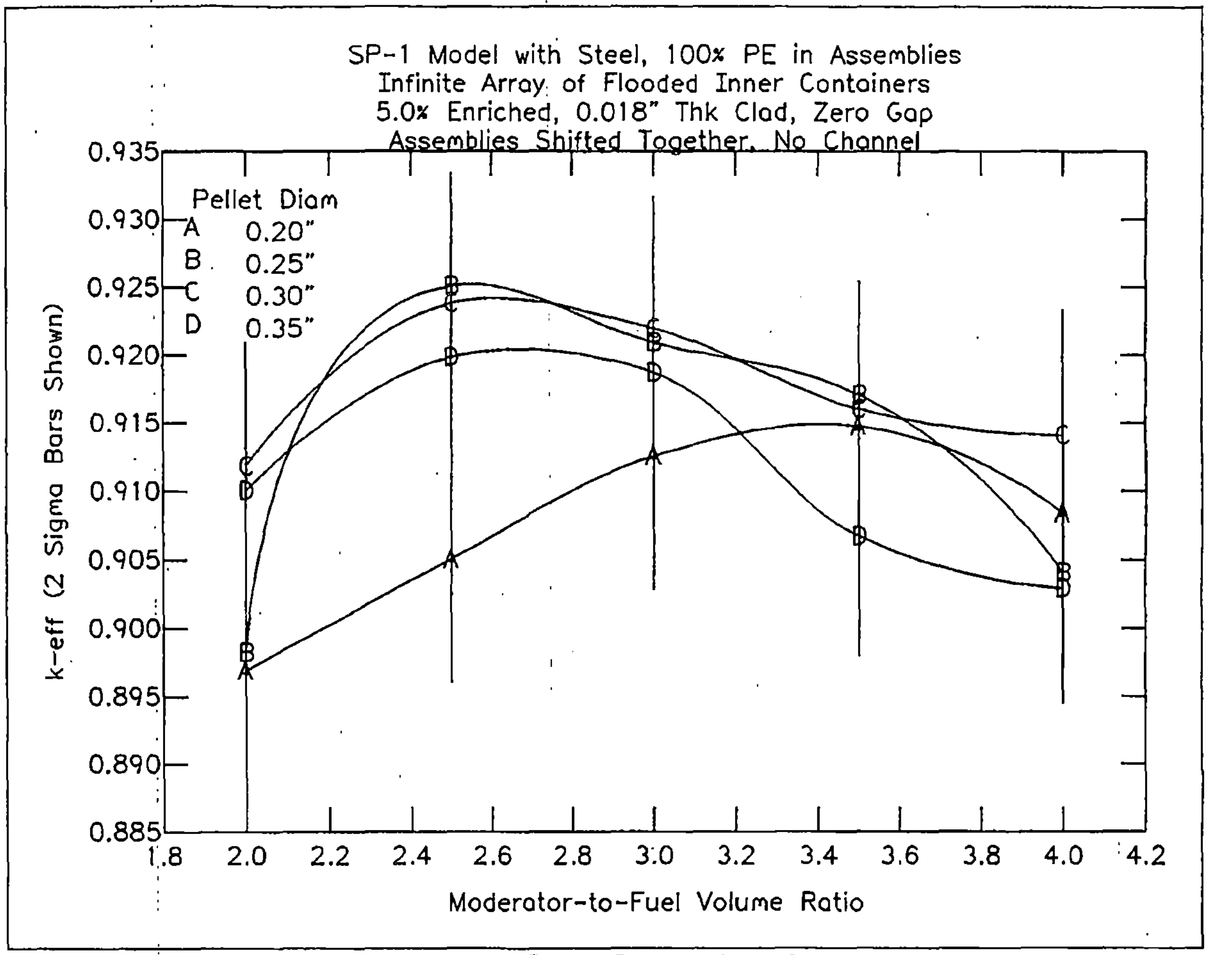
16-Group Cross Section Results



16-Group Cross Section Results



27-Group Cross Section Results



27-Group Cross Section Results

4.2 Low Density Interspersed Moderation

Unless stated otherwise, all calculation results in this Section are based on the following set of parameters.

a. All edge rods are 4.0% enriched, all UO_2-Gd_2O_3 rods are 5.0% enriched and contain 1.5 wt.% Gd_2O_3, and all other interior rods have an average 4.0% enrichment and a maximum 5.0% enrichment.

b. All assemblies contain the maximum allowable amount of polyethylene shims.

c. All rods contain 0.35" diameter pellets and are clad with 0.018" thick zircaloy. There is no gap between the pellet and clad.

d. All assemblies are 10x10 type with a 3x3 water channel at the center. The assembly envelope is 5.0" square. The assemblies are shifted apart to the outer edges of their baskets.

e. Most calculations are for "damaged" conditions. An array of edge-to-edge inner containers was modeled. Section 4.3 contains results for "normal" conditions with the wooden outer container.

The total PE volume modeled (ref. case "a-evk10") is 3.20026E6 cc for 104 packages which contain 208 assemblies. The fuel length modeled is 453.39 cm. The shims are full length except they are not in the 3x3 channel. The PE volume per assembly is 15385.865cc. The PE volume per unit length is 33.935 cc/cm. For a quick check, nine shims of dimensions 0.1267" x 5.0" would occupy 36.78 cc/cm. The 91 rods of 0.386" OD displace 10.6489 cu in/in. Assume that the 3x3 channel occupies 30% of the 5.0" assembly envelope dimension. The 1.5" square channel would then occupy 2.25 cu in/in. The volume between rods is then 12.1011 cu in/in which is 78.07 cc/cm. The shims therefore occupy 43.47% of the between-rod volume, excluding the channel. The maximum allowable volume of polyethylene shims per assembly is 33.93 cubic centimeters per centimeter length.

The calculated normalized (relative to average) fission rates for a typical 10x10 assembly with zero water rods and zero gadolinia rods and 8 volume % interspersed water are tabulated below; the model is an infinite array of edge-to-edge inner containers. It is seen that the corner rods have the highest fission rates with the edge rods declining with increased distance from the corner and interior rods declining with increased distance from the corner/edge. The corner rods have a fission rate about double that of the central 2x2 array of rods. As the water density is increased above 8 volume % (peak k-inf for infinite array), the normalized fission rates of the corner/edge rods increases but the system k-inf declines due to decreased coupling among the assemblies. For a finite array such as 13x20x1, the optimum interspersed water density is typically 8 to 12 volume %.

**TYPICAL NORMALIZED FISSION RATES FOR 10X10 ASSEMBLY
LOW DENSITY INTERSPERSED MODERATION**

1.489	1.320	1.245	1.206	1.189	1.187	1.200	1.232	1.295	1.430
1.314	1.091	1.000	.955	.935	.933	.947	.983	1.058	1.238
1.235	.996	.887	.835	.813	.810	.826	.867	.956	1.148
1.194	.950	.834	.775	.751	.747	.764	.812	.906	1.101
1.177	.930	.812	.751	.724	.721	.740	.788	.884	1.080
1.176	.930	.812	.751	.724	.720	.739	.788	.884	1.080
1.193	.949	.833	.774	.749	.746	.763	.811	.905	1.100
1.233	.994	.885	.833	.811	.808	.824	.865	.954	1.146
1.310	1.088	.997	.952	.932	.930	.944	.980	1.054	1.235
1.484	1.315	1.240	1.201	1.184	1.182	1.195	1.227	1.289	1.424

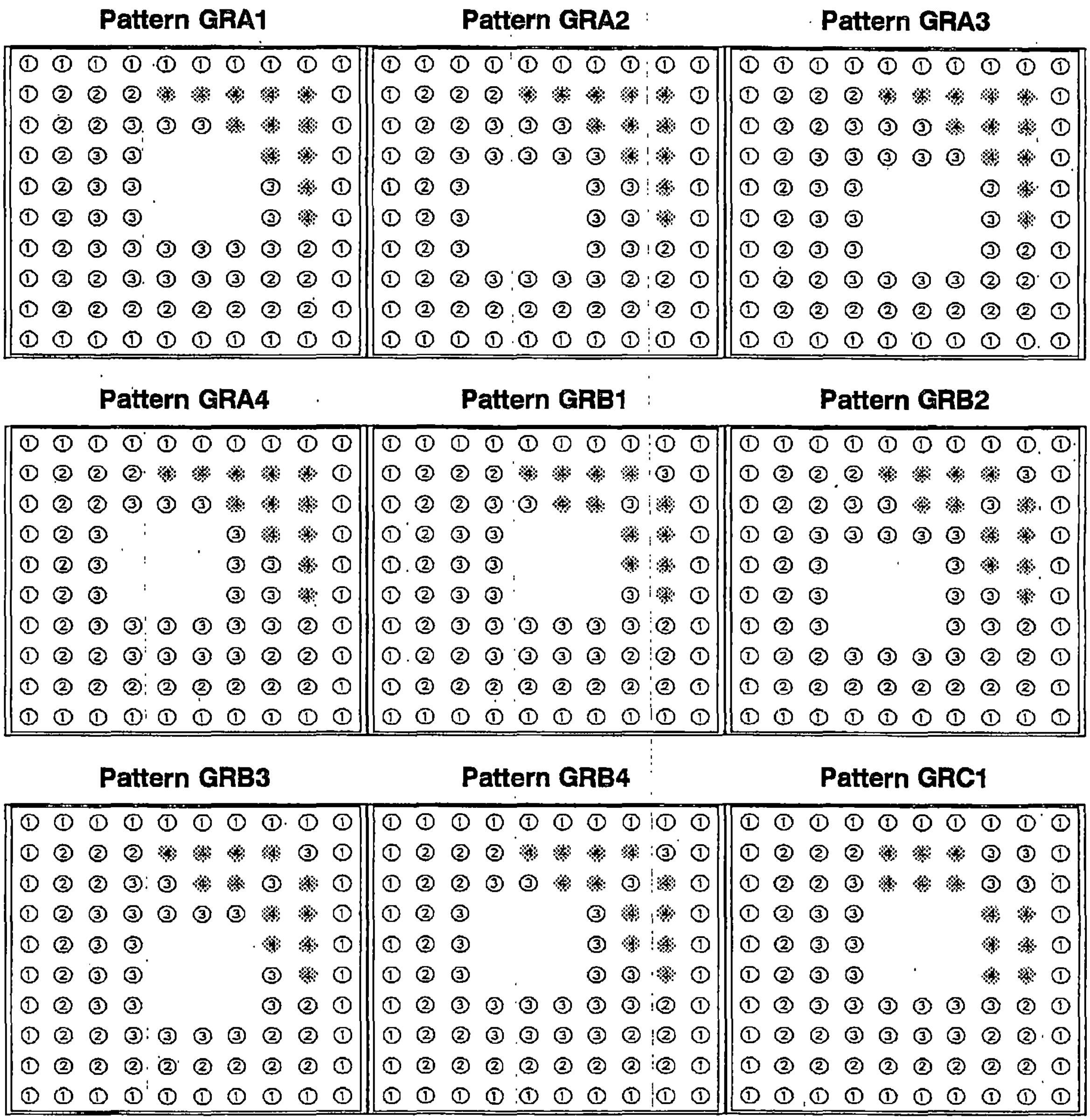
4.21 Sensitivity Study: Gadolinia Rod Locations

The fission densities tabulated above are instructive regarding the selection of locations of gadolinia rods for peak reactivity (most conservative locations). With low density interspersed moderation conditions, most of the moderation occurs **between** assemblies; relatively little occurs within assemblies. This is evidenced by Dancoff factors on the order of 0.90, meaning that neutrons leaving one rod have a 90% chance of having their next collision in another rod rather than in the between-rod moderation. As a result, the thermal flux is depressed in the assembly interior. If a thermal neutron absorber is placed into a region with a depressed thermal flux, the effectiveness of the absorber will be reduced. Similarly, if the gadolinia rods are clustered together in the central parts of the assembly, their effectiveness will be further reduced by the reduction in thermal flux caused by their companions. The most effective (least conservative) locations for gadolinia rods are near the corners/edge and spaced apart.

A simple CASMO model was used for a first series of studies on the effect of gadolinia rod arrangement. The 12 gadolinia rods contained 1.5 wt.% Gd_2O_3 and their uranium was 5.0% enriched. All other fuel rods were 4.0% enriched which results in a assembly average enrichment near 4.13%.

The CASMO model also contained a water channel in a central 3x3 lattice locations. The various gadolinia rod arrangements were tested with various channel positions. The CASMO model includes one assembly with specular reflection at all faces. The left side of the assembly faces the companion assembly and the right side faces out.

The arrangements modeled and the calculation results are presented in the following figures and table. The most reactive arrangement is "GRA2", which has all gadolinia rods clustered together in the upper right corner. The most reactive position for the 3x3 channel is to be shifted toward the lower left corner. As will shown, arrangements with the gadolinia rods concentrated on the left side are less reactive than with them on the right side (facing out). The rod type numbers shown in the figures were used for other studies with models with multiple rod enrichments. In these cases, Types 1,2, and 3 are 4.0% enriched and Type 4 (shaded) is 5.0% enriched with 1.5% gadolinia.



Pattern GRC2

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①	①	①	①	①	①	①	①	①	①

Pattern GRC3

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①	②	③	③	③	③	③	✱	✱	①
①	②	③	③				✱	✱	①
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①	②	③	③				③	②	①
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①	②	②	②	②	②	②	②	②	①
①	①	①	①	①	①	①	①	①	①

Pattern GRC4

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Pattern GRD1

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Pattern GRD2

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Pattern GRD3

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①	①	①	①	①	①	①	①	①	①

Pattern GRD4

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Pattern GRE1

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Pattern GRE2

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①	②	②	②	✱	✱	②	②	②	①
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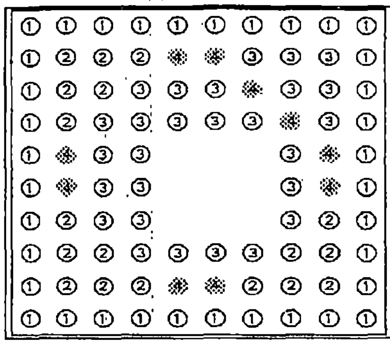
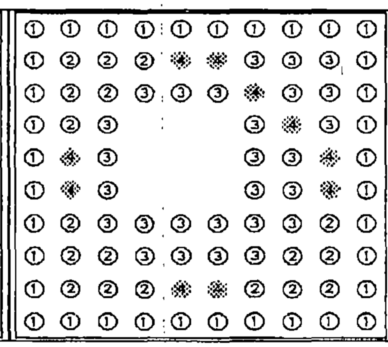
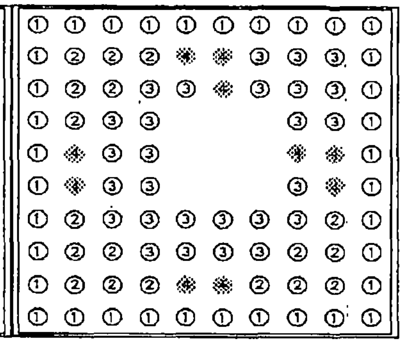
Pattern GRE3



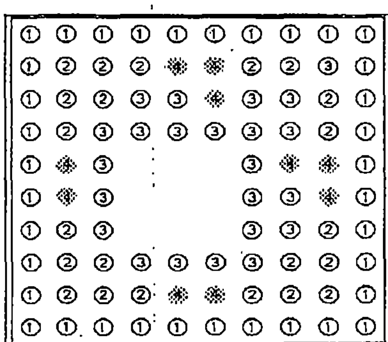
Pattern GRE4



Pattern GRF1



Pattern GRF2



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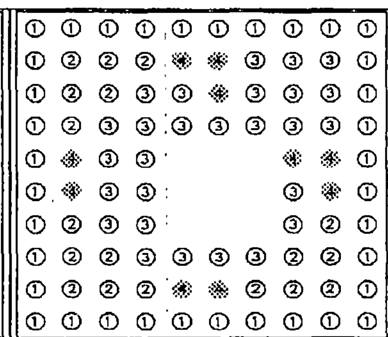
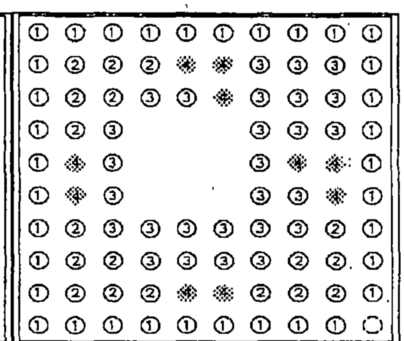
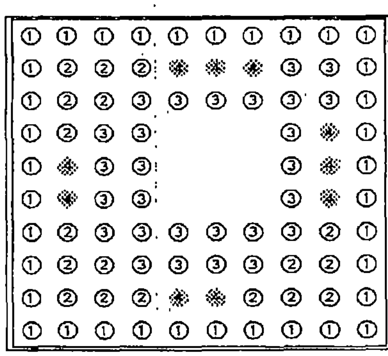


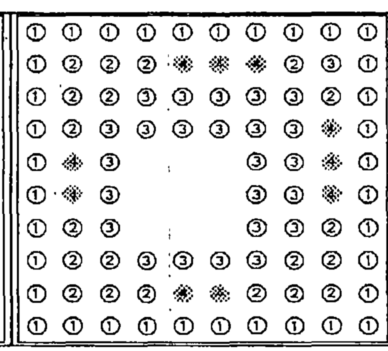
Pattern GRF4



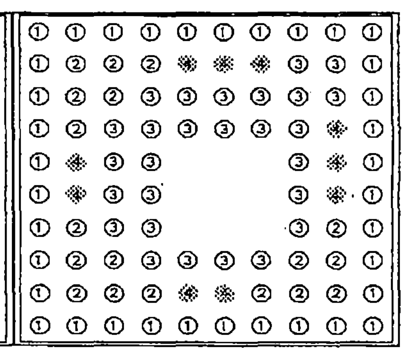
Pattern GRG1



Pattern GRG2



Pattern GRG3



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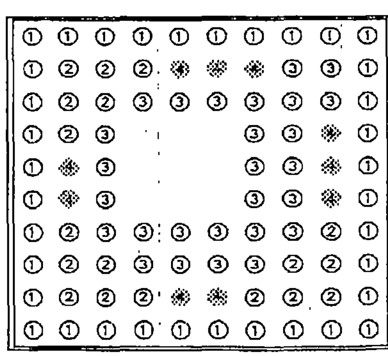
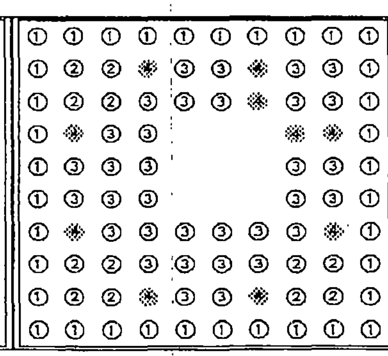


Pattern GRH1



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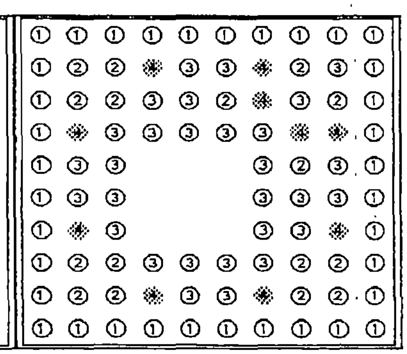

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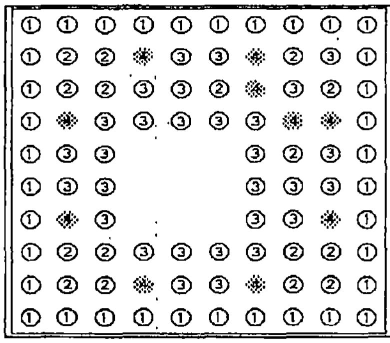

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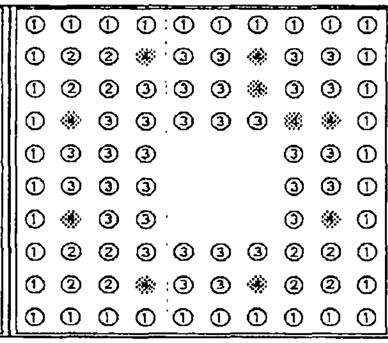
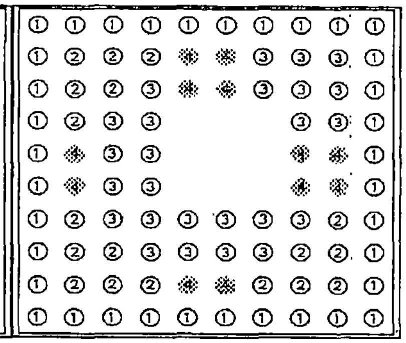
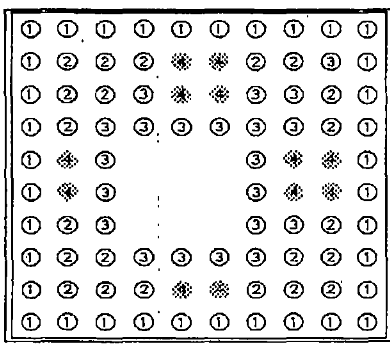


Pattern GRI1



Pattern GRI2



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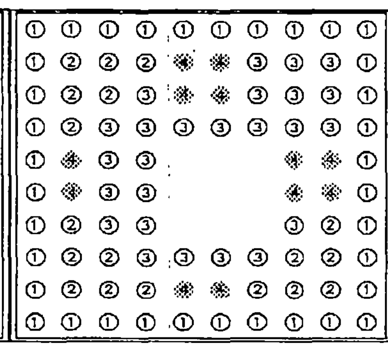
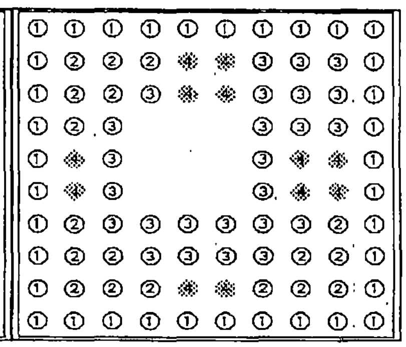
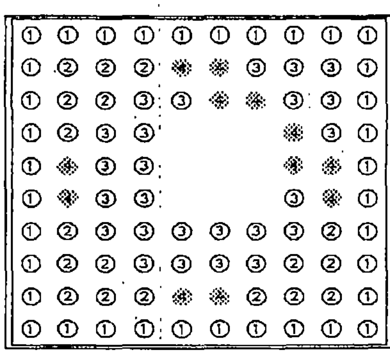


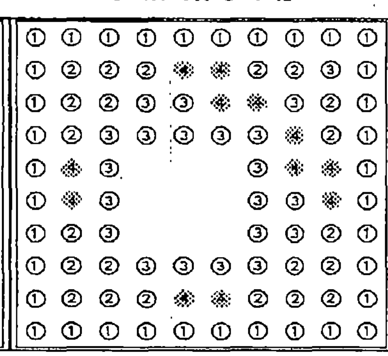
Pattern GRI4



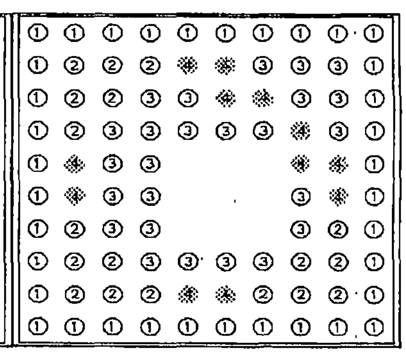
Pattern GRJ1



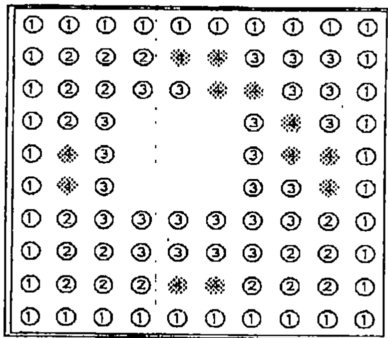
Pattern GRJ2



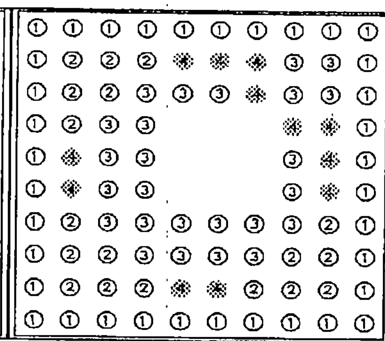
Pattern GRJ3



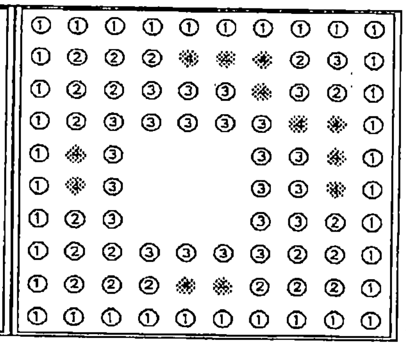
Pattern GRJ4



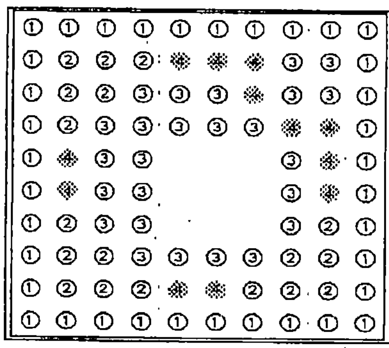
Pattern GRK1



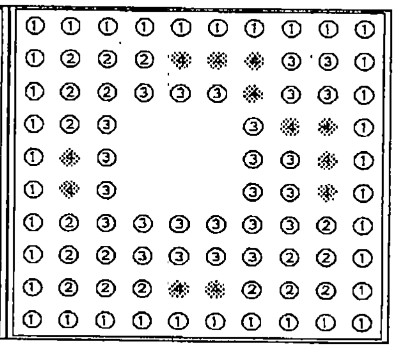
Pattern GRK2



Pattern GRK3



Pattern GRK4



Gadolinia Rod Arrangement Studies
All Gad Rods are 5.0% Enriched, All other Rods are 4.0% Enriched
Gadolinia Rods contain 1.5 wt.% Gd_2O_3
CASMO Model with Maximum Allowable Shims and 10 Vol% Interspersed Water

Gad Rod Pattern	Number of Gad Rods	Case ID	3X3 CHANNEL POSITION, CASMO k-inf			
			1	2	3	4
GRA..	12	CAVA	0.98154	0.98669	0.98460	0.98466
GRB..	12	CAVB	0.97896	0.98484	0.98197	0.98202
GRC..			0.98045	0.98638	0.98294	0.98298
GRD..			0.97658	0.98116	0.97761	0.97766
GRE..	10	CAVC	0.96905	0.97137	0.97068	0.97068
GRF..	10	CAVD	0.97211	0.97433	0.97324	0.97324
GRG..	10	CAVE	0.97097	0.97160	0.97136	0.97141
GRH..	10	CAVF	0.95944	0.96174	0.96109	0.96108
GRI..	12	CAVM	0.95538	0.95851	0.95673	0.95671
GRJ..	12	CAVMA	0.95339	0.95675	0.95530	0.95529
GRK..	12	CAVMB	0.95197	0.95450	0.95371	0.95372

4.22 Sensitivity Study: Water Rods and Water Channels

When fuel rods are replaced by "water rods", they are actually much closer to "void rods" at the typical 8-12 volume % water conditions for peak k-eff. Therefore, the net effect is closer to removal of fuel with very little added moderation, which causes a decline or no change in k-eff; i.e., the fuel is "worth" more than the slight addition of local moderation.

The new fuel category requires gadolinia rods. If a fuel rod is replaced with a "water rod", the gadolinia rods have the following effects:

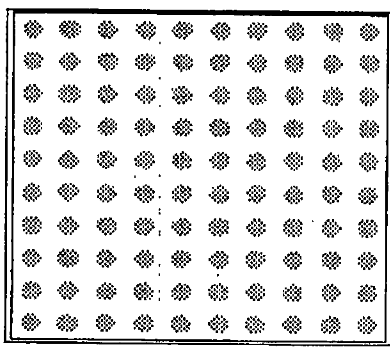
1. If the water rod is located close to gadolinia rod(s), the added moderation will increase the effectiveness of the absorber.

2. If gadolinia rods are moved toward the edge/corner to make room for water rods, the k-eff will tend to decline because of the increased thermal flux near the edge. The gadolinia rods become more effective and some of the higher worth fuel rods are replaced with absorbers.

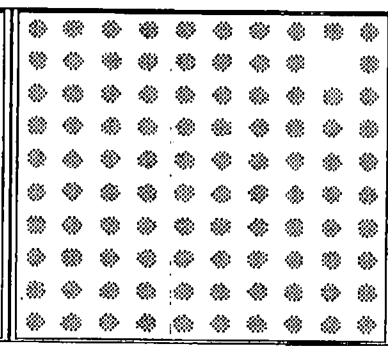
3. If gadolinia rods remain clustered in the center and fuel rods near the edge/corner are replaced with water rods, the k-eff will tend to decline because of the loss of higher worth fuel rods.

CASMO was used to calculate the k-inf for arrays of edge-to-edge inner containers with various numbers and arrangements of water rods. The model included the maximum allowable amount of polyethylene (shims) and 10 volume % interspersed water. This simple model had zero gadolinia and all fuel was 4.0% enriched. The water rod arrangements (patterns) modeled are shown in the following figures. As shown in the table following the figures, all cases with water rods are less reactive than the case with zero water rods.

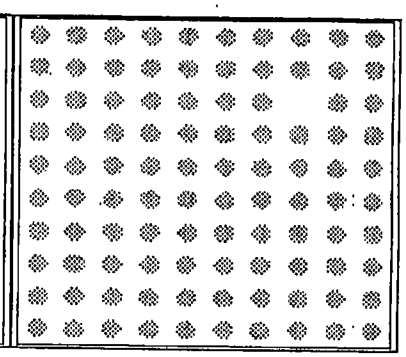
Pattern WRA



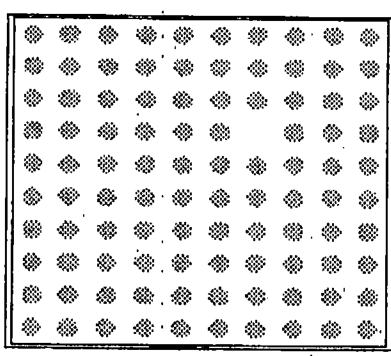
Pattern WRB



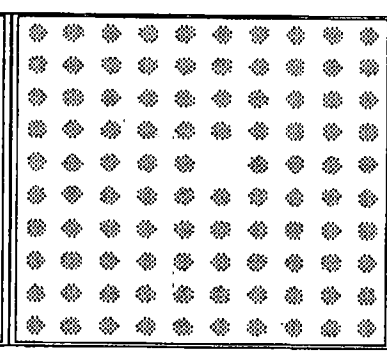
Pattern WRC



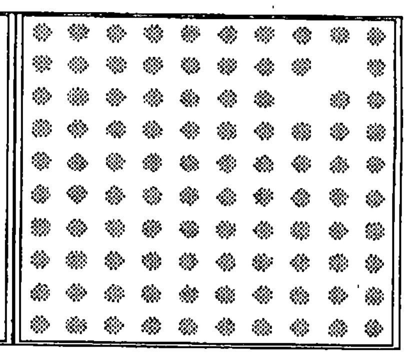
Pattern WRD



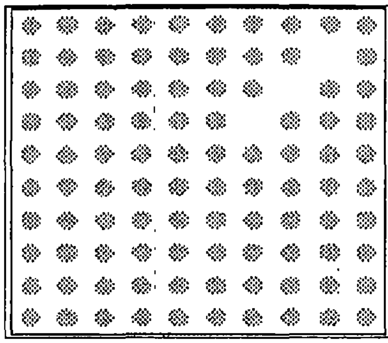
Pattern WRE



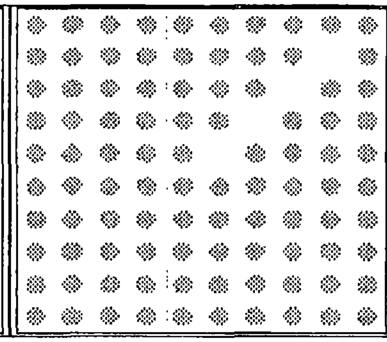
Pattern WRF



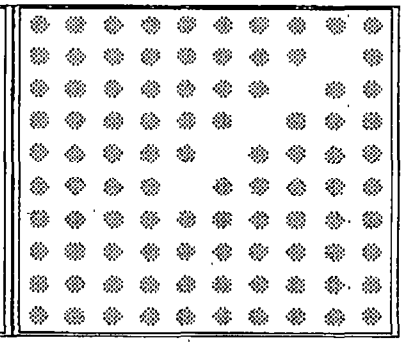
Pattern WRG



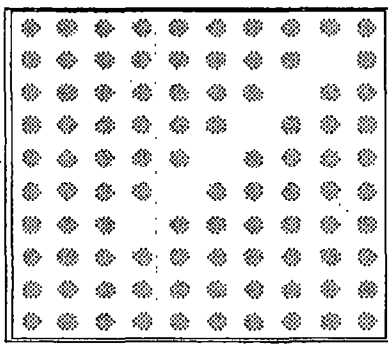
Pattern WRH



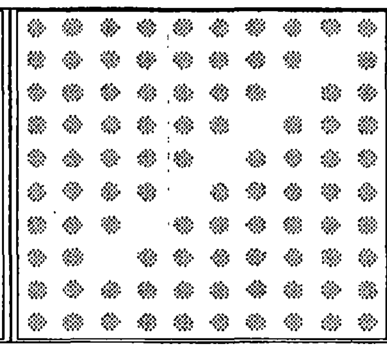
Pattern WRI



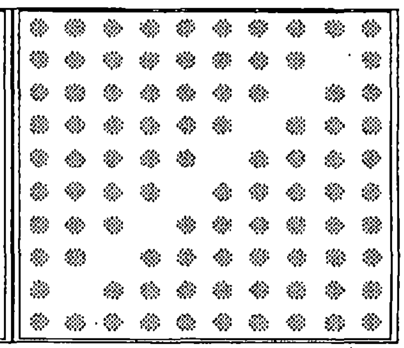
Pattern WRJ



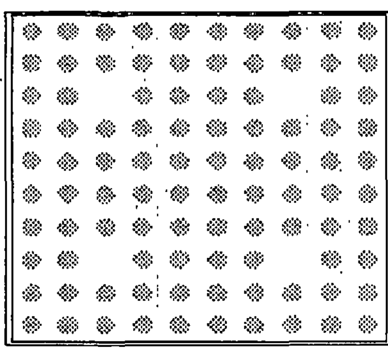
Pattern WRK



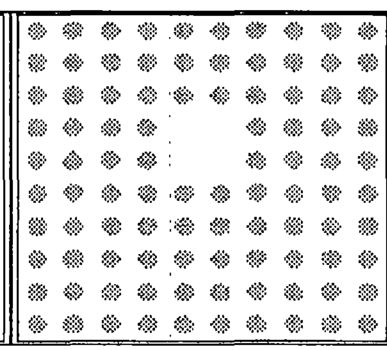
Pattern WRL



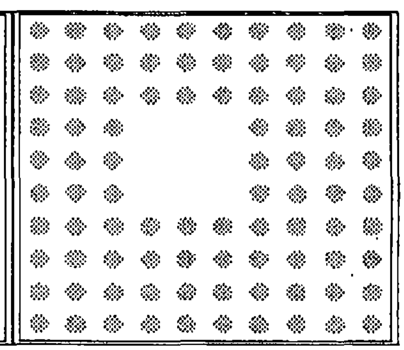
Pattern WRM



Pattern WRN

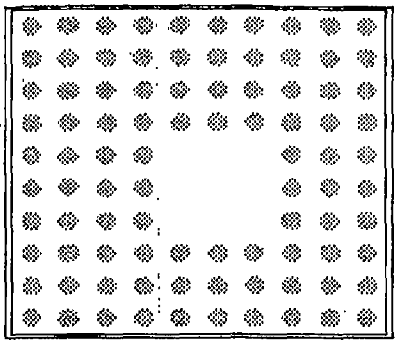


Pattern WRO



EMF-1563

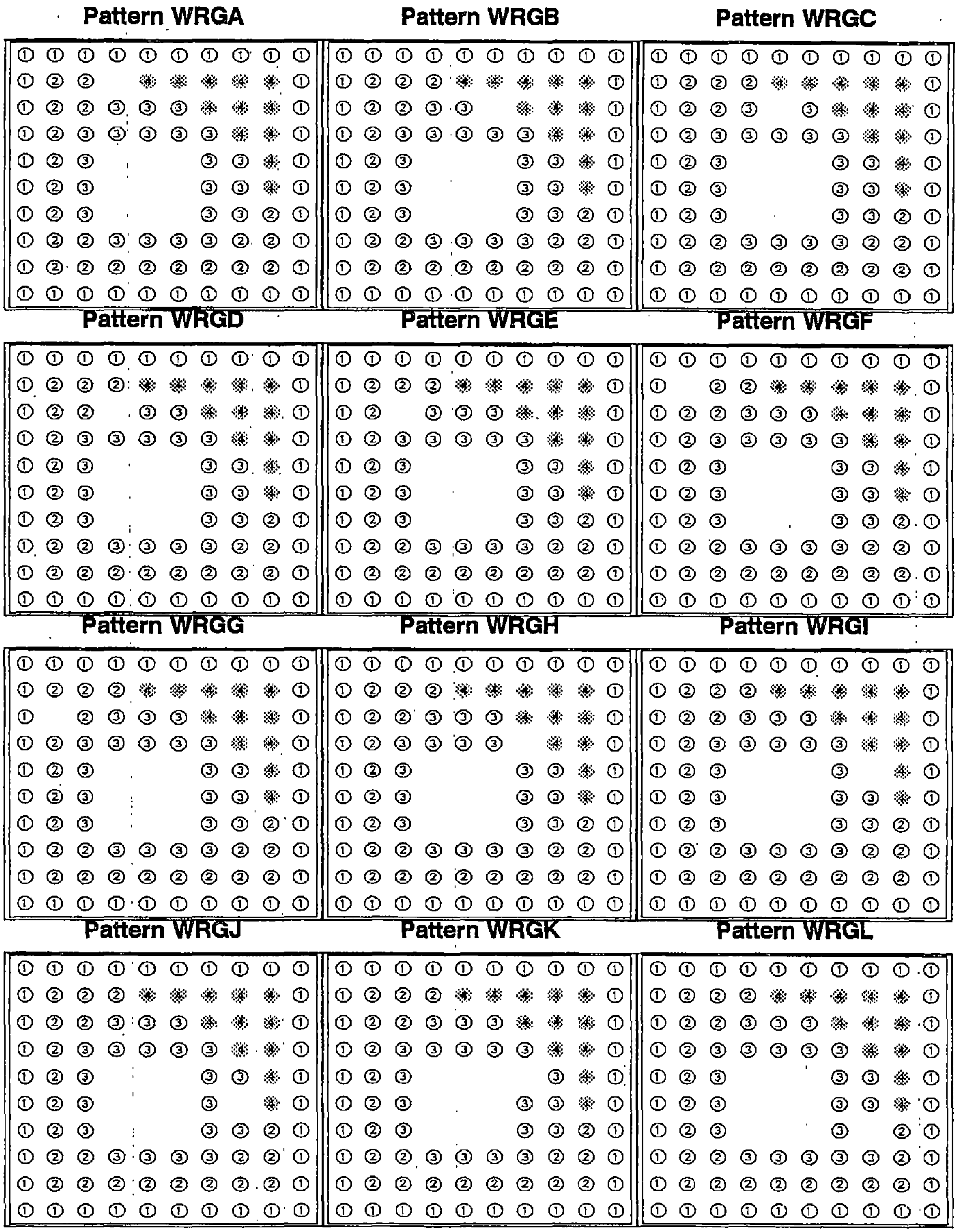
Pattern WRP



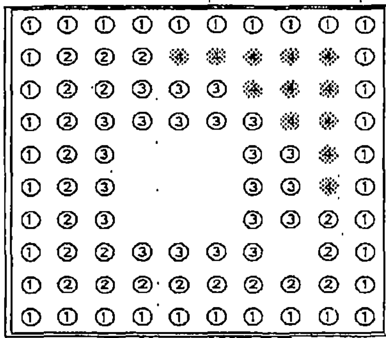
WATER ROD SENSITIVITY STUDY CASES
ALL FUEL IS 4.0% ENRICHED, ZERO GADOLINIA
CASMO MODEL WITH MAXIMUM ALLOWABLE SHIMS AND 10 VOL.% WATER

Water Rod Pattern	Case ID	CASMO k-inf
WRA	CEWA	1.11618
WRB	CEWB	1.11488
WRC		1.11558
WRD		1.11584
WRE		1.11594
WRF		1.11425
WRG		1.11389
WRH		1.11370
WRI		1.11347
WRJ		1.11312
WRK		1.11251
WRL		1.11121
WRM	CEWA	1.11383
WRN		1.11518
WRO		1.11357
WRP		1.11351

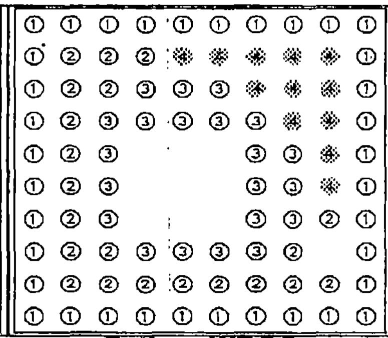
Additional water rod studies were done for assemblies with gadolinia rods. The gadolinia rod pattern tested was "GRA2", which was shown to be the most reactive in Section 4.21. As shown in the table following the figures below, adding a water rod lowers k-inf in all cases.


Pattern WRGA
Pattern WRGB
Pattern WRGC
Pattern WRGD
Pattern WRGE
Pattern WRGF
Pattern WRGG
Pattern WRGH
Pattern WRGI
Pattern WRGJ
Pattern WRGK
Pattern WRGL

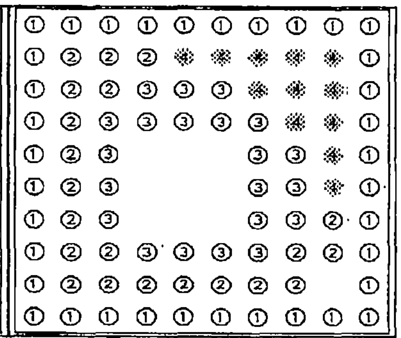
Pattern WRGM



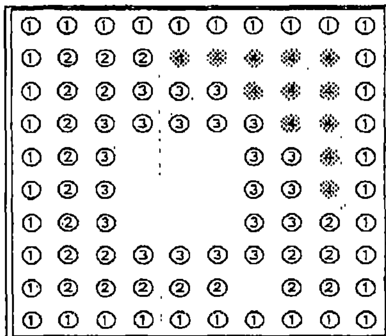
Pattern WRGN



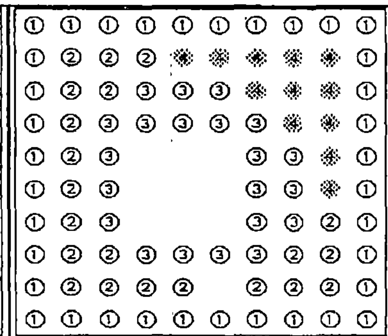
Pattern WRGO



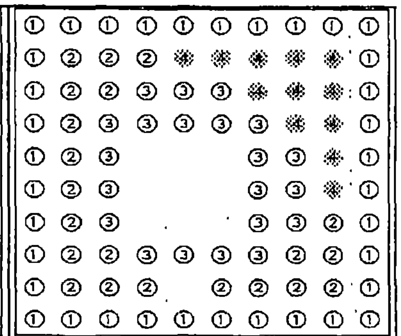
Pattern WRGP



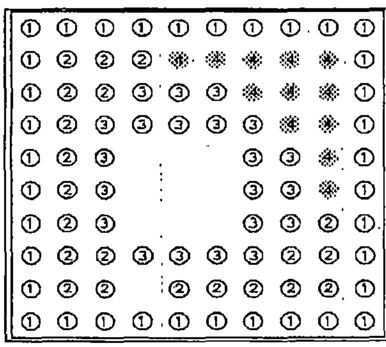
Pattern WRGQ



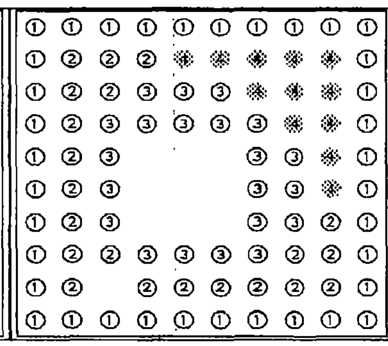
Pattern WRGR



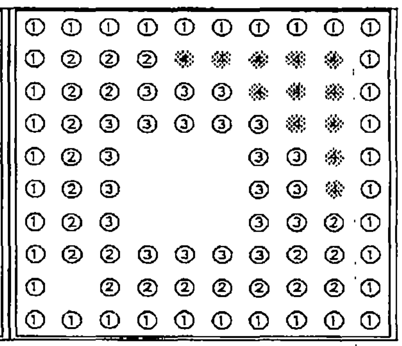
Pattern WRGS



Pattern WRGT



Pattern WRGU



WATER ROD SENSITIVITY STUDY CASES
ALL FUEL IS 4.0% ENRICHED, 12 GADOLINIA RODS
CASMO MODEL WITH MAXIMUM ALLOWABLE SHIMS AND 10 VOL.% WATER

Pattern	Case ID	CASMO k-inf
GRA2 (REF.)	CAVA	0.98669
WRGA	CAVN	0.98410
WRGB		0.98417
WRGC		0.98429
WRGD		0.98489
WRGE		0.98515
WRGF		0.98460
WRGG		0.98500
WRGH		0.98396
WRGI		0.98417
WRGJ		0.98431
WRGK		0.98438
WRGL		0.98489
WRGM		0.98512
WRGN		0.98473
WRGO		0.98453
WRGP		0.98504
WRGQ		0.98507
WRGR		0.98509
WRGS		0.98507
WRGT		0.98498
WRGU		0.98470

4.2.3 Sensitivity Study: Rod Enrichment Arrangement

Assemblies with 12 gadolinia rods in the most reactive arrangement determined in Section 4.2.1 were modeled with multiple rod enrichments. Edge rods (Type 1) were always 4.0% enriched and gadolinia rods (Type 4) were always 5.0% enriched. The average enrichment of Types 2 and 3 was 4.0% in all cases. The rod arrangements modeled and the CASMO calculation results are in the following figures and tables. The highest k-inf calculated is 0.98692 which was for Pattern "ERC". The k-inf with all Type 2 and 3 rods at 4.0% enriched is 0.98669, which is 0.00023 less than the highest value. Very small differences such as these could not be detected with KENO. It is concluded that the enrichment distribution effect is negligible.

Pattern ERA

①	①	①	①	①	①	①	①	①	①
①	②	②	②	④	④	④	④	④	①
①	②	②	③	③	③	④	④	④	①
①	②	③	③	③	③	③	④	④	①
①	②	③				③	③	④	①
①	②	③				③	③	④	①
①	②	③				③	③	②	①
①	②	②	③	③	③	③	②	②	①
①	②	②	②	②	②	②	②	②	①
①	①	①	①	①	①	①	①	①	①

Pattern ERB

①	①	①	①	①	①	①	①	①	①
①	②	②	②	④	④	④	④	④	①
①	②	③	③	③	③	④	④	④	①
①	②	③	③	③	③	③	④	④	①
①	②	③				③	③	④	①
①	②	③				③	③	④	①
①	②	③				③	③	②	①
①	②	③	③	③	③	③	③	②	①
①	②	②	②	②	②	②	②	②	①
①	①	①	①	①	①	①	①	①	①

Pattern ERC

①	①	①	①	①	①	①	①	①	①
①	②	②	②	④	④	④	④	④	①
①	②	③	③	③	③	④	④	④	①
①	②	③	③	③	③	③	④	④	①
①	③	③				③	③	④	①
①	③	③				③	③	④	①
①	②	③				③	③	②	①
①	②	③	③	③	③	③	③	②	①
①	②	②	②	③	③	②	②	②	①
①	①	①	①	①	①	①	①	①	①

Pattern ERD

①	①	①	①	①	①	①	①	①	①
①	②	②	③	④	④	④	④	④	①
①	②	③	③	③	③	④	④	④	①
①	③	③	③	③	③	③	④	④	①
①	③	③				③	③	④	①
①	③	③				③	③	④	①
①	③	③				③	③	③	①
①	②	③	③	③	③	③	③	②	①
①	②	②	③	③	③	③	②	②	①
①	①	①	①	①	①	①	①	①	①

Pattern ERE

①	①	①	①	①	①	①	①	①	①
①	③	③	③	④	④	④	④	④	①
①	③	③	③	③	③	④	④	④	①
①	③	②	②	②	②	②	④	④	①
①	③	②				②	③	④	①
①	③	②				②	③	④	①
①	③	②				②	③	③	①
①	③	②	②	②	②	②	③	③	①
①	③	③	③	③	③	③	③	③	①
①	①	①	①	①	①	①	①	①	①

PATTERN ERA CALCULATION RESULTS
CASMO MODEL WITH MAXIMUM ALLOWABLE SHIMS PLUS 10 VOL.% WATER

Case ID	Type 4 wt.% Gad	Type 4 Enr.	Type 2 Enr.	Type 3 Enr.	ALL Avg. Enr.	INT. Avg. Enr.	CASMO k-inf
cavg	1.5	5.00	5.00	2.9524	4.130	4.000	0.98540
cavg	1.5	5.00	4.75	3.2143	4.130	4.000	0.98610
cavg	1.5	5.00	4.50	3.4762	4.130	4.000	0.98654
cavg	1.5	5.00	4.25	3.7381	4.130	4.000	0.98673
cavg	1.5	5.00	4.00	4.0000	4.130	4.000	0.98669
cavg	1.5	5.00	3.75	4.2619	4.130	4.000	0.98643
cavg	1.5	5.00	3.50	4.5238	4.130	4.000	0.98595
cavg	1.5	5.00	3.25	4.7857	4.130	4.000	0.98521

PATTERN ERB CALCULATION RESULTS
CASMO MODEL WITH MAXIMUM ALLOWABLE SHIMS PLUS 10 VOL.% WATER

Case ID	Type 4 wt.% Gad	Type 4 Enr.	Type 2 Enr.	Type 3 Enr.	ALL Avg. Enr.	INT. Avg. Enr.	CASMO k-inf
cavh	1.5	5.00	5.00	3.2083	4.130	4.000	0.98625
cavh	1.5	5.00	4.75	3.4063	4.130	4.000	0.98661
cavh	1.5	5.00	4.50	3.6042	4.130	4.000	0.98680
cavh	1.5	5.00	4.25	3.8021	4.130	4.000	0.98683
cavh	1.5	5.00	4.00	4.0000	4.130	4.000	0.98669
cavh	1.5	5.00	3.75	4.1979	4.130	4.000	0.98639
cavh	1.5	5.00	3.50	4.3958	4.130	4.000	0.98594
cavh	1.5	5.00	3.25	4.5938	4.130	4.000	0.98531
cavh	1.5	5.00	3.00	4.7917	4.130	4.000	0.98447

PATTERN ERC CALCULATION RESULTS
CASMO MODEL WITH MAXIMUM ALLOWABLE SHIMS PLUS 10 VOL.% WATER

Case ID	Type 4 wt.% Gad	Type 4 Enr.	Type 2 Enr.	Type 3 Enr.	ALL Avg. Enr.	INT. Avg. Enr.	CASMO k-inf
cavi	1.5	5.00	5.00	3.4643	4.130	4.000	0.98673
cavi	1.5	5.00	4.75	3.5982	4.130	4.000	0.98688
cavi	1.5	5.00	4.50	3.7321	4.130	4.000	0.98692
cavi	1.5	5.00	4.25	3.8661	4.130	4.000	0.98686
cavi	1.5	5.00	4.00	4.0000	4.130	4.000	0.98669
cavi	1.5	5.00	3.75	4.1339	4.130	4.000	0.98641
cavi	1.5	5.00	3.50	4.2679	4.130	4.000	0.98601
cavi	1.5	5.00	3.25	4.4018	4.130	4.000	0.98552
cavi	1.5	5.00	3.00	4.5357	4.130	4.000	0.98488

PATTERN ERD CALCULATION RESULTS
CASMO MODEL WITH MAXIMUM ALLOWABLE SHIMS PLUS 10 VOL.% WATER

Case ID	Type 4 wt.% Gad	Type 4 Enr.	Type 2 Enr.	Type 3 Enr.	ALL Avg. Enr.	INT. Avg. Enr.	CASMO k-inf
cavj	1.5	5.00	5.00	3.7353	4.130	4.000	0.98683
cavj	1.5	5.00	4.75	3.8015	4.130	4.000	0.98687
cavj	1.5	5.00	4.50	3.8676	4.130	4.000	0.98686
cavj	1.5	5.00	4.25	3.9338	4.130	4.000	0.98680
cavj	1.5	5.00	4.00	4.0000	4.130	4.000	0.98669
cavj	1.5	5.00	3.75	4.0662	4.130	4.000	0.98653
cavj	1.5	5.00	3.50	4.1324	4.130	4.000	0.98630
cavj	1.5	5.00	3.25	4.1985	4.130	4.000	0.98602
cavj	1.5	5.00	3.00	4.2647	4.130	4.000	0.98568

PATTERN ERE CALCULATION RESULTS
CASMO MODEL WITH MAXIMUM ALLOWABLE SHIMS PLUS 10 VOL.% WATER

Case ID	Type 4 wt.% Gad	Type 4 Enr.	Type 2 Enr.	Type 3 Enr.	ALL Avg. Enr.	INT. Avg. Enr.	CASMO k-inf
cavk	1.5	5.00	5.00	3.4074	4.130	4.000	0.98497
cavk	1.5	5.00	4.75	3.5556	4.130	4.000	0.98557
cavk	1.5	5.00	4.50	3.7037	4.130	4.000	0.98605
cavk	1.5	5.00	4.25	3.8519	4.130	4.000	0.98642
cavk	1.5	5.00	4.00	4.0000	4.130	4.000	0.98669
cavk	1.5	5.00	3.75	4.1482	4.130	4.000	0.98685
cavk	1.5	5.00	3.50	4.2963	4.130	4.000	0.98690
cavk	1.5	5.00	3.25	4.4444	4.130	4.000	0.98682
cavk	1.5	5.00	3.00	4.5926	4.130	4.000	0.98661

4.2.4 Pellet Diameter Effects

Unless noted otherwise, all cases were modeled with a 0.35" pellet diameter (0.386" clad OD), the largest allowable for the new category. KENO calculation results are presented in Section 4.3 to demonstrate that the largest diameter is most reactive with low density interspersed moderation.

4.2.5 Sensitivity Studies: Assembly Orientation and Position

Various combinations of rod enrichment distributions and assembly orientations were evaluated in KENO models. In all cases, all gadolinia rods were 5.0% enriched and contained 1.5 wt% Gd_2O_3. Also, all edge rods were 4.0% enriched. The average enrichment of internal rods, excluding gadolinia rods, was 4.0%.

The array modeled was 8x13x1 (104 packages) which exceeds the 100 package minimum at damaged conditions for Fissile Class II with a minimum transport index of 1.0. The array was reflected by 30 cm of full density water at all six faces.

The highest bias-corrected 95% upper limit k-eff for these KENO cases is 0.93607 for case "a-evk10", which is listed in the "K10 Arrangement" subsection. Certain cases have higher k-eff values but all such cases are outside the specified limits; the data were included for information only. The package is acceptable with the specified quantities of shims and with any interspersed water density.

Arrangement K1

This arrangement has 12 Type 4 (gadolinia) rods clustered together at one of outward-facing corners. There are 36 Type 1 (Edge) rods, 22 Type 2 rods, and 21 Type 3 rods. The average enrichment of Types 2 and 3 is 4.0%. The peak k-eff with Type 2 rods at 5.0% enriched is slightly higher but not significantly higher than that with all Type 2 and 3 rods at 4.0% enriched. The 3x3 water channel is shifted toward the inside of the package. The two assemblies per package are shown in the following figure and the KENO calculation results are tabulated below the figure.

1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	2	2	2	1		1	2	2	2	4	4	4	4	4	1
1	2	2	3	3	3	3	2	2	1		1	2	2	3	3	3	4	4	4	1
1	2	3	3				3	2	1		1	2	3	3	3	3	3	4	4	1
1	4	3	3				3	2	1		1	2	3				3	3	4	1
1	4	3	3				3	2	1		1	2	3				3	3	4	1
1	4	4	3	3	3	3	3	2	1		1	2	3				3	3	2	1
1	4	4	4	3	3	3	2	2	1		1	2	2	3	3	3	3	2	2	1
1	4	4	4	4	4	2	2	2	1		1	2	2	2	2	2	2	2	2	1
1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1

Case ID	Vol.% Water	Type 4 % Gad	Type 4 Enr.	Type 2 Enr.	Type 3 Enr.	ALL Avg. Enr.	INT. Avg. Enr.	Array	k-eff Avg.	k-eff Std.Dev.
A-EVA08	8.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.92141	0.00170
A-EVA10	10.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.92883	0.00182
A-EVA12	12.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.92350	0.00167
A-EVG06	6.0	1.50	5.00	4.00	4.00	4.13	4.00	104	0.91778	0.00170
A-EVG08	8.0	1.50	5.00	4.00	4.00	4.13	4.00	104	0.92796	0.00172
A-EVG10	10.0	1.50	5.00	4.00	4.00	4.13	4.00	104	0.92391	0.00170
A-EVG12	12.0	1.50	5.00	4.00	4.00	4.13	4.00	104	0.92193	0.00191

Arrangement K2

This arrangement differs from "K1" only in the orientation of the left assembly: it was rotated 180°. The peak k-eff is slightly lower than that for "K1". The two assemblies per package are shown in the following figure and the KENO calculation results are tabulated below the figure.

1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1
1	2	2	2	4	4	4	4	4	1		1	2	2	2	4	4	4	4	4	1
1	2	2	3	3	3	4	4	4	1		1	2	2	3	3	3	4	4	4	1
1	2	3	3	3	3	3	4	4	1		1	2	3	3	3	3	3	4	4	1
1	2	3				3	3	4	1		1	2	3				3	3	4	1
1	2	3				3	3	4	1		1	2	3				3	3	4	1
1	2	3				3	3	2	1		1	2	3				3	3	2	1
1	2	2	3	3	3	3	2	2	1		1	2	2	3	3	3	3	2	2	1
1	2	2	2	2	2	2	2	2	1		1	2	2	2	2	2	2	2	2	1
1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1

Case ID	Vol.% Water	Type 4 % Gad	Type 4 Enr.	Type 2 Enr.	Type 3 Enr.	ALL Avg. Enr.	INT. Avg. Enr.	Array	k-eff	
									Avg.	Std.Dev.
A-EVB08	8.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.92213	0.00182
A-EVB10	10.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.92318	0.00176
A-EVB12	12.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.91752	0.00185

Arrangement K3

This arrangement differs from "K1" only in the orientation of the 3x3 water channel: It is now shifted toward the corner with the gadolinia rods. The peak k-eff is slightly lower than that for "K1" but the difference is not significant. The two assemblies per package are shown in the following figure and the KENO calculation results are tabulated below the figure.

1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	2	2	2	1		1	2	2	2	4	4	4	4	4	1
1	2	2	3	3	3	3	2	2	1		1	2	2	3	3	3	4	4	4	1
1	2	3	3	3	3	3	3	2	1		1	2	3	3				4	4	1
1	4	3				3	3	2	1		1	2	3	3				3	4	1
1	4	3				3	3	2	1		1	2	3	3				3	4	1
1	4	4				3	3	2	1		1	2	3	3	3	3	3	3	2	1
1	4	4	4	3	3	3	2	2	1		1	2	2	3	3	3	3	2	2	1
1	4	4	4	4	4	2	2	2	1		1	2	2	2	2	2	2	2	2	1
1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1

Case ID	Vol.% Water	Type 4 % Gad	Type 4 Enr.	Type 2 Enr.	Type 3 Enr.	ALL Avg. Enr.	INT. Avg. Enr.	Array	k-eff	
									Avg.	Std.Dev.
A-EVC08	8.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.92135	0.00184
A-EVC10	10.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.92615	0.00171
A-EVC12	12.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.92100	0.00175

Arrangement K4

This arrangement differs from "K3" only in the orientation of the right assembly: it was rotated 180°. The peak k-eff is significantly lower than that for arrangement "K1" or "K3". The two assemblies per package are shown in the following figure and the KENO calculation results are tabulated below the figure.

1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	2	2	2	1		1	2	2	2	2	2	2	2	2	1
1	2	2	3	3	3	3	2	2	1		1	2	2	3	3	3	3	2	2	1
1	2	3	3	3	3	3	3	2	1		1	2	3	3	3	3	3	3	2	1
1	4	3				3	3	2	1		1	4	3				3	3	2	1
1	4	3				3	3	2	1		1	4	3				3	3	2	1
1	4	4				3	3	2	1		1	4	4				3	3	2	1
1	4	4	4	3	3	3	2	2	1		1	4	4	4	3	3	3	2	2	1
1	4	4	4	4	4	2	2	2	1		1	4	4	4	4	4	2	2	2	1
1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1

Case ID	Vol.% Water	Type 4 % Gad	Type 4 Enr.	Type 2 Enr.	Type 3 Enr.	ALL Avg. Enr.	INT. Avg. Enr.	Array	k-eff	
									Avg.	Std.Dev.
A-EVD08	8.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.91677	0.00182
A-EVD10	10.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.91781	0.00178
A-EVD12	12.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.91623	0.00188

Arrangement K5

This arrangement differs from "K2" only in the orientation of the right assembly: it was rotated 180°. The peak k-eff is significantly lower than that for arrangement "K1" but not significantly different from that for arrangement "K2". The two assemblies per package are shown in the following figure and the KENO calculation results are tabulated below the figure.

1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1
1	2	2	2	4	4	4	4	4	1		1	2	2	2	2	2	2	2	2	1
1	2	2	3	3	3	4	4	4	1		1	2	2	3	3	3	3	2	2	1
1	2	3	3	3	3	3	4	4	1		1	2	3	3				3	2	1
1	2	3				3	3	4	1		1	4	3	3				3	2	1
1	2	3				3	3	4	1		1	4	3	3				3	2	1
1	2	3				3	3	2	1		1	4	4	3	3	3	3	3	2	1
1	2	2	3	3	3	3	2	2	1		1	4	4	4	3	3	3	2	2	1
1	2	2	2	2	2	2	2	2	1		1	4	4	4	4	4	2	2	2	1
1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1

Case ID	Vol.% Water	Type 4 % Gad	Type 4 Enr.	Type 2 Enr.	Type 3 Enr.	ALL Avg. Enr.	INT. Avg. Enr.	Array	k-eff	
									Avg.	Std.Dev.
A-EVE08	8.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.91500	0.00216
A-EVE10	10.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.92115	0.00171
A-EVE12	12.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.91602	0.00183

Arrangement K6

This arrangement is similar to "K1" and "K2". The left assembly was rotated to placed the gadolinia rods at the upper-left corner. The peak k-eff is not significantly different from that for arrangement "K1". The two assemblies per package are shown in the following figure and the KENO calculation results are tabulated below the figure.

1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1
1	4	4	4	4	4	2	2	2	1		1	2	2	2	4	4	4	4	4	1
1	4	4	4	3	3	3	2	2	1		1	2	2	3	3	3	4	4	4	1
1	4	4	3	3	3	3	3	2	1		1	2	3	3	3	3	3	4	4	1
1	4	3	3				3	2	1		1	2	3				3	3	4	1
1	4	3	3				3	2	1		1	2	3				3	3	4	1
1	2	3	3				3	2	1		1	2	3				3	3	2	1
1	2	2	3	3	3	3	2	2	1		1	2	2	3	3	3	3	2	2	1
1	2	2	2	2	2	2	2	2	1		1	2	2	2	2	2	2	2	2	1
1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1

Case ID	Vol.% Water	Type 4 % Gad	Type 4 Enr.	Type 2 Enr.	Type 3 Enr.	ALL Avg. Enr.	INT. Avg. Enr.	Array	k-eff	
									Avg.	Std.Dev.
A-EVF08	8.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.92503	0.00181
A-EVF10	10.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.92501	0.00168
A-EVF12	12.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.92378	0.00188

Arrangement K7

This arrangement is similar to "K5". The left assembly was rotated to placed the gadolinia rods at the lower-right corner. The peak k-eff is not significantly different from that for arrangement "K5" but it is significantly lower than that for arrangement "K1". The two assemblies per package are shown in the following figure and the KENO calculation results are tabulated below the figure.

1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	2	2	2	1		1	2	2	2	2	2	2	2	2	1
1	2	2	3	3	3	3	2	2	1		1	2	2	3	3	3	3	2	2	1
1	2	3				3	3	2	1		1	2	3	3				3	2	1
1	2	3				3	3	4	1		1	4	3	3				3	2	1
1	2	3				3	3	4	1		1	4	3	3				3	2	1
1	2	3	3	3	3	3	4	4	1		1	4	4	3	3	3	3	3	2	1
1	2	2	3	3	3	4	4	4	1		1	4	4	4	3	3	3	2	2	1
1	2	2	2	4	4	4	4	4	1		1	4	4	4	4	4	2	2	2	1
1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1

Case ID	Vol.% Water	Type 4 % Gad	Type 4 Enr.	Type 2 Enr.	Type 3 Enr.	ALL Avg. Enr.	INT. Avg. Enr.	Array	k-eff	
									Avg.	Std.Dev.
A-EVH08	8.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.91824	0.00166
A-EVH10	10.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.92004	0.00185
A-EVH12	12.0	1.50	5.00	5.00	2.95	4.13	4.00	104	0.91274	0.00171

Arrangement K8

This arrangement is similar to "K1" except that there are now 24 Type 2 rods . The two additional Type 2 rods were placed at the corner with gadolinia rods. The gadolinia rods are now less tightly clustered than before. The enrichment of Type 3 rods was lowered to maintain the average of Types 2 and 3 at 4.0%. The assembly orientation is as for arrangement "K1". The peak k-eff is significantly lower than that for arrangement "K1". The two assemblies per package are shown in the following figure and the KENO calculation results are tabulated below the figure.

1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	2	2	2	1		1	2	2	2	4	4	4	4	2	1
1	2	2	3	3	3	3	2	2	1		1	2	2	3	3	4	4	2	4	1
1	2	3	3				3	2	1		1	2	3	3	3	3	3	4	4	1
1	4	3	3				3	2	1		1	2	3				3	4	4	1
1	4	4	3				3	2	1		1	2	3				3	3	4	1
1	4	4	3	3	3	3	3	2	1		1	2	3				3	3	2	1
1	4	2	4	4	3	3	2	2	1		1	2	2	3	3	3	3	2	2	1
1	2	4	4	4	4	2	2	2	1		1	2	2	2	2	2	2	2	2	1
1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1

Case ID	Vol.% Water	Type 4 % Gad	Type 4 Enr.	Type 2 Enr.	Type 3 Enr.	ALL Avg. Enr.	INT. Avg. Enr.	Array	k-eff	
									Avg.	Std.Dev.
A-EVI08	8.0	1.50	5.00	5.00	2.74	4.13	4.00	104	0.92230	0.00190
A-EVI10	10.0	1.50	5.00	5.00	2.74	4.13	4.00	104	0.92283	0.00169
A-EVI12	12.0	1.50	5.00	5.00	2.74	4.13	4.00	104	0.91932	0.00184

Arrangement K9

This arrangement is similar to "K1" except that there are now 19 Type 2 rods . Three Type 2 rods near the corners without gadolinia were converted to Type 3. The enrichment of Type 3 rods was increased to maintain the average of Types 2 and 3 at 4.0%. The assembly orientation is as for arrangement "K1". The peak k-eff is not significantly from that for arrangement "K1". The two assemblies per package are shown in the following figure and the KENO calculation results are tabulated below the figure.

1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	2	2	2	1		1	2	2	2	4	4	4	4	4	1
1	2	3	3	3	3	3	3	2	1		1	2	3	3	3	3	4	4	4	1
1	2	3	3				3	2	1		1	2	3	3	3	3	3	4	4	1
1	4	3	3				3	2	1		1	2	3				3	3	4	1
1	4	3	3				3	2	1		1	2	3				3	3	4	1
1	4	4	3	3	3	3	3	2	1		1	2	3				3	3	2	1
1	4	4	4	3	3	3	3	2	1		1	2	3	3	3	3	3	3	2	1
1	4	4	4	4	4	2	2	2	1		1	2	2	2	2	2	2	2	2	1
1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1

Case ID	Vol.% Water	Type 4 % Gad	Type 4 Enr.	Type 2 Enr.	Type 3 Enr.	ALL Avg. Enr.	INT. Avg. Enr.	Array	k-eff	
									Avg.	Std.Dev.
A-EVJ10	10.0	1.50	5.00	5.00	3.21	4.13	4.00	104	0.92621	0.00197

Arrangement K10

This arrangement is similar to "K1" except that there are now 15 Type 2 rods: five near each of the corners without gadolinia. The enrichment of Type 3 rods was increased to maintain the average of Types 2 and 3 at 4.0%. The assembly orientation is as for arrangement "K1". The peak k-eff is not significantly from that for arrangement "K1". The two assemblies per package are shown in the following figure and the KENO calculation results are tabulated below the figure.

In the calculation results, other parameters were also tested. These data demonstrate that the most reactive position for the assemblies is to be shifted apart, the most reactive pellet diameter is the largest allowable, decreasing the gadolinia pellet diameter while holding all others at the largest allowable causes an increase in k-eff, and that the maximum allowable shim quantity is most reactive.

1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1
1	2	2	2	3	3	2	2	2	1		1	2	2	2	4	4	4	4	4	1
1	2	3	3	3	3	3	3	2	1		1	2	3	3	3	3	4	4	4	1
1	2	3	3				3	2	1		1	2	3	3	3	3	3	4	4	1
1	4	3	3				3	3	1		1	3	3				3	3	4	1
1	4	3	3				3	3	1		1	3	3				3	3	4	1
1	4	4	3	3	3	3	3	2	1		1	2	3				3	3	2	1
1	4	4	4	3	3	3	3	2	1		1	2	3	3	3	3	3	3	2	1
1	4	4	4	4	4	2	2	2	1		1	2	2	2	3	3	2	2	2	1
1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1

Case ID	Assembly Position	Pellet Diam, in.	Vol.% Water	Type 2 Enr.	Type 3 Enr.	Array	k-eff	
							Avg.	Std.Dev.
A-EVK08	Apart	0.35	8.0	5.00	3.46	104	0.92694	0.00169
A-EVK10			10.0	5.00	3.46	104	0.93001	0.00186
A-EVK12			12.0	5.00	3.46	104	0.92254	0.00181
A-EVO08			8.0	4.50	3.73	104	0.92756	0.00179
A-EVO10			10.0	4.50	3.73	104	0.92941	0.00158
A-EVO12			12.0	4.50	3.73	104	0.92369	0.00183
A-EVP08**			8.0	4.50	3.73	104	0.88256	0.00168
A-EVP10**			10.0	4.50	3.73	104	0.88856	0.00176
A-EVP12**			12.0	4.50	3.73	104	0.88868	0.00190
A-EVP14**			14.0	4.50	3.73	104	0.89036	0.00189
A-EVQ06***			6.0	4.50	3.73	260	0.95655	0.00169
A-EVQ08***			8.0	4.50	3.73	260	0.95867	0.00177
A-EVQ10***			10.0	4.50	3.73	260	0.95556	0.00179
A-EVQ12***			12.0	4.50	3.73	260	0.94985	0.00177
A-EVQ14***			14.0	4.50	3.73	260	0.94368	0.00176
A-EVS08		0.30	8.0	5.00	3.46	104	0.88363	0.00184
A-EVS10			10.0	5.00	3.46	104	0.88303	0.00176
A-EVS12			12.0	5.00	3.46	104	0.87964	0.00191

Case ID	Assembly Position	Pellet Diam, in.	Vol.% Water	Type 2 Enr.	Type 3 Enr.	Array	k-eff Avg.	k-eff Std.Dev.
A-EVS14			14.0	5.00	3.46	104	0.87240	0.00187
A-EVT08		0.25	8.0	5.00	3.46	104	0.81839	0.00191
A-EVT10		0.25	10.0	5.00	3.46	104	0.81099	0.00183
A-EVT12		0.25	12.0	5.00	3.46	104	0.81041	0.00182
A-EVT14		0.25	14.0	5.00	3.46	104	0.80900	0.00186
A-EVU08		0.35*	8.0	5.00	3.46	104	0.93439	0.00187
A-EVU10		0.35*	10.0	5.00	3.46	104	0.93046	0.00190
A-EVU12		0.35*	12.0	5.00	3.46	104	0.92825	0.00181
A-EVV08	Together	0.35	8.0	5.00	3.46	104	0.89402	0.00176
A-EVV10	Together	0.35	10.0	5.00	3.46	104	0.88610	0.00191
A-EVV12	Together	0.35	12.0	5.00	3.46	104	0.87489	0.00190
A-EVW08	Centered	0.35	8.0	5.00	3.46	104	0.91458	0.00196
A-EVW10	Centered	0.35	10.0	5.00	3.46	104	0.91537	0.00204
A-EVW12	Centered	0.35	12.0	5.00	3.46	104	0.90501	0.00186

* Cases "A-EVU.." had 0.30" diameter UO_2-Gd_2O_3 pellets; all other pellets were 0.35" diameter. This is not permitted by the limits specified. The data are presented for information.

** Cases "A-EVP.." had shims about half the maximum allowable thickness.

*** The "A-EVQ.." cases with 13x20x1 arrays exceed the required array size. These data are for reference only.

4.3 Normal Condition Arrays

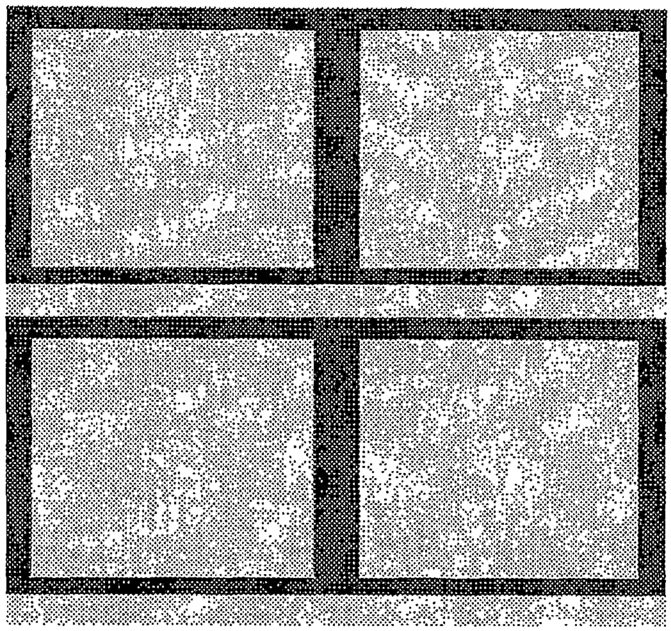
Normal conditions include the wooden outer container. The outer container wooden parts were closely modeled based on the data in Drawing EMF-306,416. The outer dimensions of the outer container are 75.6cm wide by 78.7 cm high by 523.9 cm long. The following KENO plots are transverse sections at various locations along the length of the package.

X-Y SECTION AT Z=4, 2X4 REGION

UL XYZ: 0.0000E+00 1.5750E+02 4.0000E+00

LR XYZ: 1.5200E+02 0.0000E+00 4.0000E+00

KEY:0 7 9

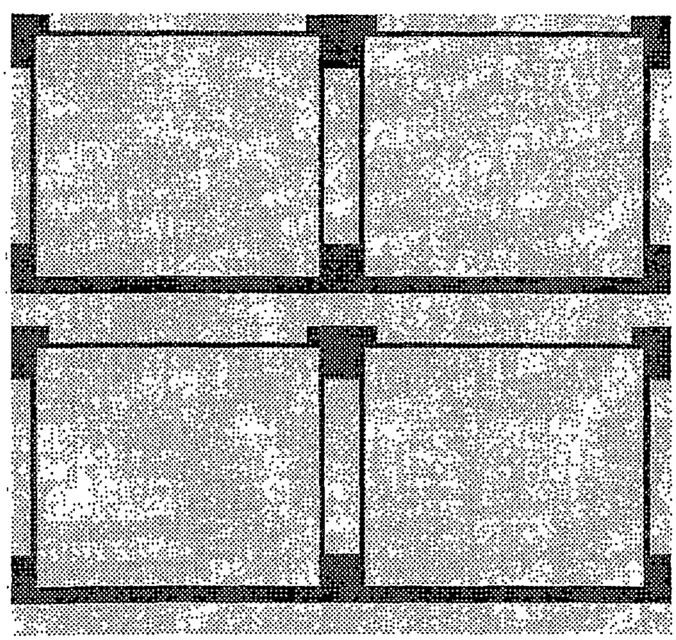


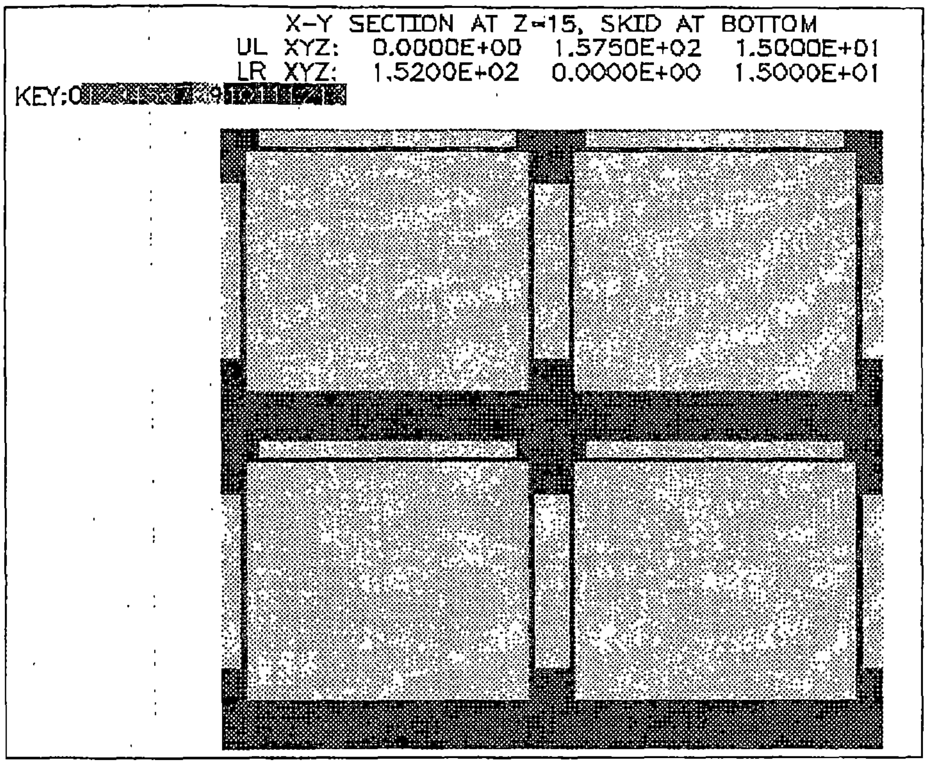
X-Y SECTION AT Z=10, PLYWOOD & 2X4

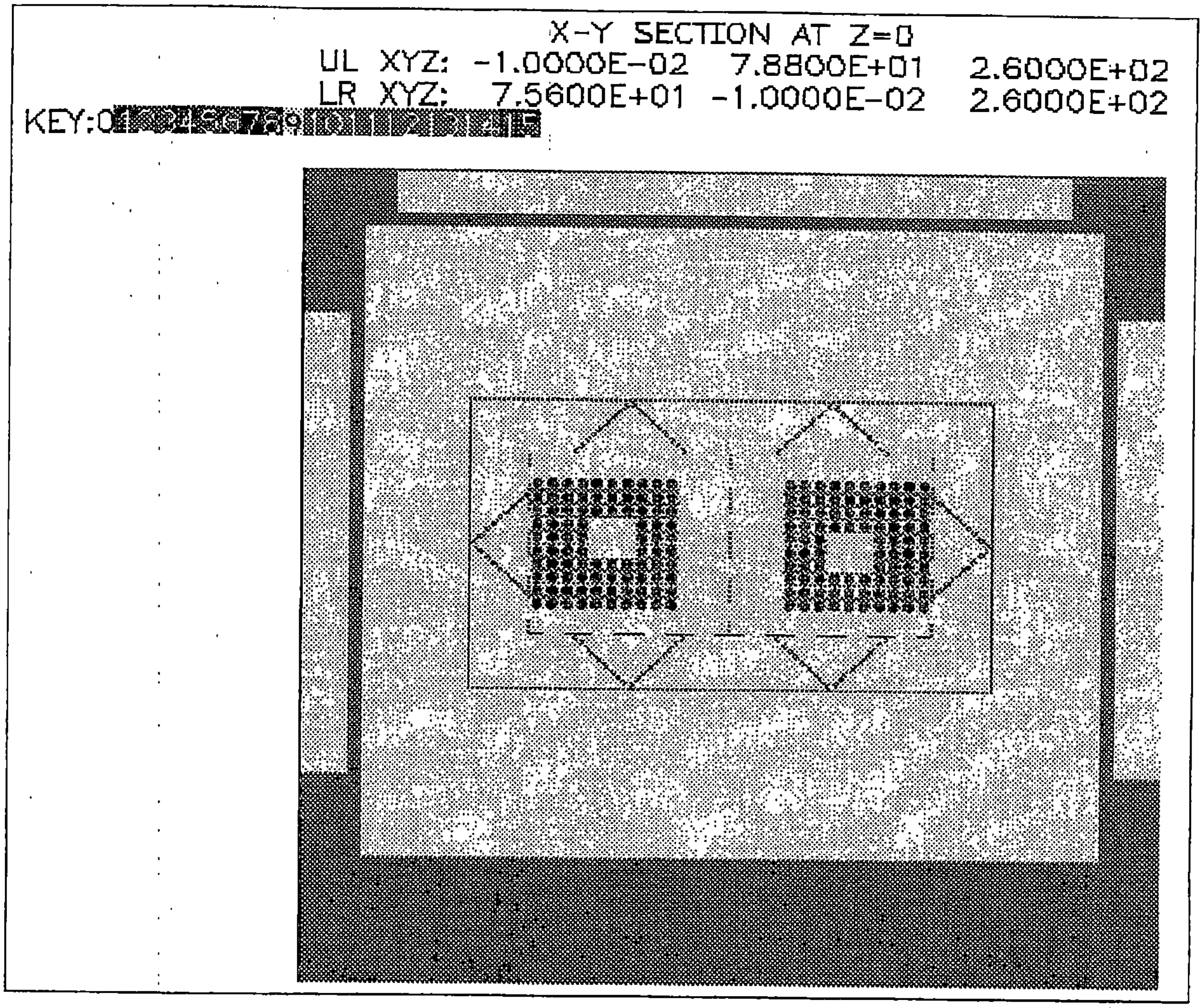
UL XYZ: 0.0000E+00 1.5750E+02 1.0000E+01

LR XYZ: 1.5200E+02 0.0000E+00 1.0000E+01

KEY:0 7 9




X-Y SECTION AT Z=15, SKID AT BOTTOM
UL XYZ: 0.0000E+00 1.5750E+02 1.5000E+01
LR XYZ: 1.5200E+02 0.0000E+00 1.5000E+01
KEY:


X-Y SECTION AT Z=0
UL XYZ: -1.0000E-02 7.8800E+01 2.6000E+02
LR XYZ: 7.5600E+01 -1.0000E-02 2.6000E+02
KEY:

The calculation results for an infinite array of edge-to-edge packages are tabulated below. The rod pattern and orientation of the assemblies in each package are shown in the following figure. All models included the maximum allowable shims quantity per assembly. The edge rods were all 4.0% enriched, the gadolinia rods were 5.0% enriched and contained 1.5 wt% Gd_2O_3, and the average of all other internal rods was 4.0% enriched. The most reactive interspersed water density with shims is zero. The largest bias-corrected 95% upper limit on the k-eff for the infinite array is 0.84425.

1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1
1	2	2	2	3	3	2	2	2	1		1	2	2	2	4	4	4	4	4	1
1	2	3	3	3	3	3	3	2	1		1	2	3	3	3	3	4	4	4	1
1	2	3	3				3	2	1		1	2	3	3	3	3	3	4	4	1
1	4	3	3				3	3	1		1	3	3				3	3	4	1
1	4	3	3				3	3	1		1	3	3				3	3	4	1
1	4	4	3	3	3	3	3	2	1		1	2	3				3	3	2	1
1	4	4	4	3	3	3	3	2	1		1	2	3	3	3	3	3	3	2	1
1	4	4	4	4	4	2	2	2	1		1	2	2	2	3	3	2	2	2	1
1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1

Case ID	Vol.% Water	Type 4 % Gad	Type 4 Enr.	Type 2 Enr.	Type 3 Enr.	k-eff			
						Avg.	Std.Dev.	D.F.	95% UL
A-NEVK00	0.0	1.50	5.00	5.00	3.46	0.83826	0.00174	38.0	0.84425
A-NEVK01	1.0	1.50	5.00	5.00	3.46	0.80016	0.00171	37.7	0.80614
A-NEVK05	5.0	1.50	5.00	5.00	3.46	0.65199	0.00172	37.8	0.65798
A-NEVK10	10.0	1.50	5.00	5.00	3.46	0.53792	0.00163	36.9	0.54386
A-NEVM00	0.0	1.50	5.00	4.00	4.00	0.83806	0.00165	37.1	0.84401
A-NEVM01	1.0	1.50	5.00	4.00	4.00	0.79571	0.00162	36.8	0.80165

5.0 REFERENCES

1. NUREG/CR-0200 SCALE A MODULAR CODE SYSTEM FOR PERFORMING STANDARDIZED COMPUTER ANALYSES FOR LICENSING

2. NUREG/CR-0073: "Critical Separation Between Subcritical Clusters of 4.31 wt% Enriched UO_2 Rods in Water with Fixed Neutron Poisons"

3. Lloyd, R.C., Durst, B.M., and Clayton, E.D.: "Effect of Soluble Neutron Absorbers on Criticality of Low U-235 Enriched UO_2 Lattices", Nuclear Science and Engineering: 71, 164-169 (1979)

4. "Criticality Safety Criteria", ANS Trans, Vol.35, p.278

Appendix A
Sample Computer Inputs For the Models Used
For This Analysis

The model of KENO case ("a=evk10") is listed below.

```
=csas25
sp-1 with 4.0% enriched 10x10 fuel
hans  infh

uo2 1 0.98 293.0 92235 3.4643 92238 96.5357 end

uo2 2 0.98 293.0 92235 3.4643 92238 96.5357 end

uo2 3 0.98 293.0 92235 4.0 92238 96.0 end

uo2 4 0.98 293.0 92235 4.0 92238 96.0 end

uo2 5 0.98 293.0 92235 4.0 92238 96.0 end

uo2 6 0.98 293.0 92235 4.0 92238 96.0 end

' poison rod with 2% gd2o3
' td of uo2-gd2o3 = 10.96 -2.65*p/[p+0.67145*(1-p)], p=wt frac.gd2o3
' "p" is 0.02 here,  td is 10.9012
' pellet density is 0.98*10.9012=10.6832
' uo2 density is 0.985*10.6832 = 10.5230
' gd2o3 density is 0.02*10.6832 = 0.1602 gm/cc
uo2 7 den=10.5230 1.0 293.0 92235 5.00 92238 95.00 end
arbmgd2o3 0.1602 2 0 1 0 64000 2 8016 3
7 1.0 293. end

zircalloy 8 1.0 293.0 end

' water, 10 vol.%
h2o 9 0.10 293.0 end

' basket steel
carbonsteel 10 1.0 293.0 end
' angle steel
carbonsteel 11 1.0 293.0 end
' shell steel
carbonsteel 12 1.0 293.0 end
' reflector water
h2o  13 1.0 293 end
' polyethylene, 100 vol%
arbmpe  0.92 2 0 1 0 6012 1 1001 2
14 1.0 293.  end
```

```
' higher enriched rods
uo2 15 0.98 293.0 92235 5.0 92238 95.0 end

end comp
more data
 res=  1 cyli  4.2093E-01 dan(  1)= 4.7667E-01
 res=  2 cyli  4.4836E-01 dan(  2)= 4.4193E-01
 res=  3 cyli  4.7632E-01 dan(  3)= 3.2526E-01
 res=  4 cyli  4.6217E-01 dan(  4)= 3.1789E-01
 res=  5 cyli  4.5874E-01 dan(  5)= 3.2938E-01
 res=  6 cyli  4.6079E-01 dan(  6)= 3.0899E-01
 res=  7 cyli  4.1701E-01 dan(  7)= 4.7594E-01
 res= 15 cyli  4.0242E-01 dan( 15)= 4.7318E-01
end more
sp-1 with 4.0% enriched 10x10 fuel
read parameters
tme=90 gen=200 npg=600 nsk=0
flx=yes fdn=yes xs1=yes nub=yes pwt=yes
end parameters
read geom

' pellet diam: 0.35"
' gap: zero
' clad thk: 0.018"
' pitch: 0.5127"

 unit 1
com="interior rod"
cyli  1 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 2p0.49022  2p226.695
' polyethylene shims between rods
cubo  14 1 4p0.6510866 2p226.695

unit 2
com="interior rods around water rod"
cyli  2 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 2p0.49022  2p226.695
' polyethylene shims between rods
cubo  14 1 4p0.6510866 2p226.695

 unit 3
com="edge rod facing up"
cyli  3 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
```

```
cubo  9 1  2p0.6510866 0.6510866 -0.49022  2p226.695
' polyethylene shims between rods
cubo  14 1 4p0.6510866 2p226.695

unit 4
com="edge rod facing down"
cyli  4 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 0.49022 -0.6510866  2p226.695
' polyethylene shims between rods
cubo  14 1 4p0.6510866 2p226.695

unit 5
com="edge rod facing other bundle"
cyli  5 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 2p0.49022  2p226.695
' polyethylene shims between rods
cubo  14 1 4p0.6510866 2p226.695

unit 6
com="edge rod facing out"
cyli  6 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 2p0.49022  2p226.695
' polyethylene shims between rods
cubo  14 1 4p0.6510866 2p226.695

unit 7
com="uo2-gd2o3 rod"
cyli  7 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 2p0.49022  2p226.695
' polyethylene shims between rods
cubo  14 1 4p0.6510866 2p226.695

unit 8
com="water rod"
cubo  9 1 4p0.6510866  2p226.695

unit 9
com='side basket element, 0.0598"x1.75"x1.75" steel with 0.75" diam. hole'
xcyl 9 1 0.9525 0.1519 0.0
cubo 10 1 0.1519 0.0 4p2.2225

unit 10
com='side basket element, 0.0598"x1.6902"x1.75" steel with 0.75" diam. hole'
```

```
xcyl 9 1 0.9525 0.1519 0.0
cubo 10 1 0.1519 0.0 2p2.14655 2p2.2225

unit 11
com='one complete basket side'
'  1x4x102 array of units 10 & 11
array 1 0.0 -8.7381 -226.695

unit 12
com='top/bottom basket element'
' 1.75"x0.0598"x1.75" steel with 0.75" diam. hole'
ycyl 9 1 0.9525 0.1519 0.0
cubo 10 1 2p2.2225 0.1519 0.0 2p2.2225

unit 13
com='top/bottom basket element'
' 1.6902"x0.0598"x1.75" steel with 0.75" diam. hole'
ycyl 9 1 0.9525 0.1519 0.0
cubo 10 1 2p2.14655 0.1519 0.0 2p2.2225

unit 14
com='one complete basket top/bottom'
'  4x1x102 array of units 13&14
array 2 -8.7381 0.0 -226.695

unit 15
com='0.0598" steel at basket corners'
cubo 10 1 0.1519 0.0 0.1519 0.0 2p226.695

unit 16
com=" spacing & steel angle at -x side of basket "
cubo  9 1  5.08 0.0 2p8.89  2p226.695
hole 22    0.15875 0.0  0.0
hole 22  0.47625 -0.3175 0.0
hole 22   0.47625  0.3175 0.0
hole 22   0.79375  0.635 0.0
hole 22  0.79375  -0.635 0.0
hole 22  1.11125  0.9525 0.0
hole 22  1.11125  -0.9525 0.0
hole 22  1.42875  1.27 0.0
hole 22  1.42875  -1.27 0.0
hole 22  1.74625  1.5875 0.0
hole 22  1.74625  -1.5875 0.0
hole 22  2.06375 1.905 0.0
hole 22  2.06375 -1.905 0.0
hole 22  2.38125  2.2225 0.0
hole 22  2.38125 -2.2225  0.0
```

```
hole 22  2.69875  2.54 0.0
hole 22  2.69875 -2.54  0.0
hole 22  3.01625  2.8575 0.0
hole 22  3.01625 -2.8575  0.0
hole 22  3.33375  3.175 0.0
hole 22  3.33375 -3.175  0.0
hole 22  3.65125  3.4925 0.0
hole 22  3.65125 -3.4925  0.0
hole 22  3.96875  3.81 0.0
hole 22  3.96875 -3.81  0.0
hole 22  4.28625  4.1275 0.0
hole 22  4.28625 -4.1275  0.0
hole 22  4.60375  4.445 0.0
hole 22  4.60375 -4.445  0.0
hole 22  4.92125  4.7625 0.0
hole 22  4.92125 -4.7625  0.0

unit 17
com=" spacing & steel angle at +x side of basket "
cubo  9 1  0.0  -5.08 2p8.89  2p226.695
hole 22  -0.15875 0.0  0.0
hole 22  -0.47625 -0.3175 0.0
hole 22  -0.47625  0.3175 0.0
hole 22   -0.79375  0.635 0.0
hole 22  -0.79375  -0.635 0.0
hole 22  -1.11125  0.9525 0.0
hole 22  -1.11125  -0.9525 0.0
hole 22  -1.42875  1.27 0.0
hole 22  -1.42875  -1.27 0.0
hole 22  -1.74625  1.5875 0.0
hole 22  -1.74625  -1.5875 0.0
hole 22  -2.06375 1.905 0.0
hole 22  -2.06375 -1.905 0.0
hole 22  -2.38125  2.2225 0.0
hole 22  -2.38125 -2.2225  0.0
hole 22  -2.69875  2.54 0.0
hole 22  -2.69875 -2.54  0.0
hole 22 -3.01625  2.8575 0.0
hole 22  -3.01625 -2.8575  0.0
hole 22  -3.33375  3.175 0.0
hole 22  -3.33375 -3.175  0.0
hole 22  -3.65125  3.4925 0.0
hole 22  -3.65125 -3.4925  0.0
hole 22  -3.96875  3.81 0.0
hole 22  -3.96875 -3.81  0.0
hole 22  -4.28625  4.1275 0.0
hole 22  -4.28625 -4.1275  0.0
```

```
hole 22  -4.60375  4.445 0.0
hole 22  -4.60375 -4.445  0.0
hole 22  -4.92125  4.7625 0.0
hole 22  -4.92125 -4.7625  0.0

unit 18
com=" angles & spacing beneath baskets "
cubo  9 1  2p8.89 5.08 0.0  2p226.695
hole 21  0.0  0.15875  0.0
hole 21 -0.3175  0.47625  0.0
hole 21  0.3175  0.47625  0.0
hole 21  0.635  0.79375  0.0
hole 21 -0.635  0.79375  0.0
hole 21  0.9525  1.11125  0.0
hole 21 -0.9525  1.11125  0.0
hole 21  1.27  1.42875  0.0
hole 21 -1.27  1.42875  0.0
hole 21  1.5875  1.74625  0.0
hole 21 -1.5875  1.74625  0.0
hole 21  1.905  2.06375  0.0
hole 21 -1.905  2.06375  0.0
hole 21  2.2225  2.38125  0.0
hole 21 -2.2225  2.38125  0.0
hole 21   2.54 2.69875 0.0
hole 21  -2.54 2.69875 0.0
hole 21  2.8575 3.01625  0.0
hole 21  -2.8575 3.01625 0.0
hole 21   3.175 3.33375 0.0
hole 21   -3.175 3.33375  0.0
hole 21    3.4925 3.65125 0.0
hole 21   -3.4925  3.65125 0.0
hole 21    3.81 3.96875 0.0
hole 21   -3.81 3.96875 0.0
hole 21    4.1275 4.28625 0.0
hole 21   -4.1275  4.28625 0.0
hole 21   4.445 4.60375 0.0
hole 21   -4.445  4.60375 0.0
hole 21    4.7625 4.92125 0.0
hole 21   -4.7625 4.92125 0.0

unit 19
com="angles & spacing above baskets "
cubo  9 1  2p8.89  0.0 -5.08  2p226.695
hole 21  0.0  -0.15875  0.0
hole 21 -0.3175  -0.47625  0.0
hole 21  0.3175  -0.47625  0.0
hole 21  0.635  -0.79375  0.0
```

```
hole 21 -0.635  -0.79375  0.0
hole 21  0.9525  -1.11125  0.0
hole 21 -0.9525  -1.11125  0.0
hole 21  1.27  -1.42875  0.0
hole 21 -1.27  -1.42875  0.0
hole 21  1.5875  -1.74625  0.0
hole 21 -1.5875  -1.74625  0.0
hole 21  1.905  -2.06375  0.0
hole 21 -1.905  -2.06375  0.0
hole 21  2.2225  -2.38125  0.0
hole 21 -2.2225  -2.38125  0.0
hole 21   2.54 -2.69875 0.0
hole 21  -2.54 -2.69875 0.0
hole 21  2.8575 -3.01625  0.0
hole 21  -2.8575 -3.01625 0.0
hole 21   3.175 -3.33375 0.0
hole 21  -3.175 -3.33375  0.0
hole 21   3.4925 -3.65125 0.0
hole 21  -3.4925  -3.65125 0.0
hole 21   3.81 -3.96875 0.0
hole 21  -3.81 -3.96875 0.0
hole 21   4.1275 -4.28625 0.0
hole 21  -4.1275  -4.28625 0.0
hole 21  4.445 -4.60375 0.0
hole 21  -4.445  -4.60375 0.0
hole 21   4.7625 -4.92125 0.0
hole 21  -4.7625 -4.92125 0.0

unit 20
com=" 2x2 inch moderation regions at corners "
cubo  9 1 4p2.54  2p226.695

unit 21
com="part of steel angle"
' 0.1552" x 0.125"
cubo  11 1 2p0.197104 2p0.15874 2p226.695

unit 22
com="part of steel angle"
' 0.125" x 0.1552"
cubo  11 1 2p0.15874 2p0.197104 2p226.695

unit 23
com="left (-x) 10x10 bundle in basket"
' bundle at outer edge, centered vertically
array  3 -8.7381 -6.510866 -226.695
cubo  9 1 2p8.7381 2p8.7381  2p226.695
```

```
unit 24
com="right 10x10 bundle in basket"
' bundle at outer edge, centered vertically
array  4 -4.2836334 -6.510866 -226.695
cubo  9 1 2p8.7381 2p8.7381  2p226.695

unit 25
com="complete left basket with bundle"
array 5 2r-8.89 -226.695

unit 26
com="complete right basket with bundle"
array 6 2r-8.89 -226.695

unit 27
com=" 1 inner container  "
array  7 -22.86 -13.97 -226.695
' add 0.0598 inch walls of carbon steel
repl  12 1 6r0.1519 1

unit 28
com=" 2x2 inch regions at corners "
cubo  9 1 4p2.54  2p226.695

unit 29
com='higher enriched rods'
cyli  15 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 2p0.49022  2p226.695
'  polyethylene shims between rods
cubo  14 1 4p0.6510866 2p226.695

global
unit 30
com=" 8x13x1 array of inners  "
array  8 -184.0952 -183.5847 -226.695
'  add 30 cm water reflector at all 6 faces
repl 13 2 6r3.0 10

end geom

read array

ara=1 nux=1 nuy=4 nuz=102
loop
9  1 1 1   2 3 1   1 102 1
```

```
10 1 1 1  1 4 3  1 102 1
end loop

ara=2 nux=4 nuy=1 nuz=102
loop
12  2 3 1  1 1 1  1 102 1
13  1 4 3  1 1 1  1 102 1
end loop

' left bundle, poison corner at ll
ara=3 nux=10 nuy=10 nuz=1
fill
04 04 04 04 04 04 04 04 04 04
06 07 07 07 07 07 29 29 29 05
06 07 07 07 01 01 01 01 29 05
06 07 07 02 02 02 02 02 29 05
06 07 01 02 08 08 08 02 01 05
06 07 01 02 08 08 08 02 01 05
06 29 01 02 08 08 08 02 29 05
06 29 01 02 02 02 02 01 29 05
06 29 29 29 01 01 29 29 29 05
03 03 03 03 03 03 03 03 03 03
end fill

' right bundle, poison corner at ur
ara=4 nux=10 nuy=10 nuz=1
fill
04 04 04 04 04 04 04 04 04 04
05 29 29 29 01 01 29 29 29 06
05 29 01 02 02 02 02 01 29 06
05 29 02 08 08 08 02 01 29 06
05 01 02 08 08 08 02 01 07 06
05 01 02 08 08 08 02 01 07 06
05 29 02 02 02 02 02 07 07 06
05 29 01 01 01 01 07 07 07 06
05 29 29 29 07 07 07 07 07 06
03 03 03 03 03 03 03 03 03 03
end fill
ara=5 nux=3 nuy=3 nuz=1
fill
15 14 15
11 23 11
15 14 15
end fill

ara=6 nux=3 nuy=3 nuz=1
```

```
fill
15 14 15
11 24 11
15 14 15
end fill

ara=7 nux=4 nuy=3 nuz=1
fill
20 18 18 20
16 25 26 17
28 19 19 28
end fill

ara=8 nux=08 nuy=13 nuz=1
fill f27 end fill

end array

read start nst=1
' xsm=-45.72 xsp=45.72 ysm=-27.94 ysp=27.94 zsm=-10 zsp=10
end start


read bounds all=vacuum end bounds
read bias id=500 2 11 end bias

end data
end
```

The model for the normal condition KENO case ("a=nevk00") is listed below.

```
=csas25
sp-1 with 4.0% enriched 10x10 fuel
hans  infh

uo2 1 0.98 293.0 92235 3.4643 92238 96.5357 end

uo2 2 0.98 293.0 92235 3.4643 92238 96.5357 end

uo2 3 0.98 293.0 92235 4.0 92238 96.0 end

uo2 4 0.98 293.0 92235 4.0 92238 96.0 end

uo2 5 0.98 293.0 92235 4.0 92238 96.0 end

uo2 6 0.98 293.0 92235 4.0 92238 96.0 end

' poison rod with 1.5% gd2o3
```

```
' td of uo2-gd2o3 = 10.96 -2.65*p/[p+0.67145*(1-p)], p=wt frac.gd2o3
' "p" is 0.015 here, td is 10.9012
' pellet density is 0.98*10.9012=10.6832
' uo2 density is 0.985*10.6832 = 10.5230
' gd2o3 density is 0.015*10.6832 = 0.1602 gm/cc
uo2 7 den=10.5230 1.0 293.0 92235 5.00 92238 95.00 end
arbmgd2o3 0.1602 2 0 1 0 64000 2 8016 3
7 1.0 293. end

zircalloy 8 1.0 293.0 end

' water, 0 vol.%
h2o 9 1.0e-15 293.0 end

' basket steel
carbonsteel 10 1.0 293.0 end
' angle steel
carbonsteel 11 1.0 293.0 end
' shell steel
carbonsteel 12 1.0 293.0 end

' douglas fir, same composition as oak, dens=0.48-0.55
oak 13 den=0.48 1.0 293 end

' polyethylene, 100 vol%
arbmpe 0.92 2 0 1 0 6012 1 1001 2
14 1.0 293. end

' higher enriched rods
uo2 15 0.98 293.0 92235 5.0 92238 95.0 end

end comp
more data
 res= 1 cyli 4.1526E-01 dan( 1)= 5.1433E-01
 res= 2 cyli 4.2949E-01 dan( 2)= 5.1633E-01
 res= 3 cyli 4.6224E-01 dan( 3)= 3.4646E-01
 res= 4 cyli 4.6288E-01 dan( 4)= 3.4454E-01
 res= 5 cyli 4.8046E-01 dan( 5)= 3.9535E-01
 res= 6 cyli 4.5837E-01 dan( 6)= 3.2355E-01
 res= 7 cyli 3.9685E-01 dan( 7)= 5.0663E-01
 res= 15 cyli 4.1040E-01 dan( 15)= 5.0891E-01
end more
sp-1 with 4.0% enriched 10x10 fuel
read parameters
tme=90 gen=200 npg=600 nsk=0
flx=yes fdn=yes xs1=yes nub=yes pwt=yes
end parameters
```

```
read geom

 ' pellet diam: 0.35"
 ' gap: zero
 ' clad thk: 0.018"
 ' pitch: 0.5127"

 unit 1
com="interior rod"
cyli  1 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 2p0.49022  2p226.695
 ' polyethylene shims between rods
cubo  14 1 4p0.6510866 2p226.695

unit 2
com="interior rods around water rod"
cyli  2 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 2p0.49022  2p226.695
 ' polyethylene shims between rods
cubo  14 1 4p0.6510866 2p226.695

 unit 3
com="edge rod facing up"
cyli  3 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 0.6510866 -0.49022  2p226.695
 ' polyethylene shims between rods
cubo  14 1 4p0.6510866 2p226.695

unit 4
com="edge rod facing down"
cyli  4 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 0.49022 -0.6510866  2p226.695
 ' polyethylene shims between rods
cubo  14 1 4p0.6510866 2p226.695

 unit 5
com="edge rod facing other bundle"
cyli  5 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 2p0.49022  2p226.695
 ' polyethylene shims between rods
cubo  14 1 4p0.6510866 2p226.695
```

```
unit 6
com="edge rod facing out"
cyli  6 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 2p0.49022  2p226.695
' polyethylene shims between rods
cubo  14 1 4p0.6510866 2p226.695

unit 7
com="uo2-gd2o3 rod"
cyli  7 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 2p0.49022  2p226.695
' polyethylene shims between rods
cubo  14 1 4p0.6510866 2p226.695

unit 8
com="water rod"
cubo  9 1 4p0.6510866  2p226.695

unit 9
com='side basket element, 0.0598"x1.75"x1.75" steel with 0.75" diam. hole'
xcyl 9 1 0.9525 0.1519 0.0
cubo 10 1 0.1519 0.0 4p2.2225

unit 10
com='side basket element, 0.0598"x1.6902"x1.75" steel with 0.75" diam. hole'
xcyl 9 1 0.9525 0.1519 0.0
cubo 10 1 0.1519 0.0 2p2.14655 2p2.2225

unit 11
com='one complete basket side'
' 1x4x102 array of units 10 & 11
array 1 0.0 -8.7381 -226.695

unit 12
com='top/bottom basket element'
' 1.75"x0.0598"x1.75" steel with 0.75" diam. hole'
ycyl 9 1 0.9525 0.1519 0.0
cubo 10 1 2p2.2225 0.1519 0.0 2p2.2225

unit 13
com='top/bottom basket element'
' 1.6902"x0.0598"x1.75" steel with 0.75" diam. hole'
ycyl 9 1 0.9525 0.1519 0.0
cubo 10 1 2p2.14655 0.1519 0.0 2p2.2225
```

```
unit 14
com='one complete basket top/bottom'
' 4x1x102 array of units 13&14
array 2 -8.7381 0.0 -226.695

unit 15
com='0.0598" steel at basket corners'
cubo 10 1 0.1519 0.0 0.1519 0.0 2p226.695

unit 16
com=" spacing & steel angle at -x side of basket "
cubo  9 1  5.08 0.0 2p8.89  2p226.695
hole 22    0.15875 0.0  0.0
hole 22  0.47625 -0.3175 0.0
hole 22   0.47625  0.3175 0.0
hole 22   0.79375  0.635 0.0
hole 22  0.79375  -0.635 0.0
hole 22  1.11125  0.9525 0.0
hole 22  1.11125  -0.9525 0.0
hole 22  1.42875  1.27 0.0
hole 22  1.42875  -1.27 0.0
hole 22  1.74625  1.5875 0.0
hole 22  1.74625  -1.5875 0.0
hole 22  2.06375 1.905 0.0
hole 22  2.06375 -1.905 0.0
hole 22  2.38125  2.2225 0.0
hole 22  2.38125 -2.2225  0.0
hole 22  2.69875  2.54 0.0
hole 22  2.69875 -2.54  0.0
hole 22  3.01625  2.8575 0.0
hole 22  3.01625 -2.8575  0.0
hole 22  3.33375  3.175 0.0
hole 22  3.33375 -3.175  0.0
hole 22  3.65125  3.4925 0.0
hole 22  3.65125 -3.4925  0.0
hole 22  3.96875  3.81 0.0
hole 22  3.96875 -3.81  0.0
hole 22  4.28625  4.1275 0.0
hole 22  4.28625 -4.1275  0.0
hole 22  4.60375  4.445 0.0
hole 22  4.60375 -4.445  0.0
hole 22  4.92125  4.7625 0.0
hole 22  4.92125 -4.7625  0.0

unit 17
com=" spacing & steel angle at +x side of basket "
cubo  9 1  0.0  -5.08 2p8.89  2p226.695
```

```
hole 22  -0.15875 0.0  0.0
hole 22  -0.47625 -0.3175 0.0
hole 22  -0.47625  0.3175 0.0
hole 22   -0.79375  0.635 0.0
hole 22  -0.79375  -0.635 0.0
hole 22  -1.11125  0.9525 0.0
hole 22  -1.11125  -0.9525 0.0
hole 22  -1.42875  1.27 0.0
hole 22  -1.42875  -1.27 0.0
hole 22  -1.74625  1.5875 0.0
hole 22  -1.74625  -1.5875 0.0
hole 22  -2.06375 1.905 0.0
hole 22  -2.06375 -1.905 0.0
hole 22  -2.38125  2.2225 0.0
hole 22  -2.38125 -2.2225  0.0
hole 22  -2.69875  2.54 0.0
hole 22  -2.69875 -2.54  0.0
hole 22 -3.01625  2.8575 0.0
hole 22  -3.01625 -2.8575  0.0
hole 22  -3.33375  3.175 0.0
hole 22  -3.33375 -3.175  0.0
hole 22  -3.65125  3.4925 0.0
hole 22  -3.65125 -3.4925  0.0
hole 22  -3.96875  3.81 0.0
hole 22  -3.96875 -3.81  0.0
hole 22  -4.28625  4.1275 0.0
hole 22  -4.28625 -4.1275  0.0
hole 22  -4.60375  4.445 0.0
hole 22  -4.60375 -4.445  0.0
hole 22  -4.92125  4.7625 0.0
hole 22  -4.92125 -4.7625  0.0

unit 18
com=" angles & spacing beneath baskets "
cubo  9 1  2p8.89 5.08 0.0  2p226.695
hole 21  0.0  0.15875  0.0
hole 21 -0.3175  0.47625  0.0
hole 21  0.3175  0.47625  0.0
hole 21  0.635  0.79375  0.0
hole 21 -0.635  0.79375  0.0
hole 21  0.9525  1.11125  0.0
hole 21 -0.9525  1.11125  0.0
hole 21  1.27  1.42875  0.0
hole 21 -1.27  1.42875  0.0
hole 21  1.5875  1.74625  0.0
hole 21 -1.5875  1.74625  0.0
hole 21  1.905  2.06375  0.0
```

```
hole 21 -1.905  2.06375  0.0
hole 21  2.2225  2.38125  0.0
hole 21 -2.2225  2.38125  0.0
hole 21   2.54 2.69875 0.0
hole 21  -2.54 2.69875 0.0
hole 21  2.8575 3.01625  0.0
hole 21  -2.8575 3.01625 0.0
hole 21   3.175 3.33375 0.0
hole 21   -3.175 3.33375  0.0
hole 21    3.4925 3.65125 0.0
hole 21   -3.4925  3.65125 0.0
hole 21    3.81  3.96875 0.0
hole 21   -3.81  3.96875 0.0
hole 21    4.1275 4.28625 0.0
hole 21   -4.1275  4.28625 0.0
hole 21   4.445 4.60375 0.0
hole 21   -4.445  4.60375 0.0
hole 21    4.7625 4.92125 0.0
hole 21   -4.7625 4.92125 0.0

unit 19
com="angles & spacing above baskets  "
cubo  9 1  2p8.89  0.0 -5.08  2p226.695
hole 21  0.0  -0.15875  0.0
hole 21 -0.3175  -0.47625  0.0
hole 21  0.3175  -0.47625  0.0
hole 21  0.635  -0.79375  0.0
hole 21 -0.635  -0.79375  0.0
hole 21  0.9525  -1.11125  0.0
hole 21 -0.9525  -1.11125  0.0
hole 21  1.27  -1.42875  0.0
hole 21 -1.27  -1.42875  0.0
hole 21  1.5875  -1.74625  0.0
hole 21 -1.5875  -1.74625  0.0
hole 21  1.905  -2.06375  0.0
hole 21 -1.905  -2.06375  0.0
hole 21  2.2225  -2.38125  0.0
hole 21 -2.2225  -2.38125  0.0
hole 21   2.54 -2.69875 0.0
hole 21  -2.54 -2.69875 0.0
hole 21  2.8575 -3.01625  0.0
hole 21  -2.8575 -3.01625 0.0
hole 21   3.175 -3.33375 0.0
hole 21   -3.175 -3.33375  0.0
hole 21    3.4925 -3.65125 0.0
hole 21   -3.4925  -3.65125 0.0
hole 21    3.81 -3.96875 0.0
```

```
hole 21   -3.81 -3.96875 0.0
hole 21    4.1275 -4.28625 0.0
hole 21   -4.1275  -4.28625 0.0
hole 21   4.445 -4.60375 0.0
hole 21   -4.445  -4.60375 0.0
hole 21    4.7625 -4.92125 0.0
hole 21   -4.7625 -4.92125 0.0

unit 20
com=" 2x2 inch moderation regions at corners "
cubo  9 1 4p2.54  2p226.695

unit 21
com="part of steel angle"
' 0.1552" x 0.125"
cubo  11 1 2p0.197104 2p0.15874 2p226.695

unit 22
com="part of steel angle"
' 0.125" x 0.1552"
cubo  11 1 2p0.15874 2p0.197104 2p226.695

unit 23
com="left (-x) 10x10 bundle in basket"
' bundle at outer edge, centered vertically
array  3 -8.7381 -6.510866 -226.695
cubo  9 1 2p8.7381 2p8.7381  2p226.695

unit 24
com="right 10x10 bundle in basket"
' bundle at outer edge, centered vertically
array  4 -4.2836334 -6.510866 -226.695
cubo  9 1 2p8.7381 2p8.7381  2p226.695

unit 25
com="complete left basket with bundle"
array 5 2r-8.89 -226.695

unit 26
com="complete right basket with bundle"
array 6 2r-8.89 -226.695

unit 27
com=" 1 inner container  "
array  7 -22.86 -13.97 -226.695
' add 0.0598 inch walls of carbon steel
repl  12 1 6r0.1519 1
```

```
cubo  9 1 2p32.385 2p30.48 2p261.9375

unit 28
com=" 2x2 inch regions at corners "
cubo  9 1 4p2.54  2p226.695

unit 29
com='higher enriched rods'
cyli  15 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 2p0.49022  2p226.695
'  polyethylene shims between rods
cubo  14 1 4p0.6510866 2p226.695

unit 30
com='top'
' plywood only width: 29.75 - 2*3.25 = 23.25"
cubo  13 1 2p29.5275 4.1275 0.0 8.255 0.0
'  38.25" im
repl  9 1 4r0.0 97.155 0.0 1
'  add stud
repl  13 1 4r0.0 8.255 0.0 1
'  36.75" im
repl  9 1 4r0.0 93.345 0.0 1
'  add stud
repl  13 1 4r0.0 8.255 0.0 1
'  36.75" im
repl  9 1 4r0.0 93.345 0.0 1
'  add stud
repl  13 1 4r0.0 8.255 0.0 1
'  36.75" im
repl  9 1 4r0.0 93.345 0.0 1
'  add stud
repl  13 1 4r0.0 8.255 0.0 1
'  38.25" im
repl  9 1 4r0.0 97.155 0.0 1
'  add studs & plywood
repl  13 1 2r8.255 0.0 1.27 8.255 0.0 1

unit 31
com='base'
'  space to first skid
cubo  9 1 2p37.7825 8.255 0.0 13.97 0.0
'  4x4 skid
repl  13 1 4r0.0 8.255 0.0 1
'  44.75" im
repl  9 1 4r0.0 113.665 0.0 1
```

```
' 4x4 skid
repl  13 1 4r0.0 8.255 0.0 1
' 44.75" im
repl  9 1 4r0.0 113.665 0.0 1
' 4x4 skid
repl  13 1 4r0.0 8.255 0.0 1
' 44.75" im
repl  9 1 4r0.0 113.665 0.0 1
' 4x4 skid
repl  13 1 4r0.0 8.255 0.0 1
' 44.75" im
repl  9 1 4r0.0 113.665 0.0 1
' 4x4 skid
repl  13 1 4r0.0 8.255 0.0 1
' add space at +z
repl  9 1 4r0.0 13.97 0.0 1
' add 1.605" wood at +y
repl  13 1 2r0.0 4.1275 3r0.0 1

unit 32
com='+x side'
' plywood only width: 24.00 - 2*3.25 = 17.5"
cubo  13 1 4.1275 0.0 2p22.225 8.255 0.0
' 38.25" im
repl  9 1 4r0.0 97.155 0.0 1
' add stud
repl  13 1 4r0.0 8.255 0.0 1
' 36.75" im
repl  9 1 4r0.0 93.345 0.0 1
' add stud
repl  13 1 4r0.0 8.255 0.0 1
' 36.75" im
repl  9 1 4r0.0 93.345 0.0 1
' add stud
repl  13 1 4r0.0 8.255 0.0 1
' 36.75" im
repl  9 1 4r0.0 93.345 0.0 1
' add stud
repl  13 1 4r0.0 8.255 0.0 1
' 38.25" im
repl  9 1 4r0.0 97.155 0.0 1
' add stud & plywood
repl  13 1 0.0 1.27 2r8.255 8.255 0.0 1

unit 33
com='-x side'
' plywood only width: 24.00 - 2*3.25 = 17.5"
```

```
cubo  13 1 4.1275 0.0 2p22.225 8.255 0.0
' 38.25" im
repl  9 1 4r0.0 97.155 0.0 1
' add stud
repl  13 1 4r0.0 8.255 0.0 1
' 36.75" im
repl  9 1 4r0.0 93.345 0.0 1
' add stud
repl  13 1 4r0.0 8.255 0.0 1
' 36.75" im
repl  9 1 4r0.0 93.345 0.0 1
' add stud
repl  13 1 4r0.0 8.255 0.0 1
' 36.75" im
repl  9 1 4r0.0 93.345 0.0 1
' add stud
repl  13 1 4r0.0 8.255 0.0 1
' 38.25" im
repl  9 1 4r0.0 97.155 0.0 1
' add stud & plywood
repl  13 1 1 27 0.0 2r8.255 8.255 0.0 1

unit 34
com='inner container & wood sides'
array 8 3r0.0

unit 35
com='complete outer container'
array 9 3r0.0

global
unit 36
com=" 10x10x1 array of inners  "
array  10 3r0.0

end geom

read array

ara=1 nux=1 nuy=4 nuz=102
loop
9  1 1 1   2 3 1   1 102 1
10  1 1 1   1 4 3   1 102 1
end loop

ara=2 nux=4 nuy=1 nuz=102
loop
```

```
12  2 3 1  1 1 1  1 102 1
13  1 4 3  1 1 1  1 102 1
end loop

' left bundle, poison corner at ll
ara=3 nux=10 nuy=10 nuz=1
fill
04 04 04 04 04 04 04 04 04 04
06 07 07 07 07 07 29 29 29 05
06 07 07 07 01 01 01 01 29 05
06 07 07 02 02 02 02 02 29 05
06 07 01 02 08 08 08 02 01 05
06 07 01 02 08 08 08 02 01 05
06 29 01 02 08 08 08 02 29 05
06 29 01 02 02 02 02 01 29 05
06 29 29 29 01 01 29 29 29 05
03 03 03 03 03 03 03 03 03 03
end fill

' right bundle, poison corner at ur
ara=4 nux=10 nuy=10 nuz=1
fill
04 04 04 04 04 04 04 04 04 04
05 29 29 29 01 01 29 29 29 06
05 29 01 02 02 02 02 01 29 06
05 29 02 08 08 08 02 01 29 06
05 01 02 08 08 08 02 01 07 06
05 01 02 08 08 08 02 01 07 06
05 29 02 02 02 02 02 07 07 06
05 29 01 01 01 01 07 07 07 06
05 29 29 29 07 07 07 07 07 06
03 03 03 03 03 03 03 03 03 03
end fill
ara=5 nux=3 nuy=3 nuz=1
fill
15 14 15
11 23 11
15 14 15
end fill

ara=6 nux=3 nuy=3 nuz=1
fill
15 14 15
11 24 11
15 14 15
end fill
```

```
ara=7 nux=4 nuy=3 nuz=1
fill
20 18 18 20
16 25 26 17
28 19 19 28
end fill

ara=8 nux=3 nuy=1 nuz=1
fill 33 27 32 end fill

ara=9 nux=1 nuy=3 nuz=1
fill 31 34 30 end fill

ara=10 nux=10 nuy=10 nuz=1
fill f35 end fill
end array

read start nst=1 end start
read bounds all=spec end bounds
' read bias id=500 2 11 end bias
end data
end
```

The model for XSDRN case ("a=h3530c") at flooded conditions is listed below.

```
=csasix
sp-1 with 5.0% enriched 10x10 fuel
hans latt

' external water, 100 vol.%
h2o 1 1.0 293.0 end

uo2 2 0.98 293.0 92235 5.0 92238 95.0 end

' polyethylene in unit cell, 100 vol%
arbmpe 0.92 2 0 1 0 6012 1 1001 2
3 1.0 293. end

zircalloy 4 1.0 293.0 end

end comp
squa 1.61775 .8890 2 3 .98044 4 end
end
=xsdrn
' inf array of inners
0$$ a3 2 e
1$$ 2 2 100 1 3 2 2 8 2r1 10 80 3r0
2$$ -1 -1 4r0 -1 e
```

```
3$$ 0 e
' 4$$ -1 16 0 e
5** 2r1.0e-5 e
t
13$$ 1 2
14$$ 500 1
15** f1.0
 t
33## f1.0
 t
35** 49i0.0 49i10.133134 20.164682
36$$ 50r1 50r2
39$$ 1 2
51$$ 14i1 16
t
end
```

A typical CASMO case ("cava") is listed below.

```
DIM 10,1
TIT TFU=293.15 TMO=293.15 BOR=0 *  INNERS ONLY
FUE 1 10.7408/4.0 *98%TD, 4.0%ENR
FUE 2 10.7408/4.0 *98%TD, 4.0%ENR
FUE 3 10.7408/4.0 *98%TD, 4.0%ENR
FUE 4 10.6832/5.00,7301=1.5 *98%TD, 5.00%ENR
 VOI, 90.
 MOD, .099820/1001=11.19,8000=88.81
 MI1  .686305/26000=84.829155 ,6000= 1.731207 ,1001= 1.503896 ,8000=11.935745
 MI2  .303433/26000=66.611275 ,6000= 1.359414 ,1001= 3.584080 ,8000=28.445229
 MI3  .494868/26000=79.243896 ,6000= 1.617222 ,1001= 2.141640 ,8000=16.997234
 MI4 6.705978/26000=97.789505 ,6000= 1.995704 ,1001=  .024035 ,8000=  .190758
 MI5  .646048/26000=83.929482 ,6000= 1.712847 ,1001= 1.606623 ,8000=12.751048
 MI6  .541578/26000=80.970863 ,6000= 1.652467 ,1001= 1.944449 ,8000=15.446123
COO   .465105/1001=13.991474,6000=75.437164,8000=10.571368
MI7 0.001/8000=100.0
* 0.5127" pitch,
* POD/CID/COD=0.35/0.35/0.386"
PIN 1  0.4445  0.49022/'1' 'CAN'//1
PIN 2  0.4445  0.49022/'2' 'CAN'//1
PIN 3  0.4445  0.49022/'3' 'CAN'//1
PIN 4  0.4445  0.49022/'4' 'CAN'//1
PIN 5  0.4445 0.6510/'MOD' 'MOD'//1
BWR  10  1.30217 13.0217 0.0 3*0.0 1
LPI
1 1 1 1 1 1 1 1 1 1
1 2 2 2 4 4 4 4 4 1
1 2 2 3 3 3 4 4 4 1
1 2 3 3 5 5 5 4 4 1
```

```
1 2 3 3 5 5 5 3 4 1
1 2 3 3 5 5 5 3 4 1
1 2 3 3 3 3 3 3 2 1
1 2 2 3 3 3 3 2 2 1
1 2 2 2 2 2 2 2 2 1
1 1 1 1 1 1 1 1 1 1
/'F'
FST 4.9281,2.54,0.1519,2.54/0.001,3*5.2319/
'MI1','MI2','MI1','MI3',3*'MI4','MI3'/
'MI7','MI7','MI7','MI5','MI6','MI5','MI6','MI5'/
8,4,2,4/1,3*8/
STA
TIT TFU=293.15 TMO=293.15 BOR=0 *  INNERS ONLY
LPI
1 1 1 1 1 1 1 1 1 1
1 2 2 2 4 4 4 4 4 1
1 2 2 3 3 3 4 4 4 1
1 2 3 3 3 3 3 4 4 1
1 2 3 5 5 5 3 3 4 1
1 2 3 5 5 5 3 3 4 1
1 2 3 5 5 5 3 3 2 1
1 2 2 3 3 3 3 2 2 1
1 2 2 2 2 2 2 2 2 1
1 1 1 1 1 1 1 1 1 1
/'F'
STA
TIT TFU=293.15 TMO=293.15 BOR=0 *  INNERS ONLY
LPI
1 1 1 1 1 1 1 1 1 1
1 2 2 2 4 4 4 4 4 1
1 2 2 3 3 3 4 4 4 1
1 2 3 3 3 3 3 4 4 1
1 2 3 3 5 5 5 3 4 1
1 2 3 3 5 5 5 3 4 1
1 2 3 3 5 5 5 3 2 1
1 2 2 3 3 3 3 2 2 1
1 2 2 2 2 2 2 2 2 1
1 1 1 1 1 1 1 1 1 1
/'F'
STA
TIT TFU=293.15 TMO=293.15 BOR=0 *  INNERS ONLY
LPI
1 1 1 1 1 1 1 1 1 1
1 2 2 2 4 4 4 4 4 1
1 2 2 3 3 3 4 4 4 1
1 2 3 5 5 5 3 4 4 1
1 2 3 5 5 5 3 3 4 1
```

```
1 2 3 5 5 5 3 3 4 1
1 2 3 3 3 3 3 3 2 1
1 2 2 3 3 3 3 2 2 1
1 2 2 2 2 2 2 2 2 1
1 1 1 1 1 1 1 1 1 1
/'F'
STA
END
```

Appendix 6E

SIEMENS POWER CORPORATION SUPPLEMENTAL APPLICATION TO ADD 9X9 AND 10X10 FUEL ASSEMBLIES TO CERTIFICATE OF COMPLIANCE 9248

Supplemental License Application for Siemens Power Corporation Model SP-1 and SP-2 Shipping Containers

Certificate of Compliance No. 9248
Docket No. 71-9248

February 1996

Issue Date: 2/9/96

SUPPLEMENTAL LICENSE APPLICATION
FOR
SIEMENS POWER CORPORATION
MODEL SP-1 AND SP-2 SHIPPING CONTAINERS

Certificate of Compliance No. 9248
Docket No. 71-9248

Siemens Power Corporation
Nuclear Division
Richland, WA

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SUPPLEMENTAL LICENSE APPLICATION
FOR
SIEMENS POWER CORPORATION
MODEL SP-1 AND SP-2 SHIPPING CONTAINERS

Certificate of Compliance No. 9248
Docket No. 71-9248

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1.0 INTRODUCTION

1.1 Purpose

This report is provided in support of the application dated February 9, 1996, to revise Certificate of Compliance No. 9248. In that application, additional categories were proposed for Section 5(b)(1) of the Certificate. Calculation descriptions and results are provided to demonstrate that the additional categories meet all criticality safety requirements in 10 CFR Part 71.

1.2 Scope of Analysis

The existing categories in Section 5(b)(1) of the Certificate are unchanged. New fuel shipment categories are added to Section 5(b)(1) for 10x10 and 9x9 assemblies.

EMF-1563, Sup. 1, Rev. 1 demonstrated that the SP-1/SP-2 inner shipping container is adequately subcritical for any array at full flooded conditions with any pellet diameter, any number of water rods in any arrangement, with or without a water channel, with or without gadolinia rods, with any arrangement of rods with enrichments up to 5.0 wt.%, with rod diameters up to .5" and minimum clad thickness of .18", and with any number of polyethylene shims in any arrangement. This report re-confirms this data for assemblies with rod diameters up to .4" and minimum clad thickness of 0.015" in addition to demonstrating safety for new fuel types at low density interspersed moderation.

1.3 Summary of Conclusions

The following new categories may be added to Certificate of Compliance No. 9248 since they meet all requirements specified in 10 CFR Part 71. The highest bias corrected 95% upper limit for k_{eff} at accident conditions for the new 10x10 and new 9x9 categories are, respectively, .9337 and .9136.

5(b)(1)(vii) UO_2 fuel assemblies with a maximum U-235 enrichment of 5.0 wt.%. Each assembly is composed of a 10x10 array of fuel rods with a water channel or water rods located in a central 3x3 array of rods location. Any number of additional water rods or water channels in any arrangement is permitted. The maximum fuel dimensions are 5.0" by 5.0" by 174". The maximum pellet diameter is 0.35" and the minimum clad thickness is 0.018".

Each assembly shall contain at least eight rods with at least 2.0 wt. % gadolinia in all axial regions with enriched pellets.

The eight gadolinia rods shall be located in a pattern symmetric about one of the assembly diagonals and meet the following constraints.

1. The nominal diameter of the gadolinia pellets shall be not less than that of the UO_2 (non-gadolinia) pellets and rods shall be in non-perimeter positions.

2. At least two gadolinia rods shall be in row two and two additional rods shall be in column nine.

3. At least two gadolinia rods shall be in rows eight and / or nine and at least two additional gadolinia rods shall be in columns eight and / or nine.

4. A unit cell containing a gadolinia rod shall not share a common face with another gadolinia rod unless those sharing a common face are counted as one rod. Gadolinia rods may share a common corner without being counted as one rod.

5(b)(1)(viii) UO_2 fuel assemblies with a maximum U-235 enrichment of 5.0 wt.%. Each assembly is composed of a 9x9 array of fuel rods with a water channel or water rods in the center 3x3 rod locations. Any number of additional water rods or water channels in any arrangement is permitted. The maximum fuel dimensions are 5.0" by 5.0" by 174". The maximum pellet diameter is 0.40" and the minimum clad thickness is 0.015".

Each assembly shall contain at least eight rods with at least 2.0 wt. % gadolinia in all axial regions with enriched pellets.

The eight gadolinia rods shall be located in a pattern symmetric about one of the assembly diagonals and meet the following constraints:

1. The nominal diameter of the gadolinia pellets shall be not less than that of the UO_2 (non-gadolinia) pellets and the rods shall be in non-perimeter positions.

2. At least 2 gadolinia rods shall be in rows two and eight and two additional rods shall be in columns two and eight.

3. A unit cell containing a gadolinia rod shall not share a common face with another gadolinia rod unless those sharing a common face are counted as one rod. Gadolinia rods may share a common corner without being counted as one rod.

Fissile Class II is authorized for both fuel types with a minimum Transport Index of 1.0. Polyethylene shims are not permitted for either fuel type.

2.0 PACKAGE AND MODEL DESCRIPTION

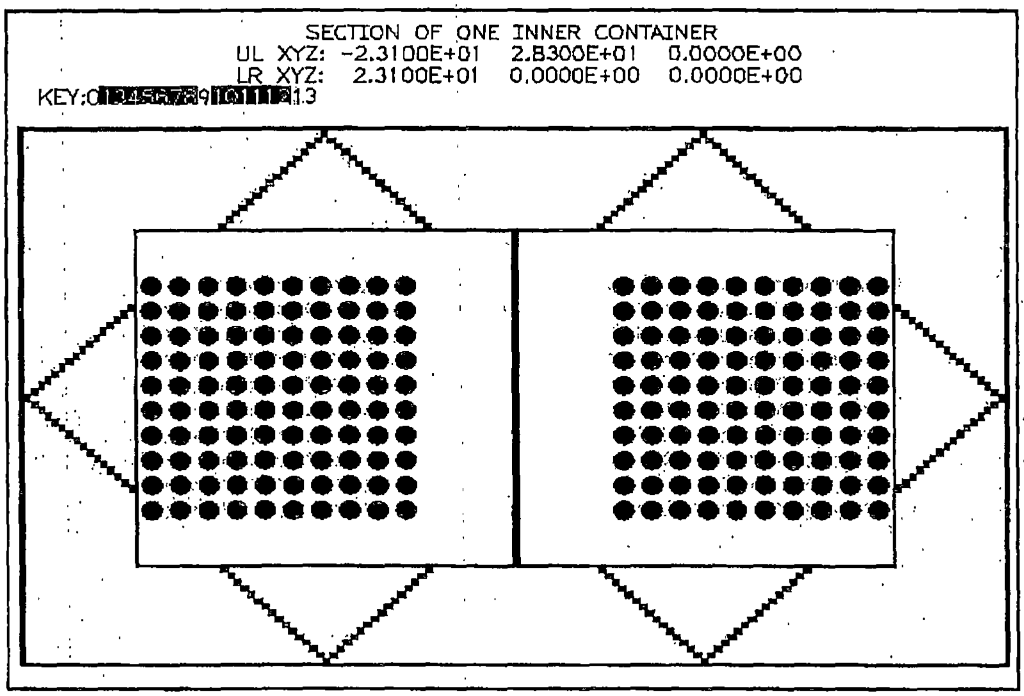
Each SP-1/SP-2 can contain up to two BWR assemblies. The SP-1/SP-2 is composed of a steel "inner container" and a wooden "outer container". Most criticality safety calculations are at "damaged" or "accident" conditions where the outer container is assumed to have burned away and the inner containers are stacked edge-to-edge in an array of at least 250 units (Fissile Class I) or at least 2N (Fissile Class II), where "N" is the maximum number of packages allowed per shipment. "N" is defined as 50 divided by the Transport Index.

The inner containers contain two "baskets" made of 0.0598" thick carbon steel with 0.75" diameter holes in a 1.75" square pitch pattern. The baskets are nominally 7"x7" in cross section. The two baskets are placed edge-to-edge in the center of the nominal 18" wide by 11" high steel inner container (0.0598" carbon steel walls). A 2" thick annulus is between the basket wall and the inner container wall. In this annulus are six carbon steel angles (2.8125"x2.8125"x0.125" nominal).

All previous calculations for the SP-1/SP-2 have demonstrated that peak reactivity with uniform interspersed moderation is with low density (typically 10 to 20 volume %) water. With low density interspersed water, the edge rods in the assemblies are the best moderated. It has been found that the most reactive position for the assemblies is to have both at the outer edges of their baskets, which allows maximum moderation of the edge rods facing the other assembly in the same package. This is the arrangement modeled in these calculations, unless noted otherwise.

The codes, cross sections, and other data from SCALE 4.2 (1) and CASMO-3G (2) were used. All components were modeled as precisely as possible in KENO-Va.

The baskets were modeled as carbon steel with moderation-filled holes (not "smeared") and the angles were closely approximated in volume and geometry using 31 steel segments with a total steel volume slightly less than the minimum (nominal minus tolerances). Finite arrays with 30 cm of water reflection were modeled in KENO-Va. The following figure is a KENO-Va plot for a typical model.



CASMO-3G was also used to calculate k-inf for several cases. The steel and moderation were "smeared" together in the various regions of the CASMO model. The CASMO model also had the assemblies to the shifted to the outer edges of their baskets. The arrays modeled were either infinite or 8x13x1.

3.0 ANALYTICAL METHODOLOGY

3.1 Nuclear Analysis

The codes, cross sections, and other data from SCALE 4.2[1] were used.

3.1.1 Codes and Databases Used

Version ujul94a of SCALE 4.2 was used for these calculations.

The computer codes used for this analysis are part of the SCALE 4.2 system of codes on the SPC HP workstation SSL01. The following codes and cross section libraries are part of the SCALE 4.2 system of codes placed on the SPC HP workstation SSL01.

3.1.2 Cross Section Preparation

BONAMI and NITAWL were used to prepare case-specific cross sections from the 16 and 27 group master libraries.

3.1.3 Benchmarking

The SCALE 4.2 system was developed for use by the USNRC and its licensees. Critical experiments were modeled using the same methodology used in these calculations. The benchmark calculations and the methodology for determining the calculation bias and its uncertainty and for determining the bias-corrected 95% upper limit on k-eff are described in this section.

3.1.3.1 Calculation of Bias and Bias Uncertainty

The bias and its standard deviation were calculated using the methods described in Reference 4. These methods use standard analysis of variance principles. The average over all cases of the KENO k-eff and its variance (square of standard deviation) are calculated. The average of the average k-eff (grand average) is weighted by the reciprocal of its variance. The average value of the variance is taken as the "within class" variance. The variance of the average k-eff data, weighted as for the grand average, is taken as the "between class" variance. The "within class" variance is subtracted from the "between class" variance to yield the variance of the class effect. Since the true value for all cases is assumed to be 1.0 (critical), the class effect (the change in average k-eff from case to case) is also the bias and the variance of the class effect is the variance of the bias. A zero variance of the bias would mean that the bias is constant from case to case. Standard statistical techniques test the ratio of the "between" and "within" variances. If this ratio does not exceed the "F" test, it is concluded that the class effect variance is not significant and the class effect (bias) is assigned the value zero. The methods in Reference 4 do not include a test of significance. The calculated bias is the value to add to the calculation result. Therefore, a negative bias indicates conservative results. The bias uncertainty is pooled with the KENO uncertainty for a given case by taking the square root of the sum of squares. The pooled uncertainty is multiplied by a factor appropriate for the degrees of freedom (calculated as shown in Ref. 4) for a one-sided 95% confidence limit. The 95% upper limit is the sum of the KENO k-eff plus the bias plus the pooled uncertainty multiplied by the factor. The one-sided confidence limit factor is used because only the upper limit is of interest.

As will be shown in Sections 3.1.3.2 and 3.1.3.3, there is no significant difference between the bias for experiments with and without gadolinium. Therefore, all experiments were combined to calculate the bias to be applied to these calculation results.

The bias and bias uncertainty with 16-group cross sections is -2.4405E-3 ± 4.6889E-3 and with 27-group cross sections it is +6.3419E-3 ± 4.9757E-3.

3.1.3.2 PNL Critical Experiments (Reference 4)

The Reference 4 experiments involve three flooded clusters of 4.31% enriched rods with variable spacings between the clusters and with various absorbers between the clusters. The case numbers referenced below were taken from Reference 4. Brief descriptions of the cases modeled follow. These experiments were selected because they were the closest available to the conditions being modeled. Experiments with stainless steel and zircaloy were selected because they are in the SP-1/SP-2 model. Cases with boron were selected to include a strong neutron absorber; gadolinium was not available in these experiments. Separate experiments with gadolinium are reported in Section 3.1.3.3.

Cases 001, 002, and 003 determine the critical size of one cluster. The critical size was interpolated based on experiments with integral numbers of rods per edge; the critical number had a fractional number of rods on one edge and either 8, 9, or 10 rods on the other edge. These three cases were modeled using cell-weighted cross sections.

Case 004 involved three 15x8 clusters with no absorber plates.

Cases 007, 008, 013, and 014 involved three clusters with 304L steel absorber plates. Two plate thicknesses and different absorber spacings from the central cluster were tested.

Cases 009, 010R, 011, and 012 are similar to the previous four except that the 304L steel contained either 1.05 or 1.62% Boron.

Case 031 involved three clusters with BORAL absorber plates.

Cases 029 and 030 involved three clusters with Zircaloy-4 absorber plates.

The "x" suffix on the case name denotes cell-weighted cross-sections. Suffixes such as "a" are for explicitly modeled rods.

The bias and bias uncertainty calculated for these benchmark cases are tabulated below.

Table 1 Reference 4 Cases
Calculation Results
With 16-Group Cross Sections

Case ID	k-eff	
	Avg.	Std.Dev.
a-c001x	1.00355	0.00249
a-c002x	1.00905	0.00257
a-c003x	1.00845	0.00252
a-c004	1.00435	0.00265
a-c005a	1.00244	0.00265
a-c005b	1.00198	0.00252
a-c006a	1.00177	0.00253
a-c006b	1.00443	0.00270
a-c007a	1.00352	0.00252
a-c007x	1.00788	0.00253
a-c008a	0.99798	0.00241
a-c008x	1.00109	0.00242
a-c009a	1.00365	0.00221
a-c010a	0.99854	0.00246
a-c011a	1.00138	0.00255
a-c012aa	1.00329	0.00244
a-c013a	0.99712	0.00258
a-c013x	1.01149	0.00227
a-c014a	0.99991	0.00241
a-c014x	1.00732	0.00259
a-c029a	0.99894	0.00254
a-c030a	1.00278	0.00257
a-c031a	1.00582	0.00250

The bias and bias uncertainty calculated for these 16-group cases are -3.3617E-3 ± 2.8457E-3.

Table 2 Reference 4 Cases
Calculation Results
With 27-Group Cross Sections

Case ID	k-eff	
	Avg.	Std.Dev.
b-c001x	1.00591	0.00264
b-c002x	0.99828	0.00274
b-c003x	1.00268	0.00234
b-c004	0.99853	0.00266
b-c005a	0.98845	0.00348
b-c006a	0.99000	0.00247
b-c007a	1.00394	0.00309
b-c007x	0.99789	0.00256
b-c008a	0.98856	0.00367
b-c008x	1.00177	0.00268
b-c009a	0.99293	0.00344
b-c010a	0.99237	0.00315
b-c011a	0.99493	0.00356
b-c012a	1.00104	0.00327
b-c013a	0.99779	0.00346
b-c013x	0.99306	0.0025
b-c014a	0.99177	0.00343
b-c014x	0.99708	0.0024
b-c029a	0.99366	0.0023
b-c030a	0.99241	0.00259

The bias and bias uncertainty calculated for these 27-group cases are 3.4601E-3 ± 4.0706E-3.

3.1.3.3 Experiments with Gadolinium (Ref. 5)

Additional critical experiments (Reference 5) with gadolinium were modeled. The experiments determined the critical number of UO_2 fuel rods with gadolinium dissolved in the water between the rods. The rods were in a triangular-pitched array in a cylindrical vessel with water reflection on all sides of the approximately cylindrical-shaped rod array. Three rod pitches were used for the 14.40 mm OD rods: 22.86mm, 27.94mm, and 33.02mm. The experiments were modeled using cell-weighted cross sections simulating the unit cell. A cylindrical fuel region with a cross sectional area equal to that of the reported critical number of rods was modeled with full water reflection. The cases were replicated with the 16, 27, 123, and 218 group cross section libraries in SCALE. The calculation results are in Table 4 and plotted below.

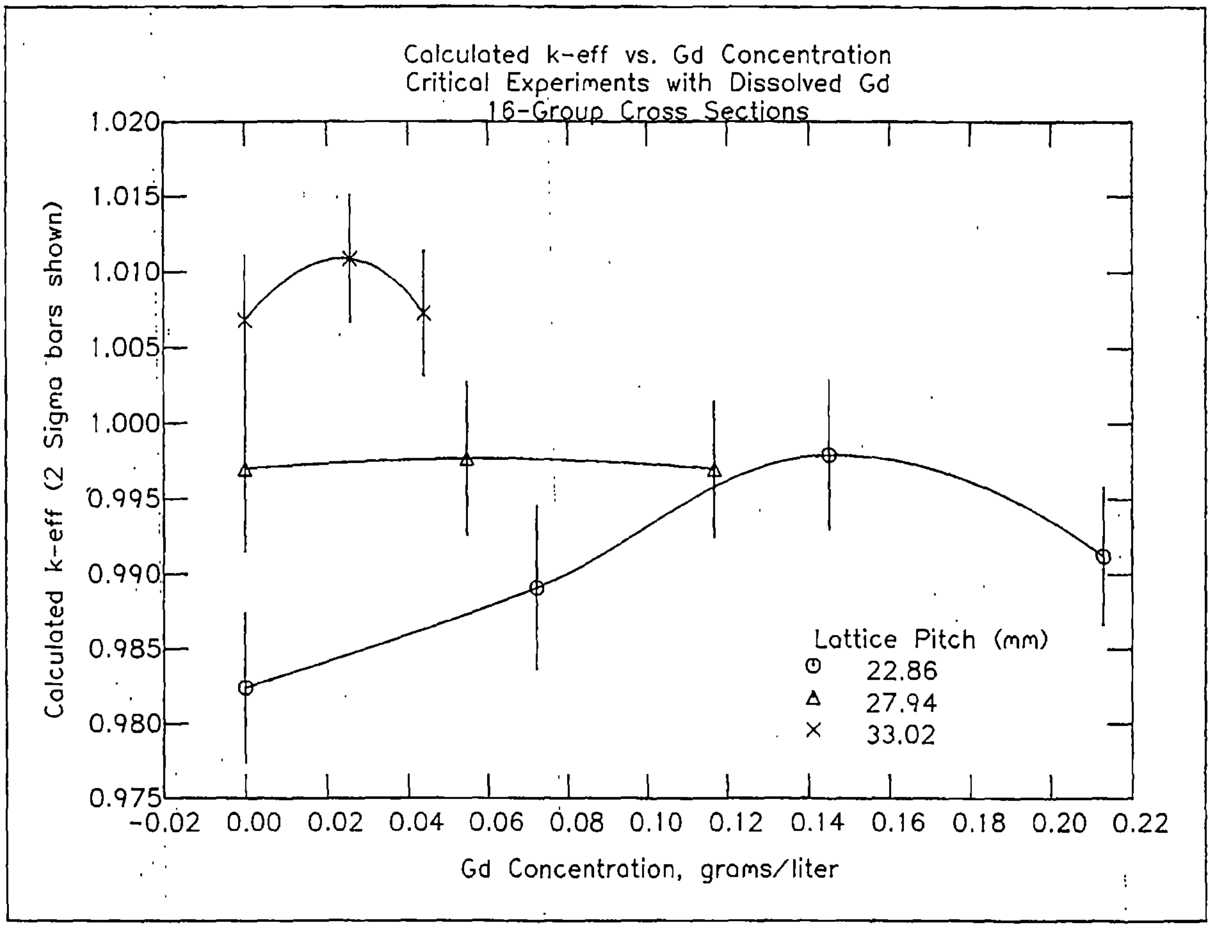
Ten experiments were modeled: seven contain gadolinium and three are water-only reference cases. The average and standard deviations of the calculation bias, based only on the seven cases with gadolinium, are in Table 3. Comparing these results with those from the previous section indicates that there is no significant difference in the bias due to gadolinium. Therefore, the two sets of data will be combined for the final bias calculation.

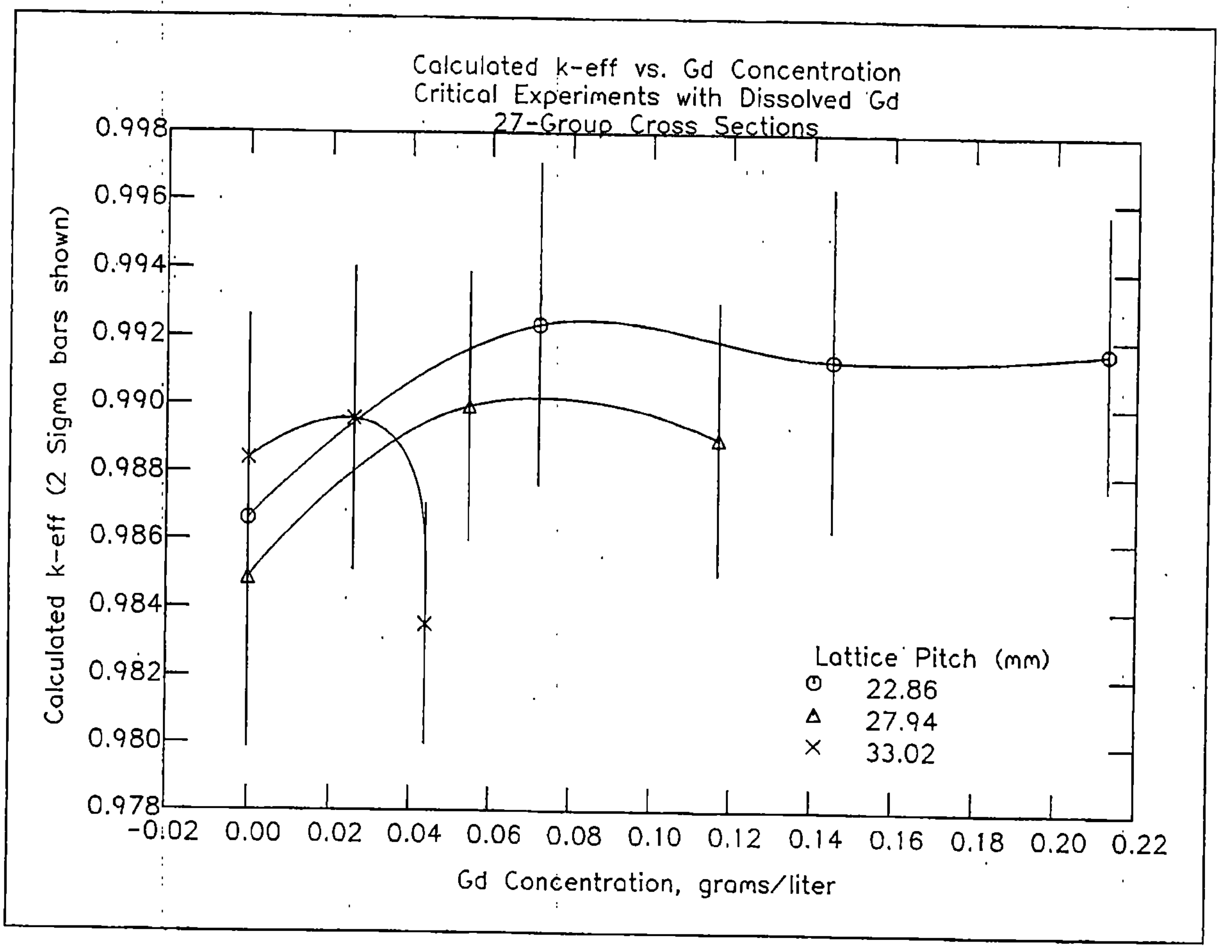
Table 3 Calculation Bias for Cases with Gadolinium

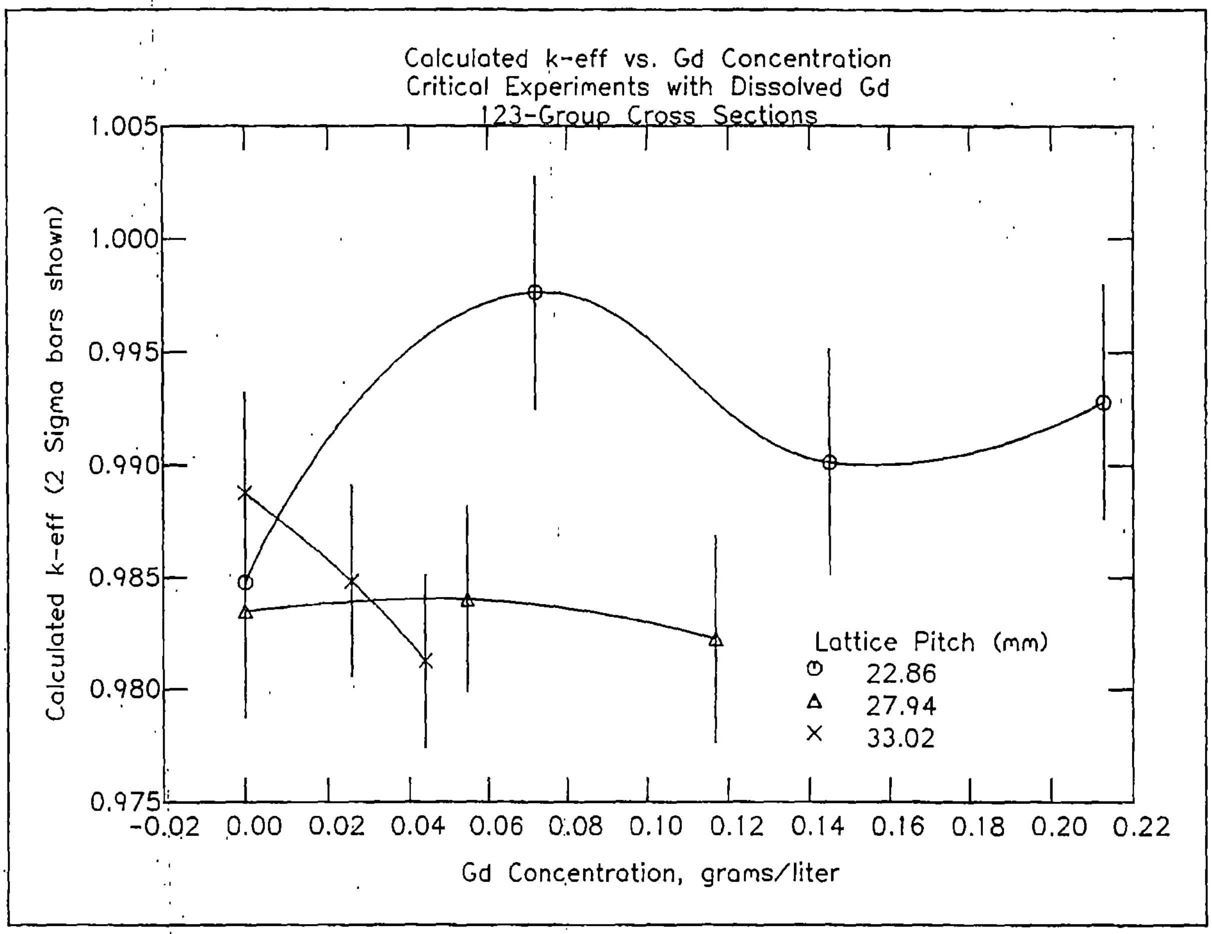
Cross Section Library (Energy Groups)	Calculation Bias Average	Calculation Bias Standard Deviation
16	0.0001875	0.00774
27	0.010864	0.002430

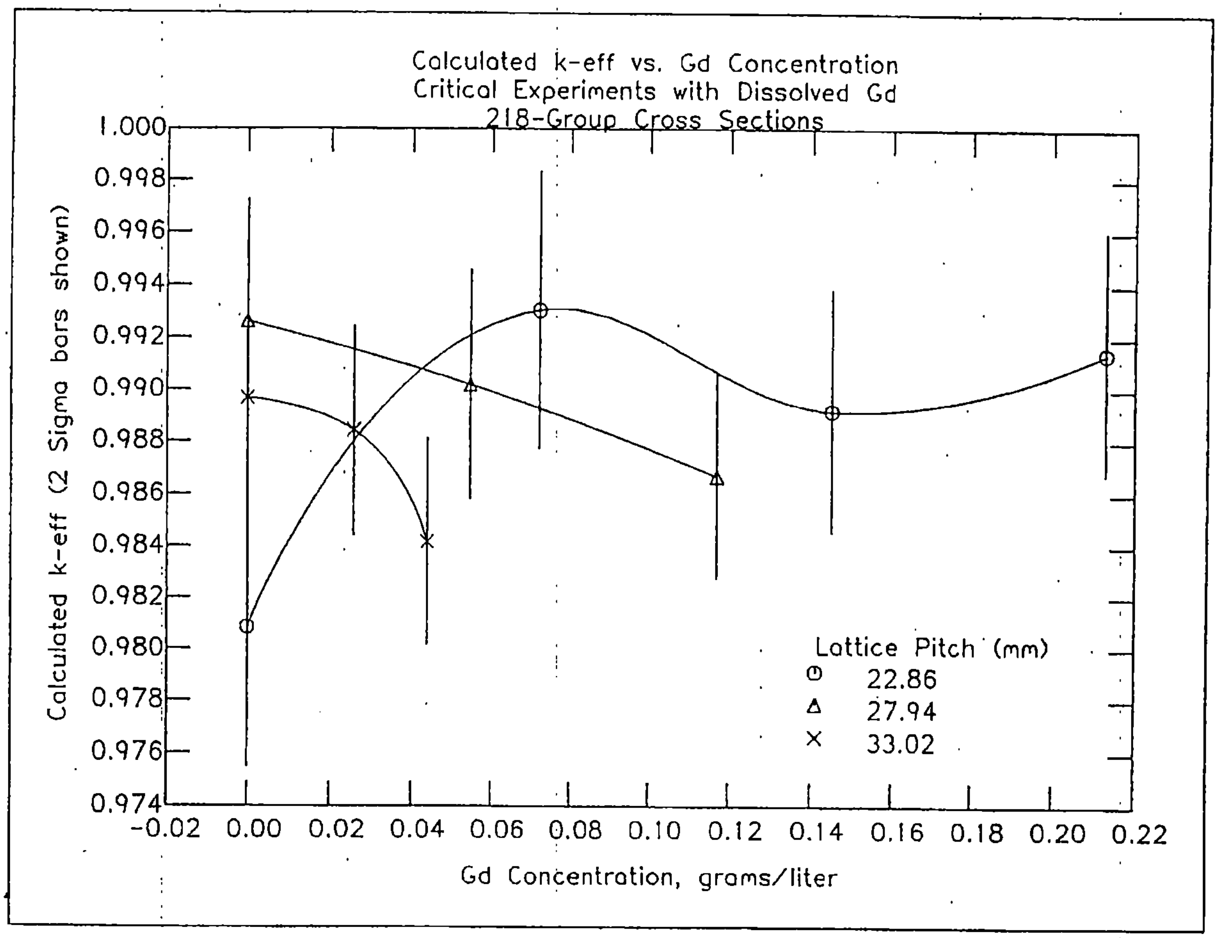
Table 4 Critical Experiments with Gadolinium
Calculation Results

Experiment No.	Triangular Lattice Pitch, mm	Gd Concentration, Grams/liter	16-Group k-eff		27-Group k-eff	
			Avg.	Std.Dev.	Avg.	Std.Dev.
001	22.86	0	0.98242	0.00251	0.98663	0.00291
009		0.0722	0.9891	0.00274	0.99236	0.00237
010		0.145	0.99793	0.00248	0.99134	0.00252
011		0.213	0.99121	0.00231	0.99164	0.00202
012	27.94	0	0.99701	0.00277	0.98487	0.0025
016		0.0547	0.99769	0.00254	0.98993	0.00198
017		0.1169	0.99698	0.00226	0.98901	0.00201
018	33.02	0	1.0068	0.00215	0.98841	0.00211
023		0.0257	1.01088	0.00211	0.98957	0.00223
024		0.044	1.00728	0.00207	0.98352	0.00177


Calculated k-eff vs. Gd Concentration
Critical Experiments with Dissolved Gd
16-Group Cross Sections
Calculated k-eff (2 Sigma bars shown)
1.020
1.015
1.010
1.005
1.000
0.995
0.990
0.985
0.980
0.975
-0.02
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
Gd Concentration, grams/liter
Lattice Pitch (mm)
22.86
27.94
33.02


Calculated k-eff vs. Gd Concentration
Critical Experiments with Dissolved Gd
27-Group Cross Sections
Calculated k-eff (2 Sigma bars shown)
0.998
0.996
0.994
0.992
0.990
0.988
0.986
0.984
0.982
0.980
0.978
-0.02 0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18 0.20 0.22
Gd Concentration, grams/liter
Lattice Pitch (mm)
22.86
27.94
33.02


Calculated k-eff vs. Gd Concentration
Critical Experiments with Dissolved Gd
123-Group Cross Sections
Calculated k-eff (2 Sigma bars shown)
1.005
1.000
0.995
0.990
0.985
0.980
0.975
-0.02 0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18 0.20 0.22
Gd Concentration, grams/liter
Lattice Pitch (mm)
22.86
27.94
33.02


Calculated k-eff vs. Gd Concentration
Critical Experiments with Dissolved Gd
218-Group Cross Sections
Calculated k-eff (2 Sigma bars shown)
1.000
0.998
0.996
0.994
0.992
0.990
0.988
0.986
0.984
0.982
0.980
0.978
0.976
0.974
-0.02 0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18 0.20 0.22
Gd Concentration, grams/liter
Lattice Pitch (mm)
22.86
27.94
33.02

4.0 ANALYSIS

The new categories proposed for Certificate Section 5(b)(1) are analyzed in this section. Included in this section are several sensitivity studies showing the effect of various parameters plus calculations with the most reactive combination of the various parameters.

The previous applications have demonstrated the key parameters affecting the peak k-eff for an array of SP-1/SP-2 packages are (see EMF-1563, Sup. 1, Rev. 1):

1. The number of packages in the array. Larger arrays tend to produce higher k-eff values. In certain cases, Fissile Class II was specified to allow use of smaller arrays.

2. The fuel enrichment. Higher enrichments lead to higher k-eff values.

3. Assembly size ("Envelope"). Larger transverse dimensions tend to increase k-eff. The length of the assembly has relatively little effect. Assemblies were modeled with the maximum allowable envelope.

4. Interspersed moderation. For limiting conditions, low density interspersed moderation produces a higher k-eff than full flooding. Additional evidence of this fact is included in this application.

5. Number, arrangement, and composition of gadolinia rods. For a given number of gadolinia rods, the most reactive arrangement is to have them clustered together in the central parts of the assembly. This was demonstrated in the previous two supplemental applications and it is also seen in comparing cases in this application. The gadolinia content was modeled at 75% of the minimum specified value.

6. Water rods and water channels. Fuel assemblies typically do not have all lattice locations occupied by fuel rods. The missing locations are called "Water Rods" or "Water Channels" in cases such as a 2x2 or 3x3 array of water rods at the assembly center. Water rods and water channels cause lower k-eff relative to assemblies with all locations occupied by fuel rods at low density interspersed moderation. This was demonstrated in the previous two supplemental applications and additional evidence is presented in this document.

7. Fuel (pellet) diameter. Larger pellet diameters, at least up to about 0.5", lead to higher k-eff values. This was demonstrated in previous supplemental applications and additional evidence is presented in this application.

4.1 Flooded Conditions

EMF-1563, Sup. 1, Rev. 1 demonstrated that damaged containers at flooded conditions were safe in an infinite array for all pellet diameters, 0.18" thick clad, and any amount of poly provided enrichment is limited to 5.0 wt. % and the lattice envelope is up to 5.0" x 5.0". This section will confirm this conclusion is also valid for pellet diameters less than 0.40" and clad thicknesses of at least 0.015". As previously shown in EMF-1563, Sup. 1, Rev. 1, a single SP-1/SP-2 has its maximum k-eff at flooded conditions and with the assemblies shifted toward the inner edges of their baskets. The assemblies are well coupled within the package but, for arrays of edge-to-edge inner containers, the assemblies are effectively decoupled between packages. Fully flooded arrays of packages (damaged) were modeled with 5.0% enriched assemblies without gadolinia rods. Infinite arrays are acceptable with zero gadolinia at flooded conditions.

4.1.1 Conservative XSDRN Model (No Steel, Flooded)

A repeated calculation of case a-h4025c from EMF-1563, Sup. 1, Rev. 1 with a 0.015" thick clad. This case had the highest k-inf of all 0.4" diameter pellet cases using 16 group cross sections. The resulting k-inf is .96436 which is a net increase of .0038. This model is a conservative 1-D model that does not include any structural steel. This simple model was a cylindrical approximation of two infinite-length edge-to-edge assemblies (10" wide by 5" high fuel region) in a 18" wide by 11" high inner container. The within-assembly moderator was either water or 100% polyethylene (PE). The between-assembly moderator was always water. The boundary conditions in XSDRN were set for an infinite array. The pellet diameter of 0.40" was modeled with a 0.015" thick zircaloy clad. The assemblies were modeled as a cell-weighted mixture with a moderator-to-fuel volume ratio of 2.5. This set of calculations was replicated with the 16 and 27 group cross section libraries.

The conservative XSDRN calculation results are in Table 5.

Table 5 Conservative XSDRN SP-1/SP-2 Model (No Steel)
Infinite Array (3-D) of Edge-to-Edge Inner Containers
5.0% Enriched, 0.015" Thick Clad, Fully Flooded
XSDRN Results with 16-Group and 27-Group Cross Sections

Case ID	Within-Assembly Moderator	Pellet Diam, inch	Moderator to Fuel Volume Ratio	Unit Cell k-inf	SP-1/SP-2 k-inf
16 Group Cross Sections					
a-h4025a	Water	0.40	2.5	1.52812	.90467
a-h4025c	PE	0.40	2.5	1.53558	.96436
27 Group Cross Sections					
b-h4025a	Water	0.40	2.5	1.52163	.90368
b-h4025c	PE	0.40	2.5	1.52577	.96222

4.1.2 Conservative KENO Model (No Steel, Flooded)

The XSDRN model cases were replicated with a conservative KENO model. The KENO model uses cuboidal geometry types (with cell-weighted cross sections) but no steel is in the model. A case with a water-filled channel at the center of the assembly was included in the KENO cases. The channel was a 1.5" by 1.5" region (30% of assembly dimension). An additional cases with discrete 0.1267" thick polyethylene shims equally spaced across the assembly was also included. The calculation results are in Table 6.

The XSDRN-KENO agreement is judged to be good. Water-moderated assemblies are clearly acceptable even without steel in the model.

Table 6 Conservative KENO SP-1/SP-2 Model (No Steel)
Infinite Array (3-D) of Edge-to Edge Inner Containers
5.0% Enriched, 0.015" Thick Clad, Fully Flooded
KENO-Va Results with 16-Group and 27-Group Cross Sections

Case ID	Within-Assembly Moderator	Pellet Diam, inch	Mod. to Fuel Vol. Ratio	KENO k-inf	
				Avg.	Std.Dev.
16 Group Cross Sections					
a-f4025c	PE/No	0.40	2.5	0.96626	0.00436
a-f4023d	PE/Yes	0.40	2.5	0.94337	0.00444
a-f4025e	Water-Shims/No	0.40	2.5	0.93330	0.00443
27 Group Cross Sections					
b-f4025C	PE/No	0.40	2.5	0.94963	0.00430
b-f4025d	PE/Yes	0.40	2.5	0.94096	0.00417
b-f4025d	Water-Shims/No	0.40	2.5	0.93242	0.00383

4.1.3 KENO Model (Flooded) With Steel Included

An infinite array (3-D) of flooded edge-to-edge inner containers was modeled with the steel basket, angles, and shell included. Each package contained two 5" by 5" assemblies shifted together as closely as possible. The assemblies were simulated by cell-weighted cross sections based on a unit cell with a pellet diameter of 0.40" and with a moderator-to-fuel ratio of 2.5. 100% polyethylene for moderator in the unit cell was used in the model. The available volume external to the assemblies was modeled as filled with water. The calculation results are in Table 7.

Table 7 KENO SP-1/SP-2 Model (With Steel)
Infinite Array (3-D) of Edge-to-Edge Inner Containers
5.0% Enriched, 0.015" Thick Clad, Fully Flooded
KENO Results with 16-Group and 27-Group Cross Sections

Case ID	Within-Assembly Moderator	Pellet Diam, inch	Mod. to Fuel Vol. Ratio	k-eff	
				Avg.	Std.Dev.
16 Group Cross Sections					
a-g4025c	PE	0.40	2.5	0.92088	0.00433
27 Group Cross Sections					
b-g4025c	PE	0.40	2.5	0.92472	0.00415

It is concluded that the package is adequately subcritical in any array at flooded conditions with any pellet diameter, any number of water rods in any arrangement, with or without a water channel, with or without gadolinia rods, with any arrangement of rods with enrichments up to 5.0%, and with any number of polyethylene shims in any arrangement.

4.2 Low Density Interspersed Moderation

Unless stated otherwise, all calculations in this section are based on the 16-group cross sections. The calculations in section 4.1 as well as those documented in EMF-1563, Sup. 1, Rev. 1 demonstrate that the 16-group cross sections produce a higher k_{eff} than the 27-group cross sections.

4.2.1 Sensitivity Study: Pellet Diameter and Water Rods and Water Channels

Previous analyses have shown that arrays of SP-1/SP-2 inner shipping containers at low density moderation are more reactive with larger pellet diameters. When fuel rods are replaced by "water rods", they are actually much closer to "void rods" at the typical 8-12 volume % water conditions for peak k-eff. Therefore, the net effect is closer to removal of fuel with very little added moderation, which causes a decline or no change in k-eff; i.e., the fuel is "worth" more than the slight addition of local moderation.

Consistent with the model used previously in EMF-1563, Sup. 1, Rev. 1 for 10x10 assemblies, the model used for 9x9 assemblies in this supplement is an infinite array of inner containers with 10 volume % interspersed water and polyethylene shims equivalent to 43.47 vol. % of the between rod volume. The rods in the modeled assembly contain zero gadolinia and enriched to 4.0 wt.% u-235. Pellet diameters of .30, .35, and .40 inches were evaluated.

The water rod arrangements (patterns) modeled are shown in the following figures. As shown in Table 8, all cases with water rods are less reactive than the case with zero water rods.

WRA

1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	2	2	1
1	2	3	3	3	3	3	3	1
1	2	3	3	3	3	3	3	1
1	2	3	3	3	3	3	3	1
1	2	3	3	3	3	3	3	1
1	2	3	3	3	3	3	3	1
1	2	2	2	2	2	2	2	1
1	1	1	1	1	1	1	1	1

WRB

1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	2	2	1
1	2	2	3	3	3		2	1
1	2	3	3	3	3	3	2	1
1	2	3	3	3	3	3	2	1
1	2	3	3	3	3	3	2	1
1	2		3	3	3		2	1
1	2	2	2	2	2	2	2	1
1	1	1	1	1	1	1	1	1

WRC

1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	2	2	1
1	2	3		3		3	2	1
1	2		3	3	3		2	1
1	2	3	3	3	3	3	2	1
1	2		3	3	3		2	1
1	2	3		3		3	2	1
1	2	2	2	2	2	2	2	1
1	1	1	1	1	1	1	1	1

WRD

1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	2	2	1
1	2	3	3	3	3	3	2	1
1	2	3	3			3	2	1
1	2	3	3			3	2	1
1	2	3	3	3	3	3	2	1
1	2	3	3	3	3	3	2	1
1	2	2	2	2	2	2	2	1
1	1	1	1	1	1	1	1	1

WRE

1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	2	2	1
1	2	3	3	3	3	3	2	1
1	2	3				3	2	1
1	2	3				3	2	1
1	2	3				3	2	1
1	2	3	3	3	3	3	2	1
1	2	2	2	2	2	2	2	1
1	1	1	1	1	1	1	1	1

Table 8 Water Rod and Pellet Diameter
Sensitivity CASMO Model with Shims and 10 Vol. % Water
All Fuel is 4.0% Enriched, Zero Gadolinia

Water Rod Pattern	Case I.D.	CASMO K-inf		
		.30" Pellet	.35" Pellet	.40" Pellet
WRA	d.podxx where xx is 10 times the pellet diameter in inches.	1.09139	1.11669	1.11865
WRB		1.08276	1.11150	1.11661
WRC		1.07217	1.10575	1.11503
WRD		1.08377	1.11267	1.11786
WRE		1.07266	1.10638	1.11633

4.2.2 Sensitivity to Pellet Diameter and Interspersed Moderators

To confirm the conclusion made in Section 4.2.1 that increasing pellet diameter increases k_{eff} and to find the optimum vol. % interspersed moderator, a series of calculations using KENO.Va were completed. The fuel assemblies modeled here had no polyethylene shims, no gadolinia, and no water rods. The bundle enrichment was 5.0 wt. % U-235 except for the exterior rods which were 4 wt. %. The bundles were moved apart. EMF-1563, Sup. 1, Rev. 1 showed that this was the worst orientation. Various pellet diameters were evaluated. The results of this evaluation are listed in Table 9.

Table 9 Sensitivity to K-eff to Pellet Diameter
and Interspersed Moderator

Case I.D.	Vol. % Water	$K_{eff} \pm \sigma$		
		.25" Pellet	.35" Pellet	.40" Pellet
a-xx.01	1	.50971 ± .00181	.60246 ± .00187	.63839 ± .00175
a-xx.03	3	.66125 ± .00177	.74158 ± .00181	.76260 ± .00184
a.xx-05	5	.76433 ± .00186	.83752 ± .00176	.85439 ± .00168
a-xx.07	7	.81774 ± .00204	.89112 ± .00184	.90678 ± .00178
a-xx.09	9	.85350 ± .00190	.93189 ± .00196	.94408 ± .00178
a-xx.11	11	.85513 ± .00187	.94169 ± .00191	
a-xx.12	12			.96837 ± .00183
a-xx.13	13	.85914 ± .00216	.95370 ± .00208	.96511 ± .00184
a-xx.14	14			.96436 ± .00200
a-xx.15	15	.85540 ± .00181	.94840 ± .00192	.96917 ± .00191
a-xx.16	16			.96708 ± .00184

4.2.3 Sensitivity Study: Gadolinia Rod Locations

EMF-1563, Sup. 1, Rev. 1 documents the calculated normalized (relative to average) fission rates for a typical 10x10 assembly with no water rods and no gadolinia rods and 8 volume % interspersed water. These normalized fission rates are listed in Table 10. The model is an infinite array of edge-to-edge inner containers. It is seen that the corner rods have the highest fission rates with the edge rods declining with increased distance from the corner and interior rods declining with increased distance from the corner/edge. The corner rods have a fission rate about double that of the central 2x2 array of rods. As the water density is increased above 8 volume % (peak k-inf for infinite array), the normalized fission rates of the corner/edge rods increases but the system k-inf declines due to decreased coupling among assemblies. For a finite array such as 13x20x1, the optimum interspersed water density is typically 8 to 12 volume %. The conclusions made from the results listed below are directly applicable to 9x9 assemblies.

Table 10 Typical Normalized Fission Rates for 10x10 Assembly
Low Density Interspersed Moderation

1.489	1.320	1.245	1.206	1.189	1.187	1.200	1.232	1.295	1.430
1.314	1.091	1.000	.955	.935	.933	.947	.983	1.058	1.238
1.235	.996	.887	.835	.813	.810	.826	.867	.956	1.148
1.194	.950	.834	.775	.751	.747	.764	.812	.906	1.101
1.177	.930	.812	.751	.724	.721	.740	.788	.884	1.080
1.176	.930	.812	.751	.724	.720	.739	.788	.884	1.080
1.193	.949	.833	.774	.749	.746	.763	.811	.905	1.100
1.233	.994	.885	.833	.811	.808	.824	.865	.954	1.146
1.310	1.088	.997	.952	.932	.930	.944	.980	1.054	1.235
1.484	1.315	1.240	1.201	1.184	1.182	1.195	1.227	1.289	1.424

The fission densities in Table 10 are instructive regarding the selection of locations of gadolinia rods for peak reactivity (most conservative locations). With low density interspersed moderation conditions, most of the moderation occurs **between** assemblies; relatively little occurs within assemblies. This is evidenced by Dancoff factors on the order of 0.90, meaning that neutrons leaving one rod have a 90% chance of having their next collision in another rod rather than in the between-rod moderation. As a result, the thermal flux is depressed in the assembly interior. If a thermal neutron absorber is placed into a region with a depressed thermal flux, the effectiveness of the absorber will be reduced. Similarly, if the gadolinia rods are clustered together in the central parts of the assembly, their effectiveness will be further reduced by the reduction in thermal flux caused by their companions. The new fuel category require gadolinia rods. If a fuel rod is replaced with a "water rod", the gadolinia rods have the following effects:

1. If the water rod is located close to gadolinia rod(s), the added moderation will increase the effectiveness of the absorber.

2. If gadolinia rods are moved toward the edge/corner to make room for water rods, the k-eff will tend to decline because of the increased thermal flux near the edge. The gadolinia rods become more effective and some of the higher worth fuel rods are replaced with absorbers.

3. If gadolinia rods remain clustered in the center and fuel rods near the edge/corner are replaced with water rods, the k-eff will tend to decline because of the loss of higher worth fuel rods.

Additional discussion on gadolinia rod locations is included in sections 4.2.4 and 4.2.5.

4.2.4 10x10 Assemblies with All Rods Enriched to 5 wt. % and Eight Gadolinia Rods at 1.5 wt. % Gd_2O_3

EMF-1563, Sup. 1, Rev. 1 concluded the most reactive arrangement of gadolinia rods in a 10x10 assembly is to have all gadolinia rods clustered together in the upper right corner and with the water channel in the central 3x3 cells that are shifted to the right and up one row and column. The same simple CASMO model used previously was used here to evaluate the most reactive gadolinia rod arrangement for 10x10 assemblies that meet the following restrictions:

- At least two gadolinia rods are in row two and at least two additional gadolinia rods are in column nine.
- At least two gadolinia rods are in rows eight and/or nine and at least two additional gadolinia rods are in columns eight and/or nine.
- A unit cell containing a gadolinia rod shall not share a common face with another gadolinia rod. i.e. they may have a common corner but not a common side unless the rods with a common side are considered one rod.

Only six gadolinia rods containing 1.5 wt.% Gd_2O_3 were modeled in most cases even though eight are specified at a minimum of 2.0 wt.% Gd_2O_3. All fuel rods were also 5.0% enriched. The arrangements modeled are shown in the following figures. The results are listed in Table 11.

ta

1	1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	2	2	G	1
1	2	3	3	3	3	3	G	2	1
1	2	3				3	3	G	1
1	2	3				3	G	2	1
1	2	3				3	3	2	1
1	2	3	3	3	3	3	3	2	1
1	2	3	3	3	3	3	3	2	1
1	G	2	2	2	2	2	2	G	1
1	1	1	1	1	1	1	1	1	1

tb

1	1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	2	2	G	1
1	2	3	3	3	3	3	G	2	1
1	2	3	3				3	G	1
1	2	3	3				G	2	1
1	2	3	3				3	2	1
1	2	3	3	3	3	3	3	2	1
1	2	3	3	3	3	3	3	2	1
1	G	2	2	2	2	2	2	G	1
1	1	1	1	1	1	1	1	1	1

tc

1	1	1	1	1	1	1	1	1	1
1	G	2	2	2	2	2	2	G	1
1	2	3	3	3	3	3	G	2	1
1	2	3	3				3	G	1
1	2	3	3				G	2	1
1	2	3	3				3	2	1
1	2	3	3	3	3	3	3	2	1
1	2	3	3	3	3	3	3	2	1
1	2	2	2	2	2	2	2	G	1
1	1	1	1	1	1	1	1	1	1

td

1	1	1	1	1	1	1	1	1	1
1	G	2	2	2	2	2	2	G	1
1	2	3	3	3	3	3	G	2	1
1	2	3	3				3	G	1
1	2	3	3				G	2	1
1	2	3	3				3	2	1
1	2	3	3	3	3	3	3	2	1
1	2	3	3	3	3	3	3	2	1
1	2	2	2	2	2	2	2	G	1
1	1	1	1	1	1	1	1	1	1

tf

1	1	1	1	1	1	1	1	1	1
1	2	2	G	2	2	2	2	2	1
1	2	G	3	3	3	3	3	2	1
1	G	3	3				3	2	1
1	2	3	3				3	2	1
1	2	3	3				3	2	1
1	2	3	3	3	3	3	3	G	1
1	2	3	3	3	3	3	G	2	1
1	2	2	2	2	2	G	2	2	1
1	1	1	1	1	1	1	1	1	1

tg

1	1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	G	2	G	1
1	2	3	3	3	3	3	G	2	1
1	2	3	3				3	G	1
1	2	3	3				3	2	1
1	2	3	3				3	2	1
1	2	3	3	3	3	3	3	2	1
1	2	3	3	3	3	3	3	2	1
1	G	2	2	2	2	2	2	G	1
1	1	1	1	1	1	1	1	1	1

th

1	1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	G	2	G	1
1	2	3	3	3	3	3	G	2	1
1	2	3	3				3	G	1
1	2	3	3				3	2	1
1	2	3	3				3	2	1
1	2	3	3	3	3	3	3	2	1
1	2	3	3	3	3	3	3	2	1
1	G	2	2	2	2	2	2	G	1
1	1	1	1	1	1	1	1	1	1

ti

1	1	1	1	1	1	1	1	1	1
1	G	2	2	2	2	G	2	G	1
1	2	3	3	3	3	3	G	2	1
1	2	3	3	3	3	3	3	G	1
1	2	3				3	3	2	1
1	2	3				3	3	2	1
1	2	3				3	3	2	1
1	2	3	3	3	3	3	3	2	1
1	2	2	2	2	2	2	2	G	1
1	1	1	1	1	1	1	1	1	1

tj

1	1	1	1	1	1	1	1	1	1
1	G	2	2	2	2	G	2	G	1
1	2	3	3	3	3	3	G	2	1
1	2	3	3				3	G	1
1	2	3	3				3	2	1
1	2	3	3				3	2	1
1	2	3	3	3	3	3	3	2	1
1	2	3	3	3	3	3	3	2	1
1	2	2	2	2	2	2	2	G	1
1	1	1	1	1	1	1	1	1	1

tk

1	1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	G	2	2	1
1	2	3	3	3	3	3	G	2	1
1	2	3	3	3	3	G	3	G	1
1	2	3				3	3	2	1
1	2	3				3	3	2	1
1	2	3				3	3	2	1
1	2	3	3	3	3	3	3	2	1
1	G	2	2	2	2	2	2	G	1
1	1	1	1	1	1	1	1	1	1

tl

1	1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	G	2	2	1
1	2	3	3	3	3	3	G	2	1
1	2	3	3			G	3	G	1
1	2	3	3				3	2	1
1	2	3	3				3	2	1
1	2	3	3	3	3	3	3	2	1
1	2	3	3	3	3	3	3	2	1
1	G	2	2	2	2	2	2	G	1
1	1	1	1	1	1	1	1	1	1

tm

1	1	1	1	1	1	1	1	1	1
1	G	2	2	2	2	2	G	G	1
1	2	3	3	3	3	3	3	G	1
1	2	3	3	3	3	G	3	2	1
1	2	3				3	3	2	1
1	2	3				3	3	2	1
1	2	3				3	3	2	1
1	2	3				3	3	2	1
1	2	2	2	2	2	2	2	G	1
1	1	1	1	1	1	1	1	1	1

tn

1	1	1	1	1	1	1	1	1	1
1	G	2	2	2	2	2	G	G	1
1	2	3	3	3	3	3	3	G	1
1	2	3	3				3	2	1
1	2	3	3				3	2	1
1	2	3	3				3	2	1
1	2	3	3	3	3	3	3	2	1
1	2	3	3	3	3	3	G	2	1
1	2	2	2	2	2	2	2	G	1
1	1	1	1	1	1	1	1	1	1

to

1	1	1	1	1	1	1	1	1	1
1	G	2	2	2	2	G	2	2	1
1	2	3	3	3	3	3	G	2	1
1	2	3				3	3	G	1
1	2	3				3	G	2	1
1	2	3				3	3	2	1
1	2	3	3	3	3	3	3	2	1
1	2	3	3	3	3	3	3	2	1
1	2	2	2	2	2	2	2	G	1
1	1	1	1	1	1	1	1	1	1

tp

1	1	1	1	1	1	1	1	1	1
1	G	2	2	2	2	G	2	2	1
1	2	3	3	3	3	3	G	2	1
1	2	3	3				3	G	1
1	2	3	3				G	2	1
1	2	3	3				3	2	1
1	2	3	3	3	3	3	3	2	1
1	2	3	3	3	3	3	3	G	1
1	2	2	2	2	2	2	2	2	1
1	1	1	1	1	1	1	1	1	1

Table 11 Gadolinia Rod Arrangement Studies
Six Gadolinia Rods, All Rods, are 5.0% Enriched,
Gadolinia Rods contain 1.5 wt.% Gd_2O_3
CASMO Model with Various Amounts of Interspersed Water

Gad Rod Pattern	Case Id	K-inf		
		14 Vol. %	15 Vol. %	10 wt.% + poly shims
ta	8GDxx where xx is the Vol. % Interspersed Moderator	1.00822	1.01026	1.07946
tb		1.00577	1.00769	1.07619
tc		1.00837	1.01045	1.07961
td		1.00571	1.00760	1.07620
te		1.01195	1.10388	1.08072
tg		1.00557	1.00769	1.07832
th		1.0391	1.00593	1.07638
ti		1.00587	1.00800	1.07861
tj		1.00395	1.00594	1.07650
tk		1.00987	1.01189	1.07965
tl		1.00812	1.00994	1.07793
tm		.99813	1.00015	1.06769
tn		1.00503	1.00711	1.07958
to		1.00971	1.01174	1.07982
tp		1.00898	1.01081	1.07738

KENO.Va was used to model an array of 104 inner shipping containers. The array was 8x13x1. The most reactive rod arrangement found using CASMO was used. The effect of various amounts of interspersed moderator on k_{eff} was evaluated. The results are in Table 12. The highest bias corrected 95% upper limit for k_{eff} for assemblies without polyethylene shims is .9337 for case t6.16.

Table 12 Gadolinia Rod Arrangement Studies
Eight Gadolinia Rods, All Rods are 5.0% Enriched,
Gadolinia Rods contain 1.5 wt.% Gd_2O_3
KENO-Va Model with Various Amounts of Interspersed Water

Case ID	Moderator Vol. %	K-eff	
		Average K-eff	σ
t6.10p	10+ poly	1.01211	.00174
t6.11	11	.91378	.00185
t6.12	12	.91903	.00171
t6.13	13	.92333	.00179
t6.14	14	.92123	.00188
t6.15	15	.92232	.00191
t6.16	16	.92544	.00186
t6.17	17	.92169	.00197

Assembly Orientation

To evaluate the possible effects of assembly orientation, several cases for fuel pattern tb at various Vol. % interspersed moderator were repeated with one of the fuel bundles in the inner container rotated 180 degrees. The results of this evaluation are listed in Table 13.

Table 13 Sensitivity of K-eff to 10x10 Assembly Orientation

Case ID	Vol. % Moderator	K-eff	σ
tb.12r180	12	.91912	.00243
tb.13r180	13	.92511	.00252
tb.14r180	14	.92244	.00242

These data imply that the orientation of these types of assemblies in the shipping container will not have a significant impact on k-eff, but will shift the point of optimum interspersed moderation.

4.2.5 9x9 Assemblies with All Other Rods Enriched to 5.0 Wt. % and Eight Gadolinia Rods at 1.5 wt.% Gd_2O_3.

EMF-1563, Sup. 1, Rev. 1 concluded the most reactive arrangement of gadolinia rods in a 10x10 assembly is to have all gadolinia rods clustered together in the upper right corner. A simple CASMO model was used to confirm this type of rod arrangement is also the most reactive for 9x9 assemblies. The water channel is in the center 3x3 cells. The rod arrangements evaluated are shown in the figures below and results are listed in Table 14.

N1

1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	2	2	1
1	2	3	3	3	3	3	2	1
1	2	3				3	2	1
1	2	3				3	2	1
1	2	3				3	2	1
1	2	3	3	3	3	3	2	1
1	2	2	2	2	2	2	2	1
1	1	1	1	1	1	1	1	1

N2

1	1	1	1	1	1	1	1	1
1	G	2	2	G	2	2	G	1
1	2	3	3	3	3	3	2	1
1	2	3				3	2	1
1	G	3				3	2	1
1	2	3				3	2	1
1	2	3	3	3	3	3	2	1
1	G	2	2	G	2	2	G	1
1	1	1	1	1	1	1	1	1

N3

1	1	1	1	1	1	1	1	1
1	G	2	2	2	G	2	G	1
1	2	3	3	3	3	G	2	1
1	2	3				3	G	1
1	2	3				3	2	1
1	2	3				3	2	1
1	2	3	3	3	3	3	2	1
1	G	2	2	2	2	2	G	1
1	1	1	1	1	1	1	1	1

N3a

1	1	1	1	1	1	1	1	1
1	G	2	2	2	G	2	G	1
1	2	3	3	3	3	G	2	1
1	G	3				3	G	1
1	2	3				3	2	1
1	2	3				3	2	1
1	2	3	3	3	3	3	2	1
1	2	2	2	2	2	2	G	1
1	1	1	1	1	1	1	1	1

N3b

1	1	1	1	1	1	1	1	1
1	G	2	2	2	G	2	G	1
1	2	3	3	3	3	G	2	1
1	2	3				3	G	1
1	G	3				3	2	1
1	2	3				3	2	1
1	2	3	3	3	3	G	2	1
1	2	2	2	2	2	2	G	1
1	1	1	1	1	1	1	1	1

N4

1	1	1	1	1	1	1	1	1
1	G	2	2	2	G	2	G	1
1	2	3	3	3	3	3	2	1
1	G	3				3	G	1
1	2	3				3	2	1
1	2	3				3	2	1
1	2	3	3	3	3	3	2	1
1	G	2	2	2	G	2	G	1
1	1	1	1	1	1	1	1	1

N5

1	1	1	1	1	1	1	1	1
1	G	2	2	2	2	2	G	1
1	2	3	3	G	3	G	2	1
1	G	3				3	2	1
1	2	3				G	2	1
1	2	3				3	2	1
1	2	3	3	3	3	3	2	1
1	2	2	2	2	G	2	G	1
1	1	1	1	1	1	1	1	1

N5a

1	1	1	1	1	1	1	1	1
1	G	2	2	2	2	2	G	1
1	2	3	3	G	3	3	2	1
1	G	3				3	2	1
1	2	3				G	2	1
1	2	3				3	2	1
1	2	3	3	3	3	G	2	1
1	2	2	2	2	G	2	G	1
1	1	1	1	1	1	1	1	1

N5b

1	1	1	1	1	1	1	1	1
1	G	2	2	2	2	2	G	1
1	2	3	3	G	3	3	2	1
1	G	3				3	2	1
1	2	3				G	2	1
1	2	3				3	2	1
1	2	3	3	G	3	3	2	1
1	2	2	2	2	G	2	G	1
1	1	1	1	1	1	1	1	1

N6

1	1	1	1	1	1	1	1	1
1	2	2	2	2	G	2	G	1
1	2	3	3	3	3	3	2	1
1	2	3				3	2	1
1	2	3				3	G	1
1	G	3				3	2	1
1	2	3	3	3	3	3	G	1
1	G	2	2	G	G	2	G	1
1	1	1	1	1	1	1	1	1

N7

1	1	1	1	1	1	1	1	1
1	2	2	2	2	G	2	G	1
1	2	G	3	3	3	3	2	1
1	2	3				3	2	1
1	2	3				3	2	1
1	G	3				3	G	1
1	2	3	3	3	3	3	2	1
1	G	2	2	2	G	2	G	1
1	1	1	1	1	1	1	1	1

Table 14 Gadolinia Rod Arrangement Studies
Eight Gadolinia Rods, All Rods are 5.0% Enriched,
Gadolinia Rods contain 1.5 wt.% Gd_2O_3
CASMO Model with Various Amounts of Interspersed Water

Gad Rod Pattern	Case ID	K-inf				
		12% Water	13% Water	14% Water	15% Water	10 Vol. % + poly shims
N1	d.8GDxx.out where xx is the Vol. % interspersed water	1.07986	1.08245	1.08512	1.08771	1.16982
N2		.96510	.96685	.96867	.97042	1.02799
N3		.97120	.97310	.97498	.979678	1.03579
N3a		.97336	.97314	.97698	.97877	1.03669
N3b		.96418	.96582	.96750	.96914	1.02277
N4		.96571	.96752	.96941	.97122	1.03014
N5		.97478	.97631	.97787	.97939	1.03193
N5a		-	.97683	-	.97990	1.03264
N5b		-	.97576	-	.97859	1.02948
N6		.97250	.97425	.97606	.97782	1.03481
N7		.97027	.97200	.97377	.97550	1.03186

KENO.Va was used to model an array of 104 inner shipping containers. The array was 13x13x1. The most reactive rod arrangement found using CASMO was used. The effect of various amounts of interspersed moderator on k_{eff} was evaluated. The results are in Table 15. The highest bias corrected 95% upper limit for k_{eff} for assemblies without polyethylene shims is .91360 for case a-3a.15.

Table 15 K-eff for Rod Patterns 3A, 5, and 5A
at Various Amounts of Interspersed Water

Case ID	Rod Pattern	Vol. % Water as Interspersed Moderator	K-eff	
			Average	σ
a-3a.11	3	11	.89078	.00154
a-3a.12		12	.89799	.00182
a-3a.13		13	.89700	.00178
a-3a.14		14	.89664	.00177
a-3a.15		15	.90532	.00173
a-3a..16		16	.90424	.00186
a-5.13	5	13	.89104	.00190
a-5.14		14	.88916	.00174
a-5.15		15	.89322	.00160
a-5.16		16	.88673	.00159
a-5.10p		10+ poly shims	.97402	.00183
a-5a.12	5a	12	.89102	.00173
a-5a.13		13	.89028	.00180
a-5a.14		14	.89085	.00187
a-5b.15		15	.89061	.00186
a-5a.16		16	.88961	.00164
a-5a.10p		10+ poly shims	.97854	.00188

Assembly Orientation

To evaluate the possible effects of assembly orientation, several cases for fuel patterns 3a and 5a at various Vol. % interspersed moderator were repeated with one of the fuel bundles in the inner container rotated 180 degrees. The results of this evaluation are listed in Table 16.

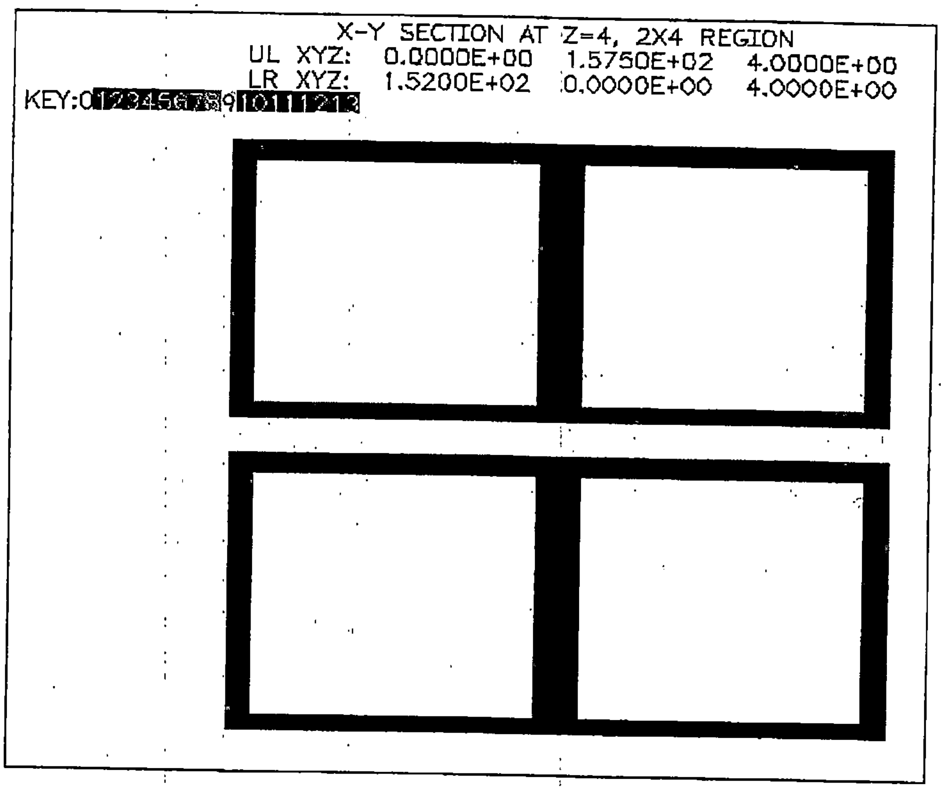
Table 16 Sensitivity of K-eff to 9x9 Assembly Orientation

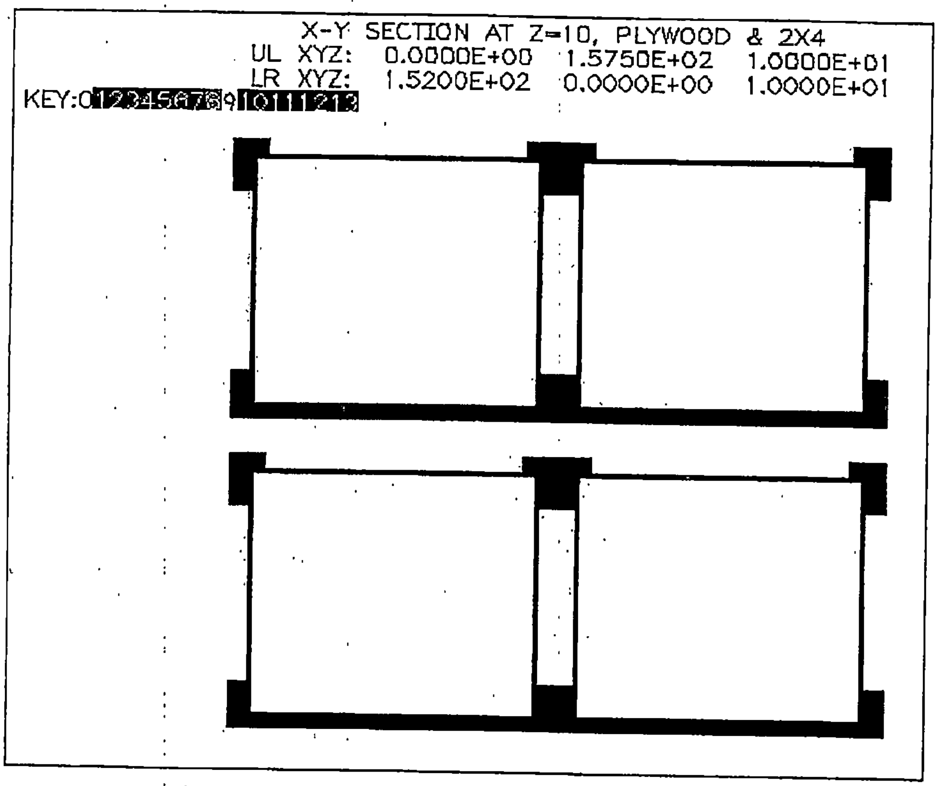
Case ID	Vol. % Moderator	K-eff	σ
a-3a.12r180	12	.90168	.00257
a-3a.13r180	13	.90470	.00239
a-3a.14r180	14	.90230	.00274
a-3a.15r180	15	.89958	.00286
a-5.14r180	14	.88917	.00260
a-5.15r180	15	.89464	.00261
a-5.16r180	16	.88397	.00264
a-5a.13r180	13	.89093	.00278
a-5a.14r180	14	.89020	.00251
a-5a.15r180	15	.89429	.00253
a-5a.16r180	16	.89416	.00270

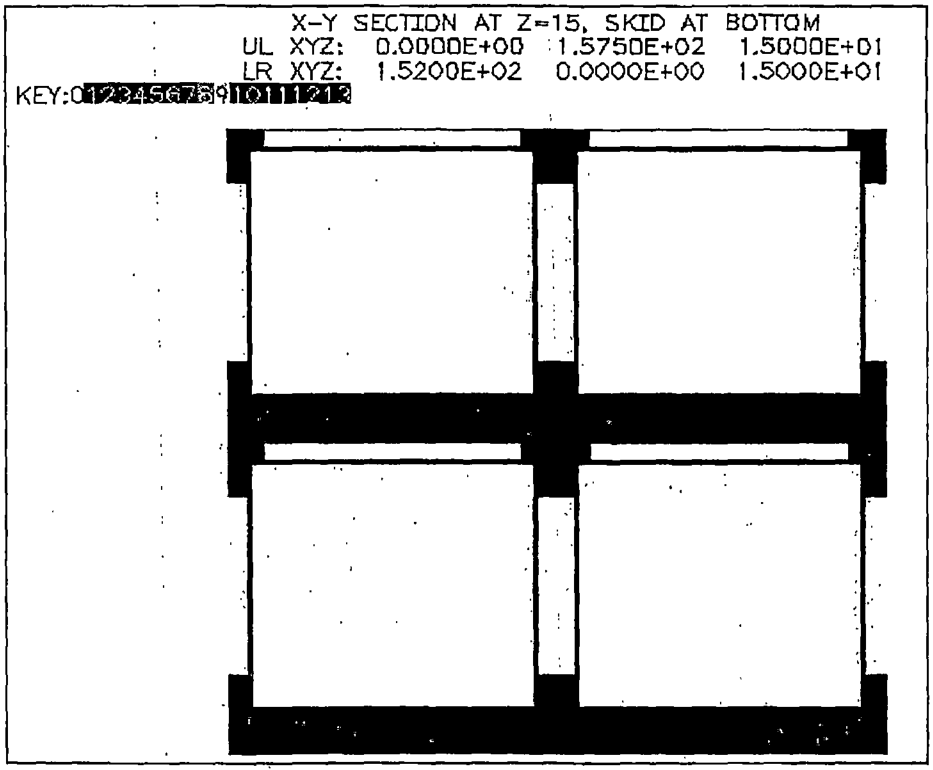
These data imply that the orientation of these types of assemblies in the shipping container will not have a significant impact on k-eff, but will shift the point of optimum interspersed moderation.

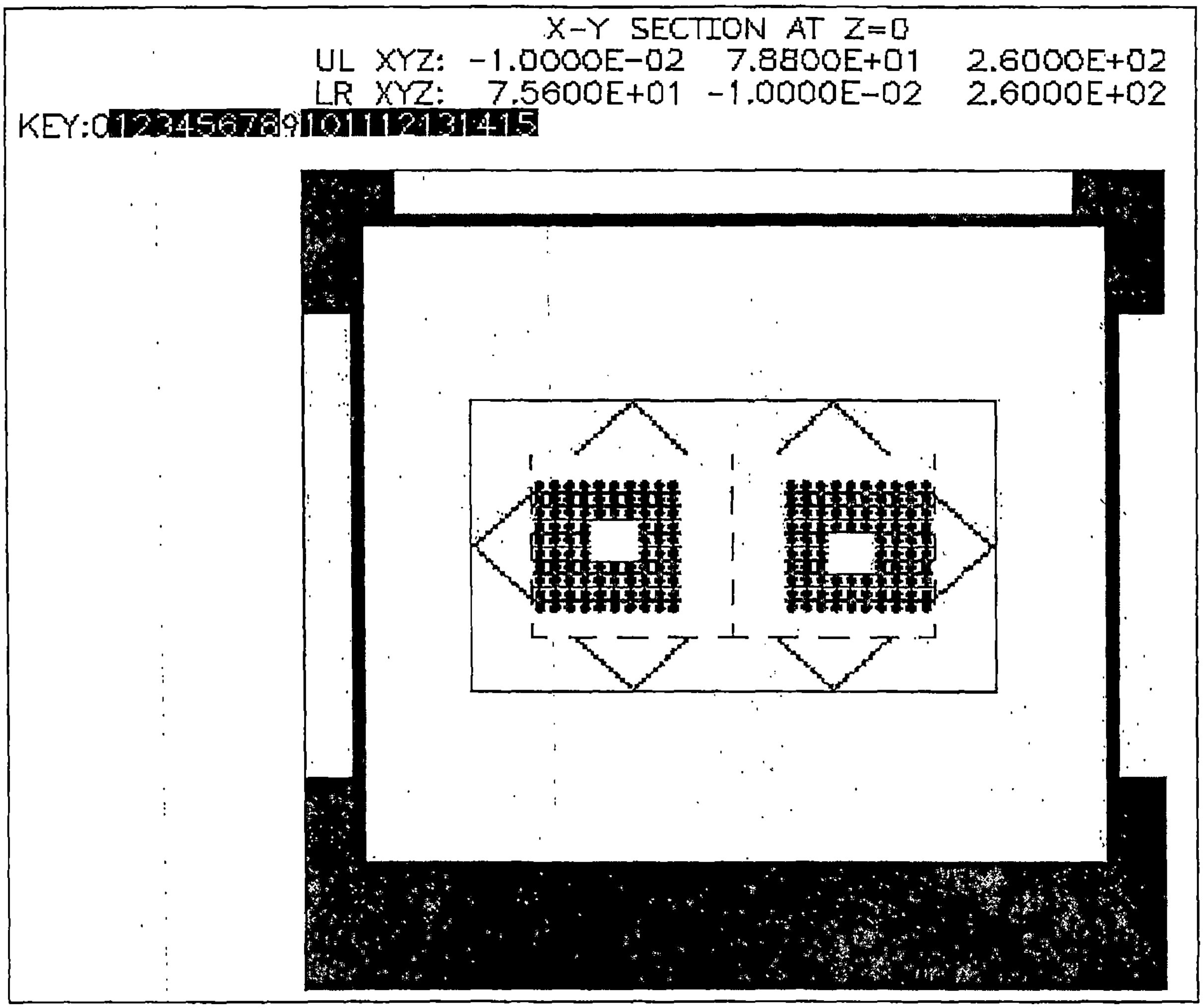
4.3 Normal Condition Arrays

Normal conditions include the wooden outer container. The outer container wooden parts were closely modeled based on the data in Drawing EMF-306,416. The outer dimensions of the outer container are 75.6cm wide by 78.7 cm high by 523.9 cm long. The following KENO plots are transverse sections at various locations along the length of the package.


X-Y SECTION AT Z=4, 2X4 REGION
UL XYZ: 0.0000E+00 1.5750E+02 4.0000E+00
LR XYZ: 1.5200E+02 0.0000E+00 4.0000E+00
KEY:0 1 2 3 4 5 6 7 8 9 10 11 12 13


X-Y SECTION AT Z=10, PLYWOOD & 2X4
UL XYZ: 0.0000E+00 1.5750E+02 1.0000E+01
LR XYZ: 1.5200E+02 0.0000E+00 1.0000E+01
KEY:012345678910111213


X-Y SECTION AT Z=15, SKID AT BOTTOM
UL XYZ: 0.0000E+00 1.5750E+02 1.5000E+01
LR XYZ: 1.5200E+02 0.0000E+00 1.5000E+01
KEY:0 1 2 3 4 5 6 7 8 9 10 11 12 13


X-Y SECTION AT Z=0
UL XYZ: -1.0000E-02 7.8800E+01 2.6000E+02
LR XYZ: 7.5600E+01 -1.0000E-02 2.6000E+02
KEY:0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

The calculation results for an infinite array of edge-to-edge packages are in Table 17. The rod patterns and orientation of the assemblies in each package are shown in sections 4.2.4 and 4.2.5.

The most reactive interspersed water density for both assembly types is zero. The largest bias-corrected 95% upper limit on k-eff for the infinite array is 0.9150.

Table 17 K-eff for Infinite Arrays of SP-1/SP-2 Containers at Normal Conditions

Case ID	Rod Pattern	Vol.% Interspersed Moderator	k-eff	
			Avg.	Std.Dev.
	3a	0	.87498	.00174
a-n3a.005		.5	.84803	.00170
a-n3a.010		1	.82883	.00159
a-n3a.015		1.5	.80380	.00175
a-nt6	t6	0	.90673	.00172
a-nt6.005		.5	.88406	.00164
a-nt6.010		1	.86140	.00179
a-nt6.015		1.5	.83264	.00161

5.0 REFERENCES

1. NUREG/CR-0200 Scale a Modular Code System for Performing Standardized Computer Analyses for Licensing

2. CASMO-3 STUDSVIK/NFA-86/7 A Fuel Assembly Burnup Program User's Manual

3. NUREG/CR-0073: "Critical Separation Between Subcritical Clusters of 4.31 wt% Enriched UO_2 Rods in Water with Fixed Neutron Poisons"

4. Lloyd, R.C., Durst, B.M., and Clayton, E.D.: "Effect of Soluble Neutron Absorbers on Criticality of Low U-235 Enriched UO_2 Lattices", Nuclear Science and Engineering: 71, 164-169 (1979)

5. "Criticality Safety Criteria", ANS Trans, Vol.35, p.278

Appendix A

Sample computer inputs used for this analysis:

The model of inner shipping containers KENO case ("a-3a.15") is listed below.

```
=csas25
sp-1 with 5.0% enriched 9x9 fuel except exterior rods 5.0%
hans  infh

' uo2 1 0.98 293.0 92235 3.4643 92238 96.5357 end
uo2 1 0.98 293.0 92235 5.0   92238 95.0   end

' uo2 2 0.98 293.0 92235 3.4643 92238 96.5357 end
uo2 2 0.98 293.0 92235 5.0   92238 95.0   end

' uo2 3 0.98 293.0 92235 4.0 92238 96.0 end
uo2 3 0.98 293.0 92235 5.0 92238 95.0 end

uo2 4 0.98 293.0 92235 5.0 92238 95.0 end

uo2 5 0.98 293.0 92235 5.0 92238 95.0 end

uo2 6 0.98 293.0 92235 5.0 92238 95.0 end

' poison rod with 2% gd2o3
' td of uo2-gd2o3 = 10.96 -2.65*p/[p+0.67145*(1-p)], p=wt frac.gd2o3
' "p" is 0.02 here,  td is 10.9012
' pellet density is 0.98*10.9012=10.6832
' uo2 density is 0.985*10.6832 = 10.5230
' gd2o3 density is 0.02*10.6832 = 0.1602 gm/cc
uo2 7 den=10.5230 1.0 293.0 92235 5.00 92238 95.00 end
arbmgd2o3 0.1602 2 0 1 0 64000 2 8016 3
7 1.0 293. end

zircalloy 8 1.0 293.0 end

' water, 15 vol.%
h2o 9 0.15 293.0 end

' basket steel
carbonsteel 10 1.0 293.0 end
' angle steel
carbonsteel 11 1.0 293.0 end
' shell steel
carbonsteel 12 1.0 293.0 end
' reflector water
h2o  13 1.0 293 end
' polyethylene, 100 vol%
arbmpe 0.92 2 0 1 0 6012 1 1001 2
14 1.0 293. end

' higher enriched rods
```

```
uo2 15 0.98 293.0 92235 5.0 92238 95.0 end

end comp
more data
 res=  1 cyli  3.8729E-01 dan(  1)=  6.8905E-01
 res=  2 cyli  4.5924E-01 dan(  2)=  6.3178E-01
 res=  3 cyli  5.4268E-01 dan(  3)=  4.1004E-01
 res=  4 cyli  5.5080E-01 dan(  4)=  4.0273E-01
 res=  5 cyli  5.3948E-01 dan(  5)=  4.6477E-01
 res=  6 cyli  5.3770E-01 dan(  6)=  4.6765E-01
 res=  7 cyli  4.3370E-01 dan(  7)=  6.1057E-01
end more
sp-1 with 5.0% enriched 9x9 fuel except 4.0% edge rods
read parameters
tme=90 gen=200 npg=600 nsk=0
flx=yes fdn=yes xs1=yes nub=yes pwt=yes
run=yes plt=yes
end parameters
read geom

' pellet diam: 0.40"
' gap: zero
' clad thk: 0.015"
' pitch: 0.5696"

unit 1
com="interior rod"
cyli  1 1 0.5080 2p226.695
cyli  8 1 0.54610  2p226.695
cubo  9 1  2p0.723428  2p0.54610  2p226.695
' polyethylene shims between rods
' cubo  14 1 4p0.7234280 2p226.695
'
' use ld water inplace of shims
cubo  9 1 4p0.7234280 2p226.695

unit 2
com="interior rods around water rod"
cyli  2 1 0.5080 2p226.695
cyli  8 1 0.54610  2p226.695
cubo  9 1  2p0.7234280 2p0.54610  2p226.695
' polyethylene shims between rods
' cubo  14 1 4p0.7234280 2p226.695
'
' use ld water inplace of shims
cubo  9 1 4p0.7234280 2p226.695

unit 3
com="edge rod facing up"
cyli  3 1 0.5080 2p226.695
cyli  8 1 0.54610  2p226.695
cubo  9 1  2p0.7234280 0.7234280 -0.54610  2p226.695
' polyethylene shims between rods
' cubo  14 1 4p0.7234280 2p226.695
```

```
'
' use ld water in place of shims
 cubo 9 1 4p0.7234280 2p226.695

unit 4
com="edge rod facing down"
cyli 4 1 0.5080 2p226.695
cyli 8 1 0.54610 2p226.695
cubo 9 1 2p0.7234280 0.54610 -0.7234280 2p226.695
' polyethylene shims between rods
' cubo 14 1 4p0.7234280 2p226.695
'
' use ld water in place of shims
 cubo 9 1 4p0.7234280 2p226.695

unit 5
com="edge rod facing other bundle"
cyli 5 1 0.5080 2p226.695
cyli 8 1 0.54610 2p226.695
cubo 9 1 2p0.7234280 2p0.54610 2p226.695
' polyethylene shims between rods
' cubo 14 1 4p0.7234280 2p226.695
'
' use ld water in place of shims
 cubo 9 1 4p0.7234280 2p226.695

unit 6
com="edge rod facing out"
cyli 6 1 0.5080 2p226.695
cyli 8 1 0.54610 2p226.695
cubo 9 1 2p0.7234280 2p0.54610 2p226.695
' polyethylene shims between rods
' cubo 14 1 4p0.7234280 2p226.695
'
' use ld water in place of shims
 cubo 9 1 4p0.7234280 2p226.695

unit 7
com="uo2-gd2o3 rod"
cyli 7 1 0.5080 2p226.695
cyli 8 1 0.54610 2p226.695
cubo 9 1 2p0.7234280 2p0.54610 2p226.695
' polyethylene shims between rods
cubo 14 1 4p0.7234280 2p226.695
'
' use ld water in place of shims
' cubo 9 1 4p0.7234280 2p226.695

unit 8
com="water rod"
cubo 9 1 4p0.7234280 2p226.695

unit 9
com='side basket element, 0.0598"x1.75"x1.75" steel with 0.75" diam. hole'
```

```
xcyl 9 1 0.9525 0.1519 0.0
cubo 10 1 0.1519 0.0 4p2.2225

unit 10
com='side basket element, 0.0598"x1.6902"x1.75" steel with 0.75" diam. hole'
xcyl 9 1 0.9525 0.1519 0.0
cubo 10 1 0.1519 0.0 2p2.14655 2p2.2225

unit 11
com='one complete basket side'
' 1x4x102 array of units 10 & 11
array 1 0.0 -8.7381 -226.695

unit 12
com='top/bottom basket element'
' 1.75"x0.0598"x1.75" steel with 0.75" diam. hole'
ycyl 9 1 0.9525 0.1519 0.0
cubo 10 1 2p2.2225 0.1519 0.0 2p2.2225

unit 13
com='top/bottom basket element'
' 1.6902"x0.0598"x1.75" steel with 0.75" diam. hole'
ycyl 9 1 0.9525 0.1519 0.0
cubo 10 1 2p2.14655 0.1519 0.0 2p2.2225

unit 14
com='one complete basket top/bottom'
' 4x1x102 array of units 13&14
array 2 -8.7381 0.0 -226.695

unit 15
com='0.0598" steel at basket corners'
cubo 10 1 0.1519 0.0 0.1519 0.0 2p226.695

unit 16
com=" spacing & steel angle at -x side of basket "
cubo 9 1 5.08 0.0 2p8.89 2p226.695
hole 22 0.15875 0.0 0.0
hole 22 0.47625 -0.3175 0.0
hole 22 0.47625 0.3175 0.0
hole 22 0.79375 0.635 0.0
hole 22 0.79375 -0.635 0.0
hole 22 1.11125 0.9525 0.0
hole 22 1.11125 -0.9525 0.0
hole 22 1.42875 1.27 0.0
hole 22 1.42875 -1.27 0.0
hole 22 1.74625 1.5875 0.0
hole 22 1.74625 -1.5875 0.0
hole 22 2.06375 1.905 0.0
hole 22 2.06375 -1.905 0.0
hole 22 2.38125 2.2225 0.0
hole 22 2.38125 -2.2225 0.0
hole 22 2.69875 2.54 0.0
hole 22 2.69875 -2.54 0.0
```

```
hole 22  3.01625  2.8575 0.0
hole 22  3.01625 -2.8575  0.0
hole 22  3.33375  3.175 0.0
hole 22  3.33375 -3.175  0.0
hole 22  3.65125  3.4925 0.0
hole 22  3.65125 -3.4925  0.0
hole 22  3.96875  3.81 0.0
hole 22  3.96875 -3.81  0.0
hole 22  4.28625  4.1275 0.0
hole 22  4.28625 -4.1275  0.0
hole 22  4.60375  4.445 0.0
hole 22  4.60375 -4.445  0.0
hole 22  4.92125  4.7625 0.0
hole 22  4.92125 -4.7625  0.0

unit 17
com=" spacing & steel angle at +x side of basket "
cubo  9 1  0.0  -5.08 2p8.89  2p226.695
hole 22  -0.15875 0.0  0.0
hole 22  -0.47625 -0.3175 0.0
hole 22  -0.47625  0.3175 0.0
hole 22   -0.79375  0.635 0.0
hole 22  -0.79375  -0.635 0.0
hole 22  -1.11125  0.9525 0.0
hole 22  -1.11125  -0.9525 0.0
hole 22  -1.42875  1.27 0.0
hole 22  -1.42875  -1.27 0.0
hole 22  -1.74625  1.5875 0.0
hole 22  -1.74625  -1.5875 0.0
hole 22  -2.06375 1.905 0.0
hole 22  -2.06375 -1.905 0.0
hole 22  -2.38125  2.2225 0.0
hole 22  -2.38125 -2.2225  0.0
hole 22  -2.69875  2.54 0.0
hole 22  -2.69875 -2.54  0.0
hole 22 -3.01625  2.8575 0.0
hole 22  -3.01625 -2.8575  0.0
hole 22  -3.33375  3.175 0.0
hole 22  -3.33375 -3.175  0.0
hole 22  -3.65125  3.4925 0.0
hole 22  -3.65125 -3.4925  0.0
hole 22  -3.96875  3.81 0.0
hole 22  -3.96875 -3.81  0.0
hole 22  -4.28625  4.1275 0.0
hole 22  -4.28625 -4.1275  0.0
hole 22  -4.60375  4.445 0.0
hole 22  -4.60375 -4.445  0.0
hole 22  -4.92125  4.7625 0.0
hole 22  -4.92125 -4.7625  0.0

unit 18
com=" angles & spacing beneath baskets  "
cubo  9 1  2p8.89 5.08 0.0  2p226.695
hole 21  0.0  0.15875  0.0
```

```
hole 21 -0.3175  0.47625  0.0
hole 21  0.3175  0.47625  0.0
hole 21  0.635  0.79375  0.0
hole 21 -0.635  0.79375  0.0
hole 21  0.9525  1.11125  0.0
hole 21 -0.9525  1.11125  0.0
hole 21  1.27  1.42875  0.0
hole 21 -1.27  1.42875  0.0
hole 21  1.5875  1.74625  0.0
hole 21 -1.5875  1.74625  0.0
hole 21  1.905  2.06375  0.0
hole 21 -1.905  2.06375  0.0
hole 21  2.2225  2.38125  0.0
hole 21 -2.2225  2.38125  0.0
hole 21   2.54 2.69875 0.0
hole 21  -2.54 2.69875 0.0
hole 21  2.8575 3.01625  0.0
hole 21  -2.8575 3.01625 0.0
hole 21   3.175 3.33375 0.0
hole 21   -3.175 3.33375  0.0
hole 21    3.4925 3.65125 0.0
hole 21   -3.4925  3.65125 0.0
hole 21    3.81 3.96875 0.0
hole 21   -3.81 3.96875 0.0
hole 21    4.1275 4.28625 0.0
hole 21   -4.1275  4.28625 0.0
hole 21   4.445 4.60375 0.0
hole 21   -4.445  4.60375 0.0
hole 21    4.7625 4.92125 0.0
hole 21   -4.7625 4.92125 0.0

unit 19
com="angles & spacing above baskets "
cubo  9 1  2p8.89  0.0 -5.08  2p226.695
hole 21  0.0  -0.15875  0.0
hole 21 -0.3175  -0.47625  0.0
hole 21  0.3175  -0.47625  0.0
hole 21  0.635  -0.79375  0.0
hole 21 -0.635  -0.79375  0.0
hole 21  0.9525  -1.11125  0.0
hole 21 -0.9525  -1.11125  0.0
hole 21  1.27  -1.42875  0.0
hole 21 -1.27  -1.42875  0.0
hole 21  1.5875  -1.74625  0.0
hole 21 -1.5875  -1.74625  0.0
hole 21  1.905  -2.06375  0.0
hole 21 -1.905  -2.06375  0.0
hole 21  2.2225  -2.38125  0.0
hole 21 -2.2225  -2.38125  0.0
hole 21   2.54 -2.69875 0.0
hole 21  -2.54 -2.69875 0.0
hole 21  2.8575 -3.01625  0.0
hole 21  -2.8575 -3.01625 0.0
hole 21   3.175 -3.33375 0.0
```

```
hole 21  -3.175 -3.33375  0.0
hole 21   3.4925 -3.65125 0.0
hole 21  -3.4925  -3.65125 0.0
hole 21   3.81 -3.96875 0.0
hole 21  -3.81 -3.96875 0.0
hole 21   4.1275 -4.28625 0.0
hole 21  -4.1275  -4.28625 0.0
hole 21  4.445 -4.60375 0.0
hole 21  -4.445  -4.60375 0.0
hole 21   4.7625 -4.92125 0.0
hole 21  -4.7625 -4.92125 0.0

unit 20
com=" 2x2 inch moderation regions at corners "
cubo  9 1 4p2.54  2p226.695

unit 21
com="part of steel angle"
' 0.1552" x 0.125"
cubo  11 1 2p0.197104 2p0.15874 2p226.695

unit 22
com="part of steel angle"
' 0.125" x 0.1552"
cubo  11 1 2p0.15874 2p0.197104 2p226.695

unit 23
com="left (-x) 10x10 bundle in basket"
' bundle at outer edge, centered vertically
array  3 -8.7381 -6.510866 -226.695
cubo  9 1 2p8.7381 2p8.7381  2p226.695

unit 24
com="right 10x10 bundle in basket"
' bundle at outer edge, centered vertically
array  4 -4.2836334 -6.510866 -226.695
cubo  9 1 2p8.7381 2p8.7381  2p226.695

unit 25
com="complete left basket with bundle"
array 5 2r-8.89 -226.695

unit 26
com="complete right basket with bundle"
array 6 2r-8.89 -226.695

unit 27
com=" 1 inner container  "
array  7 -22.86 -13.97 -226.695
' add 0.0598 inch walls of carbon steel
repl  12 1 6r0.1519 1

unit 28
com=" 2x2 inch regions at corners "
```

```
cubo  9 1 4p2.54  2p226.695

unit 29
com='higher enriched rods'
cyli  15 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 2p0.49022  2p226.695
'  polyethylene shims between rods
cubo  14 1 4p0.6510866 2p226.695

global
unit 30
com=" 8x13x1 array of inners  "
array  8 -184.0952 -183.5847 -226.695
'  add 30 cm water reflector at all 6 faces
repl 13 2 6r3.0 10

end geom

read array

ara=1 nux=1 nuy=4 nuz=102
loop
9  1 1 1   2 3 1   1 102 1
10  1 1 1   1 4 3   1 102 1
end loop

ara=2 nux=4 nuy=1 nuz=102
loop
12  2 3 1   1 1 1   1 102 1
13  1 4 3   1 1 1   1 102 1
end loop


'  left bundle, poison corner at ll
ara=3 nux=09 nuy=09 nuz=1
fill
04 04 04 04 04 04 04 04 04
05 07 01 07 01 01 01 07 06
05 01 02 02 02 02 02 01 06
05 07 02 08 08 08 02 07 06
05 01 02 08 08 08 02 01 06
05 01 02 08 08 08 02 01 06
05 01 02 02 02 02 02 01 06
05 07 01 07 01 01 01 01 06
03 03 03 03 03 03 03 03 03
end fill

'  right bundle, poison corner at ur
ara=4 nux=09 nuy=09 nuz=1
fill
04 04 04 04 04 04 04 04 04
05 07 01 01 01 07 01 07 06
05 01 02 02 02 02 02 01 06
```

```
05 07 02 08 08 08 02 07 06
05 01 02 08 08 08 02 01 06
05 01 02 08 08 08 02 01 06
05 01 02 02 02 02 02 01 06
05 01 01 01 01 07 01 07 06
03 03 03 03 03 03 03 03 03
end fill
ara=5 nux=3 nuy=3 nuz=1
fill
15 14 15
11 23 11
15 14 15
end fill

ara=6 nux=3 nuy=3 nuz=1
fill
15 14 15
11 24 11
15 14 15
end fill

ara=7 nux=4 nuy=3 nuz=1
fill
20 18 18 20
16 25 26 17
28 19 19 28
end fill

ara=8 nux=08 nuy=13 nuz=1
fill f27 end fill

end array

read start nst=1
' xsm=-45.72 xsp=45.72 ysm=-27.94 ysp=27.94 zsm=-10 zsp=10
end start


read bounds all=vacuum end bounds
read bias id=500 2 11 end bias

read plot
ttl=" yx section of single storage location        "
nch=" xx^d>g: .$$$*x"
xul=-10.0  xlr=10.0   yul=10.0 ylr=-10.0 zul=0.0 zlr=0.0
uax=1.0 vdn=-1.0 nax=120 lpi=10 end
ttl=" yx section of single storage location        "
nch=" xx^d>g: .$$$*x"
xul=-40.0  xlr=40.0   yul=40.0 ylr=-40.0 zul=0.0 zlr=0.0
uax=1.0 vdn=-1.0 nax=120 lpi=10 end

ttl=" yx section of two bundles in inner container "
nch=" 123456789abcde"
xul=-10.0  xlr=10.0   yul=10.0 ylr=-10.0 zul=1.0 zlr=1.0
```

```
ttl=" yx section of two bundles in inner container "
nch=" 123456789abcde"
xul=-25.0  xlr=25.0  yul=15.0 ylr=-15.0 zul=1.0 zlr=1.0
uax=1.0 vdn=-1.0 nax=140 lpi=10 end
ttl=" yx section of left bundle in inner container "
xul=-5.0  xlr=55.0  yul=10.0 ylr=-10.0 zul=1.0 zlr=1.0
uax=1.0 vdn=-1.0 nax=140 lpi=10 end
ttl=" yx section of left bundle in inner container "
nch=" 123456789abcde"
xul=-20.0  xlr=0.0  yul=10.0 ylr=-10.0 zul=1.0 zlr=1.0
uax=1.0 vdn=-1.0 nax=140 lpi=10 end
ttl=" yx section of risght bundle in inner container "
nch=" 123456789abcde"
xul=0.0  xlr=20.0  yul=10.0 ylr=-10.0 zul=1.0 zlr=1.0
uax=1.0 vdn=-1.0 nax=140 lpi=10 end
end plot


end data
end
```

The model for the nominal condition KENO case ("a-n3a") is listed below.

```
=csas25
sp-1 with 5.0% enriched 9x9 fuel except exterior rods 5.0%
hans  infh

' uo2 1 0.98 293.0 92235 3.4643 92238 96.5357 end
uo2 1 0.98 293.0 92235 5.0   92238 95.0   end

' uo2 2 0.98 293.0 92235 3.4643 92238 96.5357 end
uo2 2 0.98 293.0 92235 5.0   92238 95.0   end

' uo2 3 0.98 293.0 92235 4.0 92238 96.0 end
uo2 3 0.98 293.0 92235 5.0 92238 95.0 end

uo2 4 0.98 293.0 92235 5.0 92238 95.0 end

uo2 5 0.98 293.0 92235 5.0 92238 95.0 end

uo2 6 0.98 293.0 92235 5.0 92238 95.0 end

' poison rod with 2% gd2o3
' td of uo2-gd2o3 = 10.96 -2.65*p/[p+0.67145*(1-p)], p=wt frac.gd2o3
' "p" is 0.02 here,  td is 10.9012
' pellet density is 0.98*10.9012=10.6832
' uo2 density is 0.985*10.6832 = 10.5230
```

```
' gd2o3 density is 0.02*10.6832 = 0.1602 gm/cc
uo2 7 den=10.5230 1.0 293.0 92235 5.00 92238 95.00 end
arbmgd2o3 0.1602 2 0 1 0 64000 2 8016 3
7 1.0 293. end

zircalloy 8 1.0 293.0 end

' water, 0 vol.%
h2o 9 1.e-15 293.0 end

' basket steel
carbonsteel 10 1.0 293.0 end
' angle steel
carbonsteel 11 1.0 293.0 end
' shell steel
carbonsteel 12 1.0 293.0 end


' douglas fir, same composition as oak, dens=0.48-0.55
oak 13 den=0.48 1.0 293 end

' polyethylene, 100 vol%
arbmpe 0.92 2 0 1 0 6012 1 1001 2
14 1.0 293. end

' higher enriched rods
uo2 15 0.98 293.0 92235 5.0 92238 95.0 end

end comp
more data
 res= 1 cyli 3.6257E-01 dan( 1)= 7.4052E-01
 res= 2 cyli 4.5228E-01 dan( 2)= 6.8442E-01
 res= 3 cyli 5.6262E-01 dan( 3)= 4.5534E-01
 res= 4 cyli 5.7306E-01 dan( 4)= 4.5112E-01
 res= 5 cyli 5.5324E-01 dan( 5)= 4.9582E-01
 res= 6 cyli 5.4917E-01 dan( 6)= 4.9697E-01
 res= 7 cyli 3.4934E-01 dan( 7)= 7.3961E-01
end more
sp-1 with 5.0% enriched 9x9 fuel except 4.0% edge rods
read parameters
tme=90 gen=200 npg=600 nsk=0
flx=yes fdn=yes xs1=yes nub=yes pwt=yes
run=yes plt=yes
end parameters
read geom

' pellet diam: 0.40"
' gap: zero
' clad thk: 0.015"
' pitch: 0.5696"

unit 1
com="interior rod"
cyli 1 1 0.5080 2p226.695
```

```
 cyli  8 1 0.54610  2p226.695
 cubo  9 1  2p0.723428  2p0.54610  2p226.695
 ' polyethylene shims between rods
 ' cubo  14 1 4p0.7234280 2p226.695
 '
 ' use ld water inplace of shims
  cubo  9 1 4p0.7234280 2p226.695

unit 2
com="interior rods around water rod"
cyli  2 1 0.5080 2p226.695
cyli  8 1 0.54610  2p226.695
cubo  9 1  2p0.7234280 2p0.54610  2p226.695
' polyethylene shims between rods
' cubo  14 1 4p0.7234280 2p226.695
'
' use ld water inplace of shims
 cubo  9 1 4p0.7234280 2p226.695

unit 3
com="edge rod facing up"
cyli  3 1 0.5080 2p226.695
cyli  8 1 0.54610  2p226.695
cubo  9 1  2p0.7234280 0.7234280 -0.54610  2p226.695
' polyethylene shims between rods
' cubo  14 1 4p0.7234280 2p226.695
'
' use ld water in place of shims
 cubo  9 1 4p0.7234280 2p226.695

unit 4
com="edge rod facing down"
cyli  4 1 0.5080 2p226.695
cyli  8 1 0.54610  2p226.695
cubo  9 1  2p0.7234280 0.54610 -0.7234280  2p226.695
' polyethylene shims between rods
' cubo  14 1 4p0.7234280 2p226.695
'
' use ld water in place of shims
 cubo  9 1 4p0.7234280 2p226.695

unit 5
com="edge rod facing other bundle"
cyli  5 1 0.5080 2p226.695
cyli  8 1 0.54610  2p226.695
cubo  9 1  2p0.7234280 2p0.54610  2p226.695
' polyethylene shims between rods
' cubo  14 1 4p0.7234280 2p226.695
'
' use ld water in place of shims
 cubo  9 1 4p0.7234280 2p226.695

unit 6
com="edge rod facing out"
```

```
cyli  6 1 0.5080 2p226.695
cyli  8 1 0.54610  2p226.695
cubo  9 1  2p0.7234280 2p0.54610  2p226.695
' polyethylene shims between rods
' cubo  14 1 4p0.7234280 2p226.695
'
' use ld water in place of shims
 cubo  9 1 4p0.7234280 2p226.695

 unit 7
com="uo2-gd2o3 rod"
cyli  7 1 0.5080 2p226.695
cyli  8 1 0.54610  2p226.695
cubo  9 1  2p0.7234280 2p0.54610  2p226.695
' polyethylene shims between rods
' cubo  14 1 4p0.7234280 2p226.695
'
' use ld water in place of shims
 cubo  9 1 4p0.7234280 2p226.695

 unit 8
com="water rod"
cubo  9 1 4p0.7234280  2p226.695

unit 9
com='side basket element, 0.0598"x1.75"x1.75" steel with 0.75" diam. hole'
xcyl 9 1 0.9525 0.1519 0.0
cubo 10 1 0.1519 0.0 4p2.2225

unit 10
com='side basket element, 0.0598"x1.6902"x1.75" steel with 0.75" diam. hole'
xcyl 9 1 0.9525 0.1519 0.0
cubo 10 1 0.1519 0.0 2p2.14655 2p2.2225

unit 11
com='one complete basket side'
'  1x4x102 array of units 10 & 11
array 1 0.0 -8.7381 -226.695

unit 12
com='top/bottom basket element'
' 1.75"x0.0598"x1.75" steel with 0.75" diam. hole"
ycyl 9 1 0.9525 0.1519 0.0
cubo 10 1 2p2.2225 0.1519 0.0 2p2.2225

unit 13
com='top/bottom basket element'
' 1.6902"x0.0598"x1.75" steel with 0.75" diam. hole'
ycyl 9 1 0.9525 0.1519 0.0
cubo 10 1 2p2.14655 0.1519 0.0 2p2.2225

unit 14
com='one complete basket top/bottom'
'  4x1x102 array of units 13&14
```

```
array 2 -8.7381 0.0 -226.695

unit 15
com='0.0598" steel at basket corners'
cubo 10 1 0.1519 0.0 0.1519 0.0 2p226.695

unit 16
com=" spacing & steel angle at -x side of basket "
cubo  9 1  5.08 0.0 2p8.89  2p226.695
hole 22   0.15875 0.0  0.0
hole 22  0.47625 -0.3175 0.0
hole 22   0.47625  0.3175 0.0
hole 22   0.79375  0.635 0.0
hole 22  0.79375  -0.635 0.0
hole 22  1.11125  0.9525 0.0
hole 22  1.11125  -0.9525 0.0
hole 22  1.42875  1.27 0.0
hole 22  1.42875  -1.27 0.0
hole 22  1.74625  1.5875 0.0
hole 22  1.74625  -1.5875 0.0
hole 22  2.06375  1.905 0.0
hole 22  2.06375 -1.905 0.0
hole 22  2.38125  2.2225 0.0
hole 22  2.38125 -2.2225  0.0
hole 22  2.69875  2.54 0.0
hole 22  2.69875 -2.54  0.0
hole 22  3.01625  2.8575 0.0
hole 22  3.01625 -2.8575  0.0
hole 22  3.33375  3.175 0.0
hole 22  3.33375 -3.175  0.0
hole 22  3.65125  3.4925 0.0
hole 22  3.65125 -3.4925  0.0
hole 22  3.96875  3.81 0.0
hole 22  3.96875 -3.81  0.0
hole 22  4.28625  4.1275 0.0
hole 22  4.28625 -4.1275  0.0
hole 22  4.60375  4.445 0.0
hole 22  4.60375 -4.445  0.0
hole 22  4.92125  4.7625 0.0
hole 22  4.92125 -4.7625  0.0

unit 17
com=" spacing & steel angle at +x side of basket "
cubo  9 1  0.0  -5.08 2p8.89  2p226.695
hole 22  -0.15875 0.0  0.0
hole 22  -0.47625 -0.3175 0.0
hole 22  -0.47625  0.3175 0.0
hole 22   -0.79375  0.635 0.0
hole 22  -0.79375  -0.635 0.0
hole 22  -1.11125  0.9525 0.0
hole 22  -1.11125  -0.9525 0.0
hole 22  -1.42875  1.27 0.0
hole 22  -1.42875  -1.27 0.0
hole 22  -1.74625  1.5875 0.0
```

```
hole 22 -1.74625 -1.5875 0.0
hole 22 -2.06375 1.905 0.0
hole 22 -2.06375 -1.905 0.0
hole 22 -2.38125 2.2225 0.0
hole 22 -2.38125 -2.2225 0.0
hole 22 -2.69875 2.54 0.0
hole 22 -2.69875 -2.54 0.0
hole 22 -3.01625 2.8575 0.0
hole 22 -3.01625 -2.8575 0.0
hole 22 -3.33375 3.175 0.0
hole 22 -3.33375 -3.175 0.0
hole 22 -3.65125 3.4925 0.0
hole 22 -3.65125 -3.4925 0.0
hole 22 -3.96875 3.81 0.0
hole 22 -3.96875 -3.81 0.0
hole 22 -4.28625 4.1275 0.0
hole 22 -4.28625 -4.1275 0.0
hole 22 -4.60375 4.445 0.0
hole 22 -4.60375 -4.445 0.0
hole 22 -4.92125 4.7625 0.0
hole 22 -4.92125 -4.7625 0.0

unit 18
com=" angles & spacing beneath baskets "
cubo 9 1 2p8.89 5.08 0.0 2p226.695
hole 21 0.0 0.15875 0.0
hole 21 -0.3175 0.47625 0.0
hole 21 0.3175 0.47625 0.0
hole 21 0.635 0.79375 0.0
hole 21 -0.635 0.79375 0.0
hole 21 0.9525 1.11125 0.0
hole 21 -0.9525 1.11125 0.0
hole 21 1.27 1.42875 0.0
hole 21 -1.27 1.42875 0.0
hole 21 1.5875 1.74625 0.0
hole 21 -1.5875 1.74625 0.0
hole 21 1.905 2.06375 0.0
hole 21 -1.905 2.06375 0.0
hole 21 2.2225 2.38125 0.0
hole 21 -2.2225 2.38125 0.0
hole 21 2.54 2.69875 0.0
hole 21 -2.54 2.69875 0.0
hole 21 2.8575 3.01625 0.0
hole 21 -2.8575 3.01625 0.0
hole 21 3.175 3.33375 0.0
hole 21 -3.175 3.33375 0.0
hole 21 3.4925 3.65125 0.0
hole 21 -3.4925 3.65125 0.0
hole 21 3.81 3.96875 0.0
hole 21 -3.81 3.96875 0.0
hole 21 4.1275 4.28625 0.0
hole 21 -4.1275 4.28625 0.0
hole 21 4.445 4.60375 0.0
hole 21 -4.445 4.60375 0.0
```

```
hole 21   4.7625 4.92125 0.0
hole 21  -4.7625 4.92125 0.0

unit 19
com="angles & spacing above baskets  "
cubo  9 1  2p8.89  0.0 -5.08  2p226.695
hole 21  0.0  -0.15875  0.0
hole 21 -0.3175  -0.47625  0.0
hole 21  0.3175  -0.47625  0.0
hole 21  0.635  -0.79375  0.0
hole 21 -0.635  -0.79375  0.0
hole 21  0.9525  -1.11125  0.0
hole 21 -0.9525  -1.11125  0.0
hole 21  1.27  -1.42875  0.0
hole 21 -1.27  -1.42875  0.0
hole 21  1.5875  -1.74625  0.0
hole 21 -1.5875  -1.74625  0.0
hole 21  1.905  -2.06375  0.0
hole 21 -1.905  -2.06375  0.0
hole 21  2.2225  -2.38125  0.0
hole 21 -2.2225  -2.38125  0.0
hole 21   2.54 -2.69875 0.0
hole 21  -2.54 -2.69875 0.0
hole 21  2.8575 -3.01625  0.0
hole 21  -2.8575 -3.01625 0.0
hole 21   3.175 -3.33375 0.0
hole 21   -3.175 -3.33375  0.0
hole 21    3.4925 -3.65125 0.0
hole 21   -3.4925  -3.65125 0.0
hole 21    3.81 -3.96875 0.0
hole 21   -3.81 -3.96875 0.0
hole 21    4.1275 -4.28625 0.0
hole 21   -4.1275  -4.28625 0.0
hole 21   4.445 -4.60375 0.0
hole 21   -4.445  -4.60375 0.0
hole 21    4.7625 -4.92125 0.0
hole 21   -4.7625 -4.92125 0.0

unit 20
com=" 2x2 inch moderation regions at corners "
cubo  9 1 4p2.54  2p226.695

unit 21
com="part of steel angle"
' 0.1552" x 0.125"
cubo  11 1 2p0.197104 2p0.15874 2p226.695

unit 22
com="part of steel angle"
' 0.125" x 0.1552"
cubo  11 1 2p0.15874 2p0.197104 2p226.695

unit 23
com="left (-x) 10x10 bundle in basket"
```

```
' bundle at outer edge, centered vertically
array  3 -8.7381 -6.510866 -226.695
cubo  9 1 2p8.7381 2p8.7381  2p226.695

unit 24
com="right 10x10 bundle in basket"
' bundle at outer edge, centered vertically
array  4 -4.2836334 -6.510866 -226.695
cubo  9 1 2p8.7381 2p8.7381  2p226.695

unit 25
com="complete left basket with bundle"
array 5 2r-8.89 -226.695

unit 26
com="complete right basket with bundle"
array 6 2r-8.89 -226.695

unit 27
com=" 1 inner container  "
array  7 -22.86 -13.97 -226.695
' add 0.0598 inch walls of carbon steel
repl  12 1 6r0.1519 1
cubo   9 1 2p32.385  2p30.48  2p261.9375

unit 28
com=" 2x2 inch regions at corners "
cubo  9 1 4p2.54  2p226.695

unit 29
com='higher enriched rods'
cyli  15 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 2p0.49022  2p226.695
' polyethylene shims between rods
cubo  14 1 4p0.6510866 2p226.695


unit 30
com='top'
' plywood only width: 29.75 - 2*3.25 = 23.25"
cubo  13 1 2p29.5275 4.1275 0.0 8.255 0.0
'  38.25" im
repl  9 1 4r0.0 97.155 0.0 1
'  add stud
repl  13 1 4r0.0 8.255 0.0 1
'  36.75" im
repl  9 1 4r0.0 93.345 0.0 1
'  add stud
repl  13 1 4r0.0 8.255 0.0 1
'  36.75" im
repl  9 1 4r0.0 93.345 0.0 1
'  add stud
repl  13 1 4r0.0 8.255 0.0 1
```

```
' 36.75" im
repl 9 1 4r0.0 93.345 0.0 1
' add stud
repl 13 1 4r0.0 8.255 0.0 1
' 38.25" im
repl 9 1 4r0.0 97.155 0.0 1
' add studs & plywood
repl 13 1 2r8.255 0.0 1.27 8.255 0.0 1

unit 31
com='base'
' space to first skid
cubo 9 1 2p37.7825 8.255 0.0 13.97 0.0
' 4x4 skid
repl 13 1 4r0.0 8.255 0.0 1
' 44.75" im
repl 9 1 4r0.0 113.665 0.0 1
' 4x4 skid
repl 13 1 4r0.0 8.255 0.0 1
' 44.75" im
repl 9 1 4r0.0 113.665 0.0 1
' 4x4 skid
repl 13 1 4r0.0 8.255 0.0 1
' 44.75" im
repl 9 1 4r0.0 113.665 0.0 1
' 4x4 skid
repl 13 1 4r0.0 8.255 0.0 1
' 44.75" im
repl 9 1 4r0.0 113.665 0.0 1
' 4x4 skid
repl 13 1 4r0.0 8.255 0.0 1
' add space at +z
repl 9 1 4r0.0 13.97 0.0 1
' add 1.605" wood at +y
repl 13 1 2r0.0 4.1275 3r0.0 1

unit 32
com='+x side'
' plywood only width: 24.00 - 2*3.25 = 17.5"
cubo 13 1 4.1275 0.0 2p22.225 8.255 0.0
' 38.25" im
repl 9 1 4r0.0 97.155 0.0 1
' add stud
repl 13 1 4r0.0 8.255 0.0 1
' 36.75" im
repl 9 1 4r0.0 93.345 0.0 1
' add stud
repl 13 1 4r0.0 8.255 0.0 1
' 36.75" im
repl 9 1 4r0.0 93.345 0.0 1
' add stud
repl 13 1 4r0.0 8.255 0.0 1
' 36.75" im
repl 9 1 4r0.0 93.345 0.0 1
```

```
' add stud
repl  13 1 4r0.0 8.255 0.0 1
' 38.25" im
repl  9 1 4r0.0 97.155 0.0 1
' add stud & plywood
repl  13 1 0.0 1.27 2r8.255 8.255 0.0 1

unit 33
com='-x side'
' plywood only width: 24.00 - 2*3.25 = 17.5"
cubo  13 1 4.1275 0.0 2p22.225 8.255 0.0
' 38.25" im
repl  9 1 4r0.0 97.155 0.0 1
' add stud
repl  13 1 4r0.0 8.255 0.0 1
' 36.75" im
repl  9 1 4r0.0 93.345 0.0 1
' add stud
repl  13 1 4r0.0 8.255 0.0 1
' 36.75" im
repl  9 1 4r0.0 93.345 0.0 1
' add stud
repl  13 1 4r0.0 8.255 0.0 1
' 36.75" im
repl  9 1 4r0.0 93.345 0.0 1
' add stud
repl  13 1 4r0.0 8.255 0.0 1
' 38.25" im
repl  9 1 4r0.0 97.155 0.0 1
' add stud & plywood
repl  13 1 1.27 0.0 2r8.255 8.255 0.0 1

unit 34
com='inner container & wood sides'
array 8 3r0.0

unit 35
com='complete outer container'
array 9 3r0.0

global
unit 36
com=" 10x10x1 array of inners "
array  10 3r0.0


end geom

read array

ara=1 nux=1 nuy=4 nuz=102
loop
9  1 1 1   2 3 1  1 102 1
```

```
10 1 1 1  1 4 3  1 102 1
end loop

ara=2 nux=4 nuy=1 nuz=102
loop
12  2 3 1  1 1 1  1 102 1
13  1 4 3  1 1 1  1 102 1
end loop


' left bundle, poison corner at ll
ara=3 nux=09 nuy=09 nuz=1
fill
04 04 04 04 04 04 04 04 04
05 07 01 07 01 01 01 07 06
05 01 02 02 02 02 02 01 06
05 07 02 08 08 08 02 07 06
05 01 02 08 08 08 02 01 06
05 01 02 08 08 08 02 01 06
05 01 02 02 02 02 02 01 06
05 07 01 07 01 01 01 01 06
03 03 03 03 03 03 03 03 03
end fill

' right bundle, poison corner at ur
ara=4 nux=09 nuy=09 nuz=1
fill
04 04 04 04 04 04 04 04 04
05 07 01 01 01 07 01 07 06
05 01 02 02 02 02 02 01 06
05 07 02 08 08 08 02 07 06
05 01 02 08 08 08 02 01 06
05 01 02 08 08 08 02 01 06
05 01 02 02 02 02 02 01 06
05 01 01 01 01 07 01 07 06
03 03 03 03 03 03 03 03 03
end fill
ara=5 nux=3 nuy=3 nuz=1
fill
15 14 15
11 23 11
15 14 15
end fill

ara=6 nux=3 nuy=3 nuz=1
fill
15 14 15
11 24 11
15 14 15
end fill

ara=7 nux=4 nuy=3 nuz=1
fill
20 18 18 20
```

```
16 25 26 17
28 19 19 28
end fill

ara=8 nux=3 nuy=1 nuz=1
fill 33 27 32 end fill

ara=9 nux=1 nuy=3 nuz=1
fill 31 34 30 end fill

ara=10 nux=10 nuy=10 nuz=1
fill f35 end fill
end array

read start nst=1 end start
read bounds all=spec end bounds
' read bias ld=500 2 11 end bias
end data
end
```

The model for XSDRN case ("a-h4025a") at flooded conditions is listed below.

```
=csasix
sp-1 with 5.0% enriched 10x10 fuel
hans latt

' external water, 100 vol.%
h2o 1 1.0 293.0 end

uo2 2 0.98 293.0 92235 5.0 92238 95.0 end

' water in unit cell
h2o 3 1.0 293.0 end

zircalloy 4 1.0 293.0 end

end comp
' pod .4" clad .015" vw/vf=2.5 pitch=1.726326 cm
squa 1.726326 1.0160 2 3 1.09220 4 end
end
=xsdrn
' inf array of inners
0$$ a3 2 e
1$$ 2 2 100 1 3 2 2 8 2r1 10 80 3r0
2$$ -1 -1 4r0 -1 e
3$$ 0 e
```

```
' 4$$ -1 16 0 e
5** 2r1.0e-5 e
t
13$$ 1 2
14$$ 500 1
15** f1.0
 t
33## f1.0
 t
35** 49i0.0 49i10.133134 20.164682
36$$ 50r1 50r2
39$$ 1 2
t
end
```

A typical CASMO case ("d.8gd15") is listed below.

```
DIM 9,1
TIT TFU=293.15 TMO=293.15 BOR=0 *  INNERS ONLY
FUE 1 10.7408/5.0 *98%TD, 5.0%ENR
FUE 2 10.7408/5.0 *98%TD, 5.0%ENR
FUE 3 10.7408/5.0 *98%TD, 5.0%ENR
FUE 4 10.6832/5.00,7301=1.5 *98%TD, 5.00%ENR
VOI, 90.
 MOD,  .149730/1001=11.19,8000=88.81
 MI1  .686305/26000=84.829155 ,6000= 1.731207 ,1001= 1.503896 ,8000=11.935745
 MI2  .303433/26000=66.611275 ,6000= 1.359414 ,1001= 3.584080 ,8000=28.445229
 MI3  .494868/26000=79.243896 ,6000= 1.617222 ,1001= 2.141640 ,8000=16.997234
 MI4 6.705978/26000=97.789505 ,6000= 1.995704 ,1001=  .024035 ,8000=  .190758
 MI5  .646048/26000=83.929482 ,6000= 1.712847 ,1001= 1.606623 ,8000=12.751048
 MI6  .541578/26000=80.970863 ,6000= 1.652467 ,1001= 1.944449 ,8000=15.446123
*  COO   .465105/1001=13.991474,6000=75.437164,8000=10.571368
 COO,  .149730/1001=11.19,8000=88.81
MI7 0.001/8000=100.0
*  0.5127" pitch,
*  POD/CID/COD=0.40/0.40/0.436"
PIN 1  0.5080  0.55372/'1' 'CAN'//1
PIN 2  0.5080  0.55372/'2' 'CAN'//1
PIN 3  0.5080  0.55372/'3' 'CAN'//1
PIN 4  0.5080  0.55372/'4' 'CAN'//1
PIN 5  0.5080 0.7234/'MOD' 'MOD'//1
BWR  9  1.446856  13.0217 0.0 3*0.0 1
LPI
1 1 1 1 1 1 1 1 1
1 2 3 2 2 2 2 2 1
1 2 3 3 3 3 3 2 1
1 2 3 5 5 5 3 2 1
1 2 3 5 5 5 3 2 1
1 2 3 5 5 5 3 2 1
```

```
1 2 3 3 3 3 3 2 1
1 2 2 2 2 2 2 2 1
1 1 1 1 1 1 1 1 1
/'F'
FST 4.9281,2.54,0.1519,2.54/0.001,3*5.2319/
'MI1','MI2','MI1','MI3',3*'MI4','MI3'/
'MI7','MI7','MI7','MI5','MI6','MI5','MI6','MI5'/
8,4,2,4/1,3*8/
STA
TIT,*+ TRY #2
* RES,,0.0
LST,2*1
LPI
1 1 1 1 1 1 1 1 1
1 4 2 2 4 2 2 4 1
1 2 3 3 3 3 3 2 1
1 2 3 5 5 5 3 2 1
1 4 3 5 5 5 3 4 1
1 2 3 5 5 5 3 2 1
1 2 3 3 3 3 3 2 1
1 4 2 2 4 2 2 4 1
1 1 1 1 1 1 1 1 1
/'F'
STA
TIT,*+ TRY #3
* RES,0.0
LST,2*1
LPI
1 1 1 1 1 1 1 1 1
1 4 2 2 2 4 2 4 1
1 2 3 3 3 3 4 2 1
1 2 3 5 5 5 3 4 1
1 2 3 5 5 5 3 2 1
1 2 3 5 5 5 3 2 1
1 2 4 3 3 3 3 2 1
1 4 2 2 2 2 2 4 1
1 1 1 1 1 1 1 1 1
/'F'
STA
TIT,*+ TRY #3a
* RES,0.0
LST,2*1
LPI
1 1 1 1 1 1 1 1 1
1 4 2 2 2 4 2 4 1
1 2 3 3 3 3 4 2 1
1 4 3 5 5 5 3 4 1
1 2 3 5 5 5 3 2 1
1 2 3 5 5 5 3 2 1
1 2 3 3 3 3 3 2 1
1 2 2 2 2 4 2 4 1
1 1 1 1 1 1 1 1 1
/'F'
STA
```

```
TIT,*+ TRY #3b
* RES,0.0
LST,2*1
LPI
1 1 1 1 1 1 1 1 1
1 4 2 2 2 4 2 4 1
1 2 3 3 3 3 4 2 1
1 2 3 5 5 5 3 4 1
1 4 3 5 5 5 3 2 1
1 2 3 5 5 5 3 2 1
1 2 3 3 3 3 4 2 1
1 2 2 2 2 4 2 4 1
1 1 1 1 1 1 1 1 1
/'F'
STA
TIT,*+ TRY #4
* RES,0.0
LST,2*1
LPI
1 1 1 1 1 1 1 1 1
1 4 2 2 2 4 2 4 1
1 2 3 3 3 3 3 2 1
1 4 3 5 5 5 3 4 1
1 2 3 5 5 5 3 2 1
1 2 3 5 5 5 3 2 1
1 2 3 3 3 3 3 2 1
1 4 2 2 2 4 2 4 1
1 1 1 1 1 1 1 1 1
/'F'
STA
TIT,*+ TRY #5
* RES,0.0
LST,2*1
LPI
1 1 1 1 1 1 1 1 1
1 4 2 2 2 2 2 4 1
1 2 3 3 4 3 4 2 1
1 4 3 5 5 5 3 2 1
1 2 3 5 5 5 4 2 1
1 2 3 5 5 5 3 2 1
1 2 3 3 3 3 3 2 1
1 2 2 2 2 4 2 4 1
1 1 1 1 1 1 1 1 1
/'F'
STA
TIT,*+ TRY #5a
* RES,0.0
LST,2*1
LPI
1 1 1 1 1 1 1 1 1
1 4 2 2 2 2 2 4 1
1 2 3 3 4 3 3 2 1
1 4 3 5 5 5 3 2 1
1 2 3 5 5 5 4 2 1
```

```
1 2 3 5 5 5 3 2 1
1 2 3 3 3 3 4 2 1
1 2 2 2 2 4 2 4 1
1 1 1 1 1 1 1 1 1
/'F'
STA
TIT,*+ TRY #5b
* RES,0.0
LST,2*1
LPI
1 1 1 1 1 1 1 1 1
1 4 2 2 2 2 2 4 1
1 2 3 3 4 3 3 2 1
1 4 3 5 5 5 3 2 1
1 2 3 5 5 5 4 2 1
1 2 3 5 5 5 3 2 1
1 2 3 3 4 3 3 2 1
1 2 2 2 2 4 2 4 1
1 1 1 1 1 1 1 1 1
/'F'
STA
TIT,*+ TRY #6
* RES,0.0
LST,2*1
LPI
1 1 1 1 1 1 1 1 1
1 2 2 2 2 4 2 4 1
1 2 3 3 3 3 3 2 1
1 2 3 5 5 5 3 2 1
1 2 3 5 5 5 3 4 1
1 4 3 5 5 5 3 2 1
1 2 3 3 3 3 3 4 1
1 4 2 2 4 2 4 2 1
1 1 1 1 1 1 1 1 1
/'F'
STA
TIT,*+ TRY #7
* RES,0.0
LST,2*1
LPI
1 1 1 1 1 1 1 1 1
1 2 2 2 2 4 2 4 1
1 2 4 3 3 3 3 2 1
1 2 3 5 5 5 3 2 1
1 2 3 5 5 5 3 2 1
1 4 3 5 5 5 3 4 1
1 2 3 3 3 3 3 2 1
1 4 2 2 2 4 2 4 1
1 1 1 1 1 1 1 1 1
/'F'
STA
TIT,*+ TRY #8
* RES,0.0
LST,2*1
```

```
LPI
1 1 1 1 1 1 1 1 1
1 2 2 2 2 2 2 2 1
1 2 3 3 3 3 3 2 1
1 2 3 5 5 5 3 2 1
1 2 3 5 5 5 3 2 1
1 2 3 5 5 5 3 2 1
1 2 3 3 3 3 3 2 1
1 2 2 2 2 2 2 2 1
1 1 1 1 1 1 1 1 1
/'F'
STA
END
```

Appendix 6F

CRITICALITY EVALUATION FOR SIEMENS POWER CORPORATION CONSOLIDATED APPLICATION FOR CERTIFICATE OF COMPLIANCE 9248

Siemens Power Corporation - Nuclear Division

EMF-1563
Revision 3

Issue Date:

**Consolidated License Application for Siemens Power Corporation
Model SP-1 and SP-2 Shipping Containers**

Certificate of Compliance No. 9248
Docket No. 71-9248

EMF-1563
Revision 3

Consolidated License Application for Siemens Power Corporation
Model SP-1 and SP-2 Shipping Containers

Prepared: [signature] — 5/20/98
J. B. Edgar, Staff Engineer Licensing
Regulatory Compliance
Date

Concurred: [signature] for BFB — 5/20/98
B. F. Bentley, Manager
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Concurred: T M Howe — 5/20/98
T. M Howe, Manager
Product Mechanical Engineering
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Concurred: Doug Adkisson — 5/20/98
D. A. Adkisson, Manager
Quality Engineering
Date

Concurred: [signature] for CMP — 5-20-98
C. M. Powers, Vice President
Quality and Regulatory Affairs
Date

Approved: Loren Maas — 5/20/98
L. J. Maas, Manager
Regulatory Compliance
Date

Nature of Changes

Item	Paragraph or Page(s)	Description and Justification
1.	Fig.1.1, 1.2, 1.3	Revised license drawings.
2.	Table 1.1	Revised list of license drawings.
3.	Pages 1-10 through 1-12	Revised container drawings
4.	Pages 6-1 through 6-32	Revised criticality evaluation.

Contents

6. Criticality Evaluation

6.1 *Introduction and Summary*

6.1.1 Introduction

This supplemental Criticality Safety Evaluation (CSE) for the SP-1 and SP-2 shipping containers improves the CSE's provided in References 1 through 3 by justifying the use of the SP-1 and SP-2 inner containers with reduced spacing dimensions (see Section 6.3.1).

Section 6.2 details the methodologies used for the criticality analysis. Component description and analysis are provided in Section 6.3. Section 6.4 contains the Quality Assurance (QA) review. Section 6.5 provides sample input listings. Section 6.6 documents the references.

6.1.2 Summary

This CSE shows that shipping SP-1 and SP-2 inner containers with the materials and transport indices provided in the current shipping certificate (Reference 6) is justified if a space of at least 1.9375" (1-15/16") exists between the channel and the outer steel shell (this space is occupied/established by angle steel; previous analyses used 2").

6.2 *Analysis Methodology*

6.2.1 Nuclear Analysis Methodology

Monte Carlo techniques were used in this analysis. The sensitivity of pellet diameter, pellet pitch, interspersed moderator, and placement of the fuel assemblies within SP-1 and SP-2 inner containers were evaluated.

6.2.2 Computer Codes and Databases Used

The following codes and cross section libraries are part of the SCALE 4.2 system of codes (Reference 4) placed on the SPC HP workstation SSL01.

```
791176    Jun 22 1994 11:36:41 o0o001.a (XSDRN)
545416    Feb 21 1994 10:25:06 o0o002.a (NITAWL)
516744    Feb 21 1994 10:14:38 o0o008.a (BONAMI)
1094280   Jun 22 1994 11:46:27 o0o009.a (KENO.Va)
112000    Feb 23 1994 15:16:47 albdata.bin
4256216   Feb 23 1994 14:40:21 pxs123.bin (123 group master cross section
library)
362140    Feb 25 1994 16:54:21 pxs16.bin (16 group master cross section
library)
9020996   Feb 23 1994 14:53:45 pxs218.bin (218 group master cross section
library)
824404    Feb 23 1994 14:38:03 pxs27.bin (27 group master cross section
library)
94400     Feb 23 1994 15:12:03 stdcomp.bin (standard comp. library)
44812     Feb 23 1994 15:14:40 wtdata.bin
287       Jul  7 1994 09:35:35 csas25
2295      Jul  7 1994 17:07:41 drva
```

6.2.3 Cross Section Preparation

BONAMI and NITAWL adjust the cross section data for the specific problem (e.g., perform resonance self-shielding corrections). The Hansen-Roach 16-energy group cross sections available in SCALE were used for all calculations.

6.2.4 Benchmarking

The SCALE 4.2 system of codes was developed for use by the USNRC and its licensees. SPC benchmarking of SCALE 4.2 on HP Workstations includes critical experiments of 4.31% enriched assemblies from NUREG/CR-0073 (Reference 5) which were modeled using the same methodology used in these calculations. The benchmark data used for this CSE includes the same data used to support previous revisions to Certificate of Compliance 9248. A bias estimate based on 23 pooled cases was calculated from the 16-group data in Table 12 of Reference 10 and is -0.00321 ± 0.00261. Negative bias indicates conservative results.

6.3 *Component Description and Analysis*

6.3.1 Reduced Dimensions of SP-1 and SP-2 Inner Containers

The dimensions of the SP-1 and SP-2 inner containers are shown on drawings EMF-304,416 and EMF-308,257, respectively. In previous analyses, the SP-1 and SP-2 inner containers were modeled with a 2" space between the channel and the outer steel shell (this space is occupied/established by angle steel). The calculations of this section justify the use of a 1-15/16" space, instead of 2". This change in dimension only affects the calculations for damaged conditions, as the outer container provides the container spacing for undamaged conditions. The types and forms of fuel categories listed in the SP-1/SP-2 Certificate of Compliance (Reference 6) are evaluated below.

The KENO models used in this section are consistent with those used previously for the respective material types with one exception, i.e., the inner container spacing, discussed above.

6.3.1.1 Fuel Category 1

The following fuel description is listed under 5(b)(1)(i) of Reference 6:

> "UO_2 fuel assemblies in a 7x7, an 8x8, or a 9x9 square array with a maximum fuel cross-section area of 25 square inches, maximum fuel length of 174 inches and maximum average enrichment of 3.3 w/o U-235. Minimum zircaloy clad thickness is 0.025 inches; maximum pellet diameter is 0.555 inches. Any number of water rods in any arrangement are permitted."

The original calculations for this material type were performed by General Electric. In order to perform calculations supporting the reduced inner container dimensions, as discussed above, the calculations from Section 6.3.1.2, below, were modified and used here. The following changes were made to the Section 6.3.1.2 input decks:

- Reduced the ^{235}U enrichment from 4.0 to 3.3 wt%
- Replaced the Gd_2O_3 rods with 3.3 wt% enriched UO_2 rods
- Reduced the array size from infinite to 13x20x1 (260 containers)

A sensitivity study was performed for interspersed moderator and the reduced inner container dimensions, as discussed above. The results of these calculations are provided in Table 6.1 and presented graphically in Figure 6.1. As shown, the peak reactivity for both the old dimensions and the new dimensions occurs at 12 vol% interspersed moderator. The reduced dimensions result in a Δk_{eff} of +0.00507 at peak interspersed moderator. The results show sufficient margin to 0.95 to support a Transport Index of 0.4 (125 containers).

Table 6.1 Container Spacing and Interspersed Moderator (IM) Sensitivity Study for Fuel Category 1 Inside SP-1/SP-2 Inner Containers, 13x20x1 Array (260 containers), Damaged Conditions

File Name (droa-)	Vol% IM	k_{eff}	σ	$k_{eff} + 2\sigma$
2" Spacing around Channel Steel				
sp1.c1.010	10	0.89276	0.00290	0.89856
sp1.c1.011	11	0.89750	0.00265	0.90280
sp1.c1.012	***12***	***0.90216***	***0.00251***	***0.90718***
sp1.c1.013	13	0.89881	0.00262	0.90405
sp1.c1.014	14	0.89107	0.00224	0.89555
1-15/16" Spacing around Channel Steel				
sp1.c1.s2.010	10	0.89350	0.00290	0.89930
sp1.c1.s2.011	11	0.90288	0.00275	0.90838
sp1.c1.s2.012	***12***	***0.90789***	***0.00218***	***0.91225***
sp1.c1.s2.013	13	0.90547	0.00269	0.91085
sp1.c1.s2.014	14	0.90177	0.00264	0.90705

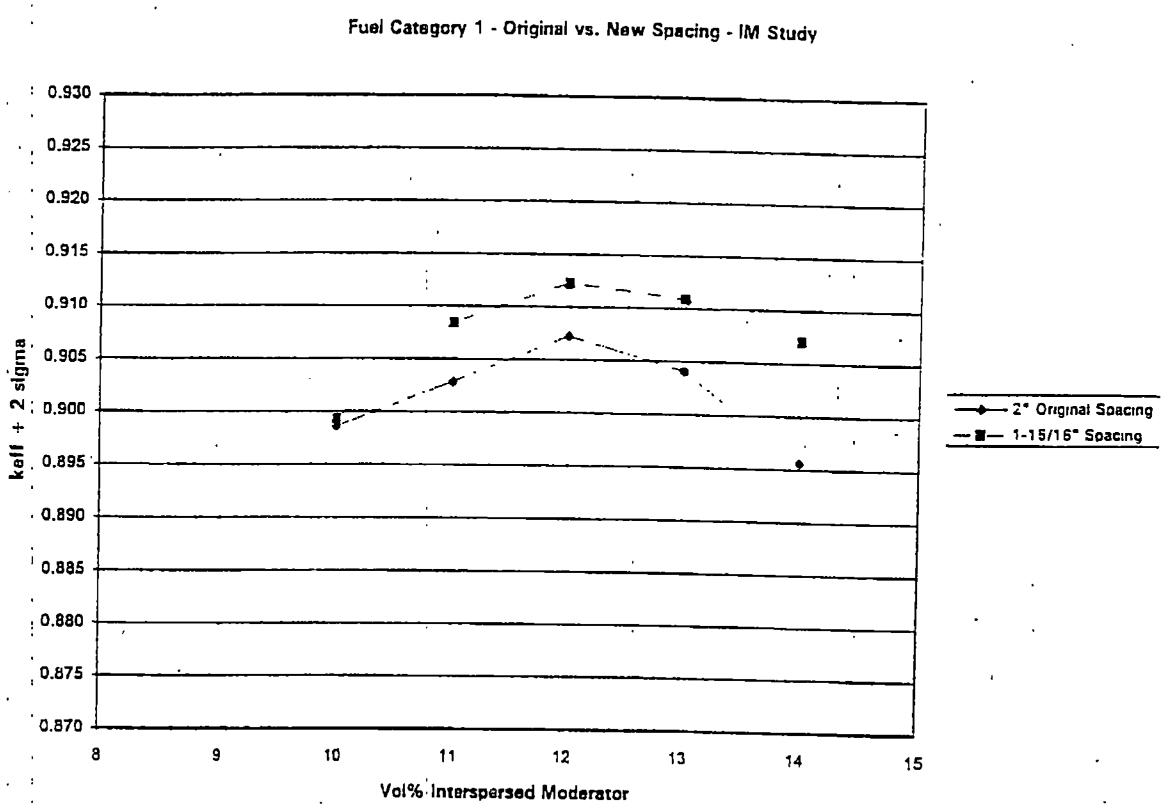

Figure 6.1 Container Spacing and Interspersed Moderator Sensitivity Study for Fuel Category 1 Inside SP-1/SP-2 Inner Container, 13x20x1 Array (260 containers), Damaged Conditions

6.3.1.2 Fuel Category 2

The following fuel description is listed under 5(b)(1)(ii) of Reference 6:

> "UO_2 fuel assemblies in a 7x7, an 8x8, or a 9x9 square array with a maximum fuel length of 174 inches, and a maximum average enrichment between 3.3 and 4.0 w/o U-235. The maximum pellet diameter is 0.555 inch, and the minimum clad thickness is 0.025 inch. Any number of water rods in any arrangement is permitted, including part length rods. Each assembly contains at least 4 rods with nominal 2 weight percent Gd_2O_3, which are in non-perimeter locations and are symmetric about the diagonal."

The original calculations for this material type are found in Appendix 6A of Reference 7. The Reference 7 calculations are unavailable from permanent storage, so the listing of the most reactive case was retyped and rerun. The most reactive case from Reference 7 is for a 9x9 assembly (type G2) with a k_{inf} of 0.9611 ± 0.0032 (see page 6-A18 of Reference 7). The retyped version of this calculation yielded a k_{inf} of 0.96200 ± 0.00306. This ensures that the correct case was found and input correctly. Note that the Reference 7 calculations are for an infinite array of containers.

Next, a sensitivity study was performed for interspersed moderator and the reduced inner container dimensions, as discussed above. The results of these calculations are provided in Table 6.2 and presented graphically in Figure 6.2. As shown, the peak reactivity for both the old and new dimensions occurs at 9 vol% interspersed moderator. The reduced dimensions result in a Δk_{inf} of +0.00320 at peak interspersed moderator.

The peak cases (both old and new dimensions) were rerun with 260 containers in a 13x20x1 array. The results are summarized below and show a Δk_{eff} of +0.00204 between the reactivities calculated for the 13x20x1 arrays with the old and new dimensions.

```
248494 May 19 15:59:55 1998 /ss101b/t3517/SP1/CAT2/droa-sp1.g2.009.260      .90362   .00376   .90990   .91114
248563 May 19 16:08:25 1998 /ss101b/t3517/SP1/CAT2/droa-sp1.g2.s2.009.260   .90508   .00405   .91184   .91318
```

The maximum reactivity for the 13x20x1 array of 0.91318 has a sufficient margin to 0.95 to support a transport index of 0.4 (125 containers).

Table 6.2 Container Spacing and Interspersed Moderator Sensitivity Study for Fuel Category 2 Inside SP-1/SP-2 Inner Containers, Infinite Array, Damaged Conditions

File Name (droa-)	Vol% IM	k_{inf}	σ	$k_{inf} + 2\sigma$
2" Spacing around Channel Steel				
sp1.g2.007	7	0.95103	0.00318	0.95739
sp1.g2	8	0.96200	0.00306	0.96812
sp1.g2.009	***9***	***0.96376***	***0.00330***	***0.97036***
sp1.g2.0010	10	0.96111	0.00337	0.96785
sp1.g2.011	11	0.95593	0.00327	0.96247
sp1.g2.012	12	0.95280	0.00362	0.96004
1-15/16" Spacing around Channel Steel				
sp1.g2.s2.007	7	0.95201	0.00318	0.95837
sp1.g2.s2.008	8	0.96354	0.00313	0.96980
sp1.g2.s2.009	***9***	***0.96674***	***0.00341***	***0.97356***
sp1.g2.s2.010	10	0.96650	0.00344	0.97338
sp1.g2.s2.011	11	0.96169	0.00311	0.96791
sp1.g2.s2.012	12	0.95505	0.00354	0.96213

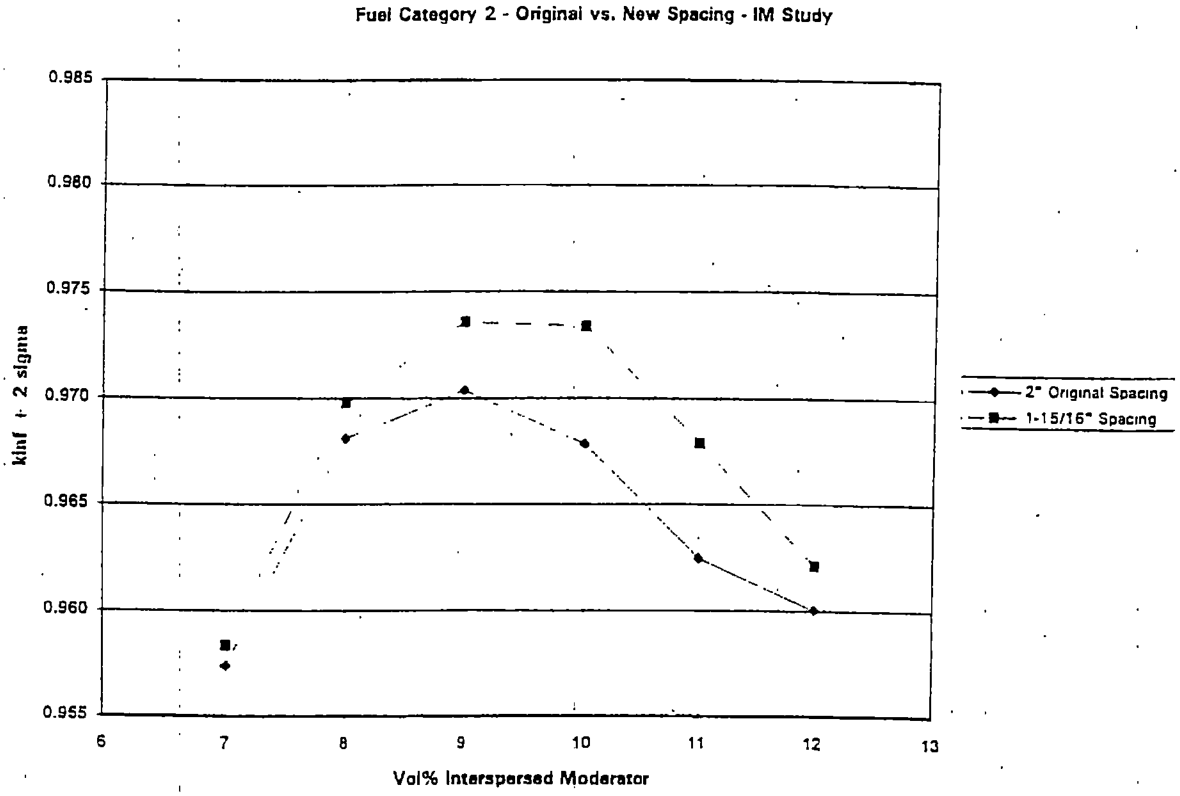

Figure 6.2 Container Spacing and Interspersed Moderator Sensitivity Study for Fuel Category 2 Inside SP-1/SP-2 Inner Containers, Infinite Array, Damaged Conditions

6.3.1.3 Fuel Category 3

The following fuel description is listed under 5 (b)(1)(iii) of Reference 6:

> "UO_2 fuel assemblies with a maximum U-235 enrichment of 5.0 percent by weight, and a maximum average U-235 enrichment of 4.0 percent by weight. Each fuel assembly is made up of fuel rods in a 10 x 10 square array, with a maximum fuel cross section of 5.022 inches square, a nominal pitch of 0.511 inch, and a maximum fuel length of 174 inches. The maximum pellet diameter is 0.3356 inch, the minimum clad thickness is 0.0225 inch, and the maximum U-235 enrichment in any edge rod is 4.0 percent by weight. Each assembly contains at least 6 rods with nominal 2 weight percent Gd_2O_3, which are symmetric about the diagonal, and each assembly contains at least 4 water rods in the 4 central rod positions."

The original calculations for this material type are found in Appendix 6B of Reference 7. The Reference 7 calculations are unavailable from permanent storage, so the listing of the most reactive case was retyped and rerun. The most reactive case from Reference 7 yielded a k_{inf} of 0.9675 (see page 6-B25 of Reference 7). The retyped version of this calculation yielded a k_{inf} of 0.96743 ± 0.00293. This ensures that the correct case was found and input correctly. Note that the Reference 7 calculations are for an infinite array of containers.

Next, a sensitivity study was performed for interspersed moderator and the reduced inner container dimensions, as discussed above. The results of these calculations are provided in Table 6.3 and presented graphically in Figure 6.3. As shown, the peak reactivity for both the old and new dimensions occurs at 8 vol% interspersed moderator. The reduced dimensions result in a Δk_{inf} of $+0.00506$ at peak interspersed moderator.

The peak cases (both old and new dimensions) were rerun with 260 containers in a 13x20x1 array. The results are summarized below and show a Δk_{eff} of $+0.00416$ between the reactivities calculated for the 13x20x1 arrays with the old and new dimensions.

```
261636 May 19 16:49:23 1998 /ss101b/t3517/SP1/CAT3/drma-sp1.c3.008.260     .88981   .00320   .89515   .89621
261694 May 19 16:13:39 1998 /ss101b/t3517/SP1/CAT3/drma-sp1.c3.s2.008.260  .89363   .00337   .89926   .90037
```

The maximum reactivity for the 13x20x1 array of 0.90037 has a sufficient margin to 0.95 to support a Transport Index of 0.4 (125 containers).

Table 6.3 Container Spacing and Interspersed Moderator Sensitivity Study for Fuel Category 3 Inside SP-1/SP-2 Inner Containers, Infinite Array, Damaged Conditions

File Name (droa-)	Vol% IM	k_{inf}	σ	$k_{inf} + 2\sigma$
2" Spacing around Channel Steel				
sp1.c3.005	5	0.94681	0.00236	0.95153
sp1.c3.006	6	0.95859	0.00259	0.96377
sp1.c3.007	7	0.96235	0.00314	0.96863
sp1.c3.008	***8***	***0.96743***	***0.00293***	***0.97329***
sp1.c3.009	9	0.96594	0.00294	0.97182
1-15/16" Spacing around Channel Steel				
sp1.c3.s2.005	5	0.94994	0.00249	0.95492
sp1.c3.s2.006	6	0.96068	0.00240	0.96548
sp1.c3.s2.007	7	0.96964	0.00295	0.97554
sp1.c3.s2.008	***8***	***0.97313***	***0.00261***	***0.97835***
sp1.c3.s2.009	9	0.96700	0.00271	0.97242

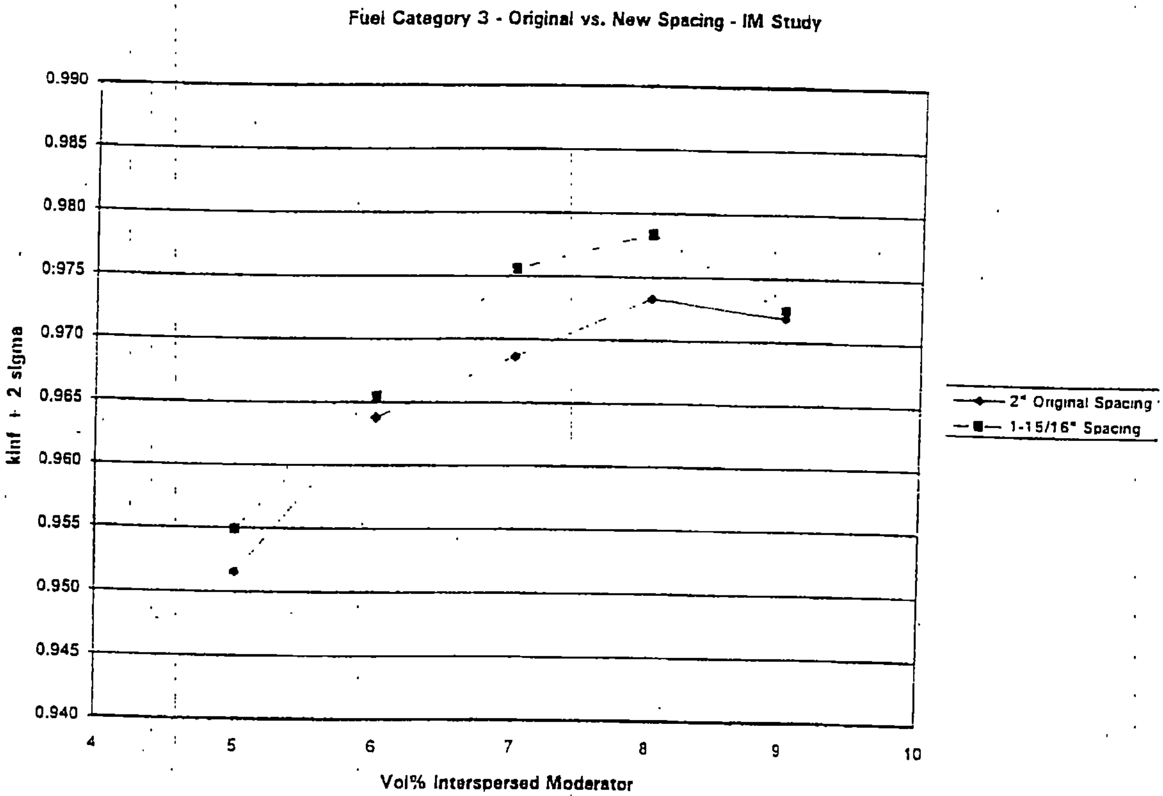

Figure 6.3 Container Spacing and Interspersed Moderator Sensitivity Study for Fuel Category 3 Inside SP-1/SP-2 Inner Containers, Infinite Array, Damaged Conditions

6.3.1.4 Fuel Category 4

The following fuel description is listed under 5(b)(1)(iv) of Reference 6:

> "UO_2 fuel rods with a maximum U-235 enrichment of 5.0 percent by weight, and a minimum Gd_2O_3 content of 1.0 percent by weight. The rods may be clad with zircaloy, steel or aluminum. The rods have a maximum fuel pellet diameter of 0.5 inch, and a maximum fuel length of 169 inches."

The calculations for this material type in Reference 3 show that this material is infinitely subcritical. Therefore, no new calculations are required to justify use of the SP-1/SP-2 container with reduced inner container dimensions for this material type.

6.3.1.5 Fuel Category 5

The following fuel description is listed under 5(b)(1)(v) of Reference 6:

> "UO_2 fuel assemblies composed of fuel rods in a 10 x 10 square array, with a maximum fuel cross section of 5.0 inches square, and a maximum fuel length of 174 inches. The maximum U-235 enrichment is 5.0 weight percent, the maximum U-235 enrichment for all edge rods is 4.0 weight percent, and the maximum average enrichment, excluding perimeter rods and rods containing gadolinia (Gd_2O_3), is 4.0 weight percent U-235. The maximum pellet diameter is 0.35 inch, and the minimum clad thickness is 0.018 inch. Each assembly must have a water channel in the central 3 x 3 rod positions. Any number of additional water rods in any arrangement is permitted, including part length rods. Each assembly must include at least twelve rods with minimum nominal content of 2.0 weight percent gadolinia (Gd_2O_3), in a pattern symmetric about one of the assembly diagonals. At least eight of the twelve gadolinia rods must be located in rows 2 and 9, and in columns 2 and 9 of the assembly."

The original calculations for this material type are found in Reference 8. The most reactive case from Reference 8 yielded a k_{eff} of 0.93001 ± 0.00186 (10 vol% interspersed moderator; case drda-evk10; page 73).

The most reactive case from Reference 8 was retrieved from tape and modified to reduce the inner container spacing, as described above. A sensitivity study was performed for interspersed moderator and the reduced inner container dimensions. The results of these calculations are provided in Table 6.4 and compared graphically to the Reference 8 results in Figure 6.4. As shown, the peak reactivity for both the old and new dimensions occurs at 10 vol% interspersed moderator. The reduced dimensions results in a Δk_{eff} of ÷0.00499 at peak interspersed moderator. The peak k_{eff} (0.93528 ± 0.00172) for the reduced dimensions and 104 containers has adequate margin to 0.95 to justify retention of a Transport Index of 1.0 for this material type.

Table 6.4 Container Spacing and Interspersed Moderator Sensitivity Study for Fuel Category 5 Inside SP-1/SP-2 Inner Containers, 8x13x1 Array (104 containers), Damaged Conditions

File Name (droa-)	Vol% IM	k_{eff}	σ	$k_{eff} + 2\sigma$
2" Spacing around Channel Steel (Results from Page 73 of Reference 8)				
evk08	8	0.92694	0.00169	0.93032
evk10	*10*	*0.93001*	*0.00186*	*0.93373*
evk12	12	0.92254	0.00181	0.92616
1-15/16" Spacing around Channel Steel				
evk10.s2.008	8	0.93017	0.00181	0.93379
evk10.s2.009	9	0.93280	0.00177	0.93634
evk10.s2.010	*10*	*0.93528*	*0.00172*	*0.93872*
evk10.s2.011	11	0.93156	0.00180	0.93516
evk10.s2.012	12	0.92962	0.00163	0.93288

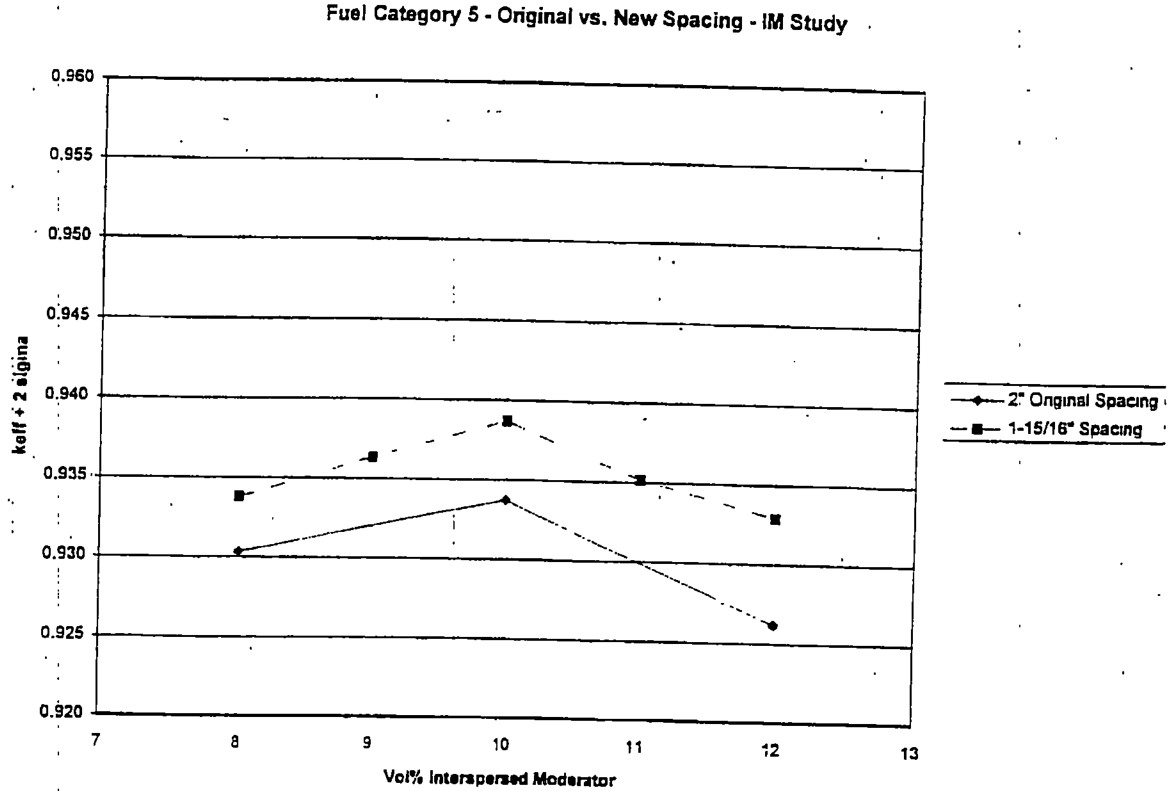

Figure 6.4 Container Spacing and Interspersed Moderator Sensitivity Study for Fuel Category 5 Inside SP-1/SP-2 Inner Containers, 8x13x1 Array (104 containers), Damaged Conditions

6.3.1.6 Fuel Category 6

The following fuel description is listed under 5(b)(1)(vi) of Reference 6:

> "UO_2 fuel assemblies composed of fuel rods in a 10 x 10 square array, with a maximum fuel cross section of 5.0 inches square, and a maximum fuel length of 174 inches. The maximum U-235 enrichment is 5.0 weight percent. The maximum pellet diameter is 0.35 inch, and the minimum clad thickness is 0.018 inch. Each assembly must have a water channel in the central 3 x 3 rod positions. Any number of additional water rods in any arrangement is permitted, including part length rods. Each assembly must include at least eight rods with minimum nominal gadolinia (Gd_2O_3) content of 2.0 weight percent in all axial regions with enriched pellets. Additional gadolinia rod specifications are included in supplement dated April 30, 1996."

The original calculations for this material type are found in Reference 9. The most reactive case from Reference 9 yielded a k_{eff} of 0.92544 ± 0.00186 (16 vol% interspersed moderator; case drda-t6.16; page 35).

The most reactive case from Reference 9 was retrieved from tape and modified to reduce the inner container spacing, as described above. A sensitivity study was performed for interspersed moderator and the reduced inner container dimensions. The results of these calculations are provided in Table 6.5 and compared graphically to the Reference 9 results in Figure 6.5. As shown, the peak reactivity for both the old and new dimensions occurs at 16 vol% interspersed moderator. The reduced dimensions result in a Δk_{eff} of +0.00494 at peak interspersed moderator. The peak k_{eff} (0.93016 ± 0.00197) for the reduced dimensions and 104 containers has adequate margin to 0.95 to justify retention of a Transport Index of 1.0 for this material type.

Table 6.5 Container Spacing and Interspersed Moderator Sensitivity Study for Fuel Category 6 Inside SP-1/SP-2 Inner Containers, 8x13x1 Array (104 containers), Damaged Conditions

File Name (droa-)	Vol% IM	k_{eff}	σ	$k_{eff} + 2\sigma$
2" Spacing around Channel Steel (Results from Page 35 of Reference 9)				
t6.15	15	0.92232	0.00191	0.92614
t6.16	*16*	*0.92544*	*0.00186*	*0.92916*
t6.17	17	0.92169	0.00197	0.92563
1-15/16" Spacing around Channel Steel				
t6.16.015	15	0.92788	0.00174	0.93136
t6.16.016	*16*	*0.93016*	*0.00197*	*0.93410*
t6.16.017	17	0.92708	0.00183	0.93074
t6.16.018	18	0.92419	0.00197	0.92813

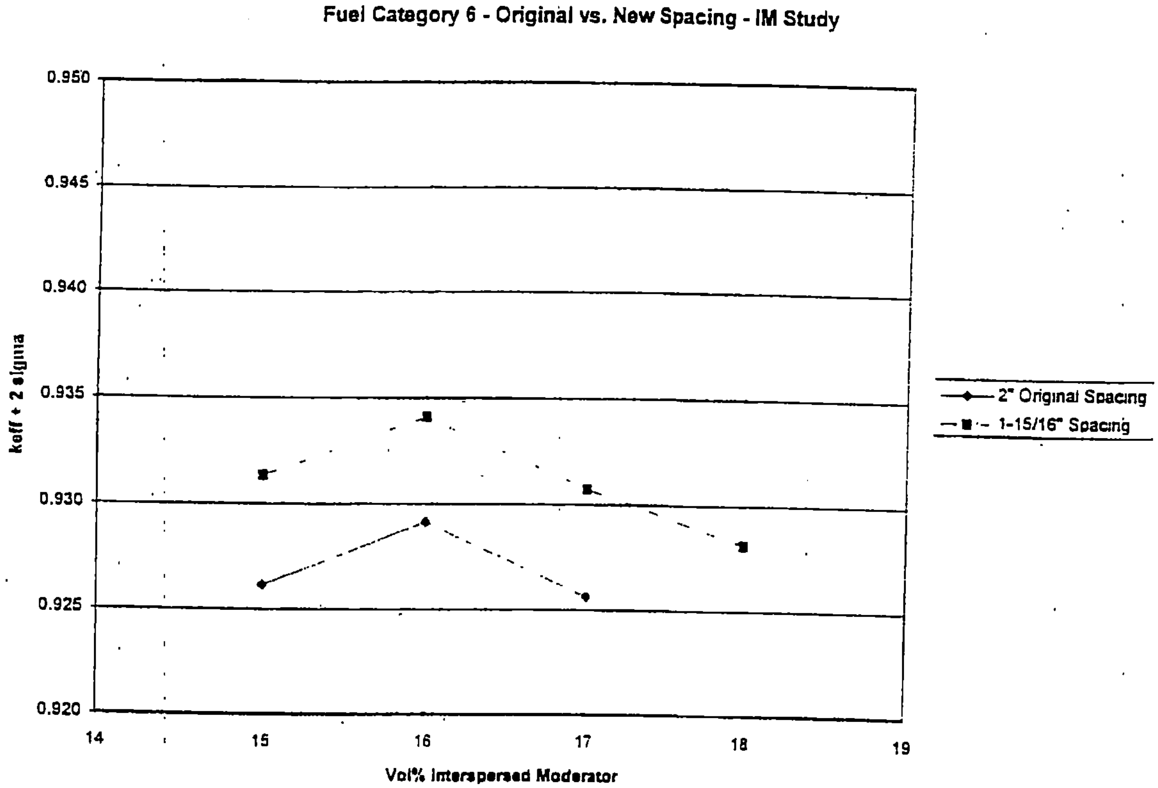

Figure 6.5 Container Spacing and Interspersed Moderator Sensitivity Study for Fuel Category 6 Inside SP-1/SP-2 Inner Containers, 8x13x1 Array (104 containers), Damaged Conditions

6.3.1.7 Fuel Category 7

The following fuel description is listed under 5(b)(1)(vii) of Reference 6:

> "UO_2 fuel assemblies composed of fuel rods in a 9 x 9 square array, with a maximum fuel cross section of 5.0 inches square, and a maximum fuel length of 174 inches. The maximum U-235 enrichment is 5.0 weight percent. The maximum pellet diameter is 0.40 inch, and the minimum clad thickness is 0.015 inch. Each assembly must have a water channel in the central 3 x 3 rod positions. Any number of additional water rods in any arrangement is permitted, including part length rods. Each assembly must include at least eight rods with minimum nominal gadolinia (Gd_2O_3) content of 2.0 weight percent in all axial regions with enriched pellets. Additional gadolinia rod specifications are included in supplement dated April 30, 1996."

The original calculations for this material type are found in Reference 9. The most reactive case from Reference 9 yielded a k_{eff} of 0.90532 ± 0.00173 (15 vol% interspersed moderator; case drda-3a.15; page 41).

The most reactive case from Reference 9 was retrieved from tape and modified to reduce the inner container spacing, as described above. A sensitivity study was performed for interspersed moderator and the reduced inner container dimensions. The results of these calculations are provided in Table 6.6 and compared graphically to the Reference 9 results in Figure 6.6. As shown, the peak reactivity shifts from 15 vol% interspersed moderator for the old dimensions to 14 vol% interspersed moderator for the new dimensions. The reduced dimensions result in a Δk_{eff} of +0.00795 at peak interspersed moderator. The peak k_{eff} (0.91283 ± 0.00195) for the reduced dimensions and 104 containers has adequate margin to 0.95 to justify retention of a Transport Index of 1.0 for this material type.

Table 6.6 Container Spacing and Interspersed Moderator Sensitivity Study for Fuel Category 7 Inside SP-1/SP-2 Inner Containers, 8x13x1 Array (104 containers), Damaged Conditions

File Name (droa-)	Vol% IM	k_{eff}	σ	$k_{eff} + 2\sigma$
2" Spacing around Channel Steel (Results from Page 41 of Reference 9)				
3a.14	14	0.89664	0.00177	0.90018
3a.15	*15*	*0.90532*	*0.00173*	*0.90878*
3a.16	16	0.90424	0.00186	0.90796
1-15/16" Spacing around Channel Steel				
3a.15.013	13	0.91079	0.00186	0.91451
3a.15.014	*14*	*0.91283*	*0.00195*	*0.91673*
3a.15.015	15	0.91075	0.00183	0.91441
3a.15.016	16	0.90957	0.00182	0.91321
3a.15.017	17	0.90689	0.00178	0.91045

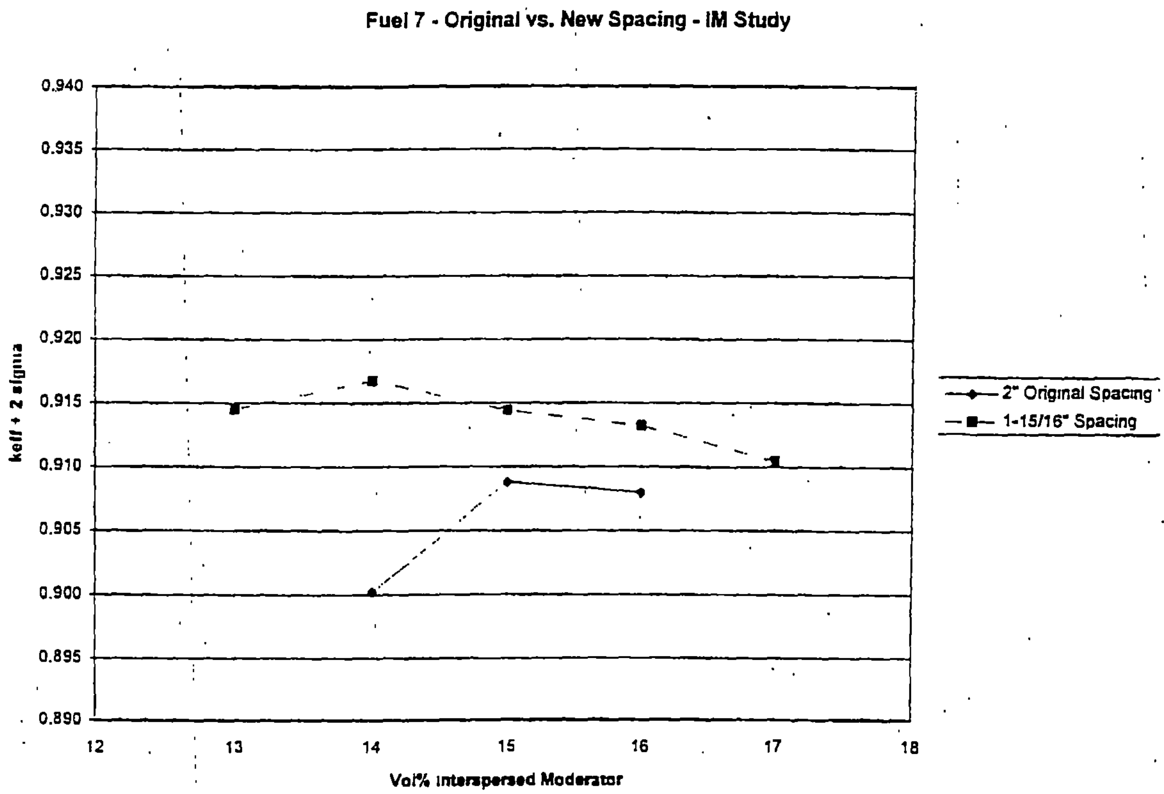

Figure 6.6 Container Spacing and Interspersed Moderator Sensitivity Study for Fuel Category 7 Inside SP-1/SP-2 Inner Containers, 8x13x1 Array (104 containers), Damaged Conditions

6.4 *QA Review Description*

1) Methodology used in this CSE is clearly defined and was verified to be applicable. The calculation methods including details on cross section preparation, atom densities assumed, and geometry models were reviewed and determined to be adequate. Each of these items was verified to be conservative.

2) Assumptions were reviewed for reasonableness and applicability to this analysis.

3) Modeling was reviewed and determined to conservatively model the actual system. A listing of one or more of the most reactive cases is included in the CSE.

4) Referenced sources were reviewed for applicability to this CSE.

5) Input information was checked against referenced sources.

6) Input for computer calculations were checked for agreement with values in the CSE text.

7) Hand calculations were independently checked.

8) K_{eff} for worst case accident conditions is specifically stated in the text.

6.5 *Sample Computer Inputs*

1) <u>Case "drda-sp1.c1.s2.012"</u>: Category 1 Material (see Reference 6) in SP-1 Inner Container, 12 vol% Interspersed Moderator, 13x20x1 Array (260 Containers), Damaged Conditions

```
=csas25
model for category 1 assembly
hans infhom

' mixture 1
'  interior uo2 pellets, 3.3 wt% u235
u-235 1 0.0 8.16852e-04 293 end
u-238 1 0.0 2.36339e-02 293 end
o     1 0.0 4.89015e-02 293 end

' mixture 2
'  edge uo2 pellets, 3.3 wt% u235
u-235 2 0.0 8.16852e-04 293 end
u-238 2 0.0 2.36339e-02 293 end
o     2 0.0 4.89015e-02 293 end

' mixture 3
'  edge uo2 pellets facing other bundle, 3.3 wt% u235
u-235 3 0.0 8.16852e-04 293 end
u-238 3 0.0 2.36339e-02 293 end
o     3 0.0 4.89015e-02 293 end

' mixture 4
```

```
'  gd-uo2 pellets, 4 wt% u235, 4 wt% gd
' u-235 4 0.0 9.4068e-04 293 end
' u-238 4 0.0 2.2291e-02 293 end
' o      4 0.0 4.6464e-02 293 end
' gd     4 0.0 6.865846e-04 293 end

' mixture 5
'  smeared zr clad
'  pod, cid, cod = 0.4221", 0.4281", 0.4781"
'  vol fract zr = 0.8988
'   at dens = 0.8988 * 4.2518-2 = 3.8215e-02
zircalloy 5 0.0 3.8215e-02 293 end

' mixture 6
'  12 vol% interspersed moderator
o 6 0.0 4.0056e-03 293 end
h 6 0.0 8.0112e-03 293 end

' mixture 7
'  carbon steel, 100 vol%
c  7 0.0 3.921682e-03 293 end
fe 7 0.0 8.350009e-02 293 end

' mixture 8
'  carbon steel, 85.57 vol% smeared with 12 vol% h2o
c  8 0.0 3.355783e-03 293 end
fe 8 0.0 7.145103e-02 293 end
o  8 0.0 5.7801e-04 293 end
h  8 0.0 1.1560e-03 293 end

' mixture 9
'  carbon steel, 8.64 vol%
c  9 0.0 3.388333e-04 293 end
fe 9 0.0 7.214408e-03 293 end
o  9 0.0 3.6595e-03 293 end
h  9 0.0 7.3190e-03 293 end

' mixture 10
'  water for reflector
o 10 0.0 3.344e-02 293 end
h 10 0.0 6.689e-02 293 end

end comp
more data
 res=  1 cyli  3.9493E-01 dan(  1)= 7.9334E-01
 res=  2 cyli  6.2643E-01 dan(  2)= 4.8377E-01
 res=  3 cyli  5.9010E-01 dan(  3)= 5.6605E-01
end more
model for category 1 assembly
read parameters
   tme=60.0 gen=103 npg=500
   flx=yes fdn=yes xs1=yes nub=yes pwt=yes
   run=yes plt=yes
end parameters
read geometry
unit  1
com="  interior uo2 rod  "
cyli  1 1 0.5361  2p225.58
cyli  5 1 0.6072  2p225.58
cubo  6  1 4p0.71785  2p225.58
unit  2
com="  edge uo2 rod  "
cyli  2  1  0.5361  2p225.58
cyli  5  1  0.6072  2p225.58
cubo  6  1 4p0.71785  2p225.58
```

```
unit  3
com="  edge rod facing other bundle  "
cyli  3  1  0.5361  2p225.58
cyli  5  1  0.6072  2p225.58
cubo  6  1 4p0.71785  2p225.58
' unit  4
' com="  uo2-gd203  rod  "
' cyli  4  1  0.5361  2p225.58
' cyli  5  1  0.6072  2p225.58
' cubo  6  1 4p0.71785  2p225.58
unit  5
com="  9x9 bundle in left basket  "
array 1  2r-6.46065 -225.58
cubo  6  1  4p8.7381  2p225.58
'  add 0.00598 inch of perforated steel
cubo  8  1  4p8.89  2p225.58
unit  6
com="  9x9 bundle in right basket  "
array 2  2r-6.46065  -225.58
cubo  6  1  4p8.7381  2p225.58
'  add 0.00598 inch of perforated steel
cubo  8  1  4p8.89  2p225.58
unit 7
com=" spacing & steel angle  beside basket  "
cubo  9  1  2p2.46063  2p4.9391  2p225.58
cubo  6  1  2p2.46063  2p8.89  2p225.58
unit 8
com="  angles & spacing beneath & above baskets  "
cubo  9  1  2p4.9392 2p2.46063 2p225.58
cubo  6  1  2p8.89  2p2.46063 2p225.58
unit 9
com="1 15/16 x 1 15/16 inch moderation regions at corners  "
cubo  6  1  4p2.46063 2p225.58
unit 10
com="  1 inner container  "
array  3  -22.86 -13.97 -225.58
'  add 0.0598 inch walls
repl  7  1 6r0.1519 1
global
unit 11
com="array of inners "
array 4 3r0.0
repl 10 2 6r3.0 10
end geometry
read array
ara=1 nux=9 nuy=9 nuz=1
fill
2 2 2 2 2 2 2 2 2
2 1 1 1 1 1 1 1 3
2 1 1 1 1 1 1 1 3
2 1 1 1 1 1 1 1 3
2 1 1 1 1 1 1 1 3
2 1 1 1 1 1 1 1 3
2 1 1 1 1 1 1 1 3
2 1 1 1 1 1 1 1 3
2 2 2 2 2 2 2 2 2
 end fill
ara=2 nux=9 nuy=9 nuz=1
fill
2 2 2 2 2 2 2 2 2
3 1 1 1 1 1 1 1 2
3 1 1 1 1 1 1 1 2
3 1 1 1 1 1 1 1 2
3 1 1 1 1 1 1 1 2
3 1 1 1 1 1 1 1 2
```

```
3 1 1 1 1 1 1 1 2
3 1 1 1 1 1 1 1 2
2 2 2 2 2 2 2 2 2
 end fill
ara=3 nux=4 nuy=3 nuz=1
fill
9 8 8 9
7 5 6 7
9 8 8 9
end fill
ara=4 nux=13 nuy=20 nuz=1
fill f10 end fill
end array
read start
nst=1
end start
read bounds
all=vacuum
end bounds

read bias
  id=500 2 11
end bias

read plot
'
ttl=' xy section of bottom left container '
xul=0           yul=28.2438    zul=10
xlr=46.0238     ylr=0          zlr=10
uax=1           vdn=-1         nax=150    lpi=10    end
'
ttl=' xy section of 5x5 array '
xul=0           yul=141.219    zul=10
xlr=230.119     ylr=0          zlr=10
uax=1           vdn=-1         nax=150    lpi=10    end
'
end plot

end data
end
```

2) **<u>Case "drda-t6.16.016"</u>:** Category 6 Material (see Reference 6) in SP-1 Inner Container, 16 vol% Interspersed Moderator, 8x13x1 Array (104 Containers), Damaged Conditions

```
=csas25
sp-1 with 5.0% enriched 10x10 fuel
hans   infh

uo2 1 0.98 293.0 92235 5.0    92238 95.0    end

uo2 2 0.98 293.0 92235 5.0    92238 95.0    end

uo2 3 0.98 293.0 92235 5.0 92238 95.0 end

uo2 4 0.98 293.0 92235 5.0 92238 95.0 end

uo2 5 0.98 293.0 92235 5.0 92238 95.0 end

uo2 6 0.98 293.0 92235 5.0 92238 95.0 end

'  poison rod with 2% gd2o3
```

```
 '  td of uo2-gd2o3 = 10.96 -2.65*p/[p+0.67145*(1-p)], p=wt frac.gd2o3
 '  "p" is 0.02 here,  td is 10.9012
 '  pellet density is 0.98*10.9012=10.6832
 '  uo2 density is 0.985*10.6832 = 10.5230
 '  gd2o3 density is 0.02*10.6832 = 0.1602 gm/cc
uo2 7 den=10.5230 1.0 293.0 92235 5.00 92238 95.00 end
arbmgd2o3 0.1602 2 0 1 0 64000 2 8016 3
7 1.0 293. end

zircalloy 8 1.0 293.0 end

 '  water, 16 vol.%
h2o 9 0.16 293.0 end

 ' basket steel
carbonsteel 10 1.0 293.0 end
 '  angle steel
carbonsteel 11 1.0 293.0 end
 '  shell steel
carbonsteel 12 1.0 293.0 end
 '  reflector water
h2o  13 1.0 293 end
 '  polyethylene, 100 vol%
arbmpe  0.92 2 0 1 0 6012 1 1001 2
14 1.0 293.  end

 '  higher enriched rods
uo2 15 0.98 293.0 92235 5.0 92238 95.0 end

end comp.
more data
 res=  1 cyli  3.3257E-01 dan(  1)= 7.2144E-01
 res=  2 cyli  4.0773E-01 dan(  2)= 6.6051E-01
 res=  3 cyli  4.9805E-01 dan(  3)= 4.3406E-01
 res=  4 cyli  4.9935E-01 dan(  4)= 4.3695E-01
 res=  5 cyli  4.8315E-01 dan(  5)= 4.7915E-01
 res=  6 cyli  4.8334E-01 dan(  6)= 4.8263E-01
 res=  7 cyli  3.2811E-01 dan(  7)= 7.3696E-01
end more
sp-1 with 4.0% enriched 10x10 fuel
read parameters
tme=90 gen=200 npg=600 nsk=0
flx=yes fdn=yes xs1=yes nub=yes pwt=yes
run=yes plt=yes
end parameters
read geom

 '  pellet diam: 0.35"
 '  gap: zero
 '  clad thk: 0.018"
 '  pitch: 0.5127"

 unit 1
com="interior rod"
cyli  1 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 2p0.49022  2p226.695
 '  polyethylene shims between rods
 '  cubo  14 1 4p0.6510866 2p226.695
 '  use 1d water in place of shims
cubo   9 1 4p0.6510866 2p226.695

unit 2
com="interior rods around water rod"
cyli  2 1 0.4445 2p226.695
```

```
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 2p0.49022  2p226.695
'  polyethylene shims between rods
'  cubo  14 1 4p0.6510866 2p226.695
'  use ld water in place of shims
cubo   9 1 4p0.6510866 2p226.695

unit 3
com="edge rod facing up"
cyli  3 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 0.6510866 -0.49022  2p226.695
'  polyethylene shims between rods
'  cubo  14 1 4p0.6510866 2p226.695
'  use ld water in place of shims
cubo   9 1 4p0.6510866 2p226.695

unit 4
com="edge rod facing down"
cyli  4 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 0.49022 -0.6510866  2p226.695
'  polyethylene shims between rods
'  cubo  14 1 4p0.6510866 2p226.695
'  use ld water in place of shims
cubo   9 1 4p0.6510866 2p226.695

unit 5
com="edge rod facing other bundle"
cyli  5 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 2p0.49022  2p226.695
'  polyethylene shims between rods
'  cubo  14 1 4p0.6510866 2p226.695
'  use ld water in place of shims
cubo   9 1 4p0.6510866 2p226.695

unit 6
com="edge rod facing out"
cyli  6 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 2p0.49022  2p226.695
'  polyethylene shims between rods
'  cubo  14 1 4p0.6510866 2p226.695
'  use ld water in place of shims
cubo   9 1 4p0.6510866 2p226.695

unit 7
com="uo2-gd2o3 rod"
cyli  7 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 2p0.49022  2p226.695
'  polyethylene shims between rods
'  cubo  14 1 4p0.6510866 2p226.695
'  use ld water in place of shims
cubo   9 1 4p0.6510866 2p226.695

unit 8
com="water rod"
cubo  9 1 4p0.6510866  2p226.695

unit 9
com='side basket element, 0.0598"x1.75"x1.75" steel with 0.75" diam. hole'
xcyl 9 1 0.9525 0.1519 0.0
cubo 10 1 0.1519 0.0 4p2.2225
```

```
unit 10
com='side basket element, 0.0598"x1.6902"x1.75" steel with 0.75" diam. hole'
xcyl 9 1 0.9525 0.1519 0.0
cubo 10 1 0.1519 0.0 2p2.14655 2p2.2225

unit 11
com='one complete basket side'
'  1x4x102 array of units 10 & 11
array 1 0.0 -8.7381 -226.695

unit 12
com='top/bottom basket element'
' 1.75"x0.0598"x1.75" steel with 0.75" diam. hole'
ycyl 9 1 0.9525 0.1519 0.0
cubo 10 1 2p2.2225 0.1519 0.0 2p2.2225

unit 13
com='top/bottom basket element'
' 1.6902"x0.0598"x1.75" steel with 0.75" diam. hole'
ycyl 9 1 0.9525 0.1519 0.0
cubo 10 1 2p2.14655 0.1519 0.0 2p2.2225

unit 14
com='one complete basket top/bottom'
'  4x1x102 array of units 13&14
array 2 -8.7381 0.0 -226.695

unit 15
com='0.0598" steel at basket corners'
cubo 10 1 0.1519 0.0 0.1519 0.0 2p226.695

unit 16
com=" spacing & steel angle at -x side of basket "
cubo  9 1  4.92126 0.0 2p8.89  2p226.695
hole 22    0.15875 0.0  0.0
hole 22  0.47625 -0.3175 0.0
hole 22   0.47625  0.3175 0.0
hole 22   0.79375  0.635 0.0
hole 22  0.79375  -0.635 0.0
hole 22  1.11125  0.9525 0.0
hole 22  1.11125  -0.9525 0.0
hole 22  1.42875  1.27 0.0
hole 22  1.42875  -1.27 0.0
hole 22  1.74625  1.5875 0.0
hole 22  1.74625  -1.5875 0.0
hole 22  2.06375 1.905 0.0
hole 22  2.06375 -1.905 0.0
hole 22  2.38125  2.2225 0.0
hole 22  2.38125 -2.2225  0.0
hole 22  2.69875  2.54 0.0
hole 22  2.69875 -2.54  0.0
hole 22  3.01625  2.8575 0.0
hole 22  3.01625 -2.8575  0.0
hole 22  3.33375  3.175 0.0
hole 22  3.33375 -3.175  0.0
hole 22  3.65125  3.4925 0.0
hole 22  3.65125 -3.4925  0.0
hole 22  3.96875  3.81 0.0
hole 22  3.96875 -3.81  0.0
hole 22  4.28625  4.1275 0.0
hole 22  4.28625 -4.1275  0.0
hole 22  4.60375  4.445 0.0
hole 22  4.60375 -4.445  0.0
```

```
unit 17
com=" spacing & steel angle at +x side of basket "
cubo  9 1  0.0  -4.92126 2p8.89  2p226.695
hole 22  -0.15875 0.0  0.0
hole 22  -0.47625 -0.3175 0.0
hole 22  -0.47625  0.3175 0.0
hole 22   -0.79375  0.635 0.0
hole 22  -0.79375  -0.635 0.0
hole 22  -1.11125  0.9525 0.0
hole 22  -1.11125  -0.9525 0.0
hole 22  -1.42875  1.27 0.0
hole 22  -1.42875  -1.27 0.0
hole 22  -1.74625  1.5875 0.0
hole 22  -1.74625  -1.5875 0.0
hole 22  -2.06375 1.905 0.0
hole 22  -2.06375 -1.905 0.0
hole 22  -2.38125  2.2225 0.0
hole 22  -2.38125 -2.2225  0.0
hole 22  -2.69875  2.54 0.0
hole 22  -2.69875 -2.54  0.0
hole 22 -3.01625  2.8575 0.0
hole 22  -3.01625 -2.8575  0.0
hole 22  -3.33375  3.175 0.0
hole 22  -3.33375 -3.175  0.0
hole 22  -3.65125  3.4925 0.0
hole 22  -3.65125 -3.4925  0.0
hole 22  -3.96875  3.81 0.0
hole 22  -3.96875 -3.81  0.0
hole 22  -4.28625  4.1275 0.0
hole 22  -4.28625 -4.1275  0.0
hole 22  -4.60375  4.445 0.0
hole 22  -4.60375 -4.445  0.0

unit 18
com=" angles & spacing beneath baskets  "
cubo  9 1  2p8.89 4.92126 0.0  2p226.695
hole 21  0.0  0.15875  0.0
hole 21 -0.3175  0.47625  0.0
hole 21  0.3175  0.47625  0.0
hole 21  0.635  0.79375  0.0
hole 21 -0.635  0.79375  0.0
hole 21  0.9525  1.11125  0.0
hole 21 -0.9525  1.11125  0.0
hole 21  1.27  1.42875  0.0
hole 21 -1.27  1.42875  0.0
hole 21  1.5875  1.74625  0.0
hole 21 -1.5875  1.74625  0.0
hole 21  1.905  2.06375  0.0
hole 21 -1.905  2.06375  0.0
hole 21  2.2225  2.38125  0.0
hole 21 -2.2225  2.38125  0.0
hole 21  2.54 2.69875 0.0
hole 21  -2.54 2.69875 0.0
hole 21  2.8575 3.01625  0.0
hole 21  -2.8575 3.01625 0.0
hole 21   3.175 3.33375 0.0
hole 21   -3.175 3.33375  0.0
hole 21   3.4925 3.65125 0.0
hole 21   -3.4925  3.65125 0.0
hole 21   3.81 3.96875 0.0
hole 21   -3.81 3.96875 0.0
hole 21   4.1275 4.28625 0.0
hole 21   -4.1275  4.28625 0.0
hole 21   4.445 4.60375 0.0
hole 21   -4.445  4.60375 0.0
```

```
unit 19
com="angles & spacing above baskets  "
cubo  9 1  2p8.89  0.0 -4.92126  2p226.695
hole 21   0.0   -0.15875  0.0
hole 21 -0.3175   -0.47625  0.0
hole 21  0.3175   -0.47625  0.0
hole 21  0.635   -0.79375  0.0
hole 21 -0.635   -0.79375  0.0
hole 21  0.9525   -1.11125  0.0
hole 21 -0.9525   -1.11125  0.0
hole 21  1.27   -1.42875  0.0
hole 21 -1.27   -1.42875  0.0
hole 21  1.5875   -1.74625  0.0
hole 21 -1.5875   -1.74625  0.0
hole 21  1.905   -2.06375  0.0
hole 21 -1.905   -2.06375  0.0
hole 21  2.2225   -2.38125  0.0
hole 21 -2.2225   -2.38125  0.0
hole 21   2.54 -2.69875 0.0
hole 21  -2.54 -2.69875 0.0
hole 21  2.8575 -3.01625  0.0
hole 21  -2.8575 -3.01625 0.0
hole 21   3.175 -3.33375 0.0
hole 21   -3.175 -3.33375  0.0
hole 21    3.4925 -3.65125 0.0
hole 21   -3.4925  -3.65125 0.0
hole 21    3.81 -3.96875 0.0
hole 21   -3.81 -3.96875 0.0
hole 21    4.1275 -4.28625 0.0
hole 21   -4.1275  -4.28625 0.0
hole 21   4.445 -4.60375 0.0
hole 21   -4.445  -4.60375 0.0

unit 20
com=" 1 15/16 x 1 15/16 inch moderation regions at corners "
cubo  9 1 4p2.46063  2p226.695

unit 21
com="part of steel angle"
'  0.1552" x 0.125"
cubo  11 1 2p0.197104 2p0.15874 2p226.695

unit 22
com="part of steel angle"
'  0.125" x 0.1552"
cubo  11 1 2p0.15874 2p0.197104 2p226.695

unit 23
com="left (-x) 10x10 bundle in basket"
'  bundle at outer edge, centered vertically
array  3 -8.7381 -6.510866 -226.695
cubo  9 1 2p8.7381 2p8.7381  2p226.695

unit 24
com="right 10x10 bundle in basket"
'  bundle at outer edge, centered vertically
array  4 -4.2836334 -6.510866 -226.695
cubo  9 1 2p8.7381 2p8.7381  2p226.695

unit 25
com="complete left basket with bundle"
array 5 2r-8.89 -226.695

unit 26
```

```
com="complete right basket with bundle"
array 6 2r-8.89 -226.695

unit 27
com=" 1 inner container "
array  7 -22.86 -13.97 -226.695
' add 0.0598 inch walls of carbon steel
repl  12 1 6r0.1519 1

unit 28
com=" 1 15/16 x 1 15/16 inch moderation regions at corners "
cubo  9 1 4p2.46063  2p226.695

unit 29
com='higher enriched rods'
cyli  15 1 0.4445 2p226.695
cyli  8 1 0.49022  2p226.695
cubo  9 1  2p0.6510866 2p0.49022  2p226.695
'  polyethylene shims between rods
cubo  14 1 4p0.6510866 2p226.695

global
unit 30
com=" 8x13x1 array of inners  "
array  8 -184.0952 -183.5847 -226.695
'  add 30 cm water reflector at all 6 faces
repl 13 2 6r3.0 10

end geom

read array

ara=1 nux=1 nuy=4 nuz=102
loop
9  1 1 1   2 3 1  1 102 1
10  1 1 1   1 4 3  1 102 1
end loop

ara=2 nux=4 nuy=1 nuz=102
loop
12  2 3 1  1 1 1  1 102 1
13  1 4 3  1 1 1  1 102 1
end loop

'  right bundle, poison corner at ll
ara=3 nux=10 nuy=10 nuz=1
fill
03 03 03 03 03 03 03 03 03 03
05 01 01 01 01 01 07 01 01 06
05 01 01 01 01 01 01 07 01 06
05 01 02 01 02 02 02 02 07 06
05 01 01 02 08 08 08 02 01 06
05 01 01 02 08 08 08 02 01 06
05 07 01 02 08 08 08 02 01 06
05 01 07 02 02 02 02 02 01 06
05 01 01 07 01 01 01 01 01 06
04 04 04 04 04 04 04 04 04 04
end fill

'  left  bundle, poison corner at ur
ara=4 nux=10 nuy=10 nuz=1
fill
04 04 04 04 04 04 04 04 04 04
06 01 01 07 01 01 01 01 01 05
06 01 07 01 01 01 01 01 01 05
```

```
06 07 02 02 02 02 02 01 01 05
06 01 02 08 08 08 02 01 01 05
06 01 02 08 08 08 02 01 01 05
06 01 02 08 08 08 02 01 07 05
06 01 02 02 02 02 02 07 01 05
06 01 01 01 01 01 07 01 01 05
03 03 03 03 03 03 03 03 03 03
end fill

ara=5 nux=3 nuy=3 nuz=1
fill
15 14 15
11 23 11
15 14 15
end fill

ara=6 nux=3 nuy=3 nuz=1
fill
15 14 15
11 24 11
15 14 15
end fill

ara=7 nux=4 nuy=3 nuz=1
fill
20 18 18 20
16 25 26 17
28 19 19 28
end fill

ara=8 nux=08 nuy=13 nuz=1
fill f27 end fill

end array

read start nst=1
'  xsm=-45.72 xsp=45.72 ysm=-27.94 ysp=27.94 zsm=-10 zsp=10
end start

read bounds all=vacuum end bounds
read bias id=500 2 11 end bias

read plot
ttl=" yx section of single storage location       "
nch=" xx^d>g: ..$$$*x"
xul=-10.0  xlr=10.0   yul=10.0 ylr=-10.0 zul=0.0 zlr=0.0
uax=1.0 vdn=-1.0 nax=120 lpi=10 end
ttl=" yx section of single storage location       "
nch=" xx^d>g: .$$$*x"
xul=-40.0  xlr=40.0   yul=40.0 ylr=-40.0 zul=0.0 zlr=0.0
uax=1.0 vdn=-1.0 nax=120 lpi=10 end

ttl=" yx section of two bundles in inner container "
nch=" 123456789abcde"
xul=-10.0   xlr=10.0   yul=10.0 ylr=-10.0 zul=1.0 zlr=1.0
ttl=" yx section of two bundles in inner container "
nch=" 123456789abcde"
xul=-25.0   xlr=25.0   yul=15.0 ylr=-15.0 zul=1.0 zlr=1.0
uax=1.0 vdn=-1.0 nax=140 lpi=10 end
ttl=" yx section of left bundle in inner container "
xul=-5.0    xlr=55.0   yul=10.0 ylr=-10.0 zul=1.0 zlr=1.0
uax=1.0 vdn=-1.0 nax=140 lpi=10 end
ttl=" yx section of left bundle in inner container "
nch=" 123456789abcde"
xul=-20.0   xlr=0.0    yul=10.0 ylr=-10.0 zul=1.0 zlr=1.0
```

```
uax=1.0 vdn=-1.0 nax=140 lpi=10 end
ttl=" yx section of risght bundle in inner container "
nch=" 123456789abcde"
xul=0.0   xlr=20.0   yul=10.0 ylr=-10.0 zul=1.0 zlr=1.0
uax=1.0 vdn=-1.0 nax=140 lpi=10 end
end plot

end data

end
```

6.6 *References*

1) SPC Criticality Safety Analysis BFQ-SP1.1, SP-1 SHIPPING CONTAINER.

2) SPC Criticality Safety Analysis BFQ-SP1.2, SP-1 SUPPLEMENTAL APPLICATION.

3) SPC Criticality Safety Analysis BFQ-SP1.3, SP-1 SHIPMENTS WITH GADOLINIA ROD CONTAINER.

4) SCALE Standardized Computer Analyses for Licensing Evaluation, NUREG/CR-2000 ORNL/NUREG/CSD-2, Volumes 1, 2, and 3.

5) Critical Separation Between Subcritical Clusters of 4.31 wt% Enriched UO_2 Rods in Water with Fixed Neutron Poisons, NUREG/CR-0073.

6) Certificate USA/9248/AF, Revision 11, SP-1 and SP-2 Shipping Certificate

7) EMF-1563, Revision 1, Consolidated License Application for Siemens Power Corporation Model SP-1 and SP-2 Shipping Containers, December 1993.

8) EMF-1563, Supplement 1, Revision 1, Supplemental License Application for Siemens Power Corporation Model SP-1 and SP-2 Shipping Containers, March 1995.

9) EMF-1563, Supplement 4, Supplemental License Application for Siemens Power Corporation Model SP-1 and SP-2 Shipping Containers, February 1996.

10) EMF-94-175, "Validation and Verification of KENO.Va" by R. E. Coen, Siemens Power Corporation - Nuclear Division, 2101 Horn Rapids Road, Richland, WA 99352.

Appendix 6G

SIEMENS POWER CORPORATION LETTERS OF APRIL 18 AND APRIL 30, 1996

SIEMENS

April 18, 1996
JBE:96:031

U.S. Nuclear Regulatory Commission
Attn: Mr. C. R. Chappell, Section Leader
Cask Certification Section
Spent Fuel Project Office: NMSS
Washington, D.C. 20555

Dear Mr. Chappell:

Subject: Application to Amend Certificate of Compliance 9248

Per my recent telephone conversation with Nancy Osgood of your staff, Siemens Power Corporation (SPC) requests the following wording changes for clarification in Certificate of Compliance 9248 when it is next revised:

> In 5(b)(1)(iii) the statement, "Any number of water rods in any arrangement are permitted." Should be changed to, "Any number of water rods in any arrangement is permitted, including part length rods."
>
> In 5(b)(1)(vi) the statement, "Any number of additional water rods in any arrangement are permitted" should be changed to, "Any number of additional water rods in any arrangement is permitted, including part length rods."
>
> In the revision applied for on February 9, 1996, in 5(b)(1)(vii) and 5 (b)(1)(viii) the statement, in the first paragraphs, "Any number of additional water rods or water channels in any arrangement is permitted" should be changed to "Any number of additional water rods or water channels in any arrangement is permitted, including part length rods."

If you need further information on this request, please call me at 509-375-8663.

Very truly yours,

James B. Edgar
Staff Engineer, Licensing

pm

Siemens Power Corporation

Nuclear Division
Engineering & Manufacturing

2101 Horn Rapids Road
PO Box 130
Richland, WA 99352-0130

Tel: (509) 375-8100
Fax: (509) 375-8402

SIEMENS

April 30, 1996
JBE:96:034

U.S. Nuclear Regulatory Commission
Attn: Mr. C. R. Chappell, Section Leader
Cask Certification Section
Spent Fuel Project Office: NMSS
Washington, D.C. 20555

Dear Mr. Chappell:

Subject: Application to Amend Certificate of Compliance 9248

Per my telephone conversation today with Nancy Osgood of your staff, this application supplements Siemens Power Corporation's (SPC's) application dated February 9, 1996. SPC requests an amendment of Certificate of Compliance 9248 to add fuel assembly types 5(b)(1)(vii) and 5(b)(1)(viii) as described below:

<u>5(b)(1)(vii)</u> - UO_2 fuel assemblies with a maximum U-235 enrichment of 5.0 wt.%. Each assembly is composed of a 10x10 array of fuel rods with a water channel or water rods in a central 3x3 rod location. Any number of additional water rods or water channels in any arrangement is permitted, including part length rods. The maximum fuel dimensions are 5.0" by 5.0" by 174". The maximum pellet diameter is 0.35" and the minimum clad thickness is 0.018". Each assembly shall include at least eight rods with at least 2.0 wt.% gadolinia in all axial regions with enriched pellets.

The eight gadolinia rods shall be located in a pattern symmetric about one of the assembly diagonals and meet the following constraints:

1. The nominal diameter of the gadolinia pellets shall be not less than that of the UO_2 (non-gadolinia) pellets and the rods shall be in non-perimeter positions.

2. At least two gadolinia rods shall be in row 2 and two additional rods shall be in column 2.

3. At least two gadolinia rods shall be in rows 8 and/or 9 and at least two additional gadolinia rods shall be in columns 8 and/or 9.

4. A unit cell containing a gadolinia rod shall not share a common face with another gadolinia rod unless those sharing a common face are counted as one rod; i.e., gadolinia rods may share a common corner.

<u>5(b)(1)(viii)</u> - UO_2 fuel assemblies with a maximum U-235 enrichment of 5.0 wt.%. Each assembly is composed of a 9x9 array of fuel rods with a water channel or water rods in

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the center 3x3 rod locations. Any number of additional water rods of water channels in any arrangement is permitted, including part length rods. The maximum fuel dimensions are 5.0" by 5.0" by 174". The maximum pellet diameter is 0.40" and the minimum clad thickness is 0.015". Each assembly shall include at least eight rods with at least 2.0 wt.% gadolinia in all axial regions with enriched pellets.

The eight gadolinia rods shall be located in a pattern symmetric about one of the assembly diagonals and meet the following constraints:

1. The nominal diameter of the gadolinia pellets shall be not less than that of the UO_2 (non-gadolinia) pellets and the rods shall be in non perimeter positions.

2. At least two gadolinia rods shall be in rows 2 and 8 and two additional rods shall be in columns 2 and 8.

3. A unit cell containing a gadolinia rod shall not have share a common face with another gadolinia rod unless those sharing a common face are counted as one rod; i.e., gadolinia rods may share a common corner.

The assemblies will be loaded and unloaded and the containers handled; maintained and shipped in accordance with Sections 7 and 8 of SPC's "Consolidated License Application for Siemens Power Corporation Model SP-1 and SP-2 Shipping Containers", document EMF-1563.

SPC has a contractual commitment to deliver a reload of assemblies of the design described in 5(b)1(viii) beginning in early June of this year. We would, therefore, appreciate an expedited review to permit these shipments.

If I can provide further information to facilitate your review, please call me at (509) 375-8663.

Very truly yours,

J. B. Edgar
Staff Engineer, Licensing

pm

Appendix 6H*

SIEMENS POWER CORPORATION SUPPLEMENTAL APPLICATION TO ADD THE SP-3 INNER CONTAINER TO CERTIFICATE OF COMPLIANCE 9248

***This Appendix 6H replaces that provided with revision 9 of EMF-1563 submitted April 12, 1999.**

Criticality Evaluation

1. Introduction and Summary

1.1 *Introduction*

This supplemental Criticality Safety Evaluation (CSE) for the SP-1 shipping container was created due to reduced spacing dimensions and the resulting impact on k_{eff}. This spacing reduction has led to some SP-1 inner containers being redesignated as SP-3. The following CSE is based on SP-3 inner containers and a new category fuel type which shall be referred to as category 8.

Section 2 of this evaluation details the methodologies used for the criticality analysis. Component description and analysis are provided in Section 3. Section 4 contains the Quality Assurance (QA) review. Section 5 documents the references.

1.2 *Summary*

This CSE replaces Appendix 6H of EMF-1563, rev. 9 (submitted to the NRC April 12, 1999) by creating a new category fuel bundle type (Category 8). To facilitate review of this CSE, only those sections described above are included. The text which is revised from Appendix H of rev. 9 is shaded.

The conclusion of this CSE is that the new fuel type (category 8) can be supported with spacing as little as 1-5/8" between the channel and outer steel box in inner containers identified as the SP-3.

2. Analysis Methodology

2.1 *Nuclear Analysis Methodology*

Monte Carlo techniques were used in this analysis. The sensitivity of pellet diameter, pellet pitch, and interspersed moderator within the SP-3 inner container were evaluated.

2.2 *Computer Codes and Databases Used*

The following codes and cross section libraries are part of the SCALE 4.2 system of codes (Reference 4) placed on the SPC HP workstation SSL01.

```
791176     Jun 22 1994 11:36:41 o0o001.a (XSDRN)
545416     Feb 21 1994 10:25:06 o0o002.a (NITAWL)
516744     Feb 21 1994 10:14:38 o0o008.a (BONAMI)
1094280    Jun 22 1994 11:46:27 o0o009.a (KENO.Va)
112000     Feb 23 1994 15:16:47 albdata.bin
4256216    Feb 23 1994 14:40:21 pxs123.bin (123 group master cross section
                                library)
362140     Feb 25 1994 16:54:21 pxs16.bin (16 group master cross section library)
9020996    Feb 23 1994 14:53:45 pxs218.bin (218 group master cross section
                                library)
824404     Feb 23 1994 14:38:03 pxs27.bin (27 group master cross section library)
94400      Feb 23 1994 15:12:03 stdcomp.bin (standard comp. library)
44812      Feb 23 1994 15:14:40 wtdata.bin
287        Jul  7 1994 09:35:35 csas25
2295       Jul  7 1994 17:07:41 drva
```

2.3 *Cross Section Preparation*

The Hansen-Roach 16-energy group cross sections available in SCALE were used for all calculations. BONAMI and NITAWL adjust the master format cross section data for the specific problem cross sections (e.g., perform resonance self-shielding corrections).

2.4 *Benchmarking*

The SCALE 4.2 system of codes was developed for use by the USNRC and its licensees. SPC benchmarking of SCALE 4.2 on HP Workstations includes critical experiments of 4.31% enriched assemblies from NUREG/CR-0073 (Reference 5) which were modeled using the same methodology used in these calculations. A bias estimate based on 23 pooled cases was calculated from the 16-group data in Table 12 of Reference 10 and is -0.00321 ± 0.00261. Negative bias indicates conservative results.

3. Component Description and Analysis

3.1 *Reduced Dimensions of SP-3 Inner Container*

The dimensions of the SP-3 inner container are shown on drawing EMF-309,818. In previous analyses, the SP-1 inner container (drawing EMF-304,416) was modeled with a 1-15/16" space between the channel and the outer steel box (space occupied by angle steel). The calculations of this section justify the use of a 1-5/8" space, instead of 1-15/16". This change in dimension only affects the calculations for damaged conditions, as the outer container provides the container spacing for undamaged conditions. The type and form of material identified in section 6.3.8 of this rev. 10 of EMF-1563, and to be added to Certificate of Compliance 9248, are evaluated below.

The KENO models used in this section are consistent with those used previously for the respective material types with one exception, i.e., the inner container spacing, discussed above.

3.2 *Category 8 Fuel Assemblies*

The following material is listed as a new Category 8 of section 6.2.8 of EMF-1563, rev. 10:

> "UO_2 fuel assemblies in a 9x9 square array with a maximum fuel cross-section area of 25 square inches, maximum fuel length of 174 inches and maximum average enrichment of 4.0 w/o U-235. The nominal pellet diameter is 0.0370 inch. At least the center 3x3 rod locations shall be a water channel. Each assembly must include eight rods with a minimum nominal gadolinia (Gd_2O_3) content of 2.0 w/o in all axial regions with enriched pellets as shown in Figure 1."

A comparison of the actual and modeled fuel bundle parameters and polyethylene (PE) shipping shim is included in Table 1.

Table 1 Comparison of Nominal vs. Modeled Conditions

Parameter	Nominal	Modeled
	Pellet	
Diameter	.94 cm	.94 cm and 1.1 cm
Density	96.5 %TD (does not include dish or land taper which is ~1.5%)	95%
^{235}U Enrichment	3.4 average	4.0
	Rod	
Cladding ID	.96 cm	Cladding and gap is conservatively omitted
Cladding OD	1.1 cm	
Pellet-Clad Gap	0.02 cm	
Active fuel Length	370.8 cm	451.16 cm
	Fuel Assembly: 9x9B	
Rod Pitch	1.445 cm	1.445 cm
Water Channel Outer Dimension	3.85 cm square	Center 3x3 rods
Number of Fuel Rods	72	72
Number of Rods with Gd_2O_3	9	8
	Poly Shipping Shims	
Total Number of Shims	128 @ 5.9 grams each =vol. Fraction of 0.028	591 @ 6 grams each modeled as vol. fraction = .13 in space between rods for normal case

The new fuel bundle type will be shipped with PE shims placed between the rods. A total of 16 shims are used in each of the 8 sections of a fuel bundle. A conservative total mass of PE shims is 3,546 grams (591*6). If this mass is homogenized over a volume of 28,527 cm^3, the effective PE density = 0.12. TD for PE is .92 therefore the volume fraction is 0.13 for a normal condition.

The volume available for shims is calculated as follows:

Assembly Envelope: 8*1.445 + 1.1= 12.7 cm ∴ Cross sectional area = 160.3 cm^2

Channel Envelope: 3.85 cm; Cross sectional area = 14.8 cm^2

Area of 72 rods: 72*π/4*1.21= 68.4 cm^2

Area of shims/cm length = 160.3 - 68.4 - 14.8= 77.1

Assuming an active fuel length of 370 cm, the volume for shims is: 28,527 cm^3

(Note: For the model with a rod diameter of .94 cm and excluding cladding, the modeled amount of PE exceeds 3,546 grams. To obtain 3,546 grams in this model, the volume fraction PE should be approximately 0.10.)

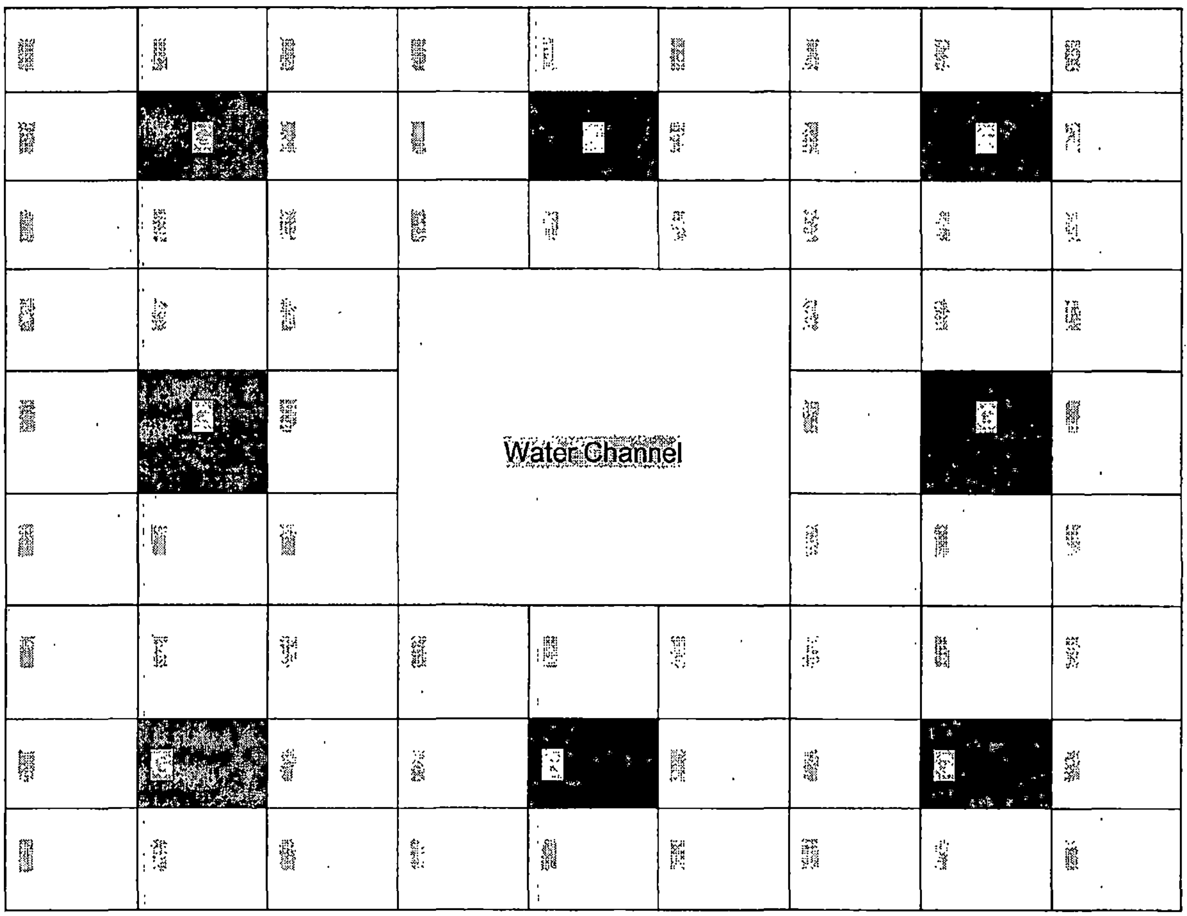

Figure 1 Gd Rod Locations

Sensitivity studies based on the load pattern in Figure 1 and the modeled parameters described in Table 1 were completed and are reported in Table 2. One can conclude from this sensitivity study that all criticality safety criteria are met for these shipping containers.

Table 2 Reactivity Results for New SP-3 Category 8 Fuel

Filename (droa-?)	Vol% IM	Comments / Description	Avg. k_{eff}	σ	Avg. keff + 2σ
260 units (13x20x1 array) at damaged conditions, nominal pellet diameter, no clad, 13 vol% PE between rods as shipping shims, and various amounts of interspersed moderator					
ex8d.000	0	Pellet Diameter = 0.94cm (0.370")	.7367	.0035	.7437
ex8d.001	1		.7642	.0037	.7717
ex8d.003	3		.8194	.0035	.8265
ex8d.008	8		.8756	.0039	.8833
ex8d.009	9		.8764	.0034	.8833
ex8d.010	10		.8691	.0032	.8754
ex8d.011	11		.8735	.0034	.8803
ex8d.012	12		.8768	.0033	.8834
ex8d.013	13		.8682	.0041	.8764
ex8d.014	14		.8689	.0035	.8759
ex8d.015	15		.8712	.0040	.8791
ex8d.100	100		.7104	.0046	.7197
Infinite number of units at damaged conditions, nominal pellet diameter, no clad, 13 vol% PE between rods as shipping shims, and various amounts of interspersed moderator					
ex8d.006inf	6	Pellet Diameter = 0.94cm (0.370")	.9436	.0028	.9491
ex8d.007inf	7		.9439	.0034	.9507
ex8d.008inf	8		.9351	.0034	.9419
ex8d.009inf	9		.9336	.0036	.9409
ex8d.010inf	10		.9274	.0036	.9345
ex8d.011inf	11		.9215	.0040	.9295
ex8d.012inf	12		.9250	.0039	.9328

260 (13x20x1 array) units at damaged conditions, nominal pellet diameter, no clad, 26 vol% PE between rods as shipping shims, and various amounts of interspersed moderator					
ex8d.008.26	8	Pellet Diameter = 0.94cm 0.370"	.9030	.0037	.9103
ex8d.009.26	9		.9089	.0042	.9172
ex8d.010.26	10		.9031	.0038	.9107
ex8d.011.26	11		.9099	.0035	.9168
ex8d.012.26	12		.9049	.0034	.9117
800 (20x20x2 array) units at undamaged spacing, nominal pellet diameter, no clad, 13 vol% PE between rods as shipping shims, and various amounts of PE as interspersed moderator between inner and outer containers.					
anc.00pe800	7	As case ex8d.007inf with 800 units at undamaged container spacing and no PE between inner and outer containers	.7622	.0045	.7713
anc.01pe800		As above 1 vol% PE between inner and outer containers	.7757	.0033	.7824
anc.03pe800		As above with 3 vol% PE	.7537	.0040	.7618
anc.05pe800		As above with 5 vol% PE	.7178	.0035	.7249
260 (13x20x1 array) units at damaged conditions, 1.1 cm diameter pellets, no clad, 13 vol% PE between rods as shipping shims, and various amounts of interspersed moderator					
ex8d.000.11	0	A 1.1 cm diameter pellet corresponds to the rod O.D. of a nominally clad fuel rod	.7226	.0037	.7299
ex8d.001.11	1		.7689	.0031	.7751
ex8d.003.11	3		.8298	.0033	.8363
ex8d.008.11	8		.8900	.0037	.8974
ex8d.009.11	9		.9092	.0042	.9175
ex8d.010.11	10		.9021	.0037	.9094
ex8d.011.11	11		.9110	.0032	.9174
ex8d.012.11	12		.9094	.0038	.9170
ex8d.013.11	13		.9003	.0033	.9069
ex8d.014.11	14		.8978	.0036	.9050
ex8d.100.11	100		.7298	.0048	.7395

Infinite number of units at damaged conditions, 1.1 cm diameter pellets, no clad, 13 vol% PE between rods as shipping shims, and various amounts of interspersed moderator					
ex8d.009.11inf	9	A 1.1 cm diameter pellet corresponds to the rod O.D. of a nominally clad fuel rod.	.9539	.0031	.9601
ex8d.011.11inf	11		.9540	.0033	.9605
ex8d.012.11inf	12		.9508	.0036	.9579
Infinite number of units at undamaged spacing, 1.1 cm diameter pellets, no clad, 13 vol% PE between rods as shipping shims, and various amounts of PE as interspersed moderator between inner and outer containers					
nc.00pe	9	As case ex8d.009.11 with undamaged container spacing and no PE between inner and outer containers	.9560	.0027	.9615
nc.01pe		1 vol% PE between inner and outer containers	.9180	.0037	.9253
nc.03pe		As above with 3 vol% PE	.8377	.0030	.8438
nc.05pe		As above with 5 vol% PE	.7746	.0038	.7822
800 units (20x20x2 array) at undamaged spacing, 1.1 cm diameter pellets, no clad, 13 vol% PE between rods as shipping shims, and various amounts of PE as interspersed moderator between inner and outer containers					
nnc.00pe800	9	As case nc.00pe with only 800 units	.8217	.0041	.8298
nnc.01pe800		As above with 1 vol% PE	.8201	.0035	.8271
nnc.03pe800		As above with 3 vol% PE	.7953	.0040	.8034
nnc.05pe800		As above with 5 vol% PE	.7461	.0037	.7536

4. QA Review Description

1) Methodology used in this CSE is clearly defined and was verified to be applicable. The calculation methods including details on cross section preparation, atom densities assumed, and geometry models were reviewed and determined to be adequate. Each of these items was verified to be conservative.

2) Assumptions were reviewed for reasonableness and applicability to this analysis.

3) Modeling was reviewed and determined to conservatively model the actual system. A listing of one or more of the most reactive cases is included in the CSE.

4) Referenced sources were reviewed for applicability to this CSE.

5) Input information was checked against referenced sources.

6) Input for computer calculations were checked for agreement with values in the CSE text.

7) Hand calculations were independently checked.

8) K_{eff} for worst case accident conditions is specifically stated in the text.

5. References

1) SPC Criticality Safety Analysis BFQ-SP1.1, SP-1 SHIPPING CONTAINER.

2) SPC Criticality Safety Analysis BFQ-SP1.2, SP-1 SUPPLEMENTAL APPLICATION.

3) SPC Criticality Safety Analysis BFQ-SP1.3, SP-1 SHIPMENTS WITH GADOLINIA ROD CONTAINER.

4) SCALE Standardized Computer Analyses for Licensing Evaluation, NUREG/CR-2000 ORNL/NUREG/CSD-2, Volumes 1, 2, and 3.

5) Critical Separation Between Subcritical Clusters of 4.31 wt% Enriched UO_2 Rods in Water with Fixed Neutron Poisons, NUREG/CR-0073.

6) Certificate USA/9248/AF, Revision 13, SP-1 and SP-2 Shipping Certificate

7) EMF-1563, Revision 1, Consolidated License Application for Siemens Power Corporation Model SP-1 and SP-2 Shipping Containers, December 1993.

8) EMF-1563, Supplement 1, Revision 1, Supplemental License Application for Siemens Power Corporation Model SP-1 and SP-2 Shipping Containers, March 1995.

9) EMF-1563, Supplement 4, Supplemental License Application for Siemens Power Corporation Model SP-1 and SP-2 Shipping Containers, February 1996.

10) EMF-94-175, "Validation and Verification of KENO.Va" by R. E. Coen, Siemens Power Corporation - Nuclear Division, 2101 Horn Rapids Road, Richland, WA 99352.

APPENDIX C SAMPLE COMPUTER INPUTS FOR SP-3 CONTAINERS WITH SPC 9X9 FUEL

Case drda-ex8d.012

```
=csas25
model for most reactive type g2 assembly
hans infhom
'
' mixture 1
'  interior uo2 pellets, 4 wt% u235
u-235 1 0.0 9.4068e-04 293 end
u-238 1 0.0 2.2291e-02 293 end
o     1 0.0 4.6464e-02 293 end
'
' mixture 2
'  edge uo2 pellets, 4 wt% u235
u-235 2 0.0 9.4068e-04 293 end
u-238 2 0.0 2.2291e-02 293 end
o     2 0.0 4.6464e-02 293 end
'
' mixture 3
'  edge uo2 pellets facing other bundle, 4 wt% u235
u-235 3 0.0 9.4068e-04 293 end
u-238 3 0.0 2.2291e-02 293 end
o     3 0.0 4.6464e-02 293 end
'
' mixture 4
'  gd-uo2 pellets, 4 wt% u235, 1.5 wt% gd
u-235 4 0.0 9.4068e-04 293 end
u-238 4 0.0 2.2291e-02 293 end
o     4 0.0 4.6464e-02 293 end
gd    4 0.0 5.32467e-04 293 end
'
' mixture 5
'  smeared zr clad
'  pod, cid, cod = 0.4221", 0.4281", 0.4781"
'  vol fract zr = 0.8988
'   at dens = 0.8988 * 4.2518-2 = 3.8215e-02
zircalloy 5 0.0 3.8215e-02 293 end
'
' mixture 6
'  12 vol% interspersed moderator
h2o 6 den=1.00 0.12  293 end
'
' mixture 7
'  carbon steel, 100 vol%
c  7 0.0 3.921682e-03 293 end
fe 7.0.0 8.350009e-02 293 end
'
' mixture 8
'  carbon steel, 85.57 vol% smeared with 10 vol% h2o
c  8 0.0 3.355783e-03 293 end
fe 8 0.0 7.145103e-02 293 end
o  8 0.0 4.8167e-04 293 end
h  8 0.0 9.6335e-04 293 end
'
' mixture 9
'  carbon steel, 8.64 vol%
c  9 0.0 3.388333e-04 293 end
fe 9 0.0 7.214408e-03 293 end
o  9 0.0 3.0496e-03 293 end
```

```
h 9 0.0 6.0992e-03 293 end
'
' mixture 10
' water for reflector
o 10 0.0 3.344e-02 293 end
h 10 0.0 6.689e-02 293 end
'
' mixture 11
' pe and interspersed water.
' vf pe = 0.126 use 0.13 here
' water at full density is (1-.13) = .87 g/cc
h2o 11 den=0.87 0.12 293 end
arbmepe 0.92 2 0 1 1 6012 1
                          1001 2
                          11 0.13 end
'
end comp
more data
 res= 1 cyli 4.2706E-01 dan( 1)= 5.5963E-01
 res= 2 cyli 4.9281E-01 dan( 2)= 3.6920E-01
 res= 3 cyli 4.7047E-01 dan( 3)= 4.2215E-01
 res= 4 cyli 3.9028E-01 dan( 4)= 5.7420E-01
end more
model for most reactive type g2 assembly
read parameters
   tme=60.0 gen=83 npg=300
   flx=yes fdn=yes xs1=yes nub=yes pwt=yes
   run=yes plt=yes
end parameters
read geometry
unit 1
com=" interior uo2 rod "
cyli 1 1 0.470 2p225.58
cubo 11 1 4p0.7225 2p225.58
unit 2
com=" edge uo2 rod "
cyli 2 1 0.470 2p225.58
cubo 11 1 4p0.7225 2p225.58
unit 23
com=" water rod "
cubo 6 1 4p0.7225 2p225.58
unit 3
com=" edge rod facing other bundle "
cyli 3 1 0.470 2p225.58
cubo 11 1 4p0.7225 2p225.58
unit 4
com=" uo2-gd2o3 rod "
cyli 4 1 0.470 2p225.58
cubo 11 1 4p0.7225 2p225.58
unit 5
com=" 9x9 bundle in left basket "
array 1 2r-6.46065 -225.58
cubo 6 1 4p8.7381 2p225.58
' add 0.00598 inch of perforated steel
cubo 8 1 4p8.89 2p225.58
unit 6
com=" 9x9 bundle in right basket "
array 2 2r-6.46065 -225.58
cubo 6 1 4p8.7381 2p225.58
' add 0.00598 inch of perforated steel
cubo 8 1 4p8.89 2p225.58
```

```
unit 7
com=" spacing & steel angle  beside basket "
cubo  9  1  2p2.06375  2p4.9391  2p225.58
cubo  6  1  2p2.06375  2p8.89  2p225.58
unit 8
com="  angles & spacing beneath & above baskets "
cubo  9  1  2p4.9392 2p2.06375 2p225.58
cubo  6  1  2p8.89  2p2.06375 2p225.58
unit 9
com="1 15/16 x 1 15/16 inch moderation regions at corners "
cubo  6  1  4p2.06375 2p225.58
unit 10
com="  1 inner container  "
array  3  -22.86 -13.97 -225.58
'  add 0.0598 inch walls
repl  7  1 6r0.1519 1
global
unit 11
com="array of inners "
array 4 3r0.0
repl 10 2 6r3.0  10
unit 16
com=" spacing & steel angle at -x side of basket "
cubo  6 1  4.12750 0.0 2p8.89  2p225.58
hole 22    0.15875 0.0  0.0
hole 22  0.47625 -0.3175 0.0
hole 22   0.47625  0.3175 0.0
hole 22   0.79375  0.635 0.0
hole 22  0.79375  -0.635 0.0
hole 22  1.11125  0.9525 0.0
hole 22  1.11125  -0.9525 0.0
hole 22  1.42875  1.27 0.0
hole 22  1.42875  -1.27 0.0
hole 22  1.74625  1.5875 0.0
hole 22  1.74625  -1.5875 0.0
hole 22  2.06375 1.905 0.0
hole 22  2.06375 -1.905 0.0
hole 22  2.38125  2.2225 0.0
hole 22  2.38125 -2.2225  0.0
hole 22  2.69875  2.54 0.0
hole 22  2.69875 -2.54  0.0
hole 22  3.01625  2.8575 0.0
hole 22  3.01625 -2.8575  0.0
hole 22  3.33375  3.175 0.0
hole 22  3.33375 -3.175  0.0
hole 22  3.65125  3.4925 0.0
hole 22  3.65125 -3.4925  0.0
hole 22  3.96875  3.81 0.0
hole 22  3.96875 -3.81  0.0

unit 17
com=" spacing & steel angle at +x side of basket "
cubo  6 1  0.0  -4.12750 2p8.89  2p225.58
hole 22  -0.15875 0.0  0.0
hole 22  -0.47625 -0.3175 0.0
hole 22  -0.47625  0.3175 0.0
hole 22   -0.79375  0.635 0.0
hole 22  -0.79375  -0.635 0.0
hole 22  -1.11125  0.9525 0.0
hole 22  -1.11125  -0.9525 0.0
hole 22  -1.42875  1.27 0.0
```

```
hole 22 -1.42875 -1.27 0.0
hole 22 -1.74625 1.5875 0.0
hole 22 -1.74625 -1.5875 0.0
hole 22 -2.06375 1.905 0.0
hole 22 -2.06375 -1.905 0.0
hole 22 -2.38125 2.2225 0.0
hole 22 -2.38125 -2.2225 0.0
hole 22 -2.69875 2.54 0.0
hole 22 -2.69875 -2.54 0.0
hole 22 -3.01625 2.8575 0.0
hole 22 -3.01625 -2.8575 0.0
hole 22 -3.33375 3.175 0.0
hole 22 -3.33375 -3.175 0.0
hole 22 -3.65125 3.4925 0.0
hole 22 -3.65125 -3.4925 0.0
hole 22 -3.96875 3.81 0.0
hole 22 -3.96875 -3.81 0.0

unit 18
com=" angles & spacing beneath baskets "
cubo 6 1 2p8.89 4.12750 0.0 2p225.58
hole 21 0.0 0.15875 0.0
hole 21 -0.3175 0.47625 0.0
hole 21 0.3175 0.47625 0.0
hole 21 0.635 0.79375 0.0
hole 21 -0.635 0.79375 0.0
hole 21 0.9525 1.11125 0.0
hole 21 -0.9525 1.11125 0.0
hole 21 1.27 1.42875 0.0
hole 21 -1.27 1.42875 0.0
hole 21 1.5875 1.74625 0.0
hole 21 -1.5875 1.74625 0.0
hole 21 1.905 2.06375 0.0
hole 21 -1.905 2.06375 0.0
hole 21 2.2225 2.38125 0.0
hole 21 -2.2225 2.38125 0.0
hole 21 2.54 2.69875 0.0
hole 21 -2.54 2.69875 0.0
hole 21 2.8575 3.01625 0.0
hole 21 -2.8575 3.01625 0.0
hole 21 3.175 3.33375 0.0
hole 21 -3.175 3.33375 0.0
hole 21 3.4925 3.65125 0.0
hole 21 -3.4925 3.65125 0.0
hole 21 3.81 3.96875 0.0
hole 21 -3.81 3.96875 0.0

unit 19
com="angles & spacing above baskets "
cubo 6 1 2p8.89 0.0 -4.12750 2p225.58
hole 21 0.0 -0.15875 0.0
hole 21 -0.3175 -0.47625 0.0
hole 21 0.3175 -0.47625 0.0
hole 21 0.635 -0.79375 0.0
hole 21 -0.635 -0.79375 0.0
hole 21 0.9525 -1.11125 0.0
hole 21 -0.9525 -1.11125 0.0
hole 21 1.27 -1.42875 0.0
hole 21 -1.27 -1.42875 0.0
hole 21 1.5875 -1.74625 0.0
hole 21 -1.5875 -1.74625 0.0
```

```
hole 21  1.905  -2.06375  0 0
hole 21 -1.905  -2.06375  0 0
hole 21  2.2225  -2.38125  0 0
hole 21 -2.2225  -2.38125  0 0
hole 21   2.54 -2.69875 0 0
hole 21  -2.54 -2.69875 0 0
hole 21  2.8575 -3.01625  0 0
hole 21  -2.8575 -3.01625 0 0
hole 21   3.175 -3.33375 0 0
hole 21   -3.175 -3.33375  0 0
hole 21    3.4925 -3.65125 0 0
hole 21   -3.4925  -3.65125 0 0
hole 21   3.81 -3.96875 0 0
hole 21   -3.81 -3.96875 0 0
unit 21
com="part of steel angle in horiz sections of stringer"
'  0.1552" x 0.125"
cubo  7 1 2p0.197104 2p0.15874 2p225.58
unit 22
com="part of steel angle in vert sections of stringer"
'  0.125" x 0.1552"
cubo  7 1 2p0.15874 2p0.197104 2p225.58
end geometry
read array
ara=1 nux=9 nuy=9 nuz=1
fill
2 2 2 2 2 2 2 2 3
2 4 1 1 4 1 1 4 3
2 1 1 1 1 1 1 1 3
2 1 1 23 23 23 1 1 3
2 4 1 23 23 23 1 4 3
2 1 1 23 23 23 1 1 3
2 1 1 1 1 1 1 1 3
2 4 1 1 4 1 1 4 3
2 2 2 2 2 2 2 2 3
 end fill
ara=2 nux=9 nuy=9 nuz=1
fill
3 2 2 2 2 2 2 2 2
3 4 1 1 4 1 1 4 2
3 1 1 1 1 1 1 1 2
3 1 1 23 23 23 1 1 2
3 4 1 23 23 23 1 4 2
3 1 1 23 23 23 1 1 2
3 1 1 1 1 1 1 1 2
3 4 1 1 4 1 1 4 2
3 2 2 2 2 2 2 2 2
 end fill
ara=3 nux=4 nuy=3 nuz=1
fill
 9 18 18  9
16  5  6 17
 9 19 19  9
end fill
ara=4 nux=13 nuy=20 nuz=1
fill f10 end fill
end array
read start
nst=1
end start
read bounds
```

```
all=vacuum
end bounds
read bias
  id=500 2 11
end bias
read plot
'
ttl='  xy section of bottom left container '
xul=0            yul=28.2438     zul=10
xlr=46.0238      ylr=0           zlr=10
uax=1            vdn=-1          nax=150   lpi=10   end
'
ttl='  xy section of 5x5 array '
xul=0            yul=141.219     zul=10
xlr=230.119      ylr=0           zlr=10
uax=1            vdn=-1          nax=150   lpi=10   end
'
end plot
'
end data
end
```

Case drda-anc.01pe800

```
=csas25
model for most reactive type g2 assembly
hans infhom
'
' mixture 1
'   interior uo2 pellets, 4 wt% u235
u-235 1 0.0 9.4068e-04 293 end
u-238 1 0.0 2.2291e-02 293 end
o     1 0.0 4.6464e-02 293 end
'
' mixture 2
'   edge uo2 pellets, 4 wt% u235
u-235 2 0.0 9.4068e-04 293 end
u-238 2 0.0 2.2291e-02 293 end
o     2 0.0 4.6464e-02 293 end
'
' mixture 3
'   edge uo2 pellets facing other bundle, 4 wt% u235
u-235 3 0.0 9.4068e-04 293 end
u-238 3 0.0 2.2291e-02 293 end
o     3 0.0 4.6464e-02 293 end
'
' mixture 4
'   gd-uo2 pellets, 4 wt% u235, 1.5 wt% gd
u-235 4 0.0 9.4068e-04 293 end
u-238 4 0.0 2.2291e-02 293 end
o     4 0.0 4.6464e-02 293 end
gd    4 0.0 5.32467e-04 293 end
'
' mixture 5
'   smeared zr clad
'   pod, cid, cod = 0.4221", 0.4281", 0.4781"
'   vol fract zr = 0.8988
'   at dens = 0.8988 * 4.2518-2 = 3.8215e-02
zircalloy 5 0.0 3.8215e-02 293 end
```

```
' mixture 6
'  7 vol% interspersed moderator
h2o 6 den=1.0 0.07 293  end
' mixture 7
'  carbon steel, 100 vol%
c  7 0.0 3.921682e-03 293 end
fe 7 0.0 8.350009e-02 293 end

' mixture 8
'  carbon steel, 85.57 vol% smeared with 10 vol% h2o
c  8 0.0 3.355783e-03 293 end
fe 8 0.0 7.145103e-02 293 end
o  8 0.0 4.8167e-04 293 end
h  8 0.0 9.6335e-04 293 end

' mixture 9
'  carbon steel, 8.64 vol%
c  9 0.0 3.388333e-04 293 end
fe 9 0.0 7.214408e-03 293 end
o  9 0.0 3.0496e-03 293 end
h  9 0.0 6.0992e-03 293 end

' mixture 10
'  water for reflector
o 10 0.0 3.344e-02 293 end
h 10 0.0 6.689e-02 293 end

' mixture 11
'  pe and interspersed water
'  vf pe = 0.126 use 0.13 here
'  water at full density is (1-.13) = .87 g/cc
h2o 11 den=0.87 0.07  293 end
arbmepe  0.92 2  0  1 1 6012 1
                          1001 2
                           11 0.13  end

' mixture 12
'  pe as interspersed moderator for ethafoam
'  vf pe use 0.01 here
arbmepe  0.92 2  0  1 1 6012 1
                          1001 2
                           12 0.01        end

end comp
more data
 res=  1 cyli  4.1453E-01 dan(  1)= 6.1766E-01
 res=  2 cyli  5.0254E-01 dan(  2)= 4.1325E-01
 res=  3 cyli  5.0311E-01 dan(  3)= 4.5282E-01
 res=  4 cyli  3.6477E-01 dan(  4)= 6.3170E-01
end more
model for most reactive type g2 assembly
read parameters
  tme=60.0 gen=83 npg=300
  flx=yes fdn=yes xs1=yes nub=yes pwt=yes
  run=yes plt=yes
end parameters
read geometry
unit  1
com="  interior uo2 rod  "
cyli  1 1 0.470   2p225.58
```

```
cubo 11 1 4p0.7225 2p225.58
unit 2
com=" edge uo2 rod "
cyli 2 1 0.470 2p225.58
cubo 11 1 4p0.7225 2p225.58
unit 23
com=" water rod "
cubo 6 1 4p0.7225 2p225.58
unit 3
com=" edge rod facing other bundle "
cyli 3 1 0.470 2p225.58
cubo 11 1 4p0.7225 2p225.58
unit 4
com=" uo2-gd203 rod "
cyli 4 1 0.470 2p225.58
cubo 11 1 4p0.7225 2p225.58
unit 5
com=" 9x9 bundle in left basket "
array 1 2r-6.46065 -225.58
cubo 6 1 4p8.7381 2p225.58
' add 0.00598 inch of perforated steel
cubo 8 1 4p8.89 2p225.58
unit 6
com=" 9x9 bundle in right basket "
array 2 2r-6.46065 -225.58
cubo 6 1 4p8.7381 2p225.58
' add 0.00598 inch of perforated steel
cubo 8 1 4p8.89 2p225.58
unit 7
com=" spacing & steel angle beside basket "
cubo 9 1 2p2.06375 2p4.9391 2p225.58
cubo 6 1 2p2.06375 2p8.89 2p225.58
unit 8
com=" angles & spacing beneath & above baskets "
cubo 9 1 2p4.9392 2p2.06375 2p225.58
cubo 6 1 2p8.89 2p2.06375 2p225.58
unit 9
com="1 15/16 x 1 15/16 inch moderation regions at corners "
cubo 6 1 4p2.06375 2p225.58
unit 10
com=" 1 inner container "
array 3 -22.86 -13.97 -225.58
' add 0.0598 inch walls
repl 7 1 6r0.1519 1
' add exterior wood box
'use low density PE here and box size of 24" x 24" x 206"
cubo 12 1 4p30.48 2p261.62
'

global
unit 11
com="array of inners "
array 4 3r0.0
repl 10 2 6r3.0 10
unit 16
com=" spacing & steel angle at -x side of basket "
cubo 6 1 4.12750 0.0 2p8.89 2p225.58
hole 22 0.15875 0.0 0.0
hole 22 0.47625 -0.3175 0.0
hole 22 0.47625 0.3175 0.0
hole 22 0.79375 0.635 0.0
hole 22 0.79375 -0.635 0.0
```

```
hole 22  1.11125  0.9525 0.0
hole 22  1.11125 -0.9525 0.0
hole 22  1.42875  1.27 0.0
hole 22  1.42875 -1.27 0.0
hole 22  1.74625  1.5875 0.0
hole 22  1.74625 -1.5875 0.0
hole 22  2.06375 1.905 0.0
hole 22  2.06375 -1.905 0.0
hole 22  2.38125  2.2225 0.0
hole 22  2.38125 -2.2225  0.0
hole 22  2.69875  2.54 0.0
hole 22  2.69875 -2.54  0.0
hole 22  3.01625  2.8575 0.0
hole 22  3.01625 -2.8575  0.0
hole 22  3.33375  3.175 0.0
hole 22  3.33375 -3.175  0.0
hole 22  3.65125  3.4925 0.0
hole 22  3.65125 -3.4925  0.0
hole 22  3.96875  3.81 0.0
hole 22  3.96875 -3.81  0.0

unit 17
com=" spacing & steel angle at +x side of basket "
cubo  6 1  0.0  -4.12750 2p8.89  2p225.58
hole 22  -0.15875 0.0  0.0
hole 22  -0.47625 -0.3175 0.0
hole 22  -0.47625  0.3175 0.0
hole 22  -0.79375  0.635 0.0
hole 22  -0.79375  -0.635 0.0
hole 22  -1.11125  0.9525 0.0
hole 22  -1.11125  -0.9525 0.0
hole 22  -1.42875  1.27 0.0
hole 22  -1.42875  -1.27 0.0
hole 22  -1.74625  1.5875 0.0
hole 22  -1.74625  -1.5875 0.0
hole 22  -2.06375 1.905 0.0
hole 22  -2.06375 -1.905 0.0
hole 22  -2.38125  2.2225 0.0
hole 22  -2.38125 -2.2225  0.0
hole 22  -2.69875  2.54 0.0
hole 22  -2.69875 -2.54  0.0
hole 22 -3.01625  2.8575 0.0
hole 22  -3.01625 -2.8575  0.0
hole 22  -3.33375  3.175 0.0
hole 22  -3.33375 -3.175  0.0
hole 22  -3.65125  3.4925 0.0
hole 22  -3.65125 -3.4925  0.0
hole 22  -3.96875  3.81 0.0
hole 22  -3.96875 -3.81  0.0

unit 18
com=" angles & spacing beneath baskets "
cubo  6 1  2p8.89 4.12750 0.0  2p225.58
hole 21  0.0  0.15875  0.0
hole 21 -0.3175  0.47625  0.0
hole 21  0.3175  0.47625  0.0
hole 21  0.635  0.79375  0.0
hole 21 -0.635  0.79375  0.0
hole 21  0.9525  1.11125  0.0
hole 21 -0.9525  1.11125  0.0
hole 21  1.27  1.42875  0.0
```

```
hole 21 -1.27 1.42875 0.0
hole 21 1.5875 1.74625 0.0
hole 21 -1.5875 1.74625 0.0
hole 21 1.905 2.06375 0.0
hole 21 -1.905 2.06375 0.0
hole 21 2.2225 2.38125 0.0
hole 21 -2.2225 2.38125 0.0
hole 21 2.54 2.69875 0.0
hole 21 -2.54 2.69875 0.0
hole 21 2.8575 3.01625 0.0
hole 21 -2.8575 3.01625 0.0
hole 21 3.175 3.33375 0.0
hole 21 -3.175 3.33375 0.0
hole 21 3.4925 3.65125 0.0
hole 21 -3.4925 3.65125 0.0
hole 21 3.81 3.96875 0.0
hole 21 -3.81 3.96875 0.0

unit 19
com="angles & spacing above baskets "
cubo 6 1 2p8.89 0.0 -4.12750 2p225.58
hole 21 0.0 -0.15875 0.0
hole 21 -0.3175 -0.47625 0.0
hole 21 0.3175 -0.47625 0.0
hole 21 0.635 -0.79375 0.0
hole 21 -0.635 -0.79375 0.0
hole 21 0.9525 -1.11125 0.0
hole 21 -0.9525 -1.11125 0.0
hole 21 1.27 -1.42875 0.0
hole 21 -1.27 -1.42875 0.0
hole 21 1.5875 -1.74625 0.0
hole 21 -1.5875 -1.74625 0.0
hole 21 1.905 -2.06375 0.0
hole 21 -1.905 -2.06375 0.0
hole 21 2.2225 -2.38125 0.0
hole 21 -2.2225 -2.38125 0.0
hole 21 2.54 -2.69875 0.0
hole 21 -2.54 -2.69875 0.0
hole 21 2.8575 -3.01625 0.0
hole 21 -2.8575 -3.01625 0.0
hole 21 3.175 -3.33375 0.0
hole 21 -3.175 -3.33375 0.0
hole 21 3.4925 -3.65125 0.0
hole 21 -3.4925 -3.65125 0.0
hole 21 3.81 -3.96875 0.0
hole 21 -3.81 -3.96875 0.0
unit 21
com="part of steel angle in horiz sections of stringer"
' 0.1552" x 0.125"
cubo 7 1 2p0.197104 2p0.15874 2p225.58
unit 22
com="part of steel angle in vert sections of stringer"
' 0.125" x 0.1552"
cubo 7 1 2p0.15874 2p0.197104 2p225.58
end geometry
read array
ara=1 nux=9 nuy=9 nuz=1
fill
2 2 2 2 2 2 2 2 3
2 4 1 1 4 1 1 4 3
2 1 1 1 1 1 1 1 3
```

```
2 1 1 23 23 23 1 1 3
2 4 1 23 23 23 1 4 3
2 1 1 23 23 23 1 1 3
2 1 1 1 1 1 1 1 3
2 4 1 1 4 1 1 4 3
2 2 2 2 2 2 2 2 3
 end fill
ara=2 nux=9 nuy=9 nuz=1
fill
3 2 2 2 2 2 2 2 2
3 4 1 1 4 1 1 4 2
3 1 1 1 1 1 1 1 2
3 1 1 23 23 23 1 1 2
3 4 1 23 23 23 1 4 2
3 1 1 23 23 23 1 1 2
3 1 1 1 1 1 1 1 2
3 4 1 1 4 1 1 4 2
3 2 2 2 2 2 2 2 2
 end fill
ara=3 nux=4 nuy=3 nuz=1
fill
 9 18 18  9
16  5  6 17
 9 19 19  9
end fill
ara=4 nux=20 nuy=20 nuz=2
fill f10 end fill
end array
read start
nst=1
end start
read bounds
all=vacuum
end bounds
read bias
  id=500 2  11
end bias
read plot
'
ttl=! xy section of bottom left container !
xul=0          yul=28.2438    zul=10
xlr=46.0238    ylr=0          zlr=10
uax=1          vdn=-1         nax=150   lpi=10   end
'
ttl=! xy section of 5x5 array !
xul=0          yul=141.219    zul=10
xlr=230.119    ylr=0          zlr=10
uax=1          vdn=-1         nax=150   lpi=10   end
'
end plot
'
end data
end
```

Appendix 6I

SIEMENS POWER CORPORATION SUPPLEMENTAL APPLICATION TO ADD THE CRITICALITY SAFETY ANALYSIS FOR ATRIUM™-10 WITH POLYETHYLENE SHIPPING SHIMS TO THE SP-1/2/3 INNER PACKAGES TO CERTIFICATE OF COMPLIANCE 9248

Criticality Evaluation

1. Introduction and Summary

1.1 *Introduction*

This Criticality Safety Evaluation (CSE) provides the criticality safety basis for shipping ATRIUM™-10 fuel assemblies with shipping shims in the SP-1/2/3 packaging.

Section 2 details the methodologies used for the criticality safety analysis. Component description and analysis are provided in Section 3. Section 4 contains the Quality Assurance (QA) review and comment resolution. Section 5 documents the references. Sample computer inputs are provided in Appendix A.

1.2 *Summary*

This CSE shows that sufficient margin to safety exists for SP-1/2/3 packagings when they contain the following payload type and transport index:

- Payload Description: "UO_2 fuel assemblies composed of fuel rods in a 10x10 square array, with a maximum fuel cross section of 5.0 inches square, and a maximum fuel length of 174 inches. The maximum U-235 enrichment is 5.0 weight percent, the maximum U-235 enrichment for all edge rods is 4.75 weight percent, the maximum U-235 enrichment for the four (4) corner edge rods is 3.05 weight percent, and the maximum U-235 enrichment for the eight (8) edge rods immediately adjacent to the four corner edge rods is 3.55 weight percent. The pellet diameter is between 0.30 and 0.3957 inch. Each assembly must have a water channel in a central 3x3 position. Any number of additional water rods in any arrangement is permitted, including part length rods. Each assembly must include at least ten rods with a minimum nominal content of 2.0 weight percent gadolinia (Gd_2O_3) in all axial regions with enriched pellets, and in a pattern symmetric about one of the assembly diagonals. At least ten gadolinia rods must be located in rows 2 and 9, and in columns 2 and 9 of the assembly and cannot be immediately adjacent to another one of the ten gadolinia rods; however, diagonally adjacent is permitted. Polyethylene (PE) shipping shims may be inserted between the rods within the fuel assemblies described above up to a maximum volume fraction (VF) of 0.14 averaged over the void volume of the assembly. An additional upper tie plate (UTP) shipping shim may be added between the UTP and the fueled region. This UTP shim may consist of a maximum of 345 g plastic or plastic composite."

- Transport Index: TI = 1.0

A summary of the results in this CSE is provided in Table 1.

Table 1 Summary of Criticality Safety Evaluation for ATRIUM™-10 Fuel Assemblies with Shipping Shims in the SP-1/2/3 Packaging

Description of Most Reactive Case	k_{eff}	σ	bias	k_{eff} + 2σ + bias[1]
ATRIUM™-10 Fuel Assemblies with PE Shipping Shims (see detailed payload description listed in Section 1.2)				
Single SP-3 Inner Package, Assemblies Moved as Close as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in Assemblies are Toward Outside of Inner Packaging, 0.35" Diameter Pellets, 0.14 VF PE[2] as Shipping Shims, Fully Flooded, All Rods 5.0 wt% ^{235}U (see Section 3.1.2)	0.75413	0.00323	-0.00321[1]	0.76059
Undamaged Spacing, 256 SP-1/2/3 Inner/Outer Packages (16 Wide x 16 High), Assemblies as Far Apart as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Inside of the Group, 0.3957" Diameter Pellets, 0.14 VF PE within Inner Packaging as Shipping Shims, 13 vol% Interspersed Moderator, 1 vol% PE between Inner and Outer Packages (see Section 3.1.3)	0.81454	0.00248	-0.00321[1]	0.81950
Damaged Spacing, 104 SP-3 Inner Packages (8 Wide x 13 High), Assemblies as Far Apart as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Inside of the Group, 0.3957" Diameter Pellets, 0.14 VF PE[2] as Shipping Shims, 13 vol% Interspersed Moderator (see Section 3.1.4)	0.93506	0.00274	-0.00321[1]	0.94054

(1) Note that as discussed in Section 2.4, the bias is negative (conservative), so it is not included in the results as presented in Table 1.

(2) Under severe accident conditions, the UTP shim may increase the PE VF between the fuel rods from 0.14 to 0.151. Calculations in Section 3 show that this increase in the PE VF within the void volume produces statistically identical results.

2. Analysis Methodology

2.1 *Nuclear Analysis Methodology*

Monte Carlo techniques were used in this analysis. The following sensitivities were evaluated in this CSE:

- Assembly rotation (for asymmetric loading of Gd_2O_3 rods) and placement within the inner packaging
- VF PE as shipping shims
- Pellet diameter
- Edge rod ^{235}U enrichment
- Interspersed moderator
- UO_2 theoretical density (TD)

2.2 *Computer Codes and Databases Used*

The following codes and cross section libraries are part of the SCALE 4.2 system of codes (Reference 1).

```
791176    Jun 22 1994 11:36:41 o0o001.a (XSDRN)
545416    Feb 21 1994 10:25:06 o0o002.a (NITAWL)
516744    Feb 21 1994 10:14:38 o0o008.a (BONAMI)
1094280   Jun 22 1994 11:46:27 o0o009.a (KENO.Va)
112000    Feb 23 1994 15:16:47 albdata.bin
4256216   Feb 23 1994 14:40:21 pxs123.bin (123 group master cross section library)
362140    Feb 25 1994 16:54:21 pxs16.bin (16 group master cross section library)
9020996   Feb 23 1994 14:53:45 pxs218.bin (218 group master cross section library)
824404    Feb 23 1994 14:38:03 pxs27.bin (27 group master cross section library)
94400     Feb 23 1994 15:12:03 stdcomp.bin (standard comp. library)
44812     Feb 23 1994 15:14:40 wtdata.bin
287       Jul  7 1994 09:35:35 csas25
2295      Jul  7 1994 17:07:41 drva
```

2.3 *Cross Section Preparation*

BONAMI and NITAWL adjust the cross section data for the specific problem (e.g., perform resonance self-shielding corrections). The Hansen-Roach 16-energy group cross sections available in SCALE were used for all calculations.

2.4 *Benchmarking*

The bias and its standard deviation are calculated using the methods described in Reference 4. These methods use standard analysis of variance principles.

k_c is the value of k_{eff} that results from the calculation of benchmark experiments using a particular calculation method. This value represents a combination of theoretical techniques and numerical data. The value for k_c is the weighted average (grand average) of the average k_{eff} values for a series of benchmark cases that are applicable to the system being modeled. Each individual benchmark case is weighted by the inverse of the k_{eff} variance (square of standard deviation).

The average value of the variance is taken as the "within class" variance. The variance of the average k_{eff} data, weighted as for the grand average, is taken as the "between class" variance. Since the true value for all benchmark cases is assumed to be 1.0 (critical), the class effect (the change in average k_{eff} from case to case) is also the bias and the variance of the class effect is the variance of the bias.

The calculation bias, Δk_b, is therefore calculated as $1-\Delta k_c$. A negative bias indicates conservative calculation results.

The SCALE 4.2 system of codes was developed for use by the USNRC and its licensees. SPC benchmarking of SCALE 4.2 on HP Workstations includes critical experiments of 4.31% enriched assemblies from NUREG/CR-0073 (Reference 2) which were modeled using the same methodology used in these calculations.

The critical experiments used for the benchmarking activities in this application are the same as those SPC has used to support licensing of other bundle packaging (SP1, SP-2, SP-3, NT-IV, and 51032). These cases were chosen because they have been validated by the international community, include bundles spaced various distances apart with neutron absorbing materials between the bundles, and the average energy group causing fission is similar to that observed in the calculations to support this license application.

A bias estimate based on 23 pooled cases was calculated from the 16-group data in Table 12 of Reference 3 and is -0.00321 ± 0.00261. Again, a negative bias indicates conservative results. The benchmark data used to calculate this bias is provided in Table 2.

Table 2 Benchmark Data Used for Determination of Calculation Bias for the SP-1/2/3 Package Analysis

CaseID	Average k_{eff}	σ
a-c001x	1.00355	0.00249
a-c002x	1.00905	0.00257
a-c003x	1.00845	0.00252
a-c004	1.00435	0.00265
a-c005a	1.00244	0.00265
a-c005b	1.00198	0.00252
a-c006a	1.00188	0.00236
a-c006b	0.99954	0.00237
a-c007a	1.00425	0.00247
a-c007x	1.00788	0.00253
a-c008a	1.00148	0.00231
a-c008x	1.00109	0.00242
a-c009a	1.00062	0.00233
a-c010a	1.00481	0.00239
a-c011a	1.00356	0.00275
a-c012a	1.00063	0.00244
a-c013a	1.00142	0.00240
a-c013x	1.01149	0.00227
a-c014a	0.99991	0.00241
a-c014x	1.00732	0.00259
a-c029a	0.99956	0.00242
a-c030a	1.00278	0.00257
a-c031a	0.99736	0.00239

3. Component Description and Analysis

The dimensions of the SP-1 outer packaging are shown on drawing EMF-306,272. The SP-1 outer packaging may contain either an SP-1, SP-2, or SP-3 inner packaging. The dimensions of these inner packagings are shown on drawings EMF-304,416; EMF-308,257; and EMF-309,818; respectively.

Since the stringer height of the SP-3 inner packaging is the smallest (most conservative) of the SP-1/2/3 inner packagings, the SP-3 inner packaging is used in the computer models in this CSE. The calculations of this section address placing ATRIUM™-10 fuel assemblies with PE shipping shims into the SP-3 inner packaging. Calculations are also provided for these packages inside the SP-1 outer packaging.

3.1 *Payload Type 1 (ATRIUM™-10 with PE Shipping Shims)*

The following material is provided as a new category of fuel to be shipped in the SP-1/2/3 packaging:

> "UO_2 fuel assemblies composed of fuel rods in a 10x10 square array, with a maximum fuel cross section of 5.0 inches square, and a maximum fuel length of 174 inches. The maximum U-235 enrichment is 5.0 weight percent, the maximum U-235 enrichment for all edge rods is 4.75 weight percent, the maximum U-235 enrichment for the four (4) corner edge rods is 3.05 weight percent, and the maximum U-235 enrichment for the eight (8) edge rods immediately adjacent to the four corner edge rods is 3.55 weight percent. The pellet diameter is between 0.30 and 0.3957 inch. Each assembly must have a water channel in a central 3x3 position. Any number of additional water rods in any arrangement is permitted, including part length rods. Each assembly must include at least ten rods with a minimum nominal content of 2.0 weight percent gadolinia (Gd_2O_3) in all axial regions with enriched pellets, and in a pattern symmetric about one of the assembly diagonals. At least ten gadolinia rods must be located in rows 2 and 9, and in columns 2 and 9 of the assembly and cannot be immediately adjacent to another one of the ten gadolinia rods; however, diagonally adjacent is permitted. PE shipping shims may be inserted between the rods within the fuel assemblies described above up to a maximum VF of 0.14 averaged over the void volume of the assembly. An additional UTP shipping shim may be added between the UTP and the fueled region. This UTP shim may consist of a maximum of 345 g plastic or plastic composite."

3.1.1 Computer Model Description

The SP-1/2/3 inner packaging and SP-1 outer packaging are modeled exactly as they were modeled in Reference 7, which was prepared for the previous submittal (EMF-1563 Appendix 6H). The only difference between the computer models of Reference 7 and this CSE is the payload type. This CSE provides an analysis of ATRIUM™-10 fuel assemblies with PE shipping shims as the payload.

A comparison of the actual and modeled ATRIUM™-10 fuel assembly parameters and PE shipping shim loading is included in Table 3.

Reference 8 provides results of an analysis that investigated various placements of the ten Gd_2O_3 rods in rows 2 and 9 and columns 2 and 9 of the ATRIUM™-10 fuel assembly. Figure 1 shows the Gd_2O_3 rod placement that provides the most reactive assembly (Reference 8).

According to Reference 6, the Taipower fuel assemblies are shipped with PE shipping shims placed between the fuel rods. The normal PE shim loading is shown in Table 3 (1213.8 g PE; 32 @ 5.194 g each and 152 @ 6.892 g each). A conservative mass of PE shims (maximum number of shims which will fit into an ATRIUM™-10 fuel assembly along the length of the assembly) is 4493 g PE (122 @ 5.5 g each and 546 @ 7.0 g each). If this mass is homogenized over a volume of 34,783 cm^2, the effective PE density is 0.129 g/cm^3. The TD of PE is 0.92. Therefore, under normal conditions, the VF of PE between the fuel rods of an assembly would be (0.129 g/cm^3)/(0.92 g/cm^3) or 0.14. The model assumes a PE VF of at least 0.14 for all conditions. The normal PE loading is approximately 0.035 g/cm^3, 3.7 times less than the amount included in the computer model.

The volume available to the PE shims is calculated as follows:

Assembly Envelope: $9*1.2954 + 1.00508 = 12.66368$ cm; Cross sectional area = 160.37 cm^2

Channel Envelope: 3.50012 cm; Cross sectional area = 12.25 cm^2

Area of 91 Rods: $91*\pi(0.4445)^2 = 56.49\ cm^2$

Area of Shims per cm Length = $160.37 - 12.25 - 56.49 = 91.63\ cm^2$

Volume Available to Shims = $91.63\ cm^2 * 379.603\ cm = 34{,}783\ cm^3$

An additional shipping shim option is to place a PE fork-shaped shim between the UTP and the shoulder of the upper end caps. This shim is to prevent the fuel rods from sliding axially toward the upper tie plate. Under normal (undamaged) conditions, this shim will remain outside the active fuel region of the assemblies. However, under damaged conditions, the shim could conceivably migrate (melt or break) into the active fuel region of the assemblies. Therefore, Sections 3.1.2 (Analysis of a Single Package) and 3.1.4 (Analysis of Array of Damaged Packages) provide additional calculations, which increase the PE content within the assemblies to include the extra shim. According to Reference 9, the upper tie plate shim has a maximum volume of 375 cm^3 and may be constructed of plastic or plastic composite. At a PE density of 0.92 g/cm^3, this shim has a maximum mass of 345 g. As previously discussed, the volume within the assemblies available to the PE shims is 34,783 cm^3. The total maximum PE mass within each assembly (including the shims between the rods and the upper tie plate shim) is 4,838 g. Therefore, the PE density averaged over the volume available is 0.139 g/cm^3 and the effective VF is (0.139 g/cm^3)/(0.92 g/cm^3) or 0.151.

Pads of ethafoam are also used within the inner packaging, but outside of the fuel assemblies. Under severe accident conditions, it is conceivable that a small amount of ethafoam could migrate between the fuel rods. However, due to its low density, the ethafoam is bounded by varying the interspersed moderator (water) between the fuel rods from dry to fully flooded. Since the upper tie plate shim is PE (a much higher density plastic), it is included in the model for damaged conditions.

Table 3 Comparison of Nominal vs. Modeled Conditions

Parameter	Nominal	Modeled	Reference For Nominal Condition
Pellet			
Diameter	0.3413"	0.30", 0.325", 0.35", 0.375", and 0.3957"	Reference 5 Page 5
Density	95.85 ± 1.5%TD (does not include dish or land taper which is minimally 1.16%)	Most cases use 96% TD The most reactive cases are run with 98% TD	Reference 10
^{235}U Enrichment	4 corner rods ≤ 3.05 wt% 8 edge rods immediately adjacent to corner rods ≤ 3.55 wt% Remainder of edge rods ≤ 4.75 wt% Remainder of rods ≤ 5.00 wt%	Maximum stated enrichments Some additional cases use edge rod enrichment of 5.00 wt%	Pending Certificate of Compliance
Rod			
Cladding ID	0.3480"	Cladding and gap is conservatively omitted	Reference 5 Page 4
Cladding OD	0.3957"		
Pellet-Clad Gap	0.00335"		
Active Fuel Length	149.45"	177.62205"	
Fuel Assembly 10x10			
Rod Pitch	0.510"	0.510"	Reference 5 Page 3
Water Channel Outer Dimension	1.378" square	Center 3x3 rods	Reference 5 Page 6
Number of Fuel Rods	91	91	Reference 5 Page 3
Number of Rods with Gd_2O_3	10 Minimum in Rows 2 & 9 and Columns 2 & 9	Minimum Nominal (Placement per Reference 8)	Pending Certificate of Compliance
Gd_2O_3 Content	2.0 wt%	1.5 wt%	Pending Certificate of Compliance
PE Shipping Shims			
Total Number of Shims Between the Fuel Rods	32 @ 5.194 g each, <152 @ 6.892 g each VF < 0.04	122 @ 5.5 g each 546 @ 7.0 g each Modeled as VF = 0.14 in space between rods for normal case	Reference 6
Upper Tie Plate Shim	1 @ <375 cm^3 (<345 g PE) VF ~ 0.01	1 @ 345 g VF ~ 0.01 in addition to other shims (damaged conditions)	Reference 9

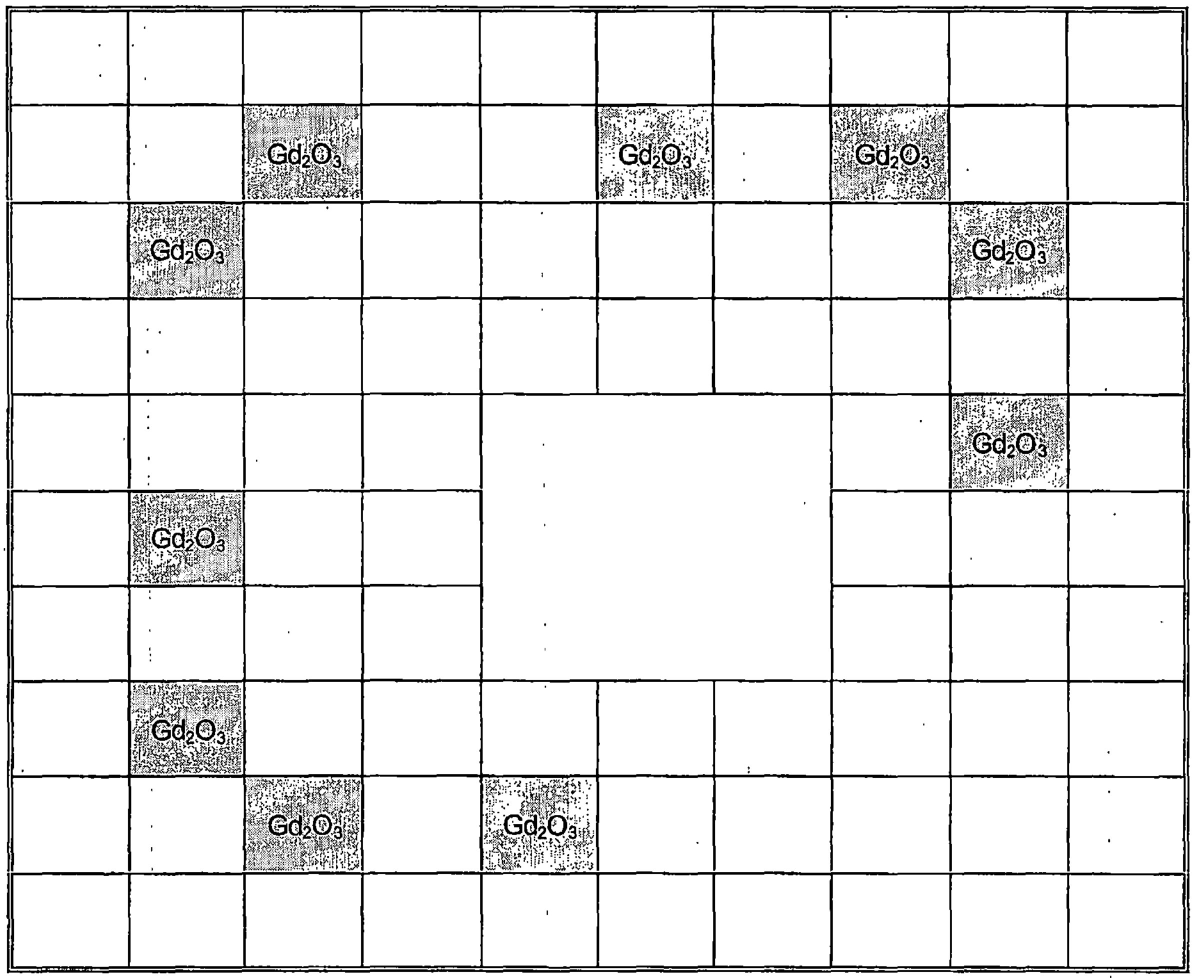

Figure 1 Gd_2O_3 Rod Placement which Produces Most Reactive Assembly (Reference 8)

3.1.2 Analysis of a Single Package with Payload 1 (ATRIUM™-10 with PE Shipping Shims)

A single SP-3 inner package was modeled to show that the k_{eff} limits are met for all normal and hypothetical accident conditions. The assemblies within the SP-3 inner packaging are ATRIUM™-10 design as specified in Table 3.

First, since the most reactive Gd_2O_3 rod placement per Reference 8 is asymmetric within the assembly (see Figure 1), a sensitivity study was performed to determine the most reactive assembly rotation within the inner packaging. The following two assembly rotations were investigated:

1. Asymmetric Gd_2O_3 rods in each assembly facing towards the inside of the inner packaging (Figure 2)

2. Asymmetric Gd_2O_3 rods in each assembly facing towards the outside of the inner packaging (Figure 3)

For this study, the assemblies were each centered horizontally and vertically within their respective channels. A pellet diameter of 0.3957" (corresponding to the actual clad OD) was used, as well as a PE VF of 0.14 as shims between the fuel rods. Interspersed moderator was varied from dry to fully flooded. The results of this study are provided in Table 4 and Table 5. The case with the asymmetric Gd_2O_3 rods in each assembly facing towards the outside of the inner packaging and fully flooded conditions provided the peak reactivity (k_{eff}=0.72089, including 2σ) in this sensitivity study.

Next, the assemblies were moved horizontally within their respective inner packaging, so that they were

1. As close as physically possible within the inner packaging (Figure 4)

2. As far apart as physically possible within the inner packaging (Figure 5)

The most reactive Gd_2O_3 rod arrangement from the previous sensitivity study (asymmetric Gd_2O_3 rods in each assembly facing towards the outside of the inner packaging) was used. Again, a pellet diameter of 0.3957" was used, as well as a PE VF of 0.14 as shims between the fuel rods. Interspersed moderator was varied from dry to fully flooded. The results of this study are provided in Table 6 and Table 7. The case with the assemblies as close as physically possible within the inner packaging and fully flooded conditions resulted in the peak reactivity (k_{eff}=0.73524, including 2σ) in this sensitivity study.

An additional sensitivity study was performed using a PE VF of 0.28 as shims between the fuel rods. This represents more than twice the amount of PE shims that will fit between the rods and 7.4 times the amount of PE shims that is called for in the parts list. For this study, 0.3957" diameter pellets were used. The asymmetric Gd_2O_3 rods in each assembly were rotated such that they face towards the outside of the inner packaging. The assemblies are located horizontally as close as physically possible within the inner packaging. Interspersed moderator was again varied from dry to fully flooded. The results of this study are provided in Table 8. Fully flooded conditions resulted in the peak reactivity (k_{eff}=0.73772, including 2σ), which is less than one standard deviation higher than the same conditions with a PE VF of 0.14 (see Table 6). This study bounds any migration of the upper tie plate shim into the active fuel region of the assemblies. Since the Δk at peak interspersed moderator conditions was less than one standard deviation higher than the same conditions with a PE VF of 0.14, the remaining calculations in this section were performed with a PE VF of 0.14.

Next, the most reactive arrangement from the previous sensitivity studies with 0.14 VF PE (asymmetric Gd_2O_3 rods in each assembly facing towards the outside of the inner packaging and the assemblies as close as physically possible within the inner packaging) was modified to reduce the pellet diameter to 0.35". Again, a PE VF of 0.14 was used as shims between the fuel rods. Interspersed moderator was again varied from dry to fully flooded. The results of this study are provided in Table 9. Again, fully flooded conditions resulted in the peak reactivity (k_{eff}=0.74572, including 2σ), which is approximately 10.5 mk higher than the same conditions with larger rods (0.3957" diameter, see Table 6).

Since, in the previous sensitivity study, the reactivity increased for smaller rods, an additional sensitivity study was performed to investigate the reactivity effect of various pellet diameters. Additional pellet diameters of 0.3", 0.325", and 0.375" were used with fully flooded conditions. All other conditions are identical to the previous sensitivity study. The results are provided in Table 10 and show that for a single package and pellet diameters from 0.30" to 0.3957", the peak reactivity occurs with 0.35" pellets.

The most reactive case from Table 10 (drda-d1a.gout.i.100) was modified to discretely model the shipping shims as shown in drawing EMF-310,001. A cross-sectional image of this model is provided in Figure 6. The shim thickness in this model was set such that the total mass of PE in an inner package equaled that used in case drda-d1a.gout.i.100. The results are summarized below and show that the maximum k_{eff}, including 2σ, is 0.74502. This is approximately 0.2 standard deviations less than the result from the Table 10 calculation, which smears the shipping shim PE throughout the void volume of the assembly. Therefore, it is adequate to smear the shipping shim PE throughout the void volume of the assembly.

```
388105 Sep 14 05:06:01 2000 droa-d1aDSR.gout.i.100    .73806   .00348   .74387   .74502
```

Next, a sensitivity study was performed which increased the enrichment of all edge rods to 5.0 wt% ^{235}U, so that all rods in the assemblies are 5.0 wt% ^{235}U. All other conditions are identical to those described above, i.e. asymmetric Gd_2O_3 rods in each assembly facing towards the outside of the inner packaging, the assemblies as close as physically possible within the inner packaging, pellet diameter of 0.35", PE VF of 0.14 as shims between the fuel rods, and interspersed moderator varied from dry to fully flooded. The results of this study are provided in Table 11. Again, fully flooded conditions resulted in the peak reactivity (k_{eff}=0.76028, including 2σ) in this sensitivity study.

The most reactive case from the previous sensitivity study (see Table 11) was reran with a 98% UO_2 TD (increased from 96%). The results are summarized below and show that the maximum k_{eff}, including 2σ, is 0.76059, slightly higher but statistically identical (~0.1σ) to the most reactive case in Table 11.

```
357440 Oct 18 08:48:37 2000 droa-table11.98           .75413   .00323   .75952   .76059
```

As shown above, all cases for a single SP-3 inner package yielded reactivities much less than 0.95.

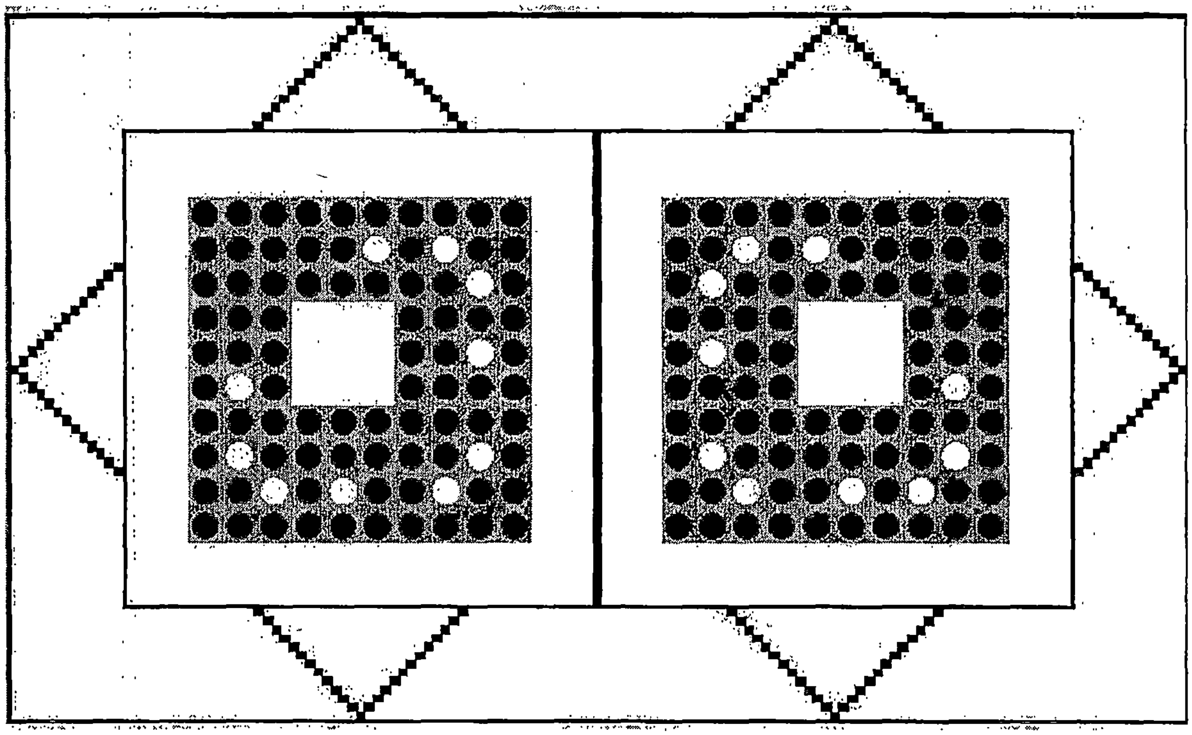

Figure 2 Assembly Rotation with Asymmetric Gd_2O_3 Rods Facing Towards Inside of Inner Packaging

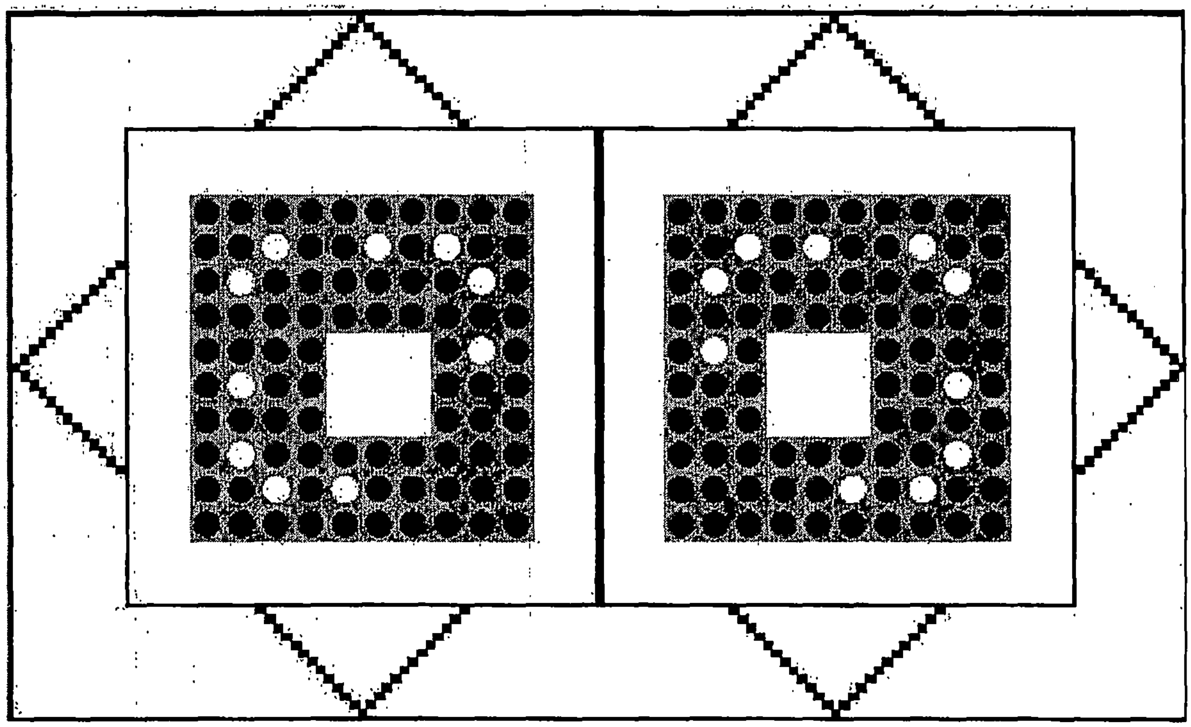

Figure 3 Assembly Rotation with Asymmetric Gd_2O_3 Rods Facing Towards Outside of Inner Packaging

Table 4 Single SP-3 Inner Package, Assemblies Centered in Channels, Asymmetric Gd_2O_3 Rods in Assemblies are Toward Inside of Inner Packaging, 0.3957" Diameter Pellets, 0.14 VF PE

Filename (droa-?)	Vol% Interspersed Moderator	k_{eff}	σ	$k_{eff}+2σ$
d1.gin.c.000	0	0.34803	0.00266	0.35335
d1.gin.c.001	1	0.34397	0.00262	0.34921
d1.gin.c.003	3	0.34563	0.00255	0.35073
d1.gin.c.005	5	0.34629	0.00244	0.35117
d1.gin.c.007	7	0.35201	0.00297	0.35795
d1.gin.c.010	10	0.35568	0.00238	0.36044
d1.gin.c.015	15	0.37439	0.00222	0.37883
d1.gin.c.020	20	0.39464	0.00224	0.39912
d1.gin.c.030	30	0.44554	0.00288	0.45130
d1.gin.c.040	40	0.49876	0.00280	0.50436
d1.gin.c.050	50	0.53914	0.00289	0.54492
d1.gin.c.060	60	0.58359	0.00310	0.58979
d1.gin.c.070	70	0.61530	0.00281	0.62092
d1.gin.c.080	80	0.64775	0.00355	0.65485
d1.gin.c.090	90	0.67351	0.00286	0.67923
d1.gin.c.100	***100***	***0.70451***	***0.00311***	***0.71073***

Table 5 Single SP-3 Inner Package, Assemblies Centered in Channels, Asymmetric Gd_2O_3 Rods in Assemblies are Toward Outside of Inner Packaging, 0.3957" Diameter Pellets, 0.14 VF PE

Filename (droa-?)	Vol% Interspersed Moderator	k_{eff}	σ	$k_{eff}+2\sigma$
d1.gout.c.000	0	0.34759	0.00252	0.35263
d1.gout.c.001	1	0.34334	0.00280	0.34894
d1.gout.c.003	3	0.34774	0.00287	0.35348
d1.gout.c.005	5	0.35203	0.00252	0.35707
d1.gout.c.007	7	0.35351	0.00260	0.35871
d1.gout.c.010	10	0.35474	0.00254	0.35982
d1.gout.c.015	15	0.37696	0.00257	0.38210
d1.gout.c.020	20	0.39556	0.00265	0.40086
d1.gout.c.030	30	0.45090	0.00258	0.45606
d1.gout.c.040	40	0.49840	0.00252	0.50344
d1.gout.c.050	50	0.54523	0.00273	0.55069
d1.gout.c.060	60	0.59099	0.00277	0.59653
d1.gout.c.070	70	0.62516	0.00313	0.63142
d1.gout.c.080	80	0.65990	0.00323	0.66636
d1.gout.c.090	90	0.68844	0.00352	0.69548
d1.gout.c.100	***100***	***0.71413***	***0.00338***	***0.72089***

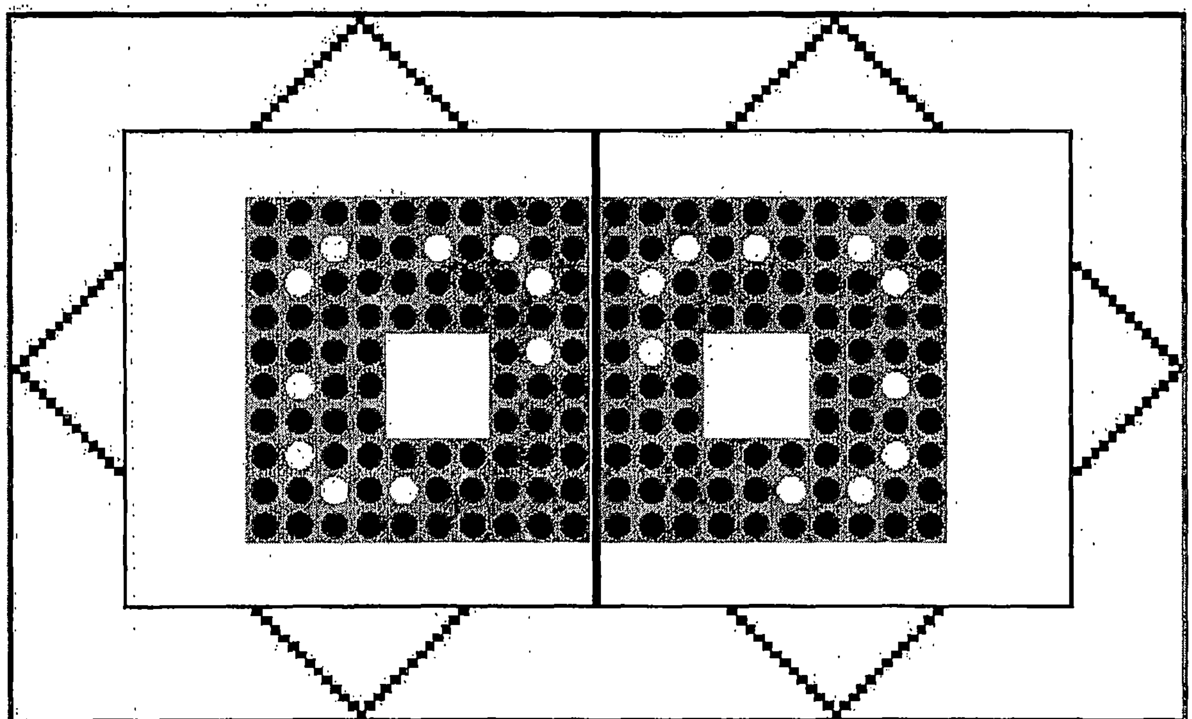

Figure 4 Assemblies Moved as Close as Physically Possible within Inner Packaging

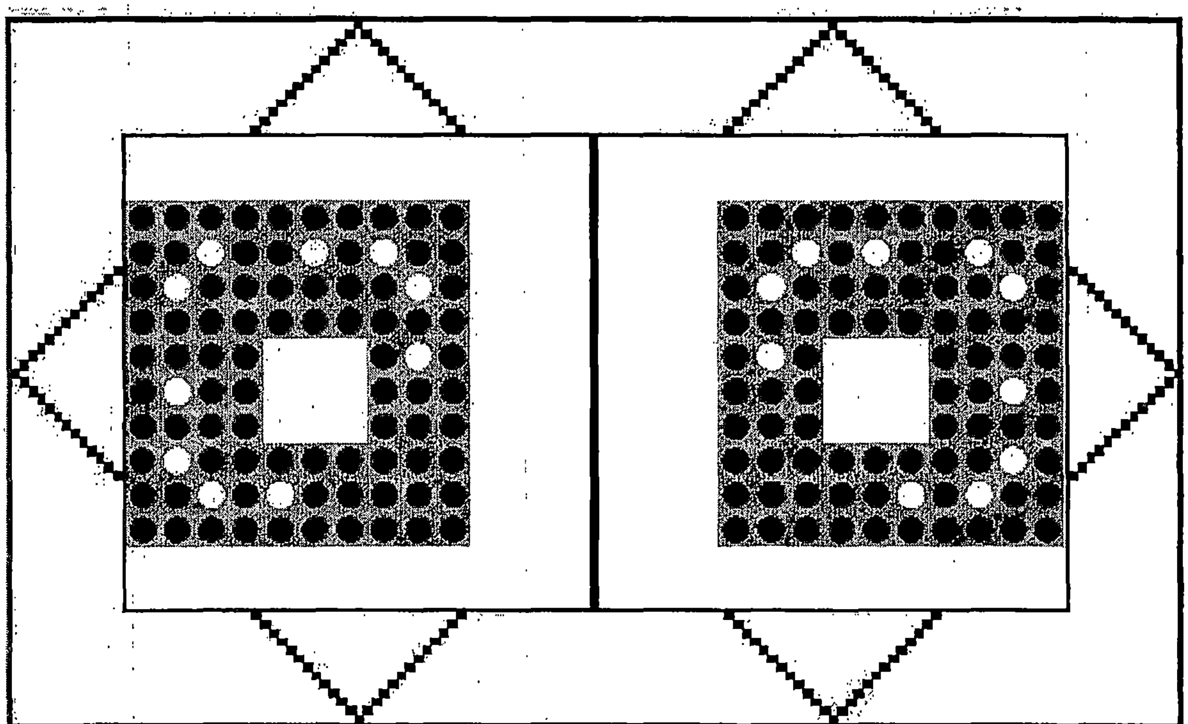

Figure 5 Assemblies Moved as Far Apart as Physically Possible within Inner Packaging

Table 6 Single SP-3 Inner Package, Assemblies Moved as Close as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in Assemblies are Toward Outside of Inner Packaging, 0.3957" Diameter Pellets, 0.14 VF PE

Filename (droa-?)	Vol% Interspersed Moderator	k_{eff}	σ	$k_{eff}+2\sigma$
d1.gout.i.000	0	0.34259	0.00271	0.34801
d1.gout.i.001	1	0.33890	0.00241	0.34372
d1.gout.i.003	3	0.34457	0.00231	0.34919
d1.gout.i.005	5	0.34598	0.00250	0.35098
d1.gout.i.007	7	0.34599	0.00266	0.35131
d1.gout.i.010	10	0.35787	0.00231	0.36249
d1.gout.i.015	15	0.36886	0.00240	0.37366
d1.gout.i.020	20	0.38776	0.00237	0.39250
d1.gout.i.030	30	0.44089	0.00265	0.44619
d1.gout.i.040	40	0.49256	0.00305	0.49866
d1.gout.i.050	50	0.54001	0.00321	0.54643
d1.gout.i.060	60	0.58479	0.00279	0.59037
d1.gout.i.070	70	0.62792	0.00338	0.63468
d1.gout.i.080	80	0.66302	0.00272	0.66846
d1.gout.i.090	90	0.70108	0.00376	0.70860
d1.gout.i.100	***100***	***0.72918***	***0.00303***	***0.73524***

Table 7 Single SP-3 Inner Package, Assemblies Moved as Far Apart as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in Assemblies are Toward Outside of Inner Packaging, 0.3957" Diameter Pellets, 0.14 VF PE

Filename (droa-?)	Vol% Interspersed Moderator	k_{eff}	σ	k_{eff}+2σ
d1.gout.o.000	0	0.34636	0.00216	0.35068
d1.gout.o.001	1	0.34747	0.00247	0.35241
d1.gout.o.003	3	0.35152	0.00255	0.35662
d1.gout.o.005	5	0.34843	0.00231	0.35305
d1.gout.o.007	7	0.35681	0.00275	0.36231
d1.gout.o.010	10	0.36141	0.00252	0.36645
d1.gout.o.015	15	0.38704	0.00249	0.39202
d1.gout.o.020	20	0.40466	0.00252	0.40970
d1.gout.o.030	30	0.44985	0.00253	0.45491
d1.gout.o.040	40	0.48696	0.00278	0.49252
d1.gout.o.050	50	0.52553	0.00270	0.53093
d1.gout.o.060	60	0.55415	0.00311	0.56037
d1.gout.o.070	70	0.58196	0.00277	0.58750
d1.gout.o.080	80	0.60583	0.00304	0.61191
d1.gout.o.090	90	0.62597	0.00307	0.63211
d1.gout.o.100	***100***	***0.65008***	***0.00296***	***0.65600***

Table 8 Single SP-3 Inner Package, Assemblies Moved as Close as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in Assemblies are Toward Outside of Inner Packaging, 0.3957" Diameter Pellets, 0.28 VF PE

Filename (droa.?)	Vol% Interspersed Moderator	k_{eff}	σ	$k_{eff}+2\sigma$
d1P.gout.i.000	0	0.37358	0.00225	0.37808
d1P.gout.i.001	1	0.37317	0.00276	0.37869
d1P.gout.i.003	3	0.37564	0.00264	0.38092
d1P.gout.i.005	5	0.37762	0.00274	0.38310
d1P.gout.i.007	7	0.38375	0.00252	0.38879
d1P.gout.i.010	10	0.39079	0.00258	0.39595
d1P.gout.i.015	15	0.40557	0.00265	0.41087
d1P.gout.i.020	20	0.42934	0.00269	0.43472
d1P.gout.i.030	30	0.47345	0.00252	0.47849
d1P.gout.i.040	40	0.52457	0.00298	0.53053
d1P.gout.i.050	50	0.56828	0.00258	0.57344
d1P.gout.i.060	60	0.60188	0.00301	0.60790
d1P.gout.i.070	70	0.64770	0.00336	0.65442
d1P.gout.i.080	80	0.67838	0.00307	0.68452
d1P.gout.i.090	90	0.70905	0.00287	0.71479
d1P.gout.i.100	***100***	***0.73174***	***0.00299***	***0.73772***

Table 9 Single SP-3 Inner Package, Assemblies Moved as Close as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in Assemblies are Toward Outside of Inner Packaging, 0.35" Diameter Pellets, 0.14 VF PE

Filename (droa-?)	Vol% Interspersed Moderator	k_{eff}	σ	$k_{eff}+2\sigma$
d1a.gout.i.000	0	0.31607	0.00240	0.32087
d1a.gout.i.001	1	0.31712	0.00255	0.32222
d1a.gout.i.003	3	0.31145	0.00220	0.31585
d1a.gout.i.005	5	0.31920	0.00241	0.32402
d1a.gout.i.007	7	0.32138	0.00220	0.32578
d1a.gout.i.010	10	0.33355	0.00241	0.33837
d1a.gout.i.015	15	0.35040	0.00238	0.35516
d1a.gout.i.020	20	0.37842	0.00260	0.38362
d1a.gout.i.030	30	0.42381	0.00261	0.42903
d1a.gout.i.040	40	0.48858	0.00302	0.49462
d1a.gout.i.050	50	0.54453	0.00272	0.54997
d1a.gout.i.060	60	0.58865	0.00331	0.59527
d1a.gout.i.070	70	0.63132	0.00301	0.63734
d1a.gout.i.080	80	0.66702	0.00307	0.67316
d1a.gout.i.090	90	0.70798	0.00299	0.71396
d1a.gout.i.100	***100***	***0.73904***	***0.00334***	***0.74572***

Table 10 Single SP-3 Inner Package, Assemblies Moved as Close as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in Assemblies are Toward Outside of Inner Packaging, Various Diameter Pellets, 0.14 VF PE, Fully Flooded Conditions

Filename (droa-?)	Pellet Diameter (in)	K_{eff}	σ	$K_{eff}+2\sigma$
d10300.100	0.300	0.72798	0.00336	0.73470
d10325.100	0.325	0.73517	0.00274	0.74065
d1a.gout.i.100	***0.350***	***0.73904***	***0.00334***	***0.74572***
d10375.100	0.375	0.73410	0.00324	0.74058
d1.gout.i.100	0.3975	0.72918	0.00303	0.73524

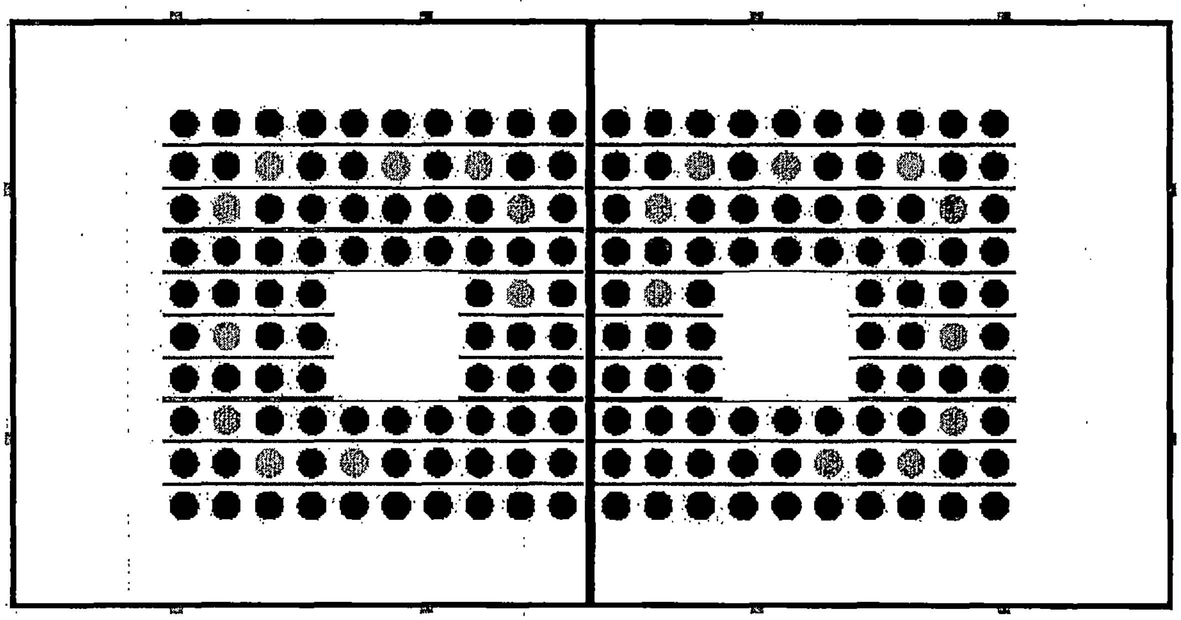

Figure 6 Discrete Model of PE Shims

Table 11 Single SP-3 Inner Package, Assemblies Moved as Close as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in Assemblies are Toward Outside of Inner Packaging, 0.35" Diameter Pellets, 0.14 VF PE, All Rods 5.0 wt% ^{235}U

Filename (droa-?)	Vol% Interspersed Moderator	k_{eff}	σ	$k_{eff}+2\sigma$
d1aE.gout.i.000	0	0.32519	0.00255	0.33029
d1aE.gout.i.001	1	0.32635	0.00238	0.33111
d1aE.gout.i.003	3	0.32574	0.00241	0.33056
d1aE.gout.i.005	5	0.32941	0.00257	0.33455
d1aE.gout.i.007	7	0.33525	0.00222	0.33969
d1aE.gout.i.010	10	0.34679	0.00279	0.35237
d1aE.gout.i.015	15	0.36086	0.00218	0.36522
d1aE.gout.i.020	20	0.38738	0.00242	0.39222
d1aE.gout.i.030	30	0.44312	0.00257	0.44826
d1aE.gout.i.040	40	0.50066	0.00281	0.50628
d1aE.gout.i.050	50	0.55570	0.00285	0.56140
d1aE.gout.i.060	60	0.60254	0.00284	0.60822
d1aE.gout.i.070	70	0.64405	0.00366	0.65137
d1aE.gout.i.080	80	0.68267	0.00259	0.68785
d1aE.gout.i.090	90	0.72017	0.00339	0.72695
d1aE.gout.i.100	***100***	***0.75376***	***0.00326***	***0.76028***

3.1.3 Analysis of Array of Undamaged Packages (Normal Conditions) with Payload 1 (ATRIUM™-10 with PE Shipping Shims)

For undamaged conditions, SP-1 outer packaging provides additional spacing between the inner packagings. As previously stated, the packaging dimensions used in this analysis are identical to those used in Reference 7, which was prepared for the previous submittal (EMF-1563 Appendix 6H).

Again, of the SP-1/2/3 inner packagings, the SP-3 inner packaging is used in all models, since it has the smallest stringer height (most conservative). The assemblies within the SP-3 inner packaging are ATRIUM™-10 design as specified in Table 3.

The cases from Table 22 and Table 23 represent the most reactive cases for credible accident conditions. Specifically, the assemblies are as far apart as physically possible within the inner packaging and the asymmetric Gd_2O_3 rods in the assemblies in each group of two vertically adjacent inner packaging face towards the inside of the group (see Figure 13). A PE VF of 0.14 is used as shims between the fuel rods and interspersed moderator within the inner packaging is at 13 vol%. The most reactive cases from Table 22 (case d112.gin.o.013) and Table 23 (case d112a.gin.o.013) were modified to represent undamaged conditions by increasing the package spacing to account for SP-1 outer packaging. The space between the inner packages was filled with low density PE to simulate the ethafoam filling. The PE density was varied until the peak reactivity was located. Pellet diameters of 0.3957" and 0.35" were studied, along with an array of packages 16 wide x 16 high x 1 long (256 packages). The results of this study are provided in Table 12 and Table 13. Since the system reactivity was maximized by varying the contributing factors in the calculations of Section 3.1.4, the peak reactivity occurred in both sets of cases with only 1 vol% PE between the inner packages. In these cases, the larger pellet diameter (0.3957") produced a higher peak reactivity (k_{eff}=0.81384, including 2σ), which is well below 0.95.

The most reactive case from the previous sensitivity study (see Table 12) was reran with a 98% UO_2 TD (increased from 96%). The results are summarized below and show that the maximum k_{eff}, including 2σ, is 0.81950, higher than the most reactive case in Table 12.

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393478 Oct 17 16:25:43 2000 droa-table14.98          .81454   .00248   .81868   .81950
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The calculations in this section demonstrate that the reactivity of an array of 256 SP-3 inner packages, each contained within an SP-1 outer packaging, remains below the 0.95 limit, provided a payload of ATRIUM™-10 fuel assemblies meeting the specifications listed in Table 3 are met. For normal (undamaged) conditions, an array of 5N packages (where N is the desired number of packages to be shipped at one time) must be shown to yield k_{eff} < 0.95. Therefore, the calculations of this section show that 256/5 or 51 SP-3 packages may be shipped at one time with the payload described herein.

Table 12 256 SP-1/2/3 Inner/Outer Packages (16 Wide x 16 High), Undamaged Spacing, Assemblies as Far Apart as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Inside of the Group, 0.3957" Diameter Pellets, 0.14 VF PE within Inner Packages, 13 vol% Interspersed Moderator, Various vol% PE between Inner and Outer Packages

Filename (droa-?)	Vol% PE Between Inner Packages	k_{eff}	σ	$k_{eff}+2σ$
u256.013.pe000	0	0.80127	0.00260	0.80647
u256.013.pe001	***1***	***0.80810***	***0.00287***	***0.81384***
u256.013.pe003	3	0.79973	0.00268	0.80509
u256.013.pe005	5	0.77434	0.00292	0.78018

Table 13 256 SP-1/2/3 Inner/Outer Packages (16 Wide x 16 High), Undamaged Spacing, Assemblies as Far Apart as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Inside of the Group, 0.35" Diameter Pellets, 0.14 VF PE within Inner Packages, 13 vol% Interspersed Moderator, Various vol% PE between Inner and Outer Packages

Filename (droa-?)	Vol% PE Between Inner Packages	k_{eff}	σ	$k_{eff}+2σ$
u256a.013.pe000	0	0.78078	0.00312	0.78702
u256a.013.pe001	***1***	***0.78456***	***0.00248***	***0.78952***
u256a.013.pe003	3	0.76862	0.00266	0.77394
u256a.013.pe005	5	0.74535	0.00269	0.75073

3.1.4 Analysis of Array of Damaged Packages (Accident Conditions) with Payload 1 (ATRIUM™-10 with PE Shipping Shims)

For damaged conditions, the outer packaging is assumed to burn away so that the inner packages contact one another. Also, water is assumed to leak into the inner packages. As previously stated, the packaging dimensions used in this analysis are identical to those used in Reference 7, which was prepared for the previous submittal (EMF-1563 Appendix 6H).

Also as previously stated, the dimensions of the SP-3 inner packaging are used in all models, since it has the smallest stringer height (most conservative). The assemblies within the SP-3 inner packaging are ATRIUM™-10 design as specified in Table 3.

First, since the most reactive Gd_2O_3 rod placement per Reference 8 is asymmetric within the assembly (see Figure 1), a sensitivity study was performed to determine the most reactive assembly rotation within the inner packaging in an infinite array. The following four assembly rotations were investigated:

1. Asymmetric Gd_2O_3 rods in each assembly facing towards the inside and bottom of the inner packaging (Figure 7)
2. Asymmetric Gd_2O_3 rods in each assembly facing towards the outside and bottom of the inner packaging (Figure 8)
3. Asymmetric Gd_2O_3 rods in the assemblies in each group of two vertically adjacent inner packages facing towards the inside of the group (Figure 9)
4. Asymmetric Gd_2O_3 rods in the assemblies in each group of two vertically adjacent inner packages facing towards the outside of the group (Figure 10)

For this study, the assemblies were each centered horizontally and vertically within their respective channels. A pellet diameter of 0.3957" (corresponding to the actual clad OD) was used, as well as a PE VF of 0.14 as shims between the fuel rods. For the first set of cases, interspersed moderator was varied from dry to fully flooded. Only dry, fully flooded, and the peak interspersed moderator region were studied in the remaining sets. The results of this study are provided in Table 14 through Table 17. At optimum interspersed moderation, arrangements 1 and 3 (Figure 7 and Figure 9) yielded statistically identical results. The same is true of arrangements 2 and 4 (Figure 8 and Figure 10). However, arrangement 3 (Figure 9; asymmetric Gd_2O_3 Rods in the assemblies in each group of two vertically adjacent inner packages facing towards the inside of the group) at 7 vol% interspersed moderator produced the highest reactivity (k_{eff}=1.01423, including 2σ) in this sensitivity study.

Next, the assemblies were moved horizontally within their respective inner packaging in conjunction with the most reactive assembly rotations. The following three sets of cases were studied:

1. Assemblies as close as physically possible within the inner packaging and asymmetric Gd_2O_3 rods in the assemblies in each group of two vertically adjacent inner packages facing towards the outside of the group (Figure 11)

2. Assemblies as close as physically possible within the inner packaging and asymmetric Gd_2O_3 rods in the assemblies in each group of two vertically adjacent inner packages facing towards the inside of the group (Figure 12)

3. Assemblies as far apart as physically possible within the inner packaging and asymmetric Gd_2O_3 rods in the assemblies in each group of two vertically adjacent inner packages facing towards the inside of the group (Figure 13)

Again, an infinite array of SP-3 inner packages were used, as well as a pellet diameter of 0.3957" and a PE VF of 0.14 as shims between the fuel rods. Dry, fully flooded, and the peak interspersed moderator region were studied, as in the previous sensitivity study. The results of this study are provided in Table 18 through Table 20. The case with the assemblies as far apart as physically possible within the inner packaging, asymmetric Gd_2O_3 rods in the assemblies in each group of two vertically adjacent inner packages facing towards the inside of the group, and 8 vol% interspersed moderator resulted in the peak reactivity (k_{eff}=1.01900, including 2σ) in this sensitivity study.

The most reactive case from the previous sensitivity study was repeated with 0.35" diameter pellets. The results of this study are provided in Table 21. The peak reactivity (k_{eff}=1.00952, including 2σ) occurs at 7 vol% interspersed moderator. These results show that in a large array of packages and low density interspersed moderator, assemblies with larger diameter pellets are more reactive than those with smaller diameter pellets.

The most reactive case from the previous sensitivity studies (assemblies as far apart as physically possible within the inner packaging and asymmetric Gd_2O_3 rods in the assemblies in each group of two vertically adjacent inner packages facing towards the inside of the group) was repeated with an array of inner packages 8 wide x 14 high x 1 long (112 packages). Pellet diameters of 0.3957" and 0.35" were studied. Again, a PE VF of 0.14 as shims between the fuel rods and dry, fully flooded, and the peak interspersed moderator region were studied, as in the previous sensitivity studies. The results of this study are provided in Table 22 and Table 23. In both sets of cases, the peak reactivity occurred with 13 vol% interspersed moderator. In these cases, the larger pellet diameter (0.3957") produced a higher peak reactivity (k_{eff}=0.94634, including 2σ), which is below 0.95.

The 0.3957" diameter pellet case from the previous sensitivity study was modified to increase the PE VF to 0.152 to account for the accident condition where all of the upper tie plate shim (345 g PE) migrates to the space between the fuel rods within the assemblies. The results are provided in Table 24. The peak interspersed moderator shifted from 13 vol% to 12 vol%. However, the peak k_{eff} from these two studies are statistically identical (differ by approximately 0.25σ). Compare these results to those in Section 3.1.2 where an increase in PE VF from 0.14 to 0.28 resulted in an increase in the peak k_{eff} of less than one standard deviation. As discussed in Section 3.1.2, since the Δk at peak interspersed moderator conditions was within one standard deviation of that at the same conditions with a PE VF of 0.14, the remaining calculations in this section were performed with a PE VF of 0.14.

The most reactive case in Table 22 was reran with a 98% UO_2 TD (increased from 96%). The results are summarized below and show that the maximum k_{eff}, including 2σ, is 0.94784, slightly higher but statistically identical (~0.6σ) to the most reactive case in Table 22.

```
380248 Oct 18 07:51:40 2000 droa-table24.98          .94242    .00271    .94695    .94784
```

In order to investigate the sensitivity of decreasing the number of packagings (increasing the TI) at damaged conditions, the following calculations were performed. The conditions for these calculations are identical to those in the calculation above (droa-table24.98 dtm=001018.075140), except for the number of packagings in the array [104 (8x13), 98 (7x14), 91 (7x13), and 84 (7x12), respectively]. The results follow and show the expected trend, i.e. as the number of packagings is decreased, k_{eff} decreases.

```
388595 Mar 14 16:58:01 2001 droa-8x13x1        .93506   .00274   .93964   .94054
382878 Mar 14 17:15:53 2001 droa-7x14x1        .93155   .00278   .93619   .93711
388572 Mar 14 16:57:53 2001 droa-7x13x1        .92962   .00246   .93373   .93454
382944 Mar 14 17:15:47 2001 droa-7x12x1        .92335   .00267   .92781   .92869
```

The calculations in this section demonstrate that the reactivity of an array of 112 SP-3 packages at credible damaged conditions remains below the 0.95 limit, provided a payload of ATRIUM™-10 fuel assemblies meeting the specifications listed in Table 3 are met. For accident (damaged) conditions, an array of 2N packages (where N is the desired number of packages to be shipped at one time) must be shown to yield $k_{eff} < 0.95$. Therefore, the calculations of this section show that 112/2 or 56 SP-3 packages may be shipped at one time with the payload described herein. Further margin to the 0.95 limit is gained if the number of packagings is decreased. Decreasing the number of packagings to 104 (N=52) provides approximately 1% margin to the 0.95 limit and maintains a TI of 1.0.

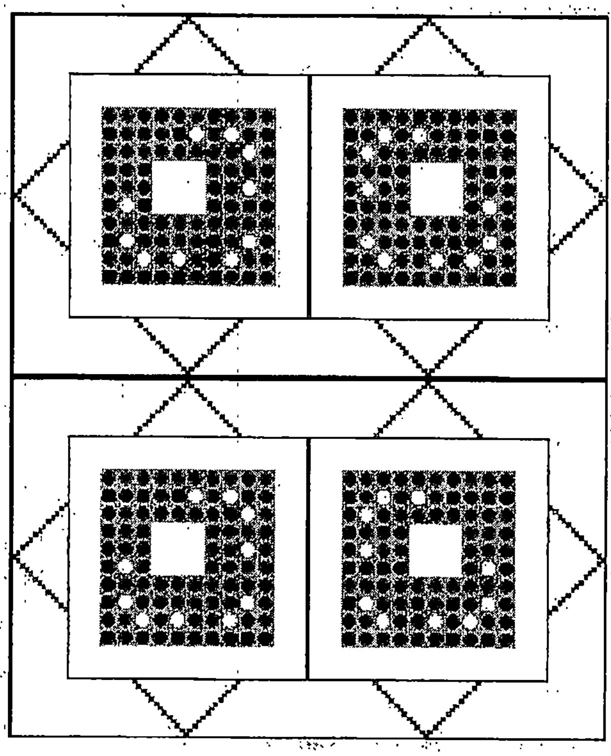

Figure 7 Assembly Rotation with Asymmetric Gd_2O_3 Rods in Each Assembly Facing Towards the Inside and Bottom of the Inner Packaging

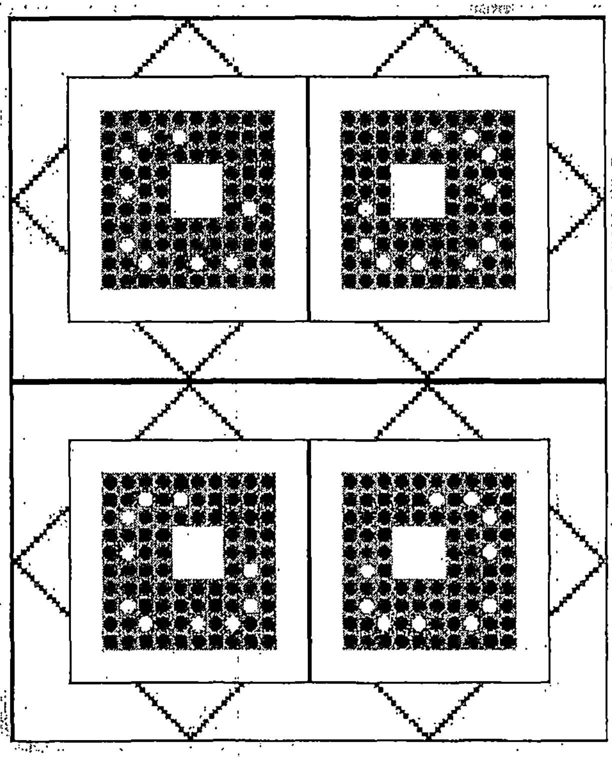

Figure 8 Assembly Rotation with Asymmetric Gd_2O_3 Rods in Each Assembly Facing Towards the Outside and Bottom of the Inner Packaging

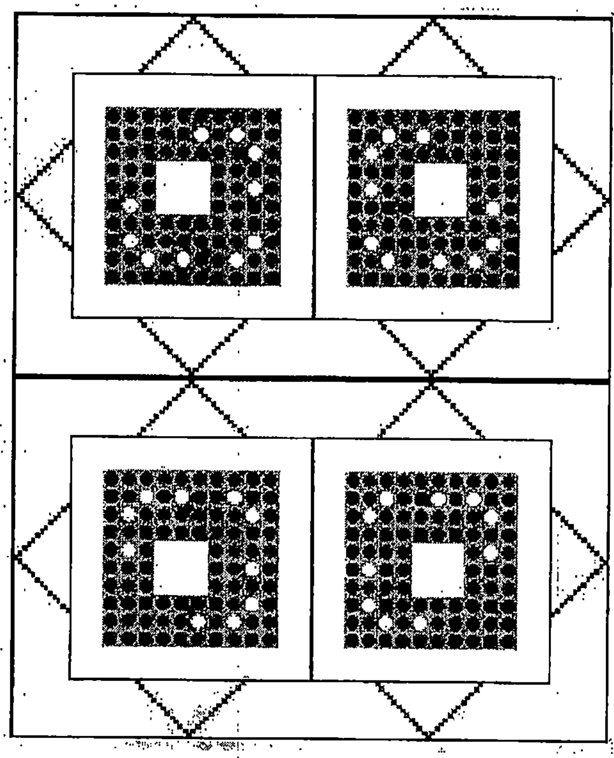

Figure 9 Assembly Rotation with Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Inside of the Group

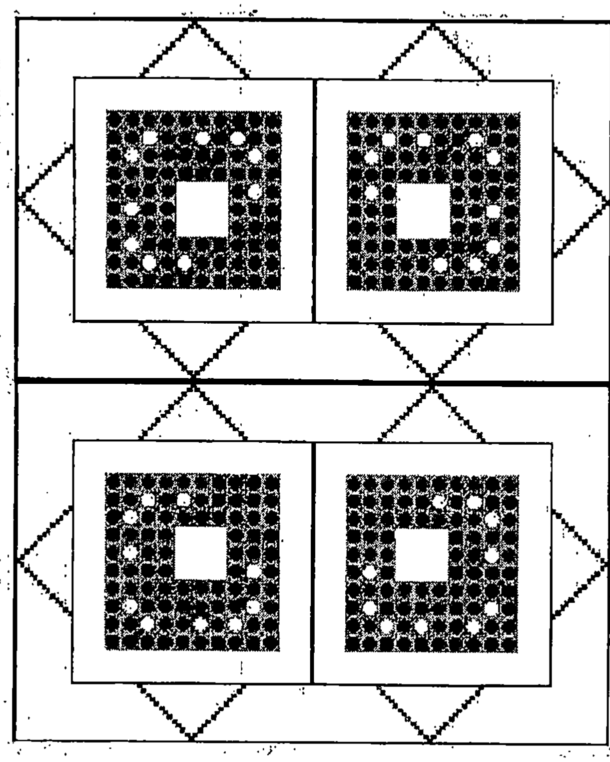

Figure 10 Assembly Rotation with Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Outside of the Group

Table 14 Infinite Array of SP-3 Inner Packages, Assemblies Centered in Channels, Asymmetric Gd_2O_3 Rods in Each Assembly Facing Towards the Inside and Bottom of the Inner Packaging, 0.3957" Diameter Pellets, 0.14 VF PE

Filename (droa-?)	Vol% Interspersed Moderator	k_{eff}	σ	$k_{eff}+2\sigma$
dinf.gaid.c.000	0	0.92323	0.00181	0.92685
dinf.gaid.c.001	1	0.94699	0.00193	0.95085
dinf.gaid.c.003	3	0.98123	0.00183	0.98489
dinf.gaid.c.005	5	0.99967	0.00186	1.00339
dinf.gaid.c.006	6	1.00265	0.00188	1.00641
dinf.gaid.c.007	***7***	***1.01025***	***0.00190***	***1.01405***
dinf.gaid.c.008	8	1.00657	0.00193	1.01043
dinf.gaid.c.009	9	1.00501	0.00241	1.00983
dinf.gaid.c.010	10	1.00394	0.00217	1.00828
dinf.gaid.c.011	11	1.00192	0.00259	1.00710
dinf.gaid.c.012	12	0.99742	0.00229	1.00200
dinf.gaid.c.013	13	0.98882	0.00236	0.99354
dinf.gaid.c.014	14	0.98946	0.00287	0.99520
dinf.gaid.c.015	15	0.98496	0.00247	0.98990
dinf.gaid.c.020	20	0.95308	0.00264	0.95836
dinf.gaid.c.030	30	0.88224	0.00286	0.88796
dinf.gaid.c.040	40	0.82924	0.00296	0.83516
dinf.gaid.c.050	50	0.79270	0.00281	0.79832
dinf.gaid.c.060	60	0.77535	0.00279	0.78093
dinf.gaid.c.070	70	0.76404	0.00276	0.76956
dinf.gaid.c.080	80	0.75932	0.00322	0.76576
dinf.gaid.c.090	90	0.75432	0.00311	0.76054
dinf.gaid.c.100	100	0.75971	0.00319	0.76609

Table 15 Infinite Array of SP-3 Inner Packages, Assemblies Centered in Channels, Asymmetric Gd_2O_3 Rods in Each Assembly Facing Towards the Outside and Bottom of the Inner Packaging, 0.3957" Diameter Pellets, 0.14 VF PE

Filename (droa-?)	Vol% Interspersed Moderator	k_{eff}	σ	$k_{eff}+2σ$
dinf.gaod.c.000	0	0.92424	0.00165	0.92754
dinf.gaod.c.001	1	0.94487	0.00190	0.94867
dinf.gaod.c.003	3	0.98327	0.00201	0.98729
dinf.gaod.c.005	5	0.99553	0.00196	0.99945
dinf.gaod.c.006	6	0.99787	0.00223	1.00233
dinf.gaod.c.007	7	1.00351	0.00208	1.00767
dinf.gaod.c.008	8	1.00517	0.00207	1.00931
dinf.gaod.c.009	***9***	***1.00629***	***0.00225***	***1.01079***
dinf.gaod.c.010	10	1.00246	0.00250	1.00746
dinf.gaod.c.011	11	1.00046	0.00242	1.00530
dinf.gaod.c.012	12	0.99507	0.00256	1.00019
dinf.gaod.c.013	13	0.98759	0.00221	0.99201
dinf.gaod.c.014	14	0.98204	0.00253	0.98710
dinf.gaod.c.015	15	0.97558	0.00230	0.98018
dinf.gaod.c.020	20	0.94668	0.00265	0.95198
dinf.gaod.c.100	100	0.76648	0.00310	0.77268

Table 16 Infinite Array of SP-3 Inner Packages, Assemblies Centered in Channels, Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Inside of the Group, 0.3957" Diameter Pellets, 0.14 VF PE

Filename (droa-7)	Vol% Interspersed Moderator	K_{eff}	σ	$K_{eff}+2\sigma$
dinf.gin.c.000	0	0.91819	0.00168	0.92155
dinf.gin.c.001	1	0.94700	0.00157	0.95014
dinf.gin.c.003	3	0.98014	0.00187	0.98388
dinf.gin.c.005	5	0.99650	0.00198	1.00046
dinf.gin.c.006	6	1.00441	0.00208	1.00857
dinf.gin.c.007	***7***	***1.01029***	***0.00197***	***1.01423***
dinf.gin.c.008	8	1.00601	0.00225	1.01051
dinf.gin.c.009	9	1.00429	0.00213	1.00855
dinf.gin.c.010	10	1.00568	0.00226	1.01020
dinf.gin.c.011	11	1.00249	0.00238	1.00725
dinf.gin.c.012	12	0.99487	0.00222	0.99931
dinf.gin.c.013	13	0.98789	0.00248	0.99285
dinf.gin.c.014	14	0.98459	0.00253	0.98965
dinf.gin.c.015	15	0.98040	0.00246	0.98532
dinf.gin.c.020	20	0.95008	0.00246	0.95500
dinf.gin.c.100	100	0.75750	0.00316	0.76382

Table 17 Infinite Array of SP-3 Inner Packages, Assemblies Centered in Channels, Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Outside of the Group, 0.3957" Diameter Pellets, 0.14 VF PE

Filename (droa-?)	Vol% Interspersed Moderator	k_{eff}	σ	$k_{eff}+2\sigma$
dinf.gout.c.000	0	0.92009	0.00168	0.92345
dinf.gout.c.001	1	0.94614	0.00222	0.95058
dinf.gout.c.003	3	0.98264	0.00201	0.98666
dinf.gout.c.005	5	0.99750	0.00211	1.00172
dinf.gout.c.006	6	1.00265	0.00232	1.00729
dinf.gout.c.007	7	1.00422	0.00210	1.00842
dinf.gout.c.008	8	1.00332	0.00203	1.00738
dinf.gout.c.009	***9***	***1.00633***	***0.00218***	***1.01069***
dinf.gout.c.010	10	0.99957	0.00227	1.00411
dinf.gout.c.011	11	0.99697	0.00202	1.00101
dinf.gout.c.012	12	0.99408	0.00233	0.99874
dinf.gout.c.013	13	0.99039	0.00259	0.99557
dinf.gout.c.014	14	0.98530	0.00263	0.99056
dinf.gout.c.015	15	0.96907	0.00239	0.97385
dinf.gout.c.020	20	0.94723	0.00242	0.95207
dinf.gout.c.100	100	0.77638	0.00332	0.78302

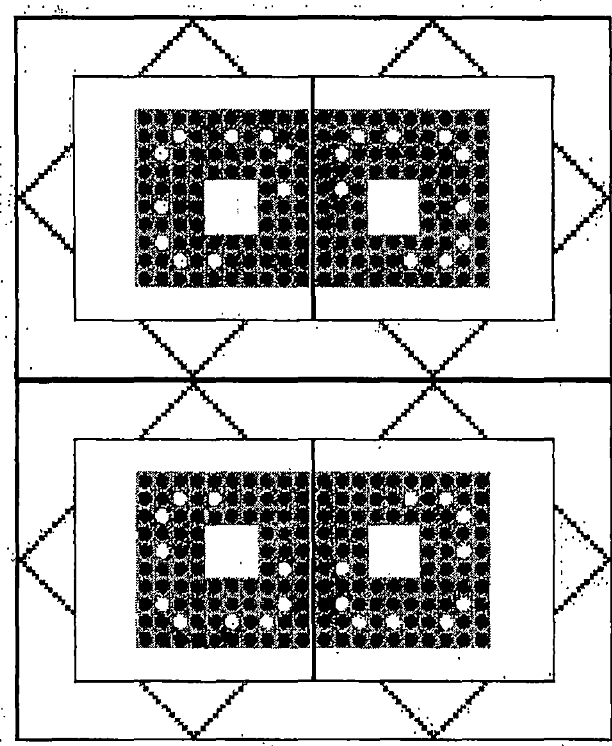

Figure 11 Assemblies as Close as Physically Possible within Inner Packaging and Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Outside of the Group

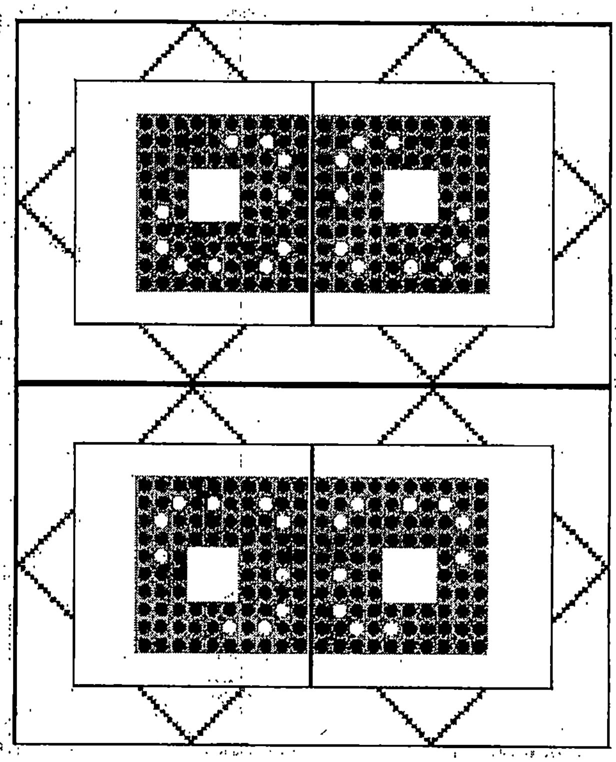

Figure 12 Assemblies as Close as Physically Possible within Inner Packaging and Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Inside of the Group

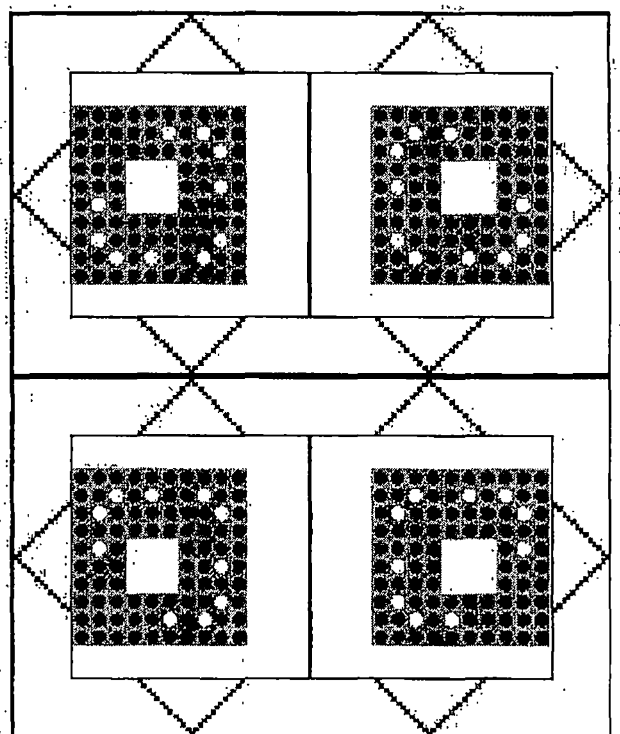

Figure 13 Assemblies as Far Apart as Physically Possible within Inner Packaging and Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Inside of the Group

Table 18 Infinite Array of SP-3 Inner Packages, Assemblies as Close as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Outside of the Group, 0.3957" Diameter Pellets, 0.14 VF PE

Filename (droa-?)	Vol% Interspersed Moderator	k_{eff}	σ	$k_{eff}+2\sigma$
dinf.gout.i.000	0	0.92285	0.00163	0.92611
dinf.gout.i.001	1	0.94633	0.00155	0.94943
dinf.gout.i.003	3	0.97010	0.00177	0.97364
dinf.gout.i.005	5	0.98161	0.00183	0.98527
dinf.gout.i.006	***6***	***0.98611***	***0.00218***	***0.99047***
dinf.gout.i.007	7	0.98110	0.00206	0.98522
dinf.gout.i.008	8	0.97736	0.00215	0.98166
dinf.gout.i.009	9	0.97445	0.00245	0.97935
dinf.gout.i.010	10	0.97364	0.00235	0.97834
dinf.gout.i.011	11	0.96551	0.00248	0.97047
dinf.gout.i.012	12	0.95505	0.00260	0.96025
dinf.gout.i.013	13	0.94978	0.00216	0.95410
dinf.gout.i.014	14	0.94445	0.00245	0.94935
dinf.gout.i.015	15	0.94069	0.00228	0.94525
dinf.gout.i.020	20	0.89590	0.00271	0.90132
dinf.gout.i.100	100	0.77836	0.00343	0.78522

Table 19 Infinite Array of SP-3 Inner Packages, Assemblies as Close as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Inside of the Group, 0.3957" Diameter Pellets, 0.14 VF PE

Filename (droa.?)	Vol% Interspersed Moderator	k_{eff}	σ	$k_{eff}+2σ$
dinf.gin.i.000	0	0.92523	0.00163	0.92849
dinf.gin.i.001	1	0.94837	0.00198	0.95233
dinf.gin.i.003	3	0.97876	0.00209	0.98294
dinf.gin.i.005	5	0.98673	0.00213	0.99099
dinf.gin.i.006	6	0.98894	0.00216	0.99326
dinf.gin.i.007	***7***	***0.99107***	***0.00206***	***0.99519***
dinf.gin.i.008	8	0.98939	0.00220	0.99379
dinf.gin.i.009	9	0.98154	0.00204	0.98562
dinf.gin.i.010	10	0.98022	0.00252	0.98526
dinf.gin.i.011	11	0.97373	0.00245	0.97863
dinf.gin.i.012	12	0.96553	0.00280	0.97113
dinf.gin.i.013	13	0.95736	0.00225	0.96186
dinf.gin.i.014	14	0.95353	0.00260	0.95873
dinf.gin.i.015	15	0.94179	0.00259	0.94697
dinf.gin.i.020	20	0.90522	0.00301	0.91124
dinf.gin.i.100	100	0.77375	0.00339	0.78053

Table 20 Infinite Array of SP-3 Inner Packages, Assemblies as Far Apart as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Inside of the Group, 0.3957" Diameter Pellets, 0.14 VF PE

Filename (droa-?)	Vol% Interspersed Moderator	k_{eff}	σ	$k_{eff}+2\sigma$
dinf.gin.o.000	0	0.92342	0.00175	0.92692
dinf.gin.o.001	1	0.94465	0.00165	0.94795
dinf.gin.o.003	3	0.98368	0.00210	0.98788
dinf.gin.o.005	5	1.00329	0.00208	1.00745
dinf.gin.o.006	6	1.00689	0.00186	1.01061
dinf.gin.o.007	7	1.00911	0.00198	1.01307
dinf.gin.o.008	***8***	***1.01488***	***0.00206***	***1.01900***
dinf.gin.o.009	9	1.01294	0.00218	1.01730
dinf.gin.o.010	10	1.01241	0.00239	1.01719
dinf.gin.o.011	11	1.01139	0.00248	1.01635
dinf.gin.o.012	12	1.01062	0.00227	1.01516
dinf.gin.o.013	13	1.00426	0.00237	1.00900
dinf.gin.o.014	14	0.99882	0.00234	1.00350
dinf.gin.o.015	15	0.99208	0.00227	0.99662
dinf.gin.o.020	20	0.96620	0.00261	0.97142
dinf.gin.o.100	100	0.73189	0.00298	0.73785

Table 21 Infinite Array of SP-3 Inner Packages, Assemblies as Far Apart as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Inside of the Group, 0.35" Diameter Pellets, 0.14 VF PE

Filename (droa-?)	Vol% Interspersed Moderator	k_{eff}	σ	$k_{eff}+2\sigma$
dinfa.gin.o.000	0	0.93601	0.00182	0.93965
dinfa.gin.o.001	1	0.95844	0.00204	0.96252
dinfa.gin.o.003	3	0.98718	0.00214	0.99146
dinfa.gin.o.005	5	1.00056	0.00216	1.00488
dinfa.gin.o.006	6	1.00266	0.00231	1.00728
dinfa.gin.o.007	***7***	***1.00500***	***0.00226***	***1.00952***
dinfa.gin.o.008	8	1.00372	0.00268	1.00908
dinfa.gin.o.009	9	0.99917	0.00231	1.00379
dinfa.gin.o.010	10	0.99534	0.00206	0.99946
dinfa.gin.o.011	11	0.99324	0.00240	0.99804
dinfa.gin.o.012	12	0.98843	0.00244	0.99331
dinfa.gin.o.013	13	0.98192	0.00268	0.98728
dinfa.gin.o.014	14	0.98071	0.00281	0.98633
dinfa.gin.o.015	15	0.97225	0.00266	0.97757
dinfa.gin.o.020	20	0.94173	0.00292	0.94757
dinfa.gin.o.100	100	0.72278	0.00315	0.72908

Table 22 112 SP-3 Inner Packages (8 Wide x 14 High), Assemblies as Far Apart as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Inside of the Group, 0.3957" Diameter Pellets, 0.14 VF PE

Filename (droa-?)	Vol% Interspersed Moderator	k_{eff}	σ	$k_{eff}+2σ$
d112.gin.o.000	0	0.73315	0.00237	0.73789
d112.gin.o.001	1	0.77394	0.00246	0.77886
d112.gin.o.003	3	0.83914	0.00241	0.84396
d112.gin.o.005	5	0.88059	0.00259	0.88577
d112.gin.o.006	6	0.89472	0.00241	0.89954
d112.gin.o.007	7	0.90996	0.00248	0.91492
d112.gin.o.008	8	0.91947	0.00278	0.92503
d112.gin.o.009	9	0.92806	0.00237	0.93280
d112.gin.o.010	10	0.93178	0.00276	0.93730
d112.gin.o.011	11	0.93350	0.00270	0.93890
d112.gin.o.012	12	0.93638	0.00273	0.94184
d112.gin.o.013	***13***	***0.94134***	***0.00250***	***0.94634***
d112.gin.o.014	14	0.93746	0.00257	0.94260
d112.gin.o.015	15	0.93109	0.00295	0.93699
d112.gin.o.020	20	0.91940	0.00279	0.92498
d112.gin.o.100	100	0.73110	0.00354	0.73818

Table 23 112 SP-3 Inner Packages (8 Wide x 14 High), Assemblies as Far Apart as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Inside of the Group, 0.35" Diameter Pellets, 0.14 VF PE

Filename (droa-?)	Vol% Interspersed Moderator	k_{eff}	σ	$k_{eff}+2\sigma$
d112a.gin.o.000	0	0.72927	0.00252	0.73431
d112a.gin.o.001	1	0.76529	0.00228	0.76985
d112a.gin.o.003	3	0.82126	0.00256	0.82638
d112a.gin.o.005	5	0.86408	0.00260	0.86928
d112a.gin.o.006	6	0.87822	0.00279	0.88380
d112a.gin.o.007	7	0.88682	0.00236	0.89154
d112a.gin.o.008	8	0.89857	0.00272	0.90401
d112a.gin.o.009	9	0.90166	0.00296	0.90758
d112a.gin.o.010	10	0.90884	0.00249	0.91382
d112a.gin.o.011	11	0.90866	0.00251	0.91368
d112a.gin.o.012	12	0.91260	0.00271	0.91802
d112a.gin.o.013	***13***	***0.91596***	***0.00234***	***0.92064***
d112a.gin.o.014	14	0.91333	0.00273	0.91879
d112a.gin.o.015	15	0.90806	0.00253	0.91312
d112a.gin.o.020	20	0.88571	0.00293	0.89157
d112a.gin.o.100	100	0.71794	0.00311	0.72416

Table 24 112 SP-3 Inner Packages (8 Wide x 14 High), Assemblies as Far Apart as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Inside of the Group, 0.3957" Diameter Pellets, 0.152 VF PE

Filename (droa-?)	Vol% Interspersed Moderator	k_{eff}	σ	$k_{eff}+2\sigma$
d112PS.gin.o.000	0	0.74824	0.00248	0.75320
d112PS.gin.o.001	1	0.78211	0.00248	0.78707
d112PS.gin.o.003	3	0.84317	0.00225	0.84767
d112PS.gin.o.005	5	0.88074	0.00270	0.88614
d112PS.gin.o.006	6	0.89791	0.00280	0.90351
d112PS.gin.o.007	7	0.90794	0.00269	0.91332
d112PS.gin.o.008	8	0.92254	0.00264	0.92782
d112PS.gin.o.009	9	0.92537	0.00276	0.93089
d112PS.gin.o.010	10	0.93228	0.00281	0.93790
d112PS.gin.o.011	11	0.93473	0.00275	0.94023
d112PS.gin.o.012	***12***	***0.94048***	***0.00261***	***0.94570***
d112PS.gin.o.013	13	0.93828	0.00250	0.94328
d112PS.gin.o.014	14	0.93512	0.00313	0.94138
d112PS.gin.o.015	15	0.93594	0.00296	0.94186
d112PS.gin.o.020	20	0.92188	0.00266	0.92720
d112PS.gin.o.100	100	0.72353	0.00276	0.72905

3.1.5 Calculation of Transport Index (TI) with Payload 1 (ATRIUM™-10 with PE Shipping Shims)

The TI for criticality safety is set such that five times the allowed number of packages at undamaged conditions and two times the allowed number of packages at damaged conditions must have a k_{eff} less than 0.95. Note that as discussed in Section 2.4, the bias is negative (conservative), so it is not included in the results as presented below.

Damaged Conditions

Array size = 8x13x1 = 104 (N=52) Maximum k_{eff} = 0.94054

Undamaged Conditions

Array size = 16x16x1 = 256 (N=51) Maximum k_{eff} = 0.81950

Using the smaller of the N values above and rounding to the highest tenth, the TI is calculated below:

TI = 50/51 = 1.0

4. QA Review Description

1) Methodology used in this CSE is clearly defined and was verified to be applicable. Agreement is indicated by a check mark in the CSE text. The calculation methods including details on cross section preparation, atom densities assumed, and geometry models were reviewed and determined to be adequate. Each of these items was verified to be conservative.

2) Assumptions were reviewed for reasonableness and applicability to this analysis. Agreement is indicated by a check mark in the CSE text.

3) Modeling was reviewed and determined to conservatively model the actual system. A listing of one or more of the most reactive cases is included in the CSE.

4) Referenced sources were reviewed for applicability to this CSE.

5) Input information was checked against referenced sources.

6) Input for computer calculations were checked for agreement with values in the CSE text.

7) Hand calculations were independently checked.

8) K_{eff} for worst case accident conditions is specifically stated in the text.

9) Comments are provided below and are referenced in the CSE text as QA-N, where N is the corresponding comment number.

4.1 *QA Review Comments and Resolution*

All comments were editorial in nature and were incorporated into the body of the text.

4.2 *Listing of Archived Computer Files*

The computer input listings for this analysis have been archived on the DMS system under the following directories:

/critsafety/CSA/SHIPPING/SP-1/SP-1-DATA/SP1.6/...

Listings of the most reactive cases are provided in Appendix A.

5. References

1) SCALE Standardized Computer Analyses for Licensing Evaluation, NUREG/CR-2000 ORNL/NUREG/CSD-2, Volumes 1, 2, and 3.

2) Critical Separation Between Subcritical Clusters of 4.31 wt% Enriched UO_2 Rods in Water with Fixed Neutron Poisons, NUREG/CR-0073.

3) EMF-94-175, "Validation and Verification of KENO.Va" by R. E. Coen, Siemens Power Corporation - Nuclear Division, 2101 Horn Rapids Road, Richland, WA 99352.

4) UCRL-53369, Nuclear Criticality Safety Experiments, Calculations, and Analyses - 1958 to 1982: Compilation of Papers from the Transactions of the American Nuclear Society, Volume 2: Summaries, Lawrence Livermore National Laboratory, W. Marshall, et al, "Criticality Safety Criteria," pp.687-688.

5) EMF-2418(P) Revision 0, Principal Reload Fuel Design Parameters Kuosheng Unit 1 Fabrication Batch KS1-F13 ATRIUM™-10, July 2000.

6) KJW:00:014, Shipping Shim Mass for ATRIUM™-10, K. J. Wahlquist to C. D. Manning, June 21, 2000.

7) CSE BFQ-SP1.5 Revision 2, SP-1 Shipping Container Supplemental Criticality Safety Evaluation, C. D. Manning, Siemens Power Corporation, 7/20/1999.

8) RF:00:012, CASMO-4 Analysis of the Kuosheng and Chinshan ATRIUM™-10 Reload Fuel Design for the SP-1 Shipping Containers, R. Fundak to J. M. Deist, September 20, 2000.

9) JKS:00:033, Upper Tie Plate Shipping Shim for Taipower ATRIUM™-10 Fuel Shipments, J. K. Schuette to J. M. Deist, June 13, 2000.

10) EMF-CS-1121, Characteristics Specification, Kuosheng Unit 1 KS1-F13 ATRIUM™-10, Siemens Power Corporation.

APPENDIX A SAMPLE COMPUTER INPUTS

Case "drda-table11.98": **Single SP-3 Inner Package**, Assemblies Moved as Close as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in Assemblies are Toward Outside of Inner Packaging, 0.35" Diameter Pellets, 0.14 VF PE as Shipping Shims, Fully Flooded

```
=csas25
atrium-10 in sp1 shipping container
hans infhom

' mixture 1
'  interior rods not immed. adj. to water channel, no gd2o3, 5 wt% u235
uo2 1 0.98 293 92235 5.0 92238 95.0 end

' mixture 2
'  interior rods immed. adj. to water channel, no gd2o3, 5 wt% u235
uo2 2 0.98 293 92235 5.0 92238 95.0 end

' mixture 3
'  interior rods, 1.5 wt% gd2o3, 5 wt% u235
'   td of uo2-gd2o3 = 10.96-2.65*p/[p+0.67145*(1-p)], p = wt fraction gd2o3
'   p is 0.015 here, so td of uo2-gd2o3 is 10.90123 g/cc
'   pellets are 0.98 td, so 0.98*10.90123 = 10.68321 g/cc
'   gd2o3 density is 0.015*10.68321 = 0.16025
uo2 3 den=10.68321 1.0 293 92235 5.0 92238 95.0 end
arbmgd2o3 0.16025 2 0 1 0 64000 2
                          8016 3 3 1.0 293 end

' mixture 4
'  corner rods facing other bundle, 5 wt% u235
uo2 4 0.98 293 92235 5.00 92238 95.00 end

' mixture 5 - not used
'  smeared zr clad
'  pod, cid, cod = 0.4221", 0.4281", 0.4781"
'  vol fract zr = 0.8988
'   at dens = 0.8988 * 4.2518-2 = 3.8215e-02
zircalloy 5 0.0 3.8215e-02 293 end

' mixture 6
'  interspersed moderator
h2o 6 1.00 293 end

' mixture 7
'  carbon steel, 100 vol%
c  7 0.0 3.921682e-03 293 end
fe 7 0.0 8.350009e-02 293 end

' mixture 8
'  carbon steel, 85.57 vol% smeared with 10 vol% h2o
c  8 0.0 3.355783e-03 293 end
fe 8 0.0 7.145103e-02 293 end
o  8 0.0 4.8167e-04 293 end
h  8 0.0 9.6335e-04 293 end

' mixture 9 - not used
'  carbon steel, 8.64 vol%
c  9 0.0 3.388333e-04 293 end
fe 9 0.0 7.214408e-03 293 end
o  9 0.0 3.0496e-03 293 end
h  9 0.0 6.0992e-03 293 end
```

```
' mixture 10
'  water for reflector
h2o 10 1.00 293 end

' mixture 11
'  pe and interspersed water
'   vf pe = 0.14
'   water at full density is (1-.14) = .86 g/cc
h2o 11 den=0.86 1.00 293 end
arbmepe  0.92 2  0  1 1 6012 1
                         1001 2 11 0.14 end

' mixture 12
'  corner rods not facing other bundle, 5 wt% u235
uo2 12 0.98 293 92235 5.00 92238 95.00 end

' mixture 13
'  rods immed. adj. to corner rod, facing other bundle, 5 wt% u235
uo2 13 0.98 293 92235 5.00 92238 95.00 end

' mixture 14
'  rods immed. adj. to corner rod, not facing other bundle, 5 wt% u235
uo2 14 0.98 293 92235 5.00 92238 95.00 end

' mixture 15
'  balance of edge rods facing other bundle, 5 wt% u235
uo2 15 0.98 293 92235 5.00 92238 95.00 end

' mixture 16
'  balance of edge rods not facing other bundle, 5 wt% u235
uo2 16 0.98 293 92235 5.00 92238 95.00 end

end comp
more data
 res=  1 cyli  4.3004E-01 dan(  1)= 2.9485E-01
 res=  2 cyli  4.4115E-01 dan(  2)= 2.0949E-01
 res=  3 cyli  4.2363E-01 dan(  3)= 2.9202E-01
 res=  4 cyli  4.3896E-01 dan(  4)= 1.8340E-01
 res= 12 cyli  4.2580E-01 dan( 12)= 1.3547E-01
 res= 13 cyli  4.4412E-01 dan( 13)= 2.9408E-01
 res= 14 cyli  4.6283E-01 dan( 14)= 2.1325E-01
 res= 15 cyli  4.2695E-01 dan( 15)= 2.7553E-01
 res= 16 cyli  4.4358E-01 dan( 16)= 2.0248E-01
end more
atrium-10 in sp1 shipping container
read parameters
   tme=90.0 gen=103 npg=500
   flx=yes  fdn=yes xs1=yes nub=yes pwt=yes
   run=yes  plt=yes
end parameters
read geometry

unit  5
com="  10x10 bundle in left basket  "
array 1  -4.2151 -6.477 -225.58
cubo  6  1  4p8.7381  2p225.58
'  add 0.00598 inch of perforated steel
cubo  8  1  4p8.89  2p225.58

unit  6
com="  10x10 bundle in right basket  "
array 2  -8.7381 -6.477 -225.58
cubo  6  1  4p8.7381  2p225.58
'  add 0.00598 inch of perforated steel
cubo  8  1  4p8.89  2p225.58

unit 9
com="1 5/8 x 1 5/8 inch moderation regions at corners  "
```

```
cubo  6  1  4p2.06375 2p225.58

global
unit 10
com="  1 inner container  "
array  3  -21.9075 -13.97 -225.58
'  add 0.0598 inch walls
repl  7  1 6r0.1519  1
repl 10  2 6r3.0    10

unit 11
com="array of inners  "
array 4 3r0.0
repl 10 2 6r3.0  10

unit 16
com=" spacing & steel angle at -x side of basket "
cubo  6 1  4.12750 0.0 2p8.89  2p225.58
hole 22   0.15875 0.0  0.0
hole 22  0.47625 -0.3175 0.0
hole 22   0.47625  0.3175 0.0
hole 22   0.79375  0.635 0.0
hole 22  0.79375  -0.635 0.0
hole 22  1.11125  0.9525 0.0
hole 22  1.11125  -0.9525 0.0
hole 22  1.42875  1.27 0.0
hole 22  1.42875  -1.27 0.0
hole 22  1.74625  1.5875 0.0
hole 22  1.74625  -1.5875 0.0
hole 22  2.06375 1.905 0.0
hole 22  2.06375 -1.905 0.0
hole 22  2.38125  2.2225 0.0
hole 22  2.38125 -2.2225  0.0
hole 22  2.69875  2.54 0.0
hole 22  2.69875 -2.54  0.0
hole 22  3.01625  2.8575 0.0
hole 22  3.01625 -2.8575  0.0
hole 22  3.33375  3.175 0.0
hole 22  3.33375 -3.175  0.0
hole 22  3.65125  3.4925 0.0
hole 22  3.65125 -3.4925  0.0
hole 22  3.96875  3.81 0.0
hole 22  3.96875 -3.81  0.0

unit 17
com=" spacing & steel angle at +x side of basket "
cubo  6 1  0.0  -4.12750 2p8.89  2p225.58
hole 22  -0.15875 0.0  0.0
hole 22  -0.47625 -0.3175 0.0
hole 22  -0.47625  0.3175 0.0
hole 22   -0.79375  0.635 0.0
hole 22  -0.79375  -0.635 0.0
hole 22  -1.11125  0.9525 0.0
hole 22  -1.11125  -0.9525 0.0
hole 22  -1.42875  1.27 0.0
hole 22  -1.42875  -1.27 0.0
hole 22  -1.74625  1.5875 0.0
hole 22  -1.74625  -1.5875 0.0
hole 22  -2.06375 1.905 0.0
hole 22  -2.06375 -1.905 0.0
hole 22  -2.38125  2.2225 0.0
hole 22  -2.38125 -2.2225  0.0
hole 22  -2.69875  2.54 0.0
hole 22  -2.69875 -2.54  0.0
hole 22 -3.01625  2.8575 0.0
hole 22  -3.01625 -2.8575  0.0
hole 22  -3.33375  3.175 0.0
hole 22  -3.33375 -3.175  0.0
hole 22  -3.65125  3.4925 0.0
```

```
hole 22  -3.65125 -3.4925  0.0
hole 22  -3.96875  3.81 0.0
hole 22  -3.96875 -3.81  0.0

unit 18
com=" angles & spacing beneath baskets  "
cubo  6 1  2p8.89 4.12750 0.0  2p225.58
hole 21  0.0  0.15875  0.0
hole 21 -0.3175  0.47625  0.0
hole 21  0.3175  0.47625  0.0
hole 21  0.635  0.79375  0.0
hole 21 -0.635  0.79375  0.0
hole 21  0.9525  1.11125  0.0
hole 21 -0.9525  1.11125  0.0
hole 21  1.27  1.42875  0.0
hole 21 -1.27  1.42875  0.0
hole 21  1.5875  1.74625  0.0
hole 21 -1.5875  1.74625  0.0
hole 21  1.905  2.06375  0.0
hole 21 -1.905  2.06375  0.0
hole 21  2.2225  2.38125  0.0
hole 21 -2.2225  2.38125  0.0
hole 21   2.54 2.69875 0.0
hole 21  -2.54 2.69875 0.0
hole 21  2.8575 3.01625  0.0
hole 21  -2.8575 3.01625 0.0
hole 21   3.175 3.33375 0.0
hole 21  -3.175 3.33375  0.0
hole 21   3.4925 3.65125 0.0
hole 21  -3.4925  3.65125 0.0
hole 21   3.81 3.96875 0.0
hole 21  -3.81 3.96875 0.0

unit 19
com="angles & spacing above baskets  "
cubo  6 1  2p8.89  0.0 -4.12750  2p225.58
hole 21  0.0  -0.15875  0.0
hole 21 -0.3175  -0.47625  0.0
hole 21  0.3175  -0.47625  0.0
hole 21  0.635  -0.79375  0.0
hole 21 -0.635  -0.79375  0.0
hole 21  0.9525  -1.11125  0.0
hole 21 -0.9525  -1.11125  0.0
hole 21  1.27  -1.42875  0.0
hole 21 -1.27  -1.42875  0.0
hole 21  1.5875  -1.74625  0.0
hole 21 -1.5875  -1.74625  0.0
hole 21  1.905  -2.06375  0.0
hole 21 -1.905  -2.06375  0.0
hole 21  2.2225  -2.38125  0.0
hole 21 -2.2225  -2.38125  0.0
hole 21   2.54 -2.69875 0.0
hole 21  -2.54 -2.69875 0.0
hole 21  2.8575 -3.01625  0.0
hole 21  -2.8575 -3.01625 0.0
hole 21   3.175 -3.33375 0.0
hole 21  -3.175 -3.33375  0.0
hole 21   3.4925 -3.65125 0.0
hole 21  -3.4925  -3.65125 0.0
hole 21   3.81 -3.96875 0.0
hole 21  -3.81 -3.96875 0.0

unit 21
com="part of steel angle in horiz sections of stringer"
'  0.1552" x 0.125"
cubo  7 1 2p0.197104 2p0.15874 2p225.58

unit 22
com="part of steel angle in vert sections of stringer"
```

```
'  0.125" x 0.1552"
cubo  7 1 2p0.15874 2p0.197104 2p225.58

unit 101
com=" interior rods not immed. adj. to water channel, no gd2o3, 5 wt% u235 "
cyli  1 1 0.44450  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 102
com=" interior rods immed. adj. to water channel, no gd2o3, 5 wt% u235 "
cyli  2 1 0.44450  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 103
com=" interior rods, 1.5 wt% gd2o3, 5 wt% u235 "
cyli  3 1 0.44450  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 104
com=" corner rods facing other bundle, 3.05 wt% u235 "
cyli  4 1 0.44450  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 105
com=" corner rods not facing other bundle, 3.05 wt% u235 "
cyli 12 1 0.44450  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 106
com=" rods immed adj. to corner rod, facing other bundle, 3.55 wt% u235 "
cyli 13 1 0.44450  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 107
com=" rods immed adj. to corner rod, not facing other bundle, 3.55 wt% u235 "
cyli 14 1 0.44450  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 108
com=" balance of edge rods facing other bundle, 4.75 wt% u235 "
cyli 15 1 0.44450  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 109
com=" balance of edge rods not facing other bundle, 4.75 wt% u235 "
cyli 16 1 0.44450  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 110
com=" water rod "
cubo  6 1 4p0.6447 2p225.58

end geometry

read array

' array 1 is bundle in left basket
ara=1 nux=10 nuy=10 nuz=1
fill
105 107 109 109 109 109 109 109 107 104
107 101 103 101 103 101 101 101 101 106
109 103 101 101 102 102 102 101 101 108
109 101 101 102 110 110 110 102 101 108
109 103 101 102 110 110 110 102 101 108
109 101 101 102 110 110 110 102 103 108
109 101 101 101 102 102 102 101 101 108
109 103 101 101 101 101 101 101 103 108
107 101 103 101 101 103 101 103 101 106
105 107 109 109 109 109 109 109 107 104
```

```
end fill

' array 2 is bundle in right basket
ara=2 nux=10 nuy=10 nuz=1
fill
104 107 109 109 109 109 109 109 107 105
106 101 101 101 101 103 101 103 101 107
108 101 101 102 102 102 101 101 103 109
108 101 102 110 110 110 102 101 101 109
108 101 102 110 110 110 102 101 103 109
108 103 102 110 110 110 102 101 101 109
108 101 101 102 102 102 101 101 101 109
108 103 101 101 101 101 101 101 103 109
106 101 103 101 103 101 101 103 101 107
104 107 109 109 109 109 109 109 107 105
end fill

ara=3 nux=4 nuy=3 nuz=1
' array 3 is 1 inner container
fill
 9 18 18  9
16  5  6 17
 9 19 19  9
end fill

' array 4 is an array of inner containers
ara=4 nux=8 nuy=13 nuz=1
fill f10 end fill

end array

read start
nst=1
end start

read bounds
all=vacuum
end bounds

read bias
  id=500 2  11
end bias

read plot
'
ttl=' xy section of one inner container '
xul=-22.0594  yul=12.2169   zul=10
xlr=22.0594   ylr=-14.1219  zlr=10
uax=1         vdn=-1        nax=150   lpi=10   end
'
ttl=' xy section of one inner container plus reflector '
xul=-54       yul=44        zul=10
xlr=54        ylr=-46       zlr=10
uax=1         vdn=-1        nax=150   lpi=10   end
'
ttl=' xz section of one inner container plus reflector '
xul=-54       yul=-5.8323   zul=-258
xlr=54        ylr=5.8323    zlr=258
uax=1         wdn=1         nax=150   lpi=10   end
'
end plot

end data
end
```

Case "drda-table14.98": **Undamaged Spacing,** 256 SP-1/2/3 Inner/Outer Packages (16 Wide x 16 High), Assemblies as Far Apart as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Inside of the Group, 0.3957" Diameter Pellets, 0.14 VF PE within Inner Packages as Shipping Shims, 13 vol% Interspersed Moderator, 1 vol% PE between Inner and Outer Packages

```
=csas25
atrium-10 in sp1 shipping container
hans infhom

' mixture 1
'  interior rods not immed. adj. to water channel, no gd2o3, 5 wt% u235
uo2 1 0.98 293 92235 5.0 92238 95.0 end

' mixture 2
'  interior rods immed. adj. to water channel, no gd2o3, 5 wt% u235
uo2 2 0.98 293 92235 5.0 92238 95.0 end

' mixture 3
'  interior rods, 1.5 wt% gd2o3, 5 wt% u235
'   td of uo2-gd2o3 = 10.96-2.65*p/[p+0.67145*(1-p)], p = wt fraction gd2o3
'   p is 0.015 here, so td of uo2-gd2o3 is 10.90123 g/cc
'   pellets are 0.98 td, so 0.98*10.90123 = 10.68321 g/cc
'   gd2o3 density is 0.015*10.68321 = 0.16025
uo2 3 den=10.68321 1.0 293 92235 5.0 92238 95.0 end
arbmgd2o3 0.16025 2 0 1 0 64000 2
                             8016 3 3 1.0 293 end

' mixture 4
'  corner rods facing other bundle, 3.05 wt% u235
uo2 4 0.98 293 92235 3.05 92238 96.95 end

' mixture 5 - not used
'  smeared zr clad
'  pod, cid, cod = 0.4221", 0.4281", 0.4781"
'  vol fract zr = 0.8988
'   at dens = 0.8988 * 4.2518-2 = 3.8215e-02
zircalloy 5 0.0 3.8215e-02 293 end

' mixture 6
'  interspersed moderator
h2o 6 0.13 293 end

' mixture 7
'  carbon steel, 100 vol%
c  7 0.0 3.921682e-03 293 end
fe 7 0.0 8.350009e-02 293 end

' mixture 8
'  carbon steel, 85.57 vol% smeared with 10 vol% h2o
c  8 0.0 3.355783e-03 293 end
fe 8 0.0 7.145103e-02 293 end
o  8 0.0 4.8167e-04 293 end
h  8 0.0 9.6335e-04 293 end

' mixture 9 - not used
'  carbon steel, 8.64 vol%
c  9 0.0 3.388333e-04 293 end
fe 9 0.0 7.214408e-03 293 end
o  9 0.0 3.0496e-03 293 end
h  9 0.0 6.0992e-03 293 end
```

```
' mixture 10
'  water for reflector
h2o 10 1.00 293 end

' mixture 11
'  pe and interspersed water
'   vf pe = 0.14
'   water at full density is (1-.14) = .86 g/cc
h2o 11 den=0.86 0.13 293 end
arbmepe  0.92 2  0  1 1 6012 1
                        1001 2 11 0.14 end

' mixture 12
'  corner rods not facing other bundle, 3.05 wt% u235
uo2 12 0.98 293 92235 3.05 92238 96.95 end

' mixture 13
'  rods immed. adj. to corner rod, facing other bundle, 3.55 wt% u235
uo2 13 0.98 293 92235 3.55 92238 96.45 end

' mixture 14
'  rods immed. adj. to corner rod, not facing other bundle, 3.55 wt% u235
uo2 14 0.98 293 92235 3.55 92238 96.45 end

' mixture 15
'  balance of edge rods facing other bundle, 4.75 wt% u235
uo2 15 0.98 293 92235 4.75 92238 95.25 end

' mixture 16
'  balance of edge rods not facing other bundle, 5 wt% u235
uo2 16 0.98 293 92235 5.00 92238 95.00 end

' mixture 17
'  pe as interspersed moderator for ethafoam
arbmepe  0.92 2  0  1 1 6012 1
                        1001 2 17 0.01 end

end comp
more data
 res=  1 cyli  3.9693E-01 dan(  1)= 7.1095E-01
 res=  2 cyli  4.9947E-01 dan(  2)= 6.3439E-01
 res=  3 cyli  3.8942E-01 dan(  3)= 7.1464E-01
 res=  4 cyli  6.1041E-01 dan(  4)= 2.9373E-01
 res= 12 cyli  6.2199E-01 dan( 12)= 3.0272E-01
 res= 13 cyli  5.0252E-01 dan( 13)= 4.8509E-01
 res= 14 cyli  5.0306E-01 dan( 14)= 4.8213E-01
 res= 15 cyli  5.4301E-01 dan( 15)= 5.0055E-01
 res= 16 cyli  5.6070E-01 dan( 16)= 4.7538E-01
end more
atrium-10 in sp1 shipping container
read parameters
   tme=90.0 gen=103 npg=500
   flx=yes  fdn=yes xs1=yes nub=yes pwt=yes
   run=yes  plt=yes
end parameters
read geometry

unit  5
com="  10x10 bundle in left basket (top inner)  "
array 1  -8.7381 -6.477 -225.58
cubo  6  1  4p8.7381  2p225.58
'  add 0.0598 inch of perforated steel
cubo  8  1  4p8.89  2p225.58

unit  6
com="  10x10 bundle in right basket (top inner)  "
array 2  -4.2151 -6.477 -225.58
cubo  6  1  4p8.7381  2p225.58
'  add 0.0598 inch of perforated steel
```

```
cubo  8  1  4p8.89  2p225.58

unit  7
com="  10x10 bundle in left basket (bottom inner)  "
array 5  -8.7381 -6.477 -225.58
cubo  6  1  4p8.7381  2p225.58
'  add 0.0598 inch of perforated steel
cubo  8  1  4p8.89  2p225.58

unit  8
com="  10x10 bundle in right basket (bottom inner)  "
array 6  -4.2151 -6.477 -225.58
cubo  6  1  4p8.7381  2p225.58
'  add 0.0598 inch of perforated steel
cubo  8  1  4p8.89  2p225.58

unit 9
com="1 5/8 x 1 5/8 inch moderation regions at corners  "
cubo  6  1  4p2.06375 2p225.58

unit 10
com="  1 inner + outer container (top)  "
array  3  -21.9075 -13.97 -225.58
'  add 0.0598 inch walls
repl  7  1 6r0.1519  1
' add exterior wood box (outer container)
'  use low density pe here and box size of 24" x 24" x 206"
cubo 17 1 4p30.48 2p261.62

unit 11
com="array of 2 inners + outers (top & bottom)  "
array 8 3r0.0
'repl 10 2 6r3.0  10

unit 12
com="  1 inner + outer container (bottom)  "
array  7  -21.9075 -13.97 -225.58
'  add 0.0598 inch walls
repl  7  1 6r0.1519  1
' add exterior wood box (outer container)
'  use low density pe here and box size of 24" x 24" x 206"
cubo 17 1 4p30.48 2p261.62

global
unit 13
com="large array of inners "
array 9 3r0.0
repl 10 2 6r3.0  10

unit 16
com=" spacing & steel angle at -x side of basket "
cubo  6 1  4.12750 0.0 2p8.89  2p225.58
hole 22    0.15875 0.0  0.0
hole 22  0.47625 -0.3175 0.0
hole 22   0.47625  0.3175 0.0
hole 22   0.79375  0.635 0.0
hole 22  0.79375  -0.635 0.0
hole 22  1.11125  0.9525 0.0
hole 22  1.11125  -0.9525 0.0
hole 22  1.42875  1.27 0.0
hole 22  1.42875  -1.27 0.0
hole 22  1.74625  1.5875 0.0
hole 22  1.74625  -1.5875 0.0
hole 22  2.06375 1.905 0.0
hole 22  2.06375 -1.905 0.0
hole 22  2.38125  2.2225 0.0
hole 22  2.38125 -2.2225  0.0
hole 22  2.69875  2.54 0.0
hole 22  2.69875 -2.54  0.0
```

```
hole 22  3.01625  2.8575 0.0
hole 22  3.01625 -2.8575  0.0
hole 22  3.33375  3.175 0.0
hole 22  3.33375 -3.175  0.0
hole 22  3.65125  3.4925 0.0
hole 22  3.65125 -3.4925  0.0
hole 22  3.96875  3.81 0.0
hole 22  3.96875 -3.81  0.0

unit 17
com=" spacing & steel angle at +x side of basket "
cubo  6 1  0.0  -4.12750 2p8.89  2p225.58
hole 22  -0.15875 0.0  0.0
hole 22  -0.47625 -0.3175 0.0
hole 22  -0.47625  0.3175 0.0
hole 22  -0.79375  0.635 0.0
hole 22  -0.79375  -0.635 0.0
hole 22  -1.11125  0.9525 0.0
hole 22  -1.11125  -0.9525 0.0
hole 22  -1.42875  1.27 0.0
hole 22  -1.42875  -1.27 0.0
hole 22  -1.74625  1.5875 0.0
hole 22  -1.74625  -1.5875 0.0
hole 22  -2.06375 1.905 0.0
hole 22  -2.06375 -1.905 0.0
hole 22  -2.38125  2.2225 0.0
hole 22  -2.38125 -2.2225  0.0
hole 22  -2.69875  2.54 0.0
hole 22  -2.69875 -2.54  0.0
hole 22 -3.01625  2.8575 0.0
hole 22  -3.01625 -2.8575  0.0
hole 22  -3.33375  3.175 0.0
hole 22  -3.33375 -3.175  0.0
hole 22  -3.65125  3.4925 0.0
hole 22  -3.65125 -3.4925  0.0
hole 22  -3.96875  3.81 0.0
hole 22  -3.96875 -3.81  0.0

unit 18
com=" angles & spacing beneath baskets  "
cubo  6 1  2p8.89 4.12750 0.0  2p225.58
hole 21  0.0  0.15875  0.0
hole 21 -0.3175  0.47625  0.0
hole 21  0.3175  0.47625  0.0
hole 21  0.635  0.79375  0.0
hole 21 -0.635  0.79375  0.0
hole 21  0.9525  1.11125  0.0
hole 21 -0.9525  1.11125  0.0
hole 21  1.27  1.42875  0.0
hole 21 -1.27  1.42875  0.0
hole 21  1.5875  1.74625  0.0
hole 21 -1.5875  1.74625  0.0
hole 21  1.905  2.06375  0.0
hole 21 -1.905  2.06375  0.0
hole 21  2.2225  2.38125  0.0
hole 21 -2.2225  2.38125  0.0
hole 21   2.54 2.69875 0.0
hole 21  -2.54 2.69875 0.0
hole 21  2.8575 3.01625  0.0
hole 21  -2.8575 3.01625 0.0
hole 21   3.175 3.33375 0.0
hole 21   -3.175 3.33375  0.0
hole 21   3.4925 3.65125 0.0
hole 21   -3.4925  3.65125 0.0
hole 21   3.81 3.96875 0.0
hole 21   -3.81 3.96875 0.0

unit 19
com="angles & spacing above baskets  "
```

```
cubo  6 1  2p8.89  0.0 -4.12750  2p225.58
hole 21  0.0  -0.15875  0.0
hole 21 -0.3175  -0.47625  0.0
hole 21  0.3175  -0.47625  0.0
hole 21  0.635  -0.79375  0.0
hole 21 -0.635  -0.79375  0.0
hole 21  0.9525  -1.11125  0.0
hole 21 -0.9525  -1.11125  0.0
hole 21  1.27  -1.42875  0.0
hole 21 -1.27  -1.42875  0.0
hole 21  1.5875  -1.74625  0.0
hole 21 -1.5875  -1.74625  0.0
hole 21  1.905  -2.06375  0.0
hole 21 -1.905  -2.06375  0.0
hole 21  2.2225  -2.38125  0.0
hole 21 -2.2225  -2.38125  0.0
hole 21   2.54 -2.69875 0.0
hole 21  -2.54 -2.69875 0.0
hole 21  2.8575 -3.01625  0.0
hole 21  -2.8575 -3.01625 0.0
hole 21   3.175 -3.33375 0.0
hole 21   -3.175 -3.33375  0.0
hole 21    3.4925 -3.65125 0.0
hole 21   -3.4925  -3.65125 0.0
hole 21    3.81 -3.96875 0.0
hole 21   -3.81 -3.96875 0.0

unit 21
com="part of steel angle in horiz sections of stringer"
'  0.1552" x 0.125"
cubo  7 1 2p0.197104 2p0.15874 2p225.58

unit 22
com="part of steel angle in vert sections of stringer"
'  0.125" x 0.1552"
cubo  7 1 2p0.15874 2p0.197104 2p225.58

unit 101
com=" interior rods not immed. adj. to water channel, no gd2o3, 5 wt% u235 "
cyli  1 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 102
com=" interior rods immed. adj. to water channel, no gd2o3, 5 wt% u235 "
cyli  2 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 103
com=" interior rods, 1.5 wt% gd2o3, 5 wt% u235 "
cyli  3 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 104
com=" corner rods facing other bundle, 3.05 wt% u235 "
cyli  4 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 105
com=" corner rods not facing other bundle, 3.05 wt% u235 "
cyli 12 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 106
com=" rods immed adj. to corner rod, facing other bundle, 3.55 wt% u235 "
cyli 13 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 107
com=" rods immed adj. to corner rod, not facing other bundle, 3.55 wt% u235 "
```

```
cyli 14 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 108
com=" balance of edge rods facing other bundle, 4.75 wt% u235 "
cyli 15 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 109
com=" balance of edge rods not facing other bundle, 4.75 wt% u235 "
cyli 16 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 110
com=" water rod "
cubo  6 1 4p0.6447 2p225.58

end geometry

read array

' array 1 is bundle in left basket (top inner)
ara=1 nux=10 nuy=10 nuz=1
fill
105 107 109 109 109 109 109 109 107 104
107 101 103 101 103 101 101 103 101 106
109 103 101 101 101 101 101 101 103 108
109 101 101 102 102 102 101 101 101 108
109 103 102 110 110 110 102 101 101 108
109 101 102 110 110 110 102 101 103 108
109 101 102 110 110 110 102 101 101 108
109 101 101 102 102 102 101 101 103 108
107 101 101 101 101 103 101 103 101 106
105 107 109 109 109 109 109 109 107 104
end fill

' array 2 is bundle in right basket (top inner)
ara=2 nux=10 nuy=10 nuz=1
fill
104 107 109 109 109 109 109 109 107 105
106 101 103 101 101 103 101 103 101 107
108 103 101 101 101 101 101 101 103 109
108 101 101 101 102 102 102 101 101 109
108 101 101 102 110 110 110 102 103 109
108 103 101 102 110 110 110 102 101 109
108 101 101 102 110 110 110 102 101 109
108 103 101 101 102 102 102 101 101 109
106 101 103 101 103 101 101 101 101 107
104 107 109 109 109 109 109 109 107 105
end fill

' array 3 is 1 inner container (top inner)
ara=3 nux=4 nuy=3 nuz=1
fill
 9 18 18  9
16  5  6 17
 9 19 19  9
end fill

' array 4 is an array of inner containers
ara=4 nux=8 nuy=13 nuz=1
fill f10 end fill

' array 5 is bundle in left basket (bottom inner)
ara=5 nux=10 nuy=10 nuz=1
fill
105 107 109 109 109 109 109 109 107 104
107 101 101 101 101 103 101 103 101 106
109 101 101 102 102 102 101 101 103 108
```

```
109 101 102 110 110 110 102 101 101 108
109 101 102 110 110 110 102 101 103 108
109 103 102 110 110 110 102 101 101 108
109 101 101 102 102 102 101 101 101 108
109 103 101 101 101 101 101 101 103 108
107 101 103 101 103 101 101 103 101 106
105 107 109 109 109 109 109 109 107 104
end fill

' array 6 is bundle in right basket (bottom inner)
ara=6 nux=10 nuy=10 nuz=1
fill
104 107 109 109 109 109 109 109 107 105
106 101 103 101 103 101 101 101 101 107
108 103 101 101 102 102 102 101 101 109
108 101 101 102 110 110 110 102 101 109
108 103 101 102 110 110 110 102 101 109
108 101 101 102 110 110 110 102 103 109
108 101 101 101 102 102 102 101 101 109
108 103 101 101 101 101 101 101 103 109
106 101 103 101 101 103 101 103 101 107
104 107 109 109 109 109 109 109 107 105
end fill

' array 7 is 1 inner container (bottom inner)
ara=7 nux=4 nuy=3 nuz=1
fill
 9 18 18  9
16  7  8 17
 9 19 19  9
end fill

' array 8 is 2 inner + outer containers (top & bottom)
ara=8 nux=1 nuy=2 nuz=1
fill 12 10 end fill

' array 9 is array of 256 (16x16x1) containers
ara=9 nux=16 nuy=8 nuz=1
fill f11 end fill

end array

read start
nst=1
end start

read bounds
all=vacuum
end bounds

read bias
  id=500 2  11
end bias

read plot
'
ttl=' xy section of two inner containers '
xul=0           yul=52.6776    zul=10
xlr=44.1188     ylr=0          zlr=10
uax=1           vdn=-1         nax=150    lpi=10    end
'
ttl=' xy section of entire array '
xul=-32         yul=401        zul=10
xlr=385         ylr=-32        zlr=10
uax=1           vdn=-1         nax=150    lpi=10    end
'
ttl=' xz section of one inner container '
xul=0           yul=7.1882     zul=0
xlr=44.1188     ylr=7.1882     zlr=452
```

```
uax=1          wdn=1          nax=150    lpi=10    end
'
ttl=' xz section of entire array '
xul=-32        yul=7.1882     zul=-32
xlr=385        ylr=7.1882     zlr=484
uax=1          wdn=1          nax=150    lpi=10    end
'
end plot

end data
end
```

Case "drda-table24.98": **Damaged Spacing**, 112 SP-3 Inner Packages (8 Wide x 14 High), Assemblies as Far Apart as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Inside of the Group, 0.3957" Diameter Pellets, 0.14 VF PE as Shipping Shims, 13 vol% Interspersed Moderator

```
=csas25
atrium-10 in sp1 shipping container
hans infhom

' mixture 1
'  interior rods not immed. adj. to water channel, no gd2o3, 5 wt% u235
uo2 1 0.98 293 92235 5.0 92238 95.0 end

' mixture 2
'  interior rods immed. adj. to water channel, no gd2o3, 5 wt% u235
uo2 2 0.98 293 92235 5.0 92238 95.0 end

' mixture 3
'  interior rods, 1.5 wt% gd2o3, 5 wt% u235
'   td of uo2-gd2o3 = 10.96-2.65*p/[p+0.67145*(1-p)], p = wt fraction gd2o3
'   p is 0.015 here, so td of uo2-gd2o3 is 10.90123 g/cc
'   pellets are 0.98 td, so 0.98*10.90123 = 10.68321 g/cc
'   gd2o3 density is 0.015*10.68321 = 0.16025
uo2 3 den=10.68321 1.0 293 92235 5.0 92238 95.0 end
arbmgd2o3 0.16025 2 0 1 0 64000 2
                             8016 3 3 1.0 293 end

' mixture 4
'  corner rods facing other bundle, 3.05 wt% u235
uo2 4 0.98 293 92235 3.05 92238 96.95 end

' mixture 5 - not used
'  smeared zr clad
'  pod, cid, cod = 0.4221", 0.4281", 0.4781"
'  vol fract zr = 0.8988
'   at dens = 0.8988 * 4.2518-2 = 3.8215e-02
zircalloy 5 0.0 3.8215e-02 293 end

' mixture 6
'  interspersed moderator
h2o 6 0.13 293 end

' mixture 7
'  carbon steel, 100 vol%
c  7 0.0 3.921682e-03 293 end
fe 7 0.0 8.350009e-02 293 end

' mixture 8
'  carbon steel, 85.57 vol% smeared with 10 vol% h2o
c  8 0.0 3.355783e-03 293 end
fe 8 0.0 7.145103e-02 293 end
o  8 0.0 4.8167e-04 293 end
h  8 0.0 9.6335e-04 293 end

' mixture 9 - not used
'  carbon steel, 8.64 vol%
c  9 0.0 3.388333e-04 293 end
fe 9 0.0 7.214408e-03 293 end
o  9 0.0 3.0496e-03 293 end
h  9 0.0 6.0992e-03 293 end

' mixture 10
'  water for reflector
```

```
h2o 10 1.00 293 end

' mixture 11
'  pe and interspersed water
'   vf pe = 0.14
'   water at full density is (1-.14) = .86 g/cc
h2o 11 den=0.86 0.13 293 end
arbmepe  0.92 2  0  1 1 6012 1
                         1001 2 11 0.14 end

' mixture 12
'  corner rods not facing other bundle, 3.05 wt% u235
uo2 12 0.98 293 92235 3.05 92238 96.95 end

' mixture 13
'  rods immed. adj. to corner rod, facing other bundle, 3.55 wt% u235
uo2 13 0.98 293 92235 3.55 92238 96.45 end

' mixture 14
'  rods immed. adj. to corner rod, not facing other bundle, 3.55 wt% u235
uo2 14 0.98 293 92235 3.55 92238 96.45 end

' mixture 15
'  balance of edge rods facing other bundle, 4.75 wt% u235
uo2 15 0.98 293 92235 4.75 92238 95.25 end

' mixture 16
'  balance of edge rods not facing other bundle, 4.75 wt% u235
uo2 16 0.98 293 92235 4.75 92238 95.25 end

end comp
more data
 res=  1 cyli  4.0208E-01 dan(  1)= 7.1142E-01
 res=  2 cyli  4.9742E-01 dan(  2)= 6.3618E-01
 res=  3 cyli  3.6730E-01 dan(  3)= 7.2001E-01
 res=  4 cyli  5.8128E-01 dan(  4)= 3.1823E-01
 res= 12 cyli  5.6362E-01 dan( 12)= 3.0332E-01
 res= 13 cyli  5.5527E-01 dan( 13)= 4.5415E-01
 res= 14 cyli  5.1895E-01 dan( 14)= 4.7205E-01
 res= 15 cyli  5.5759E-01 dan( 15)= 4.9719E-01
 res= 16 cyli  5.6282E-01 dan( 16)= 4.7439E-01
end more
atrium-10 in sp1 shipping container
read parameters
   tme=90.0 gen=103 npg=500
   flx=yes fdn=yes xs1=yes nub=yes pwt=yes
   run=yes plt=yes
end parameters
read geometry

unit  5
com="  10x10 bundle in left basket (top inner)  "
array 1  -8.7381 -6.477 -225.58
cubo  6  1. 4p8.7381  2p225.58
'  add 0.0598 inch of perforated steel
cubo  8  1  4p8.89  2p225.58

unit  6
com="  10x10 bundle in right basket (top inner)  "
array 2  -4.2151 -6.477 -225.58
cubo  6  1 .4p8.7381  2p225.58
'  add 0.0598 inch of perforated steel
cubo  8  1  4p8.89  2p225.58

unit  7
com="  10x10 bundle in left basket (bottom inner)  "
array 5  -8.7381 -6.477 -225.58
cubo  6  1. 4p8.7381  2p225.58
'  add 0.0598 inch of perforated steel
```

```
cubo  8  1  4p8.89  2p225.58

unit  8
com="  10x10 bundle in right basket (bottom inner)  "
array 6  -4.2151 -6.477 -225.58
cubo  6  1  4p8.7381  2p225.58
'  add 0.0598 inch of perforated steel
cubo  8  1  4p8.89  2p225.58

unit 9
com="1 5/8 x 1 5/8 inch moderation regions at corners  "
cubo  6  1  4p2.06375 2p225.58

unit 10
com="  1 inner container (top)  "
array  3  -21.9075 -13.97 -225.58
'  add 0.0598 inch walls
repl  7  1 6r0.1519  1

unit 11
com="array of 2 inners (top & bottom)  "
array 8 3r0.0
'repl 10 2 6r3.0  10

unit 12
com="  1 inner container (bottom)  "
array  7  -21.9075 -13.97 -225.58
'  add 0.0598 inch walls
repl  7  1 6r0.1519  1

global
unit 13
com="large array of inners "
array 9 3r0.0
repl 10 2 6r3.0  10

unit 16
com=" spacing & steel angle at -x side of basket "
cubo  6 1  4.12750 0.0 2p8.89  2p225.58
hole 22    0.15875 0.0  0.0
hole 22  0.47625 -0.3175 0.0
hole 22   0.47625  0.3175 0.0
hole 22   0.79375  0.635 0.0
hole 22  0.79375  -0.635 0.0
hole 22  1.11125  0.9525 0.0
hole 22  1.11125  -0.9525 0.0
hole 22  1.42875  1.27 0.0
hole 22  1.42875  -1.27 0.0
hole 22  1.74625  1.5875 0.0
hole 22  1.74625  -1.5875 0.0
hole 22  2.06375 1.905 0.0
hole 22  2.06375 -1.905 0.0
hole 22  2.38125  2.2225 0.0
hole 22  2.38125 -2.2225  0.0
hole 22  2.69875  2.54 0.0
hole 22  2.69875 -2.54  0.0
hole 22  3.01625  2.8575 0.0
hole 22  3.01625 -2.8575  0.0
hole 22  3.33375  3.175 0.0
hole 22  3.33375 -3.175  0.0
hole 22  3.65125  3.4925 0.0
hole 22  3.65125 -3.4925  0.0
hole 22  3.96875  3.81 0.0
hole 22  3.96875 -3.81  0.0

unit 17
com=" spacing & steel angle at +x side of basket "
cubo  6 1  0.0  -4.12750 2p8.89  2p225.58
hole 22  -0.15875 0.0  0.0
```

```
hole 22  -0.47625 -0.3175 0.0
hole 22  -0.47625  0.3175 0.0
hole 22   -0.79375  0.635 0.0
hole 22  -0.79375  -0.635 0.0
hole 22  -1.11125  0.9525 0.0
hole 22  -1.11125  -0.9525 0.0
hole 22  -1.42875  1.27 0.0
hole 22  -1.42875  -1.27 0.0
hole 22  -1.74625  1.5875 0.0
hole 22  -1.74625  -1.5875 0.0
hole 22  -2.06375 1.905 0.0
hole 22  -2.06375 -1.905 0.0
hole 22  -2.38125  2.2225 0.0
hole 22  -2.38125 -2.2225  0.0
hole 22  -2.69875  2.54 0.0
hole 22  -2.69875 -2.54  0.0
hole 22 -3.01625  2.8575 0.0
hole 22  -3.01625 -2.8575  0.0
hole 22  -3.33375  3.175 0.0
hole 22  -3.33375 -3.175  0.0
hole 22  -3.65125  3.4925 0.0
hole 22  -3.65125 -3.4925  0.0
hole 22  -3.96875  3.81 0.0
hole 22  -3.96875 -3.81  0.0

unit 18
com=" angles & spacing beneath baskets  "
cubo  6 1  2p8.89 4.12750 0.0  2p225.58
hole 21  0.0  0.15875  0.0
hole 21 -0.3175  0.47625  0.0
hole 21  0.3175  0.47625  0.0
hole 21  0.635  0.79375  0.0
hole 21 -0.635  0.79375  0.0
hole 21  0.9525  1.11125  0.0
hole 21 -0.9525  1.11125  0.0
hole 21  1.27  1.42875  0.0
hole 21 -1.27  1.42875  0.0
hole 21  1.5875  1.74625  0.0
hole 21 -1.5875  1.74625  0.0
hole 21  1.905  2.06375  0.0
hole 21 -1.905  2.06375  0.0
hole 21  2.2225  2.38125  0.0
hole 21 -2.2225  2.38125  0.0
hole 21   2.54 2.69875 0.0
hole 21  -2.54 2.69875 0.0
hole 21  2.8575 3.01625  0.0
hole 21  -2.8575 3.01625 0.0
hole 21   3.175 3.33375 0.0
hole 21   -3.175 3.33375  0.0
hole 21   3.4925 3.65125 0.0
hole 21   -3.4925  3.65125 0.0
hole 21   3.81 3.96875 0.0
hole 21   -3.81 3.96875 0.0

unit 19
com="angles & spacing above baskets  "
cubo  6 1  2p8.89  0.0 -4.12750  2p225.58
hole 21  0.0  -0.15875  0.0
hole 21 -0.3175  -0.47625  0.0
hole 21  0.3175  -0.47625  0.0
hole 21  0.635  -0.79375  0.0
hole 21 -0.635  -0.79375  0.0
hole 21  0.9525  -1.11125  0.0
hole 21 -0.9525  -1.11125  0.0
hole 21  1.27  -1.42875  0.0
hole 21 -1.27  -1.42875  0.0
hole 21  1.5875  -1.74625  0.0
hole 21 -1.5875  -1.74625  0.0
hole 21  1.905  -2.06375  0.0
```

```
hole 21 -1.905  -2.06375  0.0
hole 21  2.2225  -2.38125  0.0
hole 21 -2.2225  -2.38125  0.0
hole 21   2.54 -2.69875 0.0
hole 21  -2.54 -2.69875 0.0
hole 21  2.8575 -3.01625  0.0
hole 21  -2.8575 -3.01625 0.0
hole 21   3.175 -3.33375 0.0
hole 21   -3.175 -3.33375  0.0
hole 21    3.4925 -3.65125 0.0
hole 21   -3.4925  -3.65125 0.0
hole 21    3.81 -3.96875 0.0
hole 21   -3.81 -3.96875 0.0

unit 21
com="part of steel angle in horiz sections of stringer"
'  0.1552" x 0.125"
cubo  7 1 2p0.197104 2p0.15874 2p225.58

unit 22
com="part of steel angle in vert sections of stringer"
'  0.125" x 0.1552"
cubo  7 1 2p0.15874 2p0.197104 2p225.58

unit 101
com=" interior rods not immed. adj. to water channel, no gd2o3, 5 wt% u235 "
cyli  1 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 102
com=" interior rods immed. adj. to water channel, no gd2o3, 5 wt% u235 "
cyli  2 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 103
com=" interior rods, 1.5 wt% gd2o3, 5 wt% u235 "
cyli  3 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 104
com=" corner rods facing other bundle, 3.05 wt% u235 "
cyli  4 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 105
com=" corner rods not facing other bundle, 3.05 wt% u235 "
cyli 12 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 106
com=" rods immed adj. to corner rod, facing other bundle, 3.55 wt% u235 "
cyli 13 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 107
com=" rods immed adj. to corner rod, not facing other bundle, 3.55 wt% u235 "
cyli 14 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 108
com=" balance of edge rods facing other bundle, 4.75 wt% u235 "
cyli 15 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 109
com=" balance of edge rods not facing other bundle, 4.75 wt% u235 "
cyli 16 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58
```

```
unit 110
com=" water rod "
cubo  6 1 4p0.6447 2p225.58

end geometry

read array

' array 1 is bundle in left basket (top inner)
ara=1 nux=10 nuy=10 nuz=1
fill
105 107 109 109 109 109 109 109 107 104
107 101 103 101 103 101 101 103 101 106
109 103 101 101 101 101 101 101 103 108
109 101 101 102 102 102 101 101 101 108
109 103 102 110 110 110 102 101 101 108
109 101 102 110 110 110 102 101 103 108
109 101 102 110 110 110 102 101 101 108
109 101 101 102 102 102 101 101 103 108
107 101 101 101 101 103 101 103 101 106
105 107 109 109 109 109 109 109 107 104
end fill

' array 2 is bundle in right basket (top inner)
ara=2 nux=10 nuy=10 nuz=1
fill
104 107 109 109 109 109 109 109 107 105
106 101 103 101 101 103 101 103 101 107
108 103 101 101 101 101 101 101 103 109
108 101 101 101 102 102 102 101 101 109
108 101 101 102 110 110 110 102 103 109
108 103 101 102 110 110 110 102 101 109
108 101 101 102 110 110 110 102 101 109
108 103 101 101 102 102 102 101 101 109
106 101 103 101 103 101 101 101 101 107
104 107 109 109 109 109 109 109 107 105
end fill

' array 3 is 1 inner container (top inner)
ara=3 nux=4 nuy=3 nuz=1
fill
 9 18 18  9
16  5  6 17
 9 19 19  9
end fill

' array 4 is an array of inner containers
ara=4 nux=8 nuy=13 nuz=1
fill f10 end fill

' array 5 is bundle in left basket (bottom inner)
ara=5 nux=10 nuy=10 nuz=1
fill
105 107 109 109 109 109 109 109 107 104
107 101 101 101 101 103 101 103 101 106
109 101 101 102 102 102 101 101 103 108
109 101 102 110 110 110 102 101 101 108
109 101 102 110 110 110 102 101 103 108
109 103 102 110 110 110 102 101 101 108
109 101 101 102 102 102 101 101 101 108
109 103 101 101 101 101 101 101 103 108
107 101 103 101 103 101 101 103 101 106
105 107 109 109 109 109 109 109 107 104
end fill

' array 6 is bundle in right basket (bottom inner)
ara=6 nux=10 nuy=10 nuz=1
fill
104 107 109 109 109 109 109 109 107 105
```

```
106 101 103 101 103 101 101 101 101 107
108 103 101 101 102 102 102 101 101 109
108 101 101 102 110 110 110 102 101 109
108 103 101 102 110 110 110 102 101 109
108 101 101 102 110 110 110 102 103 109
108 101 101 101 102 102 102 101 101 109
108 103 101 101 101 101 101 101 103 109
106 101 103 101 101 103 101 103 101 107
104 107 109 109 109 109 109 109 107 105
end fill

' array 7 is 1 inner container (bottom inner)
ara=7 nux=4 nuy=3 nuz=1
fill
 9 18 18  9
16  7  8 17
 9 19 19  9
end fill

' array 8 is 2 inner containers (top & bottom)
ara=8 nux=1 nuy=2 nuz=1
fill 12 10 end fill

' array 9 is array of 112 (8x14x1) containers
ara=9 nux=8 nuy=7 nuz=1
fill f11 end fill

end array

read start
nst=1
end start

read bounds
all=vacuum
end bounds

read bias
  id=500 2 11
end bias

read plot
'
ttl=' xy section of two inner containers '
xul=0           yul=52.6776    zul=10
xlr=44.1188     ylr=0          zlr=10
uax=1           vdn=-1         nax=150    lpi=10   end
'
ttl=' xy section of entire array '
xul=-32         yul=401        zul=10
xlr=385         ylr=-32        zlr=10
uax=1           vdn=-1         nax=150    lpi=10   end
'
ttl=' xz section of one inner container '
xul=0           yul=7.1882     zul=0
xlr=44.1188     ylr=7.1882     zlr=452
uax=1           wdn=1          nax=150    lpi=10   end
'
ttl=' xz section of entire array '
xul=-32         yul=7.1882     zul=-32
xlr=385         ylr=7.1882     zlr=484
uax=1           wdn=1          nax=150    lpi=10   end
'
end plot

end data
end
```

Appendix 6J

FRAMATOME ANP SUPPLEMENTAL APPLICATION TO CERTIFICATE OF COMPLIANCE 9248 TO ADD THE CRITICALITY SAFETY ANALYSIS FOR ATRIUM™-10 FUEL ASSEMBLIES WITH 2.3 WEIGHT PERCENT U^{235} MAXIMUM ENRICHMENT AND NO GADOLINIA RODS TO THE SP-1/2/3 PACKAGES

Criticality Evaluation

1. Introduction

This Criticality Safety Evaluation (CSE) provides the criticality safety basis for shipping ATRIUM™-10 fuel assemblies with a maximum U^{235} enrichment with no gadolinia (Gd_2O_3) containing rods. The CSE is the same one that was submitted and approved by the NRC in the letter amendment submittal dated October 23, 2002 (Reference 3). That submittal was for a one time letter amendment for one particular customer. In the mean time other customers have demonstrated a need for the same type of low enriched, no poison fuel to replace multiple burned fuel assemblies due to fuel failures. Therefore FANP would like the fuel description analyzed in this appendix permanently to the certificate.

2. Evaluation

Previously burned fuel assemblies are significantly less reactive than fresh fuel, and as a result in order to match the necessary physics criteria of the operating core, replacement fuel must be comprised of lower maximum and assembly average enrichments. In addition, since the fuel assemblies are replacing previously burned fuel assemblies, gadolinia poison, typically used for reactivity hold down at the beginning of a cycle, is not necessary. The CSE shows that sufficient margin to safety exists for SP-1/2/3 packagings that contain fuel assemblies enriched to maximum of 2.3 w/o U^{235} but containing no gadolinia rods.

The following calculations will demonstrate that the reduction in fresh fuel enrichment is sufficient to offset the removal of the neutron poison gadolinia material. The analysis used in Appendix 6I was essentially repeated using the same general methodology to calculate the nuclear safety margin for the worst case conditions, using reduced enrichments and no burnable poison content. The evaluation considers a single undamaged flooded container with full water reflection, an array of undamaged reflected packages, and an array of damaged packages with various amounts of interspersed moderator and full water reflection. The previous revision of the SAR (EMF-1563 Revision 11) contains 9 categories of allowable contents. The new category 10 is essentially a modification of the category 9 ATRIUM™ 10X10 fuel design.

With the exception of the two parameters mentioned (enrichment and poison), the contents in this Appendix are the same as those in Appendix 6I and Section 5.(b)(1)(ix) of the C of C.:

> UO_2 fuel assemblies composed of fuel rods in a 10 x 10 square array, with a maximum fuel cross section of 5.0 inches square, and a maximum fuel length of 174 inches. The maximum U^{235} enrichment is 2.3 weight percent. The pellet diameter is between 0.30 and 0.3957 inch. Each assembly must have a water channel in a central 3 x 3 position. Any number of additional water rods in any arrangement is permitted, including part length rods. Polyethylene shipping shims may be inserted between the fuel rods. An additional upper tie plate (UTP) shipping shim may be added between the UTP and the fueled region. This UTP shim may consist of a maximum of 345 g plastic or plastic composite.

Reference 1 involved a transmittal to the NRC which updated Table 1 of the initial submittal (Reference 2) in accordance with concerns that were raised during the NRC review. Reference 1 also identified the most reactive isolated reflected undamaged package reactivity to be Keff = 0.75413 ± 0.00323. By maintaining all parameters the same and simply removing the gadolinia rods and making all fuel rods equal to the maximum rod enrichment of 2.3 w/o U^{235}, the reactivity decreased to Keff = 0.72278 ± 0.00335. The same calculation was repeated where enrichment in each rod was set at 1.9 w/o which represents the assembly average. The resulting multiplication factor was calculated to be Keff = 0.68706 ± 0.00296.

The second set of calculations involved determination of the effect of the reduced enrichment(s) on an undamaged array of packages. Again the evaluation involved a comparison to the data previously approved and presented in Reference 1. The original reactivity listed in Table 1 of Reference 1 was Keff = 0.81454 ± 0.00248. The reductions in reactivity based on the changes in enrichment and the removal of burnable poisons were Keff = 0.77748 ± 0.00291 and Keff = 0.73442 ± 0.00260 for 2.3 w/0 and 1.9 w/o enrichments, respectively.

Again, referencing the transmittal listed in Reference 1, the accident mode of transportation was evaluated by examining the effects of reducing the enrichments to 2.3 w/o and again to 1.9 w/o and removing the burnable poison material from the previously determined worst case accident situation. The same methodology was employed as in the isolated and the undamaged array calculations. The reduction(s) in the enrichment and removal of poisons resulted in reductions in the maximum reactivity of Keff = 0.90901 ± 0.00279 and Keff = 0.85100 ± 0.00230 for each of the two lower enrichments. This is relative to the existing values of 0.93506 ± 0.00274. The revised input deck is provided in Figure 2.

In order to demonstrate that the conditions resulting in the maximum reactivity did not change due to the reduction in enrichment or exclusion of poison material, the worst case accident case was evaluated over the entire range of interspersed moderator, from 1% to a full flooded condition. Figure 1 demonstrates the system is well behaved as evidenced by the consistency in the curves. For comparisons to the previously transmitted values, Table 1 contains reactivity values for both the existing licensed conditions, and those proposed in this appendix.

Reference: 1 Letter, Framatome ANP to NRC, Mr. Hansen, March 21, 2001 "Certificate of Compliance Amendment Request (Framatome ANP Richland, Inc. Docket 71-9248; Revision 11 of EMF-1563", PCR:01:009.

Reference: 2 Letter, Framatome ANP to NRC, Mr. Hansen, November 17, 2000 "Certificate of Compliance Amendment Request (Framatome ANP Richland, Inc. Docket 71-9248; Revision 11 of EMF-1563", PCR:01:009.

Reference: 3 Letter, Framatome ANP to NRC, Mr. Monninger, October 23, 2002 "Request for a Letter Amendment to the Certificate of Compliance No. 71-9248 for the SP-1 Shipping Package", EHSLR-02-038.

Table 1
Update to Table 1 in Ref.1
Comparative listing of Reactivity Changes

Description of Most Reactive Case	K_{eff}	σ	Bias	K_{eff} + 2σ + bias[1]
ATRIUM™-10 Fuel Assemblies with PE Shipping Shims (see detailed payload description listed in Section 1.2)				
Single SP-3 Inner Package, Assemblies Moved as Close as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in Assemblies are Toward Outside of Inner Packaging, 0.35" Diameter Pellets, 0.14 VF PE[2] as Shipping Shims, Fully Flooded, All Rods 5.0 wt% ^{235}U (see Section 3.1.2)	Base =0.75413 **2.3 w/o = 0.72278** **1.9 w/o = 0.68706**	0.00323	-0.00321[1]	0.76059
Undamaged Spacing, 256 SP-1/2/3 Inner/Outer Packages (16 Wide x 16 High), Assemblies as Far Apart as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Inside of the Group, 0.3957" Diameter Pellets, 0.14 VF PE within Inner Packaging as Shipping Shims, 13 vol% Interspersed Moderator, 1 vol% PE between Inner and Outer Packages (see Section 3.1.3)	Base =0.81454 **2.3 w/o = 0.77748** **1.9 w/o = 0.73442**	0.00248	-0.00321[1]	0.81950
Damaged Spacing, 104 SP-3 Inner Packages (8 Wide x 13 High), Assemblies as Far Apart as Physically Possible within Inner Packaging, Asymmetric Gd_2O_3 Rods in the Assemblies in Each Group of Two Vertically Adjacent Inner Packages Facing Towards the Inside of the Group, 0.3957" Diameter Pellets, 0.14 VF PE[2] as Shipping Shims, 13 vol% Interspersed Moderator (see Section 3.1.4)	Base =0.93506 **2.3 w/o = 0.90901** **1.9 w/o = 0.85100**	0.00274	-0.00321[1]	0.94054

(1) Note that as discussed in Section2.4 the bias is negative (conservative), so it is not included in the results as presented in Table 1.

(2) Under severe accident conditions, the UTP shim may increase the PE VF between the fuel rods from 0.14 to 0.151. Calculations in Section 3 show that this increase in the PE VF within the void volume produces statistically identical results.

Figure 1

Comparison of Reactivity for Reduced Enrichment,
No Burnable Poison(s) vs. Base Case

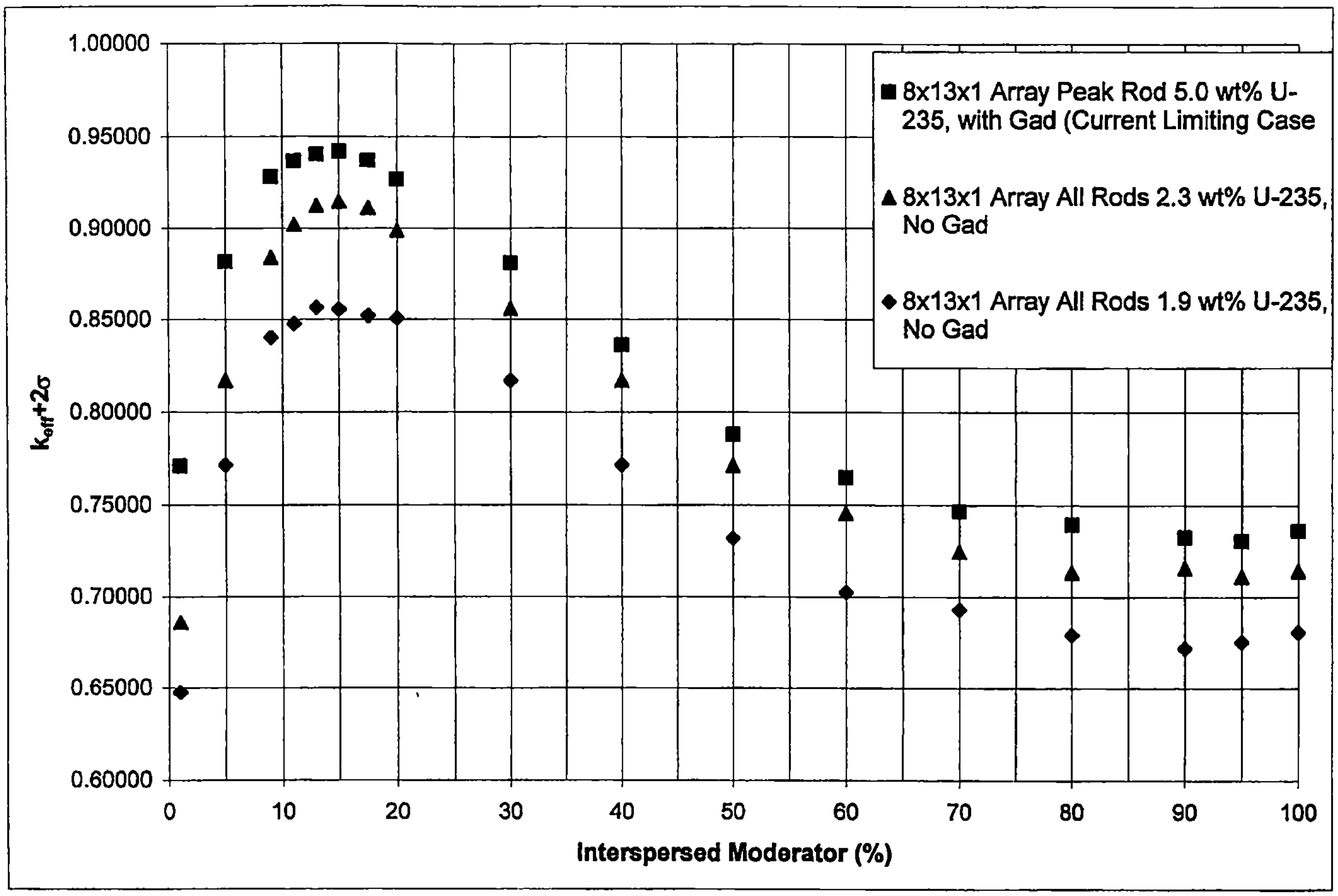

Figure 2
SCALE Input Deck
Accident Mode Array of Packages
(Changes to Ref 1 input are marked in Column)

```
=csas25
atrium-10 in sp1 shipping container
hans infhom

' mixture 1
'  interior rods not immed. adj. to water channel, no gd2o3, 2.3 wt% u235
uo2 1 0.98 293 92235 2.3 92238 97.7 end

' mixture 2
'  interior rods immed. adj. to water channel, no gd2o3, 2.3 wt% u235
uo2 2 0.98 293 92235 2.3 92238 97.7 end

' mixture 3
'  interior rods, 2.3 wt% u235

uo2 3 0.98 293 92235 2.3 92238 97.7 end

' mixture 4
'  corner rods facing other bundle, 2.30 wt% u235
uo2 4 0.98 293 92235 2.30 92238 97.70 end

' mixture 5 - not used
'  smeared zr clad
'  pod, cid, cod = 0.4221", 0.4281", 0.4781"
'  vol fract zr = 0.8988
'   at dens = 0.8988 * 4.2518-2 = 3.8215e-02
zircalloy 5 0.0 3.8215e-02 293 end

' mixture 6
'  interspersed moderator
h2o 6 0.13 293 end

' mixture 7
'  carbon steel, 100 vol%
c  7 0.0 3.921682e-03 293 end
fe 7 0.0 8.350009e-02 293 end

' mixture 8
'  carbon steel, 85.57 vol% smeared with 10 vol% h2o
c  8 0.0 3.355783e-03 293 end
fe 8 0.0 7.145103e-02 293 end
o  8 0.0 4.8167e-04 293 end
h  8 0.0 9.6335e-04 293 end

' mixture 9 - not used
'  carbon steel, 8.64 vol%
c  9 0.0 3.388333e-04 293 end
fe 9 0.0 7.214408e-03 293 end
o  9 0.0 3.0496e-03 293 end
h  9 0.0 6.0992e-03 293 end
```

```
' mixture 10
'  water for reflector
h2o 10 1.00 293 end

' mixture 11
'  pe and interspersed water
'   vf pe = 0.14
'   water at full density is (1-.14) = .86 g/cc
h2o 11 den=0.86 0.13 293 end
arbmepe  0.92 2  0  1 1 6012 1
                        1001 2 11 0.14 end

' mixture 12
'  corner rods not facing other bundle, 2.30 wt% u235
uo2 12 0.98 293 92235 2.30 92238 97.70 end

' mixture 13
'  rods immed. adj. to corner rod, facing other bundle, 2.30 wt% u235
uo2 13 0.98 293 92235 2.30 92238 97.70 end

' mixture 14
'  rods immed. adj. to corner rod, not facing other bundle, 2.30 wt% u235
uo2 14 0.98 293 92235 2.30 92238 97.70 end

' mixture 15
'  balance of edge rods facing other bundle, 2.30 wt% u235
uo2 15 0.98 293 92235 2.30 92238 97.70 end

' mixture 16
'  balance of edge rods not facing other bundle, 2.30 wt% u235
uo2 16 0.98 293 92235 2.30 92238 97.70 end

end comp
more data
 res=  1 cyli  3.9373E-01 dan(  1)= 7.1462E-01
 res=  2 cyli  4.9179E-01 dan(  2)= 6.3800E-01
 res=  3 cyli  3.7646E-01 dan(  3)= 7.1738E-01
 res=  4 cyli  5.4253E-01 dan(  4)= 3.2492E-01
 res= 12 cyli  5.7437E-01 dan( 12)= 2.9006E-01
 res= 13 cyli  4.9373E-01 dan( 13)= 4.7915E-01
 res= 14 cyli  5.1981E-01 dan( 14)= 4.6880E-01
 res= 15 cyli  5.6427E-01 dan( 15)= 4.9128E-01
 res= 16 cyli  5.6151E-01 dan( 16)= 4.7466E-01
end more
atrium-10 in sp1 shipping container
read parameters
   tme=90.0 gen=103 npg=500
   flx=yes  fdn=yes xs1=yes nub=yes pwt=yes
   run=yes  plt=yes
end parameters
read geometry

unit  5
com="  10x10 bundle in left basket (top inner)  "
array 1  -8.7381 -6.477 -225.58
cubo  6  1  4p8.7381  2p225.58
'  add 0.0598 inch of perforated steel
```

```
cubo  8  1  4p8.89  2p225.58

unit  6
com="  10x10 bundle in right basket (top inner) ."
array 2  -4.2151 -6.477 -225.58
cubo  6  1  4p8.7381  2p225.58
'  add 0.0598 inch of perforated steel
cubo  8  1  4p8.89  2p225.58

unit  7
com="  10x10 bundle in left basket (bottom inner)  "
array 5  -8.7381 -6.477 -225.58
cubo  6  1  4p8.7381  2p225.58
'  add 0.0598 inch of perforated steel
cubo  8  1  4p8.89  2p225.58

unit  8
com="  10x10 bundle in right basket (bottom inner)  "
array 6  -4.2151 -6.477 -225.58
cubo  6  1  4p8.7381  2p225.58
'  add 0.0598 inch of perforated steel
cubo  8  1  4p8.89  2p225.58

unit 9
com="1 5/8 x 1 5/8 inch moderation regions at corners  "
cubo  6  1  4p2.06375 2p225.58

unit 10
com="  1 inner container (top)  "
array  3  -21.9075 -13.97 -225.58
'  add 0.0598 inch walls
repl  7  1 6r0.1519  1

unit 11
com="array of 2 inners (top & bottom)  "
array 8 3r0.0
'repl 10 2 6r3.0  10

unit 12
com="  1 inner container (bottom)  "
array  7  -21.9075 -13.97 -225.58
'  add 0.0598 inch walls
repl  7  1 6r0.1519  1

unit 13
com="8x12 array of inners "
array 9 3r0.0

unit 14
com="8x1 array of inners "
array 10 3r0.0

global
unit 15
com="8x13 array of inners "
array 11 3r0.0
repl 10 2 6r3.0  10
```

```
hole 22  -3.96875 -3.81  0.0

unit 18
com=" angles & spacing beneath baskets  "
cubo  6 1  2p8.89 4.12750 0.0  2p225.58
hole 21  0.0  0.15875  0.0
hole 21 -0.3175  0.47625  0.0
hole 21  0.3175  0.47625  0.0
hole 21  0.635  0.79375  0.0
hole 21 -0.635  0.79375  0.0
hole 21  0.9525  1.11125  0.0
hole 21 -0.9525  1.11125  0.0
hole 21  1.27  1.42875  0.0
hole 21 -1.27  1.42875  0.0
hole 21  1.5875  1.74625  0.0
hole 21 -1.5875  1.74625  0.0
hole 21  1.905  2.06375  0.0
hole 21 -1.905  2.06375  0.0
hole 21  2.2225  2.38125  0.0
hole 21 -2.2225  2.38125  0.0
hole 21   2.54 2.69875 0.0
hole 21  -2.54 2.69875 0.0
hole 21  2.8575 3.01625  0.0
hole 21  -2.8575 3.01625 0.0
hole 21   3.175 3.33375 0.0
hole 21   -3.175 3.33375  0.0
hole 21    3.4925 3.65125 0.0
hole 21   -3.4925  3.65125 0.0
hole 21    3.81 3.96875 0.0
hole 21   -3.81 3.96875 0.0

unit 19
com="angles & spacing above baskets  "
cubo  6 1  2p8.89  0.0 -4.12750  2p225.58
hole 21  0.0  -0.15875  0.0
hole 21 -0.3175  -0.47625  0.0
hole 21  0.3175  -0.47625  0.0
hole 21  0.635  -0.79375  0.0
hole 21 -0.635  -0.79375  0.0
hole 21  0.9525  -1.11125  0.0
hole 21 -0.9525  -1.11125  0.0
hole 21  1.27  -1.42875  0.0
hole 21 -1.27  -1.42875  0.0
hole 21  1.5875  -1.74625  0.0
hole 21 -1.5875  -1.74625  0.0
hole 21  1.905  -2.06375  0.0
hole 21 -1.905  -2.06375  0.0
hole 21  2.2225  -2.38125  0.0
hole 21 -2.2225  -2.38125  0.0
hole 21   2.54 -2.69875 0.0
hole 21  -2.54 -2.69875 0.0
hole 21  2.8575 -3.01625  0.0
hole 21  -2.8575 -3.01625 0.0
hole 21   3.175 -3.33375 0.0
hole 21   -3.175 -3.33375  0.0
hole 21    3.4925 -3.65125 0.0
hole 21   -3.4925  -3.65125 0.0
```

```
hole 21    3.81 -3.96875 0.0
hole 21   -3.81 -3.96875 0.0

unit 21
com="part of steel angle in horiz sections of stringer"
'  0.1552" x 0.125"
cubo  7 1 2p0.197104 2p0.15874 2p225.58

unit 22
com="part of steel angle in vert sections of stringer"
'  0.125" x 0.1552"
cubo  7 1 2p0.15874 2p0.197104 2p225.58

unit 101
com=" interior rods not immed. adj. to water channel, no gd2o3, 5 wt% u235 "
cyli  1 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 102
com=" interior rods immed. adj. to water channel, no gd2o3, 5 wt% u235 "
cyli  2 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 103
com=" interior rods, 1.5 wt% gd2o3, 5 wt% u235 "
cyli  3 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 104
com=" corner rods facing other bundle, 3.05 wt% u235 "
cyli  4 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 105
com=" corner rods not facing other bundle, 3.05 wt% u235 "
cyli 12 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 106
com=" rods immed adj. to corner rod, facing other bundle, 3.55 wt% u235 "
cyli 13 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 107
com=" rods immed adj. to corner rod, not facing other bundle, 3.55 wt% u235 "
cyli 14 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 108
com=" balance of edge rods facing other bundle, 4.75 wt% u235 "
cyli 15 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58

unit 109
com=" balance of edge rods not facing other bundle, 4.75 wt% u235 "
cyli 16 1 0.50254  2p225.58
cubo 11 1 4p0.6447 2p225.58
```

```
unit 110
com=" water rod "
cubo  6 1 4p0.6447 2p225.58

end geometry

read array

' array 1 is bundle in left basket (top inner)
ara=1 nux=10 nuy=10 nuz=1
fill
105 107 109 109 109 109 109 109 107 104
107 101 103 101 103 101 101 103 101 106
109 103 101 101 101 101 101 101 103 108
109 101 101 102 102 102 101 101 101 108
109 103 102 110 110 110 102 101 101 108
109 101 102 110 110 110 102 101 103 108
109 101 102 110 110 110 102 101 101 108
109 101 101 102 102 102 101 101 103 108
107 101 101 101 101 103 101 103 101 106
105 107 109 109 109 109 109 109 107 104
end fill

' array 2 is bundle in right basket (top inner)
ara=2 nux=10 nuy=10 nuz=1
fill
104 107 109 109 109 109 109 109 107 105
106 101 103 101 101 103 101 103 101 107
108 103 101 101 101 101 101 101 103 109
108 101 101 101 102 102 102 101 101 109
108 101 101 102 110 110 110 102 103 109
108 103 101 102 110 110 110 102 101 109
108 101 101 102 110 110 110 102 101 109
108 103 101 101 102 102 102 101 101 109
106 101 103 101 103 101 101 101 101 107
104 107 109 109 109 109 109 109 107 105
end fill

' array 3 is 1 inner container (top inner)
ara=3 nux=4 nuy=3 nuz=1
fill
 9 18 18  9
16  5  6 17
 9 19 19  9
end fill

' array 4 is an array of inner containers
ara=4 nux=8 nuy=13 nuz=1
fill f10 end fill

' array 5 is bundle in left basket (bottom inner)
ara=5 nux=10 nuy=10 nuz=1
fill
105 107 109 109 109 109 109 109 107 104
107 101 101 101 101 103 101 103 101 106
109 101 101 102 102 102 101 101 103 108
```

```
109 101 102 110 110 110 102 101 101 108
109 101 102 110 110 110 102 101 103 108
109 103 102 110 110 110 102 101 101 108
109 101 101 102 102 102 101 101 101 108
109 103 101 101 101 101 101 101 103 108
107 101 103 101 103 101 101 103 101 106
105 107 109 109 109 109 109 109 107 104
end fill

' array 6 is bundle in right basket (bottom inner)
ara=6 nux=10 nuy=10 nuz=1
fill
104 107 109 109 109 109 109 109 107 105
106 101 103 101 103 101 101 101 101 107
108 103 101 101 102 102 102 101 101 109
108 101 101 102 110 110 110 102 101 109
108 103 101 102 110 110 110 102 101 109
108 101 101 102 110 110 110 102 103 109
108 101 101 101 102 102 102 101 101 109
108 103 101 101 101 101 101 101 103 109
106 101 103 101 101 103 101 103 101 107
104 107 109 109 109 109 109 109 107 105
end fill

' array 7 is 1 inner container (bottom inner)
ara=7 nux=4 nuy=3 nuz=1
fill
 9 18 18  9
16  7  8 17
 9 19 19  9
end fill

' array 8 is 2 inner containers (top & bottom)
ara=8 nux=1 nuy=2 nuz=1
fill 12 10 end fill

' array 9 is array of 96 (8x12x1) containers
ara=9 nux=8 nuy=6 nuz=1
fill f11 end fill

' array 10 is array of 8 (8x1x1) containers
ara=10 nux=8 nuy=1 nuz=1
fill f12 end fill

' array 11 is array of 104 (8x13x1) containers
ara=11 nux=1 nuy=2 nuz=1
fill 13 14 end fill

end array

read start
nst=1
end start

read bounds
all=vacuum
end bounds
```

```
read bias
  id=500 2  11
end bias

read plot
'
ttl=' xy section of two inner containers '
xul=0           yul=52.6776    zul=10
xlr=44.1188     ylr=0          zlr=10
uax=1           vdn=-1         nax=150   lpi=10   end
'
ttl=' xy section of entire array '
xul=-32         yul=401        zul=10
xlr=385         ylr=-32        zlr=10
uax=1           vdn=-1         nax=150   lpi=10   end
'
ttl=' xz section of one inner container '
xul=0           yul=7.1882     zul=0
xlr=44.1188     ylr=7.1882     zlr=452
uax=1           wdn=1          nax=150   lpi=10   end
'
ttl=' xz section of entire array '
xul=-32         yul=7.1882     zul=-32
xlr=385         ylr=7.1882     zlr=484
uax=1           wdn=1          nax=150   lpi=10   end
'
end plot

end data
end
```