APPLICATION FOR USE OF

MODEL NOS. 927A1 AND 927C1 FUEL ASSEMBLY

SHIPPING CONTAINERS FOR TRANSPORT

OF RADIOACTIVE MATERIAL

COMBUSTION ENGINEERING, INC.

TABLE OF CONTENTS

1. GENERAL INFORMATION

1.1 Introduction

This application is submitted for approval of Combustion Engineering's fuel assembly shipping containers, identified as Model Nos. 927A1 and 927C1. The Model 927A1 container is structurally identical to the Model 927C1 container with the exception of its reduced length. These containers meet the criteria of 10CFR71, with a limit of 8 packages per shipment.

1.2 Package Description

1.2.1 Packaging

The Model Nos. 927A1 and 927C1 containers are fabricated of carbon steel and consist of a strongback and fuel bundle clamping assembly, shock mounted to the steel outer container. The fuel bundles are separated by 3/16" thick, high carbon steel segmented separator blocks permanently attached to the strongback. The segmented separator blocks maintain a minimum 6" separation of the active fuel length in the bundle. The segmented separator blocks are installed (welded) in segments to form a continuous block for the entire active length of the fuel assembly. The Model No. 927A1 container is approximately 43" in diameter by 189" long with an approximate gross weight of 6,700 lbs. The Model No. 927C1 container is approximately 43" in diameter by 216" long with an approximate gross weight of 7,300 lbs.

Appendix 1A contains Combustion Engineering drawings which provide design details of both containers.

1.2.2 Operational Features

These containers are used for the shipment of unirradiated fuel assemblies, are of relatively simple design, and do not incorporate cooling systems, shielding, etc.

1.2.3 Contents of Packaging

Each shipping container holds a maximum of two fuel assemblies of the types described below:

a) Model No. 927A1 - fuel assemblies consisting of 0.38" diameter uranium dioxide fuel pellets clad in 0.028" thick zircaloy tubes in a 14x14 square array with a 0.580" pitch. Each fuel assembly consists of a maximum of 176 fuel rods with a maximum 5.0 wt % enrichment in the U235 isotope.

b) Model No. 927A1 - fuel assemblies consisting of 0.33" diameter uranium dioxide fuel pellets clad in 0.025" thick zircaloy tubes in a 16x16 square array with a 0.506" pitch. Each fuel assembly consists of a maximum of 236 fuel rods with a maximum 5.0 wt % enrichment in the U235 isotope.

c) Model No. 927A1 - fuel assemblies consisting of 0.31" diameter uranium dioxide fuel pellets clad in 0.024" thick zircaloy tubes in a 16x16 square array with some fuel rods removed for compatibility to a cruciform shaped control blade with a 0.472" pitch. Each fuel assembly consists of a maximum of 231 fuel rods with a maximum 5.0 wt % enrichment in the U235 isotope.

d) Model No. 927C1 - fuel assemblies consisting of 0.33" diameter uranium dioxide fuel pellets clad in 0.025" thick zircaloy tubes in a 16x16 square array with a 0.506" pitch. Each fuel assembly consists of a maximum of 236 fuel rods with a maximum 5.0 wt % enrichment in the U235 isotope.

e) Model No. 927C1 - fuel assemblies consisting of 0.324" diameter uranium dioxide fuel pellets clad in 0.0235" thick zircaloy tubes in a 17x17 square array with a 0.501" pitch. Each fuel assembly consists of a maximum of 264 fuel rods with a maximum 3.6 wt % enrichment in the U235 isotope.

f) Model No. 927A1 - unirradiated fuel assemblies consisting of 0.381" diameter uranium dioxide fuel pellets clad in 0.026" thick zircaloy tubes in a 14x14 square array with a 0.58" pitch. Each fuel assembly consists of a maximum of 176 fuel rods with a maximum 4.76 wt% enrichment in the U-235 isotope, and contains not more than 19.6 Kg U-235.

The maximum quantity of material per package, for any of the fuel assembly types specified in a) through d) and f) above, shall be less than or equal to 45.54 Kgs U235. This value is based on conservative values of the pellet O.D. and stack density of 0.330 inches and 10.412 g/cc, respectively. These conservatisms result in a nominal implied (calculated) fuel assembly weight of 1,505 pounds, which exceeds the limit of Table 2A-1 by five pounds. The actual fuel assembly weight will not, however, exceed 1,500 pounds.

For the 17x17 fuel assembly, the maximum shall be 33.70 Kgs U235. This exceeds the value implied by column (e) of Section 6.4.2 of 32.86 Kgs U235 because of a conservative value of assumed pellet density of 10.41 gm/cc.

Appendix 1A Engineering Drawings

Dimensional details of both containers are described in the engineering drawings [E-5022-8051, Rev. 0, Shipping Container (4 sheets)] provided on the following pages.

FIGURE WITHHELD UNDER 10 CFR 2.390

NOTES:

9607120158-01

CE POWER SYSTEMS

COMBUSTION ENGINEERING, INC.

SHIPPING CONTAINER

E-5022-8051

0

SCALE NONE

SHEET 1 OF 4

FIGURE WITHHELD UNDER 10 CFR 2.390

9607120158-02

POWER SYSTEMS

SHIPPING CONTAINER

E-5022-8051

0

2 of 4

FIGURE WITHHELD UNDER 10 CFR 2.390

9607120158-03

POWER SYSTEMS

SHIPPING CONTAINER

E-5022-6051

0

NONE

(

FIGURE WITHHELD UNDER 10 CFR 2.390

9607120158-04

	CE POWER SYSTEMS
TITLE	SHIPPING CONTAINER
DWG. NO.	E-5022-8051
REV	0
SCALE	NONE
SHEET	4 of 4

FIGURE WITHHELD UNDER 10 CFR 2.390

POWER SYSTEMS

SHIPPING CONTAINER

E-5022-8051

0

NONE

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure 1A-1 (Sheet 2 of 4)

July 9, 1996 Rev. 0 PAGE 1-5

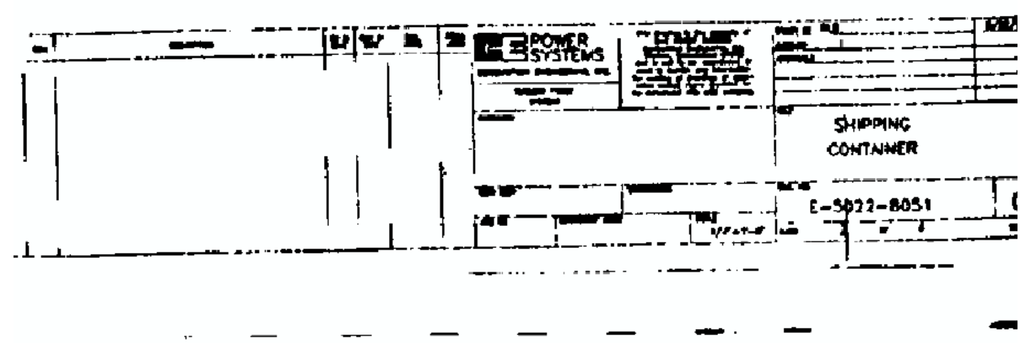


FIGURE WITHHELD UNDER 10 CFR 2.390

SEAL WELD

E-5022-8051

SHEET 3 of 4 | 0

Figure 1A-1 (Sheet 3 of 4)
July 9, 1996 Rev. 0 PAGE 1-6

POWER SYSTEMS

SHIPPING CONTAINER

E-5022-8051 | 0

NONE

FIGURE WITHHELD UNDER 10 CFR 2.390

E-5022-8051

SHEET 4 of 4 | 0

Figure 1A-1 (Sheet 4 of 4)

July 9, 1996 Rev. 0 PAGE 1-7

POWER SYSTEMS

SHIPPING CONTAINER

E-5022-8051 | 0

NONE

2. STRUCTURAL EVALUATION

2.1 Structural Design

2.1.1 Discussion

The containment vessel for the fuel assemblies consists of the 43" diameter carbon steel outer shell. The internal and external structures supporting and protecting the containment vessel for the fuel bundle(s) are shown in the engineering drawing provided in Appendix 1A as well as the internal structures for supporting the fuel bundles within the containment vessel. The external shell is supported by "L" shaped steel flanges, 1/4 inch thick, welded transversely to each half of the shell.

2.1.2 Design Criteria

The design test results described in Appendix 2B support the structural requirements specified in 10CFR71.

2.2 Weights and Centers of Gravity

The Model No. 927A1 container weighs approximately 6,700 lbs. when loaded. The bundles weigh approximately 1,400 lbs. each with the container weighing approximately 3,900 lbs.

The Model No. 927C1 container weighs approximately 7,300 lbs. when loaded. The bundles weigh approximately 1,500 lbs. each with the container weighing approximately 4,300 lbs.

The containers are approximately symmetrical; the center of gravity being at the center of the container. When the bundles are in the container, the center of gravity shifts vertically to a lower point because the bundles are vertically positioned below the center of the container.

2.3 Mechanical Properties of Materials

The container is fabricated of carbon steel.

2.4 General Standards for All Packaging

2.4.1 Chemical and Galvanic Reactions

There are no significant chemical, galvanic or other reactions among the packaging components or between the packaging components and the package contents. The shipping container is fabricated of carbon steel and the contents are zircaloy-clad unirradiated fuel assemblies wrapped in polyethylene, if required.

2.4.2 Positive Closure

The shipping container is equipped with positive closure bolts which prevent inadvertent opening.

2.4.3 Lifting Devices

There are four lifting eyes on the lid which are used to lift the loaded container. Each of the lifting eyes is capable of lifting the loaded package. This was shown by lifting the loaded container free of the floor by each of its lifting eyes and holding to illustrate no yielding in the lifting eyes.

It is necessary to demonstrate that the lifting devices are capable of supporting three times the weight of the loaded package without generating stress in any material of the container in excess of its yield strength because no more than one loaded package will be lifted at one time. This is assured because the containers shall be transported in an exclusive use vehicle with a specific restriction for sole use to be provided in the special arrangements. The special arrangements also include procedures for unloading the shipping containers one at a time. This will provide adequate administrative control to assure that lifting devices will never have to support more than the weight of one loaded container. The lifting eyes will not have to support any compressive load, because loads placed on top of the shipping container will be supported by the stacking brackets.

2.4.4 Tiedown Devices

There is no system of tiedown devices which is a structural part of the container. The container is secured to the truck bed by a cinch cable, chain or nylon strap that is passed over the container and fastened to the truck bed. In addition, the containers on the truck bed are shored with wood blocks.

This package will be transported in an exclusive use vehicle with a specific restriction for sole use to be provided in the special arrangements. Combustion Engineering will supervise the loading of the vehicle to assure that the containers are fastened to the truck as described above. This will provide adequate administrative control to assure that no structural part of the container is used as a tiedown device.

2.5 Standards for Type B and Large Quantity Packaging

N/A (Type A quantity per package).

2.6 Normal Conditions of Transport

The ability of the container to withstand conditions likely to occur in normal transport were assessed by subjecting the shipping container to the tests and assessments described in this application (see References 6 and 7 of Appendix 2B).

2.6.1 & 2.6.2 Heat and Cold

The heat and cold requirements are not applicable. Any pressure rise in the container above 8.5 psi gauge will be released by the automatic pressure relief valve.

Materials of all structural components used in the manufacture of the container have physical and mechanical properties equivalent to or better than mild steel throughout a temperature range of -40° to 1500° F.

2.6.3 Pressure

Pressure rise in the container in excess of 8.5 psi gauge will be released by the automatic pressure relief valve. The manual pressure relief valve is used for venting a pressure build-up of less than 8.5 psi gauge. It should be noted that the container is not pressurized for normal use.

2.6.4 Vibration

Vibration normally incident to transport was experienced by conducting a normal shipping test with a simulated fuel bundle inside the container. No damage was incurred.

2.6.5 Water Spray

The water spray test is not applicable since the container is safe from a criticality safety standpoint for all degrees of internal and external water moderation and reflection.

2.6.6 Free Drop

The free drop test was performed in accordance with the requirements of 10CFR71 and no significant damage occurred to the container or its contents.

2.6.7 Corner Drop

The corner drop was performed in accordance with the requirements of 10CFR71 and no significant damage to the container or its contents occurred.

2.6.8 Penetration

The penetration test was not performed because it is not credible that this test can result in the puncture of the shell and the puncture of the zirconium clad fuel rods to release radioactive material.

2.6.9 Compression

The requirement that the container support, in compression, five times its loaded weight without yielding is not applicable because the container is not loaded more than two high. The package will be transported in an exclusive use vehicle. Combustion Engineering will supervise the loading of the vehicle to assure that the containers are loaded only two high.

2.7 Hypothetical Accident Conditions

This package was subjected to the hypothetical accident conditions as specified in 10CFR71.

2.7.1 Free Drop

For the Free Drop Analysis see Appendix 2B. It is concluded that the container satisfies the test requirements by retaining the two fuel bundles within the strongback with complete separation of the two bundles.

2.7.2 Puncture (Pinnacle Test)

The container was subjected to the pinnacle test in accordance with 10CFR71. The container was allowed to drop freely onto a steel cylinder, 6 inches in diameter by 8 inches high, from a height of 42 inches. This distance is measured from the bottom of the shell to the top of the steel cylinder. The point of impact was approximately midway between the edge of the aft fork lift guide and the edge of the aft container skid.

The external birdcage structure of the container sustained no damage as a result of this test. Examination of the inside of the container indicated no damage to the simulated damage to the suspension frame.

2.7.3 Thermal

Materials of all structural components used in the manufacture of the container have physical and mechanical properties equivalent to or better than mild steel throughout a temperature range of -40° to 1500° F.

2.7.4 Water Immersion

The package is so designed and constructed, and its contents are so limited that it would be subcritical if it is assumed that water leaks into the containment vessel. A 3 high doubly infinite array, fully reflected on top and bottom, was analyzed and had a Keff of 0.9202 ± 0.0075 (see Chapter 6). Since the criticality safety analysis results in a criticality safe condition, the water immersion test was not performed.

2.7.5 Summary of Damage

It is concluded that the container satisfies the test requirements by retaining the two fuel bundles within the strongback and the separator blocks remain in place and continue to completely separate the two fuel assemblies. The strongback with the fuel assemblies in place were contained within the package structure.

2.8 Special Form

N/A (All radioactive material in the packages is in normal form).

2.9 Fuel Rods

The Model Nos. 927A1 and 927C1 containers will be used for unirradiated fuel rods only which are part of an overall fuel assembly. For both normal and accident conditions, the dummy fuel assemblies were not affected during testing. This, coupled with the fact that these are unirradiated fuel rods designed to withstand the environment of a reactor core, assure cladding integrity.

Appendix 2A Comparison of Closure Bolts

Either or any of the following bolts may be used in container closure.

Bolt-Special (SAE C-1010) - The bolt has a minimum tensile strength of 60 KPSI and a minimum core hardness (Rockwell B) of 70.

Round Head Square Neck Bolt (A307) - The bolt is constructed in accordance with specification A307, with a minimum tensile strength of 70 KPSI and a minimum core hardness (Rockwell B) of 69 assured by the vendor.

Shipping Container Stud (A1S1-4140) - The bolt is constructed in accordance with specification A1A1-4140 in the heat treated condition.

(See Applied Design Drawing #98425 (Fig. 2A-1) and Combustion Engineering Drawings #Y0885 and NFM-B-4364 (Figures 2A-2 and 2A-3, respectively).

FIGURE 2A-1

Bolt - Special

FIGURE WITHHELD UNDER 10 CFR 2.390

July 9, 1996 Rev. 0 PAGE 2A-2

FIGURE 2A-2

Round Head Square Neck Bolt

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE 2A-3

Shipping Container Stud

FIGURE WITHHELD UNDER 10 CFR 2.390

July 9, 1996 Rev. 0 PAGE 2A-4

Appendix 2B STRUCTURAL QUALIFICATION OF MODEL NOS. 927A1 AND 927C1 SHIPPING CONTAINERS FOR THIRTY FOOT DROPS

The discussions which follow describe the testing performed and/or structural analyses conducted pursuant to the requirements of 10 CFR 71.

2B-1. INTRODUCTION

The purpose of this appendix is to demonstrate that if subjected to a 30 ft. free drop in any orientation, the Model Nos. 927A1 and 927C1 shipping containers:

(a) maintain a six inch separation between the two fuel assemblies within the container,

(b) provide a spacing between the fuel assemblies and the shipping container wall of at least 5.0 inches above the fuel and 2.25 inches to the side of the fuel, and

(c) limit the movement of the fuel assemblies so that they extend above the separator block by a maximum of 1.5 inches.

The demonstration is based upon a combination of existing test data on essentially identical shipping containers and structural analyses of critical container parts. Modifications of the containers which provide added strength and margin are presented and evaluated. Test results are used to demonstrate structural integrity of the containers and to identify the most severe drop orientations to be considered in the analyses. The evaluation of the shipping containers for the 30 ft. drops is done in accordance with 10CFR71.73 (Reference 1).

2B-2. TEST RESULTS

The 30 ft. drop tests performed on shipping containers identical to Model Nos. 927A1 and 927C1 are presented in References 6 and 7. Between the two series of tests, five different drop orientations were tested.

Reference 6 documents the results of two full scale 30 ft. drop tests. The first drop was made with the longitudinal axis of the container at an angle of 30° to the horizontal. The second drop, a side drop, was made with the container oriented such that the left side closure flange struck the impact surface along its entire length. After each drop, the container and its contents were inspected. The most significant deformation resulting from the 30° angle drop was in the exterior skid brackets and very little relative motion of the fuel assemblies within the strongback was noted. The side drop resulted in a sideways shifting of the fuel assemblies within the strongback. The hold down bracket spanner angles, spanning the strongback, remained in position following the side drop test.

The container tested was identical to Model No. 927A1 except for the method of separating fuel assemblies within the strongback. The boral plate used in the tested container has been replaced by segmented separator blocks which form a continuous barrier between the assemblies. The separator blocks are rectangular carbon steel tubes, 3/16" thick, 6" wide, and 8" high.

The weight and weight per inch of the fuel assembly tested in Reference 6 was approximately 1400 lbs. and 8.8 lbs./in., respectively. The Model No. 927A1 container is used to ship fuel assemblies weighing not more than 1400 lbs. and 8.8 lbs./in.

The Model No. 927C1 container is structurally identical to Model No. 927A1 except for its additional length. The 927C1 container's longer strongback is supported by a larger number of supports, such that the weight per support is approximately equal for both the Model Nos. 927A1 and 927C1 containers. The Model No. 927C1 container is used to ship fuel assemblies weighing not more than 1506 lbs. and 9.1 lbs./in.

Reference 7 documents the results of three full scale 30 ft. drop tests. The first drop, a cover or top drop, was made with the cover side down and the container's longitudinal axis horizontal. The second drop, an axial drop, was made with the container's longitudinal axis vertical. The third drop was made with the container's longitudinal axis at 75° from the horizontal.

The original test plan called for the same container to be used for all three tests. However, assessment of the damage to the container after the cover drop test resulted in using a different container for the remaining two tests. Interior examination of the container after the cover drop test indicated that the strongback remained totally inside the container and that the fuel assemblies remained totally inside the strongback, thereby maintaining fuel assembly separation. Inspections of the container after the axial and 75° drop tests indicated interior damage was less severe than the damage due to the cover drop test. In all cases, separation between the fuel assemblies was maintained.

The full scale tests documented in Reference 7 employed the Applied Design Company Model 51032-1 shipping container. The Model 51032-1 is essentially identical to the Model No. 927C1 container. Design details of Model 51032-1 are presented in Reference 2. All the major structural support components of Model 51032-1 are identical to the Model No. 927C1 container.

The two simulated fuel assemblies used in the Reference 7 drop tests weighed 1,653 lbs. each and had a weight per inch of approximately 9.2 lbs/in. The maximum fuel assembly weight to be shipped in the Model No. 927C1 container is 1506 lbs. each and 9.1 lbs/in. The 927A1 container will be used to ship fuel assemblies weighing not more than 1,400 lbs. each.

Reference 7 describes one modification to the shipping container standard hardware for the cover drop test. In addition to the nine standard fuel assembly hold down brackets, eight additional brackets were installed across the strongback. The additional brackets were clamped across the edges of the strongback to act as safety brackets in the event the standard hold down brackets became loose. Since the results of the cover drop test indicated almost all the brackets, both the standard and safety brackets, bowed outward (away from the strongback base), the safety brackets were required to maintain the fuel assemblies within the strongback.

The following conclusions are based on the five full scale 30 ft. drop tests documented in References 6 and 7:

1. The Model Nos. 927A1 and 927C1 shipping containers' internal structure sustain the most damage as a result of striking a horizontal surface in a horizontal position: on its side (Reference 6) or on its cover (Reference 7).

2. Since the side drop tests did not contain the current segmented separator blocks, additional analyses are required to demonstrate

the separator block's capability of maintaining fuel assembly preparation as a result of a side drop.

3. The standard hold down bracket spanner angles remained intact as a result of the 30 ft. side drop.

4. Safety brackets are required to ensure fuel assembly separation during a cover drop. The brackets must be stronger than those used in the cover drop test to prevent permanent outward bowing.

5. Fuel assembly separation is maintained as a result of vertical and skewed 30 ft. drops.

2B-3. THIRTY FOOT COVER DROP

The purpose of this section is to demonstrate the capability of the Model Nos. 927A1 and 927C1 shipping containers to maintain a six inch separation between fuel assemblies within the shipping container, a 5.0 inch separation between the fuel assemblies and the container wall and to limit fuel assembly movement above the separator blocks to 1.5 inches as a result of a 30 ft. horizontal cover drop.

2B-3.1 Evaluation of Thirty Foot Cover Drop Testing

The cover drop tests described in Section 2.0 demonstrated that both hold down and safety brackets are required to maintain the fuel assemblies within the strongback and thereby assure 6" separation of the fuel assemblies.

The hold down brackets (see Figure 2B-1) used in the Model Nos. 927A1 and 927C1 containers have a 2" x 1 ½" x 1/4" angle spanning the strongback and clamped to the strongback with 5/8" bolts. The spanner angle and clamping design and hardware are identical to the brackets used on all tested shipping containers. The safety brackets (see Figure 2B-2) are significantly stronger than the safety brackets used in the top drop test. The safety bracket has a 2" x 2" x 29.75" long square steel tube spanning the strongback reinforced with a 3" x 1" x 23.87" long rectangular steel tube welded to the bottom. It is clamped to the strongback using the same design and hardware as the hold down bracket. This safety bracket has a section modulus 8.3 times as large as the spanner angles used in the top drop test.

The tested container had a total of 17 brackets and a simulated fuel assembly weight of 1,653 lbs per fuel assembly. The weight per bracket per assembly was therefore 97.2 lbs. The number of hold down and safety brackets used in the Model Nos. 927A1 and 927C1 shipping containers as given in Table 2B-1 results in a maximum weight per bracket per assembly of 84 lbs. Since the drop height, container material, geometry, and strongback supporting structure of the Applied Design 51032-1 container (see Reference 2) and the Model Nos. 927A1 and 927C1 containers are essentially identical, the dynamic application load factors due to impact will be approximately the same. Therefore, the 30-foot top drop test demonstrates that the hold down and safety brackets in the Model Nos. 927A1 and 927C1 shipping containers will keep the fuel assemblies within the strongback.

The 30 ft. cover drop test described in Reference 7 used a simulated fuel assembly which did not contain individual fuel rods. Actual fuel assemblies containing fuel rods impart a smaller dynamic load to the brackets than does an equally weighted simulated fuel assembly. Actual fuel assemblies dissipate energy via relative motion between rods and spacer grids, spacer grid deformation, and fuel rod deformation. Therefore, determining the maximum spacing between brackets from the Reference 7 test results is conservative and assures a minimum six inch separation between fuel assemblies in Model Nos. 927A1 and 927C1 shipping containers following a 30 ft. cover drop.

2B-3.2 Fuel Assembly Exposure Above the Separator Blocks

As shown in the cover drop test, the hold down and safety brackets keep the fuel assemblies within the strongback. However, for 5.0 wt % enriched fuel, there is an additional requirement imposed on the brackets. They must limit fuel assembly motion so that the assembly extends above the separator block by no more than 1.5 inches.

During a 30 ft. cover drop the fuel assemblies press first against the adjustable grid supports on the hold down brackets. These brackets will push up until the bolts bottom out in the slots and the fuel assemblies also contact the safety brackets. In this position each fuel assembly extends 1.25 inches beyond the separator block (see Figure 2B-3). The hold down and safety brackets are designed and positioned to prevent additional exposure of the fuel assemblies.

Table 2B-1 lists specific fuel assemblies and the number of hold down and safety brackets required independent of shipment in a Model Nos. 927A1 or 927C1 shipping container. The number of brackets varies with the number of spacer grids and the fuel assembly weight. Figure 2B-4 shows the bracket pattern for several fuel assembly types.

The maximum impact force applied by the fuel assemblies to the hold down bracket spanner angles and safety brackets was determined based on an evaluation of the damage done to the shipping containers during the drop tests, a review of fuel assembly spacer grid impact testing conducted by Combustion Engineering, and an estimate of the relative impact velocity between the fuel assemblies and brackets.

When a shipping container is subjected to a 30-foot drop onto a rigid surface the loads applied by the fuel to its supports are limited by energy storage and dissipation mechanisms. The outer shell including the stiffening ribs permanently deform, the shock mounts deflect, many of the bolts holding the strongback to the strongback cross beams break, the fuel assemblies deform and the individual fuel rods vibrate. References 6 and 7 document five 30-foot drop tests which show only limited damage to the containers and their contents. In the two drop tests conducted by Combustion Engineering, one of the simulated fuel assemblies was of tubular construction to closely approximate an actual fuel assembly. The pictures taken after the side drop test show little damage to this simulated assembly.

Combustion Engineering has conducted extensive impact testing of fuel assemblies to determine the strength of the fuel assembly spacer grids. These test are documented in Reference 3. In these tests, a fuel assembly section with a centrally located spacer grid was repeatedly dropped onto an anvil from progressively higher elevations. The tests show that the spacer grids deform plastically once their limit load is reached. A maximum impact load "g" factor was determined from this data by dividing the maximum impact force by the weight of the fuel assembly section. The maximum impact load was conservatively based on test data for Combustion Engineering's strongest spacer grid. A maximum impact force "g" factor of 66.7 was calculated and used in the structural analysis of the hold down and safety brackets.

The limitation in the fuel assembly section drop test data is that the maximum impact velocity was significantly less than the 527 in/sec velocity at impact of the shipping container in a 30-foot drop. However, the impact velocity of the fuel assemblies against the hold down brackets and safety brackets will be much lower than 527 in/sec due to the various energy dissipation mechanisms listed previously. A shipping container handling accident which occurred at Combustion Engineering on January 12, 1988 and was documented in Reference 4 was used to estimate the maximum relative velocity between the fuel assemblies and the strongback. In this accident, a fully loaded shipping container slid off the tines of a fork lift truck and fell about 2.5 feet, landing on its side in a paved parking lot. The damage to the container both internal and external was negligible. The hold down brackets for the upper assembly shifted but there were no sheared bolts. The fuel assemblies were carefully inspected. The only damage to the lower assembly was a slight loosening of some of the fuel rods. In the upper assembly there was slight distortion of some of the spacer grids and looseness of some of the fuel rods. The fuel rods were not damaged.

The force applied to the hold down brackets by the upper fuel assembly was estimated from this accident. The hold down brackets shifted but not enough to bottom the bolts out in their slots. An upper bound on the force necessary to shift each bracket was calculated based on tightening the hold down bracket bolts to 90% of their yield stress. Based on the fuel assembly section drop tests, this impact force required an impact velocity of about 15 in/sec. This value is approximately one-tenth of the impact velocity of the shipping container which was about 150 in/sec.

The handling accident makes it clear that the effective impact velocity of the fuel assemblies is much less than that of the shipping container. Therefore, using the fuel assembly section drop test data to determine the impact force on the hold down and safety brackets is appropriate.

The bracket material is mild carbon steel. Reference 5 provides a plot of the dynamic yield stress of mild steel as a function of the strain rate. The fuel assembly dynamic impact tests found that the duration of impact was typically 5 - 10 msec. Thus, the strain rate for a fuel assembly impact is on the order of 100 $sec.^{-1}$ For this strain rate, the yield stress of mild steel will exceed 60,000 psi. A yield stress of 60,000 psi was used in the analysis.

The structural analysis of the holddown bracket spanner angles and safety bracket is outlined below. The bending stress in both brackets was calculated based on pinned support end conditions. Pinned end conditions are appropriate because the brackets are clamped to flanges on each side of the strongback. Based on an evaluation of test data from the top drop test (Reference 7) these flanges do not provide a significant moment restraint. The holddown bracket angles reach the yield stress of 60,000 psi in the outer fiber due to an applied load of 1,202 lbs from each fuel assembly as shown in Figure 2B-2. The load for the safety brackets was determined by assuming that 1,202 lbs is the maximum load carried by each spanner angle and that the remaining load is carried by the safety brackets. Since the number of spanner angles and safety brackets varies depending on the type of fuel assembly, the load per safety bracket was calculated for each case using the following formula:

$$F = \frac{(66.7)(W_F) - (N_H)(1{,}202\ \text{lbs})}{N_S}$$

where:

F = Load per safety bracket per fuel assembly

66.7 = Impact force "g" factor

W_F = Weight of fuel assembly

N_H = Number of holddown spanner angles

N_S = Number of safety brackets

Table 2B-1 provides a list of the number of brackets used for each type of fuel assembly. The maximum load per safety bracket per fuel assembly was found to be 8,477 lbs using the above equation. A value of 8,500 lbs was actually used in the analysis of the safety brackets. The bending stress in the safety brackets was calculated at three cross sections along the safety bracket as shown in Figure 2B-6. In calculating the stress at Section A-A, the section was assumed to be a channel rather than a square tube to account in a conservative manner for the 1.5 inch diameter hole drill through the upper wall of the tube over the bolt. Also, the reinforcing plate under the head of the bolt was not considered in calculating the bending stress at this section. The maximum bending stress at each cross section is given in Figure 2B-6. Since the maximum bending stress was found to be less than the yield stress, the safety brackets will remain elastic during a 30 foot top drop and do not bow outward permanently.

The safety bracket is constructed of two rectangular tubes welded together. The weld stresses were calculated and found to be acceptable. A cross-sectional view of the safety bracket is shown in Figure 2B-7. Figure 2B-8 shows the load distribution on the safety bracket and the resulting shear diagram. In this figure and in the analysis, the thickness of the rubber (1/8 inch) on each side of the separator block was neglected. This is a conservative assumption because it results in the applied loading being located closer to the center of the safety bracket.

The horizontal shear force per inch along the length of the weld between the two tubes is given by the formula:

$v = VQ/I$ (Reference 8)

where: v = horizontal shear per inch

V = shear force

Q = area moment of the upper tube about the C.G. of the combined section

$$= (0.7959\ in^2)(1\ in + 0.1239\ in) = 0.8945\ in^3$$

$$I = \text{moment of inertia of combined section} = 3.343\ in^4$$

The maximum horizontal shear per inch is:

$$v = (8500\ lbs)(0.8945\ in^3)/(3.343\ in^4) = 2274\ lbs/in$$

The total horizontal shear on the weld is therefore:

$$R = (2)[(0.785\ in)(2274\ lbs/in) + (0.5)(2274\ lbs/in)(8.15\ in)]$$

$$= 22100\ lbs$$

The two rectangular tubes are held together with 12 inches of 1/8 inch fillet weld on each side and 1 inch of 1/16 inch fillet weld at each end of the lower tube.

The allowable shear load on the weld is given by the following equation:

$$A_W = T_W LW / \sqrt{2} \qquad \text{(Reference 8)}$$

where: T_W = allowable weld shear stress = 13,600 psi

L = length of weld

W = weld size

$$A_W = (13{,}600\ psi)[(24\ in)(0.125) + (2\ in)(0.0625\ in)] / \sqrt{2}$$

$$= 30{,}050\ lbs$$

The allowable load for the base metal is given by the following equation:

$$A_b = (0.5)(\sigma_y)(L)(t) \qquad \text{(Reference 9)}$$

where: σ_y = yield stress of steel tubing = 30,000 psi

L = length of weld = 24 in

t = thickness of lower tube = 0.083 in

$$A_b = (0.5)(30{,}000\ psi)(24\ in)(0.083\ in)$$

$$= 29{,}880\ lbs$$

The margin of safety for the safety bracket is therefore:

$$29880/22100 = 1.35$$

These calculations are conservative because a dynamic load condition has been analyzed using allowable stresses for a static load case. The allowable stresses could be increased significantly to account for the high strain rate with which the loading would actually be applied to the safety bracket.

The top safety bracket extensions were also checked to ensure that they will not crush during the impact. The compressive stress in the side walls of the tubing was found to be 6,300 psi. The buckling load for the side walls was also calculated and found to be 1.5 times the applied load. These analyses demonstrate that the fuel assemblies cannot rise above the separator block by more than 1.25 inches.

The independent brackets provide very little restraint to the fuel assemblies during a top drop and were not considered in this analysis. As shown in Figure 2B-4, hold down and safety brackets are uniformly spaced along the fuel assemblies with one or two additional safety brackets adjacent to the independent bracket to ensure a uniform loading of the brackets in a top drop. Changes in the independent bracket design will not affect the validity of this analysis.

2B-3.3 Spacing Between Fuel Assemblies and Container Wall

Following a 30 ft. cover drop the fuel assemblies would be in the upmost position with respect to the hold down and safety brackets as shown in Figure 2B-9. The spacing between the fuel assemblies and the shipping container inner surface, assuming that the shipping container shell is flattened, is the thickness of the safety brackets (5 inches).

Table 2B-1

BRACKETS REQUIRED
FOR FUEL ASSEMBLY SHIPMENTS

Fuel Assembly Type	Standard Hold Down Brackets*	Safety Brackets*
17 x 17 (1506 lbs)	6	12
16 x 16 Full Length (1500 lbs)	9	11
16 x 16 Short Length (1400 lbs)	8	10
14 x 14 (1300 lbs)	7	10
14 x 14 (1270 lbs)	7	9
Other (800 lbs)	4	6

* The hold down brackets are placed at every spacer grid except at the independent bracket location. Safety brackets are distributed as evenly as possible along the length of the fuel assembly except at the independent bracket. Three or four safety brackets are used between the hold down brackets on either side of the independent bracket as shown in Figure 2B-4.

2B-4. THIRTY FOOT SIDE DROP

The purpose of this section is to show that the Model Nos. 927A1 and 927C1 shipping containers maintain a six inch separation between fuel assemblies within the shipping container, at least a 2.25 inch separation between the fuel assemblies and the container wall and that the movement of the fuel assemblies above the separator block is not greater than 1.5 inches as a result of a 30 ft. horizontal side drop.

The only major difference between the container used in the side drop test and the current Model Nos. 927A1 and 927C1 containers is the method of separating the fuel assemblies. The boral plate in the original container has been replaced by segmented carbon steel separator blocks, welded to the strongback, which form a continuous barrier between the fuel assemblies (see Figure 2B-10). A structural analysis of the separator blocks was performed to ensure that they maintain a six inch separation between the fuel assemblies within the container following a 30 ft. side drop.

2B-4.1 Analysis of Separator Block Assembly

If a container drops 30 ft. in the side orientation, the impact will cause the upper fuel assembly to dynamically load the hold down brackets first and then the separator blocks.

The separator blocks were analyzed using elastic-plastic finite element models. The analyses were performed using the CEMARC computer code, a Combustion Engineering proprietary version of the MARC code which is in the public domain. A maximum impact load "g" factor of 66.7 and a yield stress of 60,000 psi, as discussed in Section 2B3.2, were used in the separator block analyses.

Two analyses of the separator blocks were performed. The models used are shown in Figure 2B-11. In the first analysis, the welded connection between the separator block and the strongback were represented by restraining the motion of nodes 6 and 7 in the X and Y directions. Node 4 was restrained since the strongback prevents this node from deflecting in the negative X direction. A nonlinear boundary condition was applied at node 23 to account for the 0.6 inch gap between the separator block and the lower hold down bracket. In the analysis, the separator block deflected until node 23 contacted the hold down bracket. The maximum von Mises stress intensity reached 60,000 psi so plastic deformation of the block occurred. The minimum width of the block due to permanent deflection was found to be 5.9 inches. Including the thickness of the rubber on each side of the block its minimum width was 6.1 inches. Under the maximum impact load, the blocks provided a minimum of 6 inch separation between the two fuel assemblies.

In the second analysis, the welds were assumed to have failed causing the separator block to drop down against the lower hold down bracket and fuel assembly. Since this will cause the block to be at an angle to the strongback, it was restrained in the Y direction at nodes 7 and 21 due to contact with the lower fuel assembly and lower hold down bracket respectively. Node 6 was restrained in the X direction because of contact with the strongback. Note that the hold down brackets and safety brackets will keep the separator blocks within the strongback and between the fuel assemblies even if the welds fail. In this analysis, the maximum permanent deflection at the center of the block was 0.02 inches. Clearly the separator blocks provided more than a 6 inch separation between the two fuel assemblies under the maximum impact load.

The analysis of the separator block assembly included an evaluation for buckling. The CEMARC finite element code solutions for the separator block assembly were stable and convergent. Buckling was checked by comparing the maximum load in beam elements 12 through 17 in Figure 2B-11 to the Euler buckling load for this section of the separator block. The maximum compressive load in these beam elements was 350 lbs/in along the length of the separator block. The Euler buckling load for a unit length of separator block is given by the following equation:

$$P_{cr} = \frac{n\pi^2 EI}{L^2}$$

where:

$$n = 1$$

$$E = 30 \times 10^6 \text{ lbs/in}^2$$

$$I = \frac{(3/16 \text{ in})^3}{12} = 0.00055 \text{ in}^4$$

$$L = 6 \text{ in}$$

$$P_{cr} = 4524 \text{ lbs/in}$$

The margin of safety against buckling is 12.9 (4524/350). Clearly the separator block will not buckle.

2B-4.2 Fuel Assembly Exposure Above or Below the Separator Blocks

In the event of a 30 ft. side drop the fuel assemblies and the separator blocks may move relative to one another. The maximum fuel assembly extension beyond the separator block, as shown by the dimensions given in Figure 2B-3 is 1.25 inches.

2B-4.3 Minimum Spacing Between Fuel Assemblies and Container Wall

In the five 30 ft. drop tests described in References 6 and 7, the fuel assemblies remained in the strongback within the shipping container. In the 30 ft. side drop test the hold down bracket spanner angles remained bolted across the top of the strongback. In all the drop tests the angle brackets welded to the sides of the strongback, used to fasten the strongback to the container, remained in position. These angle brackets extend out from the strongback either 2 or 3 inches depending on the design. One design is shown in Figure 2B-12. If the bolts holding the strongback fail during a side drop, the strongback could come to rest in the position shown in Figure 2B-13. The angle brackets and hold down brackets will hold the strongback away from the container wall a minimum of 2 inches. Including the thickness of the strongback, the minimum separation of a fuel assembly from a flattened container wall will be 2.25 or 3.25 inches at the bottom of the strongback and 2.375 inches at the top.

2B-5. CONCLUSIONS

Tests documented in References 6 and 7 confirm that the worst orientation for the 30 ft. drops occur during a cover drop or a side drop.

The addition of safety brackets across the strongback results in the Model Nos. 927A1 and 927C1 containers having effective strengths which exceed the strength of the container successfully tested in the Reference 7 cover drop tests.

Side drop tests documented in Reference 6 confirm that the hold down brackets (without the presence of the additional safety brackets) remain in place across the strongback following a 30 ft. side drop.

Test results, analyses and geometric considerations have conservatively demonstrated that the Model Nos. 927A1 and 927C1 shipping containers maintain a six inch separation between fuel assemblies in the strongback, provide a spacing between the fuel assemblies and the shipping container wall of at least 5.0 inches above the fuel and 2.25 inches to the sides of the fuel and limit the motion of the fuel assemblies so that the maximum extension above the separator blocks is 1.5 inches following a 30 ft. free drop of a container in any orientation.

2B-6. REFERENCES

1. 10CFR71, "Packaging and Transportation of Radioactive Material," January 1, 1987 Edition, NRC.

2. "Application for Amendment to License No. SNM-1227 for Shipments of Nuclear Fuel Assemblies in Jersey Nuclear Company's Nuclear Fuel Assembly Packaging Model 51032-1, Jersey Nuclear Co., October, 1971.

3. TR-ESE-429, "HID-2 Production Spacer Grid Tests," April 8, 1981, TR-ESE-503, "HID-1B Production Spacer Grid Tests", January 17, 1983, and TR-ESE-425, "HID-1 Production Spacer Grid Tests", April 8, 1981.

4. Memo EJP/03/88, "Fuel Assembly Damage Report", E. J. Petras to G. H. Chalder, January 15, 1988.

5. S. R. Bodner and P. S. Symonds, "Experimental and Theoretical Investigation of the Plastic Deformation of Cantilever Beams Subjected to Impulsive Loading," Journal of Applied Mechanics, December, 1962.

6. Test Report No. 2312A, Qualification Test Procedure for the Applied Design Company Model 927A Metal Shipping and Storage Container for Combustion Engineering, Inc. Fuel Bundle Assembly. Test Report No. 2312B on the Applied Design Company Model 927A Metal Shipping and Storage Container for Combustion Engineering, Inc. Fuel Bundle Assembly.

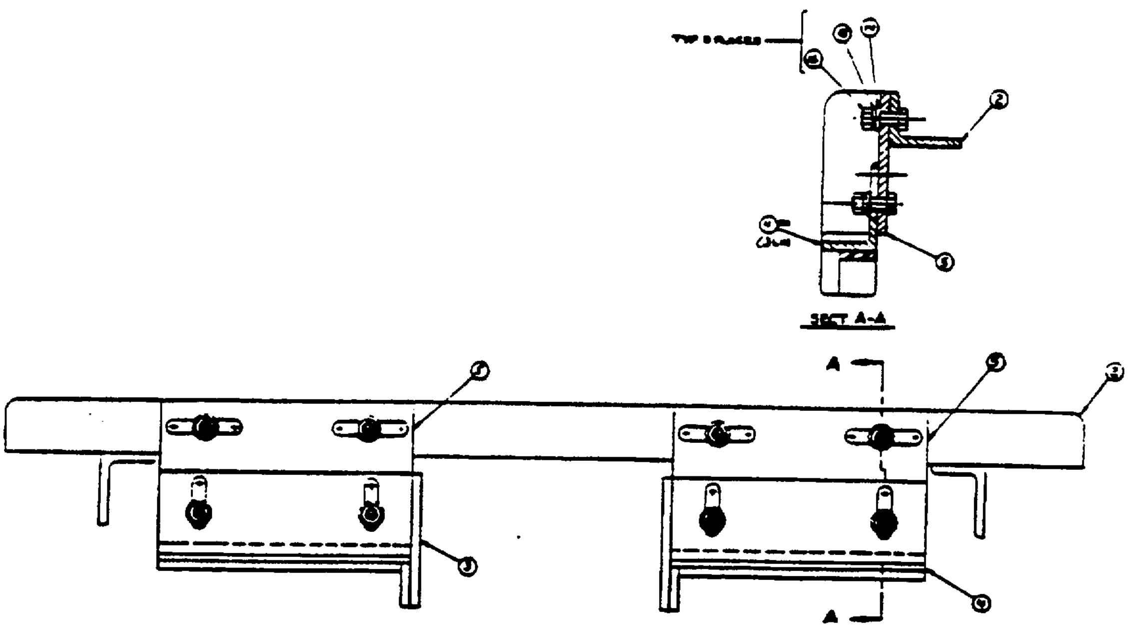
7. Jersey Nuclear Company, Inc. Shipping Container Model Number 51032-1 30 Foot Drop Test Report

8. E. C. Harris, Elements of Structural Engineering, Ronald Press Company, New York, 1954

9. J. E. Shigley, Mechanical Engineering Design, McGraw-Hill Book Company, New York, 1963

FIGURE 2B-1

Hold Down Bracket



BILL OF MATERIALS QUANTITIES ARE FOR ONE ASSY										
GROUP NO. & QUANTITY 6	5	4	3	2	1	ITEM NO.	NAME	PIECE NO.	MATERIAL	REMARKS
					X	1	BRACKET ASSY	NFM-E-23628-1		
				X	1	2	BRACKET ANGLE ASSY	-2		
			X		1	3	SUPPORT CLAMP ASSY L.H.	-3		
		X			1	4	SUPPORT CLAMP ASSY RH	-4		
	X				2	5	SIDE PLATE ASSY	-5		
				1		6	ANGLE-LONG	-6	NOTE 1	1.5x2x.25x29.75
				2		7	ANGLE-SHORT	-7	NOTE 1	1.5x2x.25x1.5 LONG
	2			4		8	BOLT-HEX HEAD	-8	NOTE 3	.375-16 UNC x 1.25 LG
		1	1			9	ANGLE	-9	NOTE 1	1.5x2.5x.19x7 LONG
		1	1			10	STOP PLATE	-10	NOTE 2	.25x1.5x4.5
		1	1			11	END CUSHION	-11	BUNA N 60 DUROM.	.25x1"x2
		1	1			12	TOP CUSHION	-12	BUNA N 60 DUROM.	.25x1"x6.75
	1					13	SIDE PLATE	-13	NOTE 2	.25x4x7
					8	14	PLAIN WASHER	-14	ZINC PLATED STEEL	SAE .375 Ø
					8	15	LOCK WASHER	-15	ZINC PLATED STEEL	.375 Ø REGULAR SIZE
					8	16	HEX NUT	-16	ZINC PLATED STEEL	.375-16 UNC

FIGURE 2B-2

Safety Bracket

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE 2B-3

Arrangement Of Fuel Assemblies In Strongback

FIGURE WITHHELD UNDER 10 CFR 2.390

July 9, 1996 Rev. 0 PAGE 2B-21

FIGURE 2B-4

Bracket Locations

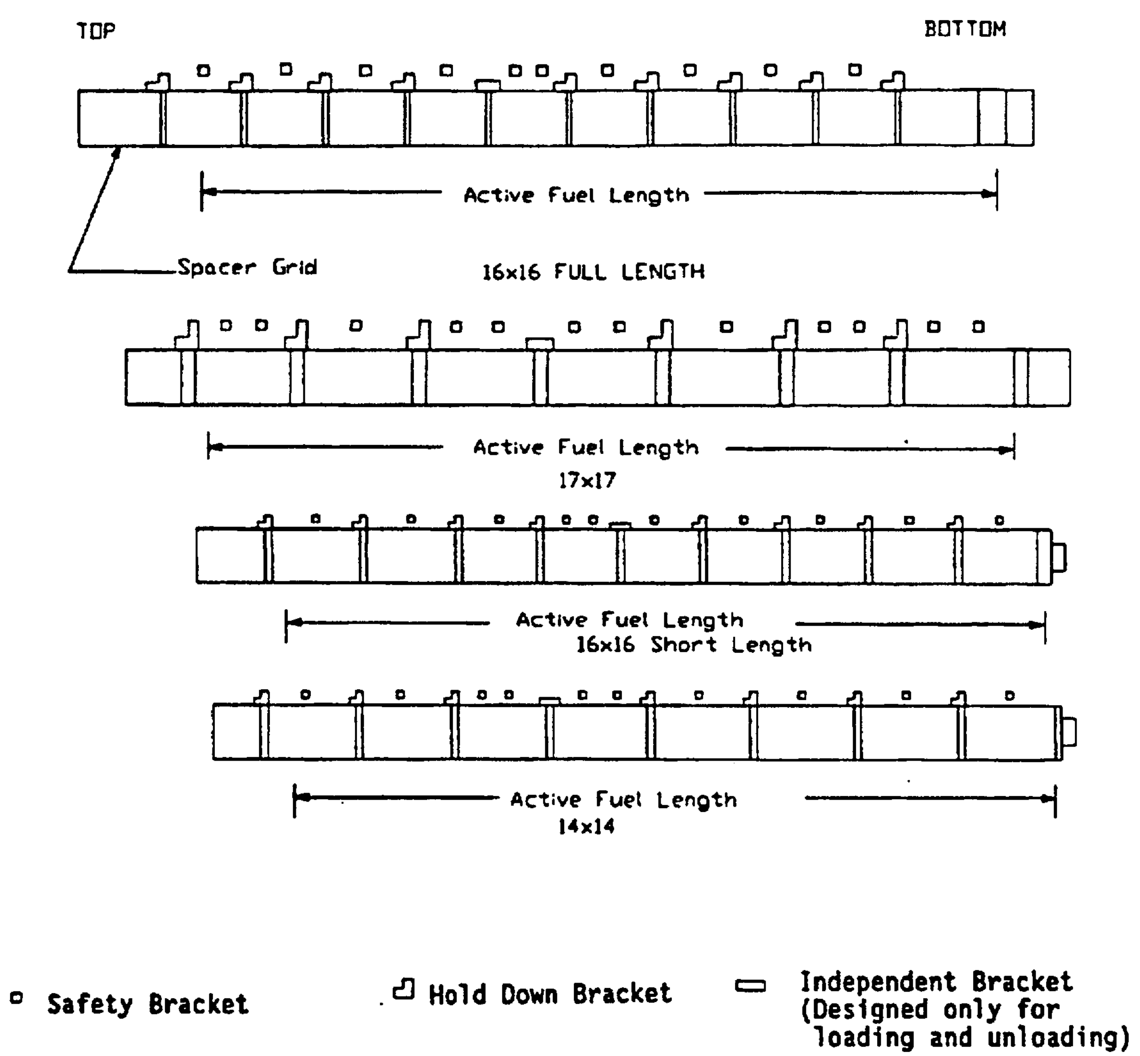


FIGURE 2B-5

Hoiddown Bracket Spanner Angle

FIGURE WITHHELD UNDER 10 CFR 2.390

July 9, 1996 Rev. 0 PAGE 213-23

FIGURE 2B-6

Safety Bracket

FIGURE WITHHELD UNDER 10 CFR 2.390

July 9, 1996 Rev. 0 PAGE 2B-24

FIGURE 2B-7

Safety Bracket Cross-Sectional View

FIGURE WITHHELD UNDER 10 CFR 2.390

July 9, 1996 Rev. 0 PAGE 2B-25

FIGURE 2B-8

Safety Bracket Load Distribution And Shear Diagram

FIGURE WITHHELD UNDER 10 CFR 2.390

July 9, 1996 Rev: 0 PAGE 213-26

FIGURE 2B-9

Minimum Fuel Assembly Separation For The 30 Foot Cover Drop

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE 2B-10

Arrangement Of Separator Block, Safety Bracket And Hold Down Bracket

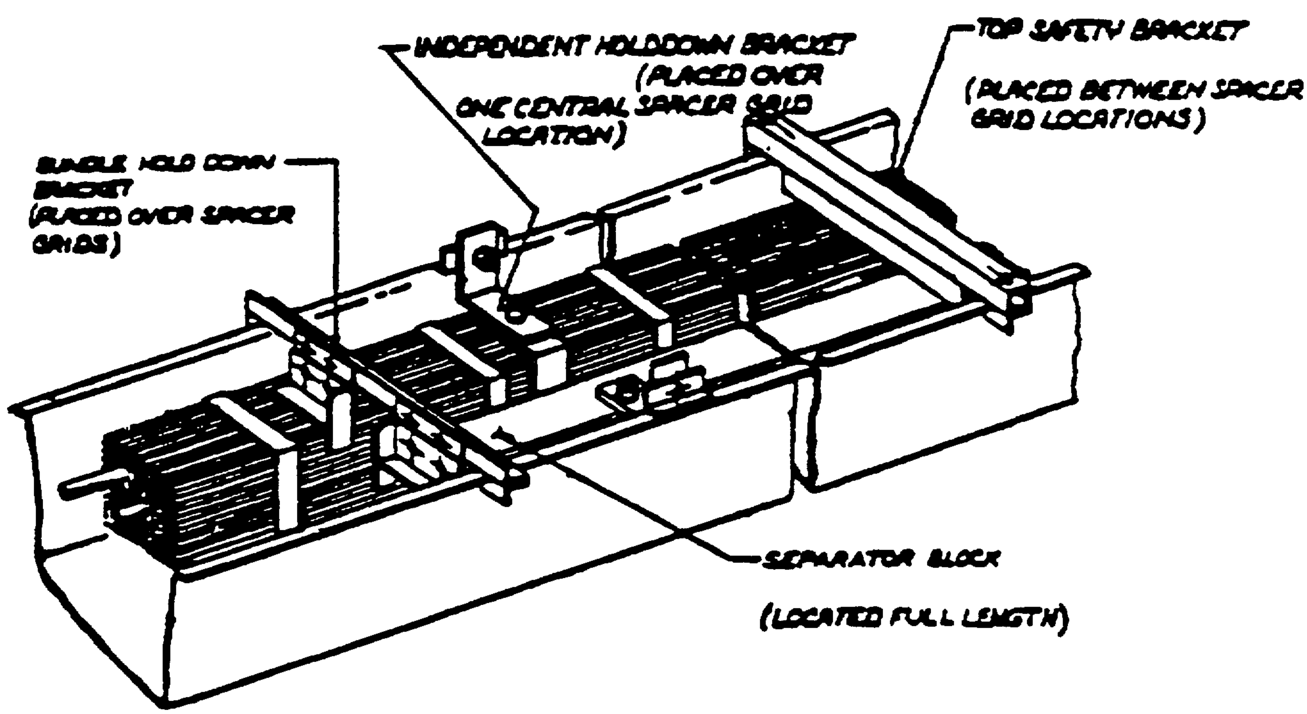


FIGURE 2B-11

Separator Block Finite Element Models

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE 2B-12

FIGURE WITHHELD UNDER 10 CFR 2.390

July 9, 1996 Rev. 0 PAGE 213-30

FIGURE 2B-13

Minimum Separation Between Fuel Assembly And Container Wall

FIGURE WITHHELD UNDER 10 CFR 2.390

July 9, 1996 Rev. 0 PAGE 213-31

3. THERMAL EVALUATION

Materials of structural components used in the manufacture of the container have physical and mechanical properties equivalent to or better than mild steel throughout a temperature range of -40° to 1500° F.

4. CONTAINMENT

4.1 Containment Boundary

The primary containment of the Model Nos. 927A1 and 927C1 packages is the 11 gauge steel shell. The unirradiated UO2 fuel pellets are placed within zircaloy tubes of approximately .025 inch thick walls. These fuel rods are then assembled into fuel assemblies.

4.1.1 Containment Vessel

The outer shell is composed of 11 gauge steel.

4.1.2 Containment Penetrations

There are a total of 5 penetrations into the primary containment. Of these, only 2 are presently needed. The remaining three are listed as optional and may be eliminated upon construction of any new containers.

4.1.3 Seals and Welds

All seals and welds are specified on the engineering drawing provided in Appendix 1A.

4.1.4 Closure

The "T" Head Special-Bolt is presently being used for closure of the containers. An approved alternate closure bolt is shown in Appendix 2A. The replacement bolt is equal to or greater than the "T" Head Special Bolt in mechanical properties. The bolts are interchangeable on a location basis.

4.2 Requirements for Normal Conditions of Transport

It is concluded that under normal conditions of transport, as specified in 10CFR71, the results described in Section 2.6 of this application indicate the following results:

1. There will be no release of radioactive material from the containment vessel.

2. The effectiveness of the packaging will not be reduced.

3. There will be no mixture of gases or vapors in the container which could, through any credible increase of pressure or an explosion, significantly reduce the effectiveness of the package.

4. The package is so designed and constructed, and its contents so limited, that under the normal conditions of transport specified in 10CFR71:

    a. The package will be subcritical,

    b. The geometric form of the package contents will not be substantially altered, and

    c. There will be no substantial reduction in the effectiveness of the packaging, including:

        1. Reduction by more than 5 per cent in the total effective volume of the packaging on which nuclear safety is assessed;

        2. Reduction by more than 5 per cent in the effective spacing on which nuclear safety is assessed, between the center of the containment vessel and the outer surface of the packaging, or;

        3. Occurrence of any aperture in the outer surface of the packaging large enough to permit the entry of a 4" cube.

4.3 Containment Requirements for the Hypothetical Accident Conditions

The effect on the loaded container of conditions likely to occur in an accident was assessed by subjecting a container with simulated fuel bundles to 30-foot free drop tests and puncture tests.

These tests demonstrated that no radioactive material would be released.

The thermal test was not performed because all structural materials in the shipping container and the fuel bundles can withstand 1475° F for thirty (30) minutes.

The water immersion test was not performed because full flooding was assumed in the nuclear safety calculations.

It is evident from the test and analysis that the package will be subcritical, because the two (2) fuel assemblies will remain in the same position with respect to each other.

5. SHIELDING EVALUATION

N/A (the packages are used for shipment of unirradiated UO2 fuel assemblies which have maximum external dose rates of 7.5 mr/hr penetrating radiation prior to loading into the containers).

6. CRITICALITY SAFETY EVALUATION

This chapter discusses the demonstration of compliance with the criticality safety requirements of 10CFR71, Packaging and Transportation of Radioactive Materials.

6.1 Discussion and Results

Criticality analyses for arrays of shipping containers under both normal transportation and hypothetical accident conditions are carried out to assess conformance with 10CFR71. Results of these evaluations demonstrate that the specified array sizes meet the following reactivity criterion - the multiplication factor computed by the KENO-IV code plus twice the KENO-IV standard deviation plus other applicable adjustments shall be less than or equal to 0.95.

Structural qualification analyses, tests, etc. confirm the following conclusions which have a significant impact on the criticality evaluations. The 927A1 and 927C1 shipping containers maintain a six inch separation between fuel assemblies in the strongback. Additionally, they provide a spacing between the fuel assemblies and the shipping container wall of at least 5.0 inches above the fuel assemblies, 2.25 inches to the sides of the fuel assemblies and limit the motion of the fuel assemblies so that the maximum extension above the separator block is 1.5 inches following a 30 foot free drop of a container in any orientation.

The following assumptions were employed in the criticality evaluations for the cases representative of the 16 x 16 and 17 x 17 fuel assemblies.

a) For the normal transportation mode, the outer shell of the shipping container was represented in its normal circular geometry. The array size was taken to be 4 x 4, with the shipping containers (and active axial fuel region) assumed to be of infinite extent.

b) For the accident mode, the cylindrical shell of the shipping container is assumed to be collapsed around the strongback and the container is assumed to be fully flooded. The accident mode analysis assumed an array of 2 x 4 containers (I. e., a total of eight containers) of infinite length.

Results of the criticality evaluations are summarized below:

		Packages/Shipment
A.	Normal Transportation Conditions	16
B.	Accident Conditions	8 (14x14, 16x16, 17x17)

6.2 Package Fuel Loading

The Model Nos. 927A1 and 927C1 shipping containers are approximately 43 inches in diameter, up to 216 inches long, and may contain a maximum of two (2) fuel assemblies of the types described in Section 1.2.3 of this application, or other less reactive fuel assemblies. The criteria for making this assessment are given in Section 6.4.2, below.

6.3 Model Specification

6.3.1 Description of Calculation Model

The analytical model for the shipping container is based on the dimensional data contained in the engineering drawing provided in Appendix 1A. The fuel assembly type employed as being representative of the 14x14 and 16x16 fuel assembly types is that of subparagraph (d) of Section 1.2.3. The 17x17 fuel assembly type is that of subparagraph e) of Section 1.2.3.

6.3.1.1 Normal Transportation Mode

In the normal transportation mode, each shipping container is assumed to contain two fuel assemblies.

The outer shell of the shipping container is represented as circular, as illustrated in Figure 6.3-1 for the 16 x 16 fuel assembly design and Figure 6.3-2 for the 17 x 17 fuel assembly design. These figures also illustrate the geometry and dimensions of the material compositions employed in the KENO model. The container array is 4 x 4 in each case. The fuel assemblies are assumed to be of infinite extent and the array is assumed to be reflected by twelve inches of water on all four sides.

6.3.1.2 Accident Mode

In the accident mode, the shipping container employs a conservative description. The outer shell is assumed to be collapsed about the strongback structure. The two fuel assemblies are assumed to be separated over their active length by the six inch wide separator block. The steel separator block and the steel strongback are each modeled explicitly in the analyses and the container is assumed to be flooded with water.

Figures 6.3-3 and 6.3-4 show the Keno models of an accident mode container for the 16 x 16 and 17 x 17 fuel assembly designs, respectively. In each of these representations, the fuel assembly is shown to be positioned one inch above the strongback and abutting the separator block to maximize the coupling between the greatest number of pairs of assemblies in the array. The accident array was taken to be 2 x 4, that is, two containers wide by four containers high.

6.3.2 Package Regional Densities

Tables 6.3-1 and 6.3-2 list the KENO-IV input for the normal transportation and accident mode analyses, respectively, for the 16 x 16 fuel assembly analyses.

Table 6.3-3 summarizes the pertinent information on number densities employed for the 16 x 16 and 17 x 17 fuel assembly analyses.

Tables 6.3-4 and 6.3-5 list the KENO-IV input for the normal transportation and accident mode analyses, respectively.

6.4 Criticality Calculations

6.4.1 Criticality Results

The KENO-IV code was employed to calculate the reactivity of the shipping container arrays. The 123 group DLC-16 library was used along with the NITAWL and XSDRNPM codes to generate a sixteen group neutron cross section library of the same energy structure as employed in the Hansen and Roach sixteen group library (Table 6.4-1).

For the normal transportation mode, the KENO-IV multiplication factors for the 4 x 4 array analyses, are as follows.

Fuel Assembly Type	w/o U-235	K_{eff}
16 x 16	5.0	0.4545 ± 0.0026
17 x 17	3.6	0.4275 ± 0.0032

For the accident mode, KENO-IV calculations were run to evaluate the multiplication factor of the array versus assumed distance of the fuel assemblies above the strongback. Table 6.4-2 summarizes the KENO-IV results for both the 16 x 16 and 17 x 17 fuel assembly designs and Figure 6.4-1 shows a plot of $K + 2\sigma$ versus elevation above the strongback. Since the maximum distance the top edge of the fuel assemblies can rise above the strongback is approximately 9.5 inches, due to mechanical constraints, $K + 2\sigma$ for the accident array can be determined from the plots of Figure 6.4-1 for each fuel assembly type in the following manner. Appendix 2B, Section 2B-3.2 discusses the fuel assembly exposure above the separator block during the drop tests and associated analyses. It is concluded that, for the 16 x 16 fuel assembly design, a conservative estimate of the upper limit of the rise of the top of the assembly above the strongback is 1.5 inches. Since the top of the 17x17 fuel assembly is approximately one half inch higher than the 16 x 16 fuel assembly, the upward movement of the 17 x 17 assembly is no greater than 1.0 inches. An examination of the data of Figure 6.4.1 indicates $K + 2\sigma$ to be no greater than 0.9286 when the 16 x 16 assemblies are postulated to rise above the strongback in the accident mode configuration. The comparable value for the 17 x 17 assembly at 1.0 inch above the top of the strongback is no greater than 0.902.

KENO analyses were also run to examine the effect of changing the water density within the containers for the accident array with the 17 x 17 fuel assemblies one inch above the strongback. Table 6.4-3 summarizes the KENO results and Figure 6.4-2 shows a plot of $K + 2\sigma$ versus water density. Based on these results it is concluded that analyses at the maximum water density provide the most conservative estimate of the multiplication factor for the accident mode. Thus, the analyses for the 16 x 16 assembly were done at full water density.

6.4.2 Alternate Fuel Assembly Loadings

The 16x16 criticality analyses reported in Section 6.4.1, above, employed the fuel assembly type identified in Section 1.2.3, subparagraph (d) whereas the 17x17 criticality analyses employed that of subparagraph (e). The following tabulation lists pertinent data on the six fuel assemblies of Section 1.2.3.

	(a)	(b)	(c)	(d)	(e)	(f)
Geometry	14x14	16x16	16x16	16x16	17x17	14x14
Clad OD (in)	0.440	0.382	0.365	0.382	0.379	0.440
Clad t (in)	0.028	0.025	0.024	0.025	0.0235	0.026
Pellet Dia. (in)	0.38	0.330	0.31	0.330	0.324	0.381
Active Fuel Length (in)	136.8	136.8	91.0	150.0	143.0	136.8
No. of Fuel Rods	176	236	231	236	264	176
Unit Cell V_{H2O}/V_{UO2}	1.656	1.654	1.560	1.654	1.676	1.617
wt % U235	5.0	5.0	5.0	5.0	3.6	4.76
g U235/cm of F.A.	56.5	59.76	50.5	59.76	45.2	56.5
Kg U235/F.A.	19.6	20.763	11.68	22.77	16.43	19.6

It is readily apparent that fuel assemblies "a", "b", "c", "e" and "f" are less reactive than assembly "d". The primary indicators are linear density of U235, total U235 per assembly and volume ratio of water to uranium oxide in the unit cell.

6.5 Validation of Calculational Methods for Nuclear Criticality Safety

6.5.1 Homogeneous UO2 - Moderator Mixtures

Validation of a calculational scheme employing the KENO-IV code (Reference 1) and the sixteen group Hansen-Roach cross section set distributed under the SCALE code system (Reference 2) is contained in Reference 3. To ascertain whether the conclusions of the latter reference are applicable to analyses carried out at Combustion Engineering, the following comparisons are noted.

1) The Hansen-Roach cross section library at Combustion Engineering, has been verified as being identical to that distributed under SCALE, and

2) Eight of the sample problems distributed with the code were run for purposes of comparing the calculated eigenvalues with those obtained by ORNL.

Table 6.5-1 summarizes the eigenvalue comparison; it is noted that the eigenvalues agree within the stated statistical deviation. Thus, it may be concluded that the conclusions of Reference 3 concerning bias and deviation are applicable to homogeneous analyses performed by Combustion Engineering.

6.5.2 Heterogeneous UO2 - Moderator Mixtures

Heterogeneous UO2 - moderator lattices for fuel shipping containers are analyzed with the KENO-IV code and a sixteen group library generated for the lattice of interest. The latter library is prepared with the NITAWL and XSDRNPM codes (Reference 4). Lattice dependent Dancoff factors are calculated for input to NITAWL to generate self-shielded 123 group cross sections from the super - XSDRN library (Reference 5). This library is employed with XSDRNPM to calculate 123 group constants which are collapsed to sixteen group flux weighted fuel cell averaged cross sections. XSDRNPM is also used to obtain separate 16 group cross section sets for the structural materials, insulation, and the moderator areas external to the UO2 regions.

Validation of this calculational scheme is based on analysis of two sets of experiments: (1) the dissolution and storage experiments carried out by the Department of Nuclear Safety of the French Atomic Energy Commission (Reference 6), and (2) the consolidated fuel rod experiments carried out at the Babcock and Wilcox Facility under the auspices of the U.S. Department of Energy (Reference 7).

Emphasis was placed on the analysis of the storage aspect of the French experiments. In these experiments, the reactivity effects of replacing water in the inter-fuel assembly gap by air, expanded polystyrene ($(C_8H_8)n$), polyethylene powder ($(CH_2)n$), and polyethylene balls were examined for gap thickness of 2.5, 5.0, and 10.0 cm. Application of the calculational scheme outlined above resulted in the KENO-IV results noted in Table 6.5-2.

The consolidated fuel rod experiments covered five core types. The first three employed a triangular spacing of the close pack fuel rods within a storage module; differences between the three cores were in the nominal intermodule spacing (1.78 to 3.81 cm). The fourth core employed close packed fuel rods in a square pitch while the fifth core employed an open square pitch. All cores were critical at full water height using soluble boron as the variable.

The following tabulation summarizes the KENO-IV multiplication factors for the first three cores.

Core No.	KENO-IV KEFF
I	1.008 $\pm$ 0.002
II	0.996 $\pm$ 0.002
III	0.978 $\pm$ 0.002

The above results demonstrate that the calculational scheme for heterogeneous lattices based in the NITAWL - XSDRNPM - KENO-IV computer codes does give acceptable agreement with experiment for use in criticality evaluations. The systematics of the deviations between calculation and experiment indicate the model to be conservative for the French experiments. In the case of the fuel consolidation experiments the same trend is observed in the calculational results as reported in Reference 7.

6.6 References

1. L. M. Petrie and N. F. Cross, "KENO-IV, An Improved MONTE CARLO Criticality Program," ORNL-2938, November, 1975.

2. "SCALE: A Modular Code System for Performing Standardized Computer Analysis for Licensing Evaluation - Book II", NUREG/CR-0200.

3. G. R. Handley and C. M. Hopper, "Validation of the "KENO" Code for Nuclear Criticality Safety Calculations of Moderated, Low-Enriched Uranium Systems", Y-1948, June 13, 1974.

4. N. M. Green, et al, "AMPX: A Modular Code System for Generating Coupled Multigroup Neutron-Gamma Libraries from ENDF/B", ORNL/TM-3706, March 1976.

5. W. R. Cable, "123 Group Neutron Cross Section Data Generated from ENDF/B-II Data for use in the XSDRN Discrete Ordinates Spectral Averaging Code", DLC-16, Radiation Shielding Information Center, 1971.

6. J. C. Manarache, et al, "Dissolution and Storage Experiment With 4.75 w/o U-235 Enriched UO2 Rods", Nuclear Technology, Vol. 50, pg 148, September 1980.

7. G. S. Hooper, et al, "Critical Experiments Supporting Storage of Tightly Packaged Configurations of Spent Fuel Rods," BAW-1645-4, November, 1981.

TABLE 6.3-1

KENO-IV Input Listing for 4x4x1 Array of Undamaged 927 Containers with 16 x 16 Fuel Assemblies

```
  UNDAMAGED 4X4 ARRAY OF 927 CONTAINERS WITH 16X16 FUEL ASSEMBLIES, OD=0.33 INCHES
   30.00     50     500     3       16
      15     11       4    11       12
       1      4       4     1      -11
       1      0    1010    00        0
       0      0       0     0        0
      00      0       0
-0. -0. -0. -0. -1. -1.
1  -92235  3.620879-4
1   92238  6.792770-3
1    8016  1.430971-2
1   26000  5.783627-5
1   40000  3.702435-3
2   11001  6.795511-2
2   26012  4.247195-2
3   26012  3.921000-3
3  226000  8.349100-2
4   61001  6.685969-2
4   68016  3.342984-2
BOX TYPE  1
CUBOID    0    7.14375  -7.14375  -0.47625 -19.84375 381.00 0.0 16*0.5
CUBOID    3    7.62000  -7.62000   0.00000 -20.32000 381.00 0.0 16*0.5
CUBOID    2    7.93750  -7.93750   0.00000 -20.32000 381.00 0.0 16*0.5
CUBOID    0    7.93750  -7.93750   0.24384 -20.32000 381.00 0.0 16*0.5
CUBOID    1   28.50134 -28.50134   0.24384 -20.32000 381.00 0.0 16*0.5
CUBOID    0   31.43250 -31.43250  10.16000 -20.32000 381.00 0.0 16*0.5
CUBOID    3   32.06750 -32.06750  10.16000 -20.95500 381.00 0.0 16*0.5
CYLINDER  0   54.61000                               381.00 0.0 16*0.5
CYLINDER  3   54.91480                               381.00 0.0 16*0.5
CUBOID    0   54.91490 -54.91490  54.91490 -54.91490 381.00 0.0 16*0.5
CORE BDY  0 439.31920    0.00000 439.31920   0.00000 381.00 0.0 16*0.5
CUBOID    4 469.79920  -30.48000 469.79920 -30.48000 381.00 0.0 16*0.5
END KENO
```

TABLE 6.3-2

KENO-IV Input Listing for 2x4x1 Array of Damaged 927 Containers with 16 x 16 Fuel Assemblies (All Fuel Assemblies Positioned 1.0 Inches Above Strongback)

```
927 CONTAINER WITH 16X16 ASSEMBLIES, OD=0.33 INCHES, I INCH ABOVE STRONGBACK
  30.00      50      500      3       16
     15      14        5     14       28
      6      18        4      1      -14
      1       0     1010     00        0
      0       0        0      0        0
     00       0        0
-0. -0. -0. -0. -1. -1.
1  -92235  3.927733-4
1   92238  7.368426-3
1   8016   3.398817-2
1   1001   3.693153-2
1   26000  6.273764-5
1   40000  4.016199-3
2   11001  6.685969-2
2   18016  3.342984-2
3   26012  3.921000-3
3  226000  8.349100-2
4   61001  6.685969-2
4   68016  3.342984-2
5    1001  6.685969-2
5    8016  3.342984-2
BOX TYPE  1
CUBOID    1   1.28524 -1.28524   7.71144   0.00000 381.00 0.0 16*0.5
CUBOID    5   1.28524 -1.28524  10.28192  -2.57048 381.00 0.0 16*0.5
CUBOID    1   3.85572 -5.14096  14.13764  -6.42620 381.00 0.0 16*0.5
CUBOID    4   3.85572 -5.14096  26.59380  -8.96620 381.00 0.0 16*0.5
CUBOID    3   3.85572 -5.14096  26.89860  -9.90600 381.00 0.0 16*0.5
BOX TYPE  2
CUBOID    5   1.28524 -1.28524   1.28524  -1.28524 381.00 0.0 16*0.5
CUBOID    1   1.28524 -1.28524  10.28192 -10.28192 381.00 0.0 16*0.5
CUBOID    4   1.28524 -1.28524  22.73808 -12.82192 381.00 0.0 16*0.5
CUBOID    3   1.28524 -1.28524  23.04288 -13.76172 381.00 0.0 16*0.5
BOX TYPE  3
CUBOID    1   1.28524 -1.28524   7.71144   0.00000 381.00 0.0 16*0.5
CUBOID    5   1.28524 -1.28524  10.28192  -2.57048 381.00 0.0 16*0.5
CUBOID    1   5.14096 -3.85572  14.13764  -6.42620 381.00 0.0 16*0.5
CUBOID    4   5.14096 -3.85572  26.59380  -8.96620 381.00 0.0 16*0.5
CUBOID    3   5.14096 -3.85572  26.89860  -9.90600 381.00 0.0 16*0.5
BOX TYPE  4
CUBOID    2   3.24866  0.00000  30.48000   0.00000 381.00 0.0 16*0.5
CUBOID    3   3.24866 -0.63500  30.48000  -0.63500 381.00 0.0 16*0.5
CUBOID    2   3.24866 -6.35000  35.56000  -0.63500 381.00 0.0 16*0.5
CUBOID    3   3.24866 -6.65480  35.86480  -0.93980 381.00 0.0 16*0.5
```

TABLE 6.3-2 (continued)

```
BOX TYPE   5
CUBOID     2  14.28750  0.00000  19.84375   0.47625 381.00 0.0 16*0.5
CUBOID     3  14.76375 -0.47625  20.32000   0.00000 381.00 0.0 16*0.5
CUBOID     2  14.76375 -0.47625  35.56000   0.00000 381.00 0.0 16*0.5
CUBOID     3  14.76375 -0.47625  35.86480  -0.93980 381.00 0.0 16*0.5
BOX TYPE   6
CUBOID     2   3.24866  0.00000  30.48000   0.00000 381.00 0.0 16*0.5
CUBOID     3   3.88366 -0.00000  30.48000  -0.63500 381.00 0.0 16*0.5
CUBOID     2   9.59866 -0.00000  35.56000  -0.63500 381.00 0.0 16*0.5
CUBOID     3   9.90346 -0.00000  35.86480  -0.93980 381.00 0.0 16*0.5
CORE BDY   0 152.3492   0.00000 147.21840   0.00000 381.00 0.0 16*0.5
CUBOID     4 182.8292 -30.4800 177.69840 -30.48000 381.00 0.0 16*0.5
004   1   1  1     1 4 1   1 1 1   0
001   2   2  1     1 4 1   1 1 1   0
002   3   3  1     1 4 1   1 1 1   0
003   4   4  1     1 4 1   1 1 1   0
005   5   5  1     1 4 1   1 1 1   0
001   6   6  1     1 4 1   1 1 1   0
002   7   7  1     1 4 1   1 1 1   0
003   8   8  1     1 4 1   1 1 1   0
006   9   9  1     1 4 1   1 1 1   0
004  10  10  1     1 4 1   1 1 1   0
001  11  11  1     1 4 1   1 1 1   0
002  12  12  1     1 4 1   1 1 1   0
003  13  13  1     1 4 1   1 1 1   0
005  14  14  1     1 4 1   1 1 1   0
001  15  15  1     1 4 1   1 1 1   0
002  16  16  1     1 4 1   1 1 1   0
003  17  17  1     1 4 1   1 1 1   0
006  18  18  1     1 4 1   1 1 1   1
END KENO
```

TABLE 6.3-3

Number Densities Employed in NITAWL, XSDRNPM, and KENO Models for the Two Fuel Assembly Analyses

Material	Density (g/cc)	16 x 16	17 x 17
UO_2	10.412		
N-235		1.175778 -3	8.465778 -4
N-238		2.20576 -2	2.238313 -2
N-Ox		4.646675 -2	4.645942 -2
Zr-4 Clad*	6.55		
N-Zr		3.536252 -2	3.1696 -4
N-Fe		5.524031 -4	4.9513 -4
Water	1.0		
N-H		6.685969 -2	6.685969 -2
N-Ox		3.342984 -2	3.342984 -2
Carbon Steel	7.82		
N-C		3.921 -3	3.921 -3
N-Fe		8.3491 -2	8.3491 -2
Rubber (C_5H_8)	0.96		
N-C		4.247195 -2	4.247195 -2
N-H		6.795511 -2	6.795511 -2
Damaged F.A. Rep.**			
N-235		3.927733 -4	2.540256 -4
N-238		7.368426 -3	6.71632 -3
N-Fe		6.273764 -5	5.472147 -5
N-Zr		4.016199 -3	3.503023 -3
N-H		3.693153 -2	3.940836 -2
N-Ox		3.398817 -2	3.364487 -2
Undamaged F.A. Rep.***			
N-235		3.620879 -4	2.540256 -4
N-238		6.792770 -3	6.71632 -3
N-Fe		5.783627 -5	5.472147 -5
N-Zr		3.702435 -3	3.503023 -3
N-H		0.0	0.0
N-Ox		1.430971 -2	1.394069 -2

* Homogenized over gap and clad regions.

** For 16x16 F.A., N's are for homogenized fuel pin cells; CEA waterholes represented explicitly, water at 1.0 g/cc. For 17x17 F.A., N's are for homogenized assembly.

*** Homogenized Fuel Assembly in both cases.

TABLE 6.3-4

KENO-IV Input Listing for 4x4x1 Array of Undamaged 927 Containers with 17 x 17 Fuel Assemblies

```
    UNDAMAGED 4X4 ARRAY OF 927 CONTAINERS WITH 17X17 FUEL ASSEMBLIES
     30.00     50     500     3       16
       15      11       4    11       12
        1       4       4     1      -11
        1       0    1010    00        0
        0       0       0     0        0
       00       0       0
  -0. -0. -0. -0. -1. -1.
  1  -92235  2.540256-4
  1   92238  6.716320-3
  1   8016   1.394069-2
  1   26000  5.472147-5
  1   40000  3.503023-3
  2   11001  6.795511-2
  2   26012  4.247195-2
  3   26012  3.921000-3
  3  226000  8.349100-2
  4   61001  6.685969-2
  4   68016  3.342984-2
  BOX TYPE  1
  CUBOID    0    7.14375  -7.14375   -0.47625 -19.84375 360.68 0.0 16*0.5
  CUBOID    3    7.62000  -7.62000    0.00000 -20.32000 360.68 0.0 16*0.5
  CUBOID    2    7.93750  -7.93750    0.00000 -20.32000 360.68 0.0 16*0.5
  CUBOID    0    7.93750  -7.93750    1.31318 -20.32000 360.68 0.0 16*0.5
  CUBOID    1   29.57068 -29.57068    1.31318 -20.32000 360.68 0.0 16*0.5
  CUBOID    0   31.43250 -31.43250   10.16000 -20.32000 360.68 0.0 16*0.5
  CUBOID    3   32.06750 -32.06750   10.16000 -20.95500 360.68 0.0 16*0.5
  CYLINDER  0   54.61000                                360.68 0.0 16*0.5
  CYLINDER  3   54.91480                                360.68 0.0 16*0.5
  CUBOID    0   54.91490 -54.91490   54.91490 -54.91490 360.68 0.0 16*0.5
  CORE BDY  0  439.31920   0.00000  439.31920   0.00000 360.68 0.0 16*0.5
  CUBOID    4  469.79920 -30.48000  469.79920 -30.48000 360.68 0.0 16*0.5
  END KENO
```

TABLE 6.3-5

KENO-IV Input Listing for 2x4x1 Array of Damaged 927 Containers with 17 x 17 Fuel Assemblies (All Fuel Assemblies Positioned 1.0 Inches Above Strongback)

```
  DAMAGED 2X4 ARRAY OF 927 CONTAINERS, FLOODED, 1.0 INCHES ABOVE STRONGBACK
   30.00      50      500      3        16
     15       12        4     12        17
      4       10        4      1       -12
      1        0     1010     00         0
      0        0        0      0         0
     00        0        0
-0. -0. -0. -0. -1. -1.
1  -92235  2.540256-4
1   92238  6.716320-3
1    8016  3.364487-2
1    1001  3.940836-2
1   26000  5.472147-5
1   40000  3.503023-3
2   11001  6.685969-2
2   18016  3.342984-2
3   26012  3.921000-3
3  226000  8.349100-2
4   61001  6.685969-2
4   68016  3.342984-2
BOX TYPE  1
CUBOID    2    2.17932  0.00000   30.48000   0.00000 360.68 0.0 16*0.5
CUBOID    3    2.17932 -0.63500   30.48000  -0.63500 360.68 0.0 16*0.5
CUBOID    2    2.17932 -6.35000   35.56000  -0.63500 360.68 0.0 16*0.5
CUBOID    3    2.17932 -6.65480   35.86480  -0.93980 360.68 0.0 16*0.5
BOX TYPE  2
CUBOID    1   21.63318  0.00000   24.17318   2.54000 360.68 0.0 16*0.5
CUBOID    2   21.63318  0.00000   35.56000   0.00000 360.68 0.0 16*0.5
CUBOID    3   21.63318  0.00000   35.86480  -0.93980 360.68 0.0 16*0.5
BOX TYPE  3
CUBOID    2   14.28750  0.00000   19.84375   0.47625 360.68 0.0 16*0.5
CUBOID    3   14.76375 -0.47625   20.32000   0.00000 360.68 0.0 16*0.5
CUBOID    2   14.76375 -0.47625   35.56000   0.00000 360.68 0.0 16*0.5
CUBOID    3   14.76375 -0.47625   35.86480  -0.93980 360.68 0.0 16*0.5
BOX TYPE  4
CUBOID    2    2.17932  0.00000   30.48000   0.00000 360.68 0.0 16*0.5
CUBOID    3    2.81432 -0.00000   30.48000  -0.63500 360.68 0.0 16*0.5
CUBOID    2    8.52932 -0.00000   35.56000  -0.63500 360.68 0.0 16*0.5
CUBOID    3    8.83412 -0.00000   35.86480  -0.93980 360.68 0.0 16*0.5
CORE BDY  0  152.3492   0.00000  147.21840   0.00000 360.68 0.0 16*0.5
CUBOID    4  182.8292  -30.4800  177.69840 -30.48000 360.68 0.0 16*0.5
```

TABLE 6.3-5 (continued)

```
001   1  10  1   1 4 1   1 1 1   0
002   2   2  1   1 4 1   1 1 1   0
002   4   4  1   1 4 1   1 1 1   0
002   7   7  1   1 4 1   1 1 1   0
002   9   9  1   1 4 1   1 1 1   0
003   3   3  1   1 4 1   1 1 1   0
003   8   8  1   1 4 1   1 1 1   0
004   5   5  1   1 4 1   1 1 1   0
004  10  10  1   1 4 1   1 1 1   1
END KENO
```

TABLE 6.4-1

Sixteen Group Library - Hanson Roach Cross Sections

Group	Energy Range	Group	Energy Range
1	3. - Mev	9	100 - 500 ev
2	1.4 - 3 Mev	10	30 - 100 ev
3	0.9 - 1.4 Mev	11	10 - 30 ev
4	0.4 - 0.9 Mev	12	3 - 10 ev
5	0.1 - 0.4 Mev	13	1 - 3 ev
6	17 - 100 Kev	14	0.4 - 1 ev
7	3 - 17 Kev	15	0.1 - 0.4 ev
8	0.55 - 3 Kev	16	Thermal (0.025ev)

TABLE 6.4-2

KENO-IV Multiplication and Adjusted Multiplication Factors versus Elevation of Top of Fuel Assembly Above Strongback for Damaged 927 Shipping Container in 2x4x1 Array with Uniform Full Density Water

16 x 16 Fuel Assembly

Inches Above Strongback	Keff	Keff + 2σ
0	0.90302 ± 0.00431	0.91164
1	0.91806 ± 0.00527	0.92860
2	0.91751 ± 0.00535	0.92821
3	0.93079 ± 0.00477	0.94033

17 x 17 Fuel Assembly

Inches Above Strongback	Keff	Keff + 2σ
0	0.88222 ± 0.00494	0.89210
1	0.89225 ± 0.00459	0.90143
2	0.89491 ± 0.00470	0.90431
3	0.89538 ± 0.00564	0.90666

TABLE 6.4-3

KENO-IV Multiplication and Adjusted Multiplication Factors versus Uniform Water Density in a 2x4x1 Array with Damaged 927 Shipping Containers (17x17 Assemblies are Elevated 1.0 Inch Above Strongbacks)

Water Density, g/cc	K-eff	K-eff + 2σ
0.01	0.50024 +/- 0.00265	0.50554
0.05	0.60550 +/- 0.00365	0.61280
0.10	0.68000 +/- 0.00424	0.68848
0.20	0.73195 +/- 0.00422	0.74039
0.40	0.73899 +/- 0.00476	0.74851
0.60	0.76588 +/- 0.00450	0.77488
0.80	0.83377 +/- 0.00525	0.84427
1.0	0.89225 +/- 0.00459	0.90143

TABLE 6.5-1

Comparison of KENO-IV Calculated Eigenvalues for Sample Problems

Problem Number	Eigenvalues	
	C-E	ORNL
1	1.00387 +/- 0.00448	1.00569 +/- 0.00446
2	0. 99733 +/- 0.00426	1.00099 +/- 0.00442
10	0.74638 +/- 0.00446	0.75215 +/- 0.00436
11	0.99846 +/- 0.00487	0.99380+/- 0.00515
12	0.92957 +/- 0.00449	0.93089 +/- 0.00419
13	2.26645 +/- 0.00603	2.26172 +/- 0.00566
14	0.98487 +/- 0.00625	0.98060 +/- 0.00558
19	0.99726 +/- 0.00452	1.00014 +/- 0.00567

TABLE 6.5-2

Results of Experiments and Benchmark Calculations in the Case of Interposition of Hydrogeneous Compounds Between Four Assemblies of 18 x 18 (4.75%) at 13.5 mm Square Pitch

Experimental Results

* Δ (cm)	Compounds: Nature	Density (g/cm³)	Concentration Hydrogen (g/cm³)	Water Critical Height (mm)	Calculated Results KENO-IV
0	1. Water	1.0	0.1119	238 ± 0.6	-
	2. Box + air	0	0	290.3 ± 0.9	0.99641 ± 0.00407
	3. Box + $(C_8H_8)n$	0.0323	0.0025	286.1 ± 0.8	0.99913 ± 0.00384
2.5	4. Box powder $(CH_2)n$	0.2879	0.0414	269.8 ± 0.6	1.01567 ± 0.00378
5.0	5. Box + balls $(CH_2)n$	0.5540	0.0800	255.4 ± 0.8	
	6. Box + water	1.0	0.1119	256.8 ± 0.7	1.02362 ± 0.00362
	7. Water	1.0	0.1119	244.8 ± 0.6	0.99775 ± 0.00391
	8. Box + air	0	0	344.8 ± 0.7	1.00412 ± 0.00422
	9. Box + $(C_8H_8)n$	0.0262	0.0020	343.9 ± 0.8	1.00647 ± 0.00421
5.0	10. Box + powder $(CH_2)n$	0.3335	0.0480	301.6 ± 0.6	-
	11. Box + balls $(CH_2)n$	0.5796	0.0833	307.3 ± 0.8	-
	12. Box + water	1.0	0.1119	238.8 ± 0.8	-
	13. Water	1.0	0.1119	314.7 ± 0.6	-
	14. Box + air	0	0	460.8 ± 0.7	1.00117 ± 0.00396
	15. Box + $(C_8H_8)n$	0.0288	0.0022	456.2 ± 0.8	1.00748 ± 0.03378
10.0	16. Box + powder $(CH_2)n$	0.3216	0.0464	420.5 ± 0.6	-
	17. Box + balls $(CH_2)n$	0.5680	0.0816	499.4 ± 0.6	-
	18. Box + water	1.0	0.1119	641.2 ± 0.9	-
	19. Water	1.0	0.1119	643.4 ± 0.8	-

*The symbol Δ is the value of the gap width between the assemblies, thus it is the value of cross-shaped box width. The actual thickness of hydrogenous compounds is Δ (H) = Δ 0.6 cm.

FIGURE 6.3-1

KENO Model for Undamaged Containers
with 16 x 16 Fuel Assemblies

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE 6.3-2

KENO Model for Undamaged Containers
with 17 x 17 Fuel Assemblies

FIGURE WITHHELD UNDER 10 CFR 2.390

July 9, 1996 Rev. 0 PAGE 6-21

Certificate of omoliance No. 6078

FIGURE 6.3-3

KENO Model for Damaged Containers with 16 x 16 Fuel Assemblies
(Fuel Assemblies Shown 1.0 Inches Above Strongback)

FIGURE WITHHELD UNDER 10 CFR 2.390

July 9, 1996 Rev. 0 PAGE 6-22

FIGURE 6.3-4

KENO Model for Damaged Containers with 17 x 17 Fuel Assemblies
(Fuel Assemblies Shown 1.0 Inches Above Strongback)

FIGURE WITHHELD UNDER 10 CFR 2.390

July 9, 1996 Rev. 0 PAGE 6-23

FIGURE 6.4-1

Adjusted Multiplication Factor versus Elevation of Assemblies Above Strongbacks
Damaged 927 Shipping Containers in a 2x4x1 Array with Uniform Full Density Water

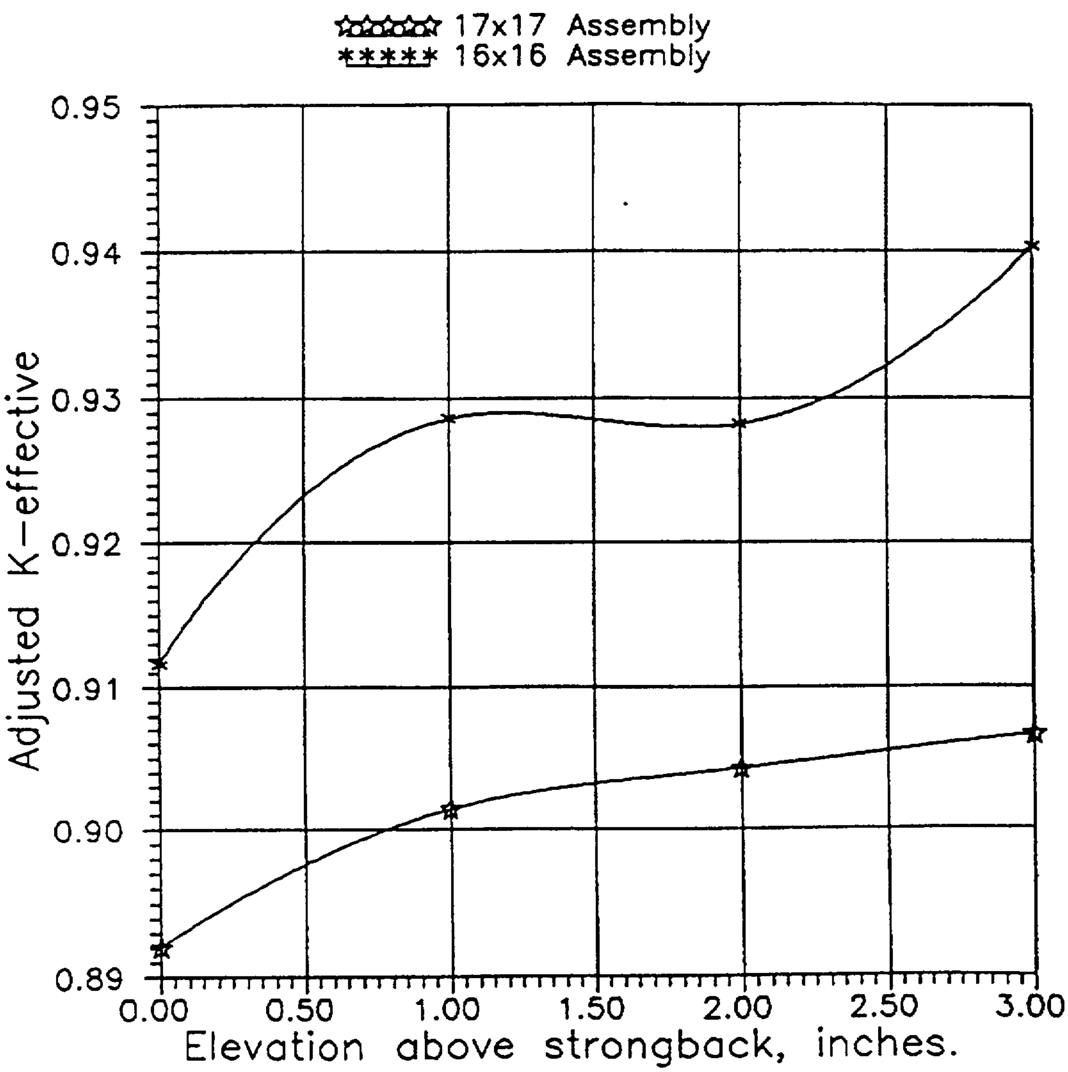
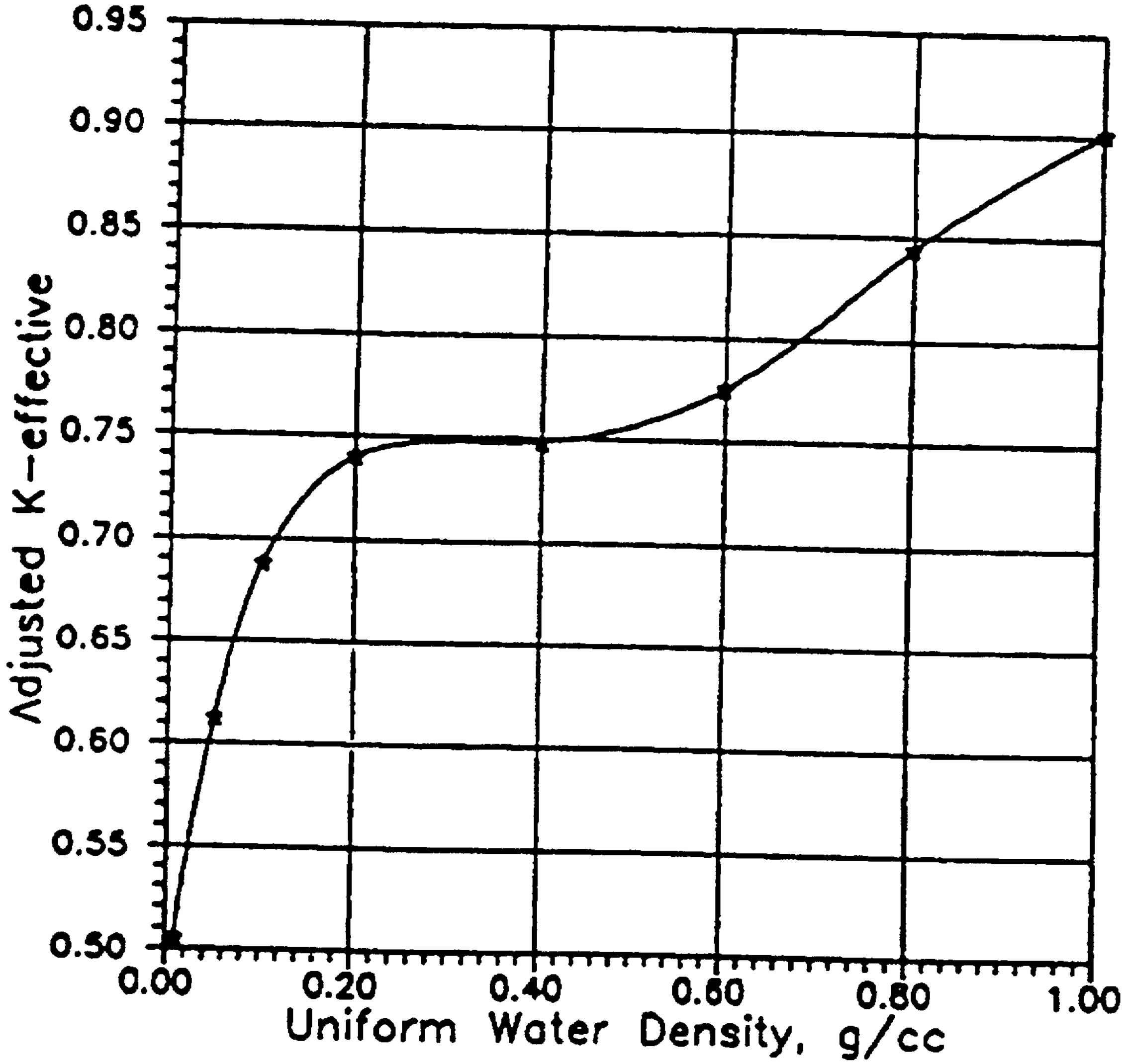


FIGURE 6.4-2

**Adjusted Multiplication Factor for
2x4x1 Accident Array of 927 Containers versus
Uniform Water Density
(All 17x17 Assemblies are 1.0 Inches Above Strongback)**



7. OPERATING PROCEDURES

The use of the Model Nos. 927A1 and 927C1 shipping containers is covered by detailed procedures. These procedures include movement of the empty shipping container into the fuel manufacturing facility, washing (discretionary), loading/unloading fuel assemblies, removal from the fuel manufacturing facility and loading on the conveyance vehicle for shipment.

The following generalized description provides a brief overview of the detailed procedures.

7.1 Procedures for Loading Package

Empty shipping containers are stored in either a warehouse or the yard area of the fuel manufacturing facility until needed. The containers are brought into the fuel manufacturing facility for loading. Washing of empty containers is discretionary and dependent on the amount of accumulated dust and dirt on the exterior of the package.

The shipping container is moved to a selected area in the manufacturing building, where the container is prepared for loading and complete fuel assemblies are loaded into the container. The container is prepared for loading by opening the pressure release valve if needed, unfastening and removing the container cover. After the cover is removed, the various container internal brackets are unfastened and removed or loosened and moved to appropriate positions. The strongback is then raised to a vertical position in preparation for fuel assembly loading. The container is inspected to assure it is in an acceptable condition for continued use. The inspection process includes:

a) Evidence of shipping and/or handling damage.
b) Cleanliness
c) General surface conditions such as rust, debris and foreign material
d) Fuel assembly support pads firmly attached.
e) O-ring gasket is acceptable for continued use.
f) Bolts are tight and have lockwashers between nut and bearing surface.
g) General container exterior labeling correct and in place.

Non-conforming conditions are identified and corrected, as necessary, before container use is permitted. Inspection instructions are included in the manufacturing facility operating procedures.

If required, individual fuel assemblies being prepared for loading into a shipping container may be enclosed in a polyethylene sheath. If so enclosed, one end of the sheath shall not be folded or taped in any manner that would prevent flow of liquid out of the sheathed fuel assembly. The fuel assembly is positioned in the container strongback. Each shipping container can hold up to two (2) fuel assemblies; one on either side of the strongback. With the fuel assemblies properly located, internal brackets which secure the assemblies in place are fastened and the strongback is lowered into its horizontal shipping position. With the strongback in the horizontal position, any remaining required fuel assembly hold down brackets are fastened and the container is secured for shipment. For both the Model Nos. 927A1 and 927C1 containers, the upper end fitting support may be secured to the strongback by either of the following hardware:*

1. Ten 3/4 inch Hex Head bolts with associated washers, lockwashers and nuts, or
2. Eight 3/4 inch diameter steel clevis pins with associated steel hair pin cotters, and two 3/4 inch Hex Head bolts with associated washers and nuts. The two bolts shall be placed in the central position for that specified part.

Once secured, an impact indicator (if required) is placed in the designated location. With the container completely loaded and prepared, the cover is moved into position and placed on the container after assuring that the "0" ring is undamaged and in the proper position. Next, the container cover bolts are fastened. An appropriate radiological survey is conducted on the container prior to shipment.

* For either of the methods described, the steel clevis pins, steel hair pin cotters or the bolts may be inserted in either direction. The function of the clevis pin and/or bolt is to secure the upper end fitting support bracket in place within the strongback. The clevis pin and/or bolt serves this purpose regardless of the direction it is facing. The direction of the bolt, clevis pin, and steel hair pin cotter will not affect the structural integrity of the container.

Appropriate labeling, a "RADIOACTIVE MATERIAL" placard, and a Type-E tamper indicating seal are affixed to each container.

The loaded shipping container may be stored inside a building or within the yard area of the fuel manufacturing facility, or loaded directly onto the conveyance vehicle.

7.2 Procedures for Unloading the Package

Upon arrival at their destination, the loaded shipping containers are removed from the conveyance vehicle. Each container is hosed or wiped down, if required, to remove dust and dirt prior to placing containers into the fuel receiving facility. The containers are also visually examined for gross external shipping damage.

Once in the fuel receiving facility and properly located, the shipping container is visually examined to assure that the appropriate container serial number is on the container and that the Type-E cup seal is intact. The Type-E cup seal is then removed and scrapped. To prepare for cover removal, the pressure release valve is opened if needed and the cover bolts are unfastened. The container cover is then removed and set aside.

The interior is inspected for evidence of water in the bottom of the container (a few inches of which is permissible). The fuel assemblies are also visually inspected to assure they are contained within the bundle support brackets and top safety brackets. Shock indicators, if so equipped, are inspected for evidence of actuation. Off normal conditions are reported to the on site Combustion Engineering representative.

Next, the various brackets securing the strongback in the horizontal position are loosened and/or removed, as appropriate. The strongback is then raised to the vertical position in preparation for removal of the fuel assemblies. Necessary retaining bolts and brackets are unfastened and the polyethylene sheath covering the fuel assembly, if so prepared, is removed. With the fuel assembly exposed, it is visually inspected for shipping damage and cleanliness.

Once the fuel assemblies have been removed, the strongback is lowered into the horizontal position, secured and prepared for cover closing. With the strongback secured, the cover is placed on the container, assuring that the "0" ring is in the proper position, and the cover bolts are secured. The "RADIOACTIVE MATERIAL" sign on the container is reversed to read "EMPTY". The empty shipping container is then removed from the fuel receiving facility and loaded onto the conveyance vehicle for return to Combustion Engineering.

7.3 Preparation of Empty Package for Transport

The procedures for loading and unloading of shipping containers on the conveyance vehicle are essentially the same, although the order of operations is reversed. The generalized discussion provided below is for loading empty shipping containers on the conveyance vehicle for return to Combustion Engineering.

Up to four (4) shipping containers are placed on the trailer bed. Wood blocks are nailed to the trailer bed between the containers at locations designated in the detailed procedures. Up to four (4) additional containers may be placed on top of the containers resting on the trailer bed. Specific fastening and positioning specifications are provided in the detailed procedures. The containers are fastened to the trailer bed by cinch cable, chain or nylon straps. Wooden wedges are inserted between flanges on the inboard sides of the containers to prevent side by side containers from touching each other. Finally, the appropriate placards are affixed to the conveyance vehicle regarding the content of the shipping containers.

8. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 Acceptance Tests

All containers to be fabricated will be constructed in accordance with the Combustion Engineering engineering drawings provided in Appendix 1A and shall be source inspected prior to leaving the vendor's facility. Changes to the design of the container which fall outside of the safety envelope specified in this application will be submitted to NRC for approval.

8.2 Maintenance Program

Maintenance for the Model No. 927 type shipping container is accomplished through an on-going in-service inspection program. Maintenance is performed, as necessary, as a result of the shipping container loading process inspections discussed in Section 7.1. Each container is treated as a separate entity and undergoes inspection and replacement of parts or repair when a deficiency is noted during the inspection process. If appropriate replacement or repair cannot be made in a timely manner the container is removed from service until corrective maintenance action is completed.