71-6206

B&W FUEL COMPANY

BW

An American Company with Worldwide Resources

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Lynchburg, VA 24506-1646
Telephone: 804-522-6000

May 4, 1992

Charles E. MacDonald
Chief Transportation Branch
Division of Safeguards and Transportation, NMSS
United States Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. MacDonald:

REFERENCE: Docket 71-6206 Certificate of Compliance

B&W Fuel Company requests to increase the allowable U-235 enrichment from 4.05% to 4.6% for our fresh fuel shipping container USA/6206/AF (Model B), Certificate of Compliance Number 6206. Due to the of controversy of the substitution a borated stainless steel plate for the horizontal positioned carbon steel plate, BWFC has elected not to incorporate any design modifications to the packaging in effort to support enrichment increases. Criticality analysis performed has determined that the container, in the present licensed design, can meet the requirements to ship 4.6% enriched fresh fuel.

Attachment I details the criticality evaluation performed for 4.6% enrichment and the results. Pages 2, 8, 9, and 10 of the SAR have been revised to indicate the 4.6% enrichment analysis. All changes are indicated by a side bar. As required, six copies of the entire SAR are provided.

Due to the upcoming contracts above the allowable 4.05% enrichment, we ask that you support us in having the requested amendment authorized for use in October.

Thank you for your time and guidance in our licensing efforts. If you have any further questions regarding this matter, please feel free to contact me at (804) 522-6202.

Sincerely,

B&W FUEL COMPANY
COMMERCIAL NUCLEAR FUEL PLANT

Kathryn S. Lester

Kathryn S. Lester
Manager, Safety and Licensing

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ATTACHMENT 1

PURPOSE

The purpose of this analysis is to evaluate the criticality safety of the B&W Fuel Company's fresh fuel shipping container, USA/6206/AF for the shipment of fresh fuel assemblies enriched to a maximum of 4.60% uranium-235. This analysis will parallel that used for the B&W operative license for fresh fuel enriched to 4.05% uranium-235.

DISCUSSION

The analyses performed for this application parallel very closely the analyses performed for the original application in scope and format. The calculational model and components are provided in FIGURES 1 through 4. The NORMAL array and the ACCIDENT array spacings are provided in Figures 5 and 6, respectively. The results consisting principally of KENO reactivity data are provided in Tables 1 through 3, and Figure 7. Similarly, Table 4 provides reactivity data from code and experiment comparison. Tables 5 and 6 provide parameters that characterize each of the five fuel assembly designs in the BWFC product line. Finally, Appendix A contains a table of material properties and the KENO code input listing for the principal cases that have output used in the license renewal application.

Background

The USA/6206/AF was originally licensed circa 1970. Criticality safety analyses were performed in late 1969 following a series of drop tests. The drop tests established the basis for conservatively defining the geometry for the accident conditions. The previous license was issued for a Fissile Class II or Fissile Class III shipment. The analyses for relicensing to 4.60% is limited to meeting Fissile Class III shipping requirements.

Amendment Request

There is not a design modification to the packaging associated with this amendment. The change consists only of increasing the maximum fuel enrichment from 4.1% to 4.60% including enrichment tolerances. It should be noted here that only 75% credit was taken for the boron content in the vertical boron-steel plates from a criticality standpoint. This is a departure from the original license application as 100% credit was taken for the borated plates. This change does not affect the geometry model used in the original license application. However, the original geometry model, identified as Geometry Model A in this application, has been modified to allow more detail modeling for final calculations. The more detailed geometry model is identified as Geometry Model C in this application and was used in all analyses reported in the current application.

Codes Used in Analyses

The NULIF code residing on the Power Computing Company (PCC) CDC 855 Computer was used to generate the Dancoff factors that was part of input to the NITAWL code. The NITAWL code residing on the BWFC IBM RISC/6000 Computer Network was used to generate a working 123 group cross section library from a NITAWL Master Library stored on the same computer. The working library was used by the KENO-IV code residing on the same computer network. KENO-IV was used for the criticality analyses contained in this application. The verification of the versions of the NITAWL and KENO-IV codes in residence on the IBM RISC/6000 Network relative to experiment has been completed. In addition, as discussed later in this application, the NITAWL - KENO-IV code package was checked to a SCALE3-CSAS2 MODULE IBM analysis package.

The critical experiments used to benchmark the KENO-IV code package consisted of low enriched UO_2 fuel pins arranged in water moderated lattices to simulate PWR fuel assemblies. The fuel was enriched to 2.459 weight percent U-235.

The KENO-IV - IBM RISC/6000 code package was benchmarked for PWR enrichment at 5.0% using as a comparison a case previously calculated by another KENO code package and different computer. The latter code/computer system (benchmark) is used extensively for criticality safety licensing analyses at B&W, Lynchburg, Va. The check case geometry model consisted of a MkBW 17x17 fuel assembly of 5.0% enrichment, resting lengthwise on a granite slab, fully moderated and reflected with water. This comparison is offered to support the extension of critical experiment benchmarking to enrichments higher than 2.5%.

A comparison of the k_{eff}s for the two calculations is given below:

Code Package - Computer	k_{eff}	$\pm 1\ \sigma$	No. Histories
KENO-IV, Benchmark	0.94577	.00302	78,800
KENO-IV, RISC/6000	0.94725	.00281	78,800

As can be seen, the agreement between the two code package-computer combinations is well within 1 σ of either case.

Bias Estimation

Detailed information on KENO-IV benchmark calculations are provided in reference 1. The methodology for the benchmark calculations is the same that is used in the analyses for this application. [1]

The calculated-to-measured k_{eff} for the criticals is provided in Table 4.[2] The maximum nonconservative difference in the calculated to measured nominal k_{eff} is 0.0145 Δk ±.00206. All of the KENO calculations[2] were performed using 134,000 neutron histories. Final analyses for this application used 100,200 histories. Since all analyses for this application were done with KENO on the IBM RISC/6000 computer network, it is reasonable to use a value of 0.02 Δk to compensate for a potential calculated negative reactivity bias for criticality safety calculations performed using KENO code. Finally, the base accident array case was recalculated to 200,400 and 400,800 histories to determine if the nominal k_{eff} changed significantly. See Table 3 cases 7, 9 and 10. The nominal k_{eff} increased by approximately .002 and the uncertainty (2 σ) decreased by about the same amount.

Analytical Method

The analysis of the USA/6206/AF is required to show that a shipment of 20 containers is critically safe under both normal and accident conditions for a Fissile Class III shipment. From the analysis for the original license application, the most reactive configuration is the accident condition. This is also true for the analyses in this application.

A bounding model for optimum moderation was developed for the hypothetical accident conditions described in a later section. The analysis is performed for the accident geometry configurations as defined in section 6.2 of the original license and given next.

> "For the purpose of this analysis, the container shell was considered to be crushed to the level of the internal structural members for its full length and entire periphery. The containers were then envisioned to be in an array of top to top and bottom to bottom. This arrangement provides for closer approach of assemblies than does the top to bottom arrangement normal to shipping configuration, and is considered to be the most reactive. Separative distances were then determined allowing only for the spacing provided by the

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1. "Critical Experiments Supporting Close Proximity Water Storage of Power Reactor Fuel," Baldwin, etal, BAW-1487-7, July 1979.
2. 32-1206525-00, KENO Benchmark Cases.

internal structurals and ignoring the contribution of such external structures as the skid frame, the stacking brackets and shell strengthening ribs. The smallest separation distances considered credible under these conditions are seven (7) inches between top to top layers, and eighteen inches between bottom to bottom layers. Minimum side to side separation between the nearest assemblies in sets is eight (8) inches. The assemblies were presumed to be retained in design relationship with the boron-steel poison plates and steel strongback plates, and contained within the steel shell."

The following conservative assumptions were used in this analyses.

1. The damaged configuration of the shipping container does not modify the design relationship of the fuel assemblies and the borated steel poison plates and the steel strongback. The original license application stated in Exhibit B Section 2 that

   "All of the required elements for a nuclear safe configuration were maintained upon complete inspection of the container following the final drop test."

   In Exhibit B, Section 1.1, a nuclear safe configuration is defined

   "as the two fuel assemblies, the boron-steel poison plates, and the steel strongback plates retained in essentially design relationship; and all retained within the container shell."

2. Damage to the fuel assembly during an accident may result in a reduced lattice spacing. This reduction in lattice moderation results in a less reactive fuel assembly than an undamaged assembly. A KENO calculation was performed whereby the fuel lattice cell pitch was reduced by 10 percent. The results are reported in another section of this application.

3. The structural material in the shipping container, but not the container shell itself, is replaced by water for the analytical model.

The one shipment of packages is modeled as an infinite XY array of USA/6206/AF containers with the Z direction represented as 1 fuel length with 8 inches of water reflection on each end of the active fuel. The end fittings and container end were not modeled. This is illustrated in Figure 1. The accident geometry described in the license application is illustrated in Figure 2. Figure 2 is made up of "boxes" and "reflectors". Boxes are stacked adjacent to each other to make up a whole region or regions, the total of which is enclosed by the "core boundary". Reflectors are regions that completely enclose the core boundary and any smaller reflector

regions. Figure 2 identifies all the dimensions and materials needed to describe the container array xy dimensions external to KENO "box" regions.

The KENO "boxes" are described in detail in figures 3 and 4. The xy dimensions and materials locations are shown for each box type. A check KENO calculation was made whereby the end reflector length was extended from 8 inches to 12 inches. The results are reported in another section of this application.

The X and Y separations between containers are defined by minimum crushed dimensions obtained from the drop tests, as reported in section 6.2 of the original license.

There are three moderator density variations of interest:

1. UNIFORM DENSITY DISTRIBUTION - the worst case scenario used in the analysis.

2. LOW DENSITY IN THE FUEL ASSEMBLY LATTICE AND HIGH DENSITY BETWEEN FUEL ASSEMBLIES - this case is least reactive because it reduces moderation within the lattice and tends to isolate each fuel assembly from others.

3. HIGH DENSITY IN THE FUEL ASSEMBLY LATTICE AND LOW DENSITY BETWEEN FUEL ASSEMBLIES - this case may be more reactive than the uniform density case because the boron plates outside the fuel are not as effective. However, this is not a physically credible moderator condition for the array for the following reasons:

   There is no water entrapment mechanism within the fuel lattice, and the polyethylene wrapper enclosing each fuel assembly is designed to gravity drain in any container position. The only water density increase that may occur in the fuel lattice relative to the associated container space is the wetted lattice surface when a fuel container drains upon being lifted during a recovery operation. Only one container is recovered at one time. At that time, the wetted lattice surface within the container being recovered is outside the boundaries of the array and has a high neutron leakage which more than offsets the loss of reduced absorption in the exposed part of the boron poison plates located between the two assemblies. In addition, a significant fraction of the neutrons thermalized and reflected by the water body surface will be absorbed by the exposed boron poison plates.

   One possible means by which a large number of containers can be simultaneously drained would be to drain the water body in which the container array has been submerged. There is a large increase in leakage from exposed fuel

due to total loss of a reflector on the exposed side of the array and again a significant fraction of neutrons thermalized and reflected from the water body surface will be absorbed by the exposed poison plates before re-entering the fuel lattice. In addition, the draining of the water body is likely to be in a controlled manner such that the wetted lattice surfaces are also drained.

Finally, no mechanism exists to create a lower density mist in the container space relative to associated fuel lattice space.

Therefore, it is concluded that credible circumstances do not exist that provide higher density water in the fuel lattice region in the array than in the surrounding container volume of the array while maintaining a close reflector around the exposed fuel lattice surface.

RESULTS

The results of the analyses for this application are given in this section which is divided into Part A and Part B. Part A contains those results that are directly incorporated into the license application. Part B contains results of relative changes in reactivity as a function of various parameters and is used to support the methodology used in the analyses reported in Part A. The case input for these case results given in Part A are contained in Appendix A.

PART A.

ACCIDENT Array Condition

An accident condition must be subcritical if the number of packages per shipment are stacked together in any arrangement, closely reflected on all sides of the stack by water, and with optimum interspersed hydrogenous moderation. Previous discussion has shown that the non uniform density of water within the fuel lattice and between fuel assemblies is precluded by the provision for draining the lattice and the containers, therefore uniform density of water throughout the array was modeled. The accident array, the dimensions of which are given in Figure 6 was modeled with Geometry Model C. The array reactivity was calculated for water densities of 100, 60, 20, 10, 7.5 and 5%. The results are given in the table below. The data is also plotted in Figure 7. From this data it is apparent that the secondary spike in k_{eff} in the vicinity of 7.5% water density is small in magnitude, and the most reactive moderation configuration for the accident array condition is the 100% moderator density condition. At the most reactive moderation configuration the k_{max} is 0.9340.

Case ID	Accident Case Description	k_{eff}	2σ	k_{max}
01800	100% Mod/Refl	.90923	.00472	.93395
01771	60% " "	.77601	.00484	.80085
01813	20% " "	.77666	.00434	.80100
01772	10% " "	.82357	.00422	.84779
01770	7.5% " "	.82981	.00384	.85365
01773	5% " "	.81741	.00370	.84111

Reduction of Damaged Container Separation Distance

The minimum separation distance between fuel assemblies of separate shipping containers in the accident condition was determined from the drop tests performed for and reported in the original license application. In order to assess the sensitivity of the array reactivity at these dimensions under accident conditions, a 20% reduction in separation distance along all three axes was made and KENO calculation was performed. The results are given below as case 1800 (nominal) and case 1767 (20% reduction). The 20% reduction in dimensions resulted in an increase in the array k_{max} of 0.017 Δk.

Case ID	Accident Case Description	k_{eff}	2σ	k_{max}
01800	100% Mod/Refl	.90923	.00472	.93395
01767	20% Reduced Dim	.92658	.00450	.95108

NORMAL Array Condition

A normal array must be subcritical if twice the number of packages per shipment are stacked together in any arrangement assuming close reflection on all sides of the stack by water.

The normal array, see Figure 5 has a minimum spacing of 24 inches between fuel assemblies in two adjacent shipping containers and no water within, or in close proximity to, the array. The normal array was modeled as an infinite XYZ array of shipping containers with a uniform array spacing between shipping containers assemblies of 24 inches and with no water reflector on the ends of the individual fuel assemblies. The calculation was performed for 100% interspersed water density although under normal array conditions the array would have no water moderation. The container carbon steel shell was replaced by water. Geometry Model C was used for this calculation with the reflector dimensions changed to represent the 24 inch minimum separation. The results are given below as Case 1330. The k_{max} of the NORMAL array is 0.9270 which is 0.007 Δk less than the most reactive accident case (Case 1800 given above).

Case	Accident Case

ID	Description	k_{eff}	2σ	k_{max}
1800	100% Mod/Refl	.90923	.00472	.93395
1330	Normal Array Dim.	.90203	.00494	.92697

Part B

Part B contains results of relative changes in reactivity as a function of various parameters and is used to support the methodology used in the analyses reported in Part A.

A small systematic nonconservative error (within 2σ on k_{max}, except 1 case was within 3 σ) exists in the geometric model used for the accident array KENO cases which provide relative reactivity supporting data. The error consists of modeling the +x and ±y spacing between containers in the crushed array as being 0.18 inches larger than the true values of 8.0, 7.0, and 18.0 inches respectively. This error did not exist in the normal array analyses.

The supporting analyses are cases that evaluate certain parameter changes, such as end reflector thickness, number of neutron histories and relative reactivity of different fuel assembly designs. Relative reactivity changes are provided by these cases and for practical purposes, the effect of the nonconservative 0.18 inch increase in accident array unit dimensions cancels out. The uncorrected cases are as follows:

Case ID	Case Purpose
1 2, 3, 4	Reactivity effect of fuel assembly design
5, 6	Reactivity effect of geometry models
7, 8	Reactivity effect of end reflector thickness
9, 10	Reactivity effect of KENO neutron case histories
11	Reactivity effect of lattice fuel rod pitch

Fuel Lattice Design Reactivity Evaluation

There are five B&W fuel assembly lattice designs. These are the MkB 15x15 the MkB 17x17, the MkBW 15x15 , the MkBW 17x17, and the Conn Yankee 15x15. The lattice parameters for each dattice design are listed in Table 5. The maximum uranium-235 loading for each fuel assembly design is provided in Table 6.

The MkBW 15x15 fuel assembly design was used as the reference design and all calculations were performed with that design. The Conn Yankee lattice design is sufficiently like the MkBW 15 x 15 design to be considered the same. The four lattices were evaluated for the array accident condition to determine the most reactive lattice. That analysis was performed for 5.1% enriched fuel in a modified Model B shipping container design. The calculational results are given in Table 1 as cases 1 through 4.

The 15x15 fuel assembly designs are the most reactive with k_{eff} within 0.5 σ. The MkBW 15x15 fuel assembly design was used for all analyses at 4.60% enrichment.

Model B Shipping Container Geometry Model Evaluation

The analyses reported in this application used two geometry models, Model B and Model C. The geometry models are the same except for the following differences:

1. Geometry Model C included the 0.008 inch thick polyethylene fuel assembly wrapper, and the 0.0625 inch thick neoprene cushion on the horizontal steel plate, the Model B did not.
2. Geometry Model C made provision for more detailed box types modeling the borated stainless steel plates and the carbon steel plates, than similar box types used for the Geometry Model B.

A comparison of the calculated reactivity difference of the two geometry models is given in Table 2 as cases 5 and 6.

The two geometry models are within 0.5 σ. Geometry model C was used for all calculations reported in this application. Model B was only used in the reactivity comparisons for the four fuel assembly designs reported above.

Array Reactivity Sensitivity to Fuel Assembly Lattice (pin pitch) Reduction

The original license Exhibit B stated that no damage was incurred to the fuel assemblies during the test program. However, in order to evaluate the sensitivity of accident array reactivity to a reduction in fuel assembly lattice (pin pitch), a KENO case was calculated whereby the fuel assembly pin pitch was reduced by 10 percent. The poison plate height was also reduced by 10 percent with all volume changes being replaced by water. The results are given in Table 3 as cases 7 and 11. The accident array k_{max} was reduced by 0.10 Δk.

Array Reactivity Sensitivity to End Water Reflector Thickness

Most of the array reactivity analyses used an 8 inch end reflector. A KENO calculation was made where the end reflector thickness was increased from 8 inches to 12 inches. The results are given in Table 3 as cases 7 and 9. The accident array Δk_{max} only increased by 0.0004. Therefore, no adjustment was made to the analytical results for end reflector thickness.

Criticality Assessment of Crushed Shipping Container Orientation in XY Array

The original license stated that for the accident condition modeling, the most reactive orientation of crushed shipping containers in an array consists of top to top and bottom to bottom orientation of crushed shipping containers in couples. This container array configuration minimizes the separation distance between the fuel assemblies in adjacent containers considered as couples. This is illustrated in Figure 15.11 of the license and reproduced as Figure 6 in this attachment with added information for geometry clarification.

CONCLUSIONS

The results of the analyses reported in this application indicate that a shipment of 20 USA/6206/AF shipping containers each containing two fresh fuel assemblies of existing designs with a maximum enrichment of 4.60 w% uranium-235 can be shipped in a Fissile Class III shipment. The maximum k_{eff} of such a shipment considering accident conditions required by 10 CFR 71, KENO-IV code statistical uncertainty, and model benchmark to experiment bias is less than 0.95.

KENO GEOMETRY MODEL - Z DIMENSIONS

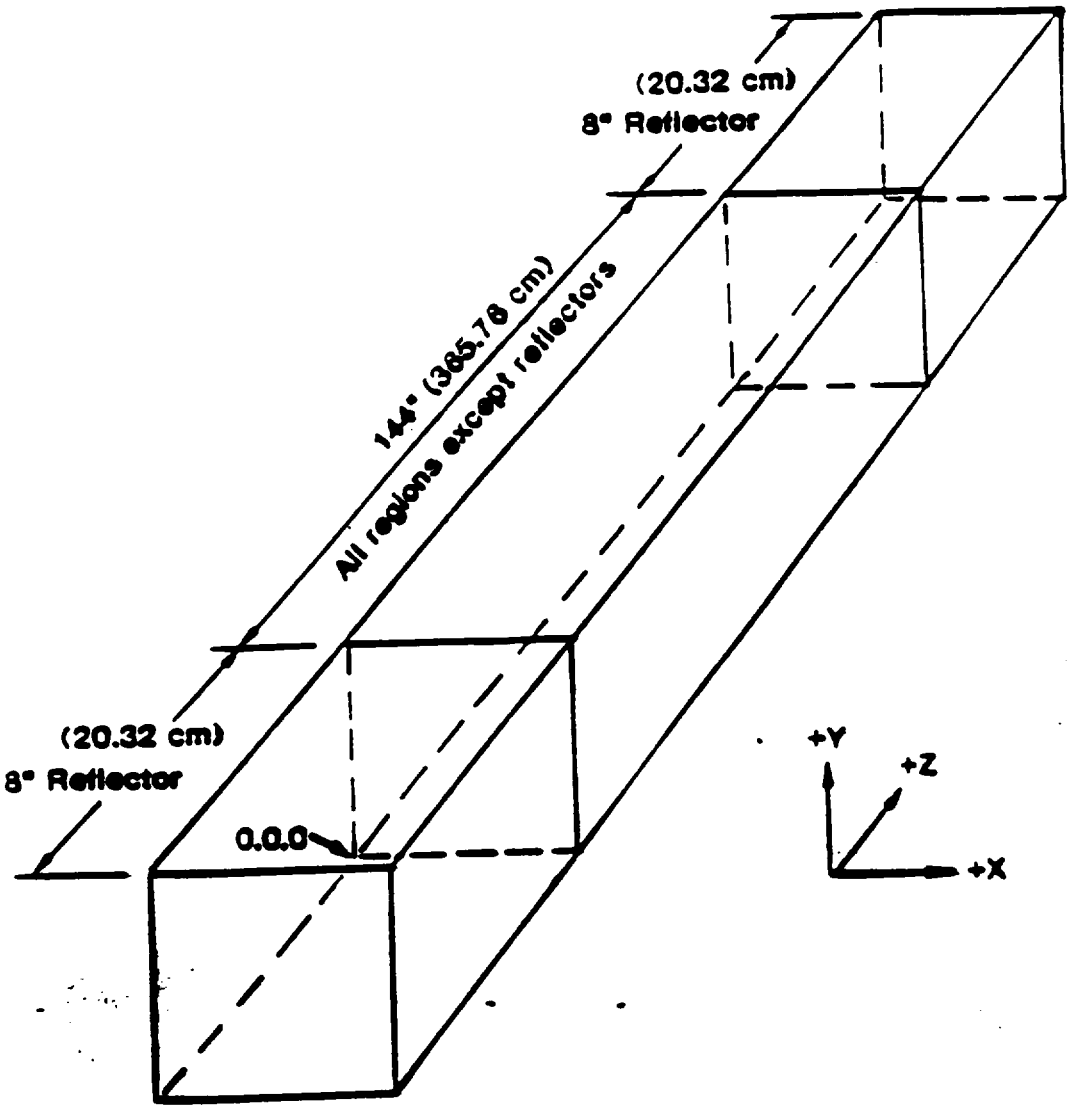


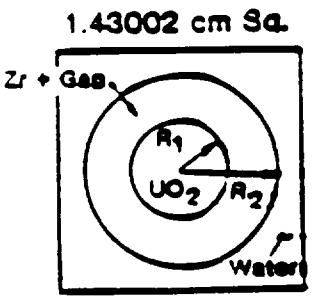
FIGURE **A:** KENO GEOMETRY MODEL - ACCIDENT CONDITIONS

FIGURE WITHHELD UNDER 10 CFR 2.390

KENO BOX TYPES

(All Boxes Have Length of 144 inches)

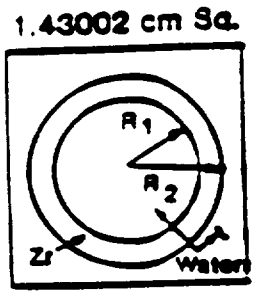
Box Type 1 - Fuel Cell



R_1 = 0.460375 cm

R_2 = 0.535940 cm

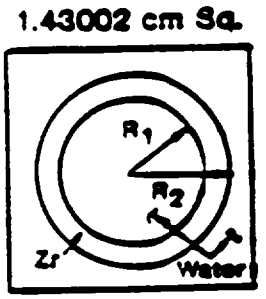
Box Type 2 - G.T. Cell



R_1 = 0.638175 cm

R_2 = 0.681355 cm

Box Type 3 - IT Cell

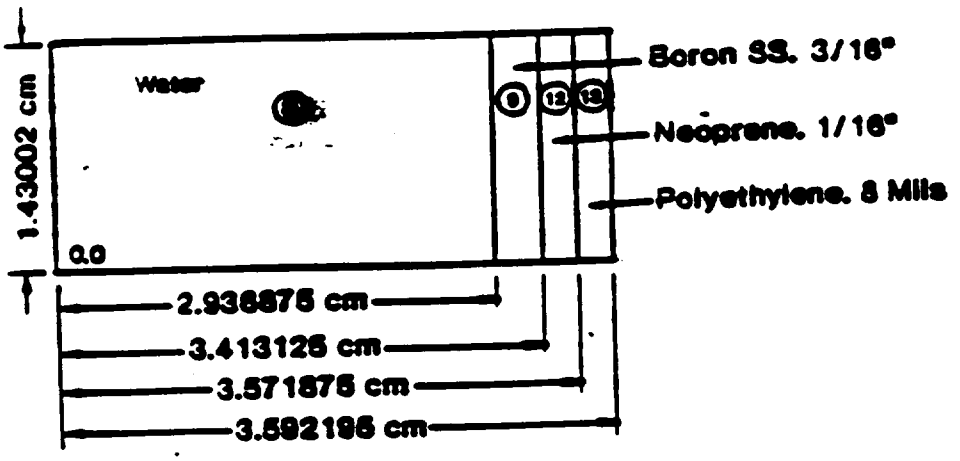


R_1 = 0.650240 cm

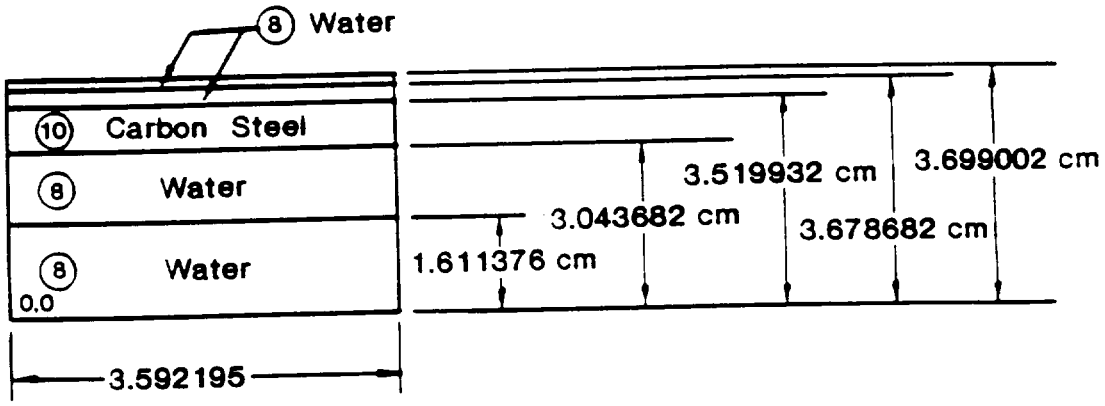
R_2 = 0.693420 cm

Box Type 5 Not Used

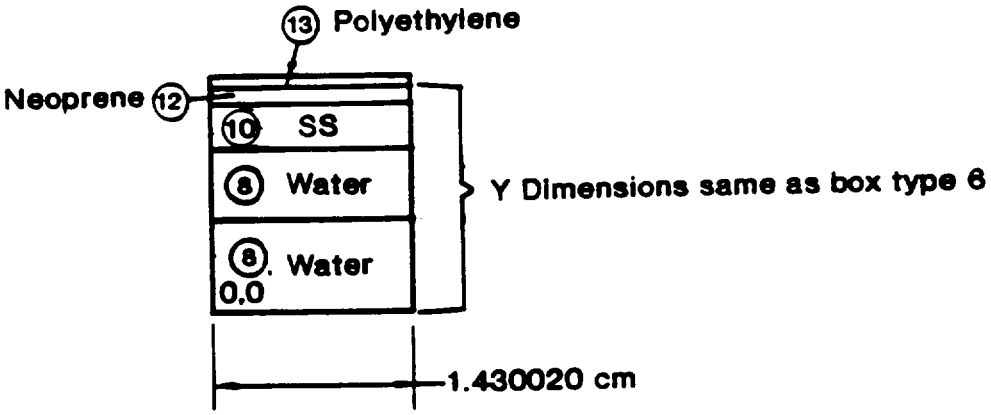
Box Type 4



Box Type 6

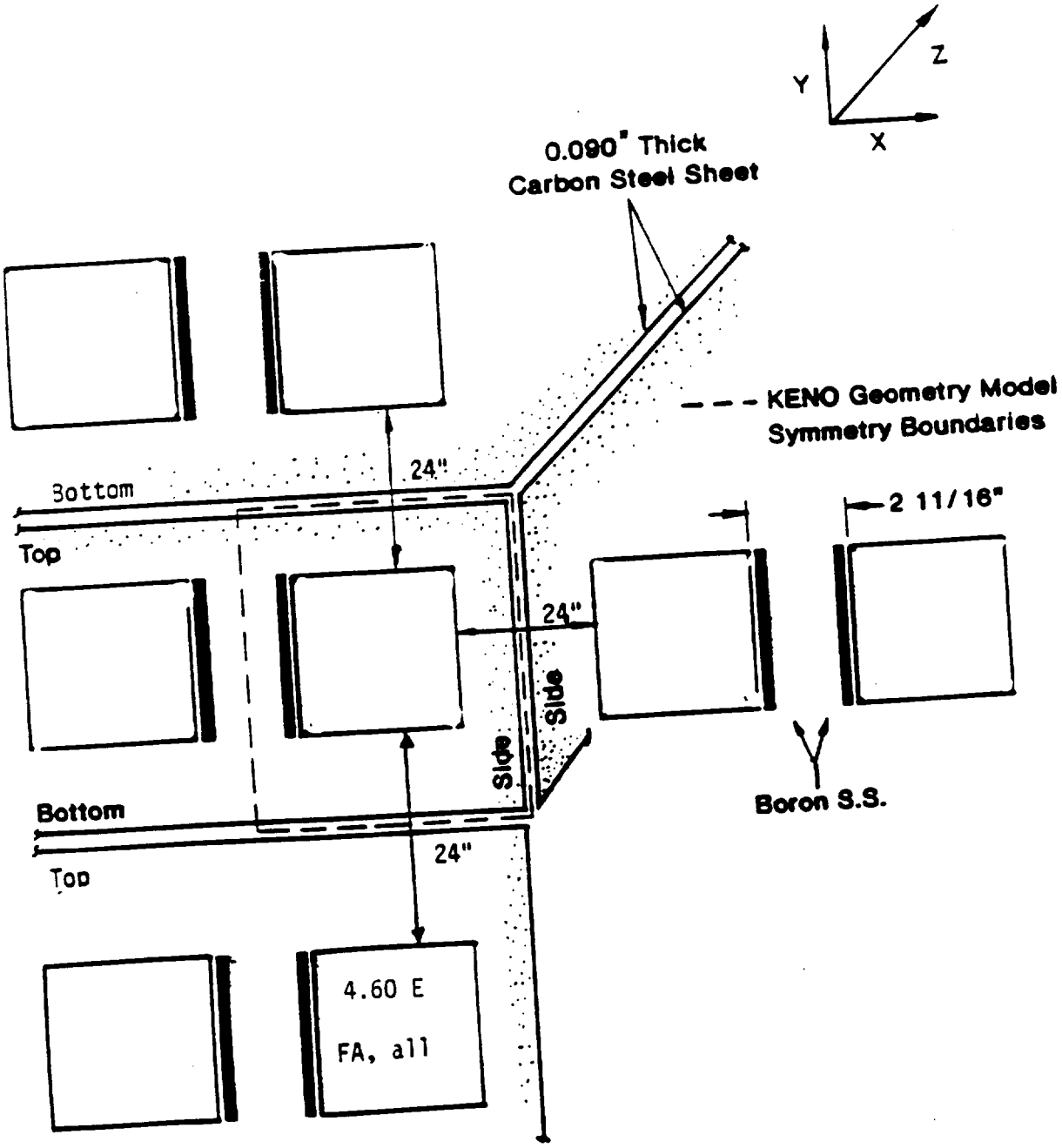


Box Type 7 = Box Type 8



NORMAL ARRAY

FA TO MINIMUM DIMENSIONS



ACCIDENT ARRAY

FA TO FA MINIMUM DIMENSIONS

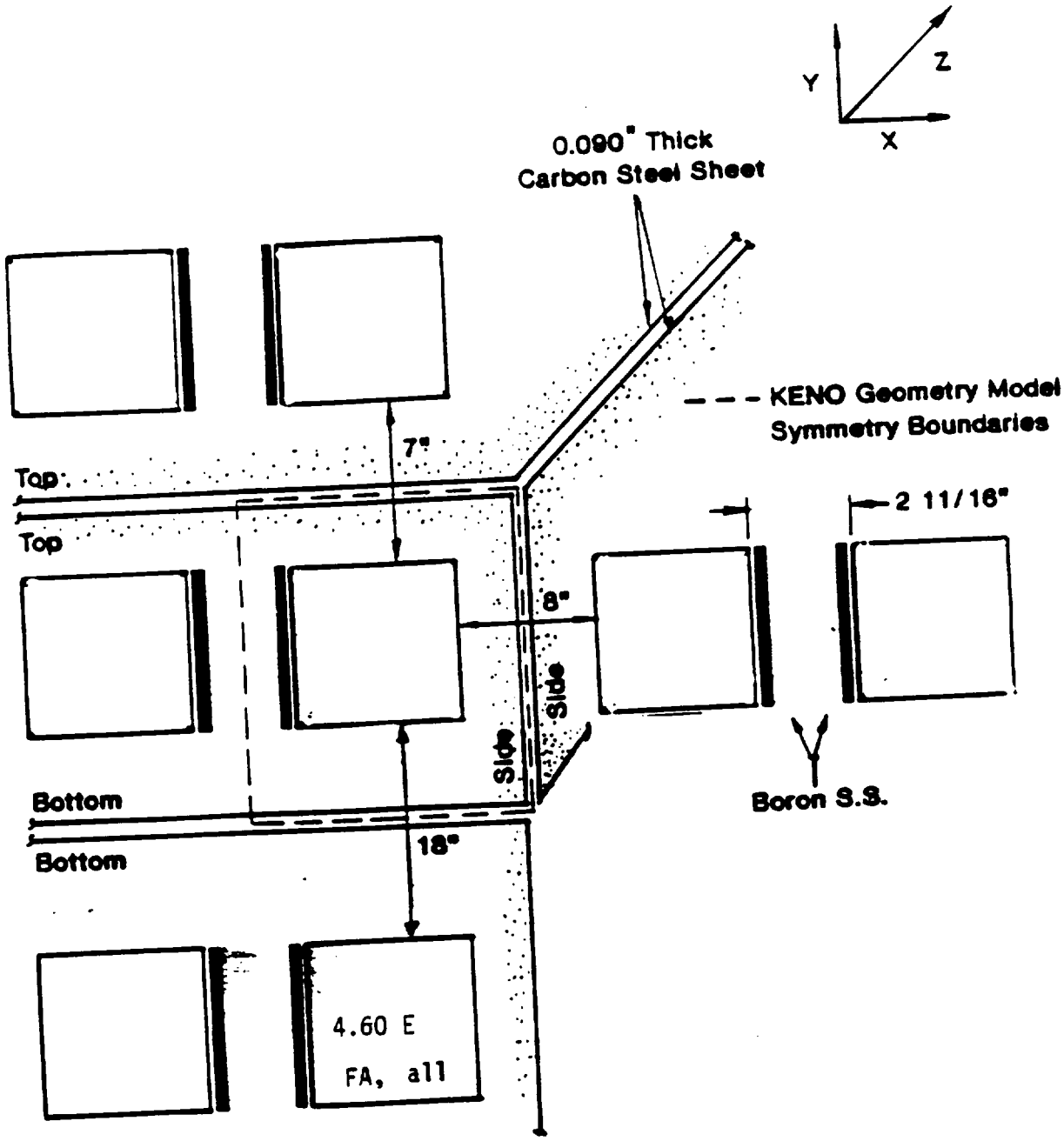


FIGURE 7

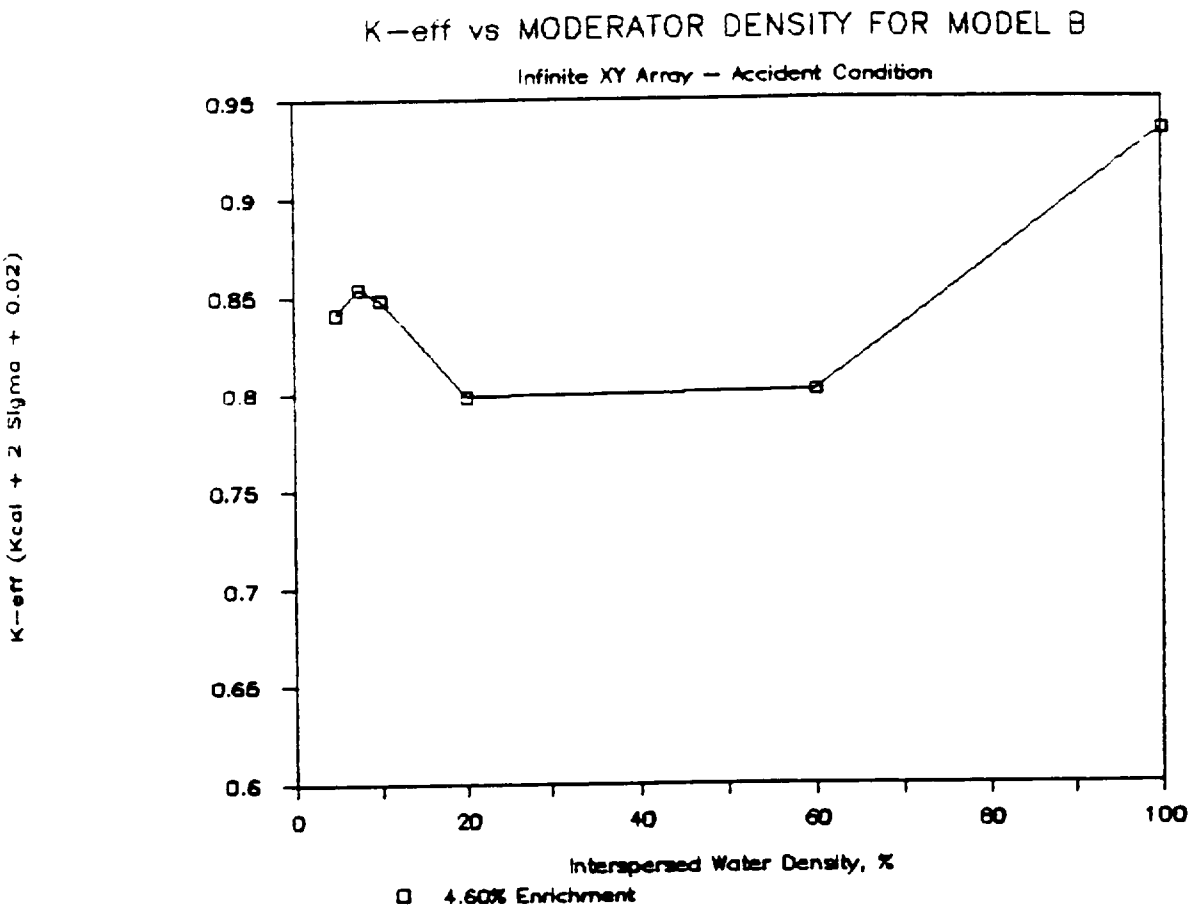

K-eff vs MODERATOR DENSITY FOR MODEL B
Infinite XY Array - Accident Condition
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
K-eff (Kcal + 2 Sigma + 0.02)
0
20
40
60
80
100
Interspersed Water Density, %
4.60% Enrichment

TABLE 1

Accident Array Case Description
for Product Fuel Assembly Designs

Case ID	Case Description[a]	K_{eff}	$\pm 2\sigma$	K_{max}	Fiche ID
1	5.1E MkBW 15x15 Modified Mod B Container Design	0.90677	.00466	0.93143	BASE51A1.868
2	5.1E MkB 15x15 Modified Mod B Container Design	0.90787	.00506	0.93293	MKB15x.886
3	5.1E MkBW 17x17 Modified Mod B Container Design	0.90012	.00534	0.92546	MKBW17x.891
4	5.1E MkB 17x17 Modified Mod B Container Design	0.89903	.00496	0.92399	MKB17x.915

TABLE 2

Accident Array Case Description
Geometry Models B and C

Case ID	Case Description[a]	K_{eff}	$\pm 2\sigma$	K_{max}	Fiche ID
5	Geometry Model C: 5.1E Mk BW 15x15 FA Design	0.90545	.00524	0.93069	NEOPREN2.941
6	Geometry Model B: 5.1E Mk BW 15x15 FA Design	0.90677	.00466	0.93143	BASE51A1.868

Table 3

ACCIDENT ARRAY CASE DESCRIPTION

Case ID	Case Description[a]	K_{eff}	$\pm 2\sigma$	K_{max}	Fiche ID
7	Base case 4.60 Enrichment	0.90907	.00502	0.93409	01281
8	Base case changed from 8" to 12" Z Refl.	0.90976	.00472	0.93448	01287
9	Base case changed to 200,400 histories	0.91133	.00336	0.93469	01293
10	Base case changed to 400,800 histories	0.91059	.00244	0.93303	01294
11	Base case with fuel pin pitch reduced by 10 percent	0.81010	.00470	0.83480	01593

$K_{max} = K_{eff} + 2\sigma + 0.02$

(a) All cases have 100,200 histories except as noted.

Table 4

KENO-IV(IBM RISC/6000) vs EXPERIMENT

Spacing Between Arrays	Core	Calculated by KENO IV on IBM RISC/6000	Measured[1]	Calculated minus Measured
None	I	1.00447(0.00181)	1.0002(0.0005)	0.00427(0.00188)*
None	II	1.00892(0.00168)	1.0001(0.0005)	0.00882(0.00175)
0.644	III	0.99937(0.00149)	1.0000(0.0006)	-0.00063(0.00161)
0.644	IV	1.00669(0.00192)	0.9999(0.0006)	0.00679(0.00201)
0.644	XI	0.99645(0.00172)	1.0000(0.0006)	-0.00355(0.00182)
0.644	XIII	1.01025(0.00188)	1.0000(0.0010)	0.01025(0.00213)
0.644	XIV	1.00405(0.00181)	1.0001(0.0010)	0.00395(0.00207)
0.644	XV	0.99596(0.00171)	0.9998(0.0016)	-0.00384(0.00234)
0.644	XVII	1.00015(0.00188)	1.0000(0.0010)	0.00015(0.00213)
0.644	XIX	1.00150(0.00176)	1.0002(0.0010)	0.00130(0.00202)
1.288	V	1.00189(0.00186)	1.0000(0.0007)	0.00189(0.00199)
1.288	VI	1.00929(0.00187)	1.0097(0.0012)	-0.00041(0.00222)
1.288	XII	0.99081(0.00163)	1.0000(0.0007)	-0.00919(0.00177)
1.288	XVI	0.99193(0.00200)	1.0001(0.0019)	-0.00817(0.00276)
1.288	XVIII	0.99139(0.00179)	1.0002(0.0011)	-0.00827(0.00205)
1.288	XX	0.99193(0.00186)	1.0003(0.0011)	-0.00837(0.00216)
1.932	VII	0.99190(0.00192)	0.9998(0.0009)	-0.00790(0.00212)
1.932	VIII	1.01708(0.00181)	1.0083(0.0012)	-0.00878(0.00217)
1.932	X	0.99279(0.00179)	1.0001(0.0009)	-0.00731(0.00200)
1.932	XXI	0.98954(0.00159)	0.9997(0.0015)	-0.01016(0.00219)
2.576	IX	0.98847(0.00185)	1.0030(0.0009)	-0.01453(0.00206)

* $(\sigma^2 + \sigma^2)^{0.5}$

1

1. BWFC Calculation File 32-1206565-00, KENO IV Benchmark Cases.

Table 5

Comparison of Fuel Assembly Design Data

	MkB 15x15	MkB 17x17	MkBW 15x15	MkBW 17x17	Conn Yank 15x15
FUEL ASSEMBLY					
No. fuel rods	208	264	204	264	204
No. guide tubes	16	24	20	24	20
No. instrument tubes	1	1	1	1	1
Fuel assembly loading, Kg/U	463.63	456.3	449.1	451.6	365.08
FUEL ROD CELL					
Fuel rod pitch, in.	0.568	0.501	0.563	0.496	0.5625
Fuel pellet O.D., in.	0.3686	0.324	0.3625	0.3195	0.361
Cladding O.D., in.	0.43	0.379	0.422	0.374	0.422
Cladding I.D., in.	0.377	0.332	0.37	0.326	0.368
Cladding material	Zr-4	Zr-4	Zr-4	Zr-4	Zr-4
Active fuel stack length, in.	≤ 144	≤ 144	≤ 144	≤ 144	119
GUIDE TUBE (GT) CELL					
GT upper section O.D., in.	0.53	0.465	0.546	0.482	0.543
GT upper section I.D., in.	0.498	0.43	0.512	0.45	0.519
GT upper section length,. in.	144	144	120	120	119
GT lower section length,. in.	-	-	24	24	
GT lower section O.D., in.	-	-	0.489	0.429	0.479
GT lower section O.D., in.	-	-	0.455	0.397	0.454
GT material	Zr-4	Zr-4	Zr-4	Zr-4	SS304
INSTRUMENT TUBE (IT) CELL					
IT O.D., in.	0.493	0.42	0.546	0.482	0.422
IT I.D., in.	0.441	0.39	0.512	0.45	0.389
IT material	Zr-4	Zr-4	Zr-4	Zr-4	SS304

Table 6

Fuel Assembly Maximum Uranium-235 Loading

	MkB 15x15	MkB 17x17	MkBW 15x15	MkBW 17x17
Maximum U-235 LOADING, KG	22.41	21.98	21.26	21.38

Parameters Used to Establish Maximum U-235 Loading

Enrichment, E	4.60	4.60	4.60	4.60
No. fuel rods	208	264	204	264
No. lattice cells	225	289	225	289
Fuel pellet O.D., in.	0.3686	0.324	0.3625	0.3195
Pellet density, %TD	96.3	96.3	96.3	96.3
Active fuel stack length, in.	144	144	144	144

APPENDIX A

MATERIALS PROPERTIES

I. Fuel

1. Fuel type - Unirradiated UO_2
2. Maximum uranium enrichment = 4.60 wt% U-235, including tolerances
3. Fuel pellet density = 96.3% of theoretical density

II. Interspersed Moderator

1. Moderator type - H_2O
2. Density range 5.0% to 100% TD
3. Temperature = 3.98F (maximum density)

III. Borated Steel Plate

1. Composition - 1.5 wt% natural boron in SS304
2. Poison credit - 75% of nominal boron concentration
3. Data source - CARP Order No. W45244 NUCLR, Carp. Tech. Corp, Reading Pa. 7/19/76.

IV. Carbon Steel Plate

1. Data source - Alloy Digest, Data on Worldwide Metals and Alloys, AISI C1010, March 1970.

V. Neoprene

1. Use - neoprene is bonded to the steel plates as a FA surface protector; thickness of 1/16 inch, width and length being the same as the steel plates.
2. Chemical formula: $CH_2C(Cl):CH.CH_2$
3. Density = 1.23 gm/cm^3
4. Data source - Lange's Handbook of Chemistry, 12th Edition.
5. Approximation:

   Substituted natural boron for chlorine on the basis of equal total absorption in a 1/v spectrum. The element chlorine is not available on the Master NITAWL library used at BWFC.

VI. Polyethylene

1. Polyethylene is used as FA wrapper; thickness of 0.008 inches, same length as FA , open both ends for drainage.
2. Chemical formula: $CH_2:CH_2$
3. Density = 0.9216 gm/cm^3
4. Data source - Lange's Handbook of Chemistry, 12th Edition.

VII. Isotopic weight source: Chart of the Nuclides, KAPL, Thirteenth Ed., July 1983.

```
HET FA XYZ1.5%BSS POISON PLATE 75% CRED,NORMAL ARRAY SPACNG,4.60%,NORMAL.46
   4000  203 501 3  123  75  12 13 31  36 8  16  16  1  -12
    1  0  2000  00  1  0  0  0  0 00  00  0  0
 -1.0 -1.0 -1.0 -1.0 -1.0 -1.0
  1     -922351  0.00109557
  1      922381  0.022434
  1       80004  0.047059
  2      400000  0.037498
  3       10001  0.06685386
  3       80004  0.03342693
  4      400000  0.0425
  5       10001  0.06685386
  5       80004  0.03342693
  6      400000  0.0425
  7       10001  0.06685386
  7       80004  0.03342693
  8       10001  0.06685386
  8       80004  0.03342693
  9       50000  4.9068-3
  9       60002  1.1777-4
  9      250005  1.4763-3
  9      140005  1.0913-3
  9      240003  1.6822-2
  9      280003  1.0991-2
  9      260001  5.3927-2
 10       60002  3.9259-4
 10      250005  3.4332-4
 10      260001  8.4011-2
 11       50000  0.081741
 11       60002  0.027247
 12       10001  0.04182
 12       50000  3.6192-4
 12       60002  0.03346
 13       10001  0.079134
 13       60002  0.039567
BOX TYPE    1
CYLINDER     1  0.460375                                    365.76  0.0  123Z
CYLINDER     2  0.535940                                    365.76  0.0  123Z
CUBOID       3  0.715010 -0.715010  0.715010 -0.715010 365.76  0.0  123Z
BOX TYPE    2
CYLINDER     5  0.638175                                    365.76  0.0  123Z
CYLINDER     4  0.681355                                    365.76  0.0  123Z
CUBOID       5  0.715010 -0.715010  0.715010 -0.715010 365.76  0.0  123Z
BOX TYPE    3
CYLINDER     7  0.650240                                    365.76  0.0  123Z
CYLINDER     6  0.693420                                    365.76  0.0  123Z
CUBOID       7  0.715010 -0.715010  0.715010 -0.715010 365.76  0.0  123Z
BOX TYPE    4
CUBOID       8  2.936875     0.0     1.430020     0.0     365.76  0.0  123Z
CUBOID       9  3.413125     0.0     1.430020     0.0     365.76  0.0  123Z
CUBOID      12  3.571875     0.0     1.430020     0.0     365.76  0.0  123Z
CUBOID      13  3.592195     0.0     1.430020     0.0     365.76  0.0  123Z
```



```
BOX TYPE    5
CUBOID      11  0.793750     0.0     1.430020     0.0     365.76  0.0  123Z
CUBOID       8  2.936875     0.0     1.430020     0.0     365.76  0.0  123Z
CUBOID       9  3.413125     0.0     1.430020     0.0     365.76  0.0  123Z
BOX TYPE    6
CUBOID       8  3.592195     0.0     1.611376     0.0     365.76  0.0  123Z
```

```
CUBOID        8  3.592195      0.0    3.043682     0.0    365.76  0.0  123Z
CUBOID       10  3.592195      0.0    3.519932     0.0    365.76  0.0  123Z
CUBOID        8  3.592195      0.0    3.678682     0.0    365.76  0.0  123Z
CUBOID        8  3.592195      0.0    3.699002     0.0    365.76  0.0  123Z
BOX TYPE    7
CUBOID        8  1.430020      0.0    1.611376     0.0    365.76  0.0  123Z
CUBOID        8  1.430020      0.0    3.043682     0.0    365.76  0.0  123Z
CUBOID       10  1.430020      0.0    3.519932     0.0    365.76  0.0  123Z
CUBOID       12  1.430020      0.0    3.678682     0.0    365.76  0.0  123Z
CUBOID       13  1.430020      0.0    3.699002     0.0    365.76  0.0  123Z
BOX TYPE    8
CUBOID        8  1.430020      0.0    1.611376     0.0    365.76  0.0  123Z
CUBOID        8  1.430020      0.0    3.043682     0.0    365.76  0.0  123Z
CUBOID       10  1.430020      0.0    3.519932     0.0    365.76  0.0  123Z
CUBOID       12  1.430020      0.0    3.678682     0.0    365.76  0.0  123Z
CUBOID       13  1.430020      0.0    3.699002     0.0    365.76  0.0  123Z
CORE BDY      0 25.042495      0.0   25.149300     0.0    365.76  0.0  123Z
CUBOID       13 25.062815      0.0   25.169622     0.0    365.76  0.0  123Z
CUBOID        8 55.3434        0.0   55.62930 -26.7810    365.76  0.0  123Z
CUBOID        8 55.5720        0.0   55.85790 -27.0096    365.76  0.0  123Z
CUBOID        8 55.5720        0.0   55.85790 -27.0096    386.08 -20.32 123Z
 1  2 16 1  2 16  1  1 1 1  0
 2  4  4 1  4  7  3  1 1 1  0
 2  4  4 1 11 14  3  1 1 1  0
 2  5  5 1  9  9  1  1 1 1  0
 2  6  6 1  6 12  6  1 1 1  0
 2  7  7 1  4 14 10  1 1 1  0
 2  9  9 1  5 13  8  1 1 1  0
 2 11 11 1  4 14 10  1 1 1  0
 2 12 12 1  6 12  6  1 1 1  0
 2 13 13 1  9  9  1  1 1 1  0
 2 14 14 1  4  7  3  1 1 1  0
 2 14 14 1 11 14  3  1 1 1  0
 3  9  9 1  9  9  1  1 1 1  0
 4  1  1 1  2 16  1  1 1 1  0
 6  1  1 1  1  1  1  1 1 1  0
 7  2 16 1  1  1  1  1 1 1  0
 8  5 13 1  1  1  1  1 1 1  1
END KENO
/EOR
```

```
HET FA XY ARRAY(MOD B DES 1.5%BSS 75% POI CRED)100%mod 4.60%E 3.98F base46.nrc
4000  203 501 3  123  75  12 13 31  36 8  16  16  1  -12
    1  0  2000  00  1  0  0  0  0 00  00  0  0
 -1.0 -1.0 -1.0 -1.0  0.0 0.0
  1     -922351  0.00109557     $ Fuel pellet
  1      922381  0.022434
  1       80004  0.047059
  2      400000  0.037498       $ Zr cladding
  3       10001  0.06685386     $ Water
  3       80004  0.03342693
  4      400000  0.0425         $ Zr guide tube
  5       10001  0.06685386     $ Water
  5       80004  0.03342693
  6      400000  0.0425         $ Instrument tube
  7       10001  0.06685386     $ Water
  7       80004  0.03342693
  8       10001  0.06685386     $ Water
  8       80004  0.03342693
  9       50000  4.9068-3       $ 1.5 wt% (@ 75% credit) natural boron in SS304
  9       60002  1.1777-4
  9      250005  1.4763-3
  9      140005  1.0913-3
  9      240003  1.6822-2
  9      280003  1.0991-2
  9      260001  5.3927-2
 10       60002  3.9259-4       $ Carbon steel 1010
 10      250005  3.4332-4
 10      260001  8.4011-2
 11       50000  0.081741       $ B4C  (@ 75% boron credit)  MATERIAL WAS NOT USED
 11       60002  0.027247
 12       10001  0.04182        $ Neoprene cushion material  CH2C(Cl):CH.CH2
 12       50000  3.6192-4         natural boron was substituted for chlorine on
 12       60002  0.03346          an absorption basis
 13       10001  0.079134       $ Polyethylene wrapper for FA
 13       60002  0.039567
BOX TYPE   1
CYLINDER    1  0.460375                                365.76  0.0  123Z
CYLINDER    2  0.535940                                365.76  0.0  123Z
CUBOID      3  0.715010 -0.715010  0.715010 -0.715010 365.76  0.0  123Z
BOX TYPE   2
CYLINDER    5  0.638175                                365.76  0.0  123Z
CYLINDER    4  0.681355                                365.76  0.0  123Z
CUBOID      5  0.715010 -0.715010  0.715010 -0.715010 365.76  0.0  123Z
BOX TYPE   3
CYLINDER    7  0.650240                                365.76  0.0  123Z
CYLINDER    6  0.693420                                365.76  0.0  123Z
CUBOID      7  0.715010 -0.715010  0.715010 -0.715010 365.76  0.0  123Z
BOX TYPE   4
CUBOID      8  2.936875     0.0    1.430020    0.0    365.76  0.0  123Z
CUBOID      9  3.413125     0.0    1.430020    0.0    365.76  0.0  123Z
CUBOID     12  3.571875     0.0    1.430020    0.0    365.76  0.0  123Z
CUBOID     13  3.592195     0.0    1.430020    0.0    365.76  0.0  123Z
```



```
BOX TYPE   5
CUBOID     11  0.793750     0.0    1.430020    0.0    365.76  0.0  123Z
CUBOID      8  2.936875     0.0    1.430020    0.0    365.76  0.0  123Z
CUBOID      9  3.413125     0.0    1.430020    0.0    365.76  0.0  123Z
BOX TYPE   6
CUBOID      8  3.592195     0.0    1.611376    0.0    365.76  0.0  123Z
```

```
CUBOID       8  3.592195      0.0     3.043682     0.0     365.76  0.0  123Z
CUBOID      10  3.592195      0.0     3.519932     0.0     365.76  0.0  123Z
CUBOID       8  3.592195      0.0     3.678682     0.0     365.76  0.0  123Z
CUBOID       8  3.592195      0.0     3.699002     0.0     365.76  0.0  123Z
BOX TYPE    7
CUBOID       8  1.430020      0.0     1.611376     0.0     365.76  0.0  123Z
CUBOID       8  1.430020      0.0     3.043682     0.0     365.76  0.0  123Z
CUBOID      10  1.430020      0.0     3.519932     0.0     365.76  0.0  123Z
CUBOID      12  1.430020      0.0     3.678682     0.0     365.76  0.0  123Z
CUBOID      13  1.430020      0.0     3.699002     0.0     365.76  0.0  123Z
BOX TYPE    8
CUBOID       8  1.430020      0.0     1.611376     0.0     365.76  0.0  123Z
CUBOID       8  1.430020      0.0     3.043682     0.0     365.76  0.0  123Z
CUBOID      10  1.430020      0.0     3.519932     0.0     365.76  0.0  123Z
CUBOID      12  1.430020      0.0     3.678682     0.0     365.76  0.0  123Z
CUBOID      13  1.430020      0.0     3.699002     0.0     365.76  0.0  123Z
CORE BDY     0 25.042495      0.0    25.149300     0.0     365.76  0.0  123Z
CUBOID      13 25.062815      0.0    25.169622     0.0     365.76  0.0  123Z
CUBOID       8 34.794825      0.0    33.81070  -18.93240    365.76  0.0  123Z
CUBOID      10 35.023425      0.0    34.03930  -19.16100    365.76  0.0  123Z
CUBOID       8 35.023425      0.0    34.03930  -19.16100    386.08 -20.32 123Z
 1  2 16 1  2 16  1  1 1 1  0
 2  4  4 1  4  7  3  1 1 1  0
 2  4  4 1 11 14  3  1 1 1  0
 2  5  5 1  9  9  1  1 1 1  0
 2  6  6 1  6 12  6  1 1 1  0
 2  7  7 1  4 14 10  1 1 1  0
 2  9  9 1  5 13  8  1 1 1  0
 2 11 11 1  4 14 10  1 1 1  0
 2 12 12 1  6 12  6  1 1 1  0
 2 13 13 1  9  9  1  1 1 1  0
 2 14 14 1  4  7  3  1 1 1  0
 2 14 14 1 11 14  3  1 1 1  0
 3  9  9 1  9  9  1  1 1 1  0
 4  1  1 1  2 16  1  1 1 1  0
 6  1  1 1  1  1  1  1 1 1  0
 7  2 16 1  1  1  1  1 1 1  0
 8  5 13 1  1  1  1  1 1 1  1
END KENO
/EOR
```

```
FA XY(Orig Design 1.5%BSS 75%Cd Poison Plat Config) 7.5MD 4.6E modB46a.075.cor
   4000  203 501 3  123  75  12 13 31  36 8  16  16  1  -12
    1  0  2000  00  1  0  0  0  0 00  00  0  0
 -1.0 -1.0 -1.0 -1.0  0.0 0.0
  1    -922351  0.00109557
  1     922381  0.022434
  1      80004  0.047059
  2     400000  0.037498
  3      10001  0.00501404
  3      80004  0.00250702
  4     400000  0.0425
  5      10001  0.00501404
  5      80004  0.00250702
  6     400000  0.0425
  7      10001  0.00501404
  7      80004  0.00250702
  8      10001  0.00501404
  8      80004  0.00250702
  9      50000  4.9068-3
  9      60002  1.1777-4
  9     250005  1.4763-3
  9     140005  1.0913-3
  9     240003  1.6822-2
  9     280003  1.0991-2
  9     260001  5.3927-2
 10      60002  3.9259-4
 10     250005  3.4332-4
 10     260001  8.4011-2
 11      50000  0.081741
 11      60002  0.027247
 12      10001  0.04182
 12      50000  3.6192-4
 12      60002  0.03346
 13      10001  0.079134
 13      60002  0.039567
BOX TYPE   1
CYLINDER    1  0.460375                                365.76  0.0  123Z
CYLINDER    2  0.535940                                365.76  0.0  123Z
CUBOID      3  0.715010 -0.715010  0.715010 -0.715010 365.76  0.0  123Z
BOX TYPE   2
CYLINDER    5  0.638175                                365.76  0.0  123Z
CYLINDER    4  0.681355                                365.76  0.0  123Z
CUBOID      5  0.715010 -0.715010  0.715010 -0.715010 365.76  0.0  123Z
BOX TYPE   3
CYLINDER    7  0.650240                                365.76  0.0  123Z
CYLINDER    6  0.693420                                365.76  0.0  123Z
CUBOID      7  0.715010 -0.715010  0.715010 -0.715010 365.76  0.0  123Z
BOX TYPE   4
CUBOID      8  2.936875     0.0    1.430020     0.0    365.76  0.0  123Z
CUBOID      9  3.413125     0.0    1.430020     0.0    365.76  0.0  123Z
CUBOID     12  3.571875     0.0    1.430020     0.0    365.76  0.0  123Z
CUBOID     13  3.592195     0.0    1.430020     0.0    365.76  0.0  123Z
```

Input Case ID: Worst Accident Array - 7.5% Mod Dens. Output Case 01770

```
BOX TYPE   5
CUBOID     11  0.793750     0.0    1.430020     0.0    365.76  0.0  123Z
CUBOID      8  2.936875     0.0    1.430020     0.0    365.76  0.0  123Z
CUBOID      9  3.413125     0.0    1.430020     0.0    365.76  0.0  123Z
BOX TYPE   6
CUBOID      8  3.592195     0.0    1.611376     0.0    365.76  0.0  123Z
CUBOID      8  3.592195     0.0    3.043682     0.0    365.76  0.0  123Z
```

```
CUBOID      10  3.592195     0.0    3.519932     0.0    365.76  0.0  123Z
CUBOID       8  3.592195     0.0    3.678682     0.0    365.76  0.0  123Z
CUBOID       8  3.592195     0.0    3.699002     0.0    365.76  0.0  123Z
BOX TYPE     7
CUBOID       8  1.430020     0.0    1.611376     0.0    365.76  0.0  123Z
CUBOID       8  1.430020     0.0    3.043682     0.0    365.76  0.0  123Z
CUBOID      10  1.430020     0.0    3.519932     0.0    365.76  0.0  123Z
CUBOID      12  1.430020     0.0    3.678682     0.0    365.76  0.0  123Z
CUBOID      13  1.430020     0.0    3.699002     0.0    365.76  0.0  123Z
BOX TYPE     8
CUBOID       8  1.430020     0.0    1.611376     0.0    365.76  0.0  123Z
CUBOID       8  1.430020     0.0    3.043682     0.0    365.76  0.0  123Z
CUBOID      10  1.430020     0.0    3.519932     0.0    365.76  0.0  123Z
CUBOID      12  1.430020     0.0    3.678682     0.0    365.76  0.0  123Z
CUBOID      13  1.430020     0.0    3.699002     0.0    365.76  0.0  123Z
CORE BDY     0 25.042495     0.0   25.149300     0.0    365.76  0.0  123Z
CUBOID      13 25.062815     0.0   25.169622     0.0    365.76  0.0  123Z
CUBOID       8 34.794825     0.0   33.81070  -18.93240   365.76  0.0  123Z
CUBOID      10 35.023425     0.0   34.03930  -19.16100   365.76  0.0  123Z
CUBOID       8 35.023425     0.0   34.03930  -19.16100   386.08 -20.32 123Z
 1  2 16 1  2 16  1  1 1 1  0
 2  4  4 1  4  7  3  1 1 1  0
 2  4  4 1 11 14  3  1 1 1  0
 2  5  5 1  9  9  1  1 1 1  0
 2  6  6 1  6 12  6  1 1 1  0
 2  7  7 1  4 14 10  1 1 1  0
 2  9  9 1  5 13  8  1 1 1  0
 2 11 11 1  4 14 10  1 1 1  0
 2 12 12 1  6 12  6  1 1 1  0
 2 13 13 1  9  9  1  1 1 1  0
 2 14 14 1  4  7  3  1 1 1  0
 2 14 14 1 11 14  3  1 1 1  0
 3  9  9 1  9  9  1  1 1 1  0
 4  1  1 1  2 16  1  1 1 1  0
 6  1  1 1  1  1  1  1 1 1  0
 7  2 16 1  1  1  1  1 1 1  0
 8  5 13 1  1  1  1  1 1 1  1
END KENO
/EOR
```