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SUBJECT: Forwards nonproprietary & proprietary responses to request for addl info re criticality analyses for spent fuel racks. Draft SER Open Item 360 completed.Proprietary response withheld (ref 10CFR2.790).

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SUBJECT: Forwards nonproprietary & proprietary responses to request for addl info re criticality analyses for spent fuel racks. Draft SER open item 560 completed.Proprietary response withheld (ref 10CFR2.790).

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OCT 21 1983

Mr. Harold R. Denton, Director
Office of Nuclear Reactor Regulation
United States Nuclear Regulatory Commission
Washington, DC 20555

SHEARON HARRIS NUCLEAR POWER PLANT
UNIT NOS. 1 AND 2
DOCKET NOS. 50-400 AND 50-401
DRAFT SAFETY EVALUATION REPORT OPEN ITEMS
AUXILIARY SYSTEMS BRANCH

Dear Mr. Denton:

This submittal is in response to an NRC reviewer's request for additional information addressing the criticality analyses for the spent fuel racks referred to in CP&L's letter dated October 11, 1983, Serial No. LAP-83-472 and completes all requested information for draft SER Open Item 360.

Enclosed are:

1. One (1) copy of Westinghouse "Shearon Harris Spent Fuel Rack Criticality Analysis" (Proprietary).

2. Forty (40) copies of Westinghouse "Shearon Harris Spent Fuel Rack Criticality Analysis" (Non-Proprietary).

3. One (1) copy of Application for Withholding (CAW-83-86) (Non-Proprietary).

4. One (1) copy of Affidavit (CAW-83-16) (Non-Proprietary).

This submittal contains proprietary information of Westinghouse Electric Corporation. In conformance with the requirements of 10CFR Section 2.790, as amended, of the Commission's regulations, we are enclosing with this submittal an application for withholding from public disclosure and an affidavit. The affidavit sets forth the basis on which the information may be withheld from public disclosure by the Commission.

Correspondence with respect to the affidavit or application for withholding should reference CAW-83-86 and should be addressed to R. A. Wiesemann, Manager, Regulatory & Legislative Affairs, Westinghouse Electric Corporation, P. O. Box 355, Pittsburgh, Pennsylvania 15230.

Yours very truly,

M. A. McDuffie

M. A. McDuffie
Senior Vice President
Nuclear Generation

MAM/pgp (8205NLU)
Enclosures

cc: Mr. B. C. Buckley (NRC)*
Mr. G. F. Maxwell (NRC-SHNPP)
Mr. J. P. O'Reilly (NRC-RII)
Mr. Travis Payne (KUDZU)
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Dr. J. H. Carpenter (ASLB)
Mr. J. L. Kelley (ASLB)

* Denotes parties which have received the proprietary information.

Shearon Harris Nuclear Power Plant
Draft SER Open Item 360
ASB Question 9.1.2

In order to permit us to evaluate K_{eff} for spent fuel pools, provide further information regarding all fuel to be stored, fuel distribution within the pool(s), a detailed description of the storage racks, a description of the calculational methods used in the determination of K_{eff} by CP&L toegther with a discussion of the calculation and mechanical uncertainties considered in the calculation. Describe how control will be maintained over the location of the fuel in the spent fuel pools.

Response

The maximum U-235 enrichment is 3.9 for the Westinghouse 17x17 fuel. The rack parameters are shown in Table 1. This table will be included in FSAR Section 9.1.2 in a future amendment.

The previously mentioned proprietary submittal addressing criticality analyses for the Shearon Harris spent fuel racks is attached.

TABLE 1

SHEARON HARRIS SPENT FUEL RACK DIMENSIONS

Fuel Type: W 17x17 and GE 8x8

RACK TYPE	POISON	BWR
C-C SPACING	10.500	6.250
CELL I.D.	8.750	6.050
POISON CAVITY	0.090	0.060
POISON WIDTH	7.500	5.100
CELL GAP (NOMINAL)	1.330	---
POISON THICKNESS	0.075	0.045
WALL THICKNESS	0.075	0.075
WRAPPER THICKNESS	0.035	0.035
POISON (GM-B10/SQ.CM)	0.020	0.0103

All Dimensions in Inches

3.4 CRITICALITY ANALYSIS

3.4.1 NEUTRON MULTIPLICATION FACTOR

Criticality of fuel assemblies in the spent fuel storage rack is prevented by the design of the racks which limits fuel assembly interaction. This is done by fixing the minimum separation between assemblies and inserting neutron poison between assemblies.

The design basis for preventing criticality outside the reactor is that, including uncertainties, there is a 95 percent probability at a 95 percent confidence level that the effective multiplication factor (K_{eff}) of the fuel assembly array will be less than 0.95 as recommended in ANSI N210-1976 and in "NRC Position for Review and Acceptance of Spent Fuel Storage and Handling Applications".

The following are the conditions that are assumed in meeting this design basis for the Shearon Harris spent fuel storage racks.

3.4.2 NORMAL STORAGE

3.4.2.1 PWR FUEL

a. The fuel assembly contains the highest enrichment authorized without any control rods or any noncontained burnable poison and is at its most reactive point in life. The enrichment of the 17 x 17 Westinghouse optimized fuel assembly is 3.9 w/o U-235 with no depletion or fission product buildup. The following assembly parameters were modeled:

WESTINGHOUSE FUEL ASSEMBLY (17 X 17 OFA)

Number of Fuel Rods per assy.	=	264
Zirc-4 Rod Clad O.D.	=	0.36"
Clad Thickness	=	0.0225"
Fuel Pellet O.D.	=	0.3088"

Fuel Pellet Density	=	95% Theoretical
Fuel Pellet Dishing	=	1.20%
Rod Pitch	=	0.496" Square
Number Zirc-4 Guide Tubes	=	25
Guide Tube O.D.	=	0.474"
Guide Tube Thickness	=	0.016"

The assembly is conservatively modeled with water replacing the assembly grid volume and no U-234 or U-236 in the fuel pellet. No U-235 burnup is assumed.

b. The storage cell nominal geometry is shown on Figure 3.4-1.

c. The moderator is pure water at the temperature within the design limits of the pool which yields the largest reactivity. A conservative value of 1.0 gm/cm^3 is used for the density of water. No dissolved boron is included in the water.

d. The array is either infinite in lateral extent or is surrounded by a conservatively chosen reflector, whichever is appropriate for the analytical model. The nominal case calculation is infinite in lateral and axial extent. Poison plates are not necessary on the periphery of the rack module except for the sides of the module adjacent to another rack module (either a PWR rack or a BWR rack). However for the Shearon Harris PWR racks, poison plates are used on all module peripheries except for one module in each pool. Poison plates are omitted from one side of the module (6 cells) for compatibility with the surveillance inspection program.

Calculations for those racks with the poison removed indicate a less reactive configuration than the nominal case of an infinite rack. Therefore, the nominal case of an infinite array of poison cells is a conservative assumption.

e. Mechanical uncertainties and biases due to mechanical tolerances during construction are treated by either using "worst case" conditions or by performing sensitivity studies to obtain the appropriate values. The items included in the analysis are:

- poison pocket thickness
- stainless steel thickness
- can ID
- center-to-center spacing
- can bowing

The calculation method uncertainty and bias is discussed in Section 3.4.4.

f. Credit is taken for the neutron absorption in full length structural materials and in solid materials added specifically for neutron absorption. The minimum poison loading (0.02 gm $B10/cm^2$) is assumed in the poison plates and B_4C particle self shielding is included as a bias in the reactivity calculation.

3.4.2.2 BWR FUEL

a. The fuel assembly contains the highest enrichment authorized without any burnable poison and is at its most reactive point in life. The enrichment of the fuel assembly is 3.20 w/o U-235 with no depletion or fission product buildup. The fuel assembly is modeled using the following parameters:

GENERAL ELECTRIC FUEL ASSEMBLY (BWR 8 x 8R)

Lattice Pitch - 0.640" square
No. Fuel Rods/Assembly - 62
No. Water Rods/Assembly - 2
Location of Water Rods - Positions #29 & #36
Fuel Rod Pellet O.D. - 0.410"
Fuel Rod Pellet Immersion Density - 95% Theoretical

Active Fuel Length -

6" Natural UO_2, 138" enriched (3.2 w/o U-235), 6" Natural UO_2

Fuel Rod Clad O.D. - 0.483"

Fuel Rod Clad Thickness - 0.032"

Fuel Rod Clad Material - Zircaloy - 2

Water Rod O.D. - 0.591"

Water Rod Thickness - 0.030"

Water Rod Material - Zircaloy - 2

FUEL - CHANNEL

Material - Zircaloy - 2

Thickness - 0.080"

Inside Square Dim. - 5.268" (min.)

Outside Square Dim. - 5.454" (max.)

Inside Square Dim. - 5.281" (avg.)

Outside Square Dim. - 5.441" (avg.)

The assembly is conservatively modeled with water replacing the assembly grid volume and no U-234 or U-236 in the fuel pellet. No U-235 burnup is assumed, nor is any credit taken for gadolinium burnable poison.

b. Figure 3.4-2 shows a schematic of the spent fuel storage racks illustrating the checkerboard arrangement of cell modules. Figure 3.4-3 shows the nominal dimensions of individual cell modules and indicates the unit cell modeled in the KENO analysis.

c. The moderator is pure water at the temperature within the design limits of the pool which yields the largest reactivity. A conservative value of 1.0 gm/cm^3 is used for the density of water.

d. The array is either infinite in lateral extent or is surrounded by a conservatively chosen reflector, whichever is appropriate for the analytical model. The nominal case analytical model is infinite in lateral extent. The following dimensions were modeled in the axial direction:

Rod Clad = 159.5"

Fuel = { 6" natural UO_2 (top)
138" enriched (3.2 w/o U-235)
6" natural UO_2 (bottom)

Channels = 164"

Boraflex = 151"

Storage Cell Can = 164"

Poison plates are not necessary on the periphery of the rack modules since adjacent BWR racks are located far enough apart to preclude an increase in reactivity relative to the infinite array model of poison cells. Furthermore, the BWR rack modules with no poison on the periphery are also located far enough from the PWR modules to preclude an increase in reactivity relative to the infinite array model of PWR or BWR poison cells.

e. Mechanical uncertainties and biases due to mechanical tolerances during construction are treated by either using "worst case" conditions or by performing sensitivity studies to obtain the appropriate values. The items included in the analysis are:

- rack assembly tolerances
- material thickness tolerances
- center-to-center spacing
- fuel channel effects
- poison loading

The calculational method uncertainty and bias is discussed in Section 3.4.4.

f. Credit is taken for the neutron absorption in full length structural materials and in solid materials added specifically for neutron absorption. The minimum poison loading (0.0103 gm-B^{10}/cm^2) is assumed in the poison plates and B_4C particle self shielding is included as a bias in the reactivity calculation.

3.4.3 POSTULATED ACCIDENTS

The following postulated accidents were analyzed:

a. Drop of fuel assembly on top of racks.

b. Drop of fuel assembly next to the unpoisoned periphery of the racks.

c. Inadvertent loading of wrong type of fuel into a storage cell.

d. Loss of cooling systems

e. Water injection into racks when used for dry storage.

Each of these accidents are discussed in the sections which follow.

3.4.3.1 Drop of Fuel Assembly on Top of Racks

Four possible accident scenarios can be postulated as follows:

1) drop of a PWR assembly on either a PWR or a BWR rack, and,
2) drop of a BWR assembly on either a PWR or a BWR rack.

A fuel assembly dropped on top of the racks will be prevented by the rack structure from interacting with the active fuel stored in the rack. The top of the active fuel stored in the BWR racks is approximately 13 inches from the top of the rack structure; the top of the active fuel stored in the PWR racks is approximately 8.5 inches from

the top of the rack structure. Furthermore, calculations show that a single isolated PWR assembly in water is more reactive ($K_{eff} \simeq 0.9$) than a single isolated BWR assembly in water ($K_{eff} \simeq 0.7$). Consequently, the worst case condition is the drop of a PWR assembly on top of a PWR rack.

Calculations show that even for an infinite array of PWR assemblies separated from each other by as little as 7 inches of water will have a nominal K_{eff} of less than 0.9 which clearly demonstrates that an assembly 8.5 inches from active fuel is essentially isolated.

3.4.3.2 Drop of Fuel Assembly Next to the Unpoisoned Perphery of the Racks

The "worst case" conditions for this accident would be the drop of a PWR fuel assembly next to an unpoisoned peripheral storage cell of a PWR storage rack. This situation could lead to an increase in K_{eff} for the array of stored fuel. Therefore, the double contingency principle of ANS N16.1-1975 is applied for this accident. This principle states that it is unnecessary to assume two unlikely, independent, concurrent events to ensure protection against a criticality accident. Thus, for accident conditions, the presence of soluble boron (~2000 ppm) in the storage pool water can be assumed as a realistic initial condition since not assuming its presence would be a second unlikely event.

In the case of Westinghouse 17 x 17 OFA fuel, the presence of approximately 2000 ppm boron in pool water will decrease reactivity by more than 30% ΔK. Thus $K_{eff} < 0.95$ can be easily met for this postulated accident since any reactivity increase would be less than the negative worth of the dissolved boron.

3.4.3.3 Inadvertent Loading of the Wrong Type of Fuel Into a Storage Cell

The design of the storage racks is such that a PWR fuel assembly (because of its physical size) cannot be inadvertently loaded into a BWR storage cell. If a BWR fuel assembly is inadvertently loaded into a PWR storage cell, the design basis K_{eff} is not exceeded since the single BWR fuel assembly is less reactive than the PWR assembly.

3.4.3.4 Loss of Cooling Systems/Water Injection Into Racks When Used for Dry Storage

For the loss of cooling accident the effect would be a decrease in the water moderator density. This accident can be grouped with the accident in which the storage racks are used as a new fuel dry storage facility and water is introduced for fire fighting or some other abnormal situation. Both accidents involve moderator densities less than 1 gm/cc and suggest the "optimum moderation" condition. However, the "optimum moderation" accident is not a problem in poisoned fuel storage racks. The presence of poison plates removes the conditions necessary for "optimum moderation" so that K_{eff} continually decreases as moderator density decreases from 1.0 gm/cm^3 to 0.0 gm/cm^3 in poison rack designs.

Figure 3.4-4 shows the behavior of K_{eff} as a function of moderator density for a BWR poisoned spent fuel rack and Figure 3.4-5 shows a similar behavior for a PWR spent fuel rack.

3.4.4 CRITICALITY ANALYTICAL METHOD

The design method which ensures the criticality safety of fuel assemblies in the PWR and BWR spent fuel storage racks uses the AMPX system of codes[1,2] for cross-section generation and KENO IV[3] for reactivity determination.

The 218 energy group cross-section library[1] that is the common starting point for all cross-sections used for the storage rack analyses was generated from ENDF/B-IV data. The NITAWL program[2] adds to this library the self-shielded resonance cross-sections that are appropriate for each particular geometry. The Nordheim Integral Treatment is used in the NITAWL program. Energy and spatial weighting of cross-sections is performed by the XSDRNPM program[2] which is a one-dimensional S_n transport theory code. These multigroup cross-section sets are then used as input to KENO IV[3], which is a three dimensional Monte Carlo theory program designed for reactivity calculations.

The calculation method and cross-section values are verified by comparison with critical experiment data for assemblies similar to those for which the racks are designed. This benchmarking data is sufficiently diverse to establish that the method bias and uncertainty will apply to rack conditions which incude strong neutron absorbers, large water gaps and low moderator densities.

A set of 27 critical experiments has been analyzed using the above method to demonstrate its applicability to criticality analysis and to establish the method bias and variability. The experiments range from water moderated, oxide fuel arrays separated by various materials (Boral, steel, water) that simulate LWR fuel shipping and storage conditions,[4,5] to dry, harder spectrum uranium metal cylinder arrays with various interspersed materials[6] (Plexiglas, steel and air) that demontrate the wide range of applicability of the method.

The results and some descriptive facts about each of the 27 benchmark critical experiments are given in Table 3.4-1. The average K_{eff} of the benchmarks is 0.9998 which demonstrates that there is no bias associated with the method. The standard deviation of the K_{eff} values is 0.0057 ΔK. The 95/95 one-sided tolerance limit factor for 27 values is 2.26. Thus, there is a 95 percent probability with a

95 percent confidence level that the uncertainty in reactivity, due to the method, is not greater than 0.013 ΔK.

These methods conform with ANSI N18.2-1973, "Nuclear Safety Criteria for the Design of Stationary Pressurized Water Reactor Plants", Section 5.7, Fuel Handling System; ANSI N210-1976, "Design Objective for LWR Spent Fuel Storage Facilities at Nuclear Power Stations", Section 5.1.12; ANSI N16.9-175, "Validation of Calculational Methods for Nuclear Criticality Safety"; NRC Standard Review Plan, Section 9.1.2, "Spent Fuel Storage"; and the NRC Guidance, "NRC Position for Review and Acceptance of Spent Fuel Storage and Handling Applications".

3.4.5 CRITICALITY ANALYSIS

This section presents the neutron multiplication factor K_{eff} calculated using the above method for the nominal designs of both the PWR and BWR racks. Biases and uncertainties are developed for both rack types and include consideration of the following variables: poison loading, poison particle size, rack construction tolerances, rack material thickness tolerances, water density and calculation method uncertainty. This section also combines the nominal K_{eff} with biases and uncertainties to develop a final K_{eff} for each type of storage rack (i.e. BWR or PWR) at a 95 percent probability with a 95 percent confidence level.

This section also presents the results of sensitivity studies which show how the K_{eff} for the array varies as a function of cell center-to-center spacing, fuel enrichment, and poison loading of the poison plates. Finally, this section discusses the combination of BWR fuel racks loaded in the same pool with PWR fuel racks and the possibility of interaction between the two fuel types.

3.4.5.1 PWR Fuel Storage Racks

a. Nominal KENO K_{eff}

The K_{eff} for the nominal design of the PWR fuel storage racks was computed by the KENO code to be 0.8968 ± .0050 (95/95). The KENO model was based on the nominal dimensions of the unit cell shown on figure 3.4-1. The minimum boron loading of 0.02 grams of B^{10} per square centimeter was incorporated in the model and the water density was 1 gram per cubic centimeter. The fuel parameters modeled for the nominal KENO are given in section 3.4.2.1.

b. Biases and Uncertainties

As discussed in section 3.4.4 the KENO method had a 0.0 bias with a 95/95 uncertainty of 0.013 Δk.

Calculations have shown that when the boron in the poison plates is modeled as a homogenized mixture of elements, the results are biased by a positive 0.0025 Δk relative to models which discretely define the B_4C particles.

The mechanical tolerances of the individual storage cells and the construction tolerances of the PWR fuel storage rack will allow storage cells to be closer together than the [ ]a,b,c,e inches shown on Figure 3.4-1. For the Shearon Harris PWR racks the worst combination of mechanical tolerances (i.e., sheet metal thickness, cell I.D. maximum, rack grid assembly, and cell bowing) will result in a reduction of the water gap between adjacent cells by [.]a,b,c,e Furthermore, a "GO-NOGO" gauge will be employed during construction to ensure that the nominal gap of [ ]a,b,c,e (see Figure 3.4-1) between the wrapper plates of adjacent cells will not be less than [ ]a,b,c,e inches. For a single can it is calculated that reactivity does not increase significantly because the increase in reactivity due to the water gap reduction on one side of the can is offset by the decrease in reactivity due to the increased water gap on the opposite side of this can. The analysis, for the effect of mechanical tolerances, however, assumes a worst case of a rack composed of an array of groups of four cans where the water gap between the four cans is reduced to [ ] a,b,c,e inch. The reactivity increase of this configuration is found to be 0.011 Δk and is included as a bias term in calculating the final K_{eff} of the rack.

Some mechanical tolerances are not included in the analysis because worst case assumptions are used in the nominal case analysis. An example of this is eccentric assembly position.. Calculations were performed which show that the most reactive condition is the assembly centered in the can which is assumed in the nominal case.

c. Final K_{eff} for PWR Fuel Storage Racks

For normal operation and using the method described in the above sections, the final K_{eff} for the rack is determined in the following manner:

$$K_{eff} = K_{nominal} + B_{mech} + B_{method} + B_{part} + [(ks_{nominal})^2 + (ks_{method})^2]^{1/2}$$

where:

$K_{nominal}$ = nominal case KENO K_{eff}

B_{mech} = bias to account for the fact that mechanical tolerances can result in water gaps between poison plates less than nominal.

B_{method} = method bias determined from benchmark critical comparisons.

B_{part} = bias to account for poison particle self-shielding.

$ks_{nominal}$ = 95/95 uncertainty in the nominal case KENO K_{eff}

ks_{method} = 95/95 uncertainty in the method bias.

Substituting calculated values as developed in items a and b, the result is:

$$K_{eff} = 0.8968 + 0.011 + 0.0 + 0.0025 + [(0.0050)^2 + (0.013)^2]^{1/2}$$

$$= 0.9242.$$

Since K_{eff} is less than 0.95 including uncertainties at a 95/95 probability/confidence level, the acceptance criteria for criticality is met.

d. Sensitivity Studies for PWR Racks

To show the dependence of K_{eff} on fuel and storage cell parameters as requested by the NRC, sensitivity studies were performed relative to the nominal model in which the boron loading of the poison plates, the fuel enrichment, and the storage cell center-to-center spacing were varied. Figure 3.4-6 shows the results of the calculations of the sensitivity studies for the Shearon Harris PWR fuel storage racks.

3.4.5.2 <u>BWR Fuel Storage Racks</u>

a. Nominal KENO K_{eff}

The K_{eff} for the nominal design of the BWR fuel storage racks was computed by the KENO computer code to be 0.9274 ± .0031 (95/95). The KENO model was based on the nominal dimensions of the unit cell shown on Figure 3.4-3. The minimum boron loading of 0.0103 grams of B^{10} per square centimeter was incorporated in the model and the water density was 1 gram per cubic centimeter. The fuel parameters modeled for the nominal KENO are given in section 3.4.2.2.

b. Biases and Uncertainties

As discussed in section 3.4.4, the KENO method had a 0.0 bias with a 95/95 uncertainty of .013 Δk.

Calculations have shown that when the boron in the poison plates is modeled as a homogenized mixture of elements, the results are biased by a positive 0.006 Δk relative to models which discretely define the B_4C particles.

The construction tolerances for BWR racks allow for the nominal center-to-center spacing of storage cells of [ ] a,b,c,e inches to be randomly reduced to [ ] a,b,c,e inches for individual cells. It was calculated that the increase in K_{eff} due to the random reduction in cell center-to-center would be less than 0.032 Δk with a (95% confidence/95% probability) level. Calculations for material thicknesses tolerances of the cell sheet metal and the poison plates indicated that the increase in Δk would be less than 0.0079 with a (95% confidence/95% probability) level.

In addition to the uncertainty in the final K_{eff} associated with the various parameters discussed above, there are other physical variables that may affect K_{eff}. Analysis showed that the infinite poisoned array was more reactive with fuel channels included than it was without the channels. It was also determined that the reactivity was higher for the fuel (either channeled or unchanneled) when the assemblies were located exactly in the center of the storage cells. The boraflex poison is specified to contain a minimum loading of .0103 grams of B^{10} per square centimeter and that value was employed throughout the analysis for the sake of conservatism. The "nominal" case KENO (see Item a) then has already incorporated three "worst case" conditions (i.e. centered fuel, channels included, and minimum poison loading).

c. Final K_{eff} For BWR Fuel Storage Racks

For normal operation and using the method described in the above sections, the final K_{eff} for the rack is determined in the following manner.

$$K_{eff} = K_{nominal} + B_{method} + B_{part} + [(ks_{nominal})^2 + (ks_{mech})^2 + (ks_{method})^2 + (ks_{mat})^2]^{1/2}$$

where:

$K_{nominal}$ = nominal case KENO K_{eff}

B_{method} = method bias determined from benchmark critical comparisons.

B_{part} = bias to account for poison particle self-shielding.

$ks_{nominal}$ = 95/95 uncertainty in the nominal case KENO K_{eff}.

ks_{mech} = 95/95 uncertainty in the calculation of the bias due to construction tolerances.

ks_{method} = 95/95 uncertainty in the method bias.

ks_{mat} = 95/95 uncertainty associated with material thickness tolerances.

Substituting calculated values given in items a and b in the order listed above, the result is:

$$K_{eff} = 0.9274 + 0.0 + 0.006 + [(.0031)^2 + (.0032)^2 + (.013)^2 + (.0079)^2]^{1/2} = 0.9493$$

Since K_{eff} is less than 0.95 including uncertainties at a 95/95 probability/confidence level, the acceptance criteria for criticality is met.

d. Sensitivity Studies for BWR Racks

To show the dependence of K_{eff} on fuel and storage cell parameters as requested by the NRC, sensitivity studies were performed relative to the nominal model in which the boron loading of the poison plates, the fuel enrichment, and the storage cell center-to-center spacing were varied. Figures 3.4-7 and 3.4-8 show the results of the calculations of the sensitivity studies.

3.4.5.3 PWR/BWR Racks in Same Pool

In the Shearon Harris spent fuel pools both PWR and BWR fuel storage racks may be placed in the same pool. In sections 3.4.5.1 and 3.4.5.2 it was determined that the maximum neutron multiplication factor, K_{eff}, for an infinite array of stored fuel, including uncertainties was 0.9242 for PWR fuel and 0.9493 for BWR fuel. Calculations were performed which showed that, if the cell centerline plane of the peripheral cells of a BWR rack were maintained at a distance equal to or greater than 9.0 inches from the cell centerline plane of the peripheral cells of a PWR rack, the resulting K_{eff} for the combined configuration was less than 0.94. Since the pool layouts indicate that the 9 inch minimum is not violated, the acceptance criteria is met for pools containing both BWR and PWR storage racks.

3.4.6 ACCEPTANCE CRITERIA FOR CRITICALITY

The neutron multiplication factor in the spent fuel pool shall be less than or equal to 0.95, including all uncertainties, under all conditions.

Generally, the acceptance criteria for postulated accident conditions can be $K_{eff} \leq 0.98$ because of the accuracy of the methods used coupled with the low probability of occurrence. For instance, in ANSI N210-1976 the acceptance criteria for the "optimum moderation" condition is $K_{eff} \leq 0.98$. However, for simiplicity, the acceptance criteria for all conditions will be $K_{eff} \leq 0.95$ including accidents.

REFERENCES

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3. L.M. Petrie and N.F. Cross, "KENO IV" - An Improved Monte Carlo Criticality Program," ORNL-4938 (November 1975).

4. S.R. Bierman, et al, "Critical Separation Between Subcritical Clusters of 2.35 wt % ^{235}U Enriched UO_2 Rods in Water with Fixed Neutron Poisons," Battelle Pacific Northwest Laboratories PNL-2438 (October 1977).

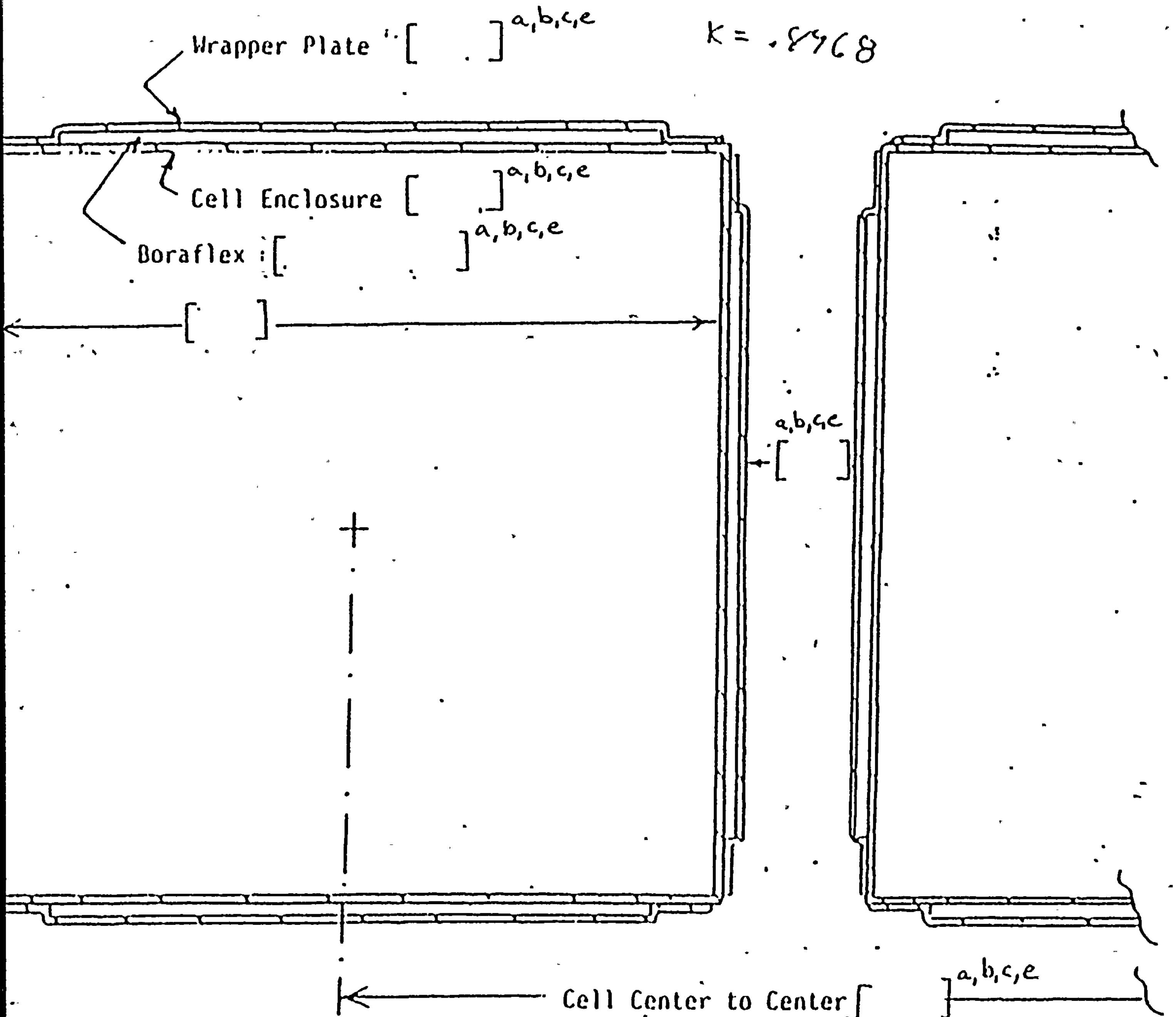
5. S.R. Bierman, et al, "Critical Separation Between Subcritical Clusters of 4.29 wt % ^{235}U Enriched UO_2 Rods in Water with Fixed Neutron Poisons," Battelle Pacific Northwest Laboratories PNL-2614 (March 1978).

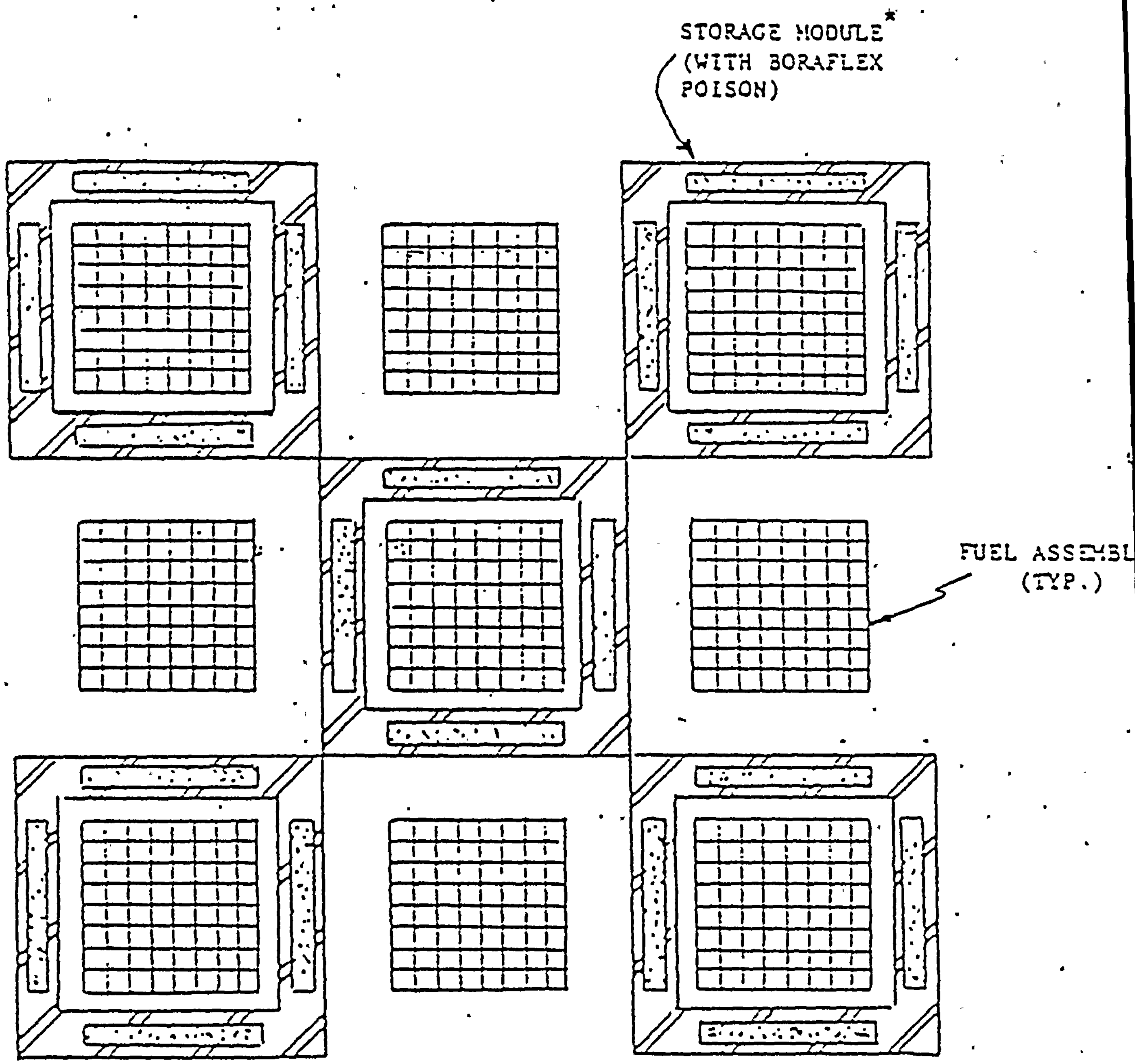
6. J.T. Thomas, "Critical Three-Dimensional Arrays of U (93.2) - Metal Cylinders," Nuclear Science and Engineering, Volume 52, pages 350-359 (1973).

BENCHMARK CRITICAL EXPERIMENTS [4, 5, 6]

General Description	Enrichment w/o U235	Reflector	Separating Material	Characterizing Separation (cm)	K_{eff}
UO_2 rod lattice	2.35	water	water	11.92	1.004 ± .004
"	"	"	"	8.39	0.993 ± .004
"	"	"	"	6.39	1.005 ± .004
"	"	"	"	4.46	0.994 ± .004
"	"	"	stainless steel	10.44	1.005 ± .004
"	"	"	"	11.47	0.992 ± .004
"	"	"	"	7.76	0.992 ± .004
"	"	"	"	7.42	1.004 ± .004
"	"	"	boral	6.34	1.005 ± .004
"	"	"	"	9.03	0.992 ± .004
"	"	"	"	5.05	1.001 ± .004
"	4.29	"	water	10.64	0.999 ± .005
"	"	"	stainless steel	9.76	0.999 ± .005
"	"	"	"	8.08	0.998 ± .006
"	"	"	boral	6.72	0.998 ± .005
U metal cylinders	93.2	bare	air	15.43	0.998 ± .003
"	"	paraffin	air	23.84	1.006 ± .005
"	"	bare	air	19.97	1.005 ± .003
"	"	paraffin	air	36.47	1.001 ± .004
"	"	bare	air	13.74	1.005 ± .003
"	"	paraffin	air	23.48	1.005 ± .004
"	"	bare	plexiglass	15.74	1.010 ± .003
"	"	paraffin	plexiglass	24.43	1.006 ± .004
"	"	bare	plexiglass	21.74	0.999 ± .003
"	"	paraffin	plexiglass	27.94	0.994 ± .005
"	"	bare	steel	14.74	1.000 ± .003

FIGURE 3.4-1 STORAGE CELL NOMINAL DIMENSIONS IN THE PWR STORAGE RACKS





*SEE FIGURE 3.4-3 FOR DETAIL DESCRIPTION OF MODULE.

ILLUSTRATION OF SPENT FUEL STORAGE ARRANGEMENT

SHOWING "CHECKERBOARD" ALIGNMENT OF STORAGE

MODULES IN THE BWR STORAGE RACKS

(NOT DRAWN TO ACTUAL SCALE)

FIGURE 3.4-2

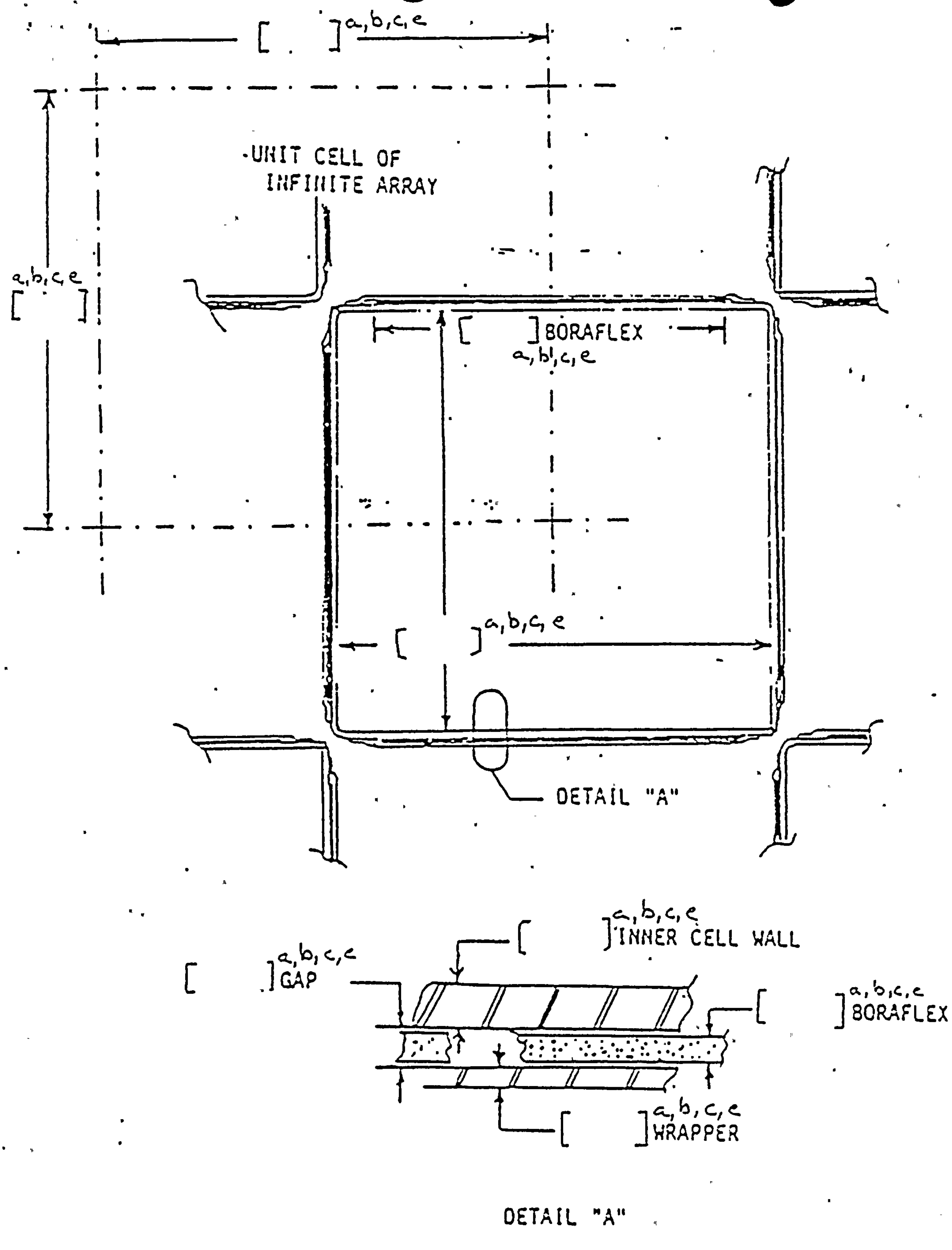


FIGURE 3.4-3. NOMINAL DIMENSIONS FOR TYPICAL SPENT FUEL STORAGE CELL

FIGURE 3.4-4

EFFECT OF WATER DENSITY ON NEUTRON

MULTIPLICATION FACTOR FOR A TYPICAL BWR

POISONED FUEL RACK

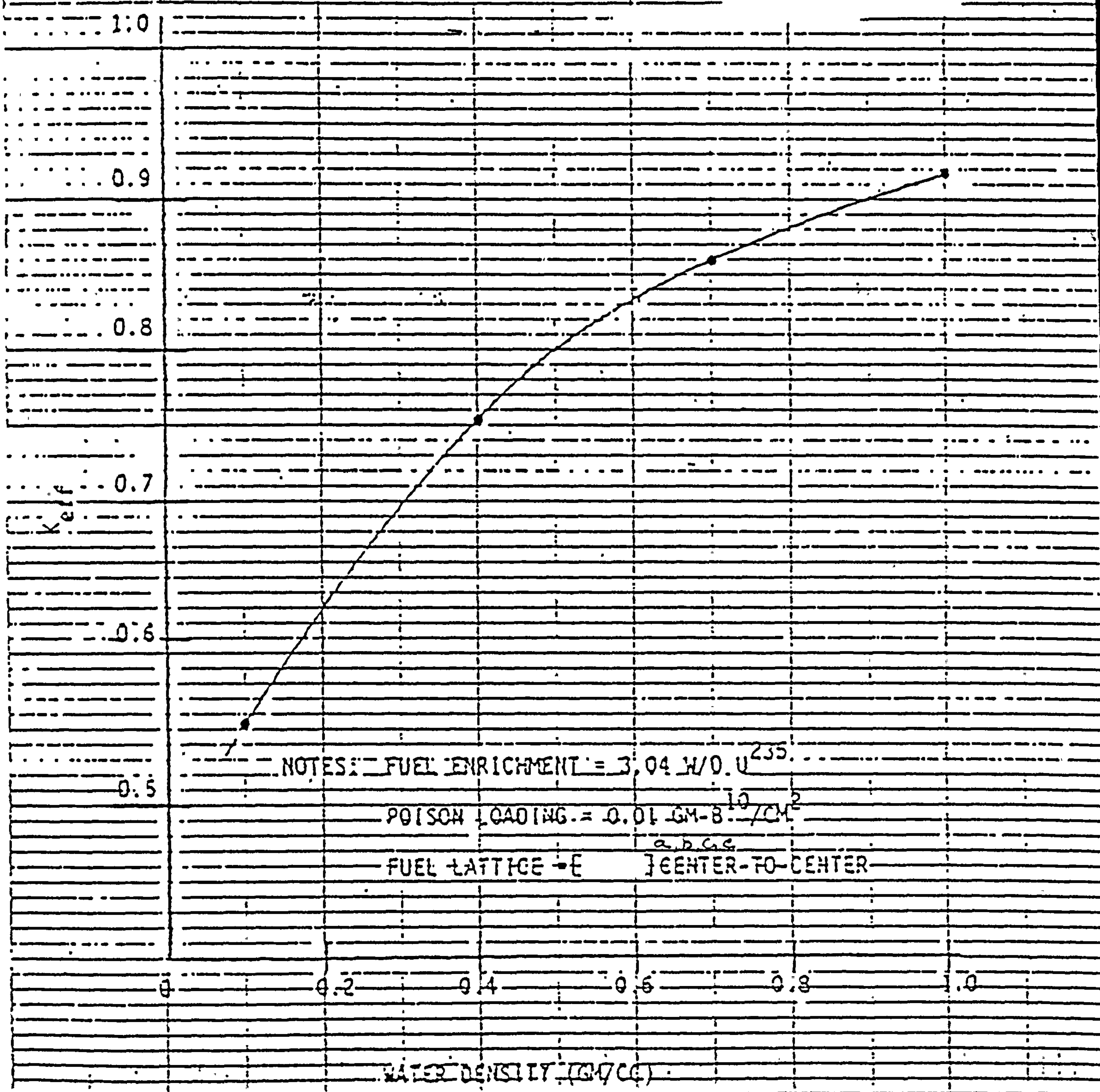


FIGURE 3.4-5 K_{eff} VS. WATER MODERATOR DENSITY

FOR A TYPICAL "POISONED" PWR SPENT FUEL STORAGE RACK

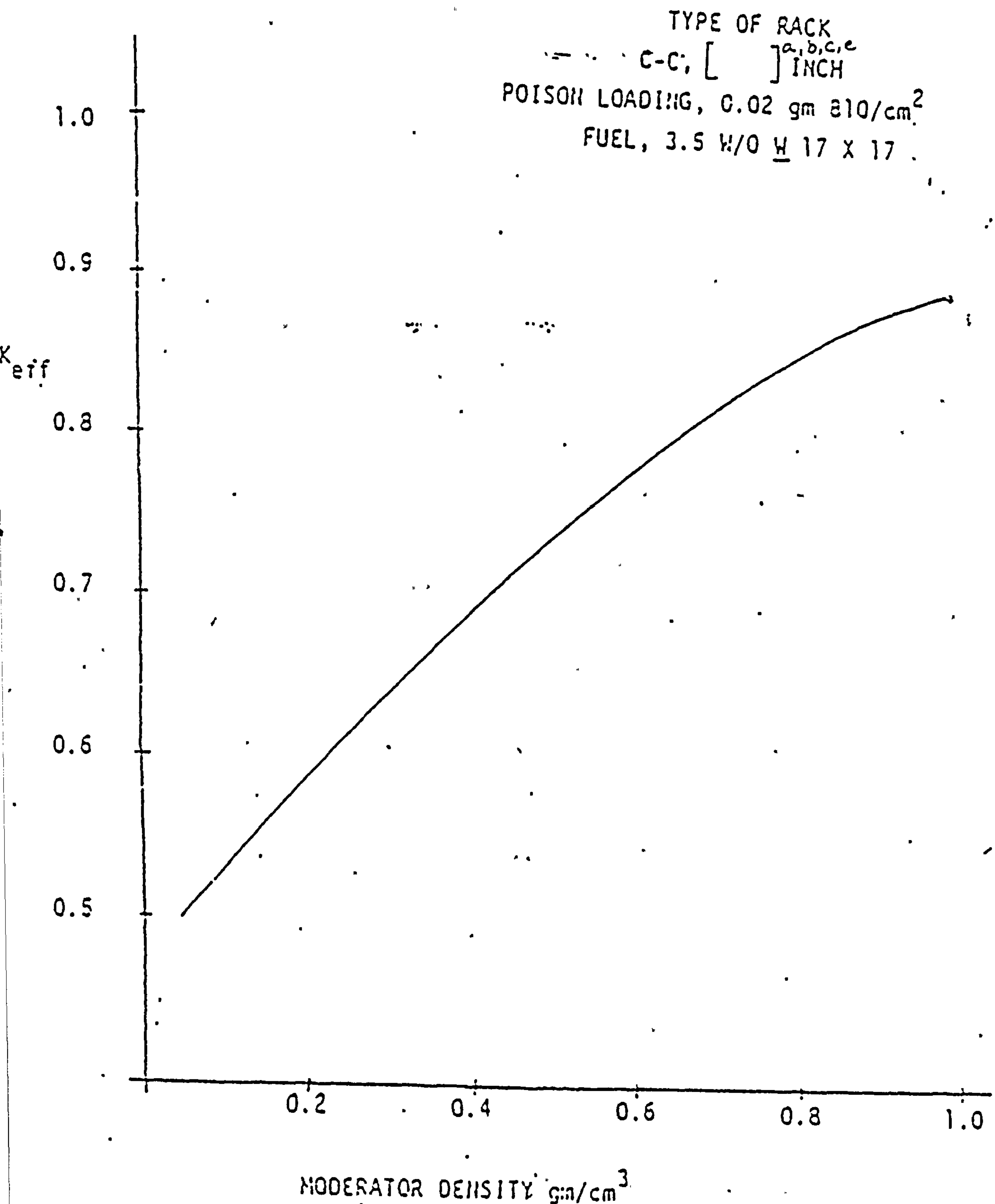
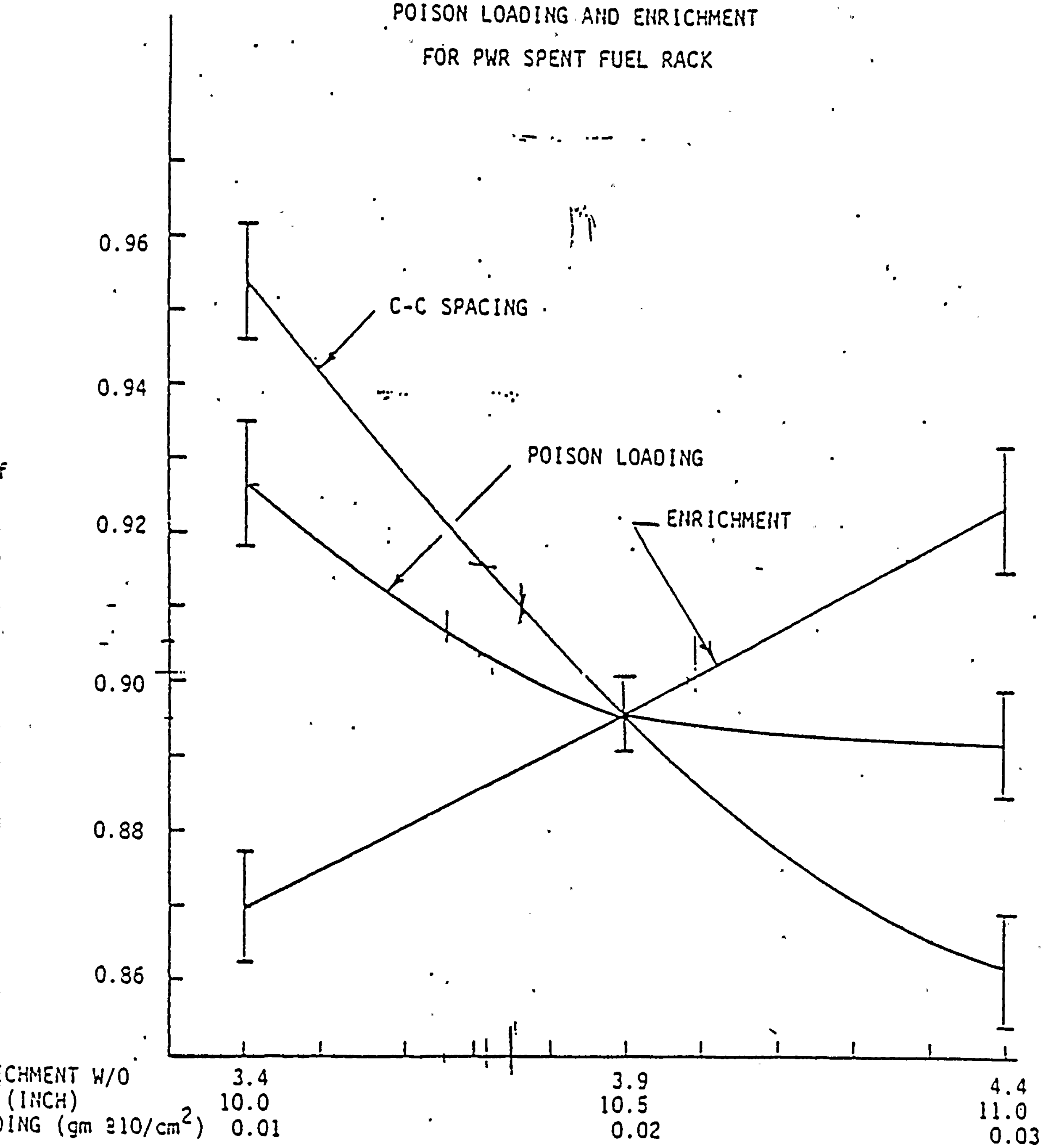


FIGURE 3.4-6

K_{eff} AS A FUNCTION OF C-C SPACING,
POISON LOADING AND ENRICHMENT
FOR PWR SPENT FUEL RACK



NOTES: FOR ENRICHMENT CURVE, C-C = [ ]a,b,c,e, LOADING = 0.02
" SPACING CURVE, W/O = 3.9, LOADING = 0.02
" LOADING " , W/O = 3.9, C-C = 10.5"

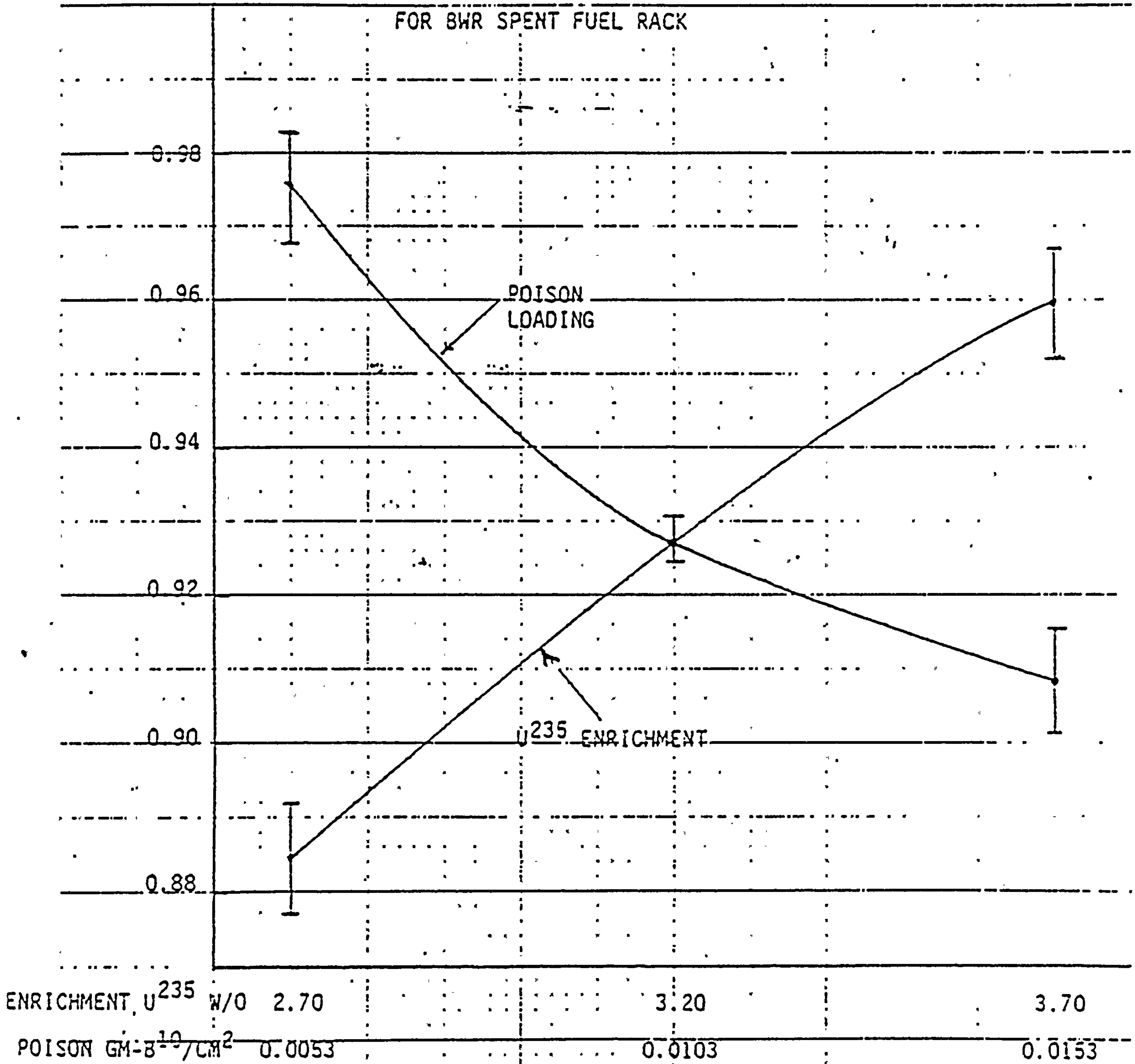
FIGURE 3.4-7

NEUTRON MULTIPLICATION FACTOR, K_{eff}

AS A FUNCTION OF FUEL ENRICHMENT

AND POISON B-10 LOADING

FOR BWR SPENT FUEL RACK



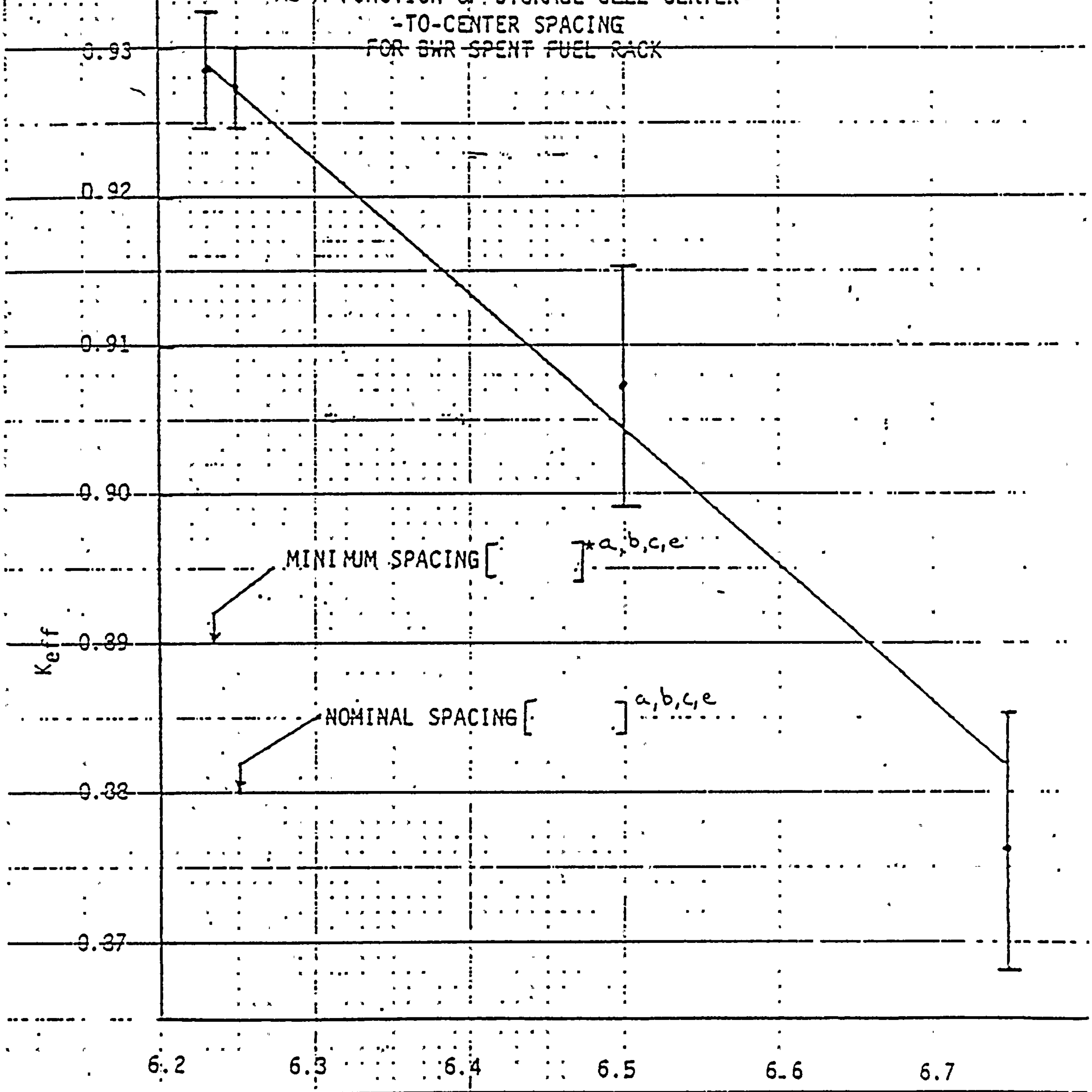
NOTES: FOR ENRICHMENT CURVE, B-10 LOADING = 0.0103

FOR POISON LOADING CURVE, ENRICHMENT = 3.20

FOR BOTH CURVES, THE CENTER-TO-CENTER SPACING

OF FUEL ASSEMBLIES - [ ]a,b,c INCHES

FIGURE 3.4-8
NEUTRON MULTIPLICATION FACTOR (K_{eff})
AS A FUNCTION OF STORAGE CELL CENTER-
-TO-CENTER SPACING
FOR BWR SPENT FUEL RACK



CELL CENTER-TO-CENTER SPACING (INCHES)

NOTES: FUEL ENRICHMENT = 3.20 W/O U^{235}
POISON LOADING = 0.0103 gm-B^{10}/CM^2
*DUE TO "CHECKERBOARD" DESIGN MINIMUM CELL
SPACING = [ ]a,b,c,e INCHES