ATTACHMENT NO. 1 TO AEP:NRC:0745B

DONALD C. COOK NUCLEAR PLANT UNIT NOS. 1 AND 2

SUMMARY OF NEW AND SPENT FUEL STORAGE ARRAY

CRITICALITY SAFETY ANALYSES

1.0 SUMMARY OF CRITICALITY ANALYSIS FOR D.C. COOK SPENT FUEL RACK

Criticality of fuel assemblies in the spent fuel storage rack is prevented by the design of the rack 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 Application."

In meeting this design basis, some of the conditions assumed are: fresh 15 x 15 Westinghouse optimized fuel assemblies (OFA) of 4.05 w/o U-235 are stored, the pool water has a density of 1.0 gm/cm^3, the storage array is infinite in lateral and axial extent which is more reactive than the actual finite array, mechanical and method biases and uncertainties are included, the minimum poison loading is used, and for some accident conditions credit for the dissolved boron in the pool water is taken.

The design method which insures the criticality safety of fuel assemblies in the spent fuel storage rack uses the AMPX system of codes for cross-section generation and KENO IV for reactivity determination. 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 which are then included in the reactivity analysis of the rack.

The result of the above considerations is that the nuclear design of the rack will meet the requirements of NRC guidelines and criteria.

2.0 CRITICALITY ANALYSIS FOR D.C. COOK SPENT FUEL RACK

2.1 NEUTRON MULTIPLICATION FACTOR

Criticality of fuel assemblies in the spent fuel storage rack is prevented by the design of the rack 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.

2.2 NORMAL STORAGE

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. Criticality analyses were done for Westinghouse 15 x 15 optimized fuel assembly (OFA) with an enrichment of 4.05 w/o. The following assembly parameters were modeled:

Number of Fuel Rods per assembly	=	204
Rod Zirc-4 Clad O.D.	=	0.422"
Clad Thickness	=	0.0243"
Fuel Pellet O.D.	=	0.3659"
Fuel Pellet Density	=	95% Theoretical
Fuel Pellet Dishing	=	1.190%
Rod Pitch	=	0.5630" Square
Number Zirc-4 Guide Tubes	=	21
Guide Tube O.D.	=	0.546"
Guide Tube Thickness	=	0.017"

The assemblies are 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 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 nominal case calculation is infinite in lateral and axial extent.

e. 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 poisoned cell walls.

f. A bias is included in the reactivity calculation to account for the B_4C particle self shielding.

g. A bias, with an uncertainty is included to account for the fact that the D.C. Cook racks have random cells closer together than for the nominal design. The minimum gap between adjacent cells may be as small as 0.953", compared to the nominal gap of 1.139".

The calculation method uncertainty and bias is discussed in Section 2.4.

2.3 POSTULATED ACCIDENTS

Most accident conditions will not result in an increase in K_{eff} of the rack. Examples are the loss of cooling systems (reactivity decreases with decreasing water density) and dropping a fuel assembly on top of the rack (the rack structure pertinent for criticality is not deformed and the assembly has more than eight inches of water separating it from the active fuel in the rack which precludes interaction).

However, accidents can be postulated which would increase reactivity such as inadvertent drop of an assembly between the outside periphery of the rack and the pool wall. Therefore, for accident conditions, the double contingency principle of ANS N16.1-1975 is applied. This states that it shall require two unlikely, independent, concurrent events to produce a criticality accident. Thus for accident conditions, the presence of soluble boron in the storage pool water can be assumed as a realistic initial condition.

The presence of the approximately 2000 ppm boron in the pool water will decrease reactivity by more than 30% Δk. In perspective, this is more negative reactivity than is present in the poisoned cell walls, (i.e., 24% Δk). Therefore, K_{eff} for the rack would be less than 0.95 even if the cell walls were unpoisoned. Thus $K_{eff} \leq 0.95$ can be easily met for postulated accidents, since any reactivity increase will be much less than the negative worth of the dissolved boron.

For fuel storage applications, water is usually present. However, accidental criticality when fuel assemblies are stored in the dry condition is also accounted for. For this case, possible sources of moderation, such as those that could arise during fire fighting operations, are included in the analysis.

This "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 2 shows the behavior of K_{eff} as a function of moderator density for a typical PWR poisoned spent fuel storage rack.

2.4 METHOD FOR CRITICALITY ANALYSIS

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 include strong neutron absorbers, large water gaps and low moderator densities.

The design method which ensures the criticality safety of fuel assemblies in the spent fuel storage rack 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 benchmarks and the storage rack is generated from ENDF/B-IV data. The NITAWL program [2] includes, in this library, the shelf-shielded resonance cross-sections that are appropriate for each particular geometry. The Nordheim Integral Treatment is used. 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.

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 and water) that simulate LWR fuel shipping and storage conditions[4,5]. to dry, harder spectrum uranium metal cylinder arrays with various interspersed materials[6] (Plexiglass, steel and air, that demonstrate 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 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.

The total uncertainty (TU) is to be added to a criticality calculation is:

$$TU = [(ks)^2_{method} + (ks)^2_{nominal} + (ks)^2_{mech}]^{1/2}$$

where $(ks)_{method}$ is 0.013 as discussed above, $(ks)_{nominal}$ is the statistical uncertainty associated with the particular KENO calculation being used, $(ks)_{mech}$ is the statistical uncertainty associated with random gap reduction between adjacent storage cells.

For a single can it is found 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 0.953 inch. KENO calculations using this minimum gap result in a bias of 0.00211 Δk and a 95%/95% uncertainty of 0.00454.

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.

The final result of the uncertainty analysis is that the criticality design criteria are met when the calculated effective multiplication factor, plus the total uncertainty (TU) and any biases, is less than 0.95.

These methods conform with ANSI N18.2-1973, "Nuclear Safety Criteria for the Design of Stationary Pressurized Water Reactor Plants", ANSI N210-1976, "Design Objectives for LWR Spent Fuel Storage Facilities at Nuclear Power Stations", ANSI N16.9-1975, "Validation of Calculational Methods for Nuclear Criticality Safety"; NRC Standard Review Plan, and the NRC Guidance, "NRC Position for Review and Acceptance of Spent Fuel Storage and Handling Applications".

2.5 CRITICALITY RESULTS

The spent fuel storage cell is shown in Figure 1. The minimum ^{10}B loading in the poisoned cell walls is 0.02 gm-$^{10}B/cm^2$. The sensitivity of storage lattice K_{eff} to U-235 enrichment of the fuel assembly, the storage lattice pitch, and ^{10}B loading in the poison plates as requested by the NRC for poison racks is given in Figures 3.

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

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

where:

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

B_{mech} = K_{eff} 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 cae KENO K_{eff}

ks_{mech} = 95/95 uncertainty in the calculation due to KENO analysis of mechanical tolerances

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

Substituting calculated values, the results are the following:

$$K_{eff} = 0.92837 + .00211 + 0.0 + .0025 + [(.006494)^2 + (.004539)^2 + (.013)^2]^{1/2} = .9482$$

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

2.6 ACCEPTANCE CRITERIA FOR CRITICALITY

The neutron multiplication factor in spent fuel pools 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 storage pools, which contain dissolved boron, the use of realistic initial conditions ensures that $K_{eff} \ll 0.95$ for postulated accidents as discussed in Section 2.3. Thus, for simplicity, the acceptance criteria for all conditions will be $K_{eff} < 0.95$.

3.0 CRITICALITY ANALYSIS FOR D. C. COOK NEW FUEL RACK

3.1 NEUTRON MULTIPLICATION FACTOR

Criticality of fuel assemblies in the new fuel storage rack is prevented by the design of the rack which limits fuel assembly interaction. This is done by fixing the minimum separation between assemblies to take advantage of neutron absorption in water and stainless steel.

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 0.98 as recommended in ANSI N18.2-1973.

The following are the conditions that are assumed in meeting this design basis for the D. C. Cook new fuel storage racks.

3.2 NORMAL STORAGE

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. Because the Westinghouse 17x17 and 15x15 are very similar neutronically[7], only the 17x17 will be examined. Sufficient margin will be maintained to cover any reactivity differences. The enrichment of the 17x17 Westinghouse standard fuel assembly is 4.5 w/o U-235 with no depletion or fission product buildup. The assembly is conservatively modeled with the assembly grid volume removed and no U-234 and U-236 in the fuel pellet.

b. The array is either infinite in lateral extent or is surrounded by a conservatively chosen reflector, whichever is appropriate for the design. The nominal case calculation is infinite in lateral and axial extent. Calculations show that the finite rack is less reactive than the nominal case infinite rack. Therefore, the nominal case of an infinite array of cells is a conservative assumption.

c. 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:

-- stainless steel thickness
-- cell ID
-- center-to-center spacing
-- asymmetric assembly position

The calculation method uncertainty and bias is discussed in Section 4.

d. Credit is taken for the neutron absorption in full length stainless steel structural material.

3.3 POSTULATED ACCIDENTS

Most accident conditions will not result in an increase in K_{eff} of the rack. An example is the dropping of a fuel assembly on top of the rack (the rack structure pertinent for criticality is not deformed and the assembly has more than eight inches separating it from the active fuel in the rest of the rack which precludes interaction).

However, accidents can be postulated (under flooded conditions) which would increase reactivity such as inadvertent drop of an assembly between the outside periphery of the rack and pool wall. Therefore, for accident conditions, the double contigency principle of ANS N16.1-1975 is applied. This states that it is unnecessary to assume two unlikely, independent, concurrent events to ensure protection against a criticality accident. Thus, for accident conditions, the absence of water in the storage pool can be assumed as a realistic initial condition since assuming its presence would be a second unlikely event.

The absence of water in the storage pool guarantees subcriticality for enrichments less than 5 w/o[1]. Thus any postulated accidents other than the introduction of water into the storage area will not preclude the pool from meeting the $K_{eff} \leq 0.98$ limit.

Because the most limiting accident is the introduction of moderation into the storage pool, this accident will be considered in determining the maximum K_{eff} for the storage pool. For this accident, possible sources of moderation, such as those that could arise during fire fighting operations, are included in the analysis. This "optimum moderation" accident is not a problem in new fuel storage racks because physically achievable water densities (caused, for instance, by sprinklers, foam generators or fog nozzles) are considerably too low (<< 0.01 gm/cm^3) to yield K_{eff} values higher than full density water. The optimum achievable moderation occurs with water at 1.0 gm/cm^3. Preferential water density reduction between cells (i.e., boiling between cells) is prevented by the rack design.

3.4 METHOD FOR CRITICALITY ANALYSIS

The most important effect on reactivity of the mechanical tolerances is the possible reduction in the center-to-center spacing between adjacent assemblies. The nominal gap between adjacent cells for D. C. Cook is 11.0 inches. The design also guarantees that the average center-to-center storage cell spacing for a module of cells will be 21.0 inches. (See Figure 4). Therefore, any reduction of cell-to-cell gap on one side of a can will produce a gap increase on the opposite side of the can. The KENO model for the gap reduction analysis consists of an infinite array of clusters of 4 cells with the gap between adjacent cells in each cluster reduced to 10.97 inches.

Another center-to-center spacing reduction can be caused by the asymmetric assembly position within the storage cell. The inside dimensions of a nominal storage cell are such that if a fuel assembly is loaded into the corner of the cell, the assembly centerline will be displaced only 0.284 inches from the cell centerline. This means that adjacent asymmetric fuel assemblies would have their center-to-center distance reduced by 0.568 inches from the nominal.

Analysis shows that the combined effect of the worst mechanical tolerances and the asymmetric assembly positioning may increase reactivity by 0.001Δk. This will be treated as a bias although the individual deviations will be random.

The final result of the uncertainty analysis is that the criticality design criteria are met when the calculated effective multiplication factor, plus the total uncertainty (TU) and any biases, is less than 0.98.

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 N16.9-1975, "Validation of Calculational Methods for Nuclear Criticality Safety".

3.5 CRITICALITY ANALYSIS FOR RACK DESIGN

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

$$K_{eff} = K_{nominal} + B_{mech} + B_{method} + \left[(ks)^2_{nominal} + (ks)^2_{method}\right]^{1/2}$$

Where:

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

B_{mech} = K_{eff} bias to account for the fact that mechanical tolerances can result in spacings between assemblies less than nominal

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

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

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

Substituting calculated values in the order listed above, the result is:

$$K_{eff} = 0.9189 + 0.0010 + 0.0 + [(.0062)^2 + (.013)^2]^{1/2} = .9343$$

Since K_{eff} is less than 0.98 including uncertainties at a 95/95 probability/confidence level, the acceptance criteria for criticality is met.

REFERENCES

1. W.E. Ford III, et al, "A 218-Group Neutron Cross-Section Library in the AMPX Master Interface Format for Criticality Safety Studies," ORNL/CSD/TM-4 (July 1976).

2. 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).

3. L.M. Petrie and N.F. Cross, "KENO IV-An Improved Monte Carlo Criticality Program," ORNL-4938 (November 1978).

4. S.R. Bierman, et al, "Critical Separation Between Subcritical Clusters of 2.35 wt % $^{235}UO_2$ 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 % $^{235}UO_2$ 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).

7. Letter No. AEP:NRC:00105 dated November 22, 1978.

BENCHMARK CRITICAL EXPERIMENTS[4,5,6]

	General Description	Enrichment w/o U235	Reflector	Separating Material	Characterizing Separation (cm)	K_{eff}
1.	UO_2 rod lattice	2.35	water	water	11.92	1.004 ± .004
2.	UO_2 rod lattice	2.35	water	water	8.39	0.993 ± .004
3.	UO_2 rod lattice	2.35	water	water	6.39	1.005 ± .004
4.	UO_2 rod lattice	2.35	water	water	4.46	0.994 ± .004
5.	UO_2 rod lattice	2.35	water	stainless steel	10.44	1.005 ± .004
6.	UO_2 rod lattice	2.35	water	stainless steel	11.47	0.992 ± .004
7.	UO_2 rod lattice	2.35	water	stainless steel	7.76	0.992 ± .004
8.	UO_2 rod lattice	2.35	water	stainless steel	7.42	1.004 ± .004
9.	UO_2 rod lattice	2.35	water	boral	6.34	1.005 ± .004
10.	UO_2 rod lattice	2.35	water	boral	9.03	0.992 ± .004
11.	UO_2 rod lattice	2.35	water	boral	5.05	1.001 ± .004
12.	UO_2 rod lattice	4.29	water	water	10.64	0.999 ± .005
13.	UO_2 rod lattice	4.29	water	stainless steel	9.76	0.999 ± .005
14.	UO_2 rod lattice	4.29	water	stainless steel	8.08	0.998 ± .006
15.	UO_2 rod lattice	4.29	water	boral	6.72	0.998 ± .005
16.	U metal cyliners	93.2	bare	air	15.43	0.998 ± .003
17.	U metal cyliners	93.2	paraffin	air	23.84	1.006 ± .005
18.	U metal cyliners	93.2	bare	air	19.97	1.005 ± .003
19.	U metal cyliners	93.2	paraffin	air	36.47	1.001 ± .004
20.	U metal cyliners	93.2	bare	air	13.74	1.005 ± .003
21.	U metal cyliners	93.2	paraffin	air	23.48	1.005 ± .004
22.	U metal cyliners	93.2	bare	plexiglass	15.74	1.010 ± .003
23.	U metal cyliners	93.2	paraffin	plexiglass	24.43	1.006 ± .004
24.	U metal cyliners	93.2	bare	plexiglass	21.74	0.999 ± .003
25.	U metal cyliners	93.2	paraffin	plexiglass	27.94	0.994 ± .005
26.	U metal cyliners	93.2	bare	steel	14.74	1.000 ± .003
27.	U metal cyliners	93.2	bare	plexiglass, steel	16.67	0.996 ± .003

FIGURE 1 D. C. COOK SPENT FUEL STORAGE CELL NOMINAL DIMENSIONS

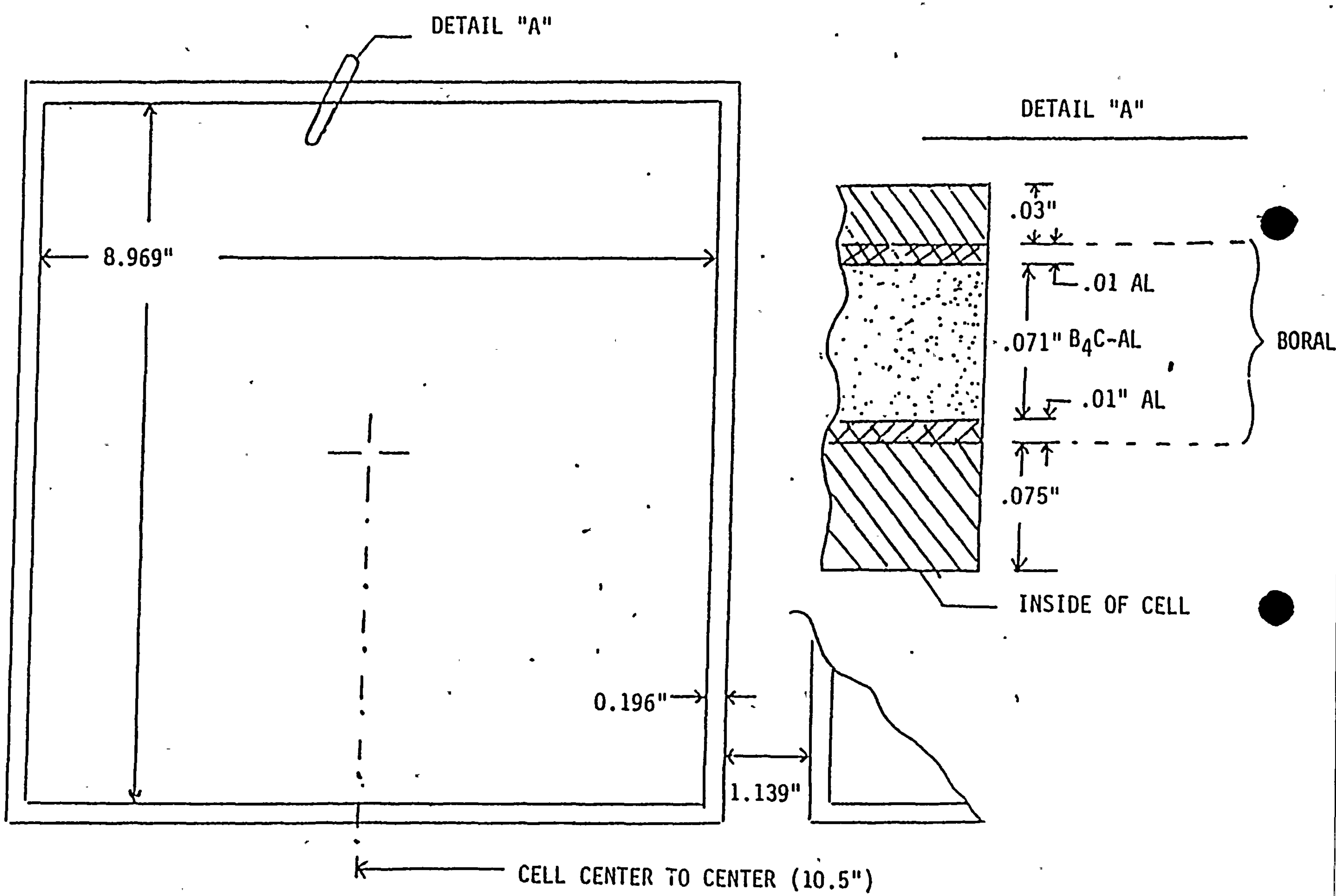


FIGURE 2 K_{eff} VS. WATER MODERATOR

FOR A TYPICAL "POISONED" SPENT FUEL STORAGE RACK

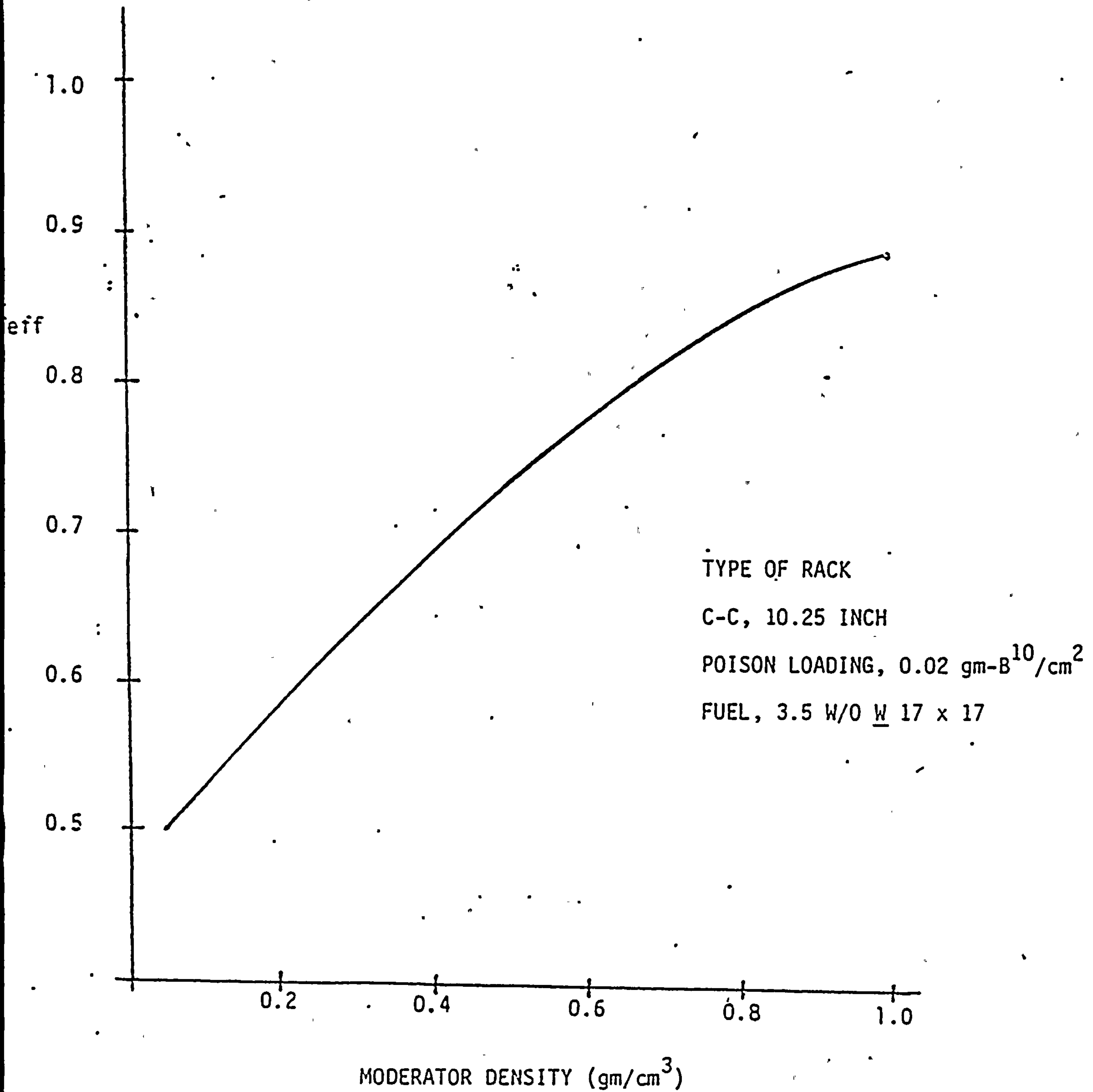
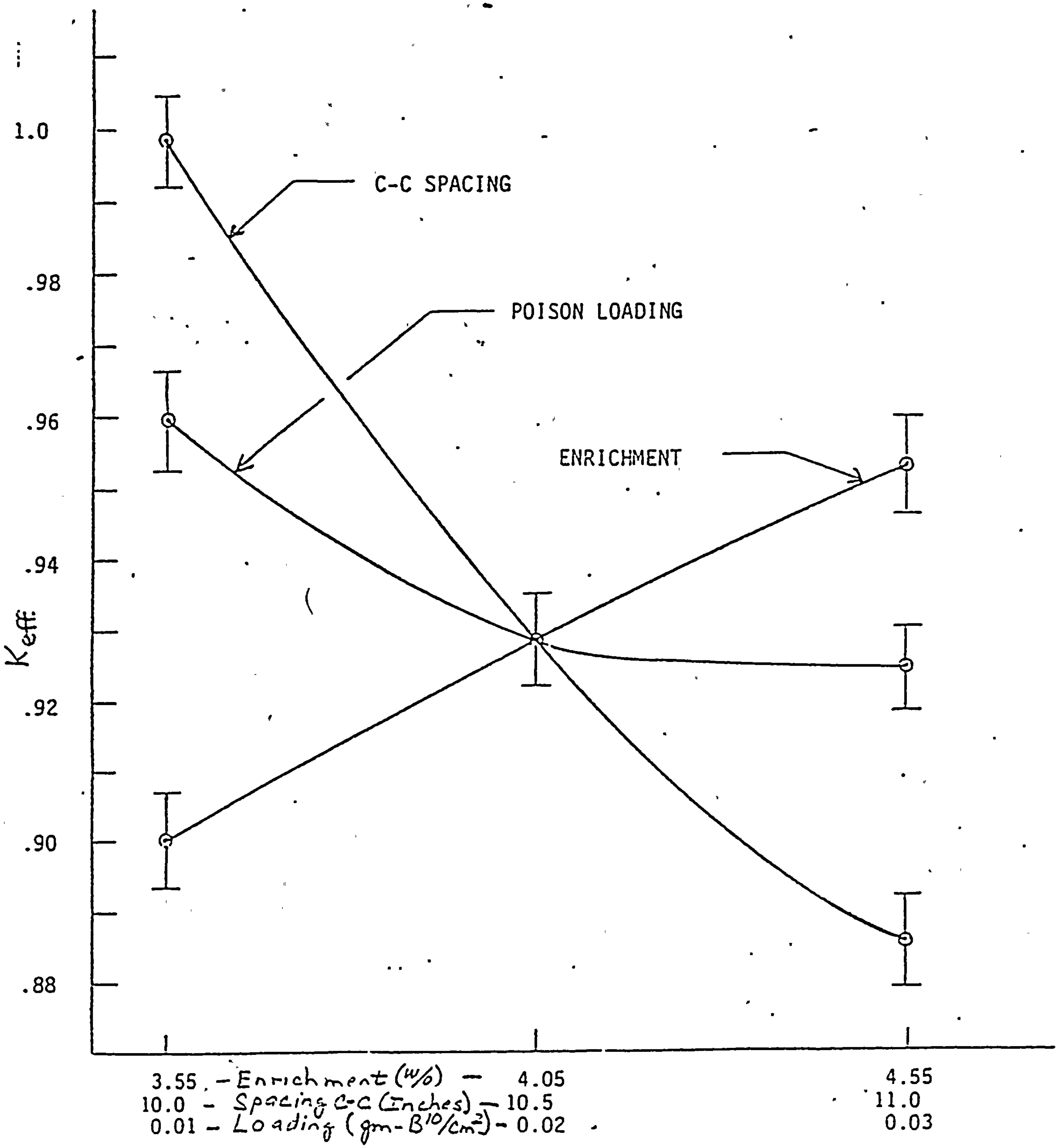


FIGURE 3

Keff AS A FUNCTION OF C-C SPACING, POISON LOADING AND ENRICHMENT FOR WESTINGHOUSE 15 x 15 OFA FUEL FOR D.C. COOK SPENT FUEL RACK

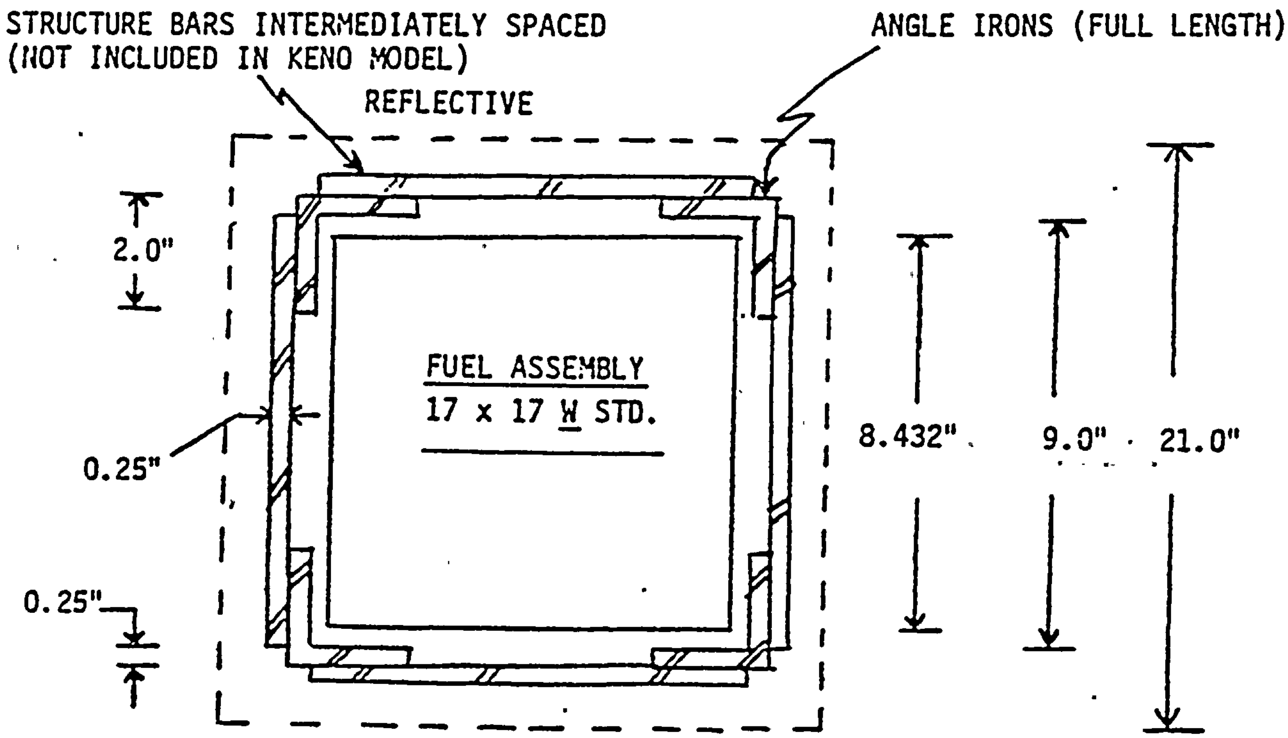


Notes: For enrichment curve, C-C = 10.5", loading = 0.02 gm-B^{10}/cm^2

For spacing curve, w/o = 4.05, loading =0.02 gm-B^{10}/cm^2

For loading curve, w/o = 4.05, C-C = 10.5"

FIGURE 4


STRUCTURE BARS INTERMEDIATELY SPACED
(NOT INCLUDED IN KENO MODEL)
ANGLE IRONS (FULL LENGTH)
REFLECTIVE
2.0"
FUEL ASSEMBLY
17 x 17 W STD.
0.25"
0.25"
8.432"
9.0"
21.0"