NUCLEAR DESIGN ANALYSIS REPORT
FOR THE CRYSTAL RIVER UNIT 3
SPENT FUEL STORAGE RACKS

Prepared Under NES Project 5127

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1. SUMMARY

A detailed nuclear analysis has been performed for the NES design for spent fuel storage racks for Crystal River Unit 3. The racks, which use B_4C poison sheets for criticality control, have been shown by this analysis to meet the criticality criterion of < 0.95 for 3.3 w/o Babcock & Wilcox 15 x 15 fuel assemblies for all anticipated normal and abnormal configurations. Certain conservative assumptions about the fuel assemblies and racks have been used in the calculations. The normal configurations considered in the nuclear analysis include the reference configuration (an array of square boxes spaced 10.5 inches on centers with centrally positioned fuel), the eccentric positioning of fuel within the storage boxes and the variations permitted in fabrication of the principal fuel rack dimensions and in poison concentration. The abnormal configurations included box displacement, spent fuel pool temperature variations and fuel handling incidents.

The principal calculational method used for the criticality analysis was diffusion theory. Cross sections were determined through use of the HAMMER code and k_{eff} was determined by EXTERMINATOR, a multigroup, two-dimensional diffusion theory code. Calculations have been performed with the KENO Monte Carlo code to establish a Monte Carlo/diffusion theory bias.

The k_{eff} value calculated by diffusion theory for the reference configuration is 0.8819 and when combined with the Monte Carlo/diffusion theory bias becomes 0.9074. Combining the variations in k_{eff} due to the other normal configurations yields a resulting k_{eff} of 0.9168. The k_{eff} value for the "worst case" abnormal configuration is 0.9313, only slightly greater than the "worst case" normal configuration. If a value of ± 0.01 is assumed for the calculational uncertainty and combined statistically with the normal variations, the resulting k_{eff} for the "worst case" abnormal configuration is 0.9356. This value meets the criticality design criterion and is substantially below 1.0. Therefore, it has been concluded that the Crystal River Unit 3 high density storage racks when loaded with the specified fuel are safe from a criticality standpoint.

2. INTRODUCTION

The NES final design for high density fuel storage racks for Crystal River Unit 3 consists of a 6 x 6 square array of storage boxes spaced 10.5" on centers. B_4C sheets 0.075" thick are placed between two 0.060" stainless steel sheets to comprise the box wall. Poison content within the B_4C plates will be a minimum of 0.012 gm/cm^2 (areal density) B^{10}, which results in an atom density of 0.00379 atoms/b-cm B^{10}.

A detailed nuclear design has been performed to assure that the NES high density storage racks, when loaded with fresh fuel of the highest enrichment available at Crystal River Unit 3, will have a k_{eff} substantially below 1.0 for all anticipated normal and abnormal configurations of fuel assemblies and racks. Certain conservative assumptions have been made in the analysis. These assumptions and the criticality design criterion are described in Section 4.

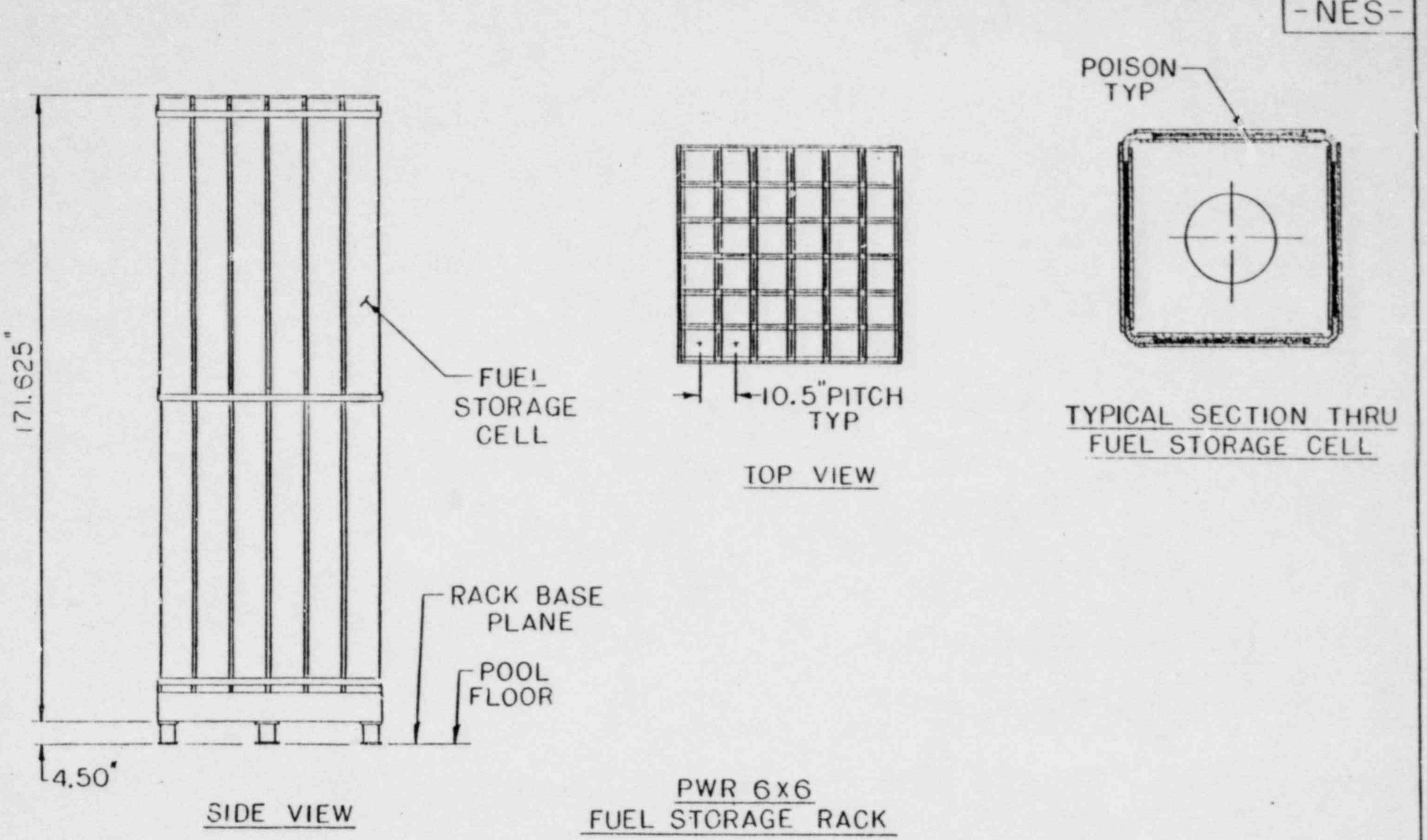
The reference configuration forms the basis for criticality calculations. This reference configuration consists of a 6 x 6 square array of boxes, each of nominal dimensions, at 68° F, containing fresh fuel centrally located, and with minimum amounts of poison and steel in the walls. The fuel assemblies are assumed to be 15 x 15 Babcock & Wilcox assemblies with 3.3 w/o average enrichment. Variations of all important parameters were separately studied in order to determine the effect on k_{eff} of all normal and abnormal deviations from the normal condition. Included among the variations studied are: changes in the spacing between the boxes, differences in the amount of boron within the box wall, changes in temperature, change of fuel enrichment, and changes in positioning of fuel assemblies and boxes. These variations and their effects on k_{eff} are described in detail in Section 5.

The principal calculational method used for the criticality analysis was diffusion theory. Cross sections were determined through use of the HAMMER code and k_{eff} was determined by EXTERMINATOR, a multigroup, two-dimensional diffusion theory code. Verification calculations have been performed with KENO, a Monte Carlo code. A detailed description of the calculational method and the computer codes is presented in Section 6. A benchmark calculation using diffusion theory is also discussed in Section 6.

The results of the criticality analysis are presented in Section 7.

3. DESCRIPTION OF SPENT FUEL STORAGE RACKS

Each storage rack contains 36 storage locations spaced 10.5" on centers. (See Figure 3.1) Each location consists of a box of 8.937" I.D. and 171.625" tall whose wall is a composite material consisting of a 0.075" poison plate sandwiched between two 0.060" (minimum) 304 stainless steel sheets. The poison plate consists of B_4C (boron carbide) within a binding material. The B^{10} areal density within the plate is 0.012 gm/cm^2 minimum. Each plate is 6.687" wide. The walls of the box are held at the edges by 1 1/4" x 1/8" stainless steel angles. Between boxes is a 0.586" water gap. Spacer grids and clips are provided to maintain center to center spacing at 10.5".



PWR 6x6
FUEL STORAGE RACK

FIGURE 3.1

4. CRITICALITY DESIGN CRITERION AND CALCULATIONAL ASSUMPTIONS

4.1 Criticality Design Criterion

A satisfactory value of k_{eff} for a spent fuel pool involves considerations of safety, licensability, and storage capacity requirements. These factors demand a k_{eff} substantially below 1.0 for safety and licensability but high enough to achieve the required storage capacity.

The published position of NRC on fuel storage criticality is presented in Section 9.1.2 of the NRC Standard Review Plan (Reference 1) which states the following:

> "Criticality information (including the associated assumptions and input parameters) in the SAR must show that the center spacing between assemblies results in a subcritical array. A k_{eff} of less than about 0.95 for this condition is acceptable."

Furthermore NRC, in evaluating the design, will "check the degree of subcriticality provided, along with the analysis and the assumptions".

On the basis of this information, the following criticality design criterion has been established for the Crystal River Unit 3 high density fuel storage racks: "The multiplication constant (k_{eff}) shall be less than 0.95 for all normal and abnormal configurations as confirmed by Monte Carlo calculation."

4.2 Calculational Assumptions

The following conservative assumptions have been used in the criticality calculations performed to verify the adequacy of the rack design with respect to the criticality design criterion:

1. The pool water has no soluble poison.
2. The fuel is fresh and of the highest enrichment of any fuel available.
3. The reference configuration contains an infinite array of storage locations. This is obviously conservative because the array is, of course, finite.

5. CRITICALITY CONFIGURATIONS

To assure that the k_{eff} of the Crystal River Unit 3 racks is suitably below 0.95 for all conditions, several normal and abnormal criticality configurations were studied in addition to the reference configuration. Normal configurations are considered to be those which can result from allowed tolerances in spacing or thickness of rack components, tolerances in fuel assembly manufacture, tolerances in poison content, and from the positioning of fuel assemblies within storage locations. Abnormal conditions are those conditions resulting from accident or malfunctions such as a fuel assembly drop onto the rack, a seismic event, an increase in fuel pool temperature due to loss of cooling, etc. This section describes the normal and abnormal configurations considered in this analysis.

5.1 Normal Configurations

5.1.1 Reference Configuration

The reference configuration consists of an infinite array of storage cells spaced 10.5" on centers. (See Figure 3.1) In each storage cell is a 15 x 15 Babcock & Wilcox fuel assembly with an average enrichment of 3.3 w/o centrally located within the storage cell. Each storage cell is represented by a box of 8.937" I.D. and wall thickness of .195". Poison content is 0.012 gm/cm^2 (areal density) B^{10} in 6.687" wide by 0.075" thick B_4C plates. The poison plates are between two 0.060" 304 stainless steel plates.

The temperature of the fuel pool is 68° F for the reference configuration.

5.1.2 Eccentric Configurations

Eccentric positioning of fuel within the storage cell is represented by a worst case configuration in which 4 adjacent assemblies are brought as close as possible to each other within their storage cells. (See Figure 5.1)

Eccentric positioning of a storage cell in the event of a mounting clip failure is represented by the displacement of adjacent rows of cans the maximum amount allowable by the physical structure of the rack, this amount being approximately 0.25". (See Figure 5.2)

5.1.3 Fuel Assembly Tolerances

The important fuel assembly parameter determining k_{eff} is the ratio of the amount of U^{235} to that of water. The amount of U^{235} per assembly is controlled to within a few tenths of a percent by weighing pellet stacks as the fuel is built and by using a known enrichment. The fuel assembly parameter which determines the volume of water in an assembly is the clad O.D. This parameter is closely controlled to typically within ±0.4 percent. The effects of these two fuel assembly tolerances on k_{eff} have been determined to be negligible on the basis of simple k_∞ cell calculations. Consequently, fuel assembly tolerances were not considered further in this analysis.

5.1.4 Fuel Design Variation

Calculations have been performed to determine the sensitivity of k_{eff} to changes in fuel enrichment ranging from 3.1 w/o to 3.5 w/o.

5.1.5 Fuel Rack Cell Pitch Variation

Calculations were performed to determine the sensitivity of k_{eff} to changes in the center to center spacing between storage locations. The pitch was varied from 10.25 to 10.75 inches.

5.1.6 Fuel Rack Cell Wall Thickness Variation

Determination of k_{eff} sensitivity to variation in stainless steel thickness was performed by adding and subtracting 0.010" to each of the two sheets which compose the wall, resulting in an overall thickness variation from 0.175" to 0.215".

5.1.7 Low Boron Content in Poison Plates

Variation of poison concentration was examined over a range of ± 10% corresponding to a variation of B^{10} atom density within the plates from 0.00341 atoms/b-cm to 0.00416 atoms/b-cm.

5.1.8 "Worst Case" Normal Configuration

The "worst case" configuration combines the adverse effects of eccentric fuel positioning, low boron content, and fuel rack manufacturing tolerances.

5.2 Abnormal Configurations

5.2.1 Fuel Handling Incidents

Two fuel handling incidents were considered. The first involves eccentric placement of assemblies within the peripherally located failed fuel storage cans. Structure will be provided to ensure that only the correct (centered) and deliberate placement is possible. The second incident involves placement of a fuel assembly along the side of the rack. Structure will be provided to prevent the accidental placement of fuel closer than 6" from the side of the rack. Calculations have been performed to determine the change in k_{eff} with an assembly 6" from the rack.

5.2.2 Pool Temperature Variation

Calculations were performed to determine the sensitivity of k_{eff} for the reference configuration to variations in the spent fuel pool temperature. The pool temperature was varied from 39° F, where water density is a maximum to 260° F, the approximate boiling point of water near the bottom of the fuel rack.

5.2.3 Fuel Drop Incident

If a fuel assembly should be dropped on the spent fuel storage rack, it would most probably strike the top of a stored fuel assembly since these assemblies project several inches above the tops of the cans. The damage would probably be confined to the uppermost part of the assembly (above the active fuel region) and consequently the effect on k_{eff} would be nil. Even if the fuel assembly were axially compressed, no increase in k_{eff} would be expected; a unit cell calculation based on an axial compression of 2 feet yielded a 0.06 decrease in k_{∞} of the fuel cell. It has been concluded, therefore, that this incident would reduce k_{eff} and need not be considered further in this analysis.

5.2.4 Seismic Incident

Seismic analyses have determined that during an SSE the pitch between two adjacent fuel assemblies could narrow locally by as much as .021 inches, due to oscillations about nodal points determined by the structural members locating the cells within the racks. However, at the same time, the local pitch at other locations is greater by the same amount, with the net effect that although the pitch may vary locally, the average pitch is unaffected.

5.2.5 "Worst Case" Abnormal Configuration

The "worst case" abnormal configuration considers the effect of the most adverse abnormal condition in combination with the "worst case" normal configuration. The results for the "worst case" abnormal configuration are presented in Section 7.4.

ILLUSTRATION OF ECCENTRICALLY LOCATED FUEL CONFIGURATION USED IN EXTERMINATOR CALCULATIONS FOR THE CRYSTAL RIVER UNIT 3 SPENT FUEL STORAGE RACKS

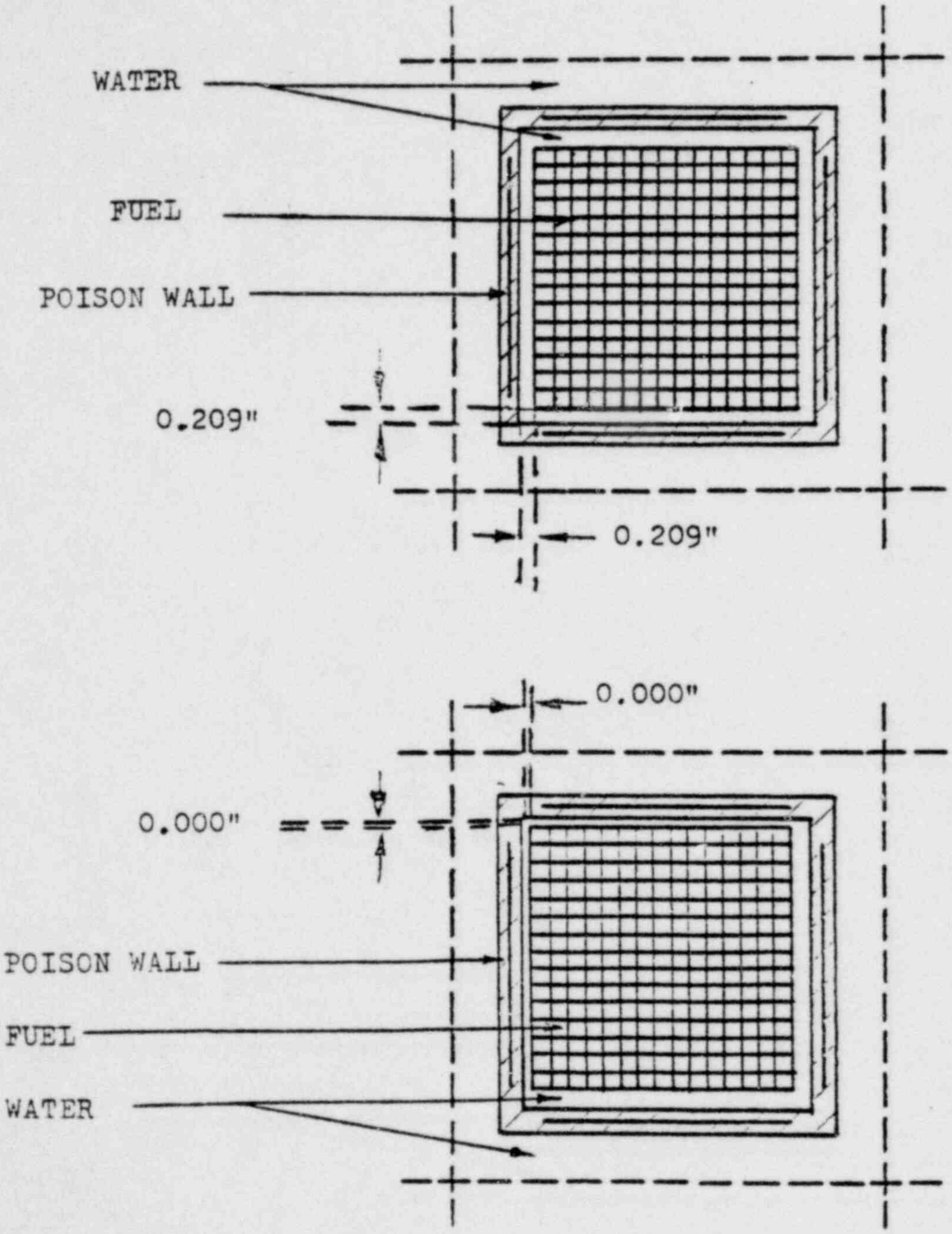
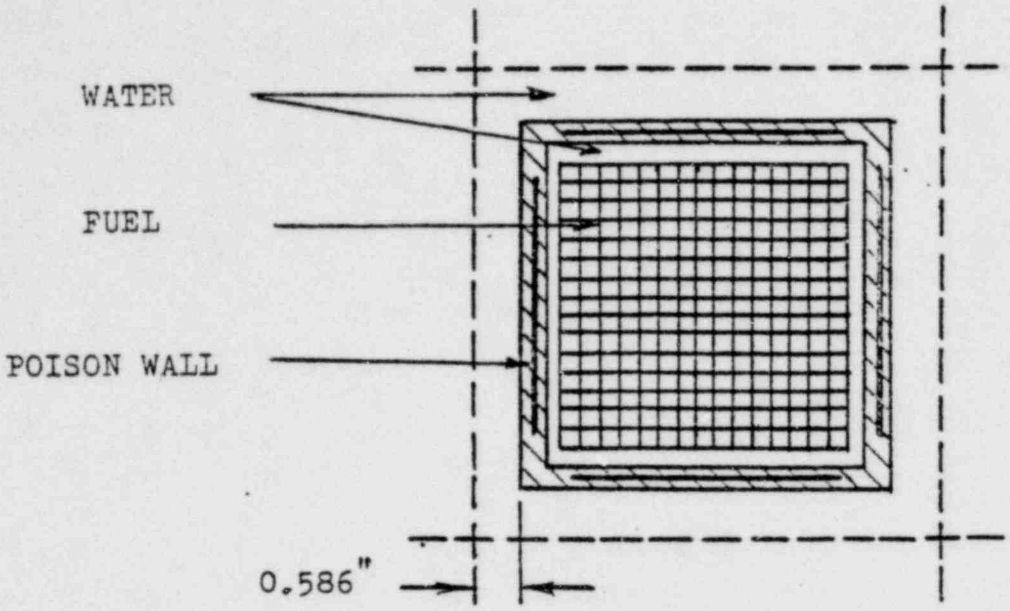


FIG. 5.1

ILLUSTRATION OF ECCENTRICALLY POSITIONED STORAGE CELL CONFIGURATION USED IN EXTERMINATOR CALCULATIONS FOR CRYSTAL RIVER UNIT 3 SPENT FUEL STORAGE RACKS



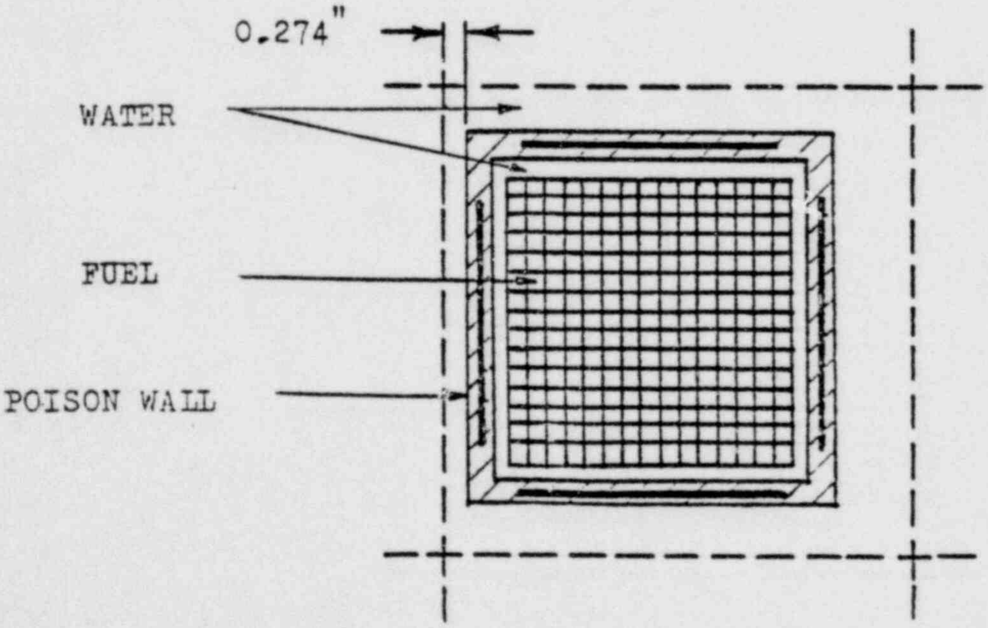


FIG. 5.2

6. CRITICALITY CALCULATION METHODS

6.1 Method of Analysis

For each of the normal and abnormal configurations discussed in Section 5, the k_{eff} was determined from a two dimensional diffusion theory calculation of an infinite array of fuel storage racks. An infinite array is used because such an array can be represented by a small repeating portion with suitable reflecting boundary conditions. Figure 6.1 shows a representation of a complete storage location with the boundary conditions necessary to represent an infinite array.

Use of an infinite array results in a conservative value of k_{eff} for a rack in which the array is obviously finite.

The effect on k_{eff} of buckling in the vertical direction was calculated from a knowledge of average fuel properties and of the composition of the reflector regions above and below the active regions of the fuel assemblies.

The diffusion theory calculations have been performed using the 2-D diffusion theory code EXTERMINATOR with cross section input determined by the HAMMER code. Normally for criticality calculations dealing with reactors, diffusion theory gives very satisfactory results since the codes and cross sections have been normalized to fit experimental data over many years.

For calculating the effect of lumped poisons such as the B_4C sheets, blackness theory was used for determination of cross sections. Backup calculations for diffusion theory were performed using the 3-D multigroup Monte Carlo criticality code, KENO.

6.2 Benchmark Calculation for Diffusion Theory

Both HAMMER and EXTERMINATOR are used by NES as versions available at Combustion Engineering at Windsor Locks, Connecticut. The combination has been benchmarked against a cold critical experiment performed at the LaCrosse Boiling Water Reactor with excellent results (see Reference 2). The calculated k_{eff} differed from the experimental value by only 0.0017.

6.3 Code Descriptions

6.3.1 The HAMMER Code

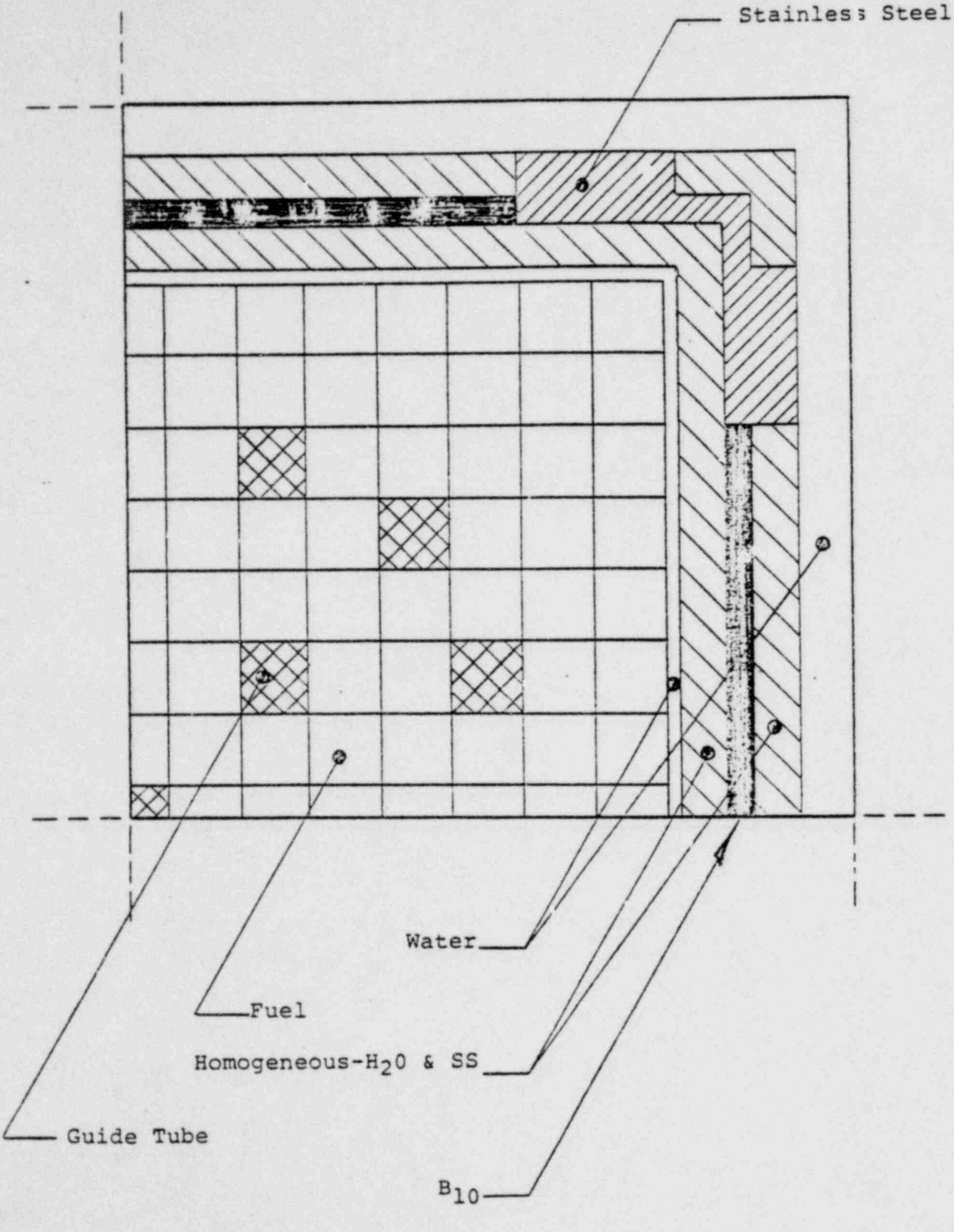
HAMMER (see Reference 3) is a multigroup integral transport theory code which is used to calculate lattice cell cross sections for diffusion theory codes. This code has been extensively benchmarked against D_2O and light water moderated lattices with good results.

6.3.2 The EXTERMINATOR Code

EXTERMINATOR (see Reference 4) is a 2-D multigroup diffusion theory code used with input from HAMMER to calculate k_{eff} values.

6.3.3 The KENO Code

KENO is a 3-D multigroup Monte Carlo criticality code used to determine k_{eff} (see Reference 5).



REPRESENTATION OF QUARTER ASSEMBLY GEOMETRY USED IN EXTERMINATOR CALCULATIONS

FIGURE 6.1

7. RESULTS OF CRITICALITY CALCULATIONS

Four group cross sections were determined by means of the HAMMER code for the criticality configurations to be evaluated. These cross sections were then used in the two dimensional diffusion theory code EXTERMINATOR to determine k_{eff}.

The effects of normal and abnormal variations were evaluated where necessary by performing separate EXTERMINATOR problems for each criticality configuration.

A check upon the diffusion theory method was made by performing an entirely separate calculation of the reference configuration using KENO. KENO contains its own library of 16-group Hansen-Roach X-sections which were used in the reference case Monte Carlo calculation.

7.1 Cross Sections from HAMMER

The HAMMER input for fuel regions was based on the description of the 15 x 15 Babcock & Wilcox fuel assembly presented in Reference 6. The properties of the fuel assembly pertinent to the nuclear calculations are summarized in Table 7.1. Figure 6.1 presents the model of the 15 x 15 assembly used in the calculations.

The basic region considered in a HAMMER problem is a fuel rod including pellets, clad, and the associated water in the area surrounding the rod. The total area is a square with the dimension of one rod pitch. (See Figure 7.1).

The HAMMER model of the poison wall is shown in Figure 7.2. The resulting homogeneous wall X-sections were used in conjunction with the Group 3 & 4 blackness theory cross sections to accurately represent the poison wall. The wall configuration can be seen in Figure 6.1.

A HAMMER problem was written to represent each variation in fuel cell characteristics: enrichment, temperature and void content. Macroscopic cross sections for stainless steel, boron, water and zirconium were determined from microscopic cross sections derived from the HAMMER calculations. The fuel was assumed to occupy the total volume inside the clad including the gap; the correct amount of fuel was determined from the fuel loading information. The input dimensions and atom densities used for the various fuel cell calculations are listed in Table 7.2.

The resulting four group cross sections for fuel regions are summarized in Table 7.3.

7.2 Two Dimensional Diffusion Theory Calculations - EXTERMINATOR

The geometry layout and material labels used for the reference configuration are shown in Table 7.4. The cross sections for each fuel enrichment, for water, and for the poison wall were chosen from the appropriate four group cross sections determined by HAMMER. The cross sections for the boron were determined from blackness theory.

The cross section input and mesh spacings used for the referenced EXTERMINATOR configurations are listed in Table 7.4. Table 7.5 presents the resulting Δk_{eff} value for each calculation.

7.3 K_{eff} Values for Normal Configurations

7.3.1 Reference Configuration

The k_{eff} for the reference configuration described in Section 5.1.1 was determined to be 0.8819 by means of HAMMER/EXTERMINATOR.

7.3.2 Eccentric Configurations

The Δk_{eff} for the first eccentric configuration described in Section 5.1.2 (four assemblies displaced diagonally towards each other the maximum amount allowed by clearances) was determined to be -0.0029.

The Δk_{eff} due to displaced cans along rows is +0.0055 in the worst case.

7.3.3 Fuel Design Variation

Fuel enrichment was varied from 3.1 w/o to 3.5 w/o and Δk_{eff} = +0.0121 @3.5 w/o with the base case being 3.3 w/o. 3.3 w/o is the highest enrichment to be used in the rack, therefore no allowance need be made for fuel enrichment variation.

7.3.4 Fuel Rack Cell Pitch Variations

The average cell pitch was varied from the reference spacing plus and minus 0.25" and resulted in Δk_{eff} = +0.0304 @10.25" average cell pitch and Δk_{eff} = -0.0264 @10.75" average cell pitch.

The nominal cell pitch is 10.5"; it is estimated that this dimension will be maintained within ±1/16" with a resulting change in k_{eff} of ±0.0076.

7.3.5 Boron Concentration Variation

The boron concentration was varied plus and minus 10% resulting in corresponding Δk's of -.0010 and +0.0014. Since the minimum B^{10} content allowed by manufacture is equal to the base case areal density of 0.012 gmB^{10}/cm^2, no allowances will be taken for its variation.

7.3.6 "Worst Case" Normal Configuration

The k_{eff} for the "worst case" normal configuration can be determined from the k_{eff} for the reference case and the variations determined above.

Reference Case k_{eff}:	0.8819
Eccentric Positioning Fuel:	negative
Cell Pitch Decrease:	+0.0076
Displaced Box:	+0.0055

$$\text{Therefore } k_{eff} = 0.8819 \pm \sqrt{0.0076^2 + 0.0055^2}$$

$$= 0.8819 \pm 0.0094.$$

The resulting k_{eff} for the "worse case" normal configuration is 0.8913.

7.4 Keff Values for Abnormal Configuration

The abnormal configurations described in Section 5.2 include fuel handling incidents, variation in fuel pool temperature, a fuel assembly drop onto the rack and a seismic event.

7.4.1 Fuel Pool Temperature Variation

The variation of k_{eff} with fuel pool temperature is shown in Figure 7.4. For temperatures above 68° F Δk_{eff} is negative. At 39° F (maximum H_2O density) $\Delta k_{eff} = +0.0112$.

7.4.2 "Worst Case" Abnormal Configuration

Lowering fuel pool temperature to 39° F results in a Δk of +0.0112. Dropped fuel 6.0" from the rack will result in a Δk of +0.0032 which when added together gives a Δk of +0.0145. Other abnormal configurations are negligible. The final k_{eff} value taking account of abnormal configurations is:

$$k_{eff} = 0.9058.$$

7.5 Monte Carlo Calculation for Reference Configuration

A Monte Carlo calculation was performed using KENO to establish the bias between Monte Carlo and diffusion theory in order to compensate for the inaccuracies of diffusion theory. The reference configuration k_{eff} using KENO resulted in a value of 0.9074 and corresponding Δk of +0.0255.

The k_{eff} for the worst case normal configuration with bias is $k_{eff} = 0.9168$. The resulting k_{eff} for the worst case abnormal configuration is $k_{eff} = 0.9313$.

7.6 Effects of Calculational Uncertainty

The k_{eff} values presented in the previous sections do not include the effect of calculational uncertainties. In order to accurately assess the uncertainty of a specified calculational system, it is necessary to compare many calculational results with the corresponding criticality experiments. Consequently, NES has investigated the open literature to determine what uncertainty values are assigned to criticality computations after comparisons with many experiments have been made. The uncertainties, depending upon the specific combination of codes used to determine the cross sections and the multiplication constant, range from less than 0.007 to less than 0.015 at the 95 percent confidence level.

For the purposes of assessing the impact of calculational uncertainty, NES has assumed a value of 0.01. When this uncertainty is combined statistically with the k_{eff} values associated with the normal configurations, the upper limit of the k_{eff} value becomes 0.9356 for the "worst case" abnormal configuration. Even if it is assumed that the calculation uncertainty is 0.02, the resulting k_{eff} for the "worst case" abnormal configuration is still less than the criticality design criterion value (0.95). Therefore it can be concluded that the Crystal River Unit 3 high density storage racks when loaded with the specified fuel are safe from a criticality viewpoint.

TABLE 7.1

COMPONENT DIMENSIONS FOR 15 x 15 BABCOCK & WILCOX FUEL

ITEM	MATERIAL	DIMENSIONS (INCHES)
(1) Mass UO_2/Assy	UO_2	Ave 528 kg Max 536.94 kg
Fuel rod:		
(a) Fuel	UO_2 sintered pellets (92.5% theoretical density) = when smeared to clad ID	0.370 diameter 9.6368 gm/cc
(b) Fuel Clad	Zircaloy-4	0.430 OD x 0.377 ID x 153-1/8 long
(c) Fuel rod pitch		0.568
(d) Active fuel length		144
(e) Ceramic spacer	ZrO_2	0.366 diameter
(f) Minimum fuel to clad gap (BOL)		0.0045
(2) Fuel assembly:		
(a) Fuel assembly square dimension		8.587
(b) Overall Length		165-5/8
(c) Control rod guide tube	Zircaloy-4	0.530 OD x 0.016 wall
(d) Instrumentation tube	Zircaloy-4	0.493 OD x 0.441 ID
(e) End Fittings	Stainless Steel (castings)	
(f) Spacer grid	Inconel-718 strips	0.020 thick exteriors 0.016 thick interiors
(g) Spacer Sleeve	Zircaloy-4	0.554 OD x 0.502 ID

TABLE 7.2

FUEL-HAMMER INPUT DATA

Enrichment, w/o	Temp, ° F	Pure Water Density, gm/cc	Fuel* atoms/b-cm			Clad atoms/b-cm	Moderator** atoms/b-cm	
			U^{235}	U^{238}	Oxygen	Zirconium	Hydrogen	Oxygen
3.3	68°	.998	7.183-4	2.078-2	4.300-2	4.29-2	6.6348-2	3.3174-2
3.3	39°	1.000	7.183-4	2.078-2	4.300-2	4.29-2	6.6466-2	3·3233-2
3.3	90°	.995	7.183-4	2.078-2	4.300-2	4.29-2	6.6137-2	3.3068-2
3.3	212°	.958	7.183-4	2.078-2	4.300-2	4.29-2	6.3699-2	3.1849-2
3.3	260°	.938	7.183-4	2.078-2	4.300-2	4.29-2	6.2345-2	3.1172-2
3.3	220°	.907	7.183-4	2.078-2	4.300-2	4.29-2	6.0309-2	3.0154-2
3.1	68°	.998	6.748-4	2.082-2	4.300-2	4.29-2	6.6348-2	3.3174-2
3.5	68°	.998	7.618-4	2.074-2	4.300-2	4.29-2	6.6348-2	3.3174-2

* Fuel Pellet O.D. = .377"
Clad O.D. = .430"
Pitch = .568"

note that pellet and gap are smeared

** In addition, the moderator has: Nickel 2.418-4,
Chrome 9.671-5,
Iron 8.953-5 atoms/b-cm

TABLE 7.3

FOUR GROUP HAMMER X-SECTIONS FOR FUEL REGIONS

Group #	D	Σr	Σa	νΣf
3.3 w/o, 68° F, 0.998 gm/cc				
1	1.94258	7.87730-2	4.28100-3	8.61700-3
2	1.00866	7.96070-2	2.60000-3	1.03200-3
3	7.15394-1	7.01250-2	2.43180-2	1.42200-2
4	2.73752-1	0.	1.11507-1	1.86895-1
3.3 w/o, 212° F, .958 gm/cc				
1	1.98237	7.65070-2	4.26300-3	8.59000-3
2	1.02964	7.64640-2	2.59900-3	1.03100-3
3	7.35263-1	6.69780-2	2.42360-2	1.42010-2
4	2.91370-1	0.	1.02900-1	1.72738-1
3.3 w/o, 260° F, .955 gm/cc				
1	2.00338	7.53460-2	4.25400-3	8.57500-3
2	1.04073	7.48570-2	2.59800-3	1.03100-3
3	7.45856-1	6.53710-2	2.41920-2	1.41910-2
4	2.98596-1	0.	1.00907-1	1.69583-1
3.3 w/o, 220° F, 5% voids, .907 gm/cc				
1	2.03584	7.36000-2	4.24000-3	8.55300-3
2	1.05787	7.24410-2	2.59800-3	1.03100-3
3	7.62364-1	6.29570-2	2.41240-2	1.41760-2
4	3.05980-1	0.	1.01507-1	1.71026-1
3.1 w/o, 68° F, 0.998 gm/cc				
1	1.94272	7.87770-2	4.26900-3	8.58400-3
2	1.00869	7.96170-2	2.57200-3	9.70000-4
3	7.15402-1	7.03420-2	2.38500-2	1.34170-2
4	2.73485-1	0.	1.07690-1	1.7850-1
3.5 w/o, 68° F, 0.998 gm/cc				
1	1.94244	7.87690-2	4.29400-3	8.65000-3
2	1.00864	7.95970-2	2.62700-3	1.09400-3
3	7.15384-1	6.99110-2	2.47820-2	1.50170-2
4	2.73969-1	0.	1.15226-1	1.95047-1

TABLE 7.3 (con't)

Group #	D	Σr	Σa	$\Sigma \nu f$
3.3 w/o, 39° F, 1-000 gm/cc				
1	1.94086	7.88730-2	4.28200-3	8.61800-3
2	1.00776	7.97460-2	2.60000-3	1.03200-3
3	7.14539-1	7.02650-2	2.43210-2	1.42200-2
4	2.73304-1	0.	1.11560-1	1.86958-1
3.3 w/o, 90° F, 0.995 gm/cc				
1	1.94570	7.85920-2	4.28000-3	8.61500-3
2	1.01031	7.93560-2	2.60000-3	1.03200-3
3	7.16943-1	6.98730-2	2.43120-2	1.42180-2
4	2.75562-1	0.	1.10279-1	1.84850-1

TABLE 7.4

CRYSTAL RIVER BASE CASE REFERENCE CASE EXTERMINATOR INPUT

```
OPTION CARD

1 1 1 1 1 1 -0 -0 -0 2 1 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 0 -0 -0 -0 -0 -0 1 -0

SPECIFICATIONS

19 ROWS   19 COLS   4 GRPS   6 COMPS   -0 NUCS   L, T,R,B BND 1 1 1 1   FPI   5.0000E-04   NORM FAC   1.000000E+00

THIS CASE HAS X-Y GEOMETRY,
AND IS AN EIGENVALUE CALC.

FISSION-SOURCE CHI(K)

.7532    .2466    .0002    0.0000

MESH SPECIFICATIONS

I   DELTA
1   1.443    7   .399    8   1.044    9   1.443    10   .148    11   .533    12   .095    14   .533    15   .317    19

J   DELTA
1   1.443    7   .399    8   1.044    9   1.443    10   .148    11   .533    12   .095    14   .533    15   .317    19

DIMENSION SPECIFICATIONS

I  DIST
 2    .721    3   2.164    4   3.606    5   5.049    6   6.491    7   7.934    8   8.333    9   9.376   10  10.819
11  10.968   12  11.502   13  11.597   14  11.692   15  12.225   16  12.542   17  12.859   18  13.175   19  13.492

I  DIST
 2    .721    3   2.164    4   3.606    5   5.049    6   6.491    7   7.934    8   8.333    9   9.376   10  10.819
11  10.968   12  11.502   13  11.597   14  11.692   15  12.225   16  12.542   17  12.859   18  13.175   19  13.492
```

TABLE 7.4 (continued)

CRYSTAL RIVER BASE CASE REACTOR MATERIAL PICTURE

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	2	1	1	1	1	1	1	1	1	3	4	5	5	4	3	3	3	3	
2	1	1	1	1	1	1	1	1	1	3	4	5	5	4	3	3	3	3	
3	1	1	2	1	1	2	1	1	1	3	4	5	5	4	3	3	3	3	
4	1	1	1	1	1	1	1	1	1	3	4	5	5	4	3	3	3	3	
5	1	1	1	1	2	1	1	1	1	3	4	5	5	4	3	3	3	3	
6	1	1	2	1	1	1	1	1	1	3	4	5	5	4	3	3	3	3	
7	1	1	1	1	1	1	1	1	1	3	4	5	5	4	3	3	3	3	
8	1	1	1	1	1	1	1	1	1	3	4	6	6	6	3	3	3	3	
9	1	1	1	1	1	1	1	1	1	3	4	6	6	6	3	3	3	3	
10	3	3	3	3	3	3	3	3	3	3	4	6	6	6	3	3	3	3	
11	4	4	4	4	4	4	4	4	4	4	4	6	6	3	3	3	3	3	
12	5	5	5	5	5	5	5	6	6	6	6	6	6	3	3	3	3	3	
13	5	5	5	5	5	5	5	6	6	6	6	6	6	3	3	3	3	3	
14	4	4	4	4	4	4	4	6	6	6	3	3	3	3	3	3	3	3	
15	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
16	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
17	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
18	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
19																			

LEGEND - 1 - Fuel
2 - Guide Tubes
3 - Water
4 - Stainless Steel & Water
5 - Poison
6 - Stainless Steel

TABLE 7.4 (Continued)

SCATTERING MATRIX

COMP	GRP	TO GRP 1	2	3	4
1	1	0.	7.87730E-02	0.	0.
	2	0.	0.	7.93070E-02	0.
	3	0.	0.	0.	7.01250E-02
	4	0.	-0.	-0.	-0.
2	1	0.	9.98090E-02	0.	0.
	2	0.	0.	0.34286E-01	0.
	3	0.	0.	0.	1.33169E-01
	4	0.	-0.	-0.	-0.
3	1	0.	1.07430E-01	0.	0.
	2	0.	0.	1.48170E-01	0.
	3	0.	0.	0.	1.45490E-01
	4	0.	-0.	-0.	-0.
4	1	0.	7.88530E-02	0.	0.
	2	0.	0.	8.92340E-02	0.
	3	0.	0.	0.	6.10430E-02
	4	0.	-0.	-0.	-0.
5	1	0.	7.88530E-02	0.	0.
	2	0.	0.	8.92340E-02	0.
	3	0.	0	0.	2.98080E-02
	4	0.	-0.	-0.	-0.
6	1	0.	3.45920E-02	0.	0.
	2	0.	0.	4.34100E-03	0.
	3	0.	0.	0.	1.53100E-03
	4	0.	-0.	-0.	-0.

TABLE 7.4 (Continued)

COMPOSITION SPECIFICATIONS

COMP	GRP	D	Σr	Σa	$\nu\Sigma f$	SOURCE	B^2	SIGE
1	1	1.94258E+00	7.87730E-02	4.28100E-03	8.61700E-03	-0.	6.29000E-05	0.
	2	1.00866E+00	7.96070E-02	2.60000E-03	1.03200E-03	-0.	6.29000E-05	0.
	3	7.15394E-01	7.01250E-02	2.43180E-02	1.42200E-02	-0.	6.29000E-05	0.
	4	2.73752E-01	0.	1.11507E-01	1.86895E-01	-0.	6.29000E-05	0.
2	1	2.06250E+00	9.98090E-02	5.79000E-04	0.	-0.	6.29000E-05	0.
	2	1.07357E+00	1.35286E-01	9.00000E-05	0.	-0.	6.29000E-05	0.
	3	6.06417E-01	1.33469E-01	1.24500E-03	0.	-0.	6.29000E-05	0.
	4	1.80181E-01	0.	1.75669E-02	0.	-0.	6.29000E-05	0.
3	1	3.16230E+00	1.07430E-01	3.53000E-04	0.	-0.	6.29000E-05	0.
	2	1.06560E+00	1.48170E-01	1.30000E-05	0.	-0.	6.29000E-05	0.
	3	5.65090E-01	1.45490E-01	1.01600E-03	0.	-0.	6.29000E-05	0.
	4	1.72260E-01	0.	1.76560E-02	0.	-0.	6.29000E-05	0.
4	1	2.13265E+00	7.88530E-02	3.58000E-04	0.	-0.	6.29000E-05	0.
	2	1.21637E+00	8.92340E-02	1.47100E-03	0.	-0.	6.29000E-05	0.
	3	5.08479E-01	6.10430E-02	3.29400E-03	0.	-0.	6.29000E-05	0.
	4	2.31480E-01	0.	3.97740E-02	0.	-0.	6.29000E-05	0.
5	1	2.13265E+00	7.88530E-02	3.48000E-04	0.	-0.	6.29000E-05	0.
	2	1.21637E+00	8.92340E-02	1.47100E-02	0.	-0.	6.29000E-05	0.
	3	4.64700E-01	2.98080E-02	6.03220E-01	0.	-0.	6.29000E-05	0.
	4	2.72310E-02	0.	6.15730E+00	0.	-0.	6.29000E-05	0.
6	1	1.69560E+00	3.45920E-02	2.09000E-04	0.	-0.	6.29000E-05	0.
	2	1.06680E+00	4.34100E-03	9.95000E-04	0.	-0.	6.29000E-05	0.
	3	3.99570E-01	1.53100E-03	9.86900E-03	0.	-0.	6.29000E-05	0.
	4	3.25580E-01	0.	1.28390E-01	0.	-0.	6.28000E-05	0.

TABLE 7.5

PARAMETERS AND RESULTS OF EXTERMINATOR CALCULATIONS

	FUEL ENRICHMENT, W/O	AVERAGE PITCH, IN	B^{10} DENSITY, ATOMS/B-CM	TEMP, °F	H_2O DENSITY gm/cc	BOX WALL THICKNESS, IN	BOX OD, INCHES	ΔK_{EFF}
Reference Case	3.3	10.5	0.00379	68	0.998	.195	9.328	Keff = 0.8819
Maximum Water Density	3.3	10.5	0.00379	39	1.000	.195	9.328	+0.0112
90°F	3.3	10.5	0.00379	90	0.995	.195	9.328	-0.00
212°F	3.3	10.5	0.00379	212	0.958	.195	9.328	-0.0156
260°F	3.3	10.5	0.00379	260	0.955	.195	9.328	-0.0209
220°F 5% Voids	3.3	10.5	0.00379	220	0.907	.195	9.328	-0.0276
High Enrichment	3.5	10.5	0.00379	68	0.998	.195	9.328	+0.0121
Low Enrichment	3.1	10.5	0.00379	68	0.998	.195	9.328	-0.0133
High B^{10} Concentration	3.3	10.5	0.00417	68	0.998	.195	9.328	-0.0010
Low B^{10} Concentration	3.3	10.5	0.00341	68	0.998	.195	9.328	+0.0014
Thick Wall	3.3	10.5	0.00379	68	0.998	.215	9.348	-0.0008
Thin Wall	3.3	10.5	0.00379	68	0.998	.175	9.308	+0.0009
Dropped Fuel 6" From Rack	3.3	10.5	0.00379	68	0.998	.195	9.328	+0.0032
Eccentric Fuel	3.3	10.5	0.00379	68	0.998	.195	9.328	-.0029
Eccentric Can	3.3	10.5	0.00379	68	0.998	.195	9.328	+0.0055
Pitch Variation +.25"	3.3	10.75	0.00379	68	0.998	.195	9.328	-.0264
Pitch Variation -.25"	3.3	10.25	0.00379	68	0.998	.195	9.328	+.0304

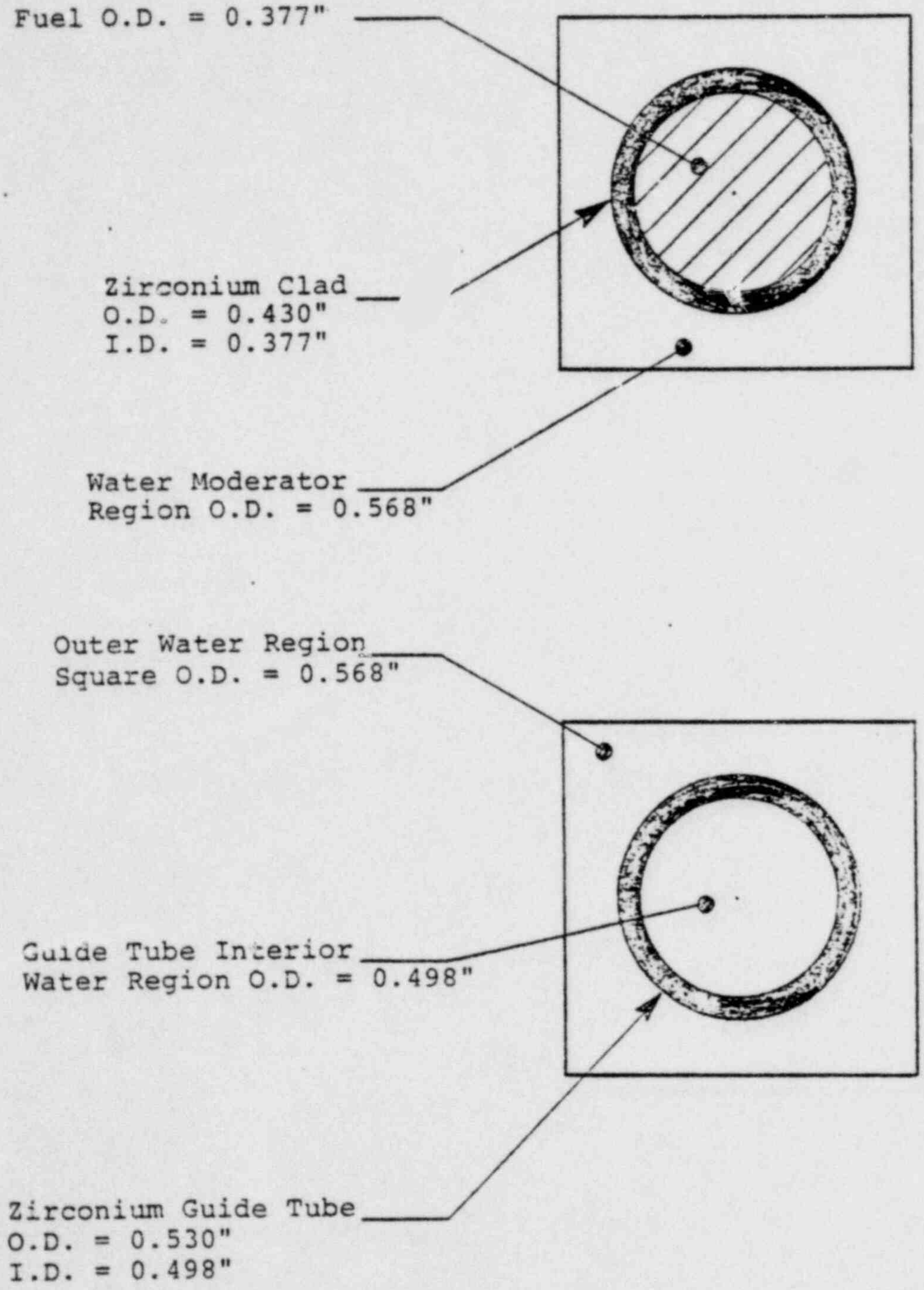
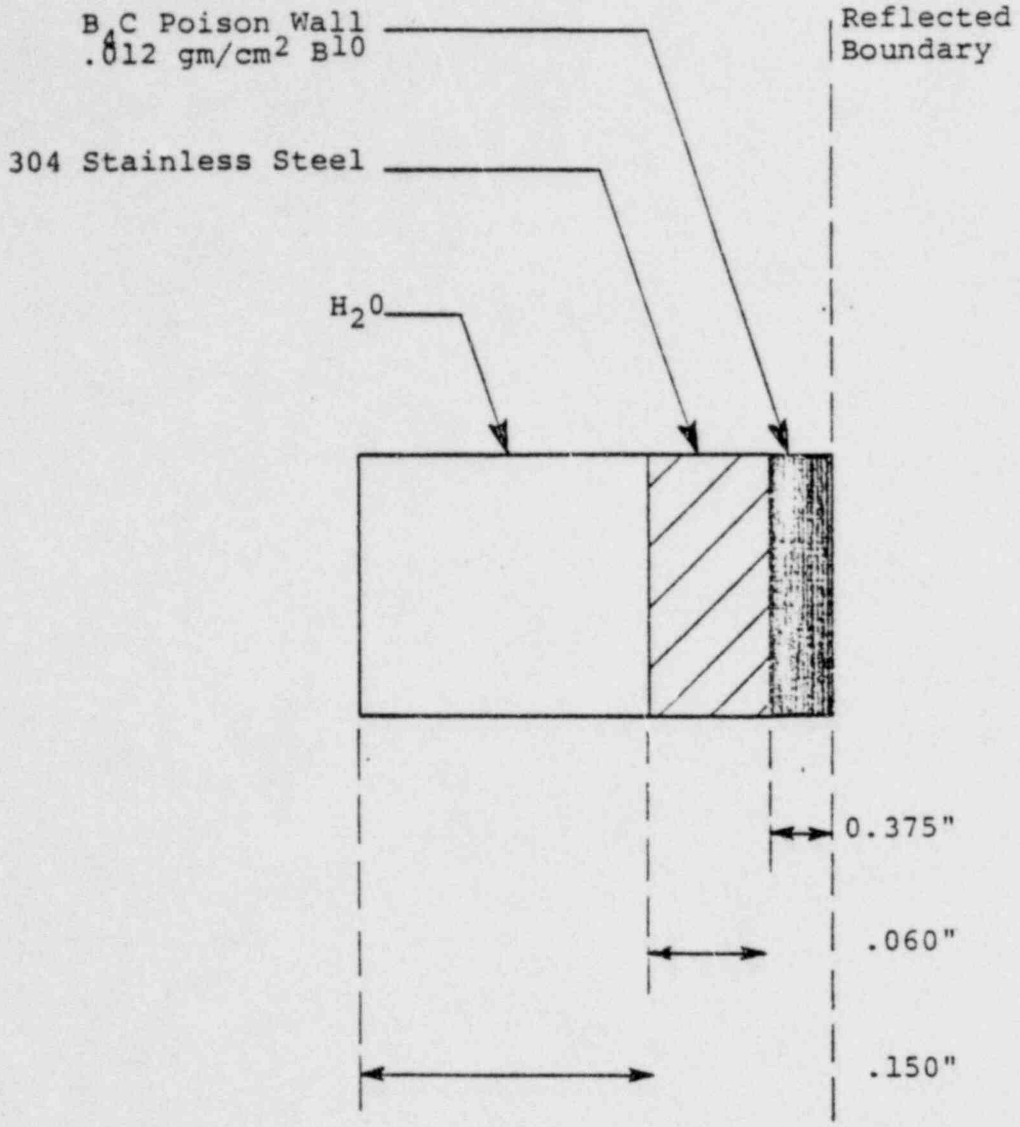


ILLUSTRATION OF HAMMER MODELS USED TO DETERMINE FUEL AND GUIDE TUBE CROSS SECTIONS FOR 15 x 15, 3.3 w/o BABCOCK & WILCOX FUEL

FIGURE 7.1



POISON WALL MODEL USED IN HAMMER CALCULATIONS
TO DETERMINE HOMEGENEOUS X-SECTIONS

FIGURE 7.2

ΔK_{EFF} VS. FUEL ENRICHMENT FOR CRYSTAL RIVER UNIT 3 SPENT FUEL STORAGE RACK

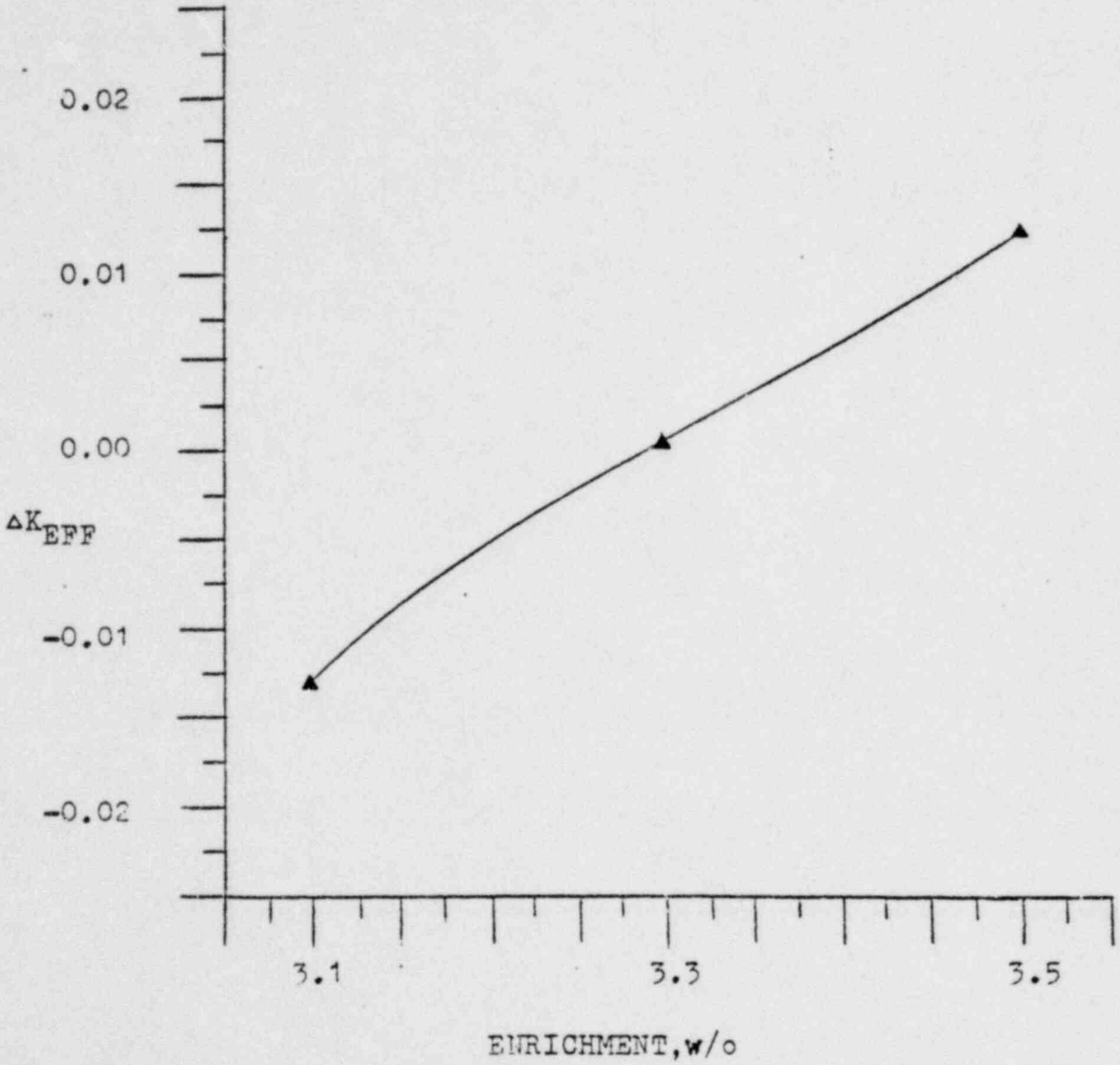


FIG. 7.3

ΔK$_{EFF}$ VS. TEMPERATURE FOR
CRYSTAL RIVER UNIT 3 SPENT
FUEL STORAGE RACK

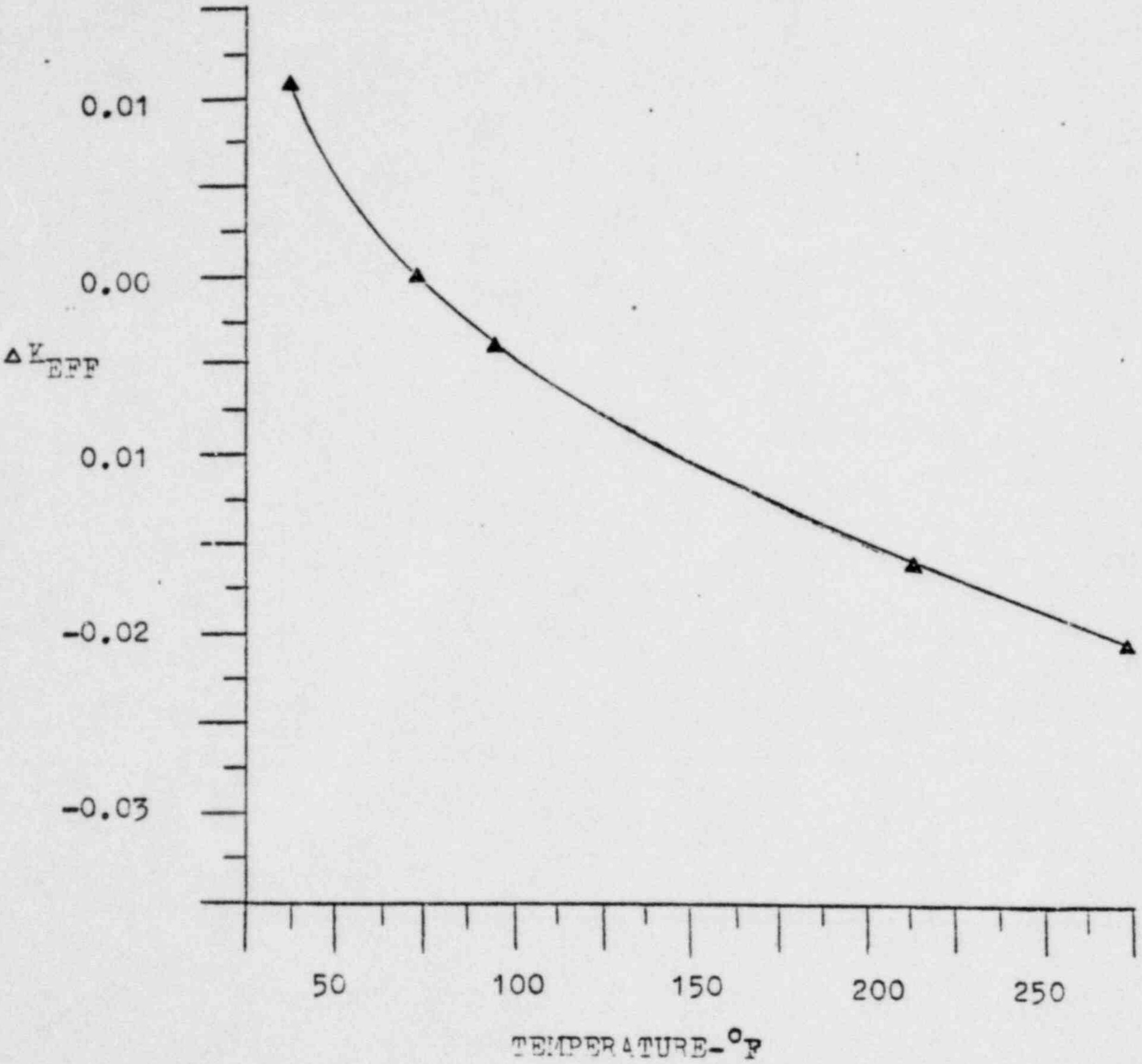


FIG. 7.4

ΔK_{EFF} VS. WATER DENSITY FOR
CRYSTAL RIVER UNIT 3 SPENT
FUEL STORAGE RACK

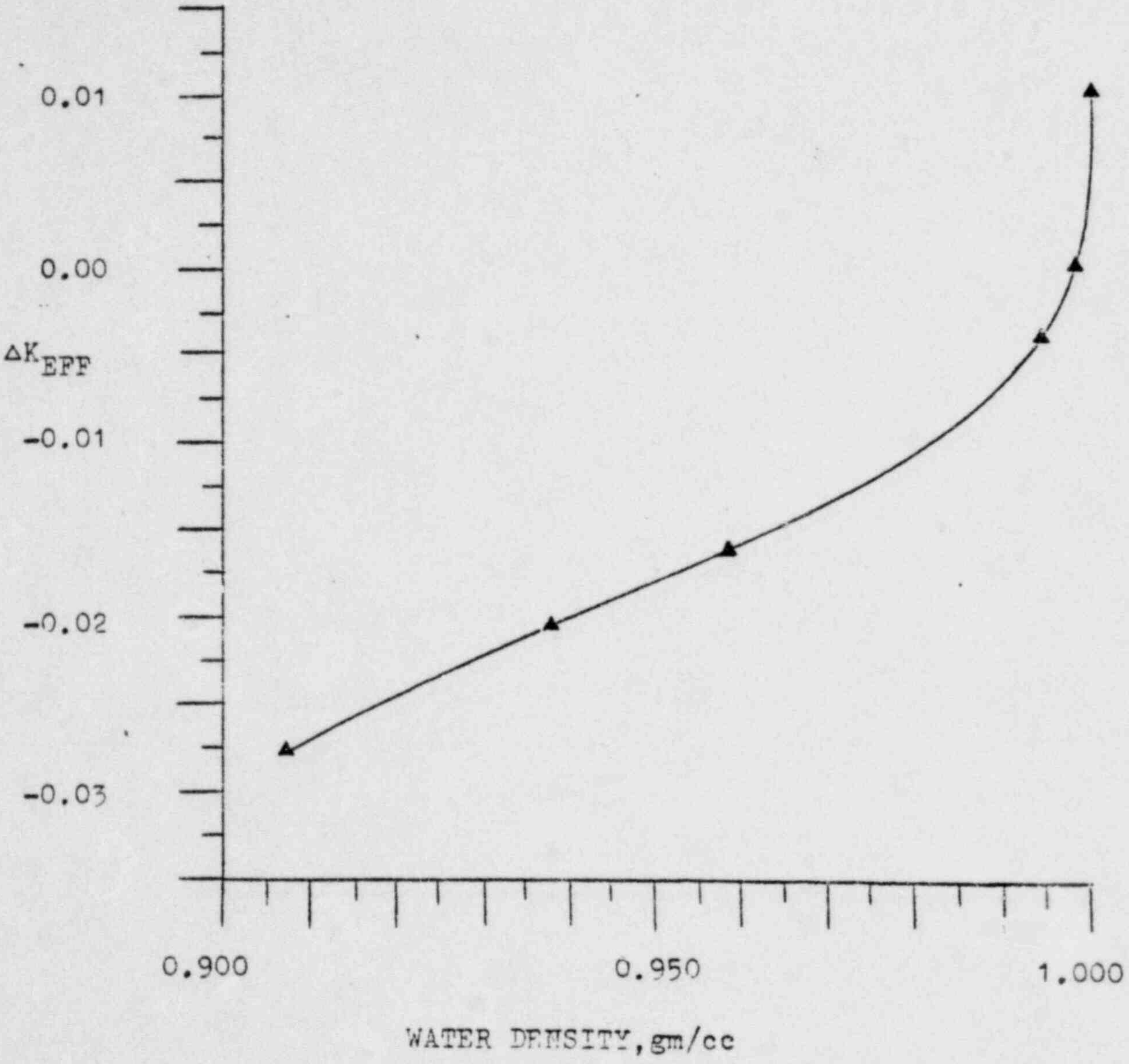


FIG. 7.5

ΔK_{EFF} VS. PITCH VARIATION FOR
CRYSTAL RIVER UNIT 3 SPENT FUEL
STORAGE RACK

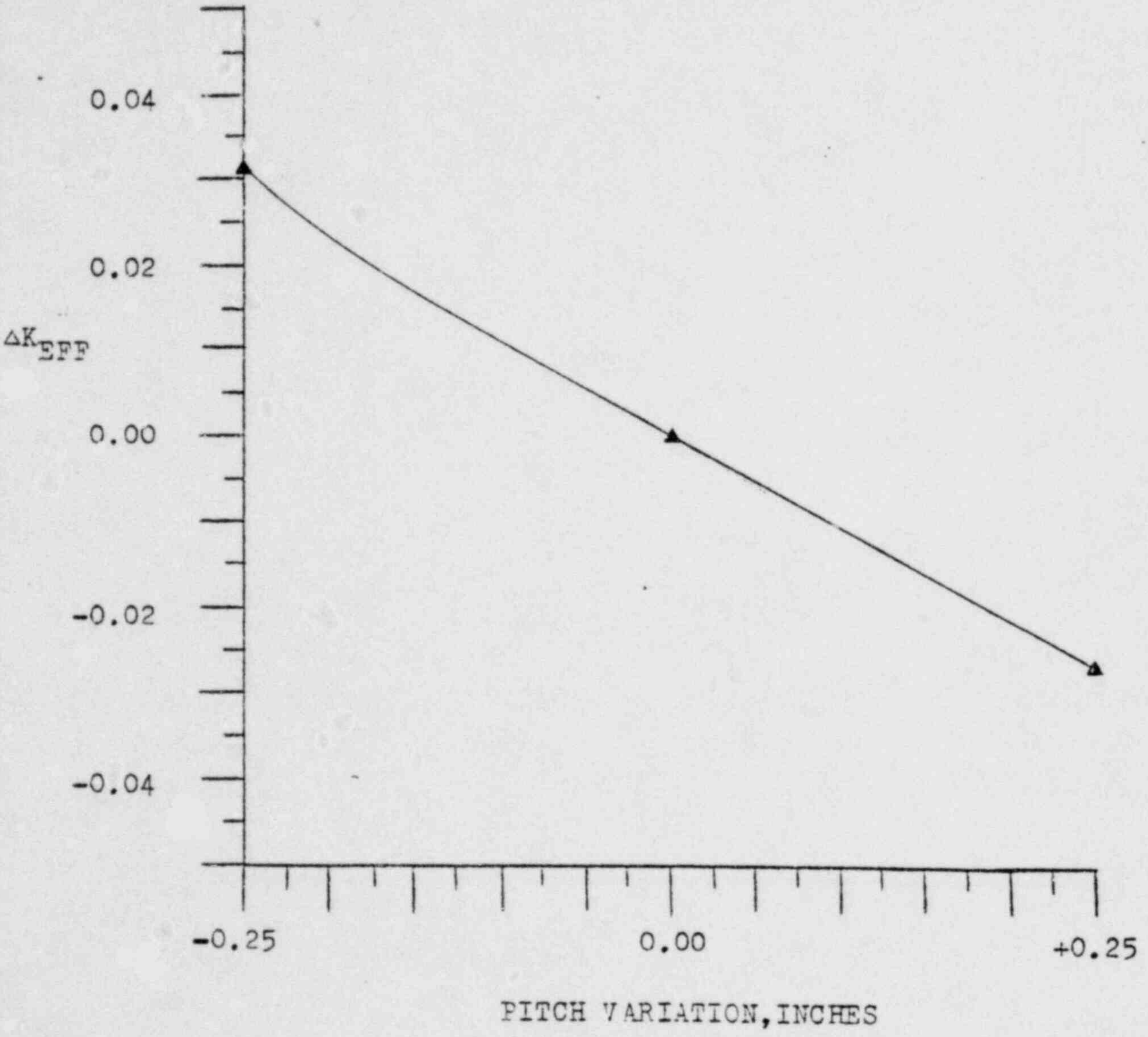


FIG. 7.6

ΔK_{EFF} VS. B^{10} CONCENTRATION FOR CRYSTAL RIVER UNIT 3 SPENT FUEL STORAGE RACK

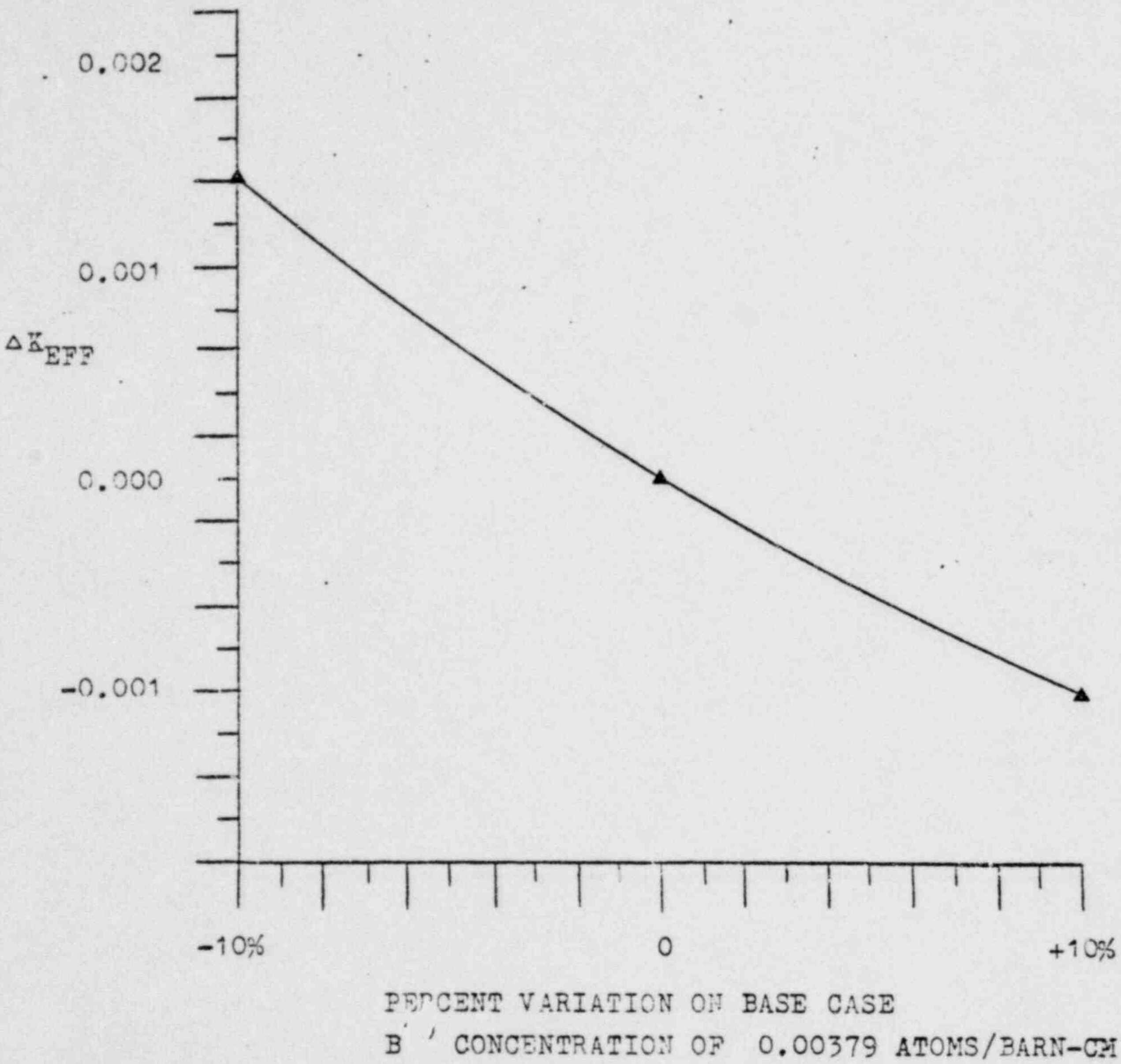


FIG. 7.7

ΔK_{EFF} VS. STAINLESS STEEL WALL THICKNESS FOR CRYSTAL RIVER UNIT 3 SPENT FUEL STORAGE RACK

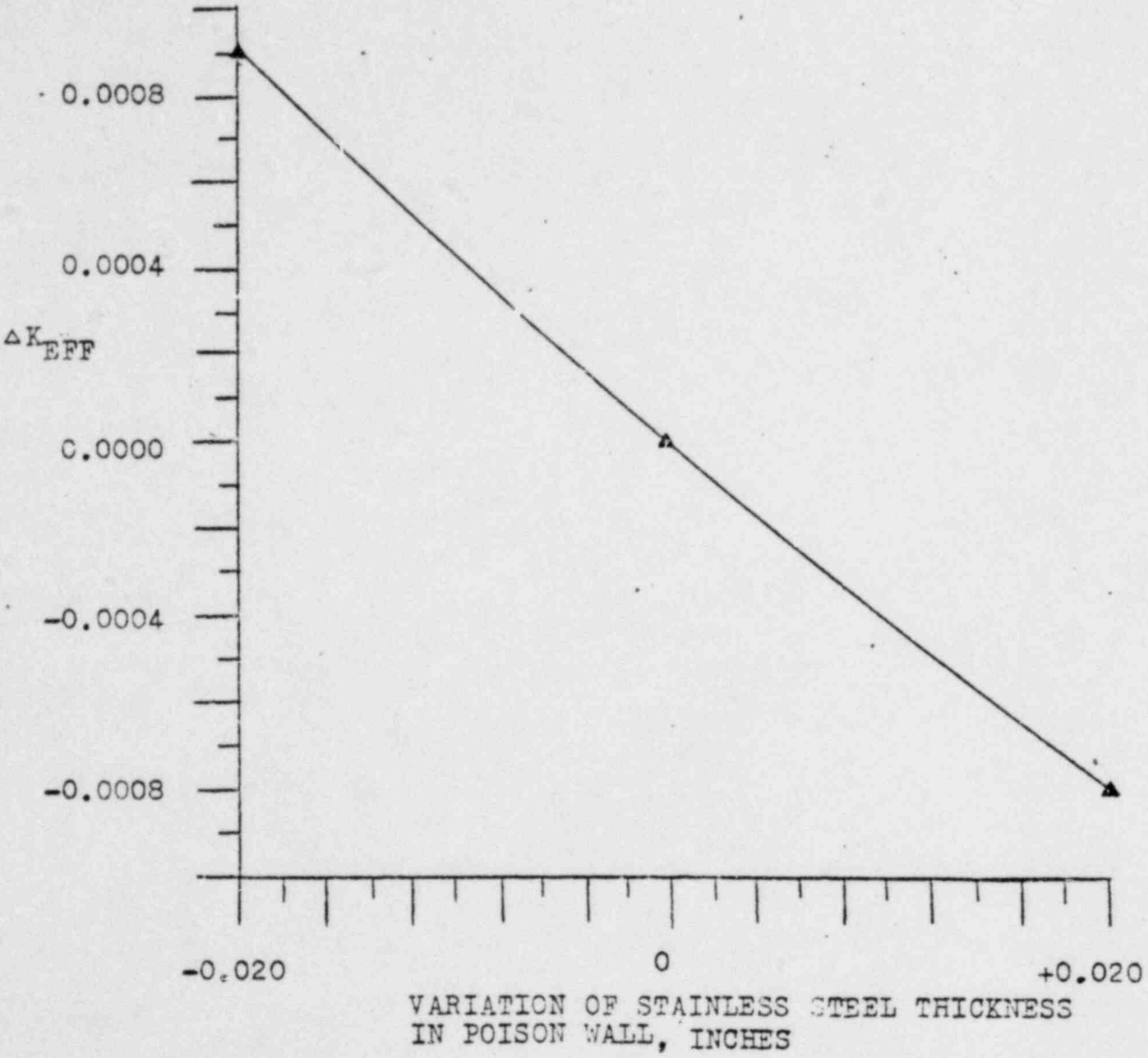


FIG. 7.8

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