NUCLEAR ENERGY SERVICES, INC.

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NUCLEAR DESIGN ANALYSIS REPORT FOR THE CALVERT CLIFFS UNIT #1 NUCLEAR PLANT HIGH DENSITY SPENT FUEL STORAGE RACKS

PREPARED UNDER NES PROJECT 5134
FOR THE
BALTIMORE GAS & ELECTRIC COMPANY

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1. SUMMARY

A detailed nuclear analysis has been performed for the NES designed fuel storage racks for the Calvert Cliffs Unit No.1 Nuclear Plant. This analysis demonstrates that, for all anticipated normal and abnormal configurations of fuel assemblies within the fuel storage racks, the k_{eff} of the system is less than the criticality criterion of 0.95 for 4.10 w/o, 14x14 Combustion Engineering fuel assemblies. Certain conservative assumptions about the fuel assemblies and racks have been used in the calculations.

Both normal and abnormal configurations were considered in the analysis. The reference configuration consists of a square array, infinite in lateral extent, of storage cells spaced 10.09375 inches on centers. Each storage location contains one centrally located 14x14 Combustion Engineering fuel assembly. Poison sheets containing boron in the form of B_4C are located in the walls of the storage cells to provide criticality control. This reference configuration provides a base of comparison relative to which effects of normal and abnormal variations have been measured. Normal configurations include: eccentrically positioned fuel, fuel enrichment variation, dimensional and material variations permitted by fabrication tolerances, and variation in the density of the boron in the poison slabs. Effects due to finite B_4C particle sizes were also considered.

Abnormal configurations include: pitch variation due to seismic events, spent fuel pool temperature variations and fuel handling accidents such as misplaced fuel assemblies.

The principal method of calculation used to determine the k_{eff} of the Calvert Cliffs spent fuel storage racks was transport theory using the Monte Carlo code KENO IV. Two cross section sets were used in KENO IV: a 16 group Hansen-Roach set and a set using 123 energy groups. Cross section input for the 123 energy group set was generated from the XSDRN library using the AMPX module NITAWL.

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Parametric studies to determine the effects on k_{eff} of changes in fuel rack dimensions, temperature, and fuel assembly enrichment were performed with diffusion theory. Fuel, water and structural cross sections were determined using the HAMMER code, while blackness theory was used to determine boron cross sections. k_{eff} values were calculated using EXTERMINATOR, a multigroup, two-dimensional diffusion theory code.

The k_{eff} value calculated by KENO for the reference configuration is 0.9001. Variations in k_{eff} due to normal configuration changes and calculational uncertainty were determined to be 0.0085. The Δk_{eff} due to the "worst case" abnormal configuration is 0.0000. Combining these two Δk_{eff} values with the k_{eff} for the reference configuration of 0.9001 results in a final k_{eff} value equal to 0.9086. This value meets the criticality design criterion and is substantially below 1.0. Therefore, it has been concluded that the high density storage racks for the Calvert Cliffs Unit No.1 Nuclear Plant when loaded with the specified fuel are safe from a criticality standpoint.

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2. INTRODUCTION

The NES design for the Calvert Cliffs Unit No.1 Nuclear Plant high density spent fuel storage racks achieves high storage density through the placement of poison sheets in the walls of the storage cells. Details of the rack materials and structure are given in Section 3.

A detailed nuclear analysis has been performed to demonstrate that, for all anticipated normal and abnormal configurations of fuel assemblies within the fuel storage racks, the k_{eff} of the system is substantially below 1.0. Certain conservative assumptions about the fuel assemblies and racks have been used in the calculations. These are described in Section 4 along with the criticality design criterion for the fuel assemblies and racks.

The reference configuration which forms the basis of the criticality calculations represents the storage racks in nominal dimensions at 68°F with all fuel assemblies centrally located within their storage cells. Variations from this reference configuration were studied, and included effects of wall thickness and pitch variations, fuel enrichment and poison content variations, water temperature variation and eccentric fuel positioning. Fuel handling accidents were studied and their effects determined. The configurations studied are described in detail in Section 5. A description of the calculational methods, benchmarking results, and computer codes is given in Section 6. The results of the criticality analysis are presented in Section 7.

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3. DESCRIPTION OF SPENT FUEL STORAGE RACKS

Three sizes of fuel storage racks, with 7x10, 8x10, and 10x10 storage cell arrays, will be used in the Calvert Cliffs Unit No.1 spent fuel storage pool (see Figure 3.1). The total number of fuel storage locations within the pool will be 830.

The inner wall of each storage cell is made up of a 0.060 inch thick sheet of 304L stainless steel, formed into a square with an inner dimension of 8-9/16 inches. On the outside of each of the four sides of this inner wall, a poison sheet 6-1/2 inches wide is sandwiched between the inner wall and an external 0.060 inch-thick stainless steel sheet (see Figure 3.2). The poison sheet is 0.090 inch thick and contains a minimum of 0.024 gm/cm^2 of B^{10}.

The external sheet extends over two fuel storage cells so that storage cells are grouped into 2x2 modules from which the storage racks are built up (Figure 3.2). The average center-to-center pitch between all fuel storage boxes is maintained by the external sheets and welded spacers at 10.09375 $\pm$0.03125 inches.

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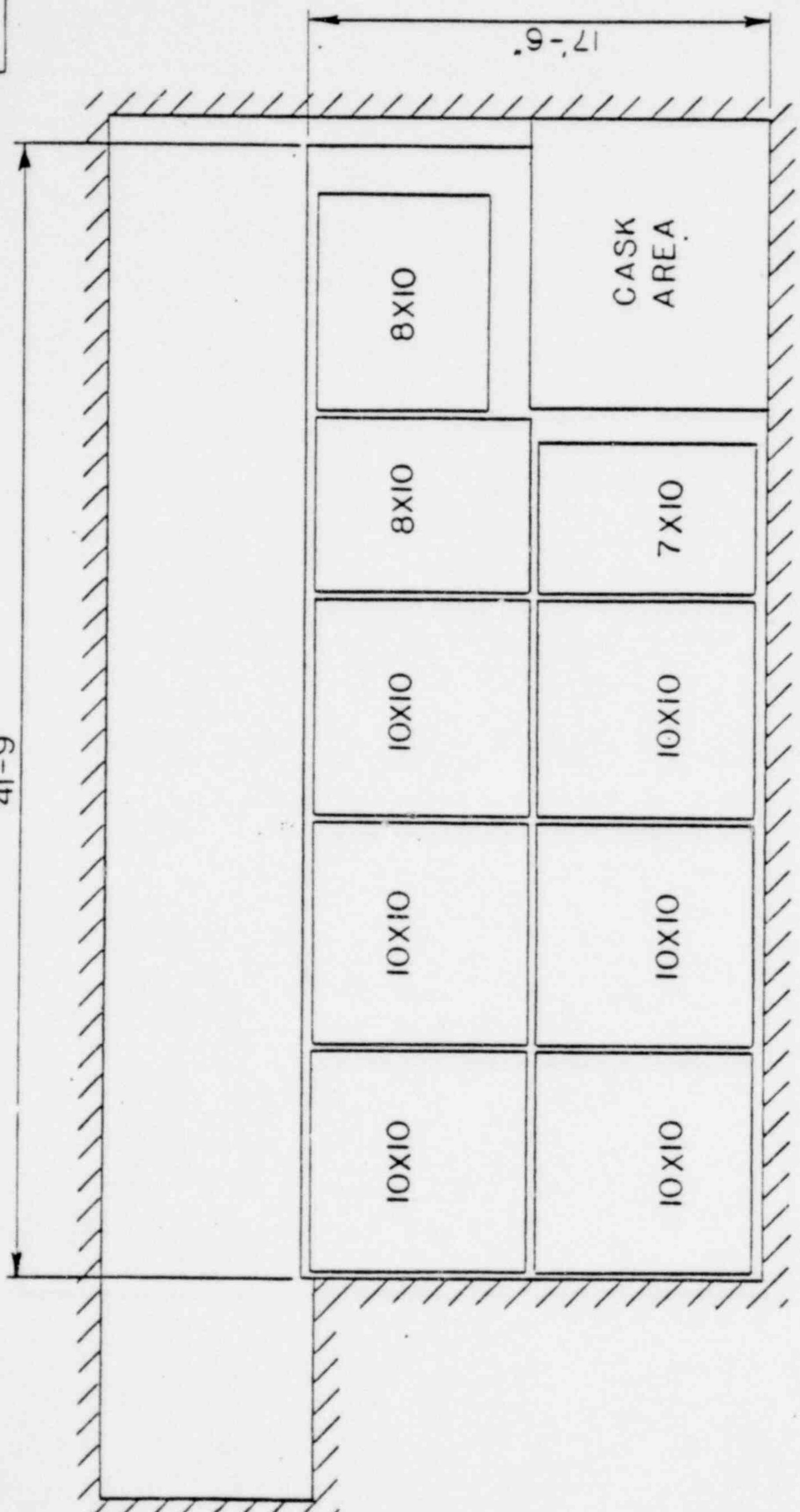
-NES-



PLAN
FUEL STORAGE RACK ARRANGEMENT
(NORTHERN POOL)

FIGURE 3-1

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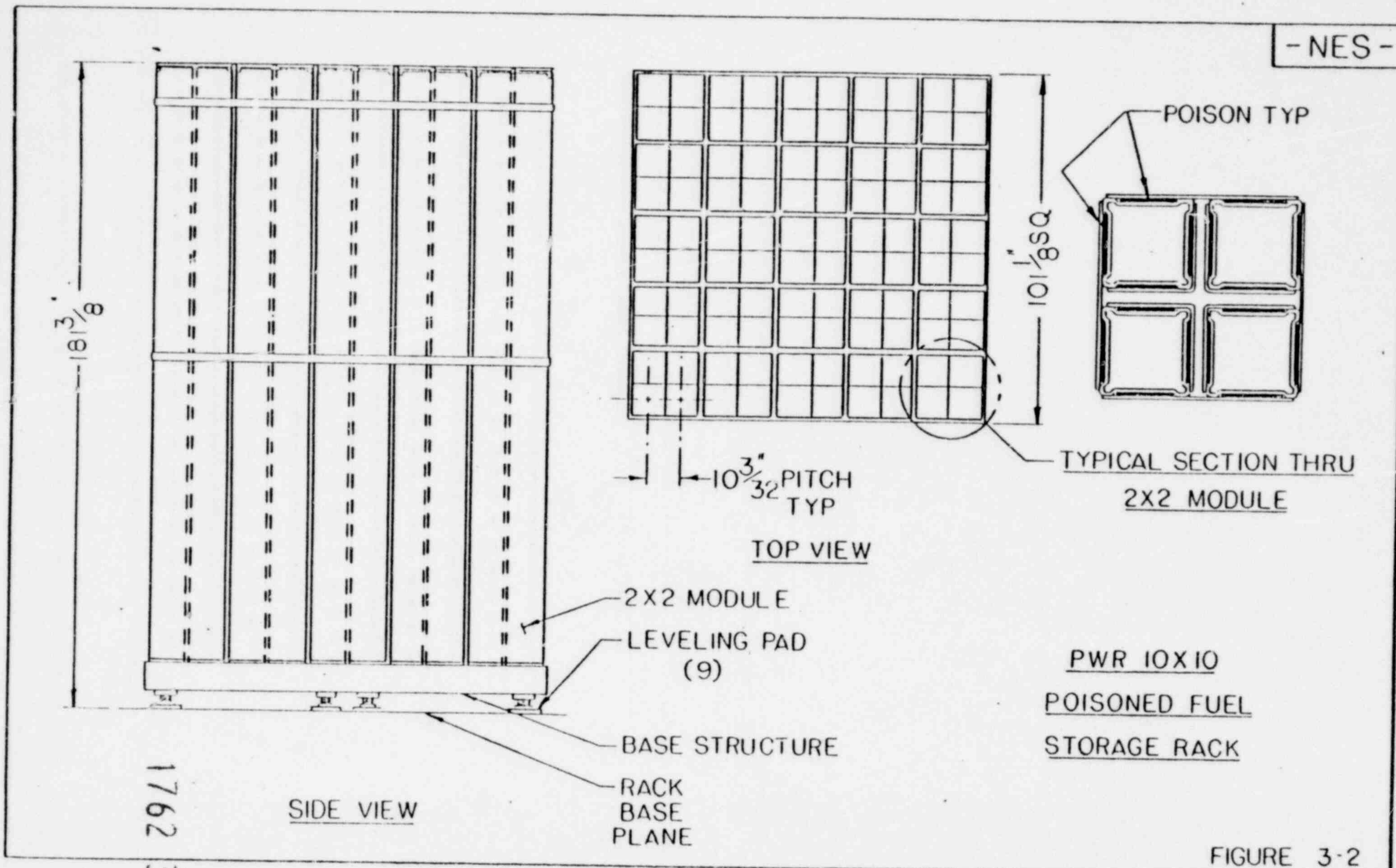
-NES-
POISON TYP
181 3/8"
101 1/8" SQ
10 3/32" PITCH TYP
TOP VIEW
TYPICAL SECTION THRU 2X2 MODULE
2X2 MODULE
LEVELING PAD (9)
BASE STRUCTURE
RACK BASE PLANE
SIDE VIEW
PWR 10X10 POISONED FUEL STORAGE RACK

FIGURE 3-2

4. CRITICALITY DESIGN CRITERION AND CALCULATION ASSUMPTIONS

4.1 CRITICALITY DESIGN CRITERION

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

The published position of the NRC on fuel storage criticality, stated in a communique to all reactor licensees* is a follows:

> "The neutron multiplication factor in spent fuel pools shall be less than or equal to 0.95, **including all uncertainties**, under all conditions".

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 Calvert Cliffs Unit No.1 Nuclear Plant high density fuel storage racks: "The multiplication constant (k_{eff}) shall be less than 0.95 for all normal and abnormal configurations as determined 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:

1. The fuel is fresh and of a specified enrichment greater than or equal to that of any fuel available (4.1 w/o)

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* See Section 8 for References.

2. The reference configuration contains an infinite square array of storage locations spaced 10-3/32 inches on centers. This is conservative because the array is not infinite, but finite.

3. The absorption of the fuel assembly spacers is ignored.

4. Any burnable poisons in the fuel assemblies are ignored.

5. The vertical buckling is ignored, i.e., the fuel assemblies are considered to be infinitely long.

6. Any soluble poison in the pool water is ignored.

5. CRITICALITY CONFIGURATIONS

In order to verify the design adequacy of the Calvert Cliffs Unit No.1 Nuclear Plant high density storage rack, it is necessary to establish the multiplication constants for the various arrangements or configurations of fuel assemblies and storage cells that are possible within the racks. These arrangements or configurations can be classified as either normal or abnormal configurations. Normal configurations result from variation in the placement of fuel within the storage cell, variation in fuel assembly dimensions and/or fuel loading because of the manufacturing process, and the variation in fuel storage rack dimensions permitted in fabrication. Abnormal configurations are typically the result of accidents or malfunctions such as the seismic event, a malfunction of the fuel pool cooling system (excessive changes in pool water temperature), a dropped fuel assembly, etc. The following sections present the normal and abnormal configurations which have been considered in this analysis.

5.1 NORMAL CONFIGURATIONS

5.1.1 Reference Configuration

The reference configuration consists of an infinite array of storage cells having nominal dimensions (see Section 3) each containing a fresh 14x14 Combustion Engineering fuel assembly centrally located within the storage cell. The water temperature within the rack is 68°F.

5.1.2 Eccentric Configuration

It is possible for a fuel assembly not to be positioned centrally within a storage cell because of the clearance allowed between the assembly and the cell wall. This clearance is nominally 0.221 inches on each side of the fuel assembly.

Calculations have been performed to determine the effects of eccentrically located fuel. In these calculations it was assumed that four fuel assemblies were diagonally displaced within their storage cells as far as possible towards each other (see Figure 5.1).

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5.1.3 Fuel Assembly Tolerance

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 parameters which determine the volume of water in an assembly are the clad O.D. and the fuel rod pitch. These parameters are closely controlled to typically within $\pm 0.4\%$. The effects of these 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 were performed to determine the sensitivity of k_{eff} to variations of fuel enrichment from the base enrichment of 4.10 w/o. The criticality configuration used for these calculations was that of the reference configuration with the exception of fuel enrichment.

5.1.5 Fuel Rack Variation

Calculations were performed to determine the sensitivity of k_{eff} to changes in pitch, the center-to-center spacing between storage cells. The pitch was varied from 9.75 to 10.25 inches. The criticality configuration was similar to that of the reference configuration except for the obvious change in center-to-center spacing.

5.1.6 Cell Wall Thickness Variation

The base case wall thickness was 0.060 inch for each of the stainless steel sheets forming the cell walls. This thickness was varied from 0.070 to 0.050 inch to determine the effect on k_{eff}.

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5.1.7 Poison Concentration Variation

Experiments have shown that the poison material used in Calvert Cliffs experiences a loss of B_4C during radiation exposure equivalent to 40 years residence in the spent fuel pool. The loss of B_4C reduced the B^{10} concentration by an average value of 15% with the maximum reduction in any single sample being 19.2%. The pre-exposed material for Calvert Cliffs has a minimum concentration of 0.024 gm B^{10}/cm^2. For the reference configuration this value is reduced to 0.020 gm B^{10}/cm^2 to reflect the 15% average loss. This concentration is varied by $\pm$10% to determine the sensitivity of k_{eff} to variations in this parameter.

5.1.8 Effect of Discrete B_4C Particle Size

Calculations were performed with KENO in which the B_4C particles in the poison sheets were represented as spheres of fixed diameter, regularly spaced throughout the sheet. The diameters studied were: 0.020 inch, 0.010 inch and zero (homogeneous). For the 0.020 inch case, an increase of about 2% $\Delta k/k$ was found compared with the homogeneous case. However, for the 0.010 inch case, the increase in k was zero within the uncertainty of the KENO calculation. Since 50% of the particles are smaller than 0.005 inch and 90% are smaller than 0.010 inch the $\Delta k/k$ due to finite particle size is taken as zero.

5.1.9 "Worst Case" Normal Configuration

The "worst case" configuration considers the effect of eccentric fuel assembly positioning, the minimum average pitch (center-to-center spacing) permitted by fabrication, the minimum wall thickness and the minimum poison concentration.

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5.2 ABNORMAL CONFIGURATIONS

5.2.1 Single Storage Cell Displacement

Displacement of a single storage cell within the array is precluded by the welded construction and the presence of structure between cells. Therefore, the effect of such a displacement is taken to be zero.

5.2.2 Fuel Handling Incident

Accidental placement of fuel between the fuel racks or the racks and pool wall will be prevented by structural material. It is, however, conceivable that an assembly could be laid across the top of a fuel rack. In this case, the distance between the tops of the stored fuel and the bottom of the misplaced fuel will be greater than 25 inches, a distance which according to calculations effectively "decouples" the two groups of fuel. No increase in k_{eff} will result from this incident.

5.2.3 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 maximum, to 250°F, the approximate boiling point of water near the bottom of the fuel rack.

5.2.4 Fuel Drop Incident

The maximum height through which a fuel assembly can be dropped onto the fuel storage racks is limited. The dropped fuel assembly will most likely impact the tops of the fuel storage rack cells. Because of the fuel rack design, damage will be limited to the upper 6 to 8 inches of the storage cells. Since the active fuel region is about 18 inches below this area, no significant change in fuel/cell geometry will occur. However, it is possible for a dropped fuel assembly to enter a cell cleanly and impact directly on the fuel stored in the cell. The effect of this type of fuel drop incident was evaluated from a criticality viewpoint by assuming that the stored assembly would be compressed axially.

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A calculation based on an axial compression of 2 feet yielded a 0.06 decrease in k_{oo} 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.

5.2.5 Heavy Object Drop

In the unlikely event that a heavy object is dropped on the storage rack with sufficient impact to cause structural deformation, it has been concluded that k_{eff} will decrease. The basis for this conclusion is that the principal effect of dropping a heavy object will be to squeeze water from the rack. Both in the case of compacted fuel and voided pool water, depletion of water leads to a decrease in k_{eff}.

It would not be possible for a dropped heavy object to eject the poison material from the rack; the crushing effect of the heavy object could only act to compress the fuel and poison together.

5.2.6 Seismic Incident

Seismic analyses have determined that during an SSE the pitch between two adjacent fuel assemblies could narrow locally by as much as 0.005 inches, due to oscillations about nodal points determined by 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. Thus, the net effect, although the pitch may vary locally, is that the average pitch is unaffected. In the event that the entire rack is displaced by a seismic event, the average pitch will also be unaffected.

It is concluded, therefore, that if the fuel assemblies deflect independently in random directions or move together in a single direction, the average pitch between assemblies and, consequently, the k_{eff} are unaffected.

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5.2.7 "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 of the "worst case" abnormal configuration are presented in Section 7.2.3.

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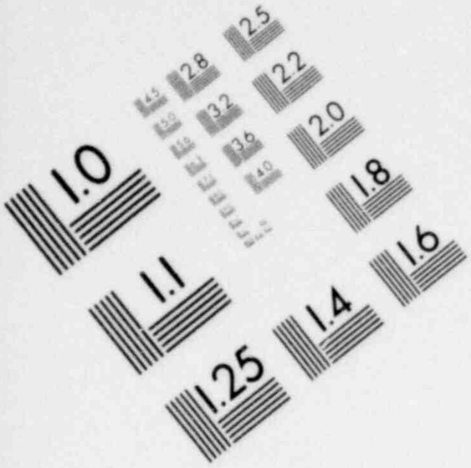


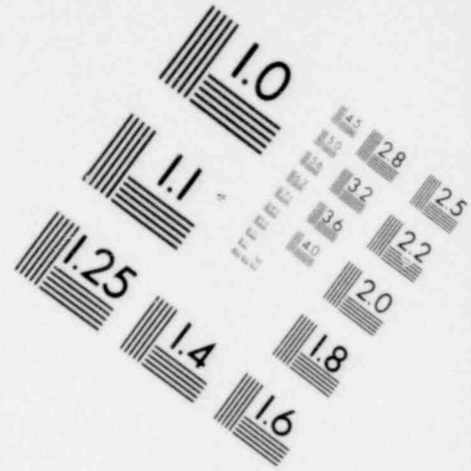
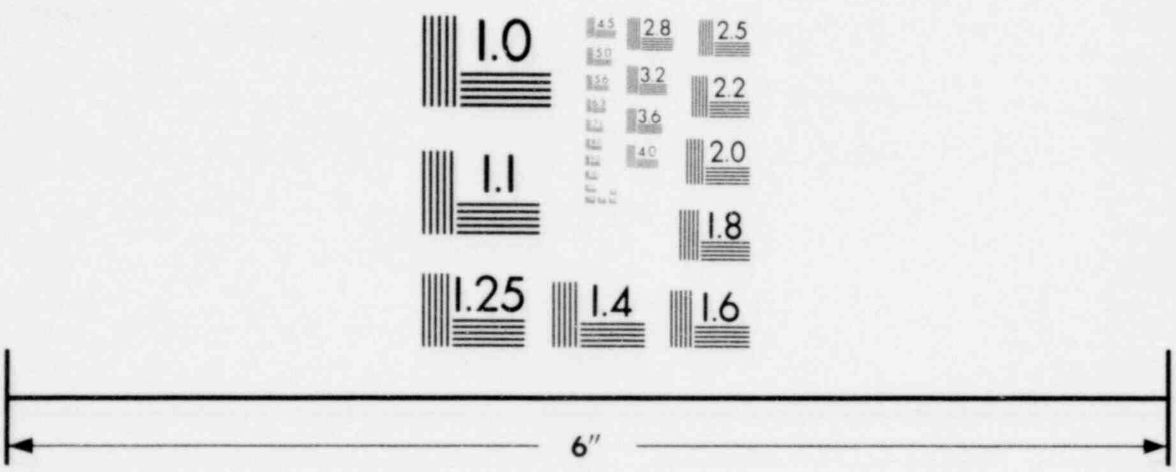
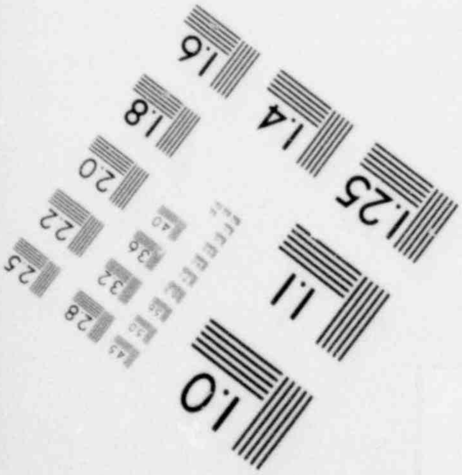


IMAGE EVALUATION
TEST TARGET (MT-3)



6″

MICROCOPY RESOLUTION TEST CHART



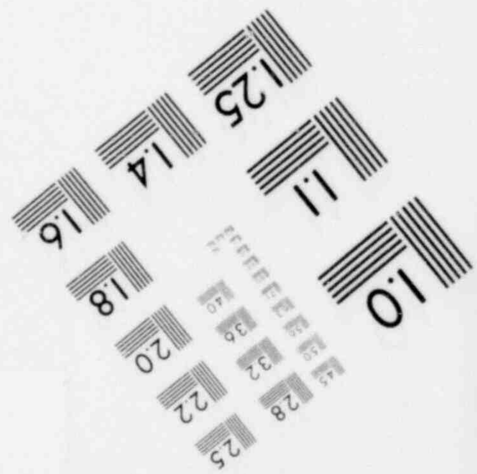


IMAGE EVALUATION
TEST TARGET (MT-3)

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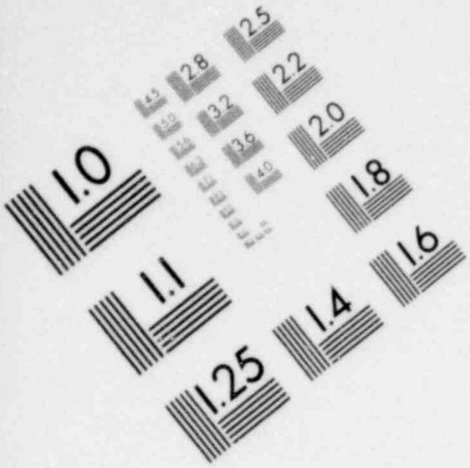
MICROCOPY RESOLUTION TEST CHART



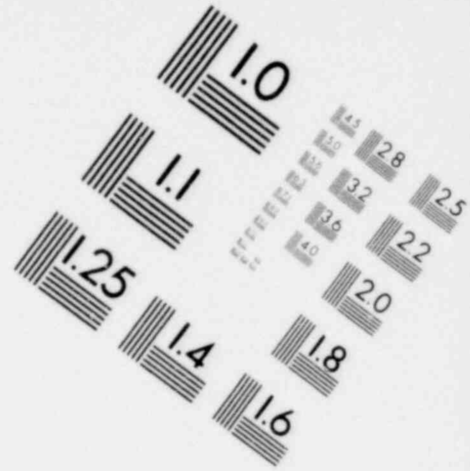
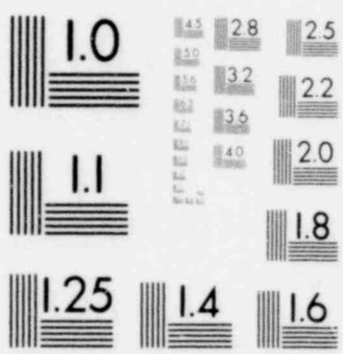
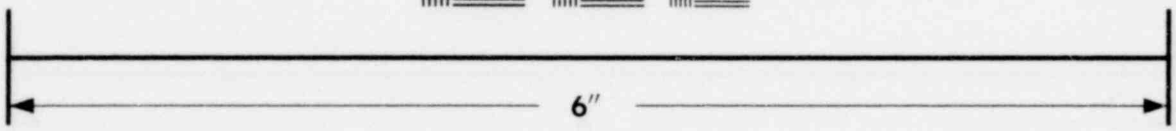


IMAGE EVALUATION
TEST TARGET (MT-3)





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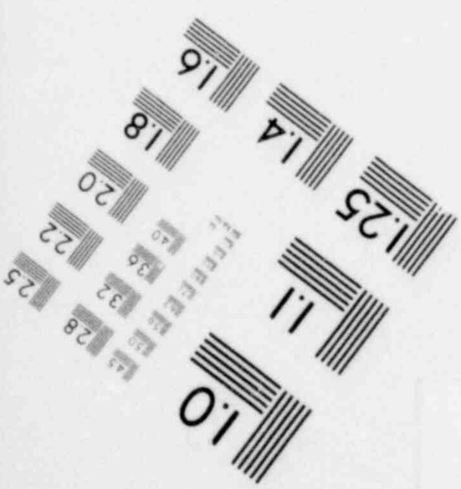


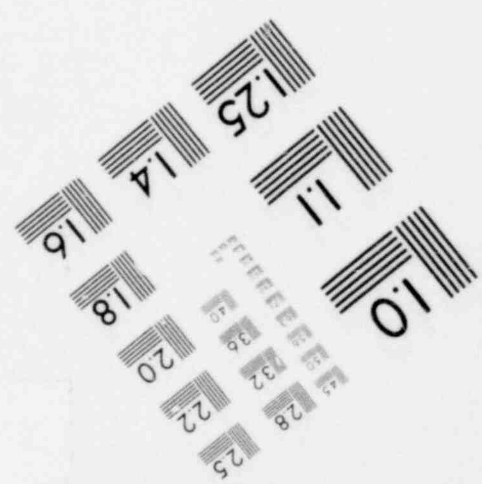
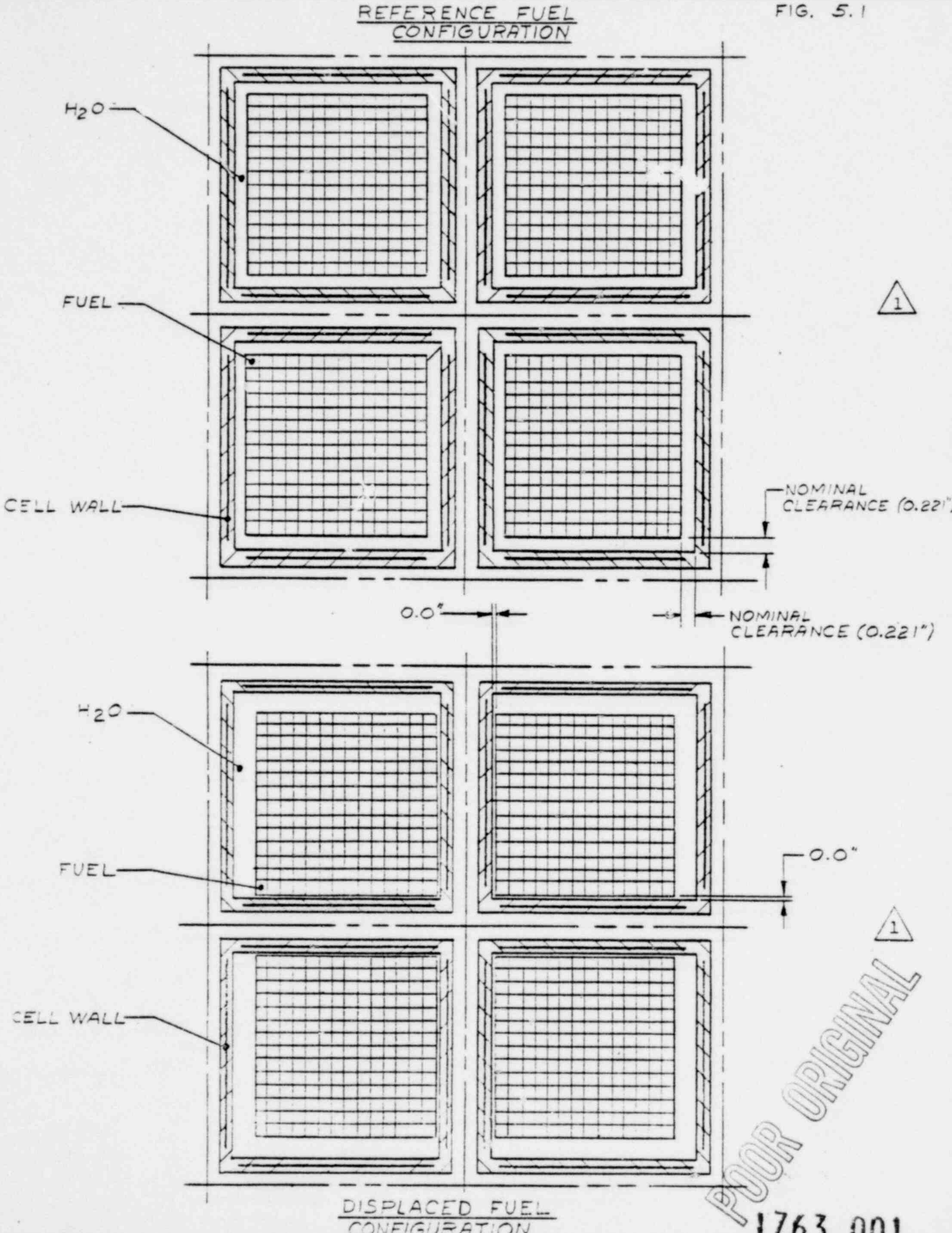


FIG. 5.1



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6. CRITICALITY CALCULATIONAL METHODS

6.1 METHOD OF ANALYSIS

For the reference configuration discussed in Section 5.1.1, the k_{eff} was determined from a three-dimensional Monte Carlo calculation using KENO IV with two sets of cross sections: the 16 group group Hansen-Roach cross section set and the 123 group cross section set. Check calculations of the reference configuration as well as the parametric studies were performed with two-dimensional diffusion theory using HAMMER and EXTERMINATOR. In both the Monte Carlo and diffusion theory methods, an infinite array of fuel assemblies loaded in spent fuel storage locations was represented by use of appropriate boundary conditions. An infinite array is used for two reasons: (1) an infinite array has a conservatively higher value of k_{eff} and (2) the problem can be suitably represented by a repeating portion of the array. Figure 6.1 shows a representation of one quarter of a storage location with reflecting boundaries on all sides. This duplicates an infinite array of storage locations.

6.2 REFERENCE CONFIGURATION

In the reference configuration KENO IV calculations, each fuel pin and associated cladding and water was represented as a rectangular parallelapiped with height equal to the active fuel length and the width equal to one fuel rod pitch (0.580 inch). Cladding and fuel were represented by concentric cylinders within the box with atom densities determined from the fuel parameters shown in Table 7.1. Water at 68°F filled the region outside the cladding. Guide tubes were represented in a similar fashion but with water inside the clad instead of fuel. The stainless steel sheets making up the box walls were represented as boxes with thickness of 0.060 inch and a width equal to the fuel storage cell edge. Poison sheets were represented by boxes 0.090 inch thick and 6-1/2 inches wide containing a homogenous mixture of B_4C. Water regions were boxes of appropriate sizes needed to fill the water gaps.

POOR ORIGINAL

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Although the reference configuration KENO IV problem did not take into account the finite size of the B_4C particles, several supplementary problems were performed in order to determine the effect on k_{eff} of particle sizes from zero to 0.020 inches in diameter. In these problems, the poison sheets were represented as layers of cubes with centrally located spheres of B_4C. The diameters of the spheres were 0.000, 0.010, and 0.020 inch in three separate problems, and the center to center spacing between spheres was chosen so as to maintain the areal density of boron constant.

6.3 UNCERTAINTIES AND BENCHMARK CALCULATIONS

The errors in Monte Carlo criticality calculations can be divided into two classes.

1. Uncertainty due to the statistical nature of the Monte Carlo methods.

2. Errors due to bias in the calculational technique.

The first class of errors can be reduced by simply increasing the number of neutrons tracked. For rack criticality calculations, the number of neutrons tracked is selected to reduce this error to less than 1%.

The second class of error is accounted for by benchmarking the calculational method against experimental results. In the benchmarking process, the calculational method is used to determine the criticality value for a critical experiment configuration. The difference between the calculated criticality value and the experimental value is identified as the calculational bias. Once determined, this bias can be applied to other calculational results obtained for similar configurations to improve the degree of calculational accuracy. If the calculated criticality value found during benchmarking is less than the experimental value, then the bias is added to other calculational results to ensure a conservative criticality value consistent with experimental results. Conversely, if the calculational criticality value is greater than the experimental value, it is appropriate to subtract the bias from the other calculational results to improve the accuracy of the criticality determination.

NES has performed benchmark calculations with KENO IV using both sets of cross sections (16 group and 123 group) for several appropriate critical experiment performed by Babcock and Wilcox (Ref. 3), Battelle Northwest Laboratories (Ref. 4), and Allis Chalmers (Ref. 5). Benchmark calculations performed by B&W and others using 16 group KENO IV show that the calculated criticality values are consistently 1.5 to 2% greater than the experimental value. This calculational method, however, has a factor σ_p (the scattering cross section per absorber atom) which can be adjusted to provide closer agreement with experimental results. NES has developed a method to select an appropriate σ_p factor. A k_{oo} lattice calculation for the fuel pin used in the experiment is performed using the NULIF (Ref. 6) code which has been specifically developed to obtain highly accurate k_{oo} values. The lattice calculation is then performed with 16 group KENO IV and the σ_p factor adjusted until the k_{oo} values are in agreement. This σ_p value is then used to perform the critical experiment benchmark calculations. Using the method, NES has determined the 16 group KENO IV bias as a function of the Dancoff factor associated with each critical experiment. Figure 6.2 is a plot of the bias for a range of Dancoff factors associated with widely spaced pins (low Dancoff) to fuel pin spacing essentially equal to Calvert Cliffs. As can be seen, the bias is essentially zero within experimental and calculational uncertainty over the full range of Dancoff factors studied.

The bias for 123 group KENO IV was also determined as a function of the Dancoff factor associated with the same experiments, and the results are shown in Figure 6.3. Although the bias is zero for widely spaced pins, it increases to 2% at spacings essentially equal to Calvert Cliff. Additional verification of the +2% bias was obtained by performing a k_{oo} lattice calculation using 123 group KENO for the Calvert Cliff pin spacing and comparing it with the k_{oo} value determined by the lattice code, NULIF. The results of the comparison show that the 123 group KENO calculational method over estimates the k_{oo} value by 2.7% (1.480 vs 1.441).

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6.4 CODE DESCRIPTION

6.4.1 KENO IV

KENO IV is a 3-D multigroup Monte Carlo code used to determine k_{eff} (see Ref. 7).

6.4.2 HAMMER

HAMMER (see Ref. 8) 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.

6.4.3 EXTERMINATOR

EXTERMINATOR (see Ref. 9) is a 2-D multigroup diffusion theory code used with input from HAMMER to calculate k_{eff} values.

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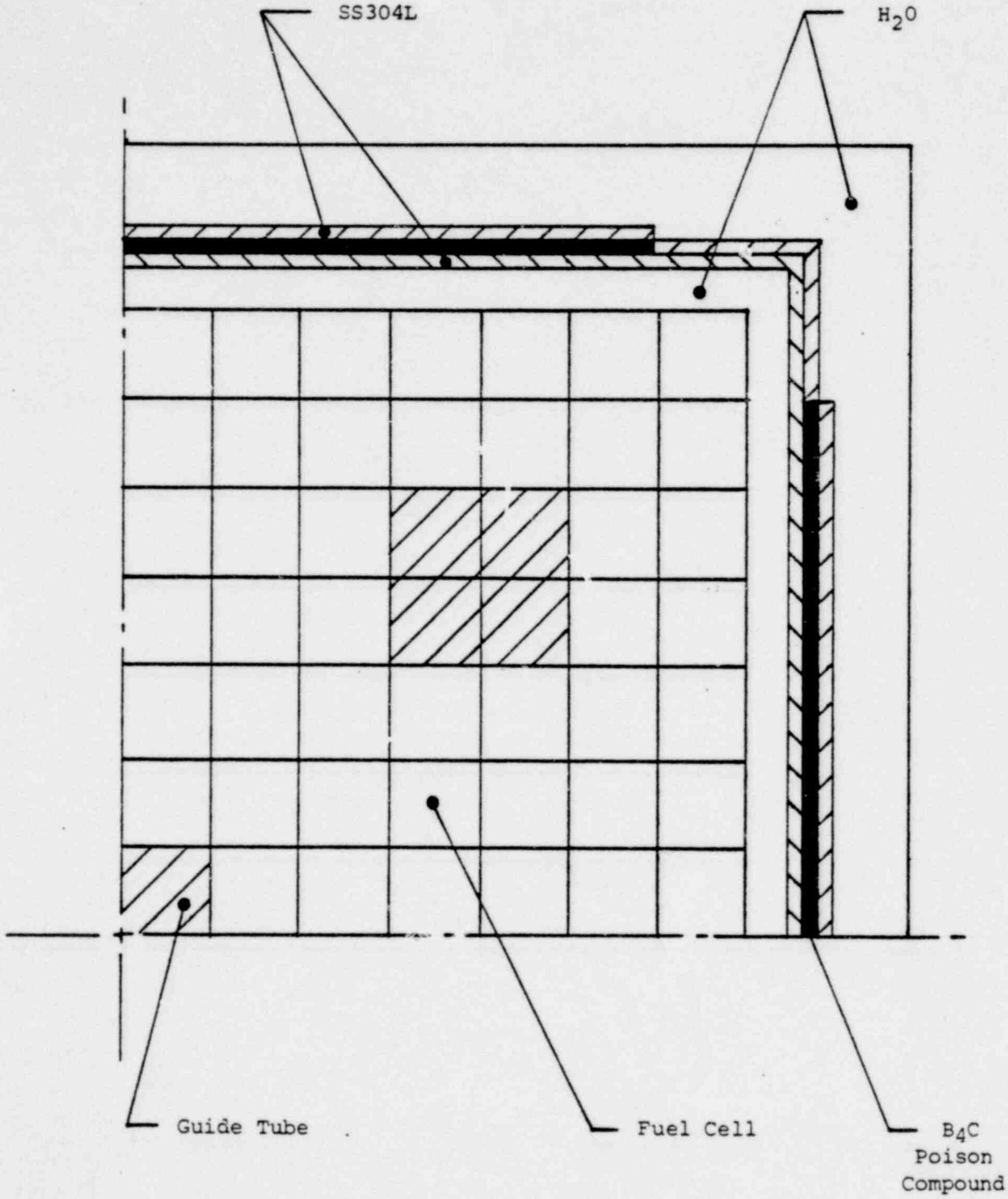

Illustration of Reference Configuration

Fig. 6.1

1763 006

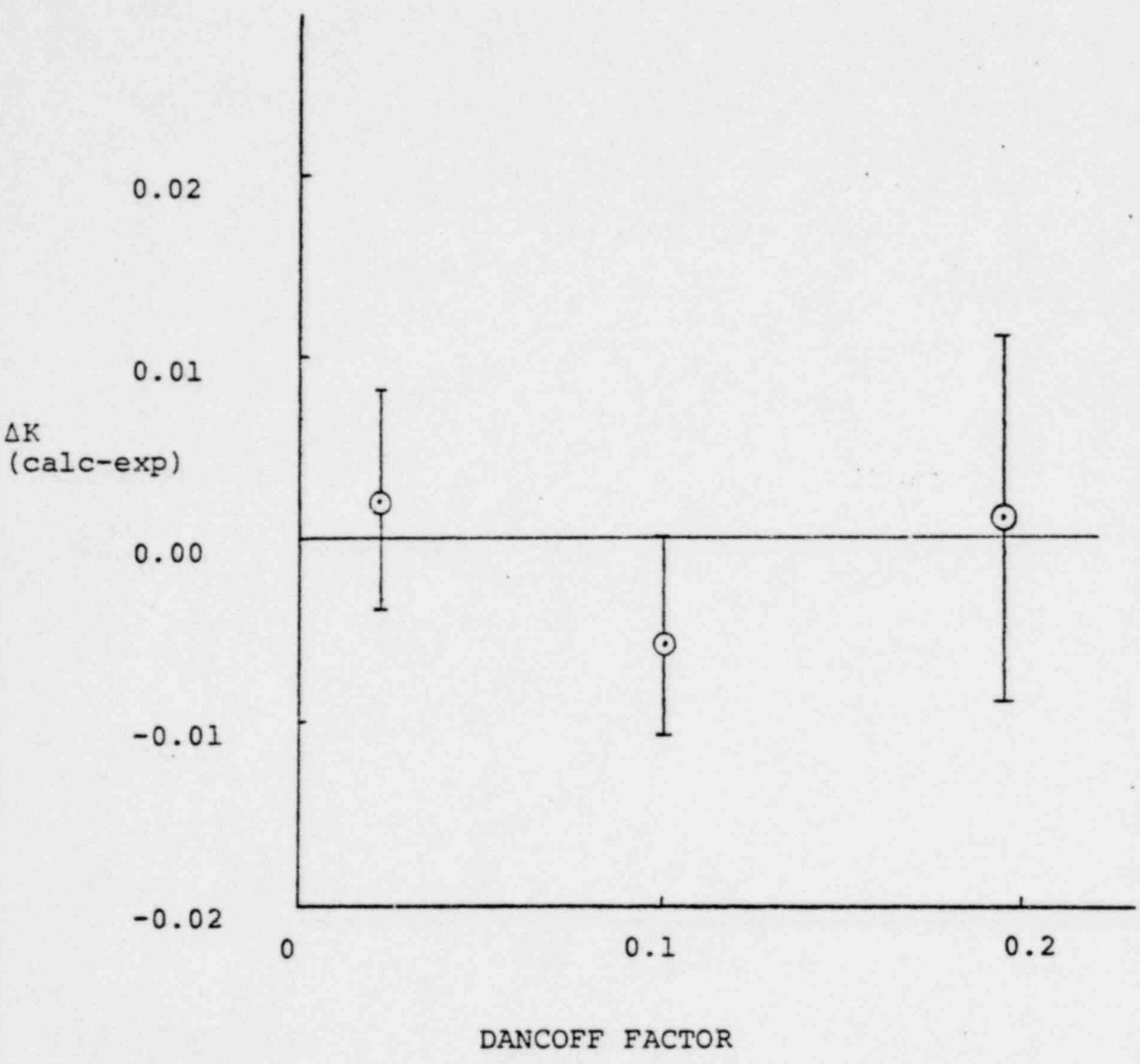

FIGURE 6.2 BIAS BETWEEN 16-GROUP KENO-IV AND EXPERIMENT

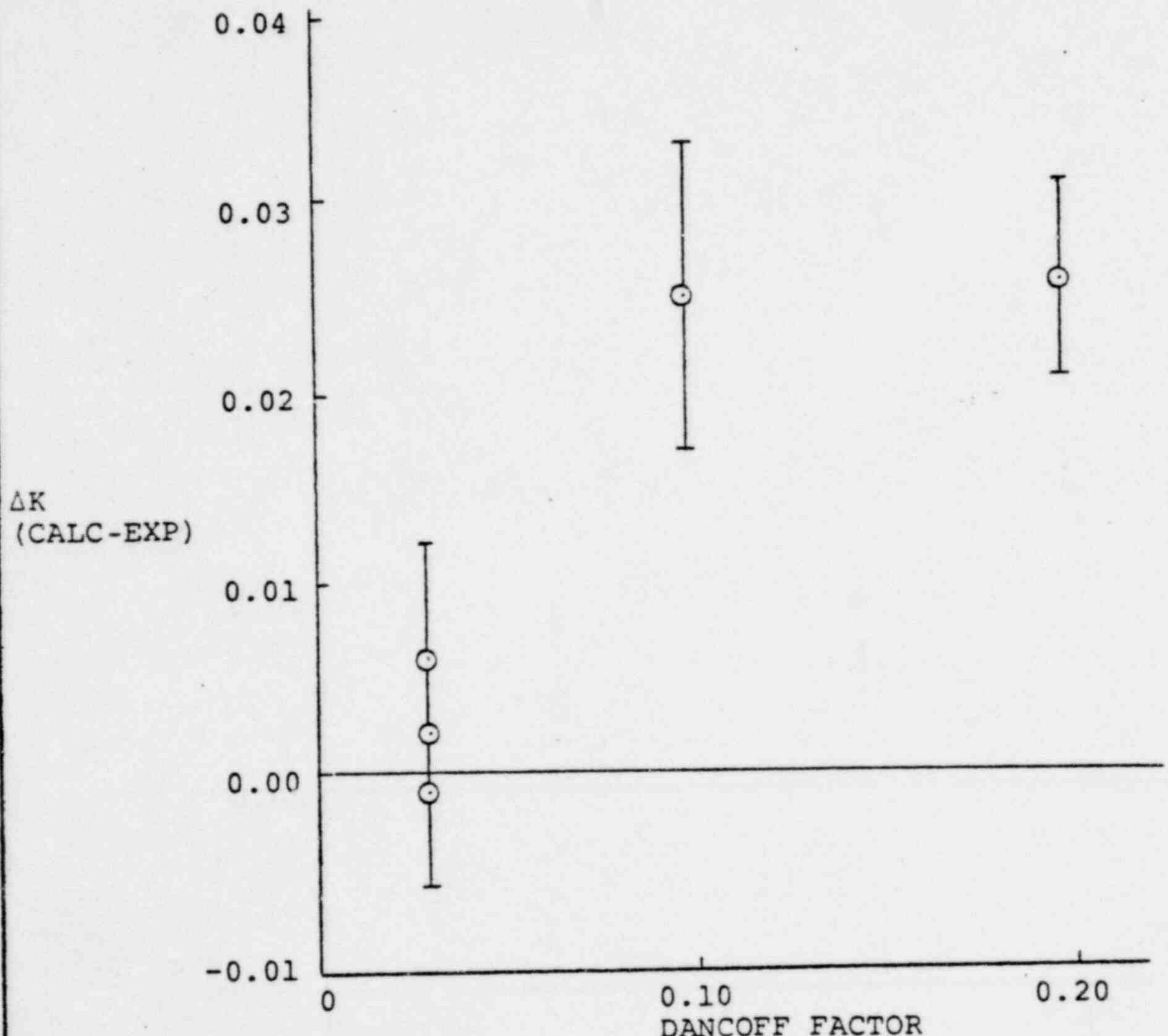

FIGURE 6.3 BIAS BETWEEN 123-GROUP KENO-IV AND EXPERIMENTS

1763 008

7. RESULTS OF CRITICALITY CALCULATIONS

The k_{eff} for the reference configuration was determined by means of KENO IV considering both 16 group cross sections and 123 group-cross sections. Parametric studies of enrichment, temperature, dimensional tolerances of the racks, and abnormal dislocations within racks due to seismic events, fuel handling incidents, fuel drop and heavy object drop were performed with either HAMMER/EXTERMINATOR diffusion theory or 123 group KENO.

7.1 REFERENCE CONFIGURATION

The k_{eff} determined by KENO IV using the 16 group cross section set was 0.8859 with an uncertainty of $\pm$0.0055 at the 95% confidence level. The k_{eff} determined by means of KENO IV using 123 groups was 0.9201 which when combined with the bias of -0.0200 determined from benchmarking (see Section 6.3) gives a k_{eff} of 0.9001. The higher of these two KENO values, 0.9001, is chosen for conservatism.

7.2 K_{eff} VALUES FOR NORMAL CONFIGURATION

7.2.1 Eccentric Configuration

The Δk_{eff} for the eccentric configuration described in Section 5.1.2 and shown in Figure 5.1 (in which fuel assemblies are diagonally displaced towards each other) was determined to be $\Delta k_{eff} = -0.0075$.

7.2.2 Fuel Design Variation

The enrichment of the fuel was changed from 4.10 w/o to 3.90 w/o. The results are shown in Figure 7.1 and Table 7.2.

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7.2.3 Fuel Rack Pitch Variation

A detailed study of the effects of variation in the rack pitch was performed with 123 group KENO. The pitch was varied from 9.75 to 10.25 inches and the results are shown in Figure 7.2. The mechanical design of the fuel rack is such that the average pitch between boxes is maintained by structural members at 10.09375 ±0.03125 inches. The change in k_{eff} for a decrease in average pitch of 0.03125 inch is +0.0062. (See Figure 7.2.)

7.2.4 Fuel Rack Cell Wall Thickness Variation

The value of the wall thickness used in the reference configuration calculation is nominally 0.060 inch. A variation of ± 0.010 inch was investigated and the results are shown in Figure 7.3. The material used for the wall will have a thickness tolerance of ±0.005 inches and the Δk for this variation, as determined from Figure 7.3, is +0.0008.

7.2.5 Poison Content Variation

The poison content was varied by 10% above and below the reference value of 0.020 gm/cm^2 of B^{10}. The results are shown in Figure 7.4 and Table 7.2. The maximum reduction in B^{10} concentration experienced by any single test sample (see Section 5.1.7) was 19.2% which results in a B^{10} concentration of 0.01939 gm. B^{10}/cm^2 (when applied to the Calvert Cliffs pre-exposure value of 0.024 gm. B^{10}/cm^2) as compared with the reference configuration value of 0.020 gm B^{10}/cm^2. The Δk value for this additional B^{10} reduction of 0.00061 gm B^{10}/cm^2 is +0.0015.

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7.2.6 "Worst Case" Normal Configuration

Results for normal configuration can be summarized as follows:

		K_{eff} or ΔK_{eff}
1.	Reference Configuration	0.9001
2.	Minimum Cell Pitch	0.0062
3.	Minimum Poison Concentration	0.0015
4.	Eccentric Positioning	0.0000
5.	Cell Wall Thickness	0.0008
6.	Enrichment Variation	0.0000 (maximum used)
7.	B_4C Particle Size Effect	0.0000 (negligible)
8.	Statistical Uncertainty in KENO	0.0055

The effects of the above normal variations are combined statistically as follows:

$$\Delta k_{eff} = (0.0062^2 + 0.0008^2 + 0.0055^2 + 0.0015^2)^{1/2} = 0.0085$$

The result for the "worst case" normal configuration is thus 0.9001 $\pm$0.0085.

7.3 K_{eff} VALUES FOR ABNORMAL CONFIGURATIONS

7.3.1 Fuel Handling Incident

Since it will not be possible to place fuel adjacent to a rack, and since the Δk caused by a fuel assembly lying horizontally on top of the rack is negligible, no allowance on k_{eff} is made for this abnormal configuration.

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7.3.2 Spent Fuel Pool Temperature Variation

The k_{eff} of the rack was studied for temperatures ranging from 39°F to 250°F. Results are given in Fi[illegible] 7.5 and Table 7.2 and show that the rack has a negative temperature coefficient with the highest k_{eff} occurring at the nominal 68°F temperature.

7.3.3 "Worst Case" Abnormal Configuration

The "worst case" abnormal configuration combines the change in k_{eff} due to the occurence of the most adverse abnormal condition with the k_{eff} value associated with the "worst case" normal configuration. However, since none of the abnormal conditions gives a positive Δk, the "worst case" abnormal condition is simply equal to the "worst case" normal condition.

		K_{eff}
1.	Worst Case Normal Configuration (per Section 7.2.6)	0.9086
2.	Most Adverse Abnormal Configuration	0.0000
3.	Final k_{eff} for "worst abnormal" configuration.	0.9086

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TABLE 7.1

FUEL PARAMETERS

Fuel Type	14 x 14 Combustion Engineering Fuel
Fuel Enrichment	4.10 w/o
Mass of Uranium per Assembly	395.2[illegible] kg
Clad I.D.	0.388 in
Clad O.D.	0.440 in
Clad Thickness	0.026 in
Clad Material	Zircaloy-4
Pitch Between Rods	0.580 in
Active Fuel Length	136.7 in
Array Dimensions	14 x 14

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TABLE 7.2

PARAMETERS AND RESULTS OF EXTERMINATOR CALCULATIONS

	Enrichment (w/o)	Average Cell Pitch (inches)	Temp. °F	H_2O Density (gm/cc)	Poison Content gm B^{10}/cm^2	k_{eff} or Δk_{eff}
Reference Configuration	4.10	10-3/32	68	0.998	0.020	0.9001
Maximum Water Density	4.10	10-3/32	39	1.000	0.020	0.0000
150°F, Temp. Case	4.10	10-3/32	150	0.980	0.020	-0.0050
212°F, Temp. Case	4.10	10-3/32	212	0.958	0.020	-0.0145
250°F, Temp. Case	4.10	10-3/32	250	0.942	0.020	-0.0165
Low Enrichment, 4.00 w/o	4.00	10-3/32	68	0.998	0.020	-0.0050
Low Enrichment, 3.90 w/o	3.90	10-3/32	68	0.998	0.020	-0.0101
Low Poison Content, -10%	4.10	10-3/32	68	0.998	0.018	+0.0050
Eccentric Fuel	4.10	10-3/32	68	0.998	0.020	-0.0075
Low Wall Thickness, 0.050 in.	4.10	10-3/32	68	0.998	0.020	-0.0016
High Wall Thickness, 0 .070 in.	4.10	10-3/32	68	0.998	0.020	+0.0016

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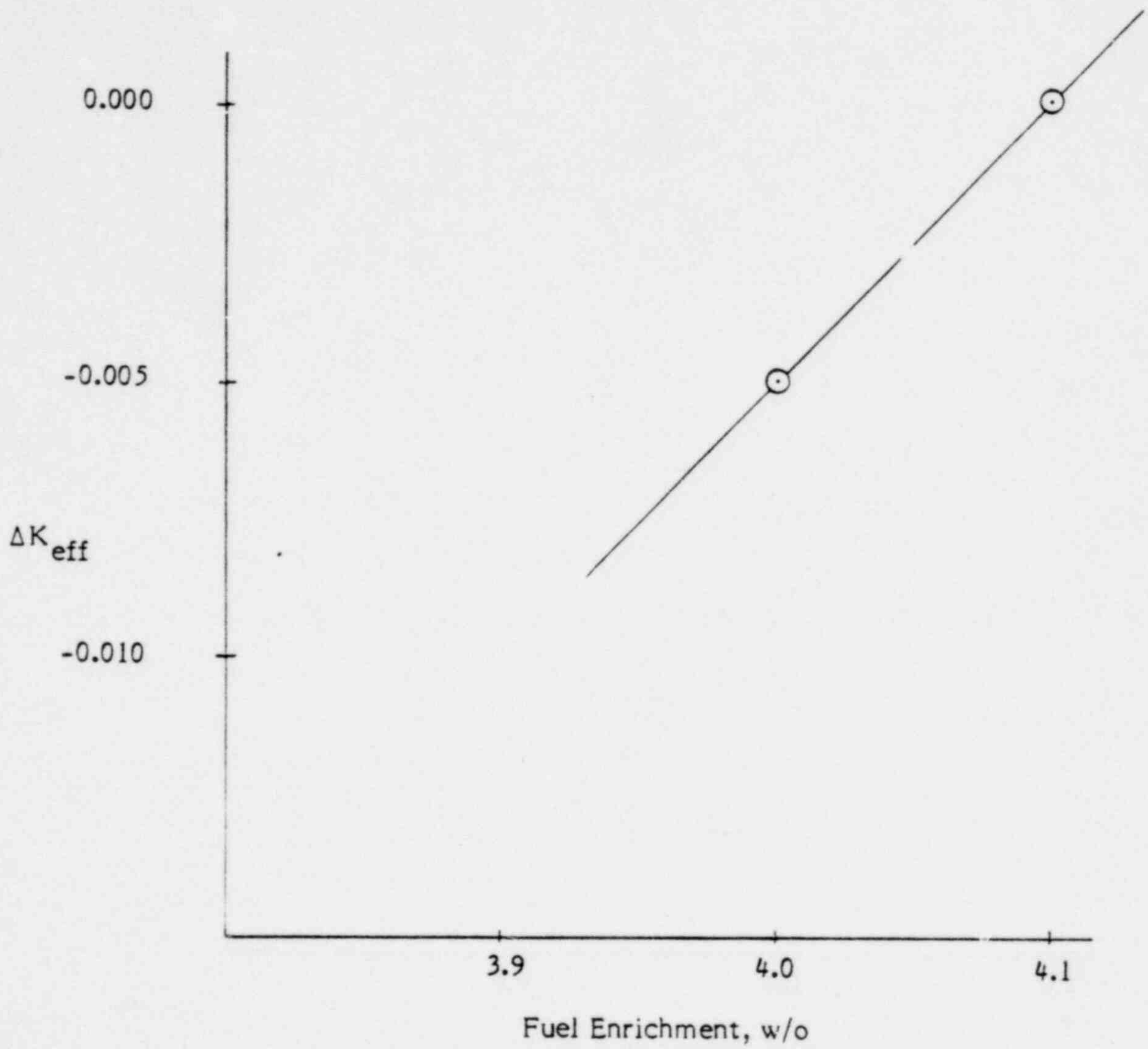

FIGURE 7.1 ΔK_{eff} vs. Enrichment

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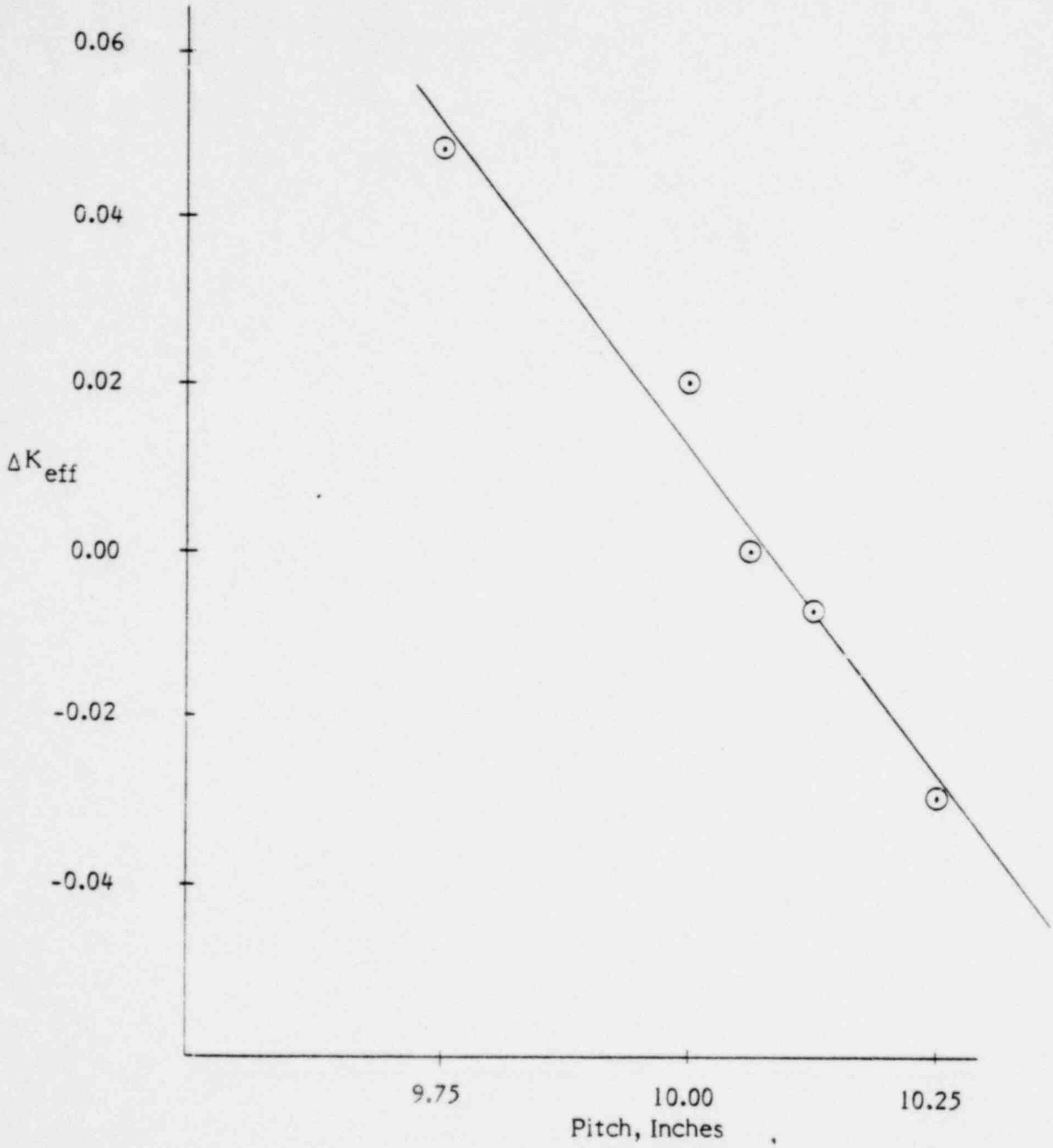

FIGURE 7.2 ΔK_{eff} vs. Pitch

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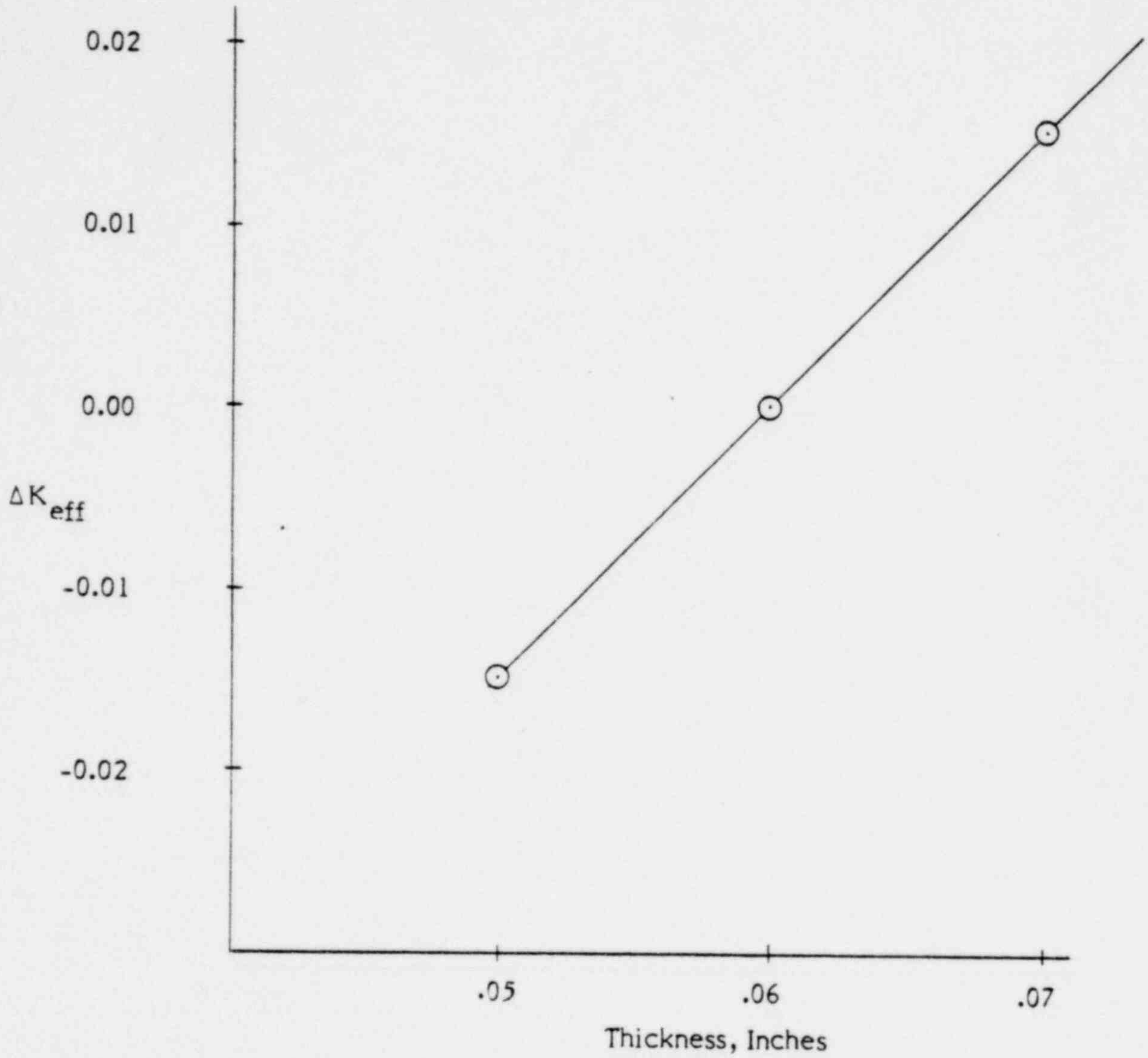

FIGURE 7.3 ΔK_{eff} vs. Stainless Steel Wall Thickness

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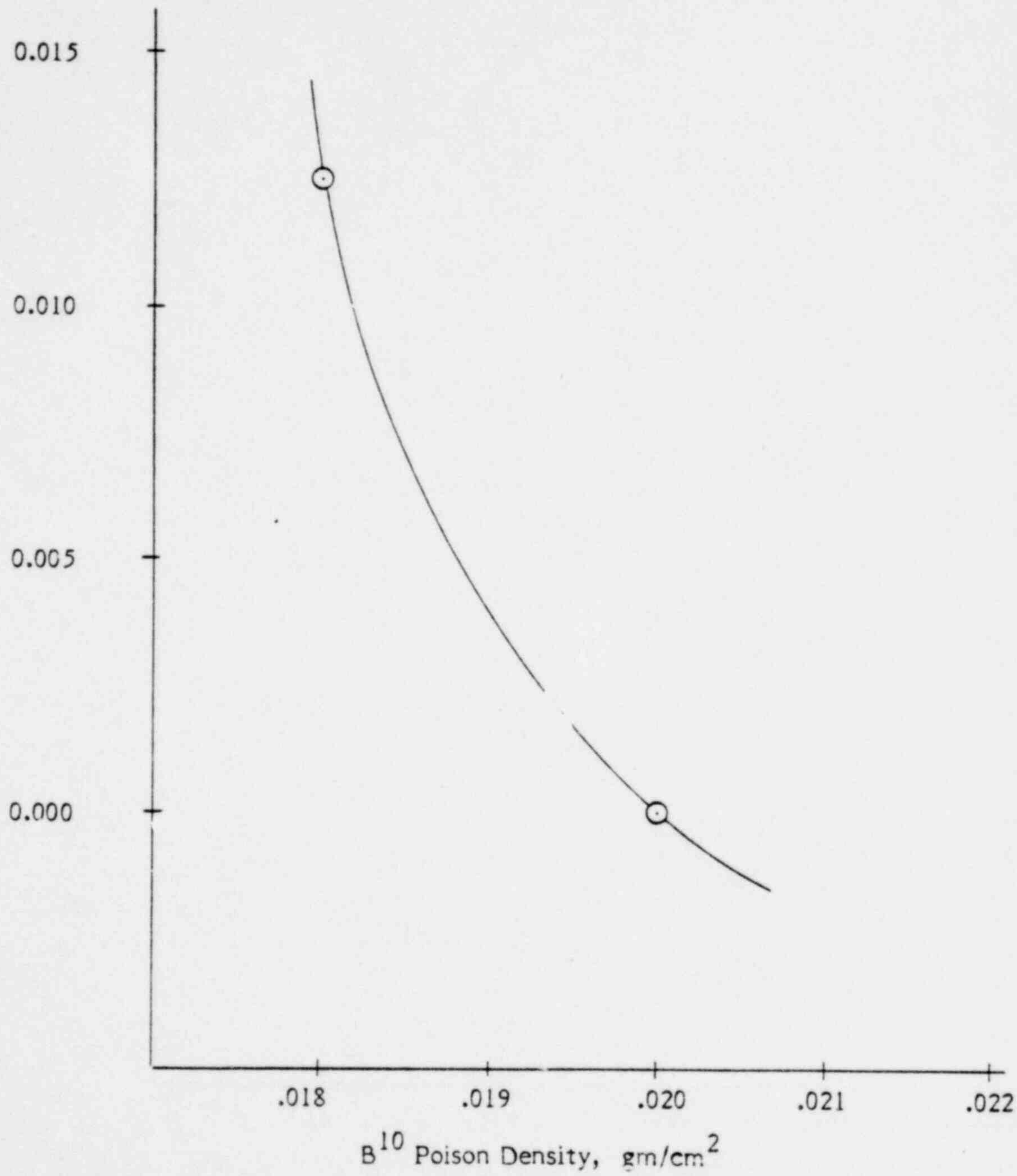

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FIGURE 7.4 ΔK_{eff} vs. Poison Content

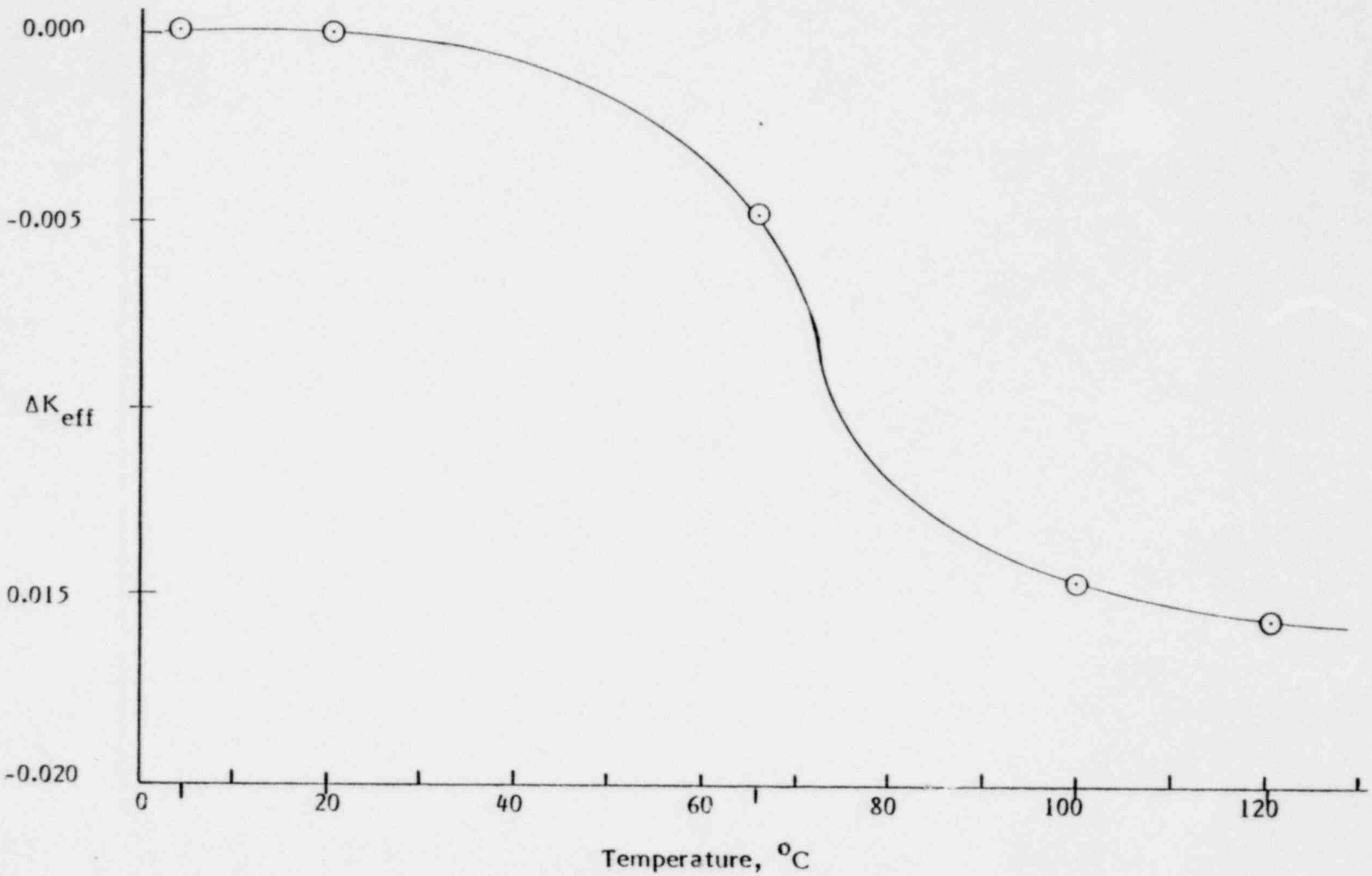

FIGURE 7.5 ΔK_{eff} vs. Temperature

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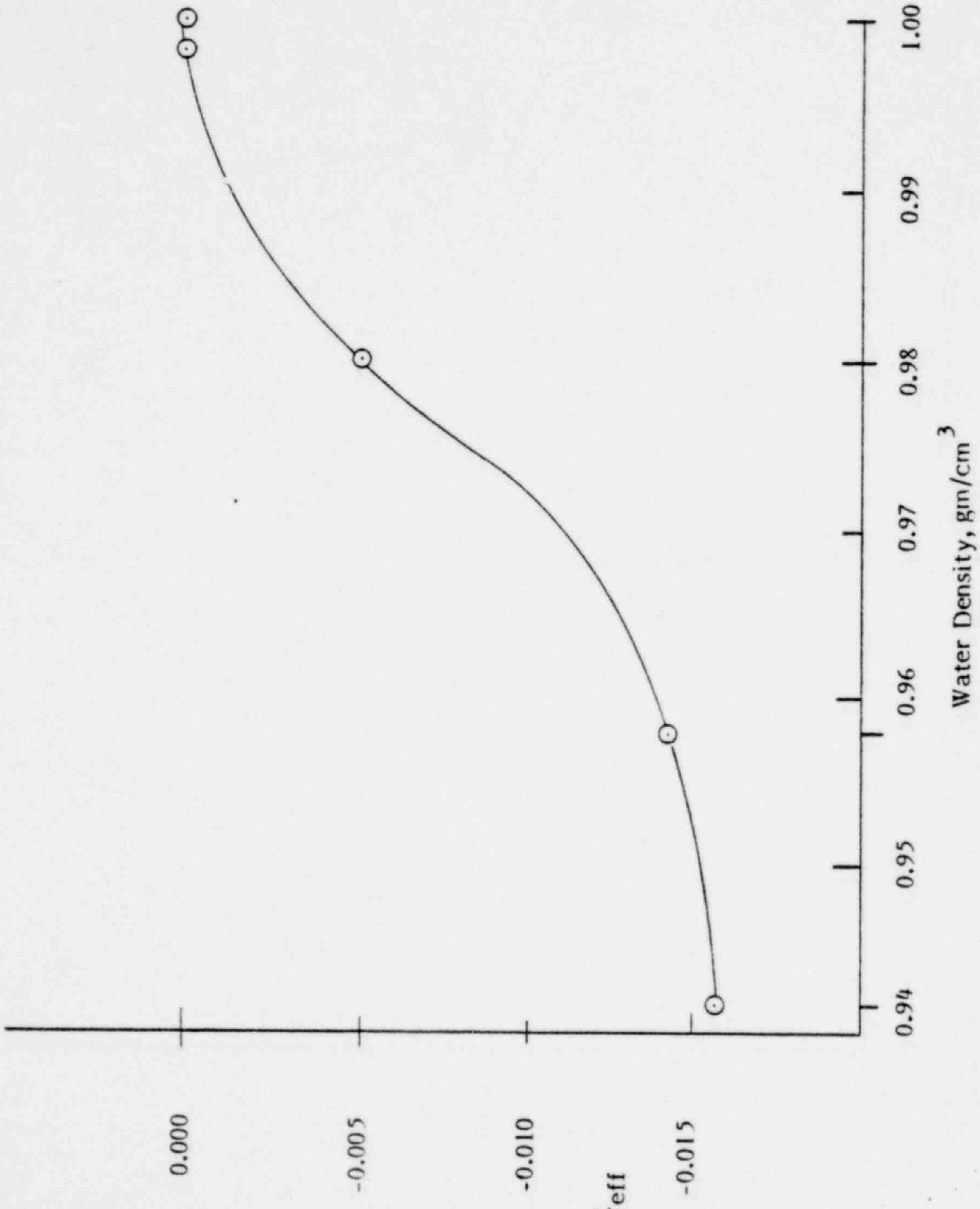

FIGURE 7.6 ΔK_{eff} vs. Water Density

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REVISION LOG

REV. NO.	DATE	PAGE NO.	DESCRIPTION	APPROVAL
1	5/9/79		See CRA No. 821	RAM
2	12/10/79		See CRA No. 1141	PB
			Since this CRA contains extensive changes to report 81A0567 which affected every page, the use of a triangle/revision number adjacent to the revised area (per 80A9003, item 8.1.3) was not used.	

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