ATTACHMENT 3

NUCLEAR DESIGN ANALYSIS REPORT

FOR THE

NEW FUEL STORAGE RACKS

FOR THE

SURRY NUCLEAR POWER STATION

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1. SUMMARY

A detailed nuclear analysis has been performed for the new fuel storage racks for the Surry Nuclear Power Station. The analysis demonstrates that for all normal and abnormal configurations considered, the K_{eff} of the system is less than the criticality criterion of 0.98 for 4.1 w/o Westinghouse fuel asssemblies stored in the rack.

Studies were performed of the effects of variations in the physical parameters of the rack and of the fuel assemblies which could affect the nuclear characteristics. These variations are classified in this report as normal and abnormal.

Normal variations include small changes in water density, fuel eccentrically positioned within a storage cell, fuel enrichment variation, storage cell pitch variation, and the cumulative effect of all of the above, the worst case normal configuration. Abnormal variations include effects of fuel handling incidents, large water density variations, dropped or compacted fuel, and cell displacement due to seismic events.

The abnormal variation resulting in the highest increase in the magnitude of K_{eff} is chosen to represent the worst case abnormal configuration. A margin of error resulting from calculational uncertainty is added to the numerical results. The calculation of K_{eff} values was carried out using the three-dimensional Monte Carlo code KENO-IV.

K_{eff} values were first calculated with a very simple geometric model with reflecting boundaries in the x and y directions that effectively represented a rack of infinite lateral extent. The K_{eff} values determined with this simple model may be summarized as follows:

K_{eff} of the new fuel storage rack dry at 68°F at nominal dimensions	0.474
K_{eff} of the new fuel storage rack including effects of normal variations and calculational uncertainty	0.713

Final K_{eff} of the new fuel storage rack including normal variations, calculational uncertainty and the worst case abnormal configuration.	0.973

Because the resulting K_{eff}, 0.973, is so close to the criticality criterion of 0.98, a further study was performed with a more detailed geometrical model with less inherent conservatism. The results of the more detailed study show the maximum K_{eff} to be approximately 0.86.

These results show clearly that the Surry new fuel storage racks meet the criticality design criterion and are safe under the specifications set forth in the Standard Review Plan (NUREG-75/087).

2. INTRODUCTION

The nuclear analysis performed for the Surry Nuclear Power Station is presented in this report in the following order:

Detailed descriptions of the fuel rack and fuel assemblies to be stored within are given in Section 3 including dimensions, tolerances and materials pertinent to the nuclear characteristics of the loaded rack.

The criticality criterion and calculational assumptions made in order to show compliance with NRC guidelines are outlined in detail in Section 4.

Section 5 contains a description of the individual criticality cases studied. The presentation in Section 5 is intended to expand and clarify the scope of the nuclear analysis required for compliance with the NRC guidelines quoted in Section 4.

The method of analysis and the models used to describe the new fuel storage racks and the fuel assemblies in the various configurations are outlined in Section 6. In addition, the computer codes used to carry out the calculations are discussed.

The results of the calculations are presented in Section 7 with their interpretation. The determination of final K_{eff} values from calculation results is explained and carried out.

A detailed parametric study versus water density, performed with a more complex geometry, is presented in Section 8.

3. DESCRIPTION OF NEW FUEL STORAGE RACKS

The new fuel storage facility at the Surry Nuclear Power Station has a total storage capacity of 126 new fuel assemblies. Each storage location consists of a stainless steel square box 165" tall with 9" I.D. and 1/8" thick walls. These boxes are located in nine parallel rows, with a pitch of 21" between boxes within a row. The pitch between rows is either 21" or 30". The storage facility has concrete walls and floor and is normally empty of water.

The structural supports and bracing which hold the rack together and provide support during potential seismic events will not be considered in this analysis. This omission is justified because these steel supports are at widely separated locations and have a fairly large absorption cross-section for neutrons so that neglecting them is conservative.

4. CRITICALITY DESIGN CRITERION AND CALCULATIONAL ASSUMPTIONS

4.1 CRITICALITY DESIGN CRITERION

The position of the NRC regarding the criticality of new fuel storage (Ref. 1) is as follows:

> "The design of the new fuel storage racks will be such that K_{eff} will not exceed 0.98 with fuel at the highest anticipated enrichment in place assuming optimum moderation."

This guide is adopted without modification as the criticality design criterion for the Surry new fuel storage racks.

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 rack is assumed to be infinite in lateral extent.

2. The pitch is assumed to be 21" throughout, whereas in fact some rows are spaced at 30".

5. CRITICALITY CONFIGURATION

To verify the adequacy of the Surry new fuel storage racks for storage of 4.1 w/o fuel, it is necessary to determine multiplication constants corresponding to the different arrangements or configurations possible within the racks. These arrangements or configurations are classified as either normal or abnormal configurations. Normal configurations include the reference configuration, small water density variations, eccentrically positioned fuel, fuel design variation, fuel rack cell pitch variation and the combination of these effects termed the worst case normal configuration.

Abnormal configurations result from accidents and disturbances not normally encountered. These include fuel handling accidents, large water density variations, fuel drop accident, seismic incident and the worst case abnormal configurations.

5.1 NORMAL CONFIGURATIONS

5.1.1 Reference Configuration

The reference configuration consists of an infinite array of storage cells having nominal dimensions, each containing a 15x15 Westinghouse fuel assembly of 4.1 w/o enrichment positioned centrally within the cell. The storage cells are spaced 21.0" on centers and consist of square cans with a 9.0" I.D. and a 1/8" wall thickness.

The new fuel rack and the fuel assemblies are at 68°F. The reference configuration is shown in Figure 5.1.

5.1.2 Eccentrically Positioned Assemblies

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 0.2775" on each side of the fuel assembly. The worst eccentric positioning occurs if four adjacent assemblies are displaced within their storage cells as far as possible towards each other.

5.1.3 Fuel Design Variation

Since 4.1 w/o is the highest enrichment expected to be used at Surry, no calculations have been performed to determine the effects of enrichment changes.

5.1.4 Fuel Rack Cell Pitch Variation

Calculations were performed to determine the sensitivity of K_{eff} to change in pitch, the center-to-center spacing between storage cells. The pitch was varied 2" above and 2" below the nominal value of 21".

5.1.5 Low Density Moderator Variation

The variation of atmospheric humidity in the rack causes a slight variation in moderator (H_2O) density. The sensitivity of K_{eff} to the variations in H_2O density over the density range from 0.0 to 0.01 gm/cc was evaluated and is included under normal configurations. The upper limit of 0.01 gm/cc was chosen deliberately high to assure conservatism.

5.1.6 Worst Case Normal Configuration

Since any of the above normal configurations can occur simultaneously, it is necessary to evaluate their combined maximum adverse effect.

The result is the worst case normal configuration. As the name implies, it represents the state of the rack under normal conditions which has the largest K_{eff} value.

5.2 ABNORMAL CONFIGURATIONS

5.2.1 Fuel Handling Incident

In some fuel storage racks it is possible during fuel handling to inadvertently position an assembly beside the loaded rack in a clearance space between racks or between storage locations within a rack. In the case of Surry new fuel racks however, a steel cover or platform located above the storage cells prevents this incident from occurring. Consequently no calculations have been performed for fuel misplaced in the rack.

5.2.2 High Moderator Density Variation

Accidents such as fire, pipe break, etc. can result in the presence of foams, steam, water and other materials containing water in the new fuel storage area. Under accident conditions it must be assumed the density of water can take any value from 0.0 to 1.0 gm/cc. Therefore, the variation of K_{eff} over the entire range must be evaluated. Since low water densities from 0.0 to 0.01 gm/cc are included under normal configurations, only densities from 0.01 gm/cc to 1.0 gm/cc will be considered as abnormal configurations.

5.2.3 Fuel Drop Incident

A fuel assembly could be dropped during insertion or removal from a storage cell and compacted within. A configuration is, therefore, considered in which one storage location contains compacted fuel. For simplicity, this was modeled as a worst case situation in which each location was filled with compacted fuel.

5.2.4 Seismic Incident

The effects of a seismic incident are evaluated in terms of pitch variation caused by storage cell displacement.

5.2.5 Worst Case Abnormal Configuration

The worst case abnormal configuration is taken to be the single abnormal configuration which results in the most adverse effect on K_{eff}.

6. CRITICALITY CALCULATION METHODS

Calculations in this analysis were performed with KENO-IV using 16 group Hansen Roach cross-sections. The HAMMER code was used as a check for accuracy. This section contains information regarding computer models and codes.

6.1 METHOD OF ANALYSIS

It was stated in Section 4 that the rack was modeled as an infinite array. This was accomplished by modeling one quarter of a storage cell containing one quarter of a fuel assembly and the associated water region surrounding it (see Figure 6.1). Reflecting boundaries on all four sides make this model the equivalent of an infinite array in a horizontal plane. In the vertical direction, nonreflecting boundaries are located below the floor, a concrete slab, and above the top of the storage rack.

The 4.1 w/o 15x15 Westinghouse fuel assemblies were modeled using the values shown in Table 6.1. Individual fuel pins were represented as concentric cylinders of UO_2 and zirconium clad (see Figure 6.2). The pellet diameter is assumed expanded to equal the clad inner diameter, thus eliminating the pellet-clad gap.

6.2 COMPUTER CODES

6.2.1 HAMMER

HAMMER (see Ref. 2) 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.

6.2.2 KENO-IV

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

KENO-IV has been benchmarked against critical experiments consisting of typical light water reactor fuel lattices. Results (see Ref. 5,6) show KENO-IV to be conservative for these configurations.

6.3 UNCERTAINTIES AND BENCHMARK CALCULATIONS

The uncertainties in Monte Carlo criticality calculations can be divided into two classes:

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

2. Uncertainty due to bias in the calculational technique.

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

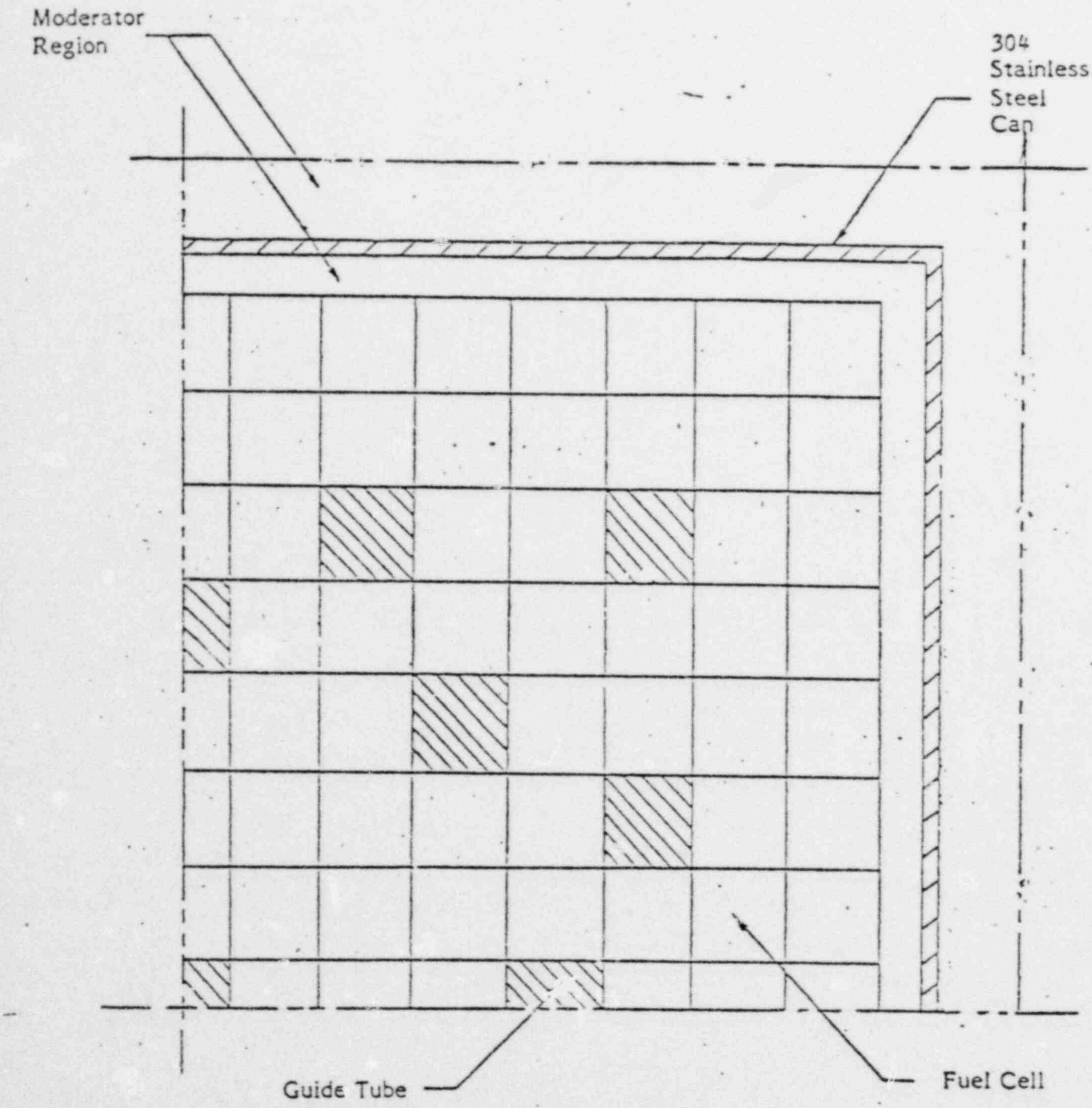
The second class of uncertainty is accounted for by benchmarking the calculational method against experimental results. In the benchmarking process, the calculational method is used to determine the criticality value for a critical experiment configuration. The difference between the calculated criticality 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 calculated results to improve the accuracy of the criticality determination.

Both HAMMER and KENO-IV have been benchmarked at NES (Ref. 4) and found to be accurate in all cases to better than $\pm 1\%$ of the experimental K_{eff} value. Benchmark calculations performed outside NES confirm these findings (see Ref. 5, 6). Calculations in this analysis were based on KENO-IV. To check the accuracy of KENO, fuel pin k_{∞} values were determined using both KENO-IV and HAMMER and then compared to assure their agreement to within 1%. Thus HAMMER was used solely to check accuracy.

TABLE 6.1

FUEL PARAMETERS

Fuel Type	15x15 Westinghouse Fuel
Fuel Enrichment	4.1 w/o
UO_2 per Assembly	1122 lb
Clad I.D.	0.3734 inch
Clad O.D.	0.422 inch
Clad Material	Zircaloy-4
Pitch Between Rods	0.563 inch
Active Fuel Length	144.0 inch
Array Dimensions	15x15
Guide Tube Material	Zircaloy-4
Fuel Rods per Assembly	204
Guide Tubes per Assembly	21
Guide Tubes, I.D.	0.455
Guide Tubes, O.D.	0.512



Quarter Storage Location Representation of Infinite Array

FIGURE 6.1

ILLUSTRATION OF SINGLE FUEL PIN

MODEL SHOWING HOMOGENIZED FUEL REGION

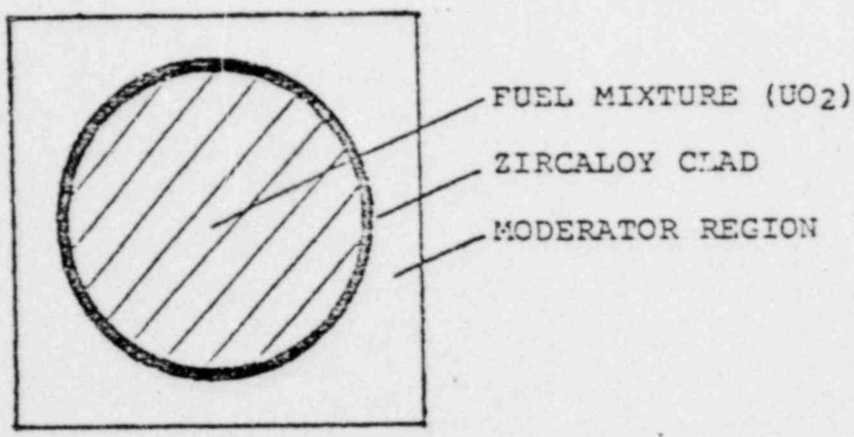


FIGURE 6.2

7. RESULTS OF CRITICALITY CALCULATIONS

Calculations performed with KENO-IV to evaluate K_{eff} for the configurations described in Section 5 resulted in a final K_{eff} value which is below the design limit of 0.98 imposed by the criticality criterion. The final value of $K_{eff} = 0.973$ allows for variations due to normal and abnormal configurations and the effects of calculational uncertainty.

7.1 REFERENCE CONFIGURATION

The K_{eff} determined by KENO-IV using the 16 group Hansen Roach cross-section set was 0.474 with an uncertainty of $\pm$0.006 at the 95% confidence level.

7.2 K_{eff} VALUES FOR NORMAL CONFIGURATIONS

7.2.1 Moderator Density Variation from 0.0 to 0.1 gm/cc of H_2O

An increase of water density in the rack from 0.0 to 0.01 gm/cc resulted in a ΔK_{eff} of 0.233 (see Figure 7.1 and Table 7.1).

7.2.2 Fuel Assembly Pitch Variation

The pitch was varied up and down by 2"; decreasing pitch by 2" caused an increase in K_{eff} of 0.043. The results of pitch variation are shown in Figure 7.2 and Table 7.1. Since the average pitch in the rack is substantially greater than the reference value of 21", no allowance for normal variation in pitch will be made.

7.2.3 Eccentric Fuel Location

In the worst case of eccentric location of fuel assemblies, four adjacent assemblies will be located in the corners of their respective cans such that all four are as close as possible to their three neighbors. In such a case, the pitch between these four neighbors will be reduced by 2 x 0.2775" where 0.2775" is the assembly to can wall clearance.

This case can conservatively be represented by a configuration in which the average pitch of the whole rack is reduced by 0.555 inches. The average pitch of the rack is much greater than the 21" assigned to the reference case because some gaps are 30". Therefore the reduction of 0.555" for eccentric can be ignored.

7.2.4 Worst Case Normal Configuration

The K_{eff} for the worst case normal configuration results from the sum of the ΔK's due to normal variations added to the K_{eff} for the reference configuration. K_{eff} for the worst case normal configuration is determined as follows:

K_{eff} of reference configuration	0.474
ΔK_{eff} due to moderator density variation	0.233
ΔK_{eff} due to pitch variation	0.00
ΔK_{eff} due to eccentric fuel positioning	0.00
Total ΔK_{eff}	= 0.233

Adding this value to the reference K_{eff} gives the value for the worst case normal configuration:

$$K_{eff} = 0.474 + 0.233$$
$$= 0.707$$

7.3 K_{eff} FOR ABNORMAL VARIATION

7.3.1 Moderator Density Variation from 0.01 gm/cc to 1.0 gm/cc of H_2O

Variation of H_2O density from 0.1 to 1.0 gm/cc resulted in a ΔK_{eff} of 0.260 (see Table 7.1 and Figure 7.1).

7.3.2 Fuel Drop Accident

The accidental drop of a fuel assembly resulting in its being compacted in its storage location was modeled by increasing the pellet O.D. of all fuel contained in the rack by 10%. Densities were maintained at their reference values for conservatism. ΔK for this configuration was found to be 0.06.

7.3.3 Seismic Incident

Rack pitch variations due to a seismic event are limited to approximately ± 0.25 inches. These deflections would likely be in random directions. If, however, we assume they combine in the worst case to reduce the average storage cell pitch 0.25 inches, it remains clear the effect on K_{eff} is small.

Interpolation from Figure 7.2 shows the ΔK_{eff} for a pitch change of 0.25" to be about 0.005 ΔK.

7.3.4 Worst Case Abnormal Configuration

The worst case abnormal configuration considers the ΔK_{eff} of the most adverse abnormal configuration in combination with the worst case normal K_{eff}. The most adverse abnormal configuration (large moderator density variation) has a ΔK_{eff} of 0.260 which when added to the worst case normal K_{eff} of 0.707 results in the worst case abnormal K_{eff} of 0.967.

7.4 EFFECTS OF CALCULATIONAL UNCERTAINTIES

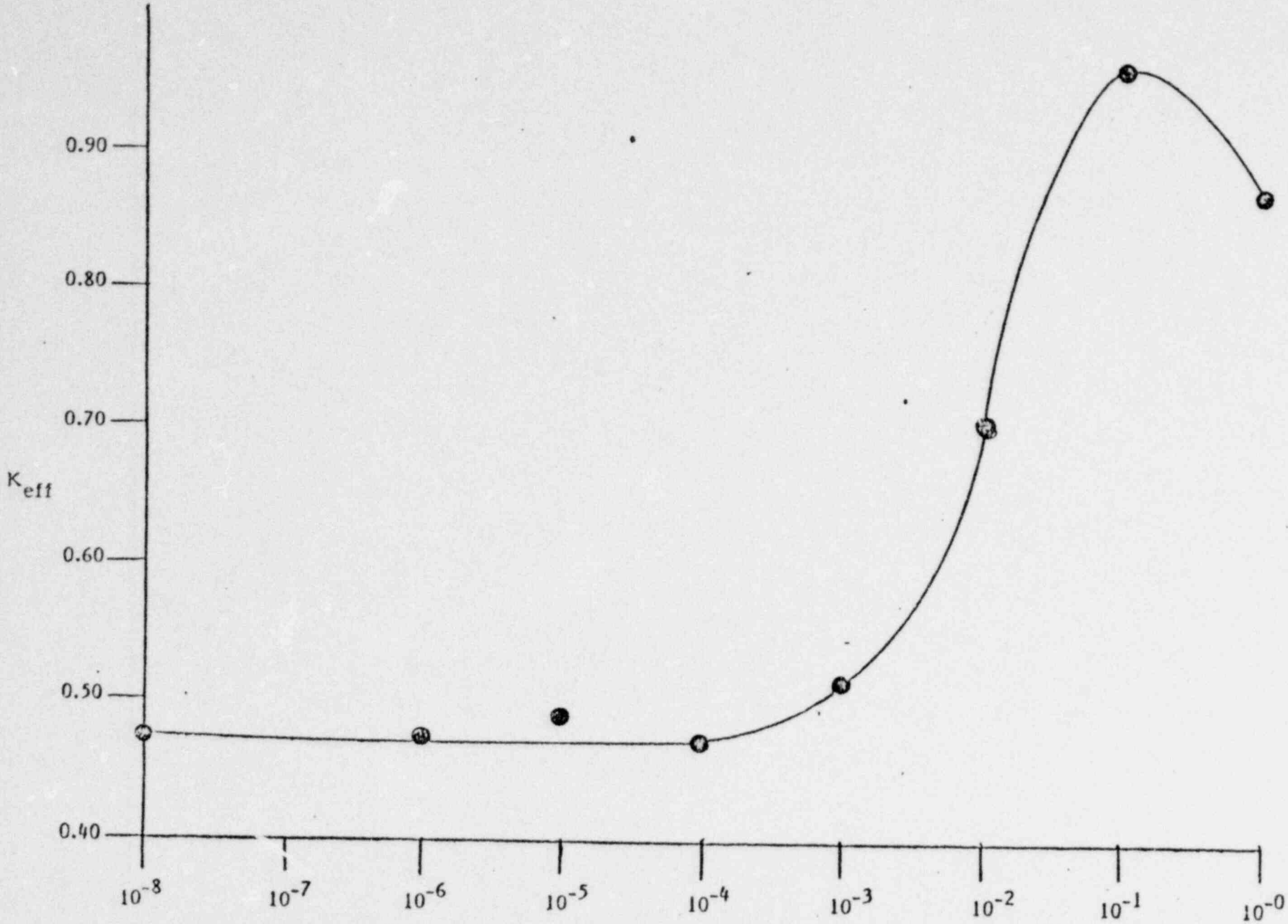
The statistical uncertainty due to KENO-IV is ± 0.006 at the 95% confidence level. The bias for KENO-IV using 16 groups is negative; in other words, KENO calculates a K_{eff} higher than the actual K_{eff} of a critical experiment. This bias is neglected for conservatism.

The total effect of all uncertainties is taken as ± 0.006. When added to the worst case abnormal K_{eff} of 0.967 this results in a final K_{eff} including uncertainties of 0.973.

Modeled Configuration	Average Storage Cell Pitch (inches)	Moderator (Water) Density (gm/cc)	Fuel Enrichment (w/o)	K_{eff}
Reference Configuration	21	10^{-8}	4.1	0.474
	21	10^{-6}	4.1	0.475
Moderator	21	10^{5}	4.1	0.486
Density	21	10^{-4}	4.1	0.473
Variation	21	10^{-3}	4.1	0.514
	21	10^{-2}	4.1	0.707
	21	10^{-1}	4.1	0.967
	21	1.0	4.1	0.873
	19	10^{-8}	4.1	0.517
	23	10^{-8}	4.1	0.446

TABLE 7.1

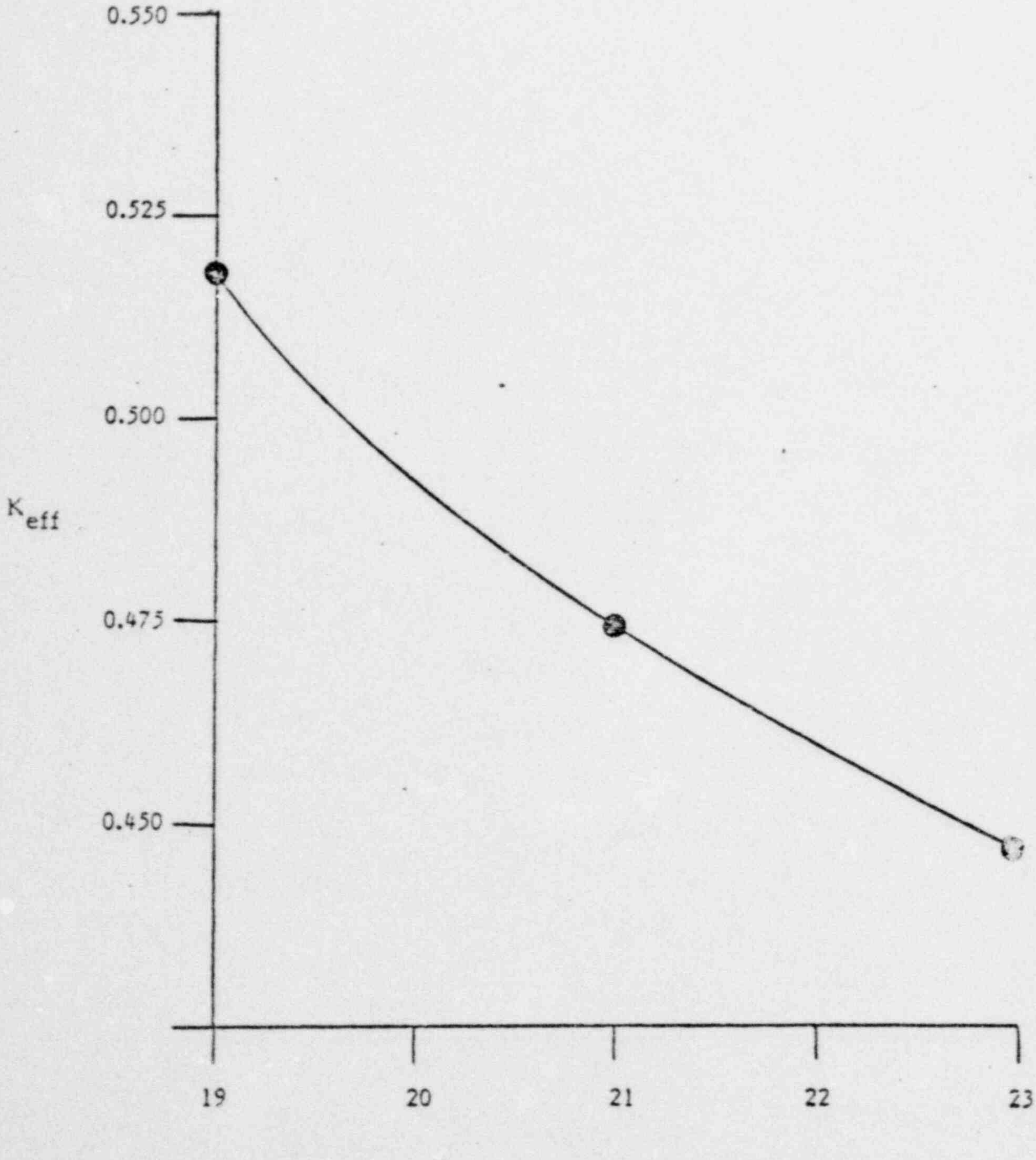
RESULTS OF K_{eff} CALCULATIONS



Water Density (gms/cc)

K_{eff} vs Water Density

FIGURE 7.1



K_{eff} vs Storage Cell Pitch

FIGURE 7.2

8. DETAILED PARAMETRIC STUDY VERSUS WATER DENSITY

Because the peak K_{eff} 0.973, found in Section 7.4, was so close to the allowed criticality criterion of 0.98, and also because it is possible that a somewhat higher value might exist in the neighborhood of the peak shown in Figure 7.1, a further parametric study was performed with a new, more detailed geometric model for KENO.

This model, instead of being infinite in lateral extent, represents the north-south axis of the rack, with the east-west axis remaining infinite in extent (see Figure 8.1). This representation does two things. First, the actual spacings (pitches) between rows are not all 21" but are either 21", 30", or 40", as can be seen from the figure. Second, since the rack is now finite in the north-south axis, a substantial leakage will occur out the north and south faces of the rack, especially at low water densities. (This model was not used at the start of the work because of the increased complexity and cost.)

The results of a detailed parametric study of K_{eff} versus water density in the vicinity of 0.1 gms/cc are shown in Figure 8.2. It is seen that there is indeed a peak K_{eff} somewhat higher than the value at 0.1 gm/cc located at about 0.06 gm/cc. The value of K_{eff} at this point using the more realistic geometric model of Figure 8.1, is 0.896, which is substantially below the peak K_{eff} of 0.967 reported for the simpler model (see Figure 7.1) and also substantially below the criticality criterion of 0.98.

The final K_{eff} for the more detailed geometric model considering the KENO uncertainty of $\pm$ 0.006 is

$$0.896 + 0.006 = 0.902$$

A further reduction in the calculated K_{eff} would occur if the east-west axis of the pool were modeled instead of being taken as infinite in extent. Such a calculation was not performed because of the great complexity and cost of such a large three-dimensional problem but simple buckling estimates show a further reduction of K_{eff} of about 0.04 would be realized. That is, the final K_{eff} for the Surry racks calculated with a geometry modeled in all three dimensions would be approximately 0.862.

DETAILED GEOMETRIC REPRESENTATION

OF FINITE ARRAY

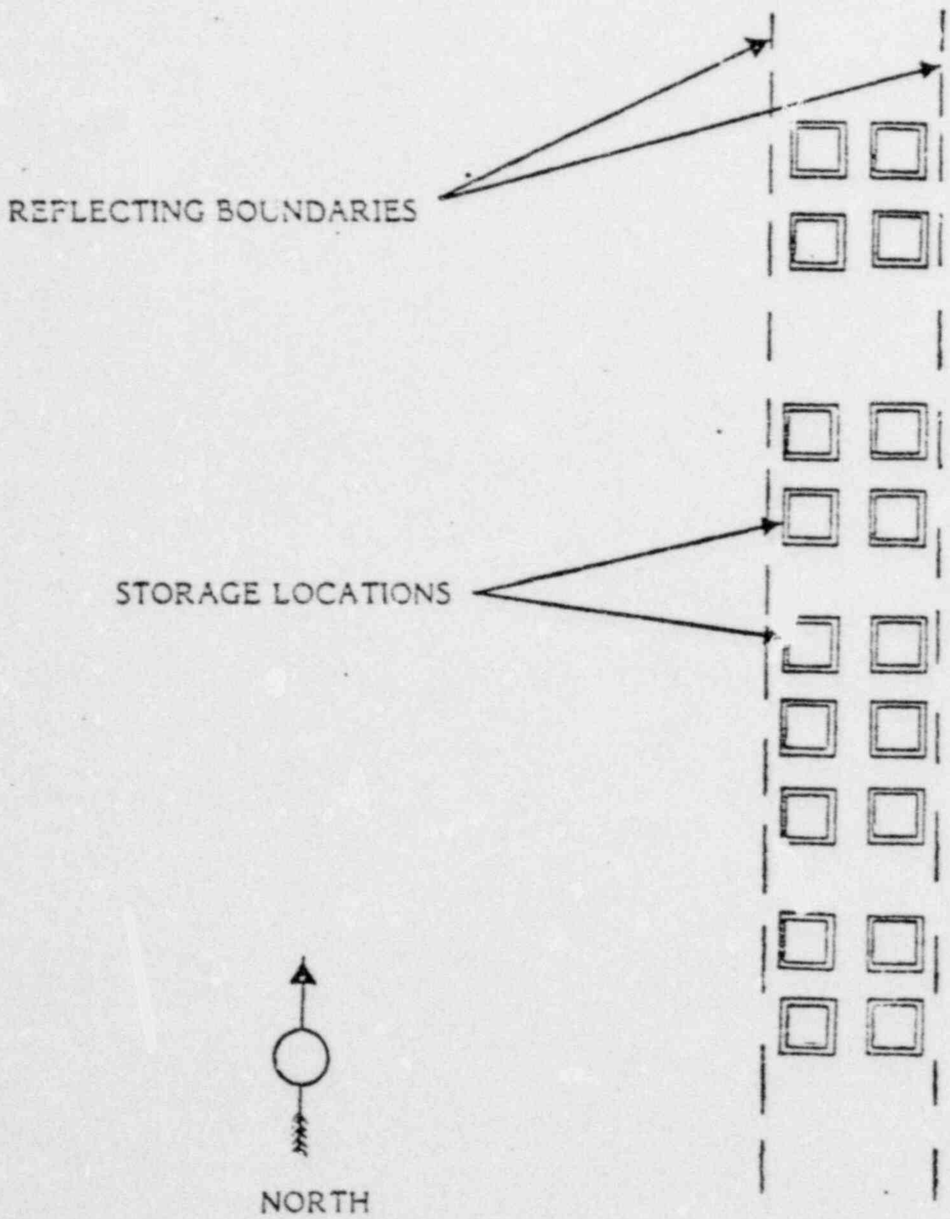


FIGURE 8.1

K_{EFF} VERSUS WATER DENSITY, FINITE ARRAY

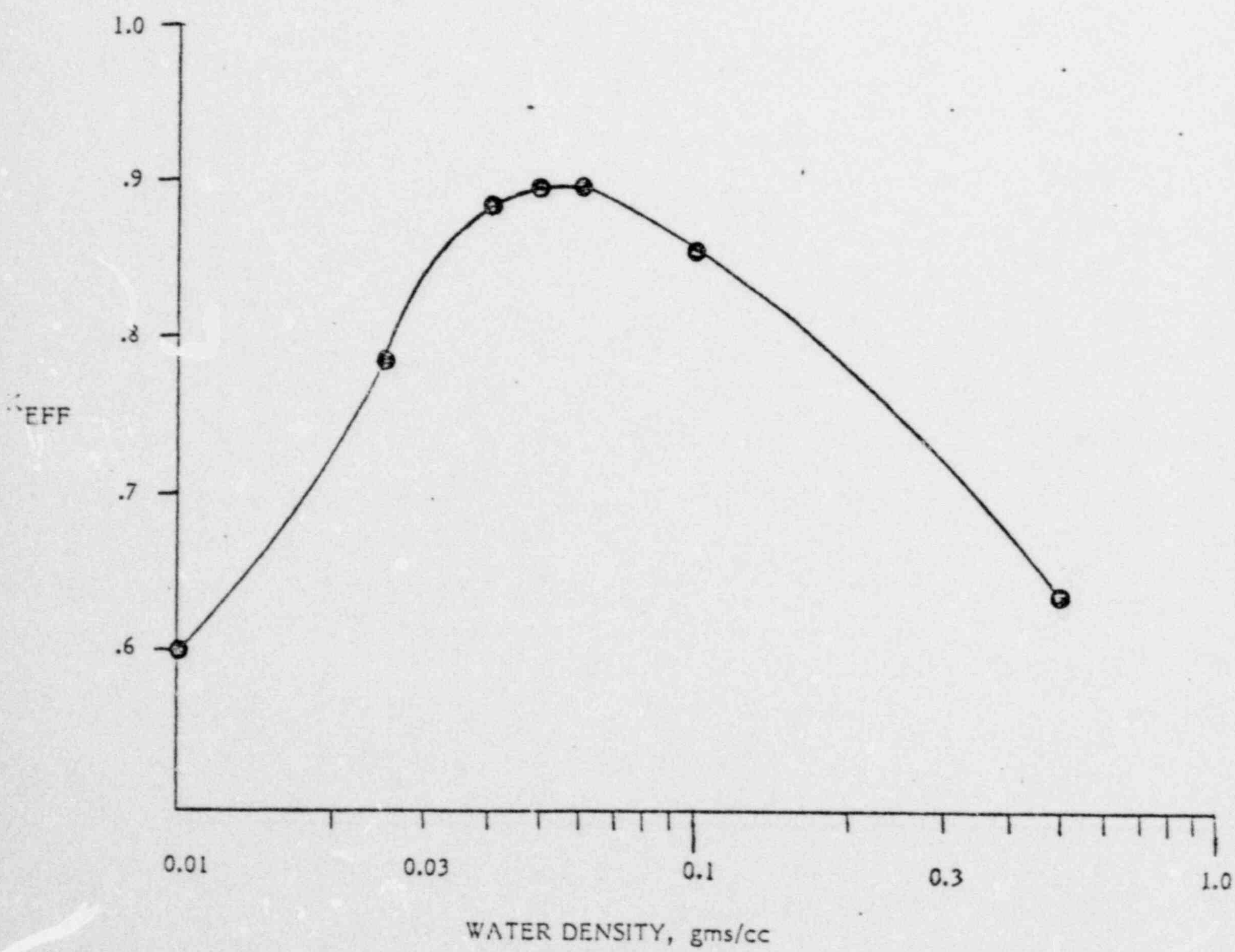


FIGURE 8.2

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