Attachment 2

Summary Report
Nuclear Criticality Re-analysis for 4.3 Weight Percent U-235 Fuel In the New Fuel Storage Rack of the Joseph M. Farley Nuclear Plant

SUMMARY REPORT
NUCLEAR CRITICALITY RE-ANALYSIS
FOR
4.3 w/o FUEL
IN
NEW FUEL STORAGE RACK
OF
JOSEPH M. FARLEY NUCLEAR PLANT
OF
ALABAMA POWER COMPANY

Prepared by K. M. Smolinske
K. M. Smolinske
Senior Project Engineer

Reviewed by R. L. Grow
R. L. Grow
Manager, Special Projects Dept.

D. T. Gournelos
D. T. Gournelos
Senior Associate

Approved by J. R. Fisher
J. R. Fisher
Technical Director

Revision 1 - March 21, 1984

UTILITY ASSOCIATES INTERNATIONAL

a consulting service of
CONTROL DATA CORPORATION

6003 EXECUTIVE BOULEVARD
ROCKVILLE, MARYLAND 20852

Revision Number	1
Date of Revision	March 21, 1984
Date Entered	
Revision Entered by	

UAI DOCUMENT REVISION NOTICE

Title of Document Summary Report, Nuclear Criticality Re-Analysis for 4.3 w/o Fuel in New Fuel Storage Rack of Joseph M. Farley Nuclear Plant of Alabama Power Company	UAI Document Number 84-17 Copy Number

- [x] Please replace entire document with the attached major revision.
- [ ] As the superseded material is proprietary to UAI, you are requested to return it in the accompanying envelope.
- [ ] Acknowledgement of receipt of this revision by return of the attached Document Transmittal sheet is requested.
- [ ] Please revise your copy of the UAI document indicated above in accordance with the changes listed below:

Page Number	Status	Comment
Title Page	Revised	Change title, revision number, and date
i	Revised	Add Section 7.0
1-1	Revised	Add FSAR reference, add second paragraph
1-2	Revised	Editorial, add explanation that low densities are not credible
2-1	Revised	Add concrete thickness of KENO benchmark
2-2	Revised	Add KENO and CASMO benchmarks
2-3	Revised	Editorial, add criteria 8
3-1,3-2	Revised	Editorial
4-1	Revised	Entire section replaced
5-1, 5-2	Revised	Rewrite introduction to section, new explanation of dropped assembly accident

Page Number	Status	Comment
6-1	Revised	Editorial, add detail on criteria
7-1	New	Add references
Figure 5	Revised	Add concrete dimension

Please insert this Notice in proper sequence in document.

Prepared by K M Smolinske
K. M. Smolinske
Sr. Project Engineer

Approved by: J R Fisher
J. R. Fisher
Technical Director

LIST OF EFFECTIVE PAGES

PAGE	REVISION
Cover	1
i	1
1-1	1
1-2	1
2-1	1
2-2	1
3-1	1
3-2	1
4-1	1
5-1	1
5-2	1
6-1	1
7-1	1
Table 1	0
Figure 1	0
Figure 2	0
Figure 3	0
Figure 4	0
Figure 5	1

TABLE OF CONTENTS

1.0 INTRODUCTION

The design and licensing basis of the Farley new fuel storage racks are described in FSAR Section 9.1.1. A nuclear criticality safety re-analysis was performed by Utility Associates International on the Joseph M. Farley new fuel storage racks. These racks had previously been approved for storage of new fuel up to 3.5 w/o U-235. This report documents the re-analysis of these racks for new fuel up to 4.3 w/o U-235.

The design basis for preventing criticality outside of the reactor is that, including uncertainties, there is a 95 percent probability at a 95 percent confidence level that the effective multiplication factor (K_{eff}) of the fuel assembly array will be less than 0.95 when fully flooded with unborated water and less than 0.98 with fuel of the highest anticipated enrichment in place assuming optimum moderation, as recommended in ANSI N18.2-1973.[1] Criticality of fuel assemblies in the new fuel storage rack is prevented by the design of the rack which limits fuel assembly interaction. This is accomplished by restricting the minimum separation between assemblies to take advantage of neutron absorption in water and stainless steel.

The new fuel racks for the Farley plant consist of double rows of fuel assemblies with a nominal pitch of 21 inches in four separate storage pits. In one of the four pits, the fuel assemblies are surrounded by a 0.075" thick stainless steel canister with an internal cavity clearance of 9.0". The other three pits use 2.0" wide and 0.25" thick stainless steel angles in the four corners around the assemblies. The internal clearance between these angles is also 9.0". These racks are illustrated in Figure 1.

Two of the four pits have nominal distances from the center of the nearest assembly to the concrete wall of 18" on one side of the double row and 15" on the other. The remaining two pits have nominal distances of 25.5" from the center of the nearest assembly to the concrete wall on both sides of the double row. These pits are illustrated in Figure 2.

The criticality analysis was based on fresh fuel with a U-235 enrichment of 4.3 w/o. Although new fuel is normally stored in the dry condition, the criticality requirements include the interjection of possible moderators. Therefore, any water present was assumed to be fresh and non-borated.

Additionally, no credit was taken for the burnable poison rods which may be present in the fuel assemblies. The parameter analysis used the transport model, CASMO-2E[2,3] to investigate various criticality safety-related aspects of the rack design, including the flooded condition and low moderator (water) density. The full range of moderator densities was considered for expediency and conservatism, even though the attainment of very low densities is not considered credible. These studies were performed using an infinite lattice of fuel assemblies on a 21" pitch. The Monte Carlo Model, KENO-IV[4], was used to assure the reactivity of the rack design in the optimum moderator density condition is less than required by the criteria stated above. This report presents a description of the criticality analysis and the results for normal and adverse conditions.

Section 2.0 of this report describes the calculational models and the basic assumptions used in the analysis. Section 3.0 presents the calculational results of the analysis. In Section 3.0, sub-section 3.1 presents the results of the dry case; sub-section 3.2 presents the results of the water density variation study; and sub-section 3.3 presents the results of the reference case calculations. In this report, the reference cases are not the nominal case but the near-optimum moderator density cases, which bound the nominal case.

Section 4.0 describes uncertainties and tolerance considerations. Section 5.0 addresses the criticality effects of two accident conditions: The case of an assembly dropped alongside of the assemblies in the rack; and the fully flooded case. Note that the optimum moderator condition is addressed in Section 3.3 by the reference cases.

Section 6.0 gives a summary of the results indicating that all applicable limits are met for 4.3 w/o U-235 enrichment.

2.0 MODEL DESCRIPTION

2.1 The Monte Carlo Transport Model

The finite rack reactivity calculation employs the KENO-IV model. The basic neutron cross-section data come from the master library of AMPX. AMPX is a 123-group GAM-THERMOS neutron library prepared from ENDF/B version II data. The NITAWL[5] module of the AMPX program is used to perform the Nordheim integral treatment of the U-238 resonances. The working library produced by the NITAWL/AMPX module retains the 123-group structure and is used directly by KENO-IV.

In the KENO-IV calculation, each fuel and water rod cell is represented discretely. The array option of KENO-IV is applied to arrange the fuel and water rod box types into a matrix representing the fuel assembly. Then a water region is added to the outside of this matrix, followed by stainless steel angles in each corner, an outer water gap region, and a concrete region on one side of the storage rack cell. To simulate the arrangement of two storage rack units wide and a large number of storage rack units long, and for a non-leakage condition in the axial directions, reflection is applied to the five non-concrete sides of this storage rack cell. For the sixth side, the concrete side, a zero flux boundary is applied 12 inches into the concrete. (See Figure 5.)

The KENO-IV/AMPX code system has been benchmarked against several critical experiments.[6] The two experiments cited below are used to benchmark KENO-IV/AMPX in this report because they contain no poison.

The first experiment is a critical configuration measured at ORNL which had 203 uranium metal rods of 4.95$\pm$ .05 w/o enrichment in water. The calculated result using KENO-IV/AMPX was K_{eff}= .998$\pm$ .005.

This K_{eff} was ~0.002 Δk below the critical value of the experiment.

The second critical experiment was a measurement made on the LaCrosse reactor. This experiment was chosen, in part, because it approaches the fuel storage rack configuration in that it was an unborated, virtually unrodded configuration. The result of this benchmark was:

	Keff
Measured:	1.009
KENO-IV/AMPX adjusted to include grids:	1.008

Therefore, the KENO-IV/AMPX result was ~0.001 Δk below the measured value, which is consistent with the ORNL critical results.

2.2 The Transport Theory Model

The criticality analysis for the Farley new fuel racks employs the CASMO-2E model to characterize the curve of k_∞ vs. water density for the infinite rack and to analyze the completely flooded and dry conditions. CASMO-2E is a multi-group, two-dimensional, transport theory code and uses a library containing data in 25 energy groups. The CASMO-2E model is an infinite lattice of assemblies separated by large water gaps. The storage rack cell in the CASMO-2E model has no leakage in any direction.

The CASMO transport code has been benchmarked against KENO-IV/AMPX for several configurations. These configurations include cases with and without boron. The result from 16 configurations is:

	Keff
CASMO-PDQ	1.002 ± 0.003
KENO-IV/AMPX	0.997 ± 0.010

Therefore, the CASMO-PDQ results over-predicts the KENO-IV/AMPX results by ~0.005 Δk over-all.

2.3 Calculation Assumptions

To ensure that the analysis follows a conservative approach and conforms to the general guidelines of criticality safety analysis, the calculations were performed with the follow assumptions:

1. The fuel is fresh (most reactive point in life) at 4.3 w/o U-235.
2. The effect of U-234, U-236, and the spacer grids is not included.
3. Other minor structural members in the assembly are replaced by water or void.
4. No soluble poison in water no fixed poison in the fuel assembly is included.
5. Stainless steel angles in the corners were selected as the more common configuration than the stainless steel canister. In the event that the K_{eff} was close to the applicable limit, the case would have been re-analyzed using the canister. However, as shown in the summary in Section 6.0, this re-analysis was not necessary.
6. The distance to the concrete wall does not have a large effect on the reactivity of the cell, so the largest distance was used since for most densities water is more reflective than concrete.
7. The properties of Portland concrete were used.
8. No axial leakage was considered.

3.0 CALCULATIONAL RESULTS

The storage rack is comprised of two side-by-side rows of assemblies. The rack pitch is 21 inches. The size of this spacing is important in determining the optimum moderator density for the criticality analysis.

The analysis took no credit for the possible presence of any burnable poison rods in the assembly. Figure 3 shows the geometry layout of the storage cell and the dimensions and materials for various components. The input parameters used in the analysis are listed in Table 1.

3.1 Dry Case

Using the input data from Table 1 and the nominal dimensions from Figure 3, an upper limit of k_∞ of the dry case at 68°F was determined by using 0.1% density with no boron present. (See Figure 4.) The CASMO-2E transport model yielded a k_∞=0.8883 in the infinite lattice configuration.

Since this case also does not include leakage, the true K_{eff} of the dry case would be considerably lower than the above result. The reference cases,in Sub-section 3.3, illustrates the magnitude of this difference.

3.2 Water Density Variation

CASMO-2E was used to determine k_∞ vs. water density. The same input data from Table 1 and Figure 3 was used for these CASMO-2E cases as in the dry case, except that the water density was varied.

Using the above described input data, the k_∞ values at 68^0F were also calculated. The shape of k_∞ vs. water density from the transport theory model is shown in Figure 4.

Since all the CASMO-2E cases are infinite lattice, the K_{eff} for the actual rack geometry is much lower, and Figure 4 was used only to characterize the curve of k_∞ vs. water density.

3.3 Reference Case

The reference cases in this report are the KENO-IV calculations in the nominal rack geometry at 2% and 5% water density. The nominal rack geometry is the same as shown in Figure 3 except that the amount of water on one side is increased and bounded by concrete as shown in Figure 5. This water distance to the concrete corresponds to a 25.5" distance from the center of the assembly to the concrete wall.

These two cases were run to demonstrate that the finite rack configuration is substantially sub-critical for all water densities. It also is noted that no credit has been taken for axial leakage, which for these low water densities is estimated to be about half of that in the XY direction.

Using the input described above, the K_{eff} values of the reference case at 68^0F were calculated. The results from the Monte Carlo model is given below:

	KENO-IV (nominal geometry)	
	K_{eff}	95% Confidence Interval
K_{eff}, 2% density	0.7094 $\pm$ .0106	0.6882 to 0.7306
K_{eff}, 5% density	0.7480 $\pm$ .0113	0.7254 to 0.7706

4.0 UNCERTAINTIES AND TOLERANCE CONSIDERATIONS

Consideration of uncertainties and tolerances include three items: the 95% confidence interval for KENO-IV; the bias between KENO-IV and measurement; and the bias due to positional and dimensional tolerances. Since the reactivity of either reference case would need to increase by more than 0.20 Δk to approach a K_{eff} of 0.95, the total of the three listed considerations need to be close to 0.20 Δk before a detailed analysis is required. The magnitude of these considerations is discussed below.

In sub-section 3.1, the largest 95% confidence interval is .0226 Δk above the nominal. The KENO-IV bias is taken to be 0.001 Δk to 0.002 Δk as described in Sub-section 2.1.

To estimate the size of the positional and dimensional tolerance adjustment, one CASMO-2E was run at 5% moderator density with a pitch of 20.386 inches as a limiting case. This case yields an .0234 Δk increase in reactivity which is on the same order of magnitude with UAI's past experience (.010 to .018 Δk) for positional and dimensional tolerance bias.

The sum of the worst of these biases and uncertainties is:

$$.0226\Delta k + .002\Delta k + .0234\Delta k = .048\Delta k$$

which is much less than 0.20 Δk.

Adding the total to the 0.05 g/cm^3 water density case yields:

$$K_{eff} = 0.748 + 0.048 = 0.796$$

This K_{eff} is much less than the 0.98 limit[1] allowed for optimum moderation, and since this case is representative of the maximum reactivity expected, no case will exceed its limit of 0.95 or 0.98 as applicable.

5.0 ACCIDENT CONSIDERATIONS

Two accidents considered were flooding of the new fuel pit and a dropped assembly between the periphery of the new fuel rack and the fuel pit wall. Each of these accidents is presented below.

5.1 Flooding

CASMO-2E was used to calculate the reactivity of the fully flooded case. The same input data from Table 1 and Figure 3 was used for this case as for the dry case, except that the rack was fully flooded.

Using the above described data, the K_∞ value of the fully flooded case at 68°F was calculated. The result of the CASMO-2E transport model was $K_\infty = 0.8160$ in the infinite lattice configuration. This result is plotted in Figure 4 with an extrapolated curve to the 25% water density result.

Since this case did not include leakage, the K_{eff} of the fully flooded rack is considerably lower.

5.2 Dropped Assembly

The second accident is a dropped assembly alongside of the assemblies in the rack. In this accident, a single assembly is dropped during fuel handling and lands on end in the pit between one of the rows of fuel assemblies and the fuel pit wall. The design of the new fuel racks preclude the possibility of dropping an assembly between the two rows of assemblies; therefore, this case was not considered.

It was assumed that the accident occurs during normal conditions, that is, for a dry condition. The possibility of a low moderator density condition is a result of an accident or malfunction and to postulate

a second accident, i.e., the dropped assembly, occurring simultaneously is not considered credible.

A conservative approach was taken to determine the upper limit of K_{eff} for this accident condition. An infinite array of assemblies infinitely long was assumed. Since this eliminates neutron leakage, and there is no material between assemblies (i.e., the racks are dry) the K_{eff} of the configuration is independent of pitch and hence also represents an infinite array of close packed assemblies. Therefore, the K_{eff} of this condition represents an upper limit of the actual rack configuration with an assembly dropped alongside, since the actual accident configuration is only three assemblies wide. Sub-section 3.1 showed that the K_{eff} of an infinite array of assemblies infinitely long is less than 0.8883, and hence the K_{eff} for the dropped assembly condition is much less than 0.8883.

The K_{eff} of the accident condition of a fuel assembly on top of a fully loaded rack is also much less than the infinite configuration. Since infinitely long fuel assemblies were assumed in the analyzed configuration and one assembly lying on top of the loaded storage rack is a much less reactive condition, $K_{eff} << 0.8883$ for this configuration as well.

6.0 SUMMARY AND CONCLUSIONS

The conclusion of this re-analysis of the Farley new fuel storage rack is that the current rack design is adequate for storage of 4.3 w/o fuel under normal and abnormal conditions. The results of the analysis are:

K_{eff} dry	<<0.8883
K_{eff}, flooded	<<0.8160
K_{eff}, 0.02 g/cm^3 water density (95% Confidence Interval	0.7094 $\pm$ 0.106 0.6882 to 0.7306)
K_{eff}, 0.05 g/cm^3 water density (95% Confidence Interval	0.7480 $\pm$ .0113 0.7254 to 0.7706)
K_{eff}, dropped assembly	<0.8883

All values are from infinite lattice calculations using CASMO-2E, except the near-optimum K_{eff}s which are nominal rack geometry calculations using AMPX/KENO-IV. All values are less than the applicable acceptance criteria of $\leq$ 0.950 for dry or flooded conditions, and $\leq$ 0.980 for postulated accidents or optimum moderation.

7.0 REFERENCES:

1. ANSI, N18.2 - 1973 "Nuclear Safety Criteria For The Design of Sationary Pressurized Water Reactor Plants."

2. M. Edenius, "CASMO-2 - A Fuel Assembly Burnup Program - User's Manual", Studsvik Energiteknik AB.

3. "Appendix to CASMO-2 User's Manual" (Containing CASMO-2E Option), Studsvik Energiteknik AB, 1982 and 1983.

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

5. "NITAWL/XSDPNPM - User Inforamtion Manual", CYBERNET Services, Control Data Corporation.

6. ANSI N18.2-1973. "Validation of Calculational Methods for Nuclear Criticality Safety".

7. NAI 76-71, "Spent Fuel Rack Criticality Calculations for Carolina Power and Light Company", Nuclear Associates International.

8. M. Edenius, K. Ekberg (Studsvik), E. Pilat, D. VerPlanck (Yankee Atomic), "CASMO Benchmarking for Fuel Rack Geometries", Studsvik Energiteknik AB.

TABLE 1
FUEL DATA

1.0	Fuel Assembly Type	17x17 Westinghouse
2.0	Pellet O.D.	0.3225"
3.0	Clad Data	
	3.1 O.D.	0.374"
	3.2 Thickness	0.0225"
	3.3 Material	Zr-4
4.0	Fuel Rod Pitch	0.496"
5.0	U-235 Enrichment	4.3 w/o
6.0	UO_2 Density	95% theoretical
7.0	Stack Density	10.287 g/cm^3
8.0	Water Hole Data	
	8.1 Thimble Material	Zr-4
	8.2 Thimble Dimensions	

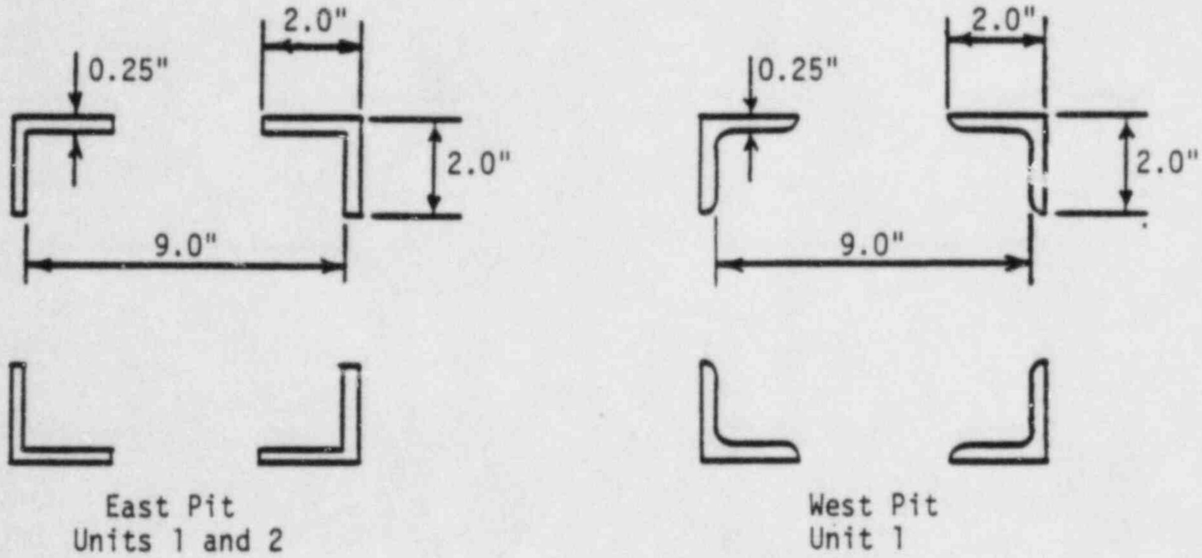
	Instrument Tube	Guide Tube Upper	Guide Tube Lower
O.D.	0.482"	0.482"	0.429"
I.D.	0.450"	0.450"	0.397"
Number	1	24	

9.0	Active Fuel Length	143.7"
10.0	Plenum Length	6.3"
11.0	Number of Intermediate Grid Spacers	8
12.0	Dry Weight of Fuel Assembly	1467 lbs.

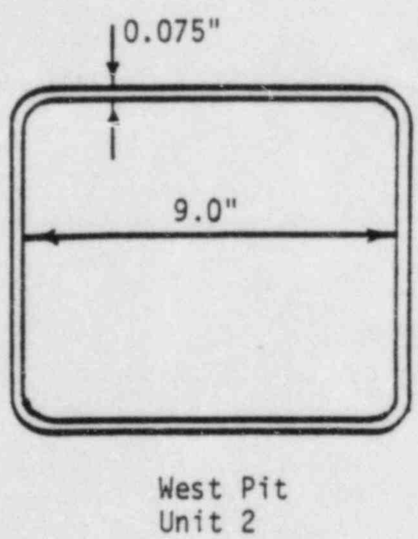
FIGURE 1

FARLEY NEW FUEL RACK DESIGNS

1) Two configurations of new fuel storage rack using angles:



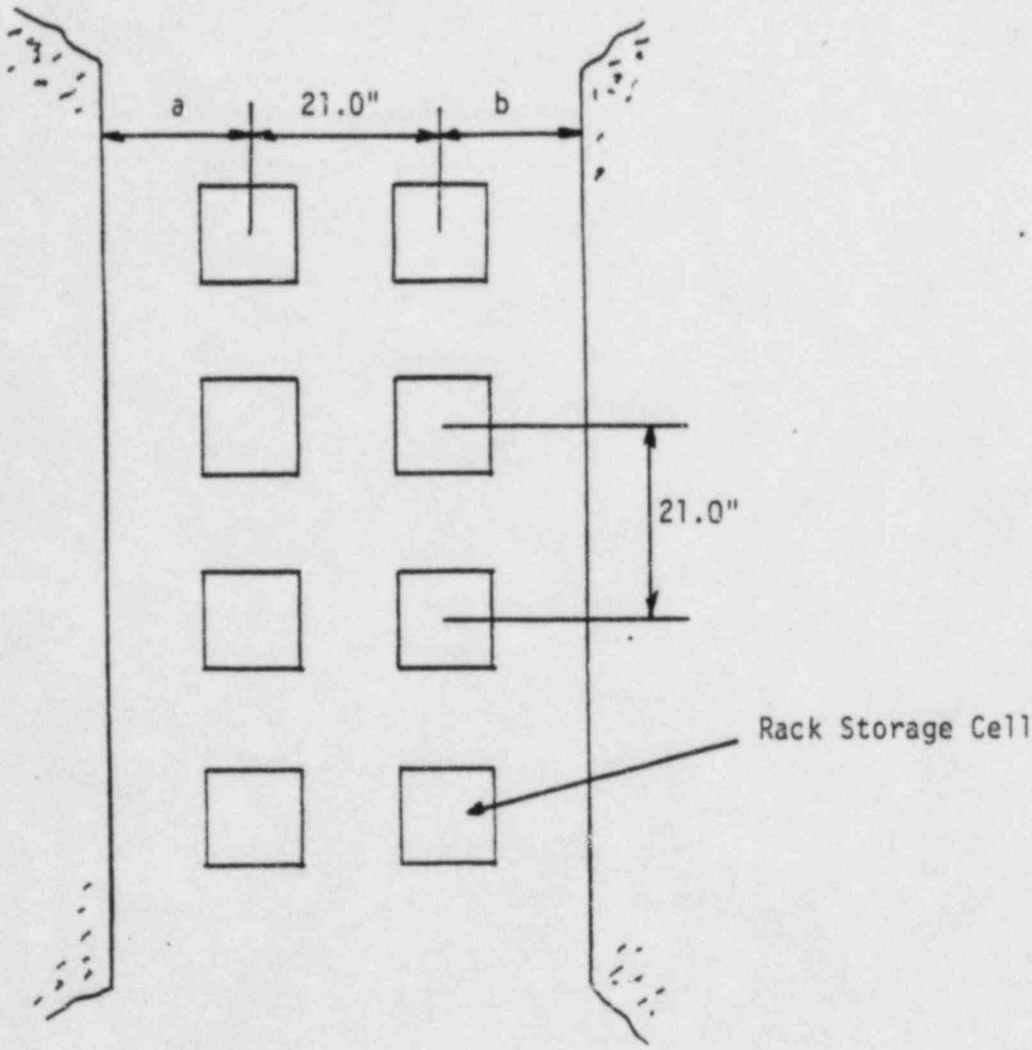
2) Configuration of new fuel storage rack canisters:



NOTE: Diagram not to scale. All dimensions are in inches.

FIGURE 2

FARLEY NEW FUEL STORAGE RACK PIT DESIGNS



West Pits, Units 1 and 2:

a = 18.0", b= 15.0"

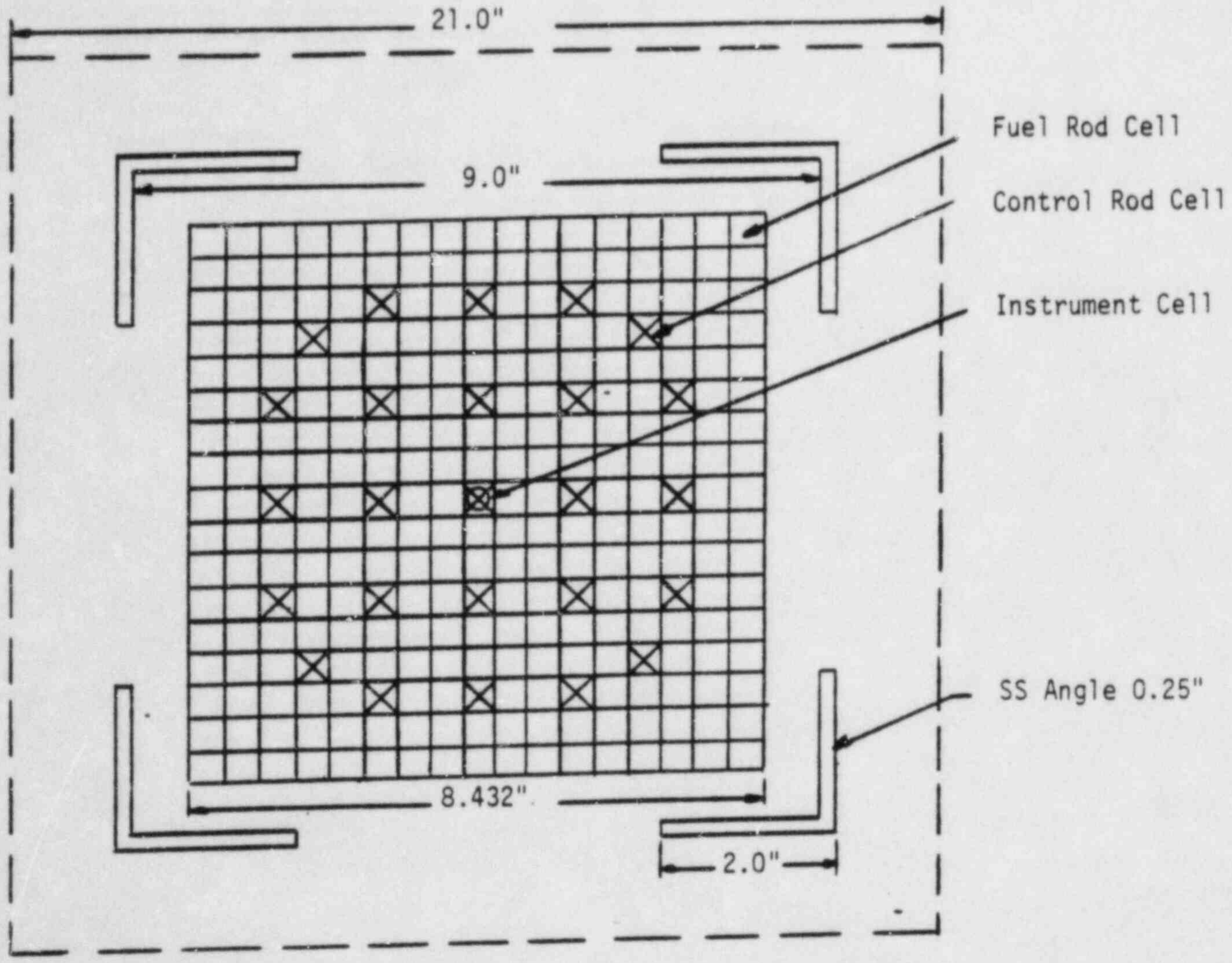
East Pits, Units 1 and 2:

a = b = 25.5"

NOTE: Diagram not to scale. All dimensions are in inches.

FIGURE 3

FARLEY PWR NEW FUEL RACK CELL GEOMERRY



NOTES:

1) All dimensions given in inches. Diagram not to scale.
2) CASMO-2E cases run without SS angles.
3) KENO-IV case run with 25.5" from center of fuel assembly to concrete wall.

FIGURE 4

JOSEPH M. FARLEY

K∞ VS. WATER DENSITY FOR AN INFINITE LATTICE OF 4.3 w/o NEW FUEL

(21" Pitch)

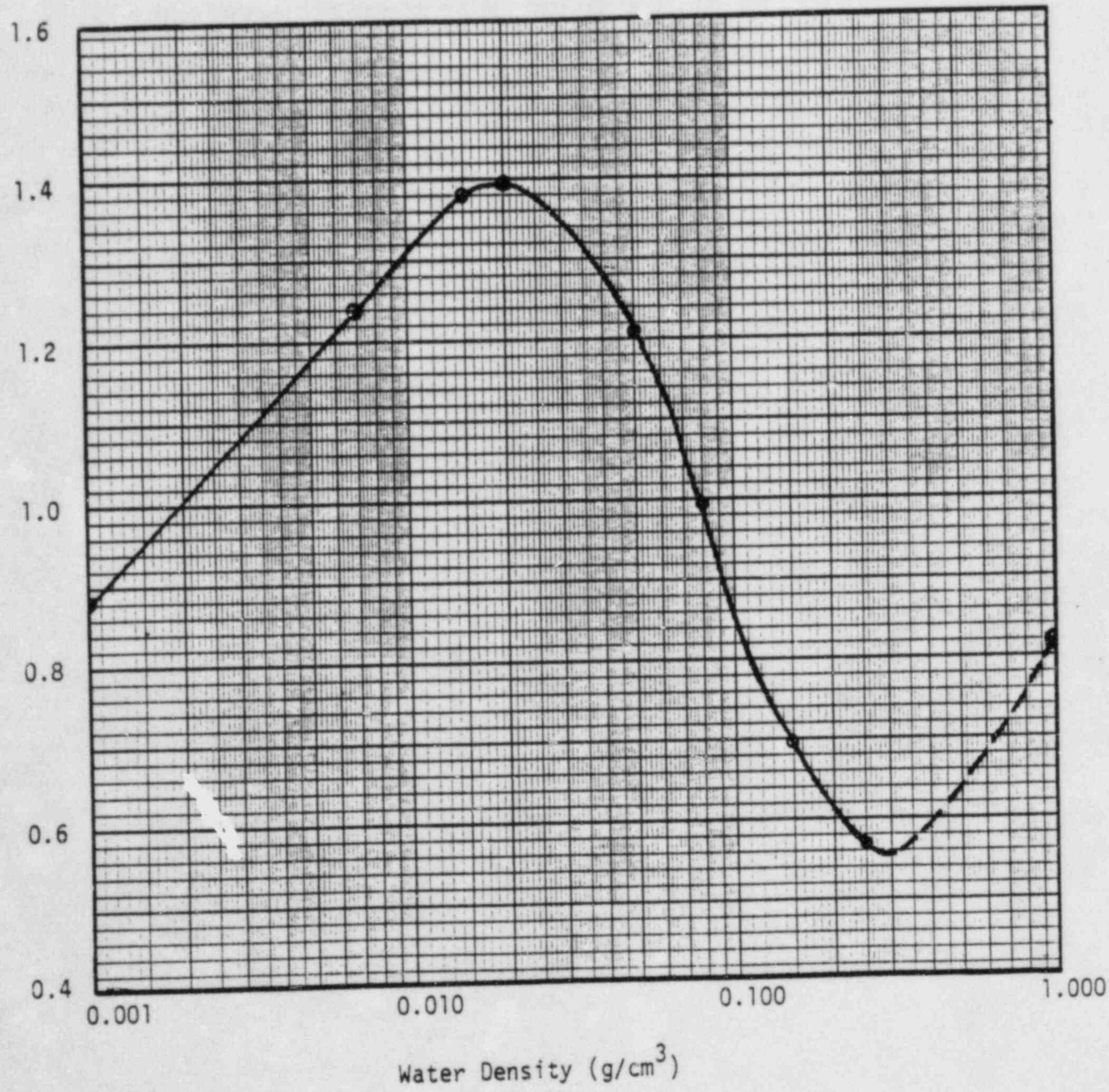
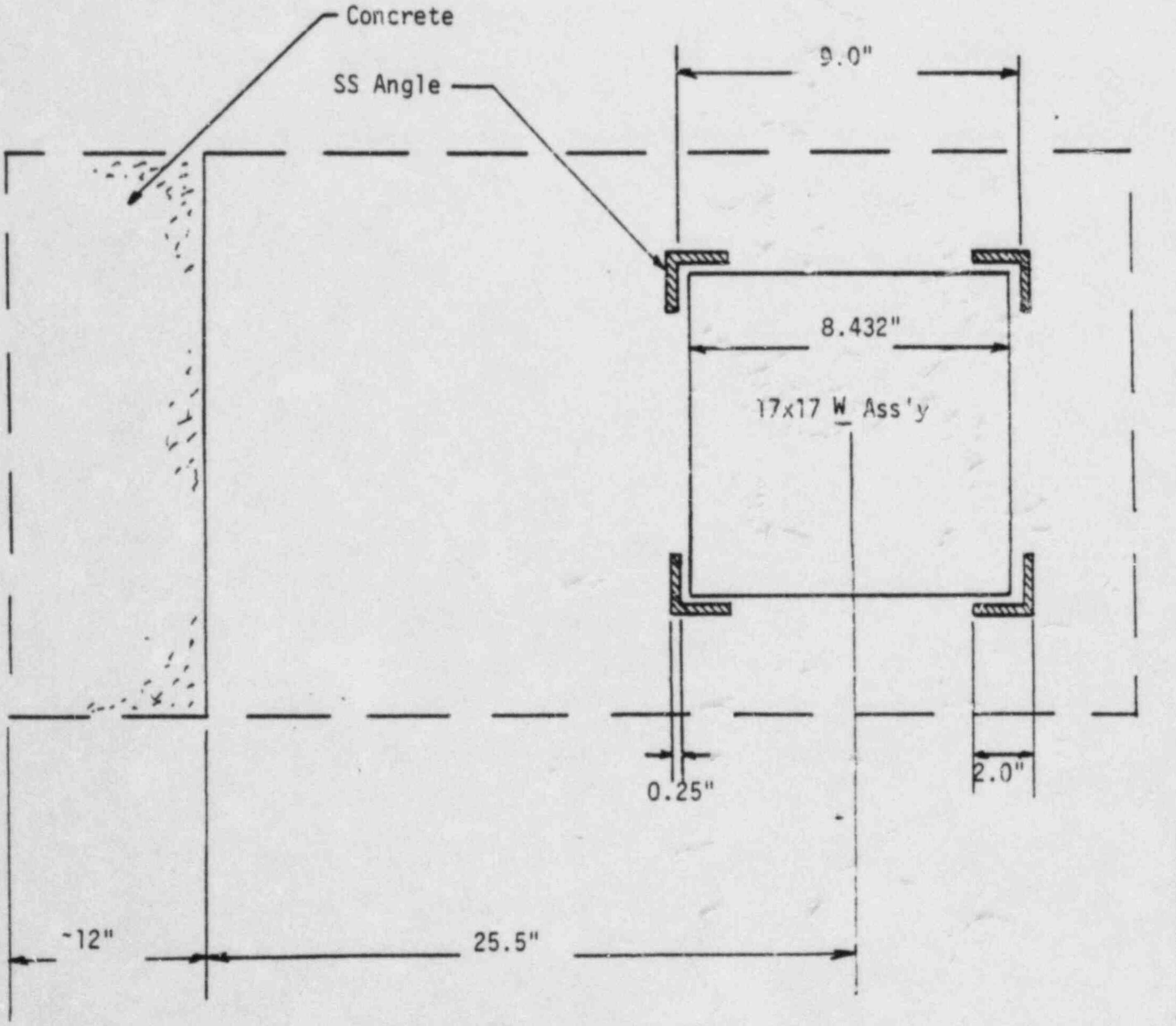


FIGURE 5

FARLEY NEW FUEL STORAGE RACK CONFIGURATION FOR KENO



NOTE: Diagram not to scale. All dimensions are in inches.