CRITICALITY ANALYSIS OF SHEARON HARRIS FUEL RACKS

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1. Introduction

The Shearon Harris Unit 1 fuel rack design described herein, referred to as Region 1, is designed on the basis of the currently accepted NRC guidance on fuel rack design.[1]

The Region 1 design is a poisoned stainless steel design previously licensed and accepted by the NRC for storage of W 17x17 Standard or W 17x17 OFA fuel up to 3.9 W/O U^{235} with utilization of every cell in the array. This rack will be reanalyzed for criticality to show that 4.2 w/o OFA and STD fuel can be stored in every storage cell in the rack and maintain $K_{eff} \leq 0.95$.

2. Design Description

The type of storage cell employed in Region 1 is shown schematically (not drawn to scale) in Figure 1. Nominal dimensions for the poison storage cell are shown on the figure.

3. Design Criteria

Criticality of fuel assemblies in a fuel storage rack is prevented by the design of the rack which limits fuel assembly interaction. This is done by fixing the minimum separation between assemblies and inserting neutron poison between assemblies.

The design basis for preventing criticality outside the reactor is that, including uncertainties, there is a 95 percent probability at a 95 percent confidence level that the effective multiplication factor (K_{eff}) of the fuel assembly array will be less than 0.95 as recommended in ANSI 57.2-1983 and in Reference 1.

4. Criticality Analytical Method

The criticality calculation method and cross-section values are verified by comparison with critical experiment data for assemblies similar to those for which the racks are designed. This benchmarking data is sufficiently diverse to establish that the method bias and uncertainty will apply to rack conditions which include strong neutron absorbers, large water gaps and low moderator densities.

The design method which insures the criticality safety of fuel assemblies in the fuel storage rack uses the AMPX system of codes[2,3] for cross-section generation and KENO IV[4] for reactivity determination.

The 227 energy group cross-section library[2] that is the common starting point for all cross-sections used for the benchmarks and the storage rack is generated from ENDF/B-V data. The NITAWL program[3] includes, in this library, the self-shielded resonance cross-sections that are appropriate for each particular geometry. The Nordheim Integral Treatment is used. Energy and spatial weighting of cross-sections is performed by the XSDRNPM program[3] which is a one-dimensional S_n transport theory code. These multigroup cross-section sets are then used as input to KENO IV[4] which is a three dimensional Monte Carlo theory program designed for reactivity calculations.

A set of 33 critical experiments has been analyzed using the above method to demonstrate its applicability to criticality analysis and to establish the method bias and variability. The experiments range from water moderated, oxide fuel arrays separated by various materials (Boral, steel, water) that simulate LWR fuel shipping and storage conditions[5] to dry, harder spectrum uranium metal cylinder arrays with various interspersed materials[6] (Plexiglas and air) that demonstrate the wide range of applicability of the method. Table 1 summarizes these experiments.

The average K_{eff} of the benchmarks is 0.992. The standard deviation of the bias value is 0.0008 Δk. The 95/95 one sided tolerance limit factor for 33 values is 2.19. Thus, there is a 95 percent probability with a 95 percent confidence level that the uncertainty in reactivity, due to the method, is not greater that 0.0018 Δk.

5. Criticality Analysis - Normal Storage

The following assumptions were used to develop the nominal case KENO model for the Region 1 storage of fresh fuel:

a. The fuel assembly contains the highest enrichment authorized, is at its most reactive point in life, and no credit is taken for any burnable poison in the fuel rods. Historically, calculations for fuel racks similar to the Region 1 racks analyzed herein have shown that the W 17x17 OFA fuel assembly yields a larger K_{eff} than does the W 17x17 Standard fuel assembly when both fuel assemblies have the same U^{235} enrichment. Thus, only W 17x17 OFA fuel assembly was analyzed for Region 1. (See Table 2 for fuel parameters).

b. All fuel rods contain uranium dioxide at an enrichment of 4.2 w/o U^{235} over the infinite length of each rod.

c. No credit is taken for any U^{234} or U^{236} in the fuel, nor is any credit taken for the buildup of fission product poison material.

d. The moderator is pure water at a temperature of 68°F. A conservative value of 1.0 gm/cm^3 is used for the density of water.

e. No credit is taken for any spacer grids or spacer sleeves.

f. The minimum poison material loading (i.e., 0.02 grams B-10 per square centimeter) is used throughout the array.

g. The array is infinite in lateral and axial extent which precludes any neutron leakage from the array.

The KENO calculation for the nominal case resulted in a K_{eff} of 0.92067 with a 95 percent probability/95 percent confidence level uncertainty of $\pm$ 0.0046.

The maximum K_{eff} under normal conditions arises from consideration of mechanical and material thickness tolerances resulting from the manufacturing process in addition to asymmetric positioning of fuel assemblies within the storage cells. The manufacturing tolerances are stacked in such a manner to minimize the water gap between cells, thereby causing an increase in reactivity. The sheet metal tolerances are considered along with construction tolerances related to the cell I.D., cell center-to-center spacing, poison and wrapper cavity. For the Region 1 storage racks, the water gap is reduced from a nominal value of 1.33" to a minimum of 0.975". Thus, the most conservative, or "worst case", KENO model of the Region 1 storage racks contains a minimum gap of 0.975". In addition, the center-to-center spacing between fuel assemblies is minimized by positioning the assemblies into adjacent corners in clusters of four storage cells. The sketch in Figure 2 shows the configuration of the "worst case" geometry.

Based on the analysis described above, the following equation is used to develop the maximum K_{eff} for the Shearon Harris Region 1 fuel storage racks:

$$K_{eff} = K_{worst} + B_{method} + B_{part} + [(ks)^2_{worst} + (ks)^2_{method}]^{1/2}$$

where:

k_{worst}	=	worst case KENO K_{eff} that includes asymmetric fuel assembly position, material tolerances, and mechanical tolerances which can result in spacings between assemblies less than nominal
B_{method}	=	method bias determined from benchmark critical comparisons
B_{part}	=	bias to account for position particle self-shielding
ks_{worst}	=	95/95 uncertainty in the worst case KENO K_{eff}

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

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

$$K_{eff} = 0.9306 + 0.0083 + 0.0014 + [(0.0041)^2 + (0.0018)^2]^{1/2} = 0.9448$$

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

6. Postulated Accidents

Most accident conditions will not result in an increase in K_{eff} of the rack. Examples are the loss of cooling systems (reactivity decreases with decreasing water density) and dropping a fuel assembly on top of the rack (the rack structure pertinent for criticality is not excessively deformed and the dropped assembly has more than 12 inches of water separating it from the active fuel height of stored assemblies which precludes interaction).

However, accidents can be postulated which would increase reactivity such as misplaced fuel assemblies. For these accident conditions, the double contingency principle of ANSI N16.1-1975 is applied. This states that one is not required to assume two unlikely, independent, concurrent events to ensure protection against a criticality accident. Thus, for accident conditions, the presence of soluble boron in the storage pool water can be assumed as a realistic initial condition since not assuming its presence would be a second unlikely event.

The presence of approximately 2000 ppm boron in the pool water will decrease reactivity by about 30 percent ΔK. In perspective, this is more negative reactivity than is present in the poison plates (25 percent ΔK), so K_{eff} for the rack would be less than 0.95 even if the poison plates were not present. Thus, for postulated accidents, should there be a reactivity increase, K_{eff} would be less than or equal to 0.95 due to the combined effects of the dissolved boron and the poison plates.

The "optimum moderation" accident is not a problem. The presence of poison plates removes the conditions necessary for "optimum moderation" so that K_{eff} continually decreases as moderator decreases from 1.0 gm/cm^3 to 0.0 gm/cm^3.

7. Sensitivity Analyses

To show the dependence of K_{eff} on fuel and storage cell parameters as requested by the NRC, the variation of the K_{eff} with respect to the following parameters was developed using the KENO computer code:

1. Fuel enrichment
2. Poison loading
3. Center-to-center spacing of storage cells.

Results of the sensitivity analysis for the Region 1 storage cells are shown in Figures 3 through 5. All error bars shown on Figures 3 through 5 are one sigma uncertainties.

8. Acceptance Criterion for Criticality

The neutron multiplication factor in the fuel pool shall be less than or equal to 0.95, including all uncertainties, under all conditions.

The analytical methods employed herein conform with ANSI N18.2-1973, "Nuclear Safety Criteria for the Design of Stationary Pressurized Water Reactor Plants," Section 5.7, Fuel Handling System; ANSI 57.2-1983, "Design Objectives for LWR Fuel Storage Facilities at Nuclear Power Stations," Section 6.4.2; ANSI N16.9-1975, "Validation of Calculational Methods for Nuclear Criticality Safety," NRC Standard Review Plan, Section 9.1.2, "Fuel Storage"; and the NRC guidance, "NRC Position for Review and Acceptance of the Fuel Storage and Handling Applications."

References

1. Nuclear Regulatory Commission, Letter to All Power Reactor Licensees, from B. K. Grimes, April 14, 1978, "OT Position for Review and Acceptance of the Fuel Storage and Handling Applications."

2. W. E. Ford III, et al., "CSRL-V: Processed ENDF/B-V 227-Neutron-Group and Pointwise Cross-Section Libraries for Criticality Safety, Reactor and Shielding Studies," ORNL/CSD/TM-160 (June 1982).

3. N. M. Greene, et. al., "AMPX: A Modular Code System for Generating Coupled Multigroup Neutron-Gamma Libraries from ENDF/B," ORNL/TM-3706 (March 1976).

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

5. M. N. Baldwin, et al., "Critical Experiments Supporting Close Proximity Water Storage of Power Reactor Fuel," BAW-1484-7, (July 1979).

6. J. T. Thomas, "Critical Three-Dimensional Arrays of U (93.2) -- Metal Cylinders," Nuclear Science and Engineering, Volume 52, pages 350-359 (1973).

Table 1

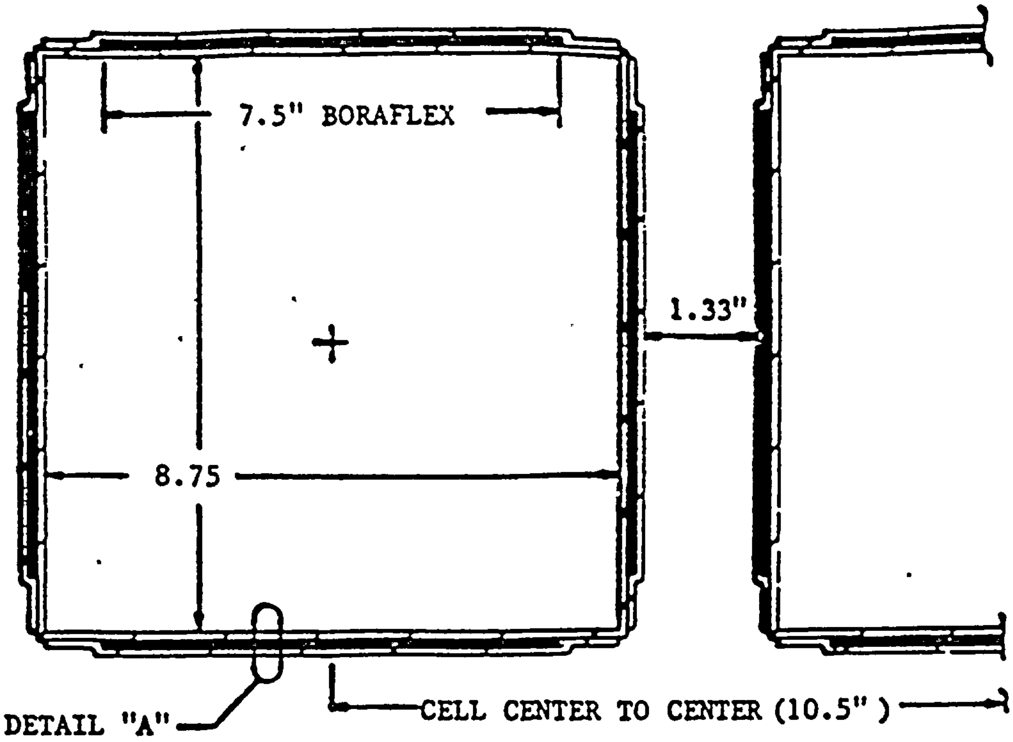
Benchmark Critical Experiments[5,6]

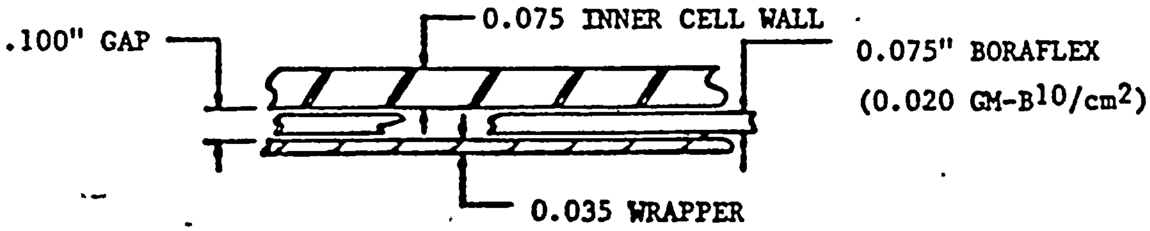
	General Description	Enrichment w/o U235	Reflector	Separating Material	Soluble B-10 ppm	K_{eff}
1.	UO_2 rod lattice	2.46	water	water	0	0.9857 ± .0028
2.	UO_2 rod lattice	2.46	water	water	1037	0.9906 ± .0018
3.	UO_2 rod lattice	2.46	water	water	764	0.9896 ± .0015
4.	UO_2 rod lattice	2.46	water	B4C pins	0	0.9914 ± .0025
5.	UO_2 rod lattice	2.46	water	B4C pins	0	0.9891 ± .0026
6.	UO_2 rod lattice	2.46	water	B4C pins	0	0.9955 ± .0020
7.	UO_2 rod lattice	2.46	water	B4C pins	0	0.9889 ± .0026
8.	UO_2 rod lattice	2.46	water	B4C pins	0	0.9983 ± .0025
9.	UO_2 rod lattice	2.46	water	water	0	0.9931 ± .0028
10.	UO_2 rod lattice	2.46	water	water	143	0.9928 ± .0025
11.	UO_2 rod lattice	2.46	water	stainless steel	514	0.9967 ± .0020
12.	UO_2 rod lattice	2.46	water	stainless steel	217	0.9943 ± .0019
13.	UO_2 rod lattice	2.46	water	borated aluminum	15	0.9892 ± .0023
14.	UO_2 rod lattice	2.46	water	borated aluminum	92	0.9884 ± .0023
15.	UO_2 rod lattice	2.46	water	borated aluminum	395	0.9832 ± .0021
16.	UO_2 rod lattice	2.46	water	borated aluminum	121	0.9848 ± .0024
17.	UO_2 rod lattice	2.46	water	borated aluminum	487	0.9895 ± .0020
18.	UO_2 rod lattice	2.46	water	borated aluminum	197	0.9885 ± .0022
19.	UO_2 rod lattice	2.46	water	borated aluminum	634	0.9921 ± .0019
20.	UO_2 rod lattice	2.46	water	borated aluminum	320	0.9920 ± .0020
21.	UO_2 rod lattice	2.46	water	borated aluminum	72	0.9939 ± .0020
22.	U metal cylinders	93.2	bare	air	0	0.9905 ± .0020
23.	U metal cylinders	93.2	bare	air	0	0.9970 ± .0020
24.	U metal cylinders	93.2	bare	air	0	0.9947 ± .0025
25.	U metal cylinders	93.2	bare	air	0	0.9928 ± .0019
26.	U metal cylinders	93.2	bare	air	0	0.9922 ± .0026
27.	U metal cylinders	93.2	bare	air	0	0.9950 ± .0027
28.	U metal cylinders	93.2	bare	plexiglass	0	0.9941 ± .0030
29.	U metal cylinders	93.2	paraffin	plexiglass	0	0.9920 ± .0041
30.	U metal cylinders	93.2	bare	plexiglass	0	0.9968 ± .0018
31.	U metal cylinders	93.2	paraffin	plexiglass	0	1.0042 ± .0019
32.	U metal cylinders	93.2	paraffin	plexiglass	0	0.9963 ± .0030
33.	U metal cylinders	93.2	paraffin	plexiglass	0	0.9919 ± .0032

Table 2

Fuel Parameters Employed in Criticality Analysis

Parameter	W 17X17 OFA	W 17X17 Standard
Number of Fuel Rods per Assembly	264	264
Rod Zirc-4 Clad O.D. (inch)	0.360	0.374
Clad Thickness (inch)	0.0225	0.0225
Fuel Pellet O.D. (inch)	0.3088	0.3225
Fuel Pellet Density (% of Theoretical)	96	96
Fuel Pellet Dishing Factor	1.0	1.0
Rod Pitch (inch)	0.496	0.496
Number of Zirc-4 Guide Tubes	24	24
Guide Tube O.D. (inch)	0.474	0.482
Guide Tube Thickness (inch)	0.016	0.016
Number of Instrument Tubes	1	1
Instrument Tube O.D. (inch)	0.474	0.482
Instrument Tube Thickness (inch)	0.016	0.016





DETAIL "A"

FIGURE 1

SHEARON HARRIS REGION 1 FUEL STORAGE CELL NOMINAL DIMENSIONS

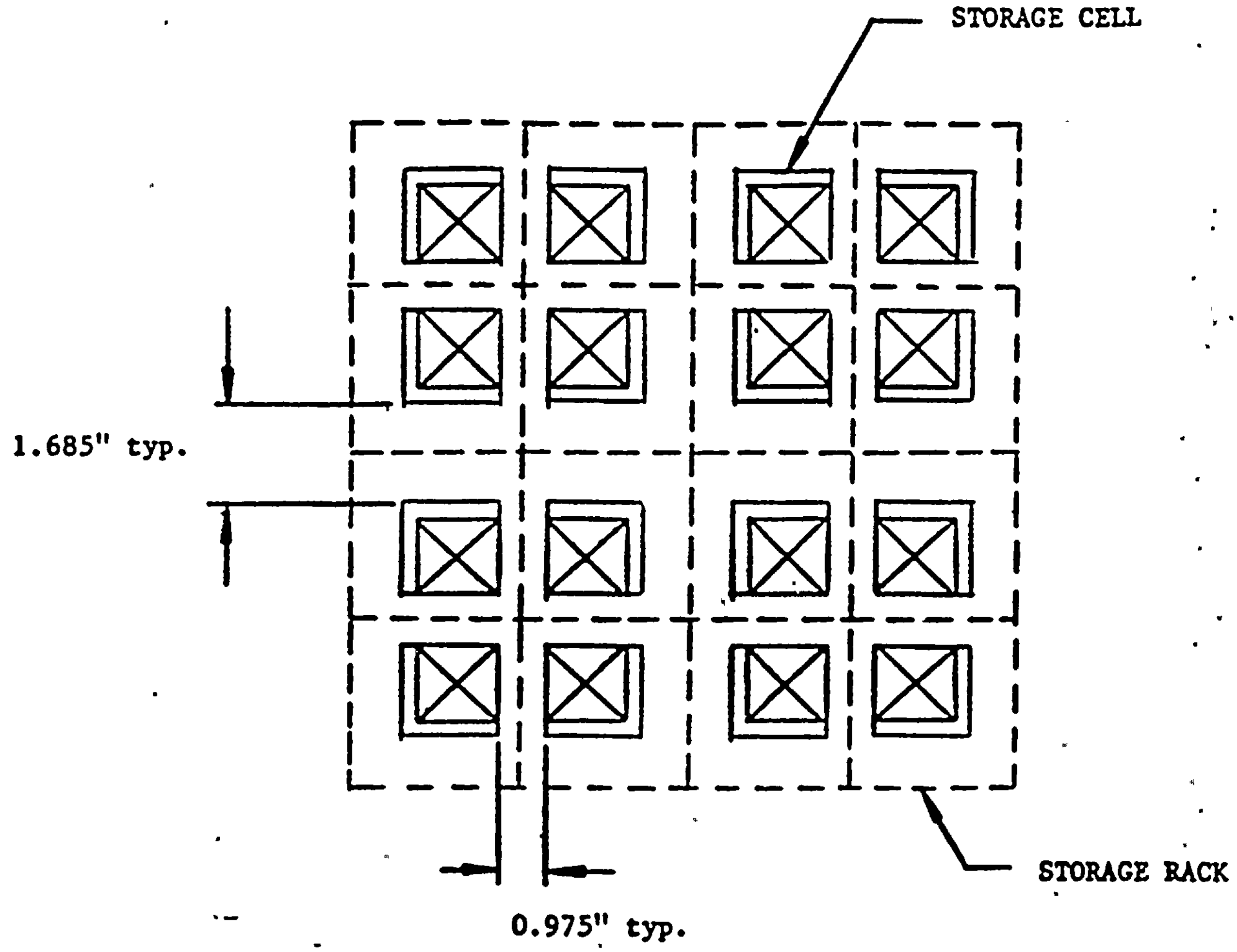


FIGURE 2

SHEARON HARRIS REGION 1 FUEL STORAGE CELL "WORST CASE" GEOMETRY

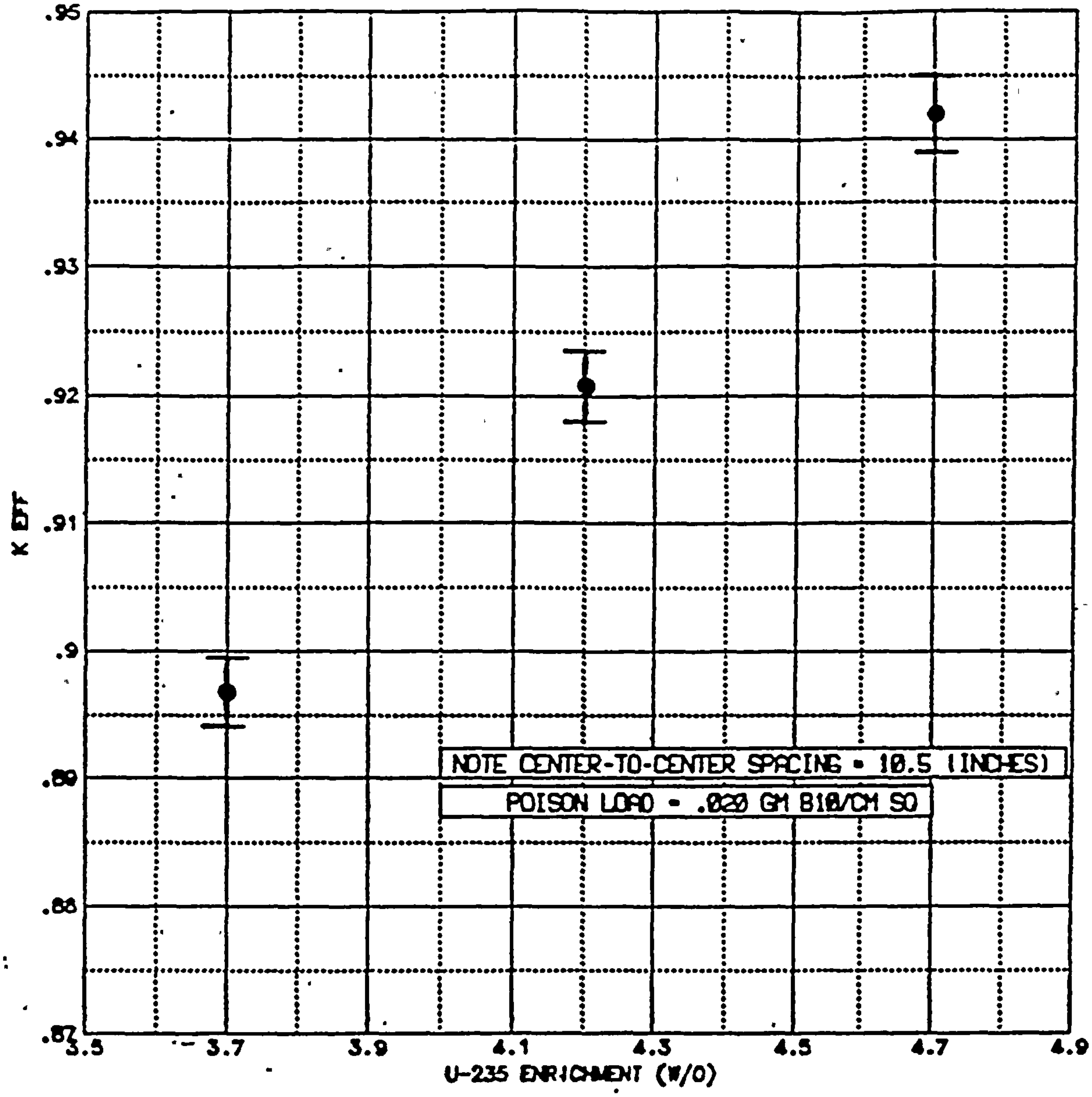


FIGURE 3

SENSITIVITY OF K-EFF TO ENRICHMENT IN THE SHEARON HARRIS
REGION 1 FUEL STORAGE RACKS

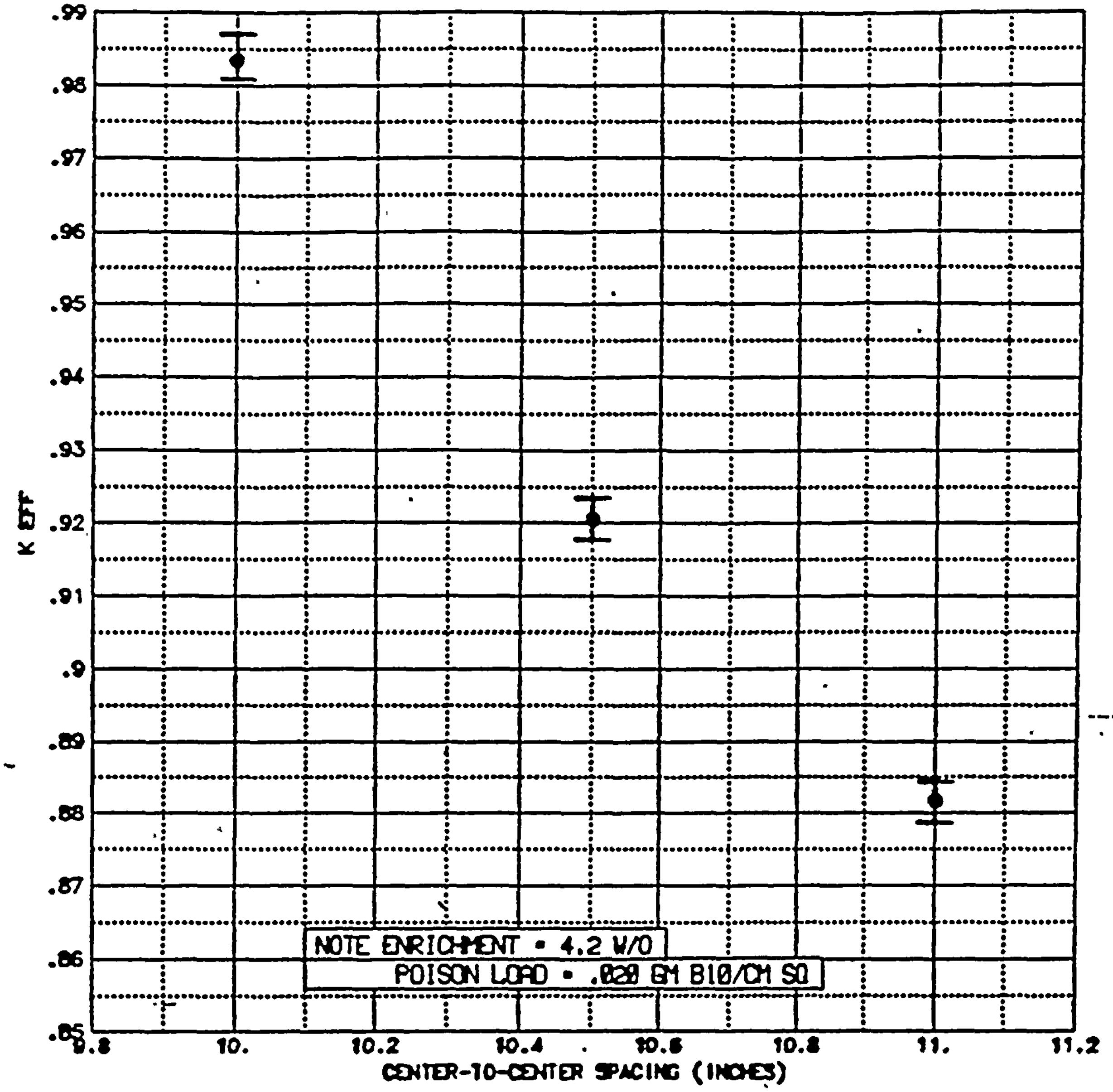


FIGURE 4

SENSITIVITY OF K-EFF TO CENTER-TO-CENTER SPACING IN THE SHEARON HARRIS REGION 1 FUEL STORAGE RACKS

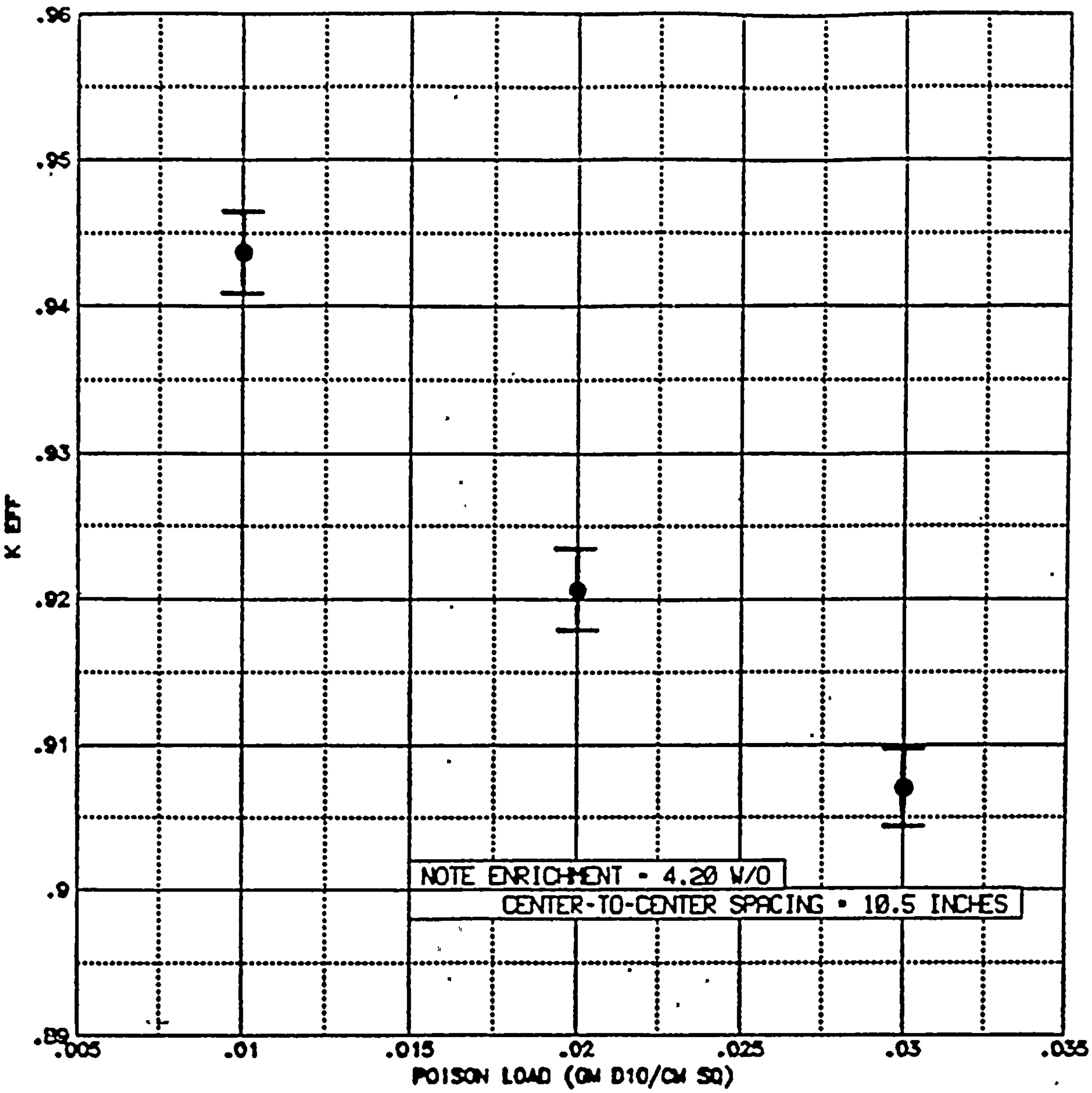


FIGURE 5

SENSITIVITY OF K-EFF TO POISON LOADING IN THE SHEARON HARRIS
REGION 1 FUEL STORAGE RACKS