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PALISADES NUCLEAR GENERATING STATION

SPENT FUEL STORAGE POOL

CRITICALITY SAFETY REANALYSIS

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PALISADES NUCLEAR GENERATING STATION
SPENT FUEL STORAGE POOL
CRITICALITY SAFETY REANALYSIS

INTRODUCTION

In November 1976 Consumers Power Co. submitted to the USNRC a request to install high density spent fuel storage racks at the Palisades Nuclear Generating Station. The subsequent safety analysis (1) showed the pool to be adequately subcritical for fuel assemblies enriched to 3.05 wt. % ^{235}U. With the trend in fuel management toward higher burnup, average reload fuel assembly enrichments have increased to as high as 3.267 w/o, (Exxon Nuclear Batch H). Thus, in July 1978 a reanalysis(2) of the high density storage racks was performed by NUS Corp. for the average Batch H reload fuel enrichment of 3.267 w/o.

The intent of this reanalysis is to define a maximum average fuel assembly enrichment (i.e. maximum axial ^{235}U loading), which will continue to meet applicable criticality safety criteria.

SUMMARY

The criticality safety reanalysis of the Palisades spent fuel storage pool, as described in Reference 1, and this report demonstrates the pool to be adequately subcritical, i.e. $k_{eff} \leq 0.95$ at the 95% CL(confidence level), for fuel assembly axial ^{235}U loadings up to and including 44.11 g/cm (3.80 w/o). The worst case k_{eff} of the racks is estimated to be 0.946 at the 95% CL for fuel assemblies enriched to 3.80 w/o.

FUEL ASSEMBLY DESCRIPTION

The Exxon Nuclear Batch H and I fuel assembly designs are depicted in Figure 1. As indicated, the 15x15 lattice arrangement includes a single instrument tube, eight guide bars, and eight locations for removable poison rods, gadolinia-bearing fuel pins or water rods. Current plans call for a Batch I reload of 68 fuel assemblies. Of these fuel assemblies 48 will contain eight water rods, twelve will contain eight gadolinia-bearing fuel pins and eight will provide eight poison rod locations.

The fuel assembly parameters assumed in this evaluation are given in Table I. From this information bundle-averaged cell parameters were calculated by including the zirconium associated with the instrument tube, guide tubes and the guide bars in the zirconium clad of each fuel rod. Water associated with each guide bar, instrument and guide tube was included by increasing the unit cell dimension (rod lattice pitch). For producing cell-averaged cross section data the above assumptions permit a conservative estimation of the effect on reactivity of the extra zirconium and water within the fuel assembly by maintaining the correct assembly water-to-fuel volume ratio.

SPENT FUEL STORAGE POOL DESCRIPTION

The Palisades spent fuel storage pool consists of racks comprising the main pool and tilt pit pool. The main pool storage racks have 8.56" square ID storage cells and a 10.25" center-to-center spacing, see Figure 2. In the tilt pit pool the rack is designed to store control rods as well as fuel assemblies. This rack has a 9.0" storage cell ID and cells are located on 10.69"x11.25" centers. As demonstrated in Reference 2 the reactivity of the main pool storage racks is ~2.0% $\Delta k/k$ higher than the tilt pit pool rack. Hence, the main pool rack design is analyzed with respect to criticality safety as the limiting case.

The neutron absorber plate is composed of B_4C bonded in a carbon matrix. The plate is 0.21" thick and 8.26" wide with a minimum ^{10}B loading of 0.0959 g/cm^2. As shown in Figure 2 each plate is centered width-wise in each storage cell wall.

CALCULATIONAL METHODS

The KENO IV Monte Carlo code[3] was utilized to calculate the reactivity (k_{eff}) of the Palisades spent fuel storage pool. Multi-group cross section data from the XSDRN 123 group data library were generated for input into KENO IV using the NITAWL[4] and XSDRNPM[4] codes. Specifically, the NITAWL code was utilized to obtain cross section data adjusted to account for resonance self-shielding using the Nordheim Integral Method. The XSDRNPM code, a discrete ordinates one-dimensional transport theory code, was then used to prepare spatially cell-weighted cross section data representative of the fuel assembly for input into KENO IV.

RESULTS OF PREVIOUS STORAGE POOL CRITICALITY SAFETY EVALUATIONS

In order to show the storage pool to be adequately subcritical for Exxon Nuclear Batch H fuel enriched to 3.267 w/o, a reanalysis[2] of the pool was performed by P. Soong of NUS in July 1978. In this analysis storage array k_{eff} values under nominal conditions were calculated using the "KENO code in conjunction with 123-group AMPX averaged cross sections".[2] The PDQ-7 code with NUMICE (NUS version of LEOPARD) cross sections was then used to calculate the reactivity changes resulting from variations in storage rack conditions. The reactivity for "worst case" conditions was then calculated by summing the KENO calculated k_{eff} for nominal conditions and the Δk_{eff} values calculated using the PDQ-7 code. Table II summarizes the results of these calculations for both the main pool and the tilt pit pool.

RESULTS OF NEW STORAGE POOL k_{eff} CALCULATIONS

In order to demonstrate the criticality safety of the storage pool for higher fuel assembly enrichments, additional k_{eff} calculations were performed using the KENO IV code. Using a geometric model of the nominal main pool storage arrangement as described in Reference 2 and depicted in Figure 2, k_{eff} was calculated for Exxon Nuclear Batch H fuel (See Table I) enriched to 3.267 w/o. The resulting k_{eff} value of $0.875 \pm .005$ represents an infinite array and is within two standard deviations of the KENO k_{eff} reported by P. Soong in Reference 2 and shown in Table II of this report. Hence, based on this result it is concluded that the calculational model used for this calculation gives conservative results for the main storage pool.

The above duplication calculation for Batch H fuel represented a fuel assembly design of 208 active fuel rods. To determine the effect on array k_{eff} of a higher fuel assembly axial ^{235}U loading based on the number of fuel rods, the above case was rerun with 216 fuel rods. For this case k_{eff} was calculated to be $0.865 \pm .005$. This result indicates a slightly greater reactivity worth of the water holes in the 208 fuel rod arrangement relative to having those positions filled with eight additional fuel rods. Since the fuel assembly design with fewer active rods gives a higher array k_{eff}, all subsequent calculations assume 208 fuel pins.

Having established a representative calculational model, additional reactivity calculations were performed for increased fuel assembly enrichments in the nominal main pool storage arrangement. These results are summarized in Table III and are shown graphically in Figure 3.

Also shown in Table III are final worst case k_{eff} values estimated at the 95% confidence level for the storage pool based on fuel assembly axial ^{235}U loading. These values were calculated from the following expression:

$$k_{eff}\,(WC) = k_{eff}(Nom) + 2\sigma + W + T$$

where, $k_{eff}(Nom)$ = the nominal storage array k_{eff}
σ = one standard deviation
W = Root-mean square of the worst case tolerance variations, see Table II.
T = Maximized moderator temperature variation, see Table II.

No reactivity penalty was assessed for either B_4C particle self-shielding or calculational bias defined by benchmark calculations. In the KENO IV calculational model B_4C was conservatively modeled to account for the effects of self-shielding (i.e. the boron was lumped in the center of the neutron absorber plate). With regard to calculational bias Exxon Nuclear Co. has had extensive experience using the above computer code calculational model and benchmark calculations[5] show no significant bias using these methods as described.

STORAGE POOL ACCIDENT CONDITIONS

Since the storage pool will under normal operating conditions contain ~2,000 ppm soluble boron[1] in the water, the actual k_{eff} of the storage array, based on the described pool conditions, will be ~20% lower[2] than calculated. Thus, for the accident conditions of a fuel assembly lying either across the racks or up against the outside of the racks, the storage array reactivity will remain well below the limiting value of 0.95.

In the event of a single failure in the storage pool cooling system, based on the assumed conditions presented in Section 6 of Reference 1, the bulk pool temperature would not exceed 118°F for a 36 hour normal off load. For this condition the maximum surface temperature of a fuel rod is less than 230°F providing greater than 9°F margin to local boiling.[1] Both initial (2200 MW_t) and stretch (2650 MW_t) power cores and their applicable design peaking factors have been considered in establishing limiting thermal conditions.[1] From the standpoint of neutronics, any localized fuel rod surface boiling inside the fuel assembly will have a negative effect on array reactivity (i.e. k_{eff} of the array will decrease).

CONCLUSIONS

This analysis conservatively demonstrates the reactivity of the Palisades spent fuel storage pool for fuel assembly axial ^{235}U loadings of $\leq$ 44.11 g/cm (3.80 w/o for Batch I fuel with 208 active fuel rods) to be less than 0.95 under existing assumptions of worst credible storage array conditions described in this report. Hence, at the 95% confidence level the k_{eff} of the storage pool will be $\leq$ 0.946.

The analytical efforts, the results of which are presented in Table III, were reviewed by a second party knowledgeable in the performance of criticality safety evaluations.

TABLE I

Palisades (Exxon Nuclear Batches H and I)
Fuel Assembly Parameters

	Nominal
Lattice Pitch, in.	0.550
Clad OD, in.	0.417
Clad Material	Zr-4
Clad Thickness, in.	0.028
UO_2 Pellet Diameter, in.	0.350
Pellet Density, % ρ_T	94 ± 1.5
Percent Dish	1.0
No. Active Fuel Rods	208 (Batch H) 208, 216 (Batch I)
Ave. Enrichment	3.267 (Batch H - 208 active rods) 3.260 (Batch I - 208 active rods) 3.232 (Batch I - 216 active rods)
Rod Array	15x15
Eff. Array Dimensions, in.	8.25 x 8.25
No. Guide Bars (Solid Zr)	8
No. Guide Tubes	8
GT OD, in.	0.416
GT TK, in.	0.011
No. Instrument tubes	1
IT OD, in.	0.415
IT TK, in.	0.029

TABLE II

Calculational Results of the Palisades
Spent Fuel Storage Pool Criticality Safety
Reanalysis[2] by P. Soong (NUS) in July 1978

Batch H Fuel (3.267 w/o)

Case	Description	Nominal Storage Lattice Cell k_∞	
		PDQ-7	KENO
1	Main Pool	0.8569	0.8693* ±.0042
2	Tilt Pit Pool	0.8397	0.8516 ±.0034
		Worst Case Parametrics, Δk	
3	Enrichment Variation	.0037	
4	UO_2 Density Variation	.0006	
5	B_4C Slab Width	.0008	
6	B_4C thickness and loading	.0038	
7	Variation in Spacing	.0081	
8	Storage Can Dim. Variation	.0097	
9	B_4C Slot thickness	.0045	
10	B_4C Slab Missing (1)	.0018	
11	Bow and Twist	.0165	
12	Storage Can thickness	.0061	
	TOTAL	.0228* (Root-mean square sum)	
			Other, Δk
13	Temperature Variation	.0028*	
14	Two Standard Deviations		.0084*
15	Particle Self Shielding (B_4C)		.0040*
16	Benchmark Bias		.0086*
		Total Sum of (*) Values, k_∞	
17	Maximum Credible Worst Case		0.9309

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* These Values summed to establish maximum "worst case" storage pool k_{eff}.

TABLE III

Palisades Nominal Main Pool Storage Array
k_{eff} Versus Enrichment Calculations

Fuel Assembly Parameters - See Table I
Storage Array Description - Main Pool (Nominal)
See also Figure 2

Case	Enrichment, w/o	Axial ^{235}U Loading, g/cm	Nominal KENO IV (123 group) $k_{eff} \pm \sigma$	Worst Case* k_{eff} at 95% CL
1	3.267	37.92	0.875 ± .005	0.9106
2	3.50	40.63	0.892 ± .005	0.9276
3	3.70	42.95	0.906 ± .004	0.9396
4	3.80	44.11	-	0.9460 (est.)
5	3.90	45.27	0.918 ± .004	0.[illegible]516

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* For Cases 1, 2, 3, and 5 worst case values are calculated as follows:

$$k_{eff}(WC) = k_{eff}(Nom) + 2\sigma + W + T$$

where W = 0.0228 (Root-Mean square sum of tolerance variations, see Table II).
T = 0.0028 (Maximized moderator temperature variations).

Case 4 worst case k_{eff} value taken from graph, see Figure 3.

FIGURE 1

PALISADES (EXXON NUCLEAR BATCHES I** AND H) FUEL ASSEMBLY DESIGNS

```
L L L L G L L L L L G L L L L
L L L H H H H H H H H H L L L
L L L H H P H H H P H H L L L
L H H H H H H H H H H H H H L
G H H H H H H H H H H H H H G
L H P H H H H H H H H H P H L
L H H H H H H H H H H H H H L
L H H H H H H I H H H H H H L
L H H H H H H H H H H H H H L
L H P H H H H H H H H H P H L
G H H H H H H H H H H H H H G
L H H H H H H H H H H H H H L
L L L H H P H H H P H H L L L
L L L H H H H H H H H H L L L
L L L L G L L L L L G L L L L
```

Exxon Nuclear Batch H

L - 2.90 w/o Fuel

H = 3.43 w/o Fuel

G = Guide Bar

I = Instrument Tube

P = Poison Rod Location

```
L M M M G M M M M M G M M M L
M M M H H H H H H H H H M M M
M M M H H P H H H P H H M M M
M H H H H H H H H H H H H H M
G H H H H H H H H H H H H H G
M H P H H H H H H H H H P H M
M H H H H H H H H H H H H H M
M H H H H H H I H H H H H H M
M H H H H H H H H H H H H H M
M H P H H H H H H H H H P H M
G H H H H H H H H H H H H H G
M H H H H H H H H H H H H H M
M M M H H P H H H P H H M M M
M M M H H H H H H H H H M M M
L M M M G M M M M M G M M M L
```

Exxon Nuclear Batch I

L = 2.52 w/o Fuel

M = 2.90 w/o Fuel

H = 3.43 w/o Fuel

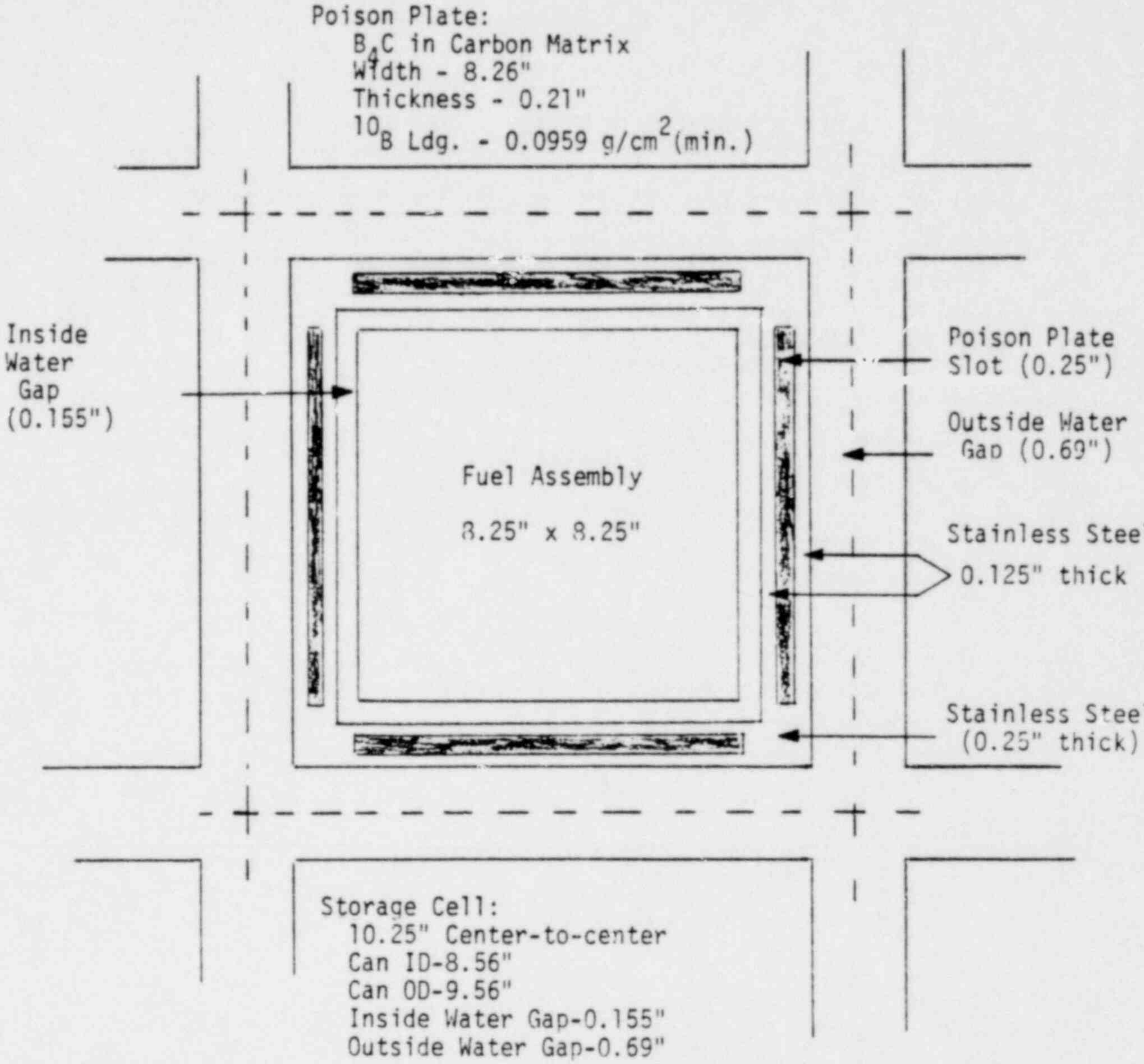
G = Guide Bar

I = Instrument Tube

P = 2.52 w/o Fuel
with 4.0 w/o Gadolinia*
or, Water Hole;
or, Poison Rod Location

* Gadolinia-bearing pin locations may vary slightly from P locations as shown.

** Correction of typographical error.



Note: With the poison plate in place a gap of 0.04" (total) is allowed in the poison plate slot.

Figure 2 Palisades Main Pool Storage Cell Nominal Arrangement

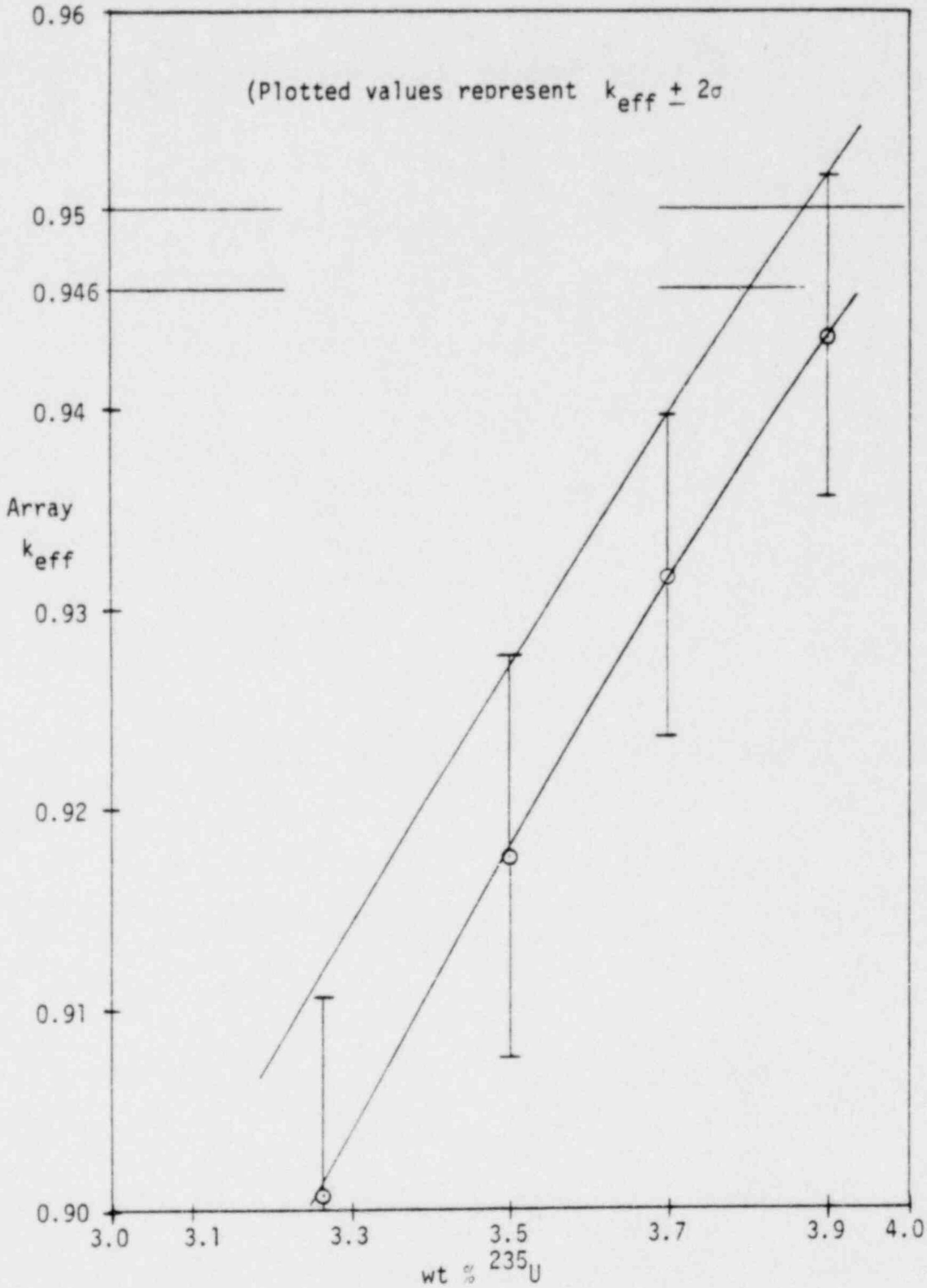


Figure 3 Palisades Worst Case Main Pool k_{eff} Versus Enrichment

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