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CRITICALITY SAFETY EVALUATION OF REGION 1 OF THE DIABLO CANYON SPENT FUEL STORAGE RACKS WITH FUEL OF 5.0% ENRICHMENT

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PACIFIC GAS AND ELECTRIC COMPANY

by

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This document conforms to the requirements of the design specification and the applicable sections of the governing codes.

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1.0 INTRODUCTION

The present study is part of an evaluation of the fuel storage facilities at the Diablo Canyon Power Plant in order to qualify the facilities for fuel of 5.0% average initial enrichment. This report addresses Region 1 of the spent fuel pool while companion reports evaluate Region 2 (HI-931077) and the new-fuel vault (HI-931075).

Region 1 of the storage rack was originally designed(1) to accommodate fresh fuel of 4.5% enrichment or spent fuel of any lower reactivity, using Boraflex and a water gap to control reactivity. Supplementary studies(2,3,4) were made to evaluate the reactivity consequences of potential gap formation(2,3) in the Boraflex poison material and to upgrade the capability of the racks to accommodate OFA fuel(4) (also referred to in the supplementary studies as Vantage 5 fuel). These previous criticality safety evaluations confirmed that:

- Westinghouse OFA fuel results in a higher reactivity than the standard fuel in Region 1,
- the maximum gaps that might credibly form in the Boraflex results in an increase in reactivity of + 0.0220 Δk, including the potential effect of a manufacturing deficiency along the periphery of the racks,
- the temperature and void coefficients of reactivity are negative, and
- the reactivity effect of eccentric fuel positioning is negative.

In the present evaluation, the analyses were extended to encompass 5.0% enriched fuel. The effect of boron burnable poison coating on some fuel pellets (<u>I</u>ntegral <u>F</u>uel <u>B</u>urnable <u>A</u>bsorber or "IFBA" rods) was also assessed. There are three possible ways to safely accommodate fuel with enrichments greater than 4.5% with assurance that the maximum k_{eff} (95% probability 95% confidence level) will be

less than the regulatory limit. These include (1) the use of IFBA rods, (2) checkerboarding of fuel assemblies (with water-filled cells or with IFBA-rod assemblies), and (3) with credit for limited fuel burnup. Credit for poison material (i.e., burnable poison) contained in the fuel rods is acceptable under the guidelines of Regulatory Guide 1.13, Rev. 2.

To assure criticality safety under all conditions and to conform to the requirements of General Design Criterion 62, "Prevention of Criticality in Fuel Storage and Handling", the definitive criteria contained in the April 14, 1978 USNRC letter and in draft Regulatory Guide 1.13 (Rev. 2) are applicable. Credit for the soluble poison normally present in the pool water is permitted under accident conditions (double contingency principle).

Acceptance criteria for the safe storage of fuel of 5.0% enrichment are the following:

- Fuel assemblies with at least 16 IFBA rods in each assembly,

or

- Fuel assemblies which have attained a minimum burnup as defined herein,

or

- Checkerboard patterns with one of the following arrangements:
    (1) Fuel assemblies in checkerboard pattern, alternating with cells filled with water (or non-fuel bearing materials), or,
    (2) Fuel assemblies in linear rows, alternating with cells filled with water (or non-fuel bearing materials), or,
    (3) Fuel assemblies in checkerboard pattern, alternating with cells containing fuel with a minimum of 32 IFBA rods.

2.0 SUMMARY AND CONCLUSIONS

The fuel storage racks in Region 1 are poisoned racks, using Boraflex absorber material. A water-gap between the steel walls of adjacent storage cells affords a flux-trap to augment reactivity control. Initial calculations with 5.0% enriched Westinghouse standard and OFA fuel (KENO-5a) confirmed that the OFA fuel gave a slightly higher reactivity in the storage rack (k_{eff} of 0.9329 without uncertainties) than the corresponding standard fuel (corresponding k_{eff} of 0.9246). This is consistent with results of the previous evaluation(4). Therefore, subsequent evaluations in Region 1 assumed the Westinghouse OFA fuel type. (Note: The Westinghouse OFA fuel type is controlling in Region 1 whereas the standard fuel type is controlling in Region 2.) Manufacturing and calculational uncertainties were assumed to remain the same as determined in the previous evaluation (±0.0068 Δk).

Calculations of Region 1 with OFA fuel of 4.5% enrichment (gave a maximum reactivity of 0.943, including potential gaps and with credit for the finite axial length of the active fuel (ie, includes neutron leakage in the axial direction). Increasing the enrichment to 5.0% increased the maximum k_{eff} to 0.964 which would not be acceptable in the absence of any IFBA rods in the assemblies. With 16 IFBA rods present in each assembly (in a conservative array), the maximum k_{eff} is 0.944 with 5.0% fuel which is below the regulatory guideline and therefore acceptable. A greater number of IFBA rods would result in lower reactivities.

In addition, fuel which has attained a burnup within the acceptable domain of Figure 1 may be safely stored in Region 1 with a calculated maximum k_{eff} of 0.9425. The data in Figure 1 is described by the following linear equation:

Minimum Burnup, MWD/KgU = -33.565 + 7.46 * E(%)

Checkerboarding of fresh fuel of 5% initial enrichment may also be safely used in the following patterns:

case	maximum k_{eff}
Checkerboard pattern of fuel assemblies (no IFBA) and water-filled cells	0.852
Checkerboard pattern of fuel assemblies (no IFBA) and assemblies with 32 IFBA rods	0.9436
Pattern with alternate rows of fuel assemblies (no IFBA) and water-filled cells	0.8948

As determined in the initial evaluation$^{(1)}$, the temperature and void coefficients of reactivity are negative and 20°C was used as the design basis temperature. Region 1 is well removed from the cask handling area and therefore is not subject to the cask drop accident. Other accident conditions were evaluated in the original analysis and found acceptable. However, the increase in enrichment capability necessitated the evaluation of the mis-loaded fuel accident in which a new-fuel assembly of 5.0% enrichment without IFBA rods is accidentally loaded into a Region 1 cell intended to receive either an assembly with IFBA rods or fuel of acceptable burnup (Figure 1). The analysis indicated that the k_{eff} would be increased by only 0.0015 Δk (to 0.946) and would therefore still be acceptable.

Based upon the calculations reported here (see Table 1), it is concluded that fuel of 5.0% initial enrichment is acceptable for storage in Region 1 of the Diablo Canyon storage pool, provided that one of the criteria defined above are satisfied.

3.0 CRITICALITY SAFETY ANALYSES

3.1 Fuel Assembly Specifications

The reference fuel assembly used for the analyses is the Westinghouse 17 x 17 OFA fuel - the same as that used in the previous analyses(4). For standard fuel (also considered in Reference 4), calculations confirm that, in Region 1 with water-gaps between cells, standard fuel results in a lower reactivity, k_{eff} of 0.9248, than the OFA fuel with a corresponding k_{eff} of 0.9329 (both as calculated without uncertainties or IFBA rods). Therefore, the OFA fuel is controlling as was found in the previous study. In region 2 (where there is no water-gap) the standard fuel exhibits the higher reactivity.

Table 2 attached lists the design specifications for the fuel used in the analyses. For the higher enriched fuel, IFBA coating is used on the pellets of certain rods of the assemblies. Characteristics of the boron-10 coating are also listed in Table 2 and discussed in Section 3.4.2 below.

An axial blanket of natural UO_2 would result in slightly lower and more conservative reactivities. Fuel enrichments, as used in this report, refer to the enriched fuel zone in the assembly without consideration of any axial blankets that might be present.

3.2 Storage Rack Specifications

The nominal spent fuel storage cell used for the criticality analyses of Region 1 storage cells is shown in Figure 2. The rack is composed of Boraflex absorber material on the outside of a 0.080-inch thick stainless steel box. The fuel assemblies are centrally located in each storage cell on a nominal lattice spacing of 10.930 inches, with a 1.786 ± 0.050 inch water flux-trap between the two (thermal-neutron opaque) Boraflex absorber panels. The

Boraflex absorber has a nominal thickness of 0.047 ± 0.007 inch and a nominal B-10 areal density of 0.0148 ± 0.0028 g/cm^2 (including the tolerance in thickness). At any point where the minimum thickness and B-10 concentration may coincide, the B-10 loading would be 0.012 g/cm^2 minimum.

3.3 Manufacturing Tolerances and Uncertainties

The small reactivity increments associated with manufacturing tolerances developed in the previous evaluation(4) were assumed to remain applicable. The higher 5.0% enrichment would result in a slightly smaller penalty due to the tolerance in enrichment, which, for conservatism, was neglected. The effect of any eccentric positioning of the assemblies in the cells is negative and is therefore unaffected by the increased enrichment.

Assuming a 10% tolerance on the average B-10 loading in the IFBA coating, calculations indicate an uncertainty in reactivity of ±0.0015. This uncertainty is included with the uncertainties previously determined. Table 3 lists the manufacturing tolerance effects and includes the calculational uncertainties, yielding a total uncertainty of ± 0.0070 Δk.

3.4 Calculational Methodology

3.4.1 Computer Codes

The principal method of analysis was the NITAWL-KENO(5) code package, a three dimensional Monte Carlo code package, using the 27-group SCALE* cross-section library. Supplementary calculations were made with the CASMO-3(6) code. The calculational methods used

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* SCALE is an acronym for Standardized Computer Analyses for Licensing Evaluation, developed for the USNRC by the Oak Ridge National Laboratory.

for the present evaluation are comparable to those used in the original calculations, differing only in that updated versions of the codes were used, ie, KENO-5a rather than KENO-4 and CASMO-3 rather than CASMO-2E. Results of these codes are not significantly different from those of the earlier versions, and benchmarking of the updated codes resulted in a bias of 0.0000 ± 0.0024 for CASMO-3 and 0.0101 ± 0.0018 for NITAWL-KENO-5a (at the 95% probability, 95% confidence level(7)). A summary of the detailed bench-marking analyses will be included in Appendix A.

In the geometric model used in the calculations, each fuel rod and its cladding were described explicitly in both the KENO-5a and CASMO-3 models. Reflecting boundary conditions (zero neutron current) were used in the radial direction which has the effect of creating an infinite array of storage cells in X-Y directions. In the KENO-5a model, the actual fuel assembly length was used in the axial direction, assuming thick (30 cm) water reflectors top and bottom. Monte Carlo (KENO-5a) calculations inherently include a statistical uncertainty due to the random nature of neutron tracking. To minimize the statistical uncertainty of the KENO-calculated reactivity, a minimum of 500,000 neutron histories in 1000 generations of 500 neutrons each, were accumulated in each calculation.

3.4.2 Integral Fuel Burnable Absorber (IFBA) Rods

For enrichments above 4.5%, IFBA rods are necessary to limit the maximum reactivity to less than 0.95. For Diablo Canyon, the IFBA rods contain 2.25 mg B-10/inch, assumed to be in the central 10 feet of the active fuel length (ie, 12-inch cutback top and bottom). This is believed to be a conservative assumption encompassing current and expected fuel assembly designs.

Several arrangements of IFBA rods in an assembly are possible. In general, clustering of IFBA rods more toward the outer fuel rods

yields the higher reactivity and is therefore the more conservative configuration. The boron-10 in the IFBA coating has a higher neutron absorption cross-section than the fuel and will therefore burnout somewhat faster than the fuel depending upon the number of IFBA rods. Figure 3 shows results of burnup calculations for 0, 64, and 104 IFBA rods per assembly. The two 64-IFBA rod cases represent different loading patterns of IFBA rods. With 104 IFBA rods, the reactivity increases with burnup to a maximum at about 10 MWD/KgU burnup. However, with 64 IFBA rods the peak reactivity is very nearly that at the beginning of life. For cases with fewer number of IFBA rods, the peak reactivity will occur at zero burnup.

Calculations were made for the configurations illustrated in Figure 4 for 16 and 32 IFBA rods per assembly where the maximum reactivity occurs at zero fuel burnup. The results, listed below, show that 16 IFBA rods per assembly is adequate to assure a k_{eff} less than 0.95 for the conservative configuration of IFBA rod locations.

	Maximum k_{eff} (5% E Fuel)	
CASE	Conservative	Nominal
16 IFBA Rods	0.9444	0.9362
32 IFBA Rods	0.9218	0.9158

Initial fuel enrichments between 4.5% and 5.0% enrichment will require less than 16 IFBA rods, although it is unlikely that less than 16 IFBA rods would be used. Linear interpolation between 0 IFBA rods at 4.5% enrichment and 16 IFBA rods at 5.0% enrichment will give an acceptable estimate of the number of IFBA rods required for intermediate enrichments.

4.0 REFERENCES

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4. S. E. Turner, "Criticality Safety Analyses For Vantage 5 Fuel Assemblies in the Spent Fuel Storage Racks of the Diablo Canyon Nuclear Power Plant", Holtec International, Report HI-88306, October 1988.

5. R.M. Westfall, et. al., "NITAWL-S: Scale System Module for Performing Resonance Shielding and Working Library Production" in SCALE: A Modular Code System for performing Standardized Computer Analyses for Licensing Evaluation,, NUREG/CR-0200, 1979.

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6. A. Ahlin, M. Edenius, H. Haggblom, "CASMO - A Fuel Assembly Burnup Program," AE-RF-76-4158, Studsvik report (proprietary).

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   "CASMO-3 A Fuel Assembly Burnup Program,. Users Manual", Studsvik/NFA-87/7, Studsvik Energitechnik AB, November 1986

   M. Edenius and A. Ahlin, "CASMO-3: New Features, Benchmarking, and Advanced Applications", Nuclear Science and Engineering, 100, 342-351, (1988)

7. M.G. Natrella, Experimental Statistics, National Bureau of Standards, Handbook 91, August 1963.

Table 1

SUMMARY OF CRITICALITY SAFETY ANALYSES
REGION 1 STORAGE RACKS

Type of Fuel (Westinghouse)	OFA	
Fuel Enrichment, wt% U-235	4.50	5.00
Reference Temperature, °C	20	20
Number IFBA Rods	0	16
Reference k∞ (KENO-5a)	0.9030	0.9051
Calculational Bias, Δk(1)	0.0101	0.0101
Boraflex Gaps	0.0220	0.0220
Uncertainties(2)	±0.0068	0.0070(3)
Total	0.9365 ±0.0068	0.9386 ±0.0077
Maximum Reactivity (k∞)	0.9433	0.9444

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(1) Appendix A

(2) Section 3.3 and Table 3

(3) Includes uncertainty on B-10 loading in IFBA rods.

Table 2

DESIGN BASIS FUEL ASSEMBLY SPECIFICATIONS

FUEL ROD DATA	OFA	STANDARD
Outside diameter, in.	0.360	0.374
Cladding inside diameter, in.	0.315	0.329
Cladding material	Zr-4	
Stack density, g UO_2/cc	10.41 ± 0.20	
Pellet diameter, in.	0.3088	0.3225
Maximum enrichment, wt % U-235(1)	5.00 ± 0.05	
IFBA Rods		
IFBA Rod Loading, mg/inch	-	2.25
Axial Length of IFBA Coating, ft.	-	10
IFBA Cutback Top and Bottom, inches	-	12
FUEL ASSEMBLY DATA		
Fuel rod array	17x17	
Number of fuel rods	264	
Fuel rod pitch, in.	0.496	
Number of control rod guide and instrument thimbles	25	
Thimble O.D., in. (nominal)	0.474(2)	0.482
Thimble I.D., in. (nominal)	0.442(2)	0.450

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(1) Enriched fuel zone, excluding any axial blanket.

(2) Alternative Thimble Dimensions of 0.440" ID and 0.476" OD have a negligible effect on reactivity.

Table 3

REACTIVITY EFFECTS OF MANUFACTURING TOLERANCE AND CALCULATIONAL UNCERTAINTIES (REGION 1)

Quantity	Δk_∞	Reference
Uncertainty in Bias	±0.0018	Appendix A
B-10 Concentration	±0.0013	Reference 2
Boraflex Thickness	±0.0042	Reference 2
Boraflex Width	±0.0020	Reference 2
Inner Box Dimension	±0.0006	Reference 2
Water Gap Thickness	±0.0034	Reference 2
SS Thickness	±0.0006	Reference 2
Pellet Diameter	±0.0004	Reference 2
Fuel Enrichment	±0.0020	Reference 2
Fuel Density	±0.0018	Reference 2
B-10 Loading in IFBA Rods	±0.0015	Section 3.3
Eccentric Position	Negative	Section 3.3
Statistical combination(1) of uncertainties	±0.0070(2)	

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(1) Square root of sum of squares of all independent tolerance effects.

(2) Without IFBA rods, total uncertainty is ±0.0068

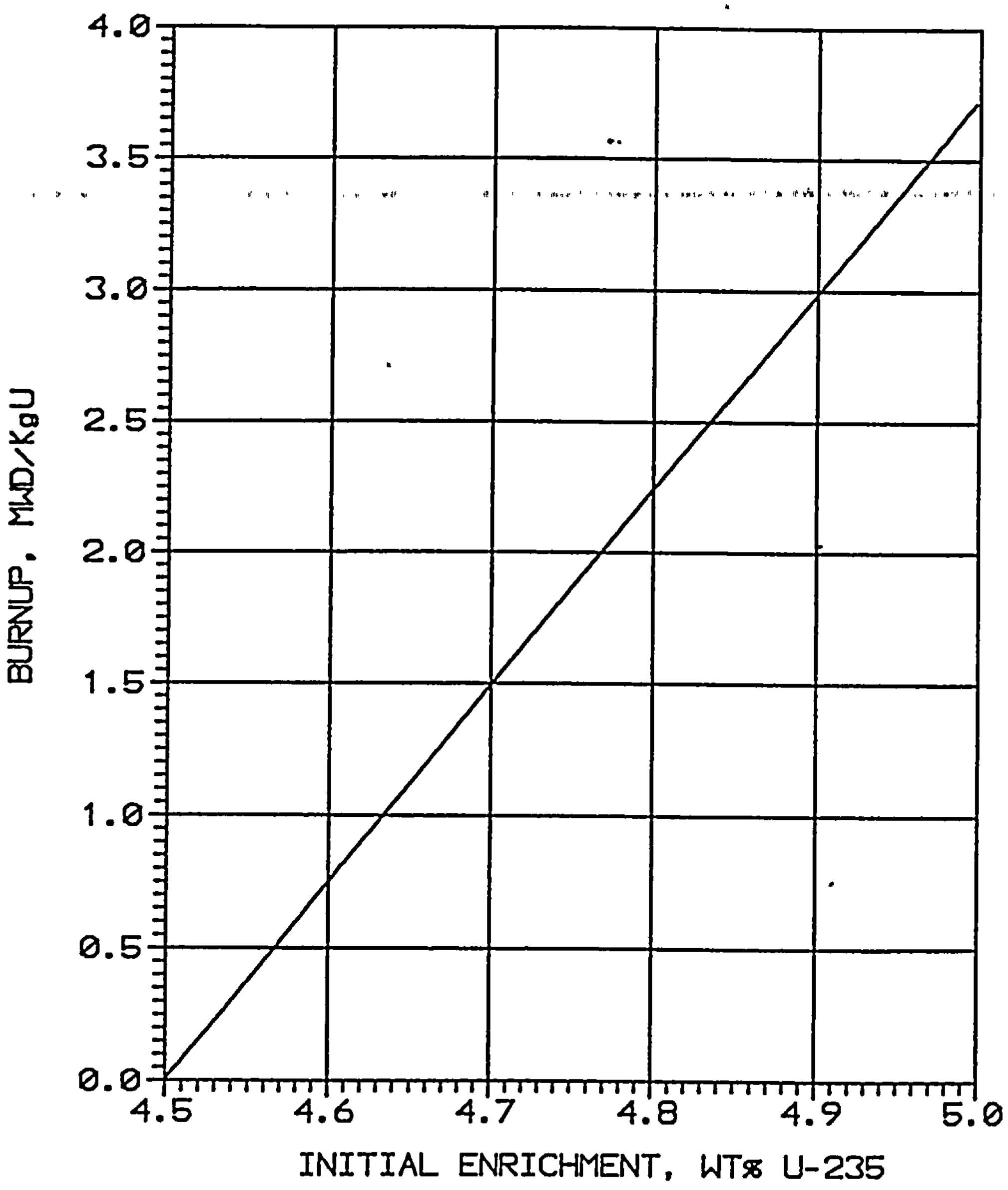


FIG. 1 ACCEPTABLE BURNUP DOMAIN IN REGION 1 (WITHOUT IFBA RODS)

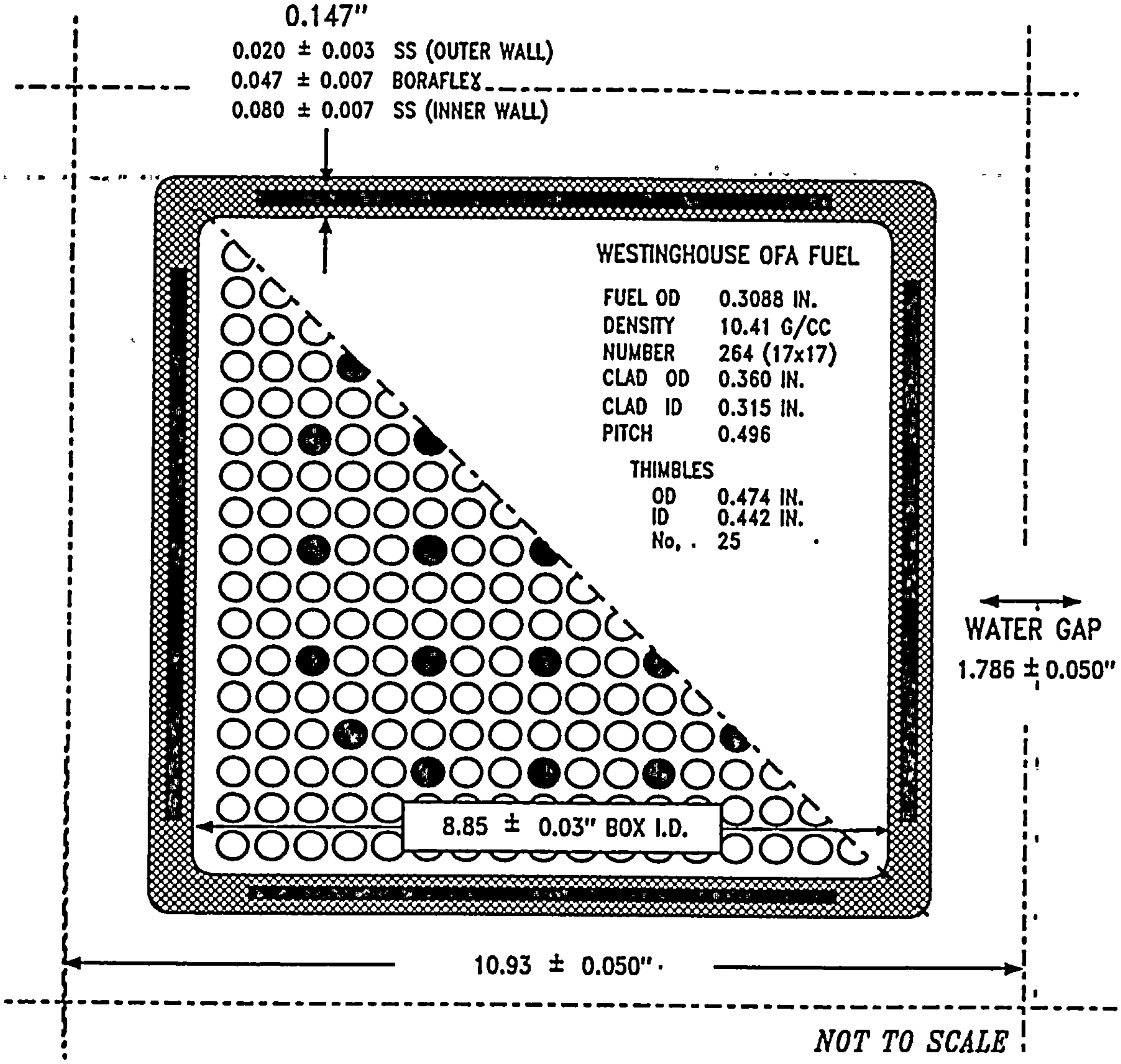


FIG. 2 REGION 1 FUEL STORAGE CELL

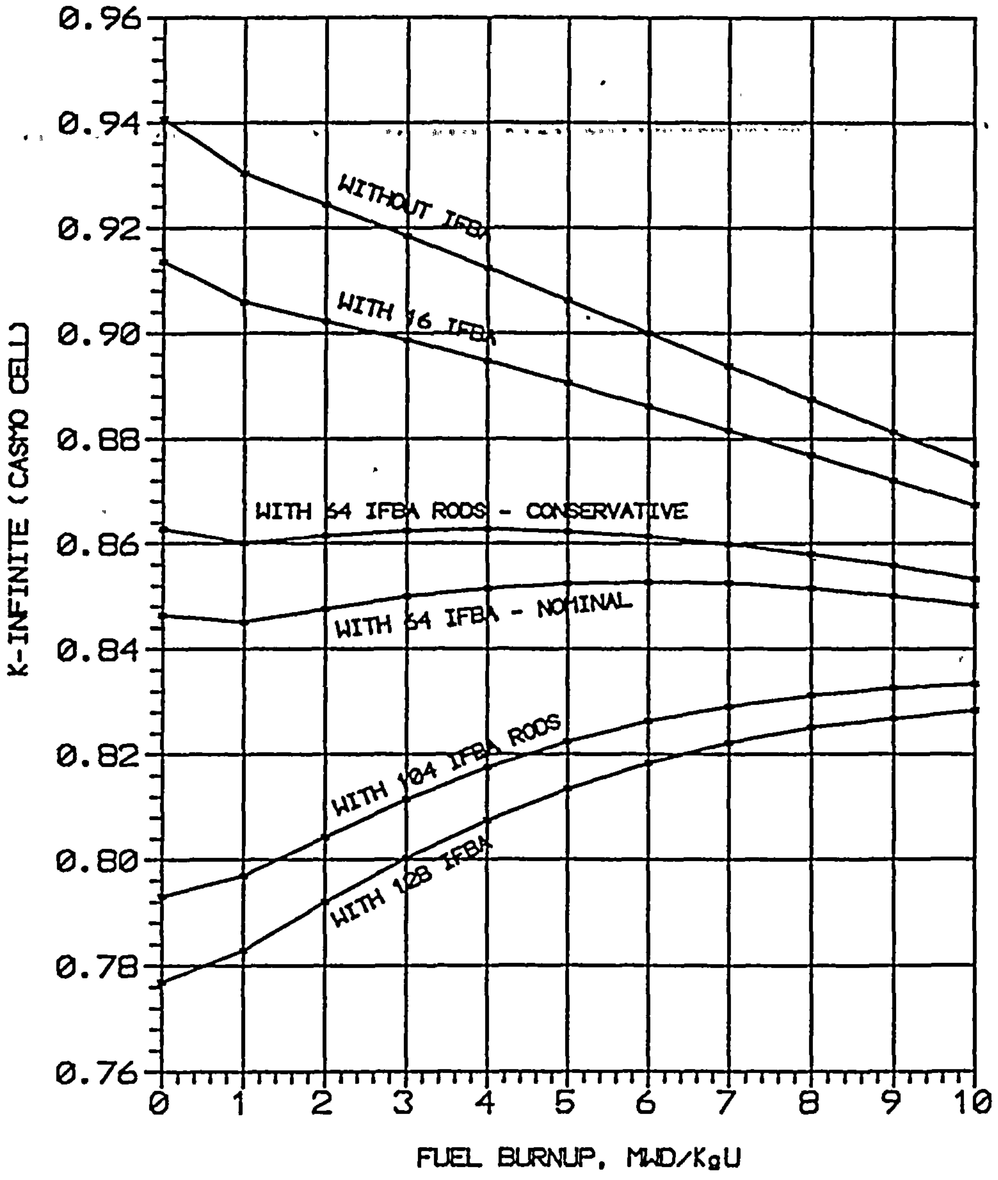
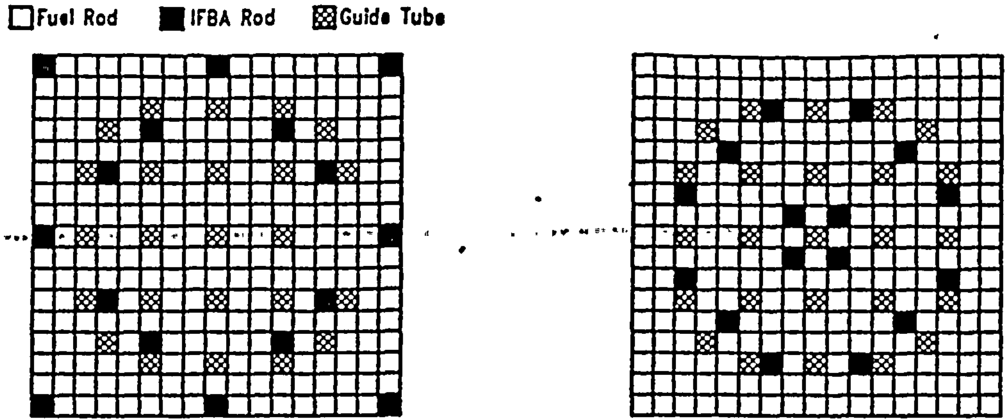
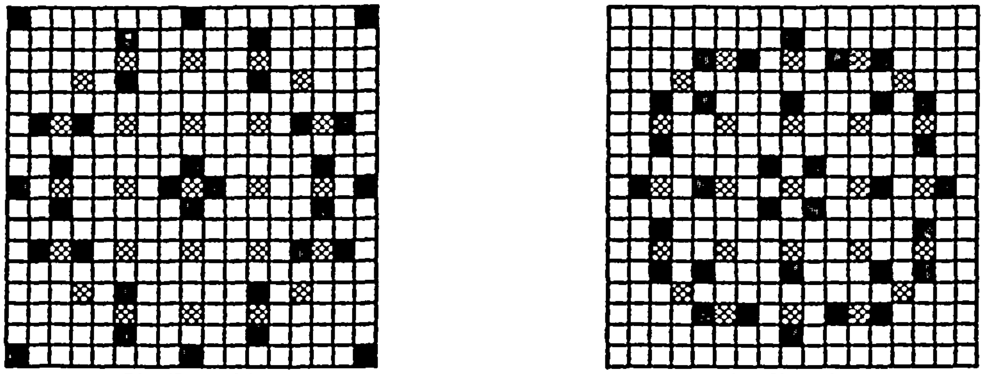


FIG. 3 k_{eff} Dependence on Fuel Burnup with IFBA Rods



16 IFBA RODS (CONSERVATIVE)

16 IFBA RODS (NOMINAL)



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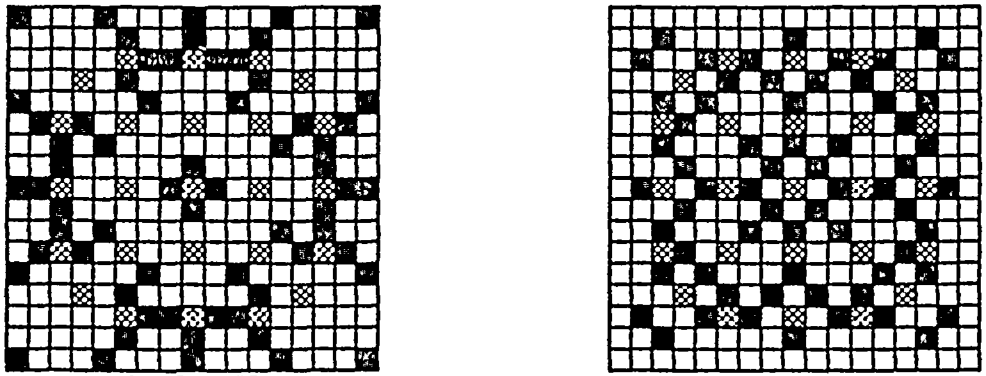
32 IFBA RODS (NOMINAL)



64 IFBA RODS (CONSERVATIVE)

64 IFBA RODS (NOMINAL)

FIG. 4 IFBA Rod Configurations

ATTACHMENT F

CRITICALITY SAFETY EVALUATION OF REGION 2 OF THE DIABLO CANYON SPENT FUEL STORAGE RACKS WITH FUEL OF 5.0% ENRICHMENT