CRITICALITY ANALYSIS OF THE SOUTH TEXAS UNITS 1 & 2 FRESH FUEL RACKS

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1.0 INTRODUCTION

The South Texas fresh fuel rack design described herein employs an existing array of unpoisoned racks, which will be analyzed for the storage of Westinghouse 17x17 STD, XL, OFA, and VANTAGE 5 fuel assemblies. This analysis will show that Westinghouse 17x17 STD, XL, OFA, and VANTAGE 5 fuel assemblies with nominal enrichments up to 4.5 w/o U^{235} can be stored in the fresh fuel rack array utilizing every storage location.

The fresh fuel rack analysis is based on maintaining $K_{eff} \leq 0.95$ for storage of Westinghouse 17x17 STD, XL, OFA, and VANTAGE 5 fuel with nominal enrichments up to 4.5 w/o U^{235} under full water density and optimum moderation conditions.

1.1 DESIGN DESCRIPTION

The fresh fuel rack storage cell design is depicted schematically in Figure 1 on page 10. The fresh fuel rack layout as used in the optimum moderation analysis is shown in Figure 2 on page 11.

1.2 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.

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 57.3-1983 and in Reference 1.

2.0 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 spent fuel storage rack uses the AMPX[2, 3] system of codes for cross-section generation and KENO IV[4] for reactivity determination.

The 227 energy group cross-section library that is the common starting point for all cross-sections used for the benchmarks and the storage rack analysis is generated from ENDF/B-V[2] data. The NITAWL[3] program 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[3] program 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 (B4C, steel, water, etc) 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 on page 8 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 than 0.0018 Δk.

3.0 CRITICALITY ANALYSIS OF FRESH FUEL RACKS

Since the fresh fuel racks are maintained in a dry condition, the criticality analysis will show that the rack K_{eff} is less than 0.95 for the full water density and low water density (optimum moderation) conditions. The full density and low density optimum moderation scenarios are accident situations in which no credit can be taken for soluble boron.

The following assumptions were used to develop the KENO model for the storage of fresh fuel in the fresh fuel racks under full density and low density optimum moderation conditions:

1. The fuel assembly contains the highest enrichment authorized, is at its most reactive point in life, and no credit is taken for any natural enrichment axial blankets or burnable absorbers in the fuel rods.

2. All fuel rods contain uranium dioxide at an enrichment of 4.50 w/o (nominal) and 4.55 w/o ("worst case") U^{235}.

3. All fuel rods are modelled with a fuel stack height which is infinitely long for the full density moderation scenario and 168 inches long for the optimum moderation scenario.

4. All fuel pellets are modelled at 96 percent theoretical density without dishing or chamfers to bound the maximum fuel assembly loading.

5. No credit is taken for any U^{234} or U^{236} in the fuel.

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

3.1 FULL DENSITY MODERATION ANALYSIS

In the KENO model for the full density moderation analysis, 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. The fuel array is infinite in lateral and axial extent which precludes any neutron leakage from the array. Figure 1 on page 10 depicts the fresh fuel rack cell nominal dimensions.

The Westinghouse 17x17 OFA fuel assembly yields a larger K_{eff} (by approximately 1 to 2 %$\Delta k/k$) than does the Westinghouse 17x17 STD/XL fuel assembly under full density moderation conditions when both fuel assemblies have the same U^{235} enrichment and fuel stack height. The VANTAGE 5 fuel design parameters relevant to the criticality analysis are the same as the OFA parameters and will yield equivalent results. Thus, for the full density optimum moderation scenario, an infinitely long Westinghouse 17x17 OFA fuel assembly was analyzed (see Table 2 on page 9 for fuel parameters).

The KENO calculation for the nominal case resulted in a K_{eff} of 0.9044 with a 95 percent probability/95 percent confidence level uncertainty of ±0.0082.

The maximum K_{eff} under normal conditions arises from consideration of mechanical and material thickness tolerances resulting from the manufacturing process. Due to the relatively large cell spacing, the small tolerances on the cell I.D. and center-to-center spacing are not considered since they will have an insignificant effect on the fuel rack reactivity. However, the sheet metal thickness is reduced to its minimum tolerance. The assemblies are symmetrically positioned within the storage cells since the relatively large cell-to-cell spacing causes the reactivity effects of asymmetric assembly positioning to be insignificant. Furthermore, fuel enrichment is assumed to be 4.55 w/o U^{235} to conservatively account for enrichment variability. Thus, the most conservative, or "worst case" KENO model of the fresh fuel storage racks contains the minimum sheet metal thickness with symmetrically placed fuel assemblies at 4.55 w/o U^{235}.

Based on the analysis described above, the following equation is used to develop the maximum K_{eff} for the South Texas fresh fuel storage racks:

$$K_{eff} = K_{worst} + B_{method} + \sqrt{[(ks)^2_{worst} + (ks)^2_{method}]}$$

where:

K_{worst}	=	worst case KENO K_{eff} with full density water
B_{method}	=	method bias determined from benchmark critical comparisons
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:

$$K_{eff} = 0.9080 + 0.0083 + \sqrt{[(0.0087)^2 + (0.0018)^2]} = 0.9252$$

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

3.2 LOW DENSITY OPTIMUM MODERATION ANALYSIS

For the low density optimum moderation analysis, the fuel array is finite in all directions. The "worst case" cell configuration from the full density analysis is used in modelling the actual fresh fuel rack array which is depicted in Figure 2 on page 11. Concrete walls and floor are modelled. Under low water density conditions, the presence of concrete is conservative because neutrons are reflected back into the fuel array more efficiently than they would be with just low density water. The area above the fresh fuel rack is filled with water at the optimum moderation density.

The Westinghouse 17x17 STD/XL fuel assembly was analyzed in the model with a fuel stack height of 168 inches (see Table 2 on page 9 for fuel parameters). The STD/XL fuel assembly is more reactive than the 17x17 OFA or VANTAGE 5 fuel assembly (by approximately 0.5 to 1.5 %Δk/k) under low moderator density conditions when the fuel assemblies have the same U^{235} enrichment and fuel stack height. This is because the STD/XL fuel assembly contains a higher uranium loading than the OFA assembly, and when optimum moderation conditions are present, higher loadings result in higher reactivity.

Analysis of the South Texas fresh fuel racks has shown that the maximum rack K_{eff} under low density moderation conditions occurs at 0.043 gm/cm^3 water density. The K_{eff} of the South Texas fresh rack at 0.043 gm/cm^3 water density is 0.9190 with a 95 percent probability and 95 percent confidence level uncertainty of ±0.0086. Figure 3 on page 12 shows the fresh fuel rack reactivity as a function of water density.

Based on the analysis described above, the following equation is used to develop the maximum K_{eff} for the South Texas fresh fuel storage racks under low density optimum moderation conditions:

$$K_{eff} = K_{base} + B_{method} + \sqrt{[(ks)^2_{base} + (ks)^2_{method}]}$$

where:

K_{base}	=	maximum K_{eff} with optimum moderation
B_{method}	=	method bias determined from benchmark critical comparisons
ks_{base}	=	95/95 uncertainty in the maximum K_{eff}
ks_{method}	=	95/95 uncertainty in the method bias

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

$$K_{eff} = 0.9190 + 0.0083 + \sqrt{[(0.0086)^2 + (0.0018)^2]} = 0.9361$$

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

3.3 POSTULATED ACCIDENTS

Under normal conditions, the fresh fuel racks are maintained in a dry environment. The introduction of water into the fresh fuel rack area is the worst case accident scenario. The full density and low density optimum moderation cases are bounding accident situations which result in the most conservative fuel rack K_{eff}.

Other accidents can be postulated which would cause some reactivity increase (i.e., dropping a fuel assembly between the rack and wall or on top of the rack). For these other 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 these other accident conditions, the absence of a moderator in the fresh fuel storage racks can be assumed as a realistic initial condition since assuming its presence would be a second unlikely event.

The maximum reactivity increase for postulated accidents (such as those mentioned above) will be less than 10 %$\Delta k/k$. Furthermore, the normal, dry fresh fuel rack reactivity is less than 0.70. As a result, for postulated accidents, the maximum rack K_{eff} will be less than 0.95.

4.0 ACCEPTANCE CRITERION FOR CRITICALITY

The neutron multiplication factor in the fresh fuel racks 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 N16.9-1975, "Validation of Calculational Methods for Nuclear Criticality Safety," NRC Standard Review Plan, Section 9.1.2, "Spent Fuel Storage"; and ANSI 57.3-1983, "Design Requirements for New Fuel Storage Facilities at Light Water Reactor Plants."

Table 1. Benchmark Critical Experiments [5,6]

	General Description	Enrichment w/o U235	Reflector	Separating Material	Soluble Boron ppm	Keff
1.	UO2 rod lattice	2.46	water	water	0	0.9857 +/- .0028
2.	UO2 rod lattice	2.46	water	water	1037	0.9906 +/- .0018
3.	UO2 rod lattice	2.46	water	water	764	0.9896 +/- .0015
4.	UO2 rod lattice	2.46	water	B4C pins	0	0.9914 +/- .0025
5.	UO2 rod lattice	2.46	water	B4C pins	0	0.9891 +/- .0026
6.	UO2 rod lattice	2.46	water	B4C pins	0	0.9955 +/- .0020
7.	UO2 rod lattice	2.46	water	B4C pins	0	0.9889 +/- .0027
8.	UO2 rod lattice	2.46	water	B4C pins	0	0.9983 +/- .0025
9.	UO2 rod lattice	2.46	water	water	0	0.9931 +/- .0028
10.	UO2 rod lattice	2.46	water	water	143	0.9928 +/- .0025
11.	UO2 rod lattice	2.46	water	stainless steel	514	0.9967 +/- .0020
12.	UO2 rod lattice	2.46	water	stainless steel	217	0.9943 +/- .0019
13.	UO2 rod lattice	2.46	water	borated aluminum	15	0.9892 +/- .0023
14.	UO2 rod lattice	2.46	water	borated aluminum	92	0.9884 +/- .0023
15.	UO2 rod lattice	2.46	water	borated aluminum	395	0.9832 +/- .0021
16.	UO2 rod lattice	2.46	water	borated aluminum	121	0.9848 +/- .0024
17.	UO2 rod lattice	2.46	water	borated aluminum	487	0.9895 +/- .0020
18.	UO2 rod lattice	2.46	water	borated aluminum	197	0.9885 +/- .0022
19.	UO2 rod lattice	2.46	water	borated aluminum	634	0.9921 +/- .0019
20.	UO2 rod lattice	2.46	water	borated aluminum	320	0.9920 +/- .0020
21.	UO2 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	0.9976 +/- .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	0.9928 +/- .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 & VANTAGE 5	W 17x17 STD/XL
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	0.0	0.0
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

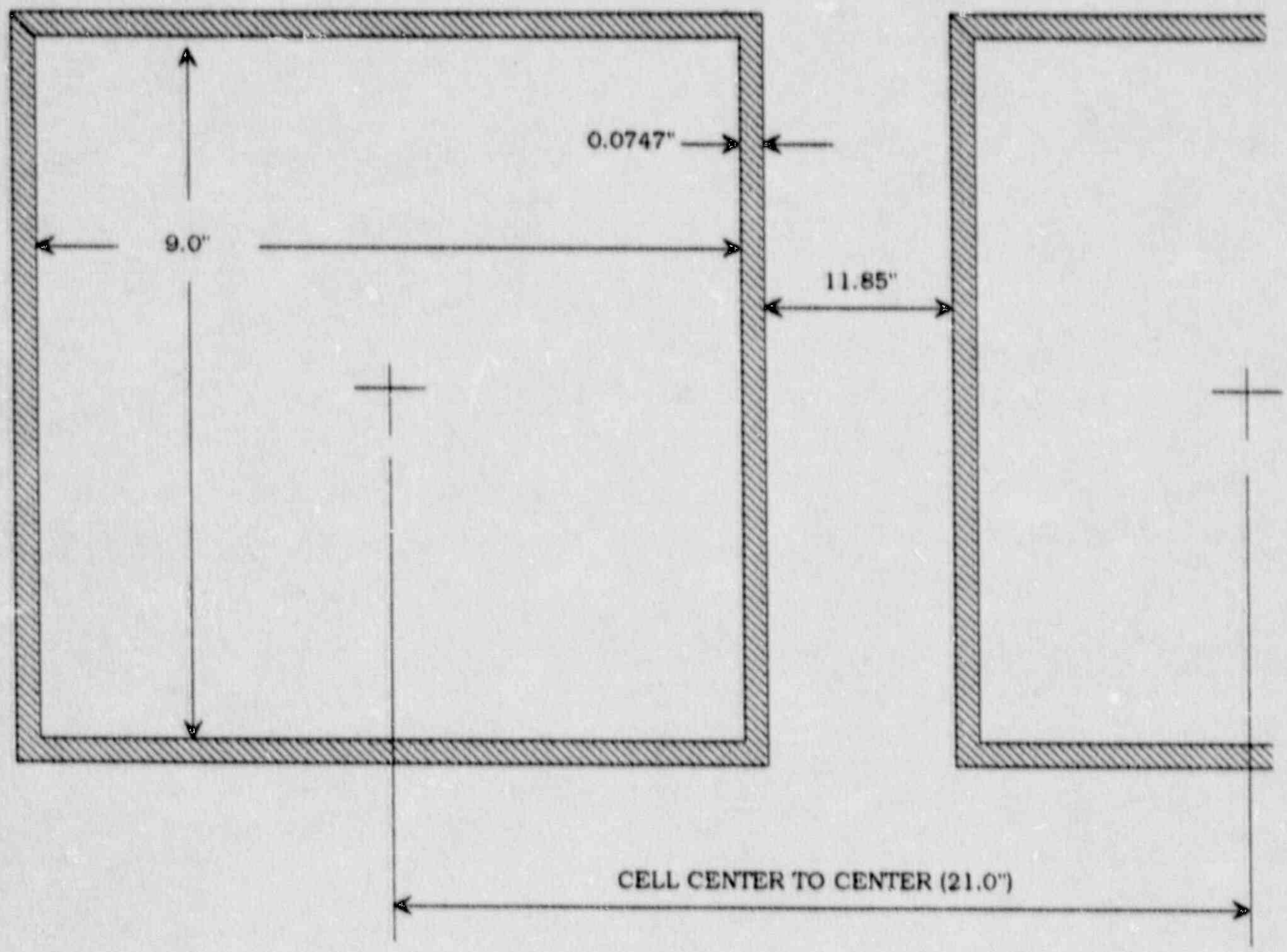
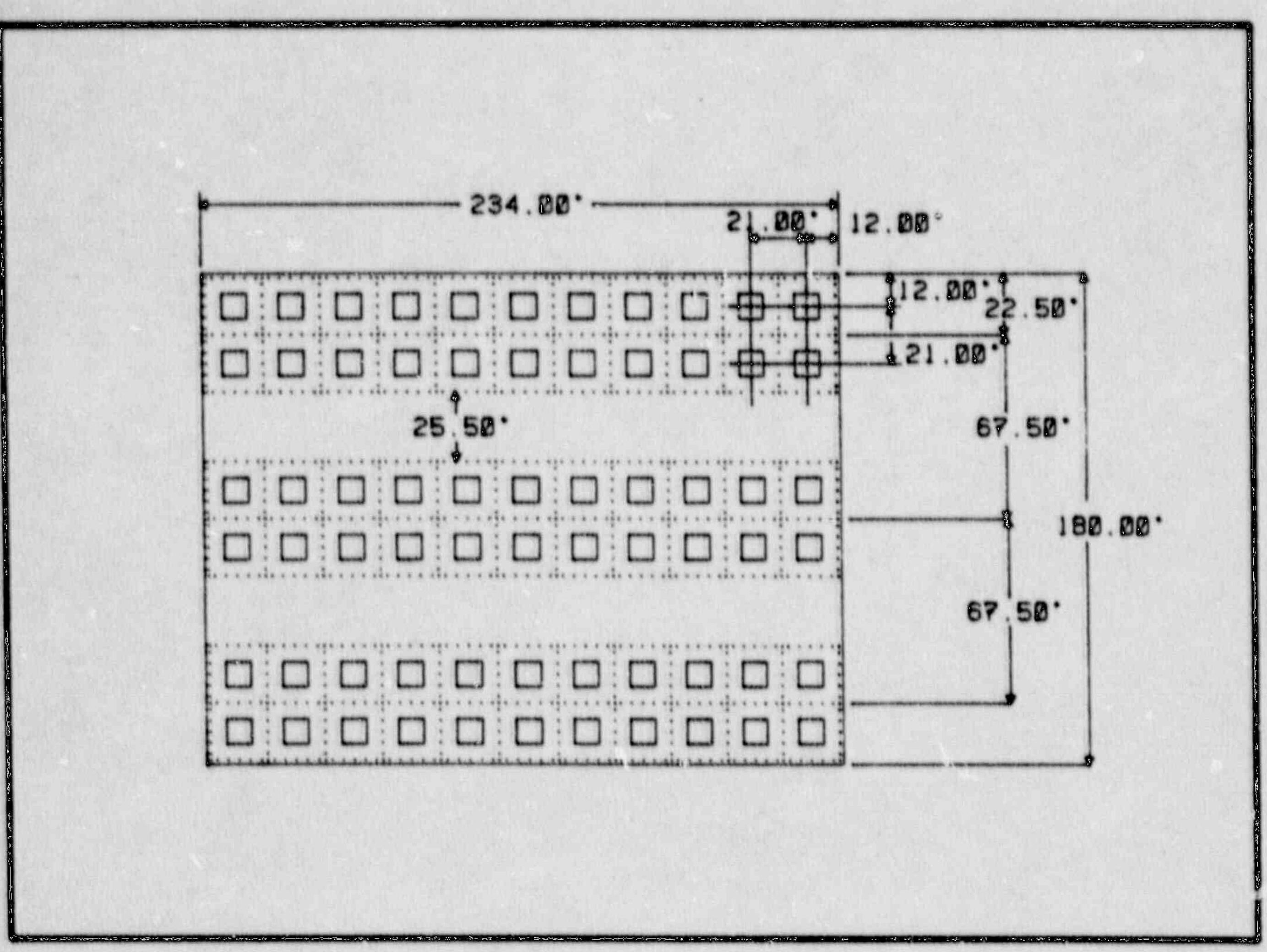
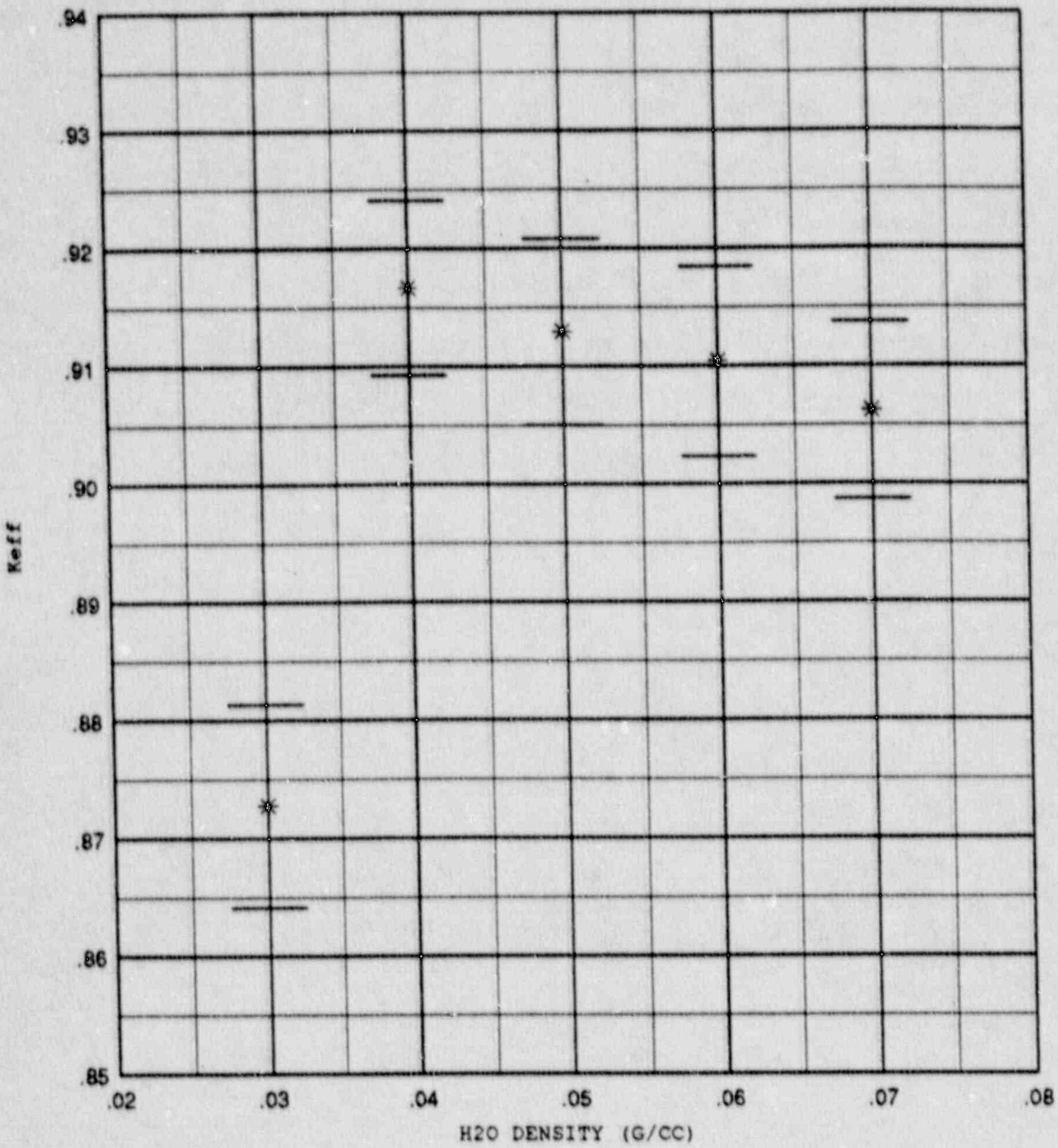


Figure 1. South Texas Fresh Fuel Storage Cell Nominal Dimensions



BASIC FUEL CELL 21" X 21"

Figure 2. South Texas Fresh Fuel Storage Array Layout



Note: Error bars represent 95/95 tolerance about the keno calculated Keff

Figure 3. Sensitivity of K_{eff} to Water Density in the South Texas Fresh Fuel Storage Racks

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ATTACHMENT 4
MARK-UP OF THE UPDATED
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products accumulate, this restriction is relaxed. However, for the reference final core design described in this chapter, no such withdrawal limit is required.

Ejected rod worths are given in Section 15.4.8 for several different conditions.

Allowable deviations due to misaligned control rods are discussed in the Technical Specifications.

A representative calculation for two banks of control rods withdrawn simultaneously (rod withdrawal accident) is given on Figure 4.3-37.

Calculation of control rod reactivity worth versus time following reactor trip involves both control rod velocity and differential reactivity worth. The rod position versus time of travel after rod release assumed is given on Figure 4.3-38. For nuclear design purposes, the reactivity worth versus rod position is calculated by a series of steady-state calculations at various control rod positions assuming all rods out of the core as the initial position in order to minimize the initial reactivity insertion rate. Also, to be conservative, the rod of highest worth is assumed stuck out of the core and the flux distribution (and thus reactivity importance) is assumed to be skewed to the bottom of the core. The result of these calculations is shown on Figure 4.3-39.

The shutdown groups provide additional negative reactivity to assure an adequate shutdown margin. Shutdown margin is defined as the amount by which the core would be subcritical at hot shutdown if all RCCAs are tripped, but assuming that the highest worth assembly remains fully withdrawn and no changes in xenon or boron take place. The loss of control rod worth due to the material irradiation is negligible since only bank D may be in the core under normal operating conditions.

The values given in Table 4.3-3 show that the available reactivity in withdrawn RCCAs provides the design bases minimum shutdown margin allowing for the highest worth cluster to be at its fully withdrawn position. An allowance for the uncertainty in the calculated worth of N-1 rods is made before determination of the shutdown margin.

4.3.2.6 <u>Criticality of the Reactor During Refueling and Criticality of Fuel Assemblies</u>. The basis for maintaining the reactor subcritical during refueling is presented in Section 4.3.1.5 and a discussion of how control requirements are met is given in Section 4.3.2.4 and 4.3.2.5.

Criticality of fuel assemblies outside the reactor is precluded by adequate design of fuel transfer and fuel storage facilities and by administrative control procedures. This section identifies those criteria important to criticality safety analyses.

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4.3.2.6.1 <u>New Fuel Storage</u>: For Unit 1, new fuel is stored in 21-in., center-to-center racks in the new fuel storage facilities in a dry condition. Prior to initial core loading, new fuel was stored wet in the 14-in., center-to-center spent fuel racks. For subsequent refuelings, new fuel may also be stored in the flooded condition in the 10.95-in. center-to-center high density spent fuel racks. For the flooded condition (with unborated water assuming new fuel of the highest antici ated enrichment [4.5 weight percent uranium-235] in the new or high density spent fuel racks) the effective multiplication factor does not exceed 0.95. For the normally dry condition in the new fuel storage racks, the effective multiplication facto. does not exceed 0.98 (with fuel of the highest anticipated enrichment in place and assuming possible sources of moderation such as aqueous foam or mist).

For Unit 2, new fuel is stored in 21-in., center-to-center racks in the new fuel storage facilities in a dry condition. Prior to initial core loading, new fuel can be stored dry in the 10.95-inch-nominal, center-to-center high density spent fuel racks. For subsequent refuelings, new fuel may also be stored in the flooded condition in the 10.95-in., center-to-center high density spent fuel racks. For the normally dry or flooded condition (with unborated water assuming new fuel of the highest anticipated enrichment [4.5 weight percent uranium-235] in the high density spent fuel racks), the effective multiplication factor does not exceed 0.95. For the new fuel racks the effective multiplication factors for the dry and flooded conditions do not exceed 0.98 and 0.95, respectively, as discussed above for Unit 1.

In the analysis for the storage facilities, the fuel assemblies are assumed to be in their most reactive condition, namely fresh or undepleted and with no control rods or removable neutron absorbers present. Credit is taken for the inherent neutron-absorbing effect of the construction materials of the racks. Assemblies cannot be closer together than the design separation provided by the storage facility, except in special cases such as in fuel shipping containers where analyses are carried out to establish the acceptability of the design. The mechanical integrity of the fuel assembly is assumed.

4.3.2.6.2 Spent Fuel Storage:

4.3.2.6.2.1 Unit 1 (Interim Design) - The following describes wet spent fuel storage in the spent fuel pool in the 14-in. racks in the event spent fuel storage is required prior to their replacement with the 9.15-inch- and 10.95-inch-nominal high density spent fuel racks. Unborated water of 1.0 g/cm^3 is assumed in the analysis. Over the range of water densities of interest (corresponding to 60°F through 212°F), full density water is a conservative assumption since a decrease in water density will cause the effective multiplication factor (k_{eff}) of the system to decrease.

The design basis for wet fuel storage criticality analysis is that, considering possible variations, there is a 95 percent confidence level that the effective multiplication factor (k_{eff}) of the fuel storage array will be less than 0.95 per ANSI Standard N18.2-1973. The possible variations in the criticality analyses are in three categories: 1) calculational uncertainties, 2) fuel rack fabrication uncertainties, and 3) transport effects.

The results of comparing standard calculations with 101 critical experiments as summarized in Table 4.3-4 (Ref. 4.3-14) indicate that:

1. The average difference between the calculations and experimental results or bias in the computations, was 0.1 percent Δk which is denoted as the calculational bias, and

2. The standard deviation in the difference between the calculations and experimental results was 0.86 percent Δk. Multiplying the standard deviation by the appropriate one-sided upper tolerance factor results in a calculational uncertainty valid at the 95 percent confidence level.

INSERT

"4.3.2.6.1 New Fuel Storage: New fuel is stored in 21 inch center to center racks in the new fuel storage facilities in a dry condition. For the flooded condition and for the low water density optimum moderator condition (with unborated water assuming fuel of the highest anticipated enrichment of 4.5 w/o U-235) the effective multiplication factor does not exceed 0.95.

In the analysis for the storage facilities, the fuel assemblies are assumed to be in their most reactive condition, namely fresh or undepleted and with no control rods or removable neutron absorbers present. Credit is taken for the inherent neutron-absorbing effect of the construction materials of the racks. Assemblies cannot be closer together than the design separation provided by the storage facility, except in special cases such as in fuel shipping containers where analyses are carried out to establish the acceptability of the design.

In the case of an accident that would increase reactivity, such as an assembly drop in the normal dry condition ($k_{eff} \leq 0.70$), the maximum k_{eff} will be less than 0.95."