QUAD-1-79-372

Attachment 3

BALTIMORE GAS & ELECTRIC CO.

LICENSING REPORT

CALVERT CLIFFS NUCLEAR POWER PLANT

UNIT 2

STORAGE OF 4.1% ENRICHED FUEL

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1.0 INTRODUCTION

The spent fuel storage racks presently in use in the spent fuel pool of Calvert Cliffs Unit 2 were designed by Nuclear Services Corporation for storage of spent fuel with a maximum enrichment of 3.7 weight percent U-235, which corresponds to 43.8 g/cm of U-235. It now anticipated that storage of fuel with 4.1 weight percent (48.5 g/cm) U-235 will be necessary in the future.

To ensure the safety of storage of 4.1% enriched fuel NSC has performed a new criticality analysis for the Unit 2 spent fuel racks. This analysis and report follow the same format as the previous analysis which was described in report number NSC-BGE-0101-R001, Revision 1.

The analysis for 4.1% enriched fuel is described in the following section.

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TABLE 1

CALVERT CLIFFS, UNIT NO. 2
K_{eff} RESULTS

Term	Value	Method
k_0	.9199	Calculated for cell at 212°F
Δk_1	.005	Estimated from similar design
Δk_2	.0082	Calculated from sensitivity analysis
Δk_3	.0025	Calculated for 0.050" displacement
Δk_4	-.0048	Critical experiment calculations
Δk_5	.0077	Critical experiments results, 95% confidence level
Δk_6	.0039	Sensitivity analysis, 0.01" tolerance
Δk_7	.0025	Estimated for 0.02% enrichment increase

$$k_{eff} \leq k_0 + \Delta k_1 + \Delta k_2 + \Delta k_3 + \Delta k_4 + (\Delta k_5^2 + \Delta k_6^2 + \Delta k_7^2)^{1/2}$$

$$= 0.9398$$

2.0 NUCLEAR ANALYSIS

The 12.5 x 13.0 inch spacing of the fuel assemblies is sufficient to maintain k_{eff} below 0.95 for all normal and abnormal fuel storage conditions. The analysis results are described below.

2.1 Summary of Results

The value of k_{eff} is determined as follows:

$$k_{eff} = k_0 + \Delta k_1 + \Delta k_2 + \Delta k_3 + \Delta k_4 + (\Delta k_5^2 + \Delta k_6^2 + \Delta k_7^2)^{1/2}$$

where

k_0 = nominal calculated k (2-D diffusion theory)

Δk_1 = transport correction

Δk_2 = assembly location effect (fuel in tube)

Δk_3 = rack spacing tolerance effect (tube in rack)

Δk_4 = methods bias

Δk_5 = uncertainty in methods bias (95% confidence level)

Δk_6 = channel thickness tolerance effect

Δk_7 = fuel fabrication tolerance effect

The value of k_{eff} is maintained below 0.95 for all normal and abnormal storage conditions in accordance with Standard Review Plan 9.1.2. Results are summarized in Table 1.

2.2 Method of Calculation

Verification of k_{eff} is obtained using a two dimensional (X-Y) diffusion theory computer code calculation. The calculational model covers both finite and infinite arrays of stored fuel assemblies. Neutron cross sections are developed for a four group energy range using the CHEETAH code which is an adaptation of the LEOPARD-CINDER code. The output of CHEETAH is used for a diffusion theory calculation using the CITATION code to establish the k_{eff}. In order to verify the accuracy of the CHEETAH-CITATION diffusion calculation, a comparison was made with various critical experiments as shown in Table 2. The data in the table defines the actual fuel used in the critical experiments. This data was placed into a CHEETAH-CITATION calculation with the results shown in the last column for comparison. These results may be compared with a measured k_{eff} of 1.000. Deviations vary from a few tenths of one percent to a little over one percent as indicated by the table. The standard deviation for the uranium oxide cases is 1.0047 $\pm$ 0.005 for CHEETAH and 1.0050 $\pm$ 0.005 for CITATION.

A transport-theory correction between 0 and 0.7% has been used for similar fuel storage configurations. (Refer to Wisconsin Electric Power Company, Publication March 28, 1975, Docket Nos. 50-266 and 5-301). The transport correction is not independent of other uncertainties, as it is in effect included in Δk_4 for critical lattices. We conservatively estimate it to be 0.5%.

2.3 Data and Assumptions Used in the Calculations

Table 3 summarizes the fuel design values which were used in the calculations.

TABLE 2

DATA FOR UO_2 CRITICAL EXPERIMENTS

BENCHMARK EVALUATION

CASE NUMBER	ENRICHMENT AT.%	H_2O:U VOLUME RATIO	FUEL DENSITY c/cm^3	PELLET DIAMETER cm	CLAD MATERIAL	CLAD OD cm	CLAD THICKNESS cm	LATTICE PITCH cm	$\frac{N(B^{10})}{N(U^{235})}$	CRITICAL BUCKLING m^{-2}	CALCULATED MULTIPLICATION FACTOR k
9*	2.734	2.18	10.18	0.7620	SS-304	0.8594	0.04085	1.0287	0	40.75	1.00614** (1.00646)***
10	2.734	2.93	10.18	0.7620	SS-304	0.8594	0.04085	1.1049	0	53.23	1.00937 (1.00950)
11	2.734	3.86	10.18	0.7620	SS-304	0.8594	0.04085	1.1938	0	63.26	1.00804 (1.00809)
12	2.734	7.02	10.18	0.7620	SS-304	0.8594	0.04085	1.4554	0	65.64	1.01153 (1.01154)
13	2.734	8.49	10.18	0.7620	SS-304	0.8594	0.04085	1.5621	0	60.07	1.01233 (1.01233)
14	2.734	10.38	10.18	0.7620	SS-304	0.8594	0.04085	1.6891	0	52.92	1.00623 (1.00615)
15	2.734	2.50	10.18	0.7620	SS-304	0.8594	0.04085	1.0617	0	47.5	1.00530 (1.00552)
19	3.745	4.51	10.37	0.7544	SS-304	0.8600	0.0406	1.2522	0	95.68	1.00618 (1.00622)
20	3.745	4.51	10.37	0.7544	SS-304	0.8600	0.0406	1.2522	0.0128	74.64	1.00189 (1.00195)
21	3.745	4.51	10.37	0.7544	SS-304	0.8600	0.0406	1.2522	0.0199	63.66	1.00021 (1.00027)
22	3.745	4.51	10.37	0.7544	SS-304	0.8600	0.0406	1.2522	0.0354	40.99	0.99877 (0.99884)
23	3.745	4.51	10.37	0.7544	SS-304	0.8600	0.0406	1.2522	0.0374	38.39	0.99818 (0.99825)
24	3.745	4.51	10.37	0.7544	SS-304	0.8600	0.0406	1.2522	0.0414	33.38	0.99679 (0.99686)
W-15†	5.809	3.13	10.193	0.9068	SS-304	0.9931	0.0381	1.3208	0	117.6	1.00511

CITATION AVG. k_{eff} = 1.00477 ± 0.00510 STD. DEVIATION

CHEETAH AVG. k_{eff} = 1.00472 ± 0.00491

*Nuclear Science and Engineering, 23, 58-73 (1965)

†WCAP-3385-54

** CHEETAH

*** CITATION

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TABLE 2 (Continued)

UO_2 AND PuO_2-UO_2 CRITICAL EXPERIMENT

BENCHMARK EVALUATION

WESTINGHOUSE REACTOR EVALUATION CENTER*

(0.625ev CUTOFF IN CHEETAH)

CASE NUMBER	UO_2 WT.%	WT.% PuO_2 WT.% Pu-240	H_2O:U+Pu VOLUME RATIO	FUEL DENSITY g/cm^3	PELLET DIAMETER IN.	CLAD MATERIAL	CLAD THICKNESS IN.	SQUARE LATTICE PITCH IN.	^{10}B ppm	MEASURED B_Z^2, m^{-2}	MEASURED CRITICAL BUCKLING m^{-2}	k_{eff} CALCULATED BY CHEETAH	X-Y MOCK-UP CALCULATED BY CITATION
W-14	2.719	-	4.60	10.40	0.40	Zr-2	0.03145	0.69	0	5.475	-	1.00284**	1.01281
W-14A	2.719	-	12.29	10.40	0.40	↓	0.03145	0.9758	0	6.042	-	1.00311†	-
W-19	0.72	2.00/7.65	2.51	9.54	0.505	↓	0.030	0.69	0	8.56	69.1	1.01768	-
W-19A	↓	↓	18.37	↓	↓	↓	↓	1.380	0	9.520	50.3	0.99561	-
W-19B	↓	↓	9.70	↓	↓	↓	↓	1.0607	0	9.471	96.4	1.02099	-
W-20	↓	↓	7.76	↓	↓	↓	↓	0.9758	0	9.466	105.9	1.02086	-
W-20A	↓	↓	7.76	↓	↓	↓	↓	0.9758	261	9.526	83.7	1.01070	-
W-20B	↓	↓	7.76	↓	↓	↓	↓	0.9758	526	9.635	63.1	1.00480	
W-21	↓	↓	2.48	↓	↓	↓	↓	0.69	526	8.954	58.3	1.02294	-
W-21A	↓	↓	2.48	↓	↓	↓	↓	0.69	261	8.731	62.6	1.02679	-
W-21B	↓	↓	3.43	↓	↓	↓	↓	0.75	0	8.967	90.0	1.02007	-
W-22	↓	2.00/23.50	7.80	↓	↓	↓	↓	0.9758	0	9.436	79.5	1.01522	-
W-22A	↓	↓	9.72	↓	↓	↓	↓	1.0607	0	9.639	73.3	1.01148	-

AVG. k_{eff} = 1.01308 ± 0.00936 STD. DEVIATION, FOR CHEETAH

*R. D. Leamer et. al., "PuO_2-UO_2 Fuel Critical Experiment", WCAP-3726-1, July 1967.

**Using B_R^2 = 73.5 estimated from reflector savings of 6.77 cm

†Using B_R^2 = 97.3 estimated from reflector savings of 6.77 cm

TABLE 2 (Continued)

RESULTS FROM CHEETAH CALCULATIONS

OF SELECTED UO_2/PuO_2 CRITICAL EXPERIMENTS

BENCHMARK EVALUATION

CASE NUMBER	REFERENCE	PuO_2 ENRICHMENT WT.%	H_2O:U+Pu VOLUME RATIO	FUEL DENSITY g/cm^3	PELLET DIAMETER IN.	CLAD MATERIAL	CLAD OD IN.	CLAD THICKNESS IN.	SQUARE LATTICE PITCH IN.	D_2O MOLE FRACTION	B^{10} ppm	CRITICAL BUCKLING m^{-2}	CALCULATED MULTIPLICATION FACTOR k
B-3	WCAP-3385-54*	6.60†	11.78	10.99	0.3374	Zircaloy-4	0.391	0.02325	0.792	0	0	159.3	1.01994
B-4			4.50						0.56	0	0	122.1	1.02551
B-5			4.50						0.56	0	337	112.3	1.03223
B-6			9.75						0.735	0	0	159.6	1.01708
B-7			3.51						0.52	0	0	108.8	1.01397
B-8			22.28						1.04	0	0	128.4	1.01704
B-9			4.48						0.56	0	0	120.9	1.02846

*E. G. Taylor, "Saxton Plutonium Program". Critical Experiments for the Saxton Partial Plutonium Core, WCAP-3385-54, December 1965.

†Wt. Percent Pu-239, Pu-240, Pu-241, Pu-242 is 90.49, 8.57, 0.89 and 0.04%.

AVG. k_{eff} = 1.0220 ± 0.0068 (STD. DEVIATION)

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TABLE 3
FUEL DESIGN PARAMETERS

Fuel Assembly Array	14 x 14
Number of Fuel Rods	176
Number of Water Rods	5
Rod Pitch	0.580"
Fuel Pellet O.D.	0.3805"
Clad O.D.	0.440"
Clad I.D.	0.388"
Clad Thickness	0.026"
Clad Material	Zircaloy 4
Pellet Density, % T.D.	95.0
Maximum Bundle Enrichment, Wt. % U-235	4.1
Nominal Active Fuel Length	137.18"

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The following assumptions were used in the calculations:

a. Pool is filled with fuel at the highest enrichment stored in an infinite array.

b. The water in the fuel storage pool is clean and unborated.

c. The pool temperature is 212°F. (100°C)

d. No credit is taken for the fuel assembly support structure. However, the neutron absorption of the 3/16" (4.7625 mm) thick stainless stell tubes in which the fuel assemblies are supported while in the storage racks is considered in the calculation.

e. Neutron absorption in fuel assembly grids is excluded.

f. Axial neutron leakage is included.

g. No credit is taken for U-234 and U-236 in the fuel.

The above assumptions are considered as a conservative base for the calculations.

2.4 Nuclear Design Criteria

The following criteria were used to evaluate the results of the nuclear calculations:

Normal Storage and Handling

Maximum k_{eff} = 0.95

Included as normal conditions are fuel reactivities up to the maximu, pool water temperature $\leq$ 212°F and eccentric positioning of the fuel in the proper location.

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Abnormal Storage and Handling

Maximum k_{eff} = 0.95

"Abnormal" refers to a single operator error. Included as abnormal conditions are dropping of a fuel assembly, dropping a fuel handling grapple, movement of the refueling bridge before the fuel is out of the rack or the fuel grapple is released, and placement of a single fuel assembly outside the storage racks.

2.5 Results of Calculations

The results of the k_{eff} calculations for various storage and handling conditions are listed as follows:

Condition	K_{eff}
1. Normal positioning in the spent fuel storage array (Figure 1)	0.9199
2. Eccentric positioning in the spent fuel storage array (clumped in groups of two or four)	
a. Fuel at side of channel, x-direction (Figure 2)	0.9239
b. Fuel at side of channel, y-direction (Figure 3)	0.9232
c. Fuel at corner of channel (Figure 4, Case 1)	0.9281
3. Eccentric positioning in the spent fuel storage array with the channel offset 1/8" (3.175 mm) in both X and Y directions (Figure 4, Case 2)	0.9336
4. One extra fuel assembly at side of rack (Figure 5, Case 2)	0.9402

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The value of k_{eff} is not expected to change significantly under abnormal storage situations. Consideration was given to a fuel assembly lying on top of a rack. Due to the small axial neutron leakage reactivity of 0.2% Δk, and the separation of the fuel assembly from active fuel in the rack, the increase in reactivity is <0.002.

The drop of a fuel assembly onto the rack and abnormal fuel handling machine loads of 1650 pounds vertical and 825 pounds horizontal are also considered. The fuel rack is designed to prevent any plastic deformation in the fuel region for these loads. Therefore, the reactivity effect of these abnormal loading conditions is insignificant.

Sensitivity studies were performed to evaluate the influence on k_{eff} of fuel tube spacing, pool t ature, and fuel tube thickness. The results of these anal are summarized below.

Spacing Effects

Table 4 lists the effects of fuel spacing.

TABLE 4

K_{eff} VERSUS SPACING, 212°F

Cell Pitch, Inches	K_{eff}
9.25 x 9.75	1.238
10.00 x 10.50	1.133
10.75 x 11.25	1.048
11.50 x 12.00	0.9822
12.25 x 12.75	0.9331
12.50 x 13.00	0.9199
12.75 x 13.25	0.9084

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TABLE 4 (continued)

13.50 x 14.00	0.8839
15.50 x 16.00	0.8436
17.50 x 18.00	0.8304

Temperature Effects

The reference rack unit cell was analyzed at several temperatures in order to determine the temperature effect on k_{eff}. The fuel pellet, clad, moderator, and rack pitch were assumed to expand normally. The results are shown in Table 5. The change is less than one (1) percent. The numbers quoted in this report are the values for the highest temperature (212°F).

TABLE 5

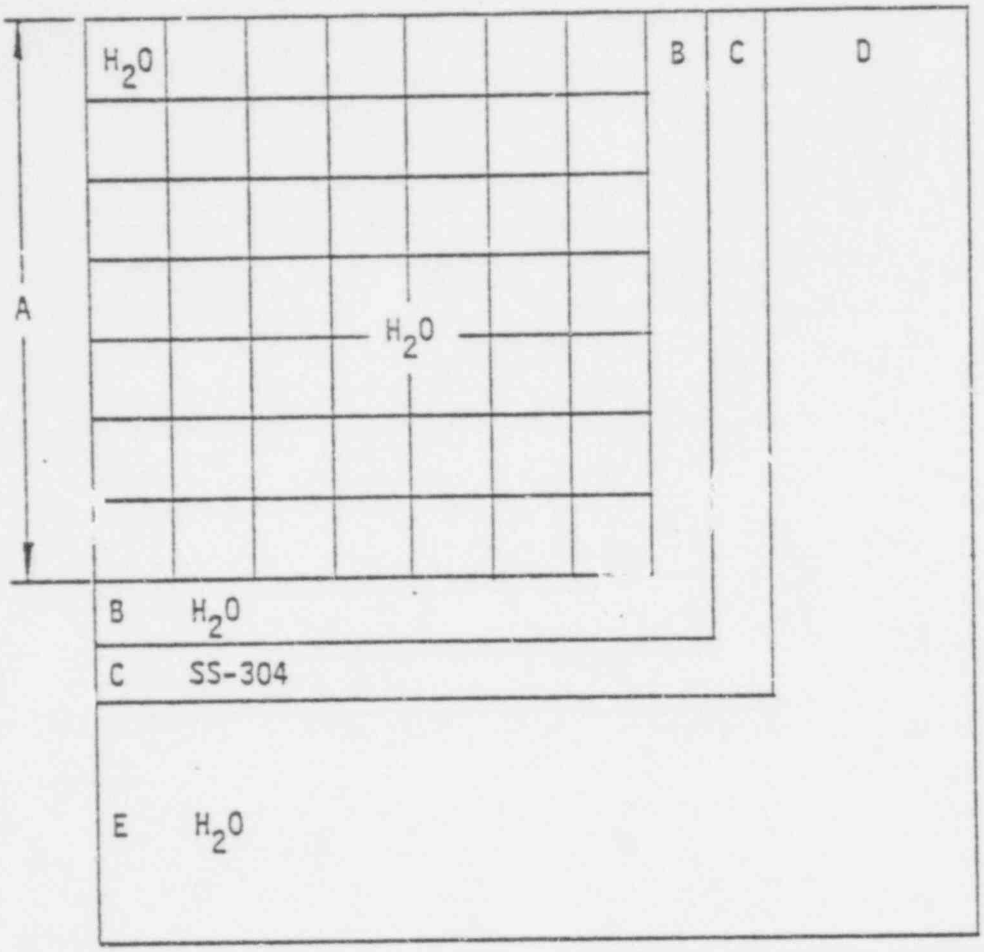
K_{eff} Infinite Lattice	Temperature, °C
0.9138	4
0.9186	60
0.9199	100

Effect of Variation in Steel Channel Thickness

For the reference 13" x 12.5" (330.2 x 317.5 mm) pitch rack, the steel channels are 3/16" thick. In order to estimate $\frac{\Delta\rho}{\Delta t}$ for the steel channels, we have the following data:

Steel Thickness t, in. (mm)	K_{eff}
0.1875 (4.7625)	0.9199
0.16875 (4.28625)	0.9273

$$\frac{\Delta\rho}{\Delta t} = \frac{k_2 - k_1}{k_1 x k_2} \quad 0.01875 = 0.4627 \text{ per inch } (0.0182 \text{ per mm}) \text{ of reduced thickness}$$



NOTE: NOT TO SCALE

212°F	INCH	4.06573	0.37798	0.18776	1.62728	1.87763
	(CM)	(10.32694)	(0.96007)	(0.47692)	(4.13329)	(4.76918)

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Figure 1. Unit Cell Model for Normal
Fuel Positioning

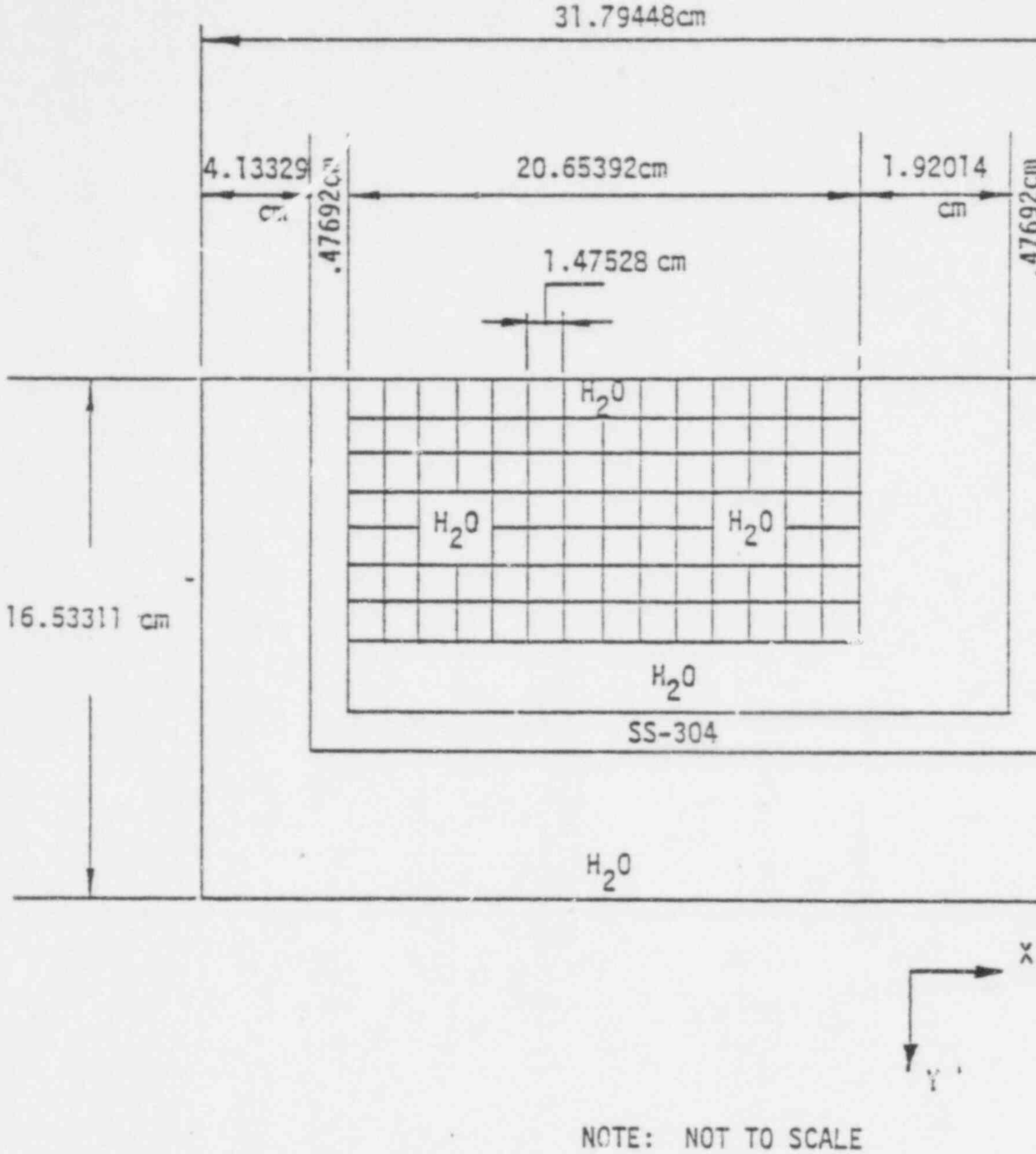

Figure 2. Eccentric Positioning
X Direction Offset

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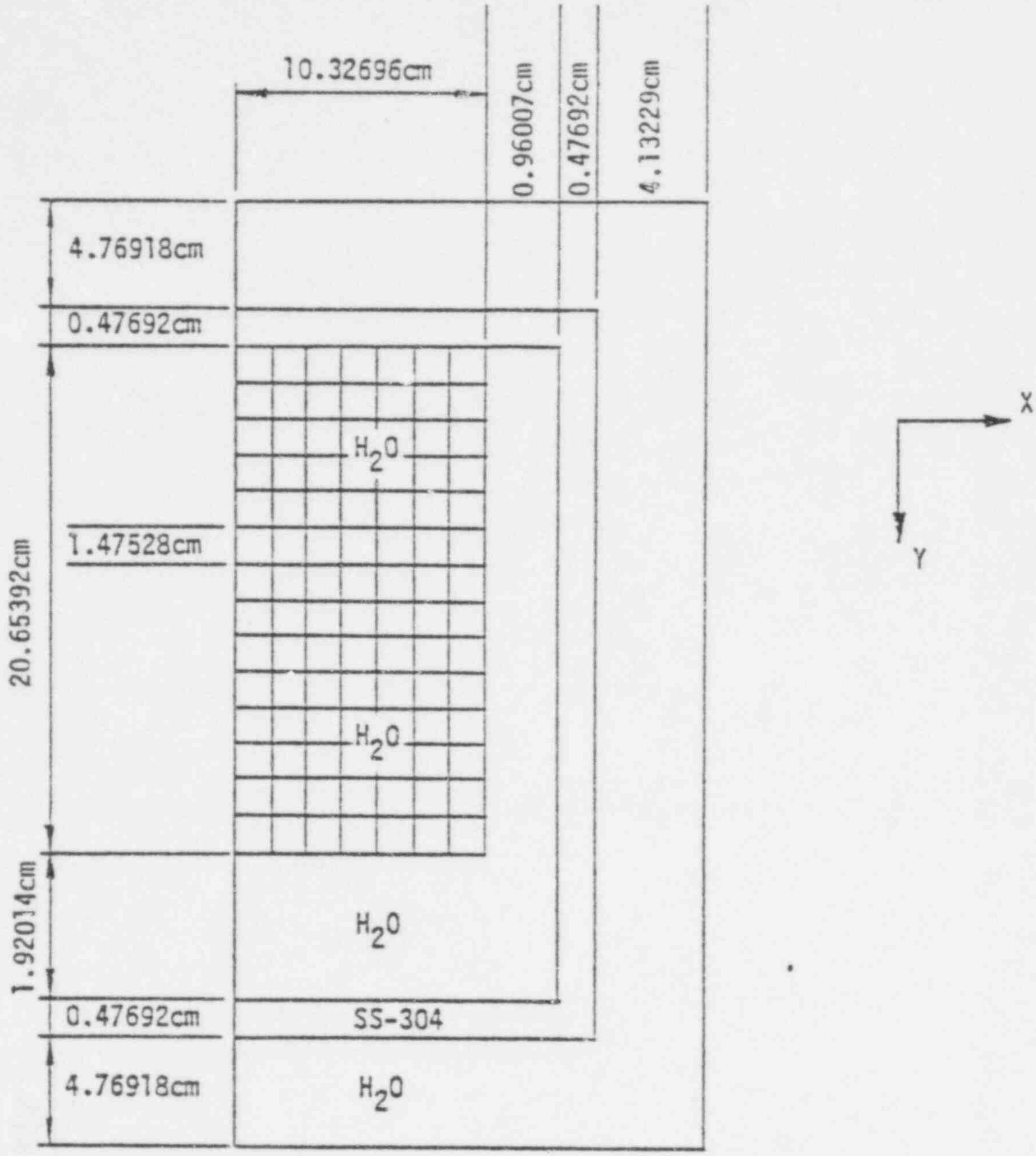

NOTE: NOT TO SCALE

Figure 3. Eccentric Positioning
Y Direction Offset

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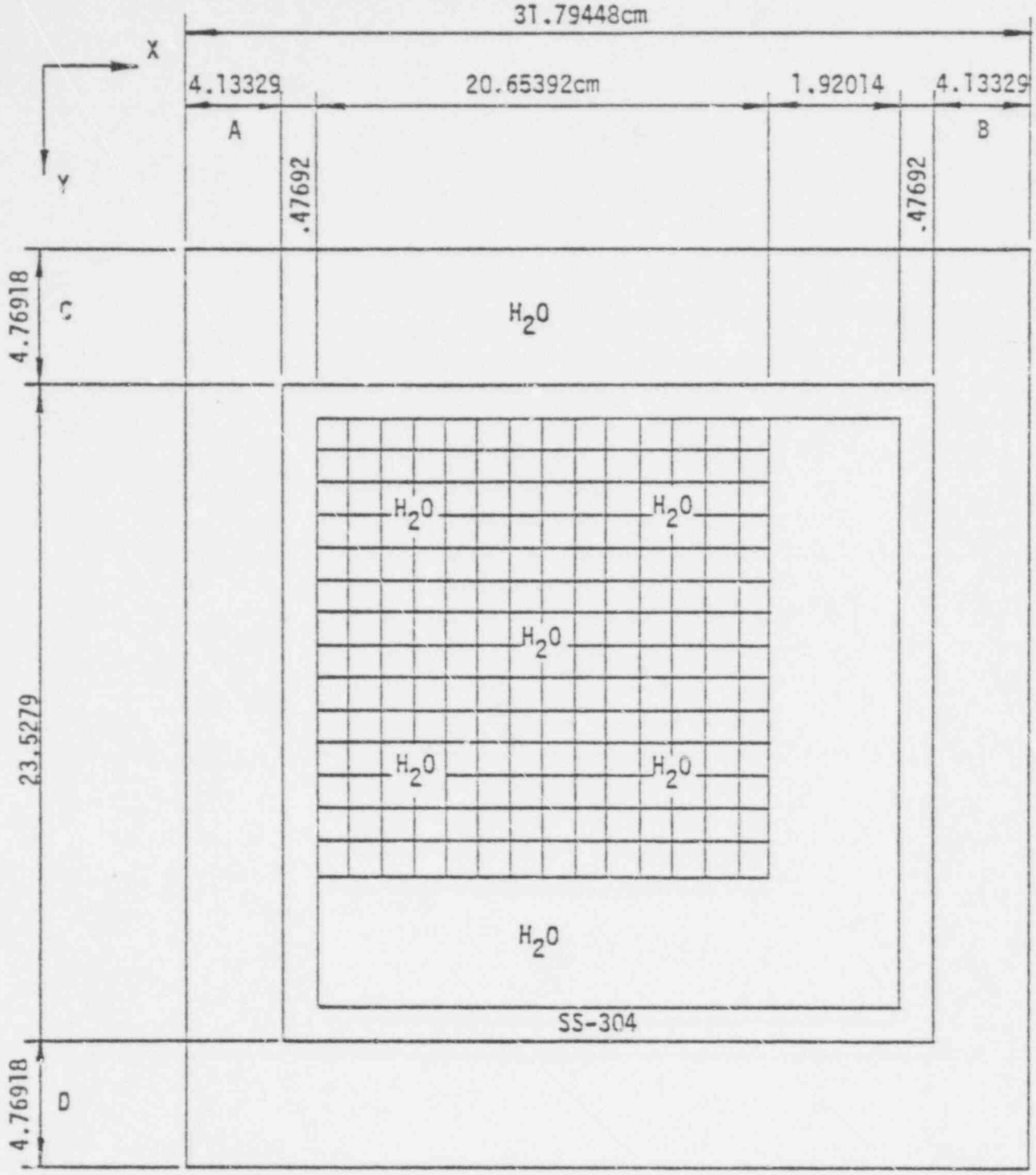

NOTE: NOT TO SCALE

CASE 1 - AS SHOWN. FUEL OFFSET DIAGONALLY.

CASE 2 - AS SHOWN, EXCEPT: A = 4.13329cm - .3175cm = 3.81579
B = 4.13329cm + .3175cm = 4.45079
C = 4.76918cm - .3175cm = 4.45168
D = 4.76918cm + .3175cm = 5.08668

BOTH FUEL AND CHANNEL OFFSET DIAGONALLY

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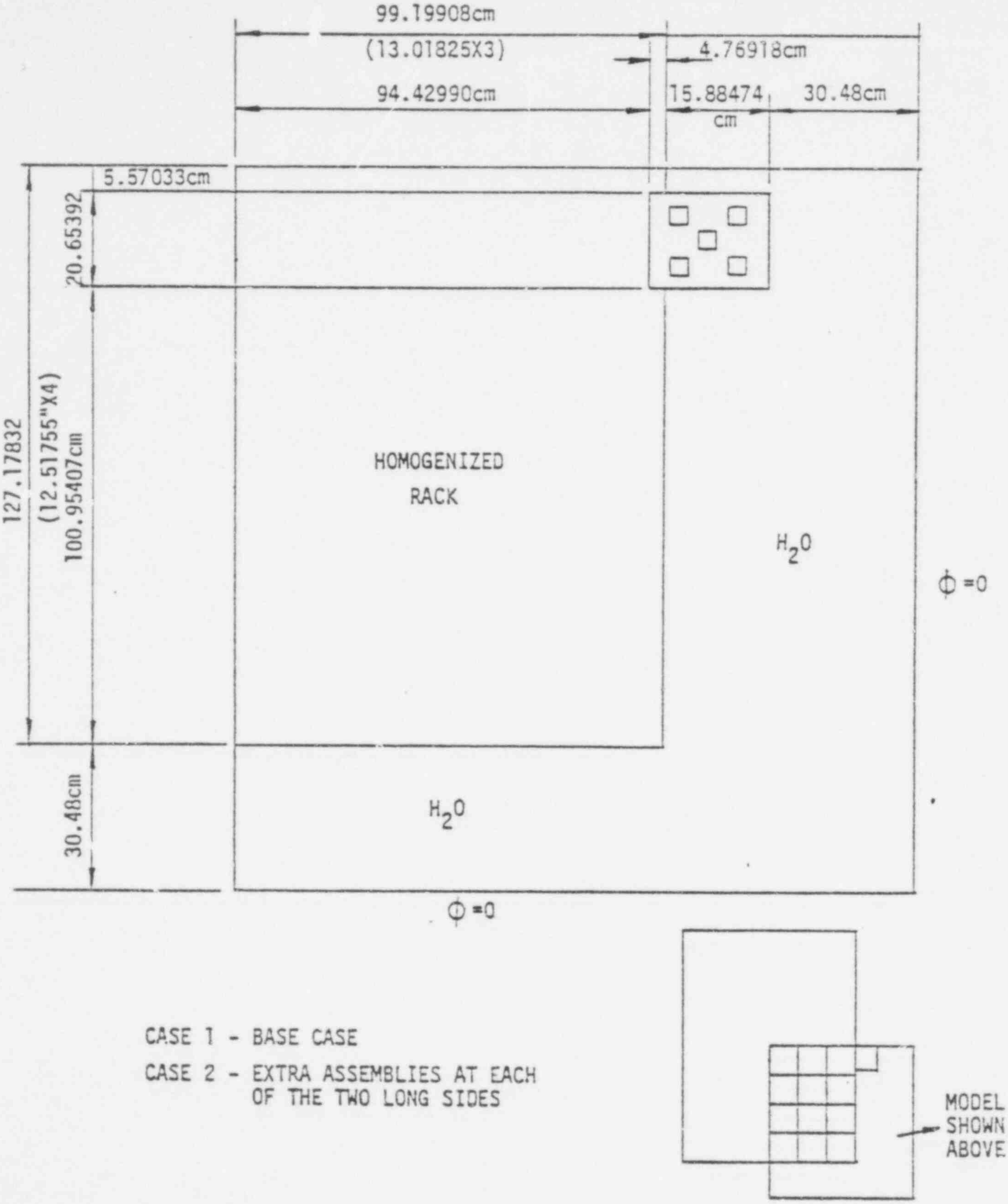
Figure 4. Eccentric Positioning
Diagonal Offset



CASE 1 - BASE CASE

CASE 2 - EXTRA ASSEMBLIES AT EACH OF THE TWO LONG SIDES

NOTE: NOT TO SCALE

Figure 5. Extra Fuel Assembly at the Side of the Rack

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3.0 CONCLUSION

The criticality analysis shows that with all uncertainties included the calculated k_{eff} for storage of fuel with 4.1% U-235 is still well below the limit of 0.95. Therefore, storage of this fuel in the Calvert Cliffs Unit 2 spent fuel racks presents no safety problem.

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DESIGN FEATURES

VOLUME

5.4.2 The total water and steam volume of the reactor coolant system is 10,614 ± 460 cubic feet at a nominal T_{avg} of 532°F.

5.5 METEOROLOGICAL TOWER LOCATION

5.5.1 The meteorological tower shall be located as shown on Figure 5.1-1.

5.6 FUEL STORAGE

CRITICALITY - SPENT FUEL

5.6.1 The spent fuel storage racks are designed and shall be maintained with a minimum 12.5 x 18 inch center-to-center distance between fuel assemblies placed in the storage racks to ensure a k_{eff} equivalent to < 0.95 with the storage pool filled with unborated water. The k_{eff} of < 0.95 includes the conservative allowances for uncertainties described in Section 9.7.2 of the FSAR. In addition, fuel in the storage pool shall have a U-235 loading of ≤ 46.5 grams of U-235 per axial centimeter of fuel assembly.

CRITICALITY - NEW FUEL

5.6.2 The new fuel storage racks are designed and shall be maintained with a nominal 18 inch center-to-center distance between new fuel assemblies such that K_{eff} will not exceed 0.98 when fuel having a maximum enrichment of 4.0 weight percent U-235 is in place and aqueous foam moderation is assumed. The K_{eff} of ≤ 0.98 includes the conservative allowance for uncertainties described in Section 9.7.2 of the FSAR.

DRAINAGE

5.6.3 The spent fuel storage pool is designed and shall be maintained to prevent inadvertent draining of the pool below elevation 63 feet.

CAPACITY

5.6.4 The fuel storage pool is designed and shall be maintained with a combined storage capacity, for both Units 1 and 2, limited to no more than ~~1056~~ fuel assemblies.
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5.7 COMPONENT CYCLIC OR TRANSIENT LIMITS

5.7.1 The components identified in Table 5.7-1 are designed and shall be maintained within the cyclic or transient limits of Table 5.7-1.

DESIGN FEATURES

VOLUME

5.4.2 The total water and steam volume of the reactor coolant system is 10,614 ± 460 cubic feet at a nominal T_{avg} of 532°F.

5.5 METEOROLOGICAL TOWER LOCATION

5.5.1 The meteorological tower shall be located as shown on Figure 5.1-1.

5.6 FUEL STORAGE

CRITICALITY - SPENT FUEL

5.6.1 The spent fuel storage racks are designed and shall be maintained with a minimum 9.75 inch center-to-center distance between fuel assemblies placed in the storage racks to ensure a k_{eff} equivalent to $\leq$ 0.95 with the storage pool filled with unborated water. The k_{eff} of $\leq$ 0.95 includes the conservative allowances for uncertainties described in Section 9.7.2 of the FSAR. In addition, fuel in the storage pool shall have a U-235 loading of $\leq$ 46.6 grams of U-235 per axial centimeter of fuel assembly.

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