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REVISION 1

ADVANCED NUCLEAR FUELS CORPORATION

CRITICALITY SAFETY ANALYSIS D.C. COOK SPENT FUEL STORAGE RACKS WITH 15X15 AND 17X17 FUEL ENRICHMENTS UP TO 5.0 PERCENT

AUGUST 1988

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CRITICALITY SAFETY ANALYSIS
D. C. COOK SPENT FUEL STORAGE RACKS
WITH 15X15 AND 17X17 FUEL ENRICHMENTS UP TO 5.0 PERCENT

1.0 INTRODUCTION

Criticality safety of new fuel assemblies for Units 1 and 2 (15x15 and 17x17) in the spent fuel storage racks is conservatively demonstrated in accordance with NUREG-0800 and ANSI/ANS-57.2-1983.

2.0 SUMMARY

The subject racks meet the applicable criticality safety criteria subject to the limits and controls listed below.

- Fuel Design: 15x15 and 17x17 fuel designs with nominal parameters listed in Table 1.
- Storage Rack Design: As described in Section 4.0.
- Storage Rack Loading:
  - For new fuel enrichments up to 4.23 percent, the racks may be fully loaded with new or exposed assemblies.
  - To enable storage of new fuel enrichments in the range 4.24 to 5.0 percent, exposed bundles (10 GWD/MTU minimum) must first be loaded into the racks in the "black squares" of a checkerboard arrangement. New or exposed fuel assemblies with enrichments up to 5.0 percent may then be loaded into the "red squares".
- Dissolved Boron: At least 1000 ppm dissolved boron shall be assured during fuel handling.

3.0 FUEL DESIGN

Bundles for Units 1 and 2 were analyzed for safety within the racks. The 15x15 and 17x17 fuel design parameters modeled are listed in Table 1. Fuel designs of Advanced Nuclear Fuels Corporation (ANF) and Westinghouse (W) are included.

TABLE 1 FUEL DESIGN PARAMETERS

Design	Pellet Diameter (inch)	Clad ID/OD (inch)	Guide Tube ID/OD (inch)	Rod Pitch (inch)
ANF 17x17	0.303	0.310/0.360	0.448/0.480	0.496
W 17x17	0.3225	0.329/0.374	0.450/0.482	0.496
ANF 15x15	0.3565	0.364/0.424	0.511/0.544	0.563
W 15x15	0.3659	0.3734/0.422	0.515/0.545	0.563
W 15x15 (OFA)	0.3659	0.3734/0.422	0.512/0.546	0.563

The 15x15 bundle has 21 "water rods" (guide tubes). The 17x17 bundle has 25 water rods. The arrangement of the guide tubes is shown in the attached listings of typical CASMO inputs.

4.0 SYSTEM GEOMETRY

The spent fuel racks were modeled as an infinite x infinite array of infinite length cells filled with infinite length assemblies.

Each cell contains the regions described below.

- Fuel assembly: 8.432 inch square (17x17) or 8.445 inch square (15x15)
- Water to inner surface of cell wall at 8.969 inch square
- Cell wall to 9.361 inch square
- Water to 10.5 inch square (cell boundary)

The cell wall is 0.196 inch thick with the following regions, starting at the inner surface.

- 0.075 inch thick stainless steel
- 0.010 inch thick aluminum clad for Boral
- 0.071 inch thick Boral
- 0.010 inch thick aluminum clad for Boral
- 0.030 inch thick stainless steel

The Boral was conservatively modeled at 0.020 gm B-10 per square cm. Average and standard deviation values for 175 samples of the Boral used in the racks are 0.0234 and 0.0010 gm B-10 per square cm.

The system was flooded with water (zero voids, zero dissolved boron) at 20°C.

5.0 CALCULATION METHODS

Most calculations, including rack k-inf, in-core k-inf, and fuel depletion were performed using CASMO-3 with 40-group cross sections. CASMO has been extensively benchmarked.

Additional and replicate calculations were performed using KENO-Va with 16-group cross sections from the SCALE(1) system. Sixteen group cross sections were prepared using BONAMI/NITAWL.

5.1 Methods Verification

The SCALE codes and cross sections have been extensively benchmarked against data from critical experiments.

Supplemental benchmarking was performed immediately before the calculations reported here. The experiments selected are described in References 2 and 3. The experiments were selected particularly to establish the calculational bias for the poisoned spent fuel storage rack analysis.

The results are listed in Table 2.

TABLE 2 BENCHMARK CALCULATION RESULTS FROM KENO-Va
16 GROUP CROSS SECTIONS

Case No.	Calculated k-eff
	Reference 2 Experiments
2378	1.00395 ± 0.00376
2384	1.00037 ± 0.00306
2388	0.99886 ± 0.00341
2420	1.00038 ± 0.00367
2396	0.99443 ± 0.00360
2402	1.00694 ± 0.00283
2411	1.01223 ± 0.00286
2407	1.00647 ± 0.00332
2414	1.00967 ± 0.00327
	Reference 3 Experiments
9	1.00092 ± 0.00487
10	1.00181 ± 0.00412
11	0.99786 ± 0.00413
12	0.99885 ± 0.00487
31	1.00442 ± 0.00421

The average and standard deviation are 1.00265 and 0.00490, respectively.

The 95 percent upper limit (UL) on the KENO k-eff is calculated by pooling the KENO variance and the bias variance.

For example, the 95 percent UL k-eff for case 2378 is calculated below.

k-eff (95% UL) = 1.00395 - 0.00265 + 1.66 * SQRT(3.76E-3**2 + 4.90E-3**2) = 1.00130 + 0.01025 = 1.01155

The 1.66 multiplier is the one-sided Student t (5%) with about 80 degrees of freedom. (The KENO results had at least 80 degrees of freedom.)

For reference, the bias-corrected results are reported in Table 3.

TABLE 3 BIAS-CORRECTED BENCHMARK RESULTS

Case No.	k-eff	k-eff (95% UL)
2378	1.00130 ± 0.00376	1.01155
2384	0.997716 ± 0.00306	1.00731
2388	0.996206 ± 0.00341	1.00612
2420	0.997726 ± 0.00367	1.00789
2396	0.991776 ± 0.00360	1.00187
2402	1.00429 ± 0.00283	1.01368
2411	1.00958 ± 0.00286	1.01900
2407	1.00382 ± 0.00332	1.01364
2414	1.00702 ± 0.00327	1.01680
9	0.998266 ± 0.00487	1.00973
10	0.999156 ± 0.00412	1.00978
11	0.995206 ± 0.00413	1.00584
12	0.996196 ± 0.00487	1.00766
31	1.00177 ± 0.00421	1.01249

The 95 percent UL which is the parameter used in judging acceptability exceeds 1.0 in every case after bias correction. The average 95 percent UL is 1.0102. Therefore, the results remain conservative.

All reported results in this report have <u>not</u> been bias-corrected, unless otherwise stated. Therefore, these results would tend to be conservative by about 0.00265.

6.0 RESULTS

6.1 CASMO Model of Spent Fuel Storage Racks

The spent fuel racks were modeled as filled with new fuel with enrichments in the range 2.5 to 5.0 percent. The CASMO results for four fuel designs are listed in Table 4.

TABLE 4 CASMO RESULTS
SPENT FUEL RACKS WITH FRESH FUEL ENRICHMENT - BUNDLE-TYPE EFFECTS

Enrichment (wt% U-235)	ANF 17x17 k-inf	ANF 15x15 k-inf	W 17x17 k-inf	W 15x15(OFA) k-inf
2.5	0.82961	0.82403	0.83049	0.83296
3.0	0.87037	0.86360	0.86926	0.87204
3.5	0.90270	0.89471	0.89970	0.90271
4.0	0.92887	0.92028	0.92464	0.92791
4.5	0.95105	0.94154	0.94514	0.94869
5.0	0.96947	0.95938	0.96277	0.96643

The Table 4 results indicate that all designs will be subcritical by substantial margin at all enrichments up to 5.0 percent. However, the 0.95 limit on k-eff will be exceeded at enrichments somewhat less than 4.5 percent.

The Table 4 results also indicate that the in-rack k-inf values for the four bundle types differ little and that, for the higher enrichments of main interest, all results are bounded by the ANF 17x17 values.

6.2 KENO-Va Models of Spent Fuel Storage Racks

Since the rack k-inf exceeds 0.95 when fully loaded with new 5.0 percent enriched fuel, partial loading of the racks was evaluated. A checkerboard loading of new 5.0 percent enriched bundles (red squares) with bundles of lower reactivity (black squares) is the selected partial loading arrangement.

The KENO-Va results from checkerboard loadings of new ANF 17x17 fuel bundles are in Table 5. Appropriate CASMO results from Table 4 are included for comparison.

TABLE 5 CHECKERBOARD LOADINGS OF SPENT FUEL RACKS
FRESH ANF 17X17 BUNDLES OF TWO ENRICHMENTS
KENO-Va RESULTS WITH 16-GROUP CROSS SECTIONS

Low Enrichment (wt% U-235)	High Enrichment (wt% U-235)	KENO-Va k-inf	CASMO k-inf
2.5	2.5	0.8307 ± 0.0033	0.8296
3.0	3.0	0.8730 ± 0.0039	0.8704
3.5	3.5	0.9077 ± 0.0037	0.9027
4.0	4.0	0.9342 ± 0.0036	0.9289
4.5	4.5	0.9512 ± 0.0035	0.9511
5.0	5.0	0.9721 ± 0.0038	0.9695
3.0	4.0	0.9063 ± 0.0033	
3.0	5.0	0.9253 ± 0.0034	
4.0	5.0	0.9509 ± 0.0035	
Results below have empty (water-filled) low enriched cells			
(Empty)	3.0	0.7323 ± 0.0031	
(Empty)	4.0	0.7820 ± 0.0038	
(Empty)	5.0	0.8101 ± 0.0040	

The KENO results from Table 5 are very close to the CASMO results from Table 4.

For the first six cases in Table 5, the bias-corrected 95 percent UL k-inf (rounded to nearest 0.0001) is well estimated by the regression line:

k-inf (95% UL) = 0.33236 + 0.32918 ENR - 0.061743 ENR**2 + 0.0043556 ENR**3.

Based on the 7.7257E-6 sum of squares of residuals for six values, the average residual is 0.00113. For an enrichment of 4.23 percent, the calculated k-inf value is 0.9497.

Repeating the regression after deleting the points at enrichments 2.5 and 3.0, the regression equation is:

k-inf (95% UL) = -0.69480 + 1.0739 ENR - 0.2398 ENR**2 + 0.01840 ENR**3.

The above equation with four fitted coefficients is an exact fit to the four data points in the enrichment range 3.5 to 5.0 percent. For an enrichment of 4.23 percent, the calculated k-inf value is 0.9497.

Using the results from Tables 4 and 5, and the data from Section 5.1, the average and standard deviation of the KENO-CASMO bias (KENO result minus CASMO result) are:

- 0.0028 ± 0.0021 (based on nominal KENO value)
- 0.0002 ± 0.0021 (based on bias-corrected KENO value)
- 0.0103 ± 0.0021 (based on bias-corrected 95% UL from KENO)

There is no significant effect of enrichment on this bias. Again, the KENO-CASMO results agree very well and the 95 percent UL on KENO is very conservative.

6.3 CASMO Models for In-core k-inf

The previous section contains correlations between the enrichment in the racks and the resulting k-inf. Good KENO-CASMO agreement was also demonstrated.

The more generic correlation desired is between the reactivities of the bundles in the rack and the rack k-inf. A convenient index of bundle reactivity is the in-core k-inf. This index will be based on a 8.466 inch bundle pitch, 20°C temperature, zero dissolved boron, and zero Xe-131/135.

The k-inf for new bundles with enrichments in the range 2.5 to 5.0 percent were calculated using CASMO. The results are in Table 6.

TABLE 6 CASMO RESULTS
NEW FUEL BUNDLE ON 8.466 INCH CENTERS, ZERO BORON, TEMP=20°C
ENRICHMENT - BUNDLE-TYPE EFFECTS

Enrichment (wt% U-235)	ANF 17x17 k-inf	ANF 15x15 k-inf	W 17x17 k-inf	W 15x15(OFA) k-inf
2.5	1.34557	1.34688	1.34611	1.35002
3.0	1.39596	1.39528	1.39312	1.39743
3.5	1.43427	1.43200	1.42870	1.43335
4.0	1.46434	1.46082	1.45658	1.46152
4.5	1.48858	1.48403	1.47898	1.48419
5.0	1.50852	1.50310	1.49740	1.50281

6.4 Correlation of In-Rack k-inf vs. In-core k-inf

A regression of the spent fuel rack k-inf (95% UL) value (checkerboard loading, Table 5) versus the in-core k-inf values of the bundles (Table 6, ANF 17x17) in the racks yielded the equation below with a standard error of 0.0016.

k-inf (95% UL) = -0.31517 + 0.40406 k-inf(low) + 0.45206 k-inf(high)

The goodness-of-fit of the regression is demonstrated in Table 7.

TABLE 7 REGRESSION RESULTS
IN RACK K-INF (95% UL) VS. IN-CORE K-INF

k-inf (In-core) (Low)	k-inf (In-core) (High)	k-inf (In Rack) (KENO)	k-inf (In Rack) (Regression)
1.34557	1.34557	0.83618	0.83680
1.39596	1.39596	0.87947	0.87994
1.43427	1.43427	0.91384	0.91274
1.46434	1.46434	0.94018	0.93848
1.48858	1.48858	0.95701	0.95923
1.50852	1.50852	0.97751	0.97630
1.39596	1.46434	0.91178	0.91085
1.39596	1.50852	0.93094	0.93082
1.46434	1.50852	0.95671	0.95845

Using the regression equation with an assumed k-inf (high) of 1.50852 (5.0 percent enriched) and with a rack k-inf of 0.95, the maximum acceptable value for k-inf (low) is 1.44342. This k-inf (low) value corresponds to a new ANF 17x17 bundle with an enrichment slightly greater than 3.5 percent (Table 4). This means that a checkerboard loading of new bundles with enrichments 3.5 and 5.0 percent would meet the 0.95 limit on rack k-eff.

6.5 In-core k-inf vs. Burnup

All previous calculations were for new fuel assemblies. The reduced reactivity bundles are now assumed to be exposed ANF 17x17 bundles with an initial (BOL) enrichment of 5.0 percent. The minimum burnup to produce an in-core k-inf less than 1.44342 was determined. This minimum burnup will be conservative for all BOL enrichments less than 5.0 percent.

The effect of burnup on bundle k-inf was calculated for the ANF 17x17 bundle at various combinations of temperature and dissolved boron concentration. The objective is to assure that the burnup effect is conservative regardless of operating parameters and also to assure that axial temperature effects are addressed. The ANF 17x17 bundle was selected because it has the highest in-core k-inf values in Table 6.

Fuel depletion runs (0 to 60 GWD/MTU) were made at the temperature at the top and bottom of the bundle and with a constant 500 or 1000 ppm dissolved boron concentration. The modeled fuel/moderator temperatures were 986.8/555.9 K (bottom) and 1023/592.1 K (top).

After the depletion run, the bundle cold (20°C), clean (zero Xe-131/135) k-inf was calculated with zero dissolved boron. The results are in Table 8.

TABLE 8 BUNDLE K-INF VS. BURNUP (ANF 17X17 BUNDLE)
CASMO RESULTS FOR 5.0 PERCENT ENRICHED FUEL AT BOL
BUNDLES ON 8.466 INCH CENTERS (INFINITE LATTICE)
ZERO DISSOLVED BORON, ZERO Xe-131/135, TEMPERATURE = 20°C
FUEL DEPLETION RUNS AT TOP/BOTTOM TEMPERATURE AND AT 500/1000 PPM BORON

Burnup (GWD/MTU)	Top/500 k-inf	Bottom/500 k-inf	Top/1000 k-inf	Bottom/1000 k-inf
5	1.45971	1.46028	1.45958	1.46014
10	1.41219	1.41308	1.41208	1.41295
15	1.36139	1.36210	1.36150	1.36220
20	1.30853	1.30849	1.30910	1.30906
25	1.25366	1.25225	1.25494	1.25358
30	1.19725	1.19373	1.19959	1.19624
35	1.13903	1.13258	1.14282	1.13673
40	1.07910	1.06884	1.08478	1.07518
45	1.01774	1.00289	1.02581	1.01200
50	0.95561	0.93557	0.96652	0.94804
55	0.89379	0.86841	0.90791	0.88464
60	0.83394	0.80384	0.85137	0.82383

The indications are:

- A 10 GWD/MTU minimum burnup will be more than adequate to lower the in-core k-inf value below the 1.44342 reference value.

- Temperature/boron effects become significant only at higher burnups.

6.6 Axial Effects

All models in previous sections assumed an infinite fuel length with uniform properties. The actual fuel length is finite and the burnup is lower at the two ends than in the central region.

Additional calculations were performed to demonstrate that the infinite length model with the bundle-average burnup includes adequate margin for axial burnup effects.

The bases for these additional calculations were:

- The enriched fuel length is 12 feet.

- The enriched fuel has three regions: a central eight foot region with a constant burnup B and two end regions. The burnup in the two foot long end regions varies linearly from 0.5B (at end) to B. These values were taken from ANF neutronics calculations.

- The average burnup for this model is 0.9167B (11B/12).

- Since the average burnup modeled is 10 GWD/MTU, the value B is 10.91.

- Only half (six feet) of the symmetric fuel region was modeled. Specular reflection was applied at the plane of symmetry.

- The two foot long region was modeled as four 6-inch long zones with burnups 10.23, 8.86, 7.50 and 6.14 GWD/MTU (progressing toward the end of the enriched zone). Expressed as fractions of the value B, the average burnups of the four end regions are 0.9375B, 0.8125B, 0.6875B and 0.5625B, respectively.

- The calculations were performed using XSDRNPM (1-D discrete-ordinates transport code) with 16-group cross sections.

- All fueled regions contained new fuel. The reduced reactivity due to burnup was matched by adjusting the enrichment. The reactivities for low burnup ANF 17x17 fuels used for interpolation are listed below.

TABLE 9 ANF 17X17 IN-CORE K-INF VERSUS BURNUP
(SAME BASES AS TABLE 8)

Burnup	k-inf
0	1.50852
0.5	1.49724
1	1.49186
2	1.48417
3	1.47651
5	1.45957
7.5	1.43637
10	1.41209
12.5	1.38706

The k-inf values for burnups 10.91, 10.23, 8.86, 7.50 and 6.14 were estimated at 1.4030, 1.4098, 1.4231, 1.4364 and 1.4490. The k-inf values for cell-weighted cross sections representing new fuel enrichments of 3.0, 3.1, 3.3, 3.5 and 3.7 percent are 1.4025, 1.4107, 1.4259, 1.4396 and 1.4520, respectively. The enrichments used to match the burnups (k-infs) listed above are 3.006, 3.089, 3.263, 3.453 and 3.662 percent.

- The XSDRNPM model is an infinite slab with 30 cm of water reflection. The infinite slab has five regions (one at four feet plus four at six inches) as described earlier.

- The XSDRNPM result for the five region model with 30 cm of water reflection is 1.4247. The value for the infinite length model at 10 GWD/MTU is 1.4121. An infinite length model with a burnup near 8.70 would yield the 1.4247 value from the finite length model. The 1.4247 vlaue is well below the 1.4434 limit established earlier.

Therefore, 10 GWD/MTU minimum burnup value includes conservative allowance for axial burnup effects.

6.7 Fuel Handling Accidents

The worst credible accident is bringing two bundles together in the pool. Accidents such as placing a bundle next to the storage racks are less reactive.

The k-eff of two edge-to-edge bundles (new, 5.0 percent enriched, infinite length) with full water reflection is 1.0785 ± 0.0052. This case has zero dissolved boron.

Repeating the above case with 1000 ppm dissolved boron in all water reduced the k-eff to 0.9075 ± 0.0038.

A minimum dissolved boron concentration of 1000 ppm is more than adequate to assure criticality safety during fuel handling.

7.0 COMPUTER INPUT LISTINGS

7.1 CASMO Model for Spent Fuel Rack

The CASMO-3 input for the spent fuel racks containing the ANF 17x17 bundle is listed below. All rack cells contain the same enrichment.

```
DIM,17,2
TIT TFU=293.15 TMO=293.15 BOR=0 * DC COOK
FUE 1 10.412/5.0 *95% TD, 5.0% ENR
MI1 5.41/347=78.24 13000=16.58 5000=4.06 6000=1.13
*  MIX1 IS SMEARED RACK CHANNEL
PIN 1 0.38481 0.3937 0.4572/'FUE' 'AIR' 'CAN'//1
PIN 2 0.5690 0.6096/'COO' 'CAN'//1 * GUIDE TUBE
PWR,17,1.25984,22.76348,4*0,2
*  INNER SHROUD: 8.962 IN SQ (IN PWR)
* METAL: 0.075 STL, 0.010 AL, 0.071 BORAL, 0.010 AL, 0.030 STL
*  OUTER WATER: 1.45542CM
```

```
LPI
1 *ROW 1
1 1 *ROW 2
1 1 1 *ROW 3
1 1 1 2 *ROW 4
1 1 1 1 1 *ROW 5
1 1 2 1 1 2 *ROW 6
1 1 1 1 1 1 1 *ROW 7
1 1 1 1 1 1 1 1 *ROW 8
1 1 2 1 1 2 1 1 2 *ROW 9
1 1 1 1 1 1 1 1 1 1 *ROW 10
1 1 1 1 1 1 1 1 1 1 1 *ROW 11
1 1 2 1 1 2 1 1 2 1 1 2 *ROW 12
1 1 1 1 1 1 1 1 1 1 1 1 1 *ROW 13
1 1 1 2 1 1 1 1 1 1 1 1 1 2 *ROW 14
1 1 1 1 1 2 1 1 2 1 1 2 1 1 1 *ROW 15
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 *ROW 16
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 *ROW 17
LFU
1 *ROW 1
1 1 *ROW 2
1 1 1 *ROW 3
1 1 1 0 *ROW 4
1 1 1 1 1 *ROW 5
1 1 0 1 1 0 *ROW 6
1 1 1 1 1 1 1 *ROW 7
1 1 1 1 1 1 1 1 *ROW 8
1 1 0 1 1 0 1 1 0 *ROW 9
1 1 1 1 1 1 1 1 1 1 *ROW 10
1 1 1 1 1 1 1 1 1 1 1 *ROW 11
1 1 0 1 1 0 1 1 0 1 1 0 *ROW 12
1 1 1 1 1 1 1 1 1 1 1 1 1 *ROW 13
1 1 1 0 1 1 1 1 1 1 1 1 1 0 *ROW 14
1 1 1 1 1 0 1 1 0 1 1 0 1 1 1 *ROW 15
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 *ROW 16
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 *ROW 17
FST,4*0.49784/4*1.45542/8*'MI1'/8*'COO'/
STA
TIT TFU=293.15 TMO=293.15 BOR=0 * DC COOK
FUE 1 10.412/4.5 *95% TD, 4.5% ENR
STA
TIT TFU=293.15 TMO=293.15 BOR=0 * DC COOK
FUE 1 10.412/4.0 *95% TD, 4.0% ENR
STA
TIT TFU=293.15 TMO=293.15 BOR=0 * DC COOK
FUE 1 10.412/3.5 *95% TD, 3.5% ENR
```

```
STA
TIT TFU=293.15 TMO=293.15 BOR=0 * DC COOK
FUE 1 10.412/3.0 *95% TD, 3.0% ENR
STA
TIT TFU=293.15 TMO=293.15 BOR=0 * DC COOK
FUE 1 10.412/2.5 *95% TD, 2.5% ENR
STA
END
```

7.2 KENO-Va Model for Checkerboard Loading

The KENO model for the spent fuel racks with a checkerboard loading of 4.0 and 5.0 percent enrichments is listed below.

```
DC COOK, SPENT FUEL RACKS, 4.0% X 5.0% CHECKERBOARD LOADING
READ PARAMETERS
TME=60.0 GEN=103 NPG=500 LIB=41 TBA=2.0
FLX=YES FDN=YES XS1=YES NUB=YES PWT=YES
PLT=NO
END PARAMETERS
READ MIXT  SCT=1
MIX= 1
'  UO2 PELLET, 4.0% ENR, 95% TD
     92235  9.406816E-04
     92238  2.229106E-02
      8016  4.646348E-02
MIX= 2
'  UO2 PELLET, 5.0% ENR, 95% TD
     92235  1.175834E-03
     92238  2.205852E-02
      8016  4.646871E-02
MIX= 3
'  ZIRCALOY
     40302  4.251812E-02
MIX= 4
'  WATER
      8016  3.337967E-02
      1001  6.675933E-02
MIX= 5
'  BORAL, 0.020 GM B-10/SQCM, 0.071" THK
'  BORAL, B-10 = 0.020 GM/SQCM (95% MIN VALUE = 0.0232)
'  AT 0.071" THICK, B-10=1.1090E-1 GM/CC
'  = 0.1109/10.0129 G MOL/CC = 1.1076E-2 GMOL/CC (B-10 ONLY)
'  TOTAL BORON = 1.1076E-2/0.1976 G MOL/CC = 5.6052E-2 GMOL/CC
'  = 3.3761E-2 ATOM/(BARN-CM) = 0.606 GM B/CC
```

```
  5000 3.3761-2
  6012 8.4402-3
'  BORAL DENSITY IS 2.49 GM/CC
'  = 0.606 GM B/CC + 0.1683 GM C/CC + 1.7157 GM AL/CC
     13027  3.8299-2
MIX= 6
'  ALUMINUM
     13027  6.024185E-02
MIX= 7
'  304SS
     24304  1.742958E-02
     25055  1.736443E-03
     26304  5.935923E-02
     28304  7.718178E-03
END MIXT
READ GEOMETRY
UNIT  1
COM="  4.0% ROD, BUNDLE 1        "
CYLI  1 1 0.38481 2P100.0
CYLI  0 1 0.3937 2P100.0
CYLI  3 1 0.4572 2P100.0
CUBO  4 1 4P0.62992 2P100.0
UNIT  2
COM="  5.0% ROD, BUNDLE 2        "
CYLI  2 1 0.38481 2P100.0
CYLI  0 1 0.3937 2P100.0
CYLI  3 1 0.4572 2P100.0
CUBO  4 1 4P0.62992 2P100.0
UNIT  3
COM="  GUIDE TUBE                "
CYLI  4 1 0.56895 2P100.0
CYLI  3 1 0.60955 2P100.0
CUBO  4 1 4P0.62992 2P100.0
UNIT  4
COM="  BUNDLE 1                  "
ARRAY 1 2*-10.70864 -100.0
REPLICATE  4 1 4R0.6731 2R0.0 1
REPLICATE  7 1 4R0.1905 2R0.0 1
REPLICATE  6 1 4R0.0254 2R0.0 1
REPLICATE  5 1 4R0.18034 2R0.0 1
REPLICATE  6 1 4R0.0254 2R0.0 1
REPLICATE  7 1 4R0.0762 2R0.0 1
REPLICATE  4 1 4R1.45542 2R0.0 1
UNIT  5
COM="  BUNDLE 2                  "
ARRAY 2 2*-10.70864 -100.0
REPLICATE  4 1 4R0.6731 2R0.0 1
```

```
REPLICATE  7 1 4R0.1905 2R0.0 1
REPLICATE  6 1 4R0.0254 2R0.0 1
REPLICATE  5 1 4R0.18034 2R0.0 1
REPLICATE  6 1 4R0.0254 2R0.0 1
REPLICATE  7 1 4R0.0762 2R0.0 1
REPLICATE  4 1 4R1.45542 2R0.0 1
GLOBAL
UNIT 6
ARRAY 3 3R0.0
END GEOMETRY
READ ARRAY
ARA=1 NUX=17 NUY=17 NUZ=1
LOOP
1  1 17 1  1 17 1  1 1 1
3  6 12 3  3 15 12  1 1 1
3  4 14 10  4 14 10  1 1 1
3  3 15 3  6 12 3  1 1 1
END LOOP
ARA=2 NUX=17 NUY=17 NUZ=1
LOOP
2  1 17 1  1 17 1  1 1 1
3  6 12 3  3 15 12  1 1 1
3  4 14 10  4 14 10  1 1 1
3  3 15 3  6 12 3  1 1 1
END LOOP
ARA=3 NUX=2 NUY=2 NUZ=1
FILL 4 5 5 4 END FILL
END ARRAY
READ START
NST=1
END START
READ BOUNDS
XYF=PERIODIC ZFC=SPECULAR
END BOUNDS
END DATA
```

7.3 Fuel Depletion Runs (CASMO)

The CASMO-3 input below performed the fuel depletion calculation up to 60 GWD/MTU and then, using the results from the depletion calculations, calculated the in-core k-inf values at 20°C temperature, zero dissolved boron, and zero Xe-131/135.

```
DIM,17,8
TIT TFU=1023.0 TMO=592.1 BOR=1000 IDE='REST' * DC COOK, TOP OF BUNDLE
FUE 1 10.412/5.0 *95%TD, 5.0%ENR
PIN 1 0.38481 0.3937 0.4572/'FUE' 'AIR' 'CAN'//1
PIN 2 0.5690 0.6096/'COO' 'CAN'//1 * GUIDE TUBE
PWR,17,1.25984,21.50364,4*0,8
LPI
2
1 1
1 1 1
2 1 1 2
1 1 1 1 1
1 1 1 1 1 2
2 1 1 2 1 1 1
1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1
LFU
0
1 1
1 1 1
0 1 1 0
1 1 1 1 1
1 1 1 1 1 0
0 1 1 0 1 1 1
1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1
DEP,-60
WRE,-60
STA
TIT * COLD, ZERO BORON
RES,'REST',5,10,15,20,25,30,35,40,45,50,55,60
TMO,293
TFU,293
BOR,0
CNU,'FUE',54131,0
CNU,'FUE',54135,0
LIS
STA
END
```

8.0 REFERENCES

(1) "SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation," NUREG/CR-0200.

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

(3) S. R. Bierman, B. M. Durst and E. D. Clayton, "Critical Separation Between Subcritical Clusters of 4.31% Enriched UO_2 Rods in Water With Fixed Neutron Poisons,' NUREG/CR-0073, May 1978.

CRITICALITY SAFETY ANALYSIS

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WITH 15X15 AND 17X17 FUEL ENRICHMENTS UP TO 5.0 PERCENT

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Attachment 5 to AEP:NRC:1071
ANF 88-09, "Thermal-Hydraulic Analysis
Of The D. C. Cook Spent Fuel Pool"