LFNF-95-02
CALLAWAY PLANT REGION 1
SPENT FUEL RACK
CRITICALITY ANALYSIS
REV.0

Nuclear Fuel Group
Licensing and Fuels Department
Union Electric Company
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SPENT FUEL RACK CRITICALITY ANALYSIS

REV.0

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ABSTRACT

This report describes Union Electric Company's methodology and techniques for analyzing the criticality safety of fuel storage in Region 1 of the Callaway spent fuel racks. The development of the limiting IFBA versus enrichment curve for storage of fresh fuel is also discussed. Benchmarking of the applicable codes is also presented herein.

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1.0 INTRODUCTION

1.1 PURPOSE

The Callaway Region 1 spent fuel rack is an unpoisoned rack, which will be analyzed for storage of Westinghouse 17x17 Vantage-5 (V-5) fuel assemblies. The fuel assemblies are stored in two of four storage locations in the fuel racks in a checkerboard array. The criticality analysis assumes non-borated water in the fuel pool, and utilizes Integral Fuel Burnable Absorber (IFBA) credit to ensure that K_{eff} is ≤ 0.95.

Currently, new fuel for Callaway which exceeds an enrichment of 3.85 w/o U-235 requires the presence of a certain number of IFBA rods to maintain the subcriticality of the spent fuel pool. The analysis given herein presents the overall methodology for updating the IFBA vs. enrichment curve for fuel specific to Callaway.

The neutron absorbing material utilized in the IFBA rods is a thin zirconium diboride coating on the outside of the fuel pellets, containing enriched Boron-10. This neutron absorbing material is non-removable and thus an integral part of the fuel assembly.

1.2 GENERAL METHODOLOGY

Two independent code packages were used for determining criticality safety. The overall methodology for determining criticality safety and the IFBA vs. enrichment curve used the NITAWL code for cross section generation and the KENO-V.a code for reactivity determination. The CASMO code was utilized for generating an equivalent reference k-infinity for use as an option in determining the acceptability of spent fuel storage.

The methodologies for determining criticality safety have been verified by comparison with critical experiment data for configurations that impose a stringent test of the capability of the analytical methodologies. These experiments are chosen to ensure that the method bias and uncertainty are conservative and, with a high level of confidence, applicable to the Callaway spent fuel racks.

1.3 DESIGN CRITERIA

The results of the benchmarking and production runs are used to determine the IFBA vs. enrichment curve for V-5 fuel assemblies. The IFBA vs. enrichment curve is developed to ensure that there is a 95 percent probability at a 95 percent confidence level that the effective multiplication factor of the Region 1 fuel racks will be ≤ 0.95 as recommended in Reference 1.

1.4 SIMILARITY TO PREVIOUSLY-LICENSED METHODS

Union Electric's criticality analysis methodology, as described in this report, is based on methods developed by HOLTEC International[2], which have been previously accepted by the USNRC.

2.0 BENCHMARK CALCULATIONS

Two separate and independent design methods were used to analyze the Callaway Region 1 spent fuel racks. The first method uses the SCALE* code system[3] which includes the NITAWL program to provide cross section data, including self-shielded resonance cross sections, for input into the Monte Carlo theory KENO-V.a program. The second method utilizes the transport theory CASMO-3[4] code to generate a reference fuel assembly k-infinity.

Union Electric controls the use of the codes described above through firm adherence to procedures governed by Union Electric's Quality Assurance program. These procedures address such subjects as preparation of calculations; software validation, verification, installation, and documentation; software development; and control of nuclear analysis activities.

2.1 NITAWL/KENO-V.a BENCHMARKING

The 27 group SCALE cross section library (derived from the ENDF/B-IV data compilation and collapsed from the 218 group library) was chosen for this analysis since it was developed specifically for criticality safety analysis of more thermal systems. The Nordheim integral resonance treatment is used to account for the effects of the resonance absorption in U-238. NITAWL calculates the Uranium-238 self-shielding, accounting for the presence of other fuel in an assembly through the use of a Dancoff factor (evaluated with the ORNL SUPERDAN routine).

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*SCALE is an acronym for Standardized Computer Analyses for Licensing Evaluation (NUREG/CR-0200)

Two sets of critical experiments have been selected for analysis. The first set is the Babcock & Wilcox (B & W) Critical Experiments[5] which consist of low-enriched (2.46 w/o) UO_2 fuel pins in a water-moderated lattice that simulates close-packed LWR fuel storage configurations. The critical experiments consist of nine LWR-type fuel assemblies grouped in a 3x3 array, using both spacing and absorber materials to provide numerous critical configurations. The second set of experiments is the Battelle Northwest Laboratory (BNWL) Critical Experiments[6] which utilize a higher U-235 enrichment (4.306 w/o) for simulating LWR fuel storage configurations. A total of 23 experiments were analyzed which included various spacings, enrichments, and neutron absorbing materials to adequately demonstrate the accuracy of the methodology and code packages.

A summary of the NITAWL/KENO-V.a results[7,8] for the 23 critical experiments analyzed is presented in Table 1. The average calculated K_{eff} for the 23 experiments is 0.9918 with a standard deviation of the mean of 0.0007 delta k. Since the measured average of the 23 criticals is 1.0000, the final methodology bias to be applied to the NITAWL/ KENO-V.a model is +0.0082 ± 0.0017 delta k, evaluated at the 95% probability, 95% confidence level (the 95%/95% one sided tolerance limit for 23 values is 2.329[9]).

2.2 CASMO-3 BENCHMARKING

CASMO-3 is a multigroup two-dimensional transport theory code used for burnup calculations on BWR and PWR assemblies or simple pin cells. The nuclear data library contains microscopic cross sections in 40 energy groups covering neutron energies from 0 to 10 Mev.

To confirm the ability of CASMO-3 to properly perform depletion calculations and calculate isotopic inventories, a set of benchmark calculations was previously performed[10]. The Union Electric version of CASMO-3 was validated against the Yankee Rowe Core I isotopic benchmarks. Those results clearly show that CASMO-3 correctly performs depletion/burnup calculations and also calculates the correct isotopic inventories.

2.3 BENCHMARK COMPARISONS

The results of the above benchmark calculations are consistent with the published benchmark results of ORNL[11] and Studsvik[12].

TABLE 1

NITAWL/KENO-V.a BENCHMARK CRITICAL RESULTS

CRITICAL EXPERIMENT	ENRICHMENT U-235 W/O	ABSORBER MATERIAL	SOLUBLE BORON	K-EFFECTIVE
B & W I	2.46	WATER	0	0.98808 +/- 0.00308
B & W II	2.46	WATER	1037	0.99600 +/- 0.00305
B & W III	2.46	WATER	764	0.99540 +/- 0.00260
B & W IX	2.46	WATER	0	0.98842 +/- 0.00300
B & W X	2.46	WATER	143	0.99434 +/- 0.00261
B & W XI	2.46	STAINLESS STEEL	514	0.99024 +/- 0.00279
B & W XII	2.46	STAINLESS STEEL	217	0.99297 +/- 0.00285
B & W XIII	2.46	BORATED AL	15	0.99905 +/- 0.00334
B & W XIV	2.46	BORATED AL	92	0.98768 +/- 0.00325
B & W XV	2.46	BORATED AL	395	0.98875 +/- 0.00300
B & W XVI	2.46	BORATED AL	121	0.98639 +/- 0.00315
B & W XVII	2.46	BORATED AL	487	0.98939 +/- 0.00241
B & W XVIII	2.46	BORATED AL	197	0.98868 +/- 0.00297
B & W XIX	2.46	BORATED AL	634	0.98905 +/- 0.00264
B & W XX	2.46	BORATED AL	320	0.98877 +/- 0.00289
B & W XXI	2.46	BORATED AL	72	0.98948 +/- 0.00290
BNWL 9	4.306	BORATED AL	0	0.99055 +/- 0.00308
BNWL 11	4.306	BORATED AL	0	0.99633 +/- 0.00297
BNWL 12	4.306	BORATED AL	0	0.99622 +/- 0.00328
BNWL 13	4.306	STAINLESS STEEL	0	0.99234 +/- 0.00288
BNWL 14	4.306	STAINLESS STEEL	0	0.99419 +/- 0.00362
BNWL 29	4.306	ZIRCALOY	0	0.99324 +/- 0.00303
BNWL 32	4.306	WATER	0	0.99501 +/- 0.00325

MEAN = 0.9918   SIGMA = 0.0007

BIAS = 0.0082 +/- 0.0017

(95%/95%)

3.0 CALCULATIONAL APPROACH

3.1 GENERAL DESCRIPTION

As previously discussed, two separate and independent code packages were utilized in analyzing Region 1 of the Callaway spent fuel racks. The NITAWL/KENO-V.a code set was used for determining the maximum spent fuel rack reactivity for developing the limiting fresh fuel IFBA vs. enrichment curve. The 3-dimensional geometry modeled in KENO-V.a took into account the details of the fuel assemblies and the fuel rack storage cells. The reference model geometry used for the KENO-V.a calculations was a repeating array of four stainless steel boxes, two of which contain fuel assemblies and the remaining two contain only water and serve as flux traps. The specific geometry and nominal dimensions of the Region 1 spent fuel racks are shown in Figure 1.

The NITAWL/KENO-V.a calculational approach was to use the reference model to calculate the reactivity of an array of uniform spent fuel racks and to account for any deviations of the actual spent fuel rack array as uncertainties on the calculated reactivity of the basic cell. Calculational bias, manufacturing tolerances, and uncertainties were evaluated in terms of the reactivity changes to the reference model.

The CASMO-3 code was used in determining a reference k-infinity which can be used as an alternate for determining the acceptability of a fuel assembly for storage in the spent fuel racks. This calculation is performed using the maximum Region 1 enrichment with no credit for burnable absorbers.

3.2 KENO-V.a REACTIVITY CALCULATIONS

3.2.1 Zero IFBA Enrichment Calculations

This analysis was performed for Vantage-5 fuel. The key fuel parameter in this analysis is fuel rod size. Grids and axial blankets are not taken into account. Consequently this analysis is considered applicable to all Westinghouse designs with fuel rod parameters similar to those described herein. The V-5 fuel design parameters are provided in Table 2. The reference V-5 fuel assembly chosen for evaluation was a typical Callaway assembly with an initial enrichment of 4.0 w/o at zero burnup, with no IFBA rods. The following assumptions were utilized in developing the nominal zero IFBA enrichment cases:

1) The fuel assembly is a Westinghouse V-5 assembly and does not include any burnable absorbers.

3) The fuel pellets are modelled at nominal 95.25 percent theoretical density, with nominal dishing and chamfering.

3) No credit is taken for any grid material.

4) The fuel assemblies are loaded in 2 of 4 cells in the checkerboard Callaway Region 1 fuel rack configuration.

5) The array is infinite in the lateral and axial directions.

Initial NITAWL/KENO-V.a calculations were performed to determine the point of maximum reactivity within the operating temperature range of the spent fuel pool, i.e. 68°F to 248°F. The reactivity change due to temperature is shown in Figure 2 and shows a peak in reactivity at 68°F; thus the principle calculations were performed at a temperature of 68°F.

A number of tolerances which result in reactivity uncertainties must be considered in the criticality analysis. From the KENO-V.a runs, the reactivity uncertainties which result in a positive deviation are as follows (in units of delta k):

TOLERANCE OR UNCERTAINTY	REACTIVITY DEVIATION
Stainless Steel Box Spacing Tolerance (8.996" ± 0.030")	0.0019
Stainless Steel Thickness Tolerance (0.120" ± 0.004")	0.0017
Fuel Density Tolerance (increase from 95.25% to 97%)	0.0035
Fuel Enrichment Tolerance (increase of 0.05 w/o)	0.0024

Reference 1 allows the reactivity deviations due to independent tolerances and uncertainties to be combined statistically, i.e. an RMS average, to determine a single reactivity uncertainty which is added to the calculated reference cell multiplication factor (including bias). When this is done, the total reactivity deviation to be added to the reference cell to account for all of the tolerances and uncertainties is 0.0050 delta k. An additional uncertainty term to be included is the KENO-V.a run statistics, with a 1σ of 0.0007 delta k, which must be evaluated at the one-sided tolerance limit for a 95% probability at the 95% confidence level. The KENO-V.a run utilized 2500 generations, thus the 95%/95% one-sided tolerance limit is 1.696, resulting in a KENO-V.a calculational uncertainty of 0.0017.

The following equation was used to determine the maximum k-effective for the Region 1 spent fuel racks.

$$K_m = 0.95 - B_m - \sqrt{((K_S)^2 + (K_U)^2 + (K_B)^2)}$$

where: K_m = the maximum k-effective

B_m = the UE KENO-V.a method bias from analysis of the critical experiments
= 0.0082

K_S = the KENO-V.a run statistics (95%/95%)
= 0.0012

K_U = the reactivity deviation due to tolerances and uncertainties
= 0.0050

K_B = the calculational uncertainty due to the method
= 0.0017

Using the above inputs, the maximum allowable calculated k-effective from KENO-V.a for a V-5 assembly is :

$$K_m = 0.95 - 0.0082 - \sqrt{((0.0012)^2 + (0.0050)^2 + (0.0017)^2)}$$
$$= 0.9364$$

Using the KENO-V.a run results and the above k-effective, the maximum enrichment for utilizing zero IFBAs to maintain $k \leq 0.95$ is calculated to be 4.15 w/o. To ensure added conservatism, an enrichment of 4.10 w/o is chosen as the maximum enrichment with no IFBAs. This results in a maximum spent fuel rack k-effective of 0.9481, including bias and uncertainties.

3.2.2 IFBA vs. Enrichment Curve Development

This section describes the methodology for determining the limiting IFBA versus enrichment curve for storing fresh fuel above the nominal 4.10 w/o in the Callaway Region 1 spent fuel racks. The concept of reactivity equivalencing is utilized in establishing the number of IFBA rods required to maintain k-effective ≤ 0.95. Reactivity equivalencing is utilized by accounting for the decrease in reactivity associated with the addition of IFBA fuel rods and fuel depletion, if applicable. The IFBA vs. enrichment curve is determined from the NITAWL/ KENO-V.a data.

The reference calculations are performed with a 5.0 w/o U-235 V-5 fuel assembly with various IFBA rod configurations to determine a k-effective equivalent to that determined in Section 3.2.1. The calculations are performed at zero burnup. Calculations performed using CASMO-3 show that for the number of IFBA rods considered in this analysis, the maximum reactivity for rack geometry occurs at zero burnup. Although the boron concentration in the IFBA rods decreases with fuel depletion, the fuel assembly reactivity decreases more rapidly, resulting in a maximum fuel rack reactivity at zero burnup.

The following assumptions were used for the IFBA rod assemblies:

1) The IFBA absorber material is a zirconium diboride (ZrB_2) coating on the fuel pellet. Each IFBA rod has a nominal poison material loading of 3.00 mg B-10 per inch (as enriched boron).

2) The IFBA rod locations are modeled with the standard Westinghouse patterns of 16, 32, and 48 rods per assembly.

3) Each IFBA rod is modeled for the nominal Callaway length of 120 inches.

4) The fuel pellets are modelled at nominal 95.25 percent theoretical density, with nominal dishing and chamfering.

5) No credit is taken for any grid material.

6) The fuel assemblies are loaded in 2 of 4 cells in the checkerboard Callaway Region 1 fuel rack configuration.

7) The array is infinite in the lateral direction and finite in the axial directions.

A number of IFBA tolerances and uncertainties which result in reactivity uncertainties which must be considered in the criticality analysis. From the KENO-V.a runs, the reactivity uncertainties which result in a positive deviation are as follows (in units of delta k):

TOLERANCE OR UNCERTAINTY	REACTIVITY DEVIATION
B-10 Loading Tolerance (5% [13])	0.0006
IFBA Stack Length Tolerance (± 6 in.)	0.0061
IFBA Rod Position Uncertainty	0.0069

The IFBA stack length uncertainty is based on Westinghouse manufacturing gamma scan limitations. The IFBA configuration for the rod position uncertainty case was chosen to maximize the reduction in the reactivity holddown of the assembly.

Reference 1 allows the reactivity deviations due to tolerances and uncertainties to be combined statistically, i.e. an RMS average, to determine a single reactivity uncertainty which is added to the calculated reference cell multiplication factor (including bias). The above IFBA uncertainties are combined with the uncertainties determined in Section 3.2.1, and thus, for an IFBA assembly the total reactivity deviation to be added to the reference cell to account for all of the tolerances and uncertainties is 0.0105 delta k.

The maximum allowable k-effective determined in Section 3.2.1 is 0.9481, for an equivalent 4.10 w/o U-235 fuel assembly. The following equation was used to determine the limiting IFBA vs. enrichment curve for the Region 1 spent fuel racks.

$$K_m = 0.9481 - B_m - \sqrt{((K_S)^2 + (K_U)^2 + (K_B)^2)}$$

where: K_m = the maximum k-effective

B_m = the UE KENO-V.a method bias from the critical experiments
= 0.0082

K_S = the KENO-V.a run statistics (95%/95%)
= 0.0012

K_U = the reactivity deviation due to tolerances and uncertainties
= 0.0105

K_B = the calculational uncertainty due to the method
= 0.0017

Using the above inputs, the maximum allowable calculated k-effective from the KENO-V.a IFBA calculations is :

$$K_m = 0.9481 - 0.0082 - \sqrt{((0.0012)^2 + (0.0105)^2 + (0.0017)^2)}$$
$$= 0.9292$$

Using the KENO-V.a run results, the final IFBA vs. enrichment limits were determined by interpolating for the number of IFBAs to satisfy the above k-effective. For V-5 fuel, the required number of IFBAs as a function of initial enrichment are presented graphically in Figure 3. The curve shows the enrichment for zero IFBA rods at 4.10 w/o

U-235, and at 5.0 w/o U-235 enrichment the required number of IFBA rods is 21. Current Westinghouse IFBA patterns are limited to 16 or 32 rods per assembly. Thus the practical limits for assemblies with enrichments greater than 4.1 w/o U-235 and less than 4.8 w/o U-235 are 16 IFBA rods, and for assemblies with enrichments greater than 4.8 w/o U-235 are 32 IFBA rods. The data in Figure 3 is also presented in Table 3.

3.3 REFERENCE K-INFINITY CALCULATION

The reference k-infinity calculation performed using CASMO-3 provides an option for determining the acceptability of storing fuel assemblies in the Callaway Region 1 spent fuel racks. The reference k-infinity calculation is performed utilizing the nominal 4.10 w/o V-5 fuel assembly.

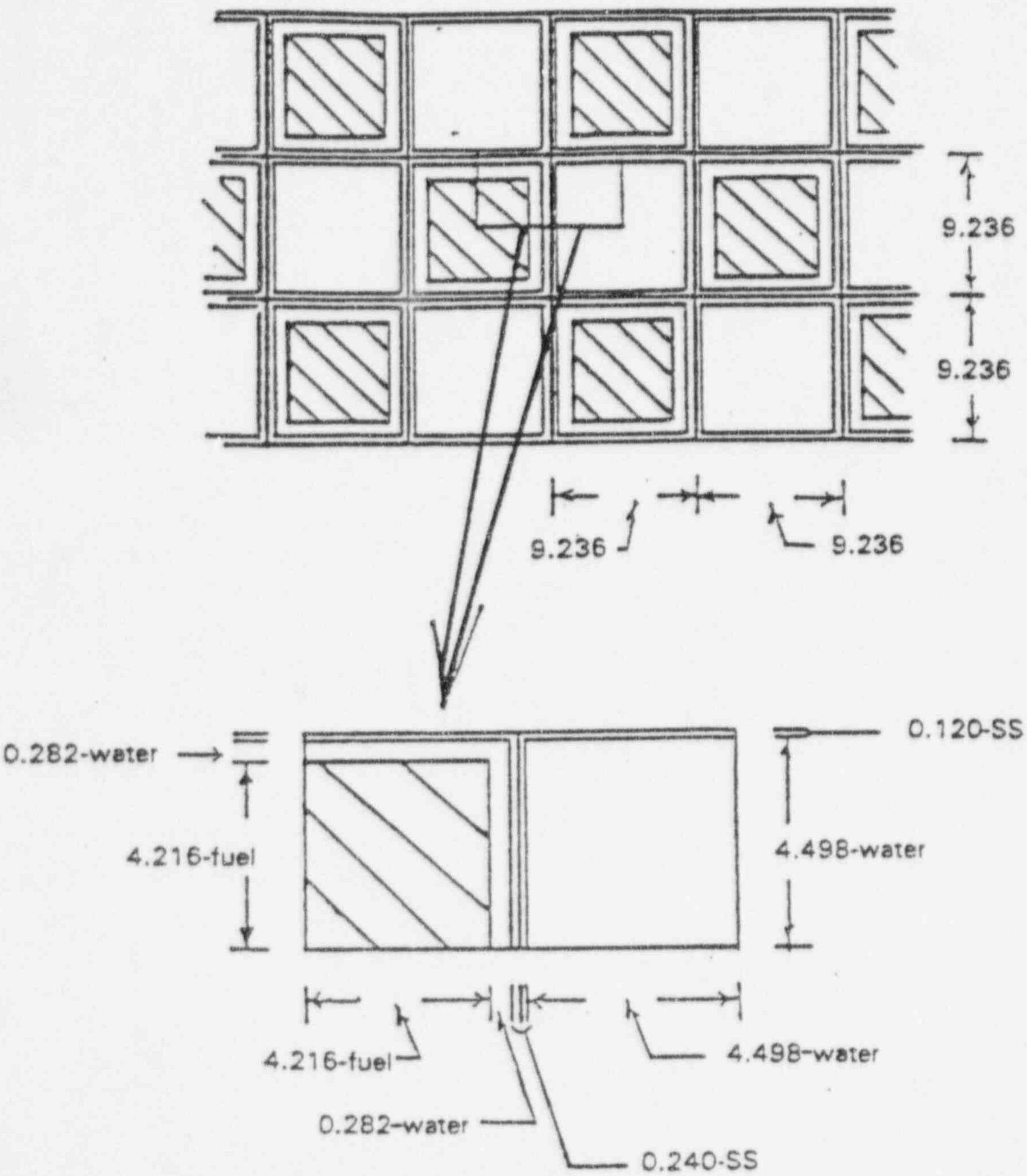
The k-infinity calculation is performed with the CASMO-3 code, with the following assumptions:

1) The fuel assembly is a Westinghouse V-5 assembly and does not include any burnable absorbers.
2) The fuel rod enrichment is 4.10 w/o U-235 over the infinite length of each rod.
3) The fuel pellets are modelled at nominal 95.25 percent theoretical density, with nominal dishing and chamfering.
4) The fuel array is in the Callaway reactor geometry.
5) The moderator is at a temperature of 68°F.

The calculated reference k-infinity is determined to be 1.480. This includes a 1% delta k reactivity bias as recommended in Reference 13. This bias is used to conservatively account for calculational uncertainties and is consistent with the standard conservatism included in the Callaway core design refueling shutdown margin calculations. Fuel assemblies which are to be placed in the Callaway Region 1 spent fuel racks must meet the requirements of Figure 3, or have a reference k-infinity less than or equal to the above value, to ensure that the final k-effective of the Callaway Region 1 spent fuel racks is ≤ 0.95.

FIGURE 1

CALLAWAY REGION 1 GEOMETRY



NOTE: ALL DIMENSIONS IN INCHES.

TABLE 2

FUEL PARAMETERS FOR CRITICALITY ANALYSIS

PARAMETER	17 X 17 V-5 ASSEMBLY
Number of Fuel Rods Per Assembly	264
Cladding O.D. (in.)	0.360
Cladding Thickness (in.)	0.0225
Fuel Pellet O.D. (in.)	0.3088
Fuel Pellet Density	0.9525
Fuel Pellet Dishing & Chamfering Factor	0.9881
Rod Pitch (in.)	0.496
Number of Instrument/ Guide Tubes	25
Guide Tube O.D. (in.)	0.474
Guide Tube Thickness (in.)	0.016

FIGURE 2

CALLAWAY REGION 1
REACTIVITY VS. TEMPERATURE

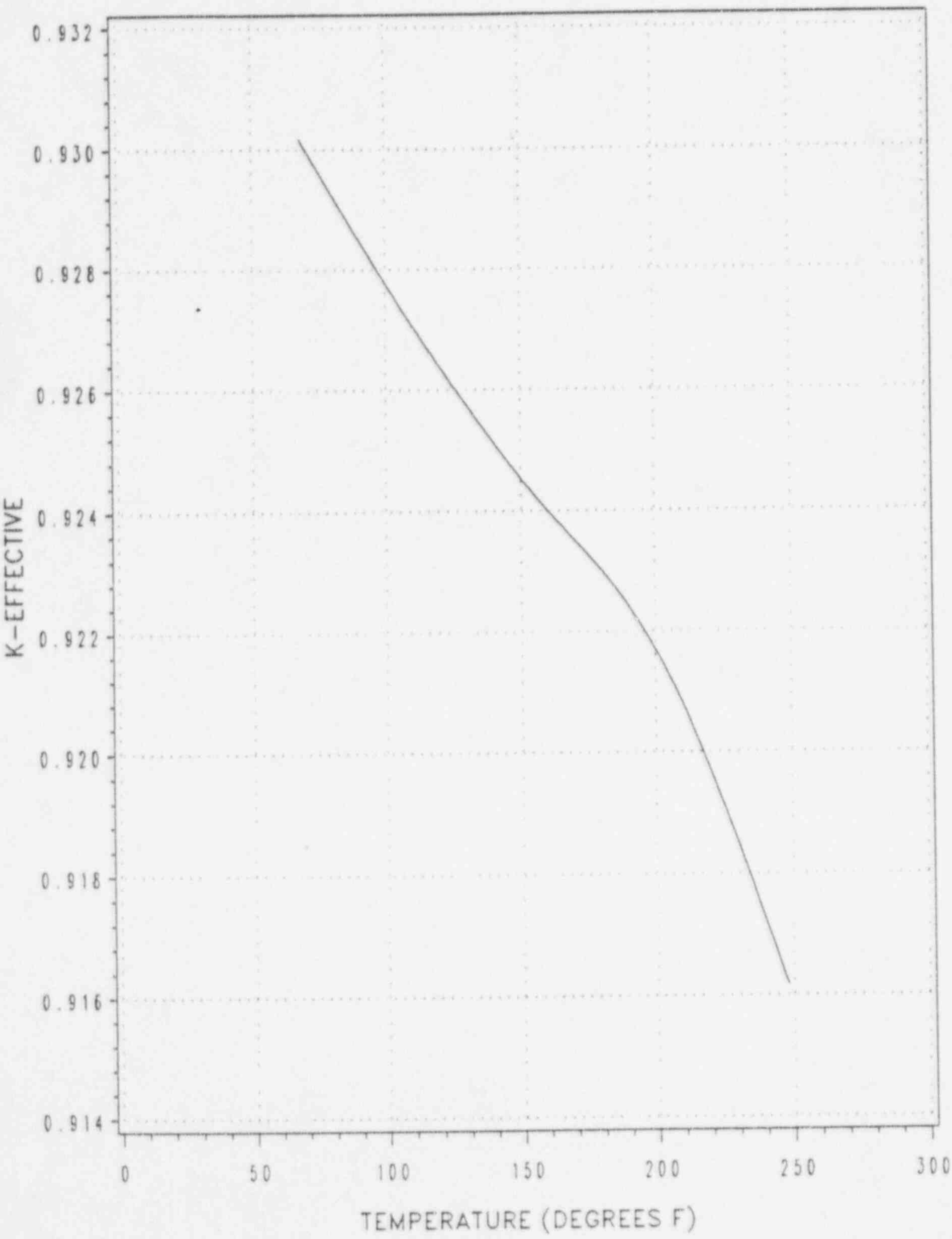


FIGURE 3

CALLAWAY REGION 1

IFBA VS. ENRICHMENT CURVE

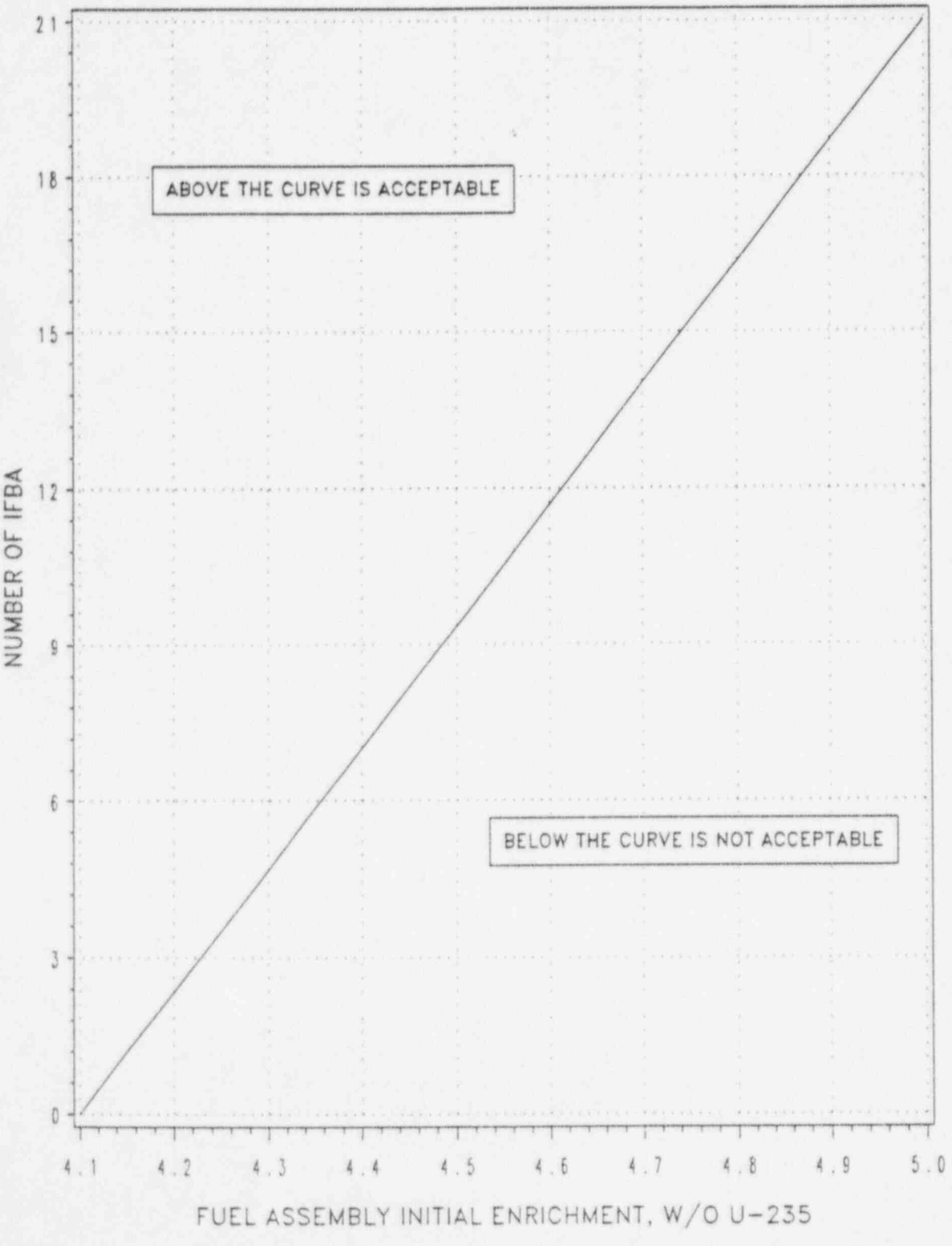


TABLE 3

CALLAWAY FUEL ASSEMBLY MINIMUM IFBA RODS VS. INITIAL U-235 ENRICHMENT FOR REGION 1 SPENT FUEL RACK

INITIAL ENRICHMENT	NUMBER OF IFBA RODS
4.1 w/o	0
4.2 w/o	3
4.4 w/o	7
4.6 w/o	12
4.8 w/o	17
5.0 w/o	21

4.0 ACCIDENT CONDITIONS

To ensure the safety of fuel storage in the spent fuel racks, an evaluation of the reactivity consequences of abnormal/accident conditions must be performed. These conditions are as follows[14]:

(1) Fuel assembly positioned eccentrically in the cells
(2) Fuel element located outside and adjacent to the rack
(3) Fuel element dropped on top of the rack
(4) Misloading an assembly with an unacceptable number of IFBAs
(5) Misloading an assembly in an empty water cell

Conditions 1, 3, & 5 will not result in an increase in k-effective. Studies of asymmetric positioning performed by Westinghouse for similar rack configurations[13] have shown that symmetrically positioned fuel assemblies yield the most conservative results. For the case of the fuel assembly dropped on the racks, the dropped assembly is separated from the active fuel height of the assemblies in the rack by more than 21 inches of water. The distance from the bottom of the rack to the top of the lead-in guides is 169.05", and the distance from the bottom of the bottom nozzle to the top of the active fuel is 147.499", resulting in a separation of >21". Since 30 cm of water (~12") is considered infinite reflection, the separation precludes neutron interaction between the assemblies. Fuel assemblies are prevented from insertion into water cells by the permanently installed lead-in guides.

Conditions 2 & 4 are postulated conditions which would result in an increase in reactivity. For these cases, the double contingency principle of ANSI N16.1-1975 can be applied; thus the presence of borated water can be assumed as a realistic initial condition. The typical boron concentration of the Callaway spent fuel pool is 2000 ppm boron. The above accident conditions were thus analyzed using a soluble boron concentration of 2000 ppm.

4.1 FUEL ELEMENT ADJACENT TO AND OUTSIDE RACK

This case assumes that an assembly is accidentally placed outside of, but adjacent to, the fuel storage racks. As stated above, this accident condition allows for analysis with the presence of soluble boron. The assemblies in the rack were assumed to be the nominal 4.10 w/o V-5 assembly in a 2 out of 4 condition, with zero IFBAs. The assembly outside of the racks was assumed to be a fresh fuel assembly of the maximum reactivity, which was determined to also be a 4.10 w/o V-5 assembly with no IFBAs.

The results of this accident show that with a boron concentration of 2000 ppm, the k-effective of the spent fuel racks is 0.7602, including bias and uncertainties.

4.2 MISLOADING OF AN ASSEMBLY WITH AN UNACCEPTABLE IFBA PATTERN

This case assumes that an assembly with an unacceptable number of IFBAs is accidentally misplaced in Region 1 of the spent fuel racks. The most limiting case for this scenario is placing a fresh 5.00 w/o V-5 fuel assembly with no IFBAs in the middle of an 8 X 8 array of 4.10 V-5 fuel with no IFBAs.

The results of this accident show that with a boron concentration of 2000 ppm, the k-effective of the spent fuel racks is 0.7119, including bias and uncertainties.

5.0 SUMMARY AND CONCLUSIONS

The NITAWL/KENO-V.a code package was utilized to assess the criticality safety of Region 1 of the Callaway spent fuel racks and to determine the final k-effective value for developing the limiting IFBA versus enrichment curve. Using KENO-V.a, a maximum calculated k-effective for the spent fuel racks of 0.9481, including bias and uncertainties, ensures that the final k-effective of the Callaway Region 1 spent fuel racks is ≤ 0.95. The IFBA versus enrichment curve for V-5 fuel was developed using data from the NITAWL/KENO-V.a calculations, and includes the methodology bias and the manufacturing tolerances and uncertainties. The CASMO-3 code was utilized for determining a reference k-infinity for use as an option in determining acceptability for fuel storage in Region 1. The reference k-infinity value was calculated to be 1.480, which includes a 1% delta k bias to account for calculational uncertainties. Analysis of the credible accident conditions confirms that the resulting k-effective, taking into account a soluble boron concentration of 2000 ppm, is ≤ 0.95, including bias and uncertainties.

Results of the critical experiment benchmarks demonstrate that Union Electric's methods for performing criticality analyses are both appropriate and valid. The results are consistent with previous analyses performed for the Callaway spent fuel racks. Furthermore, Union Electric's criticality analysis methods are similar to methods previously accepted by the NRC. Therefore, in view of the demonstrated validity of the methods described herein, Union Electric concludes that the criticality analysis for the Callaway Region 1 spent fuel storage racks is acceptable.

6.0 REFERENCES

1. OT Position for Review and Acceptance of Spent Fuel Storage and Handling Applications, Nuclear Regulatory Commission Letter to All Power Reactor Licensees, from B. K. Grimes, April 14, 1978

2. Criticality Safety Evaluation of Region 1 of the Diablo Canyon Spent Fuel Storage Racks with Fuel of 5% Enrichment, HOLTEC International, HI-931076, (1995)

3. SCALE 4, A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation, Oak Ridge National Laboratory

4. CASMO-3, A Fuel Assembly Burnup Program, User's Manual, Version 4.4, Studsvik/NFA-89/3

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

6. NUREG/CR-0073, Critical Separation Between Subcritical Clusters of 4.29 wt% U235 Enriched UO2 Rods in Water with Fixed Neutron Poisons, S. R. Bierman, et al, August 1979

7. Calculation NFDC 91-024, B & W Critical Experiments - KENO-Va Benchmarking, J. M. Moose, January 1992

8. Calculation NFDC 92-025, BNWL Critical Experiments - KENO-Va Benchmarking, J. M. Moose, January 1992

9. National Bureau of Standards Handbook 91, Experimental Statistics

10. Report LFNF 92-002, Rev. 0, Callaway Plant Region 2 Spent Fuel Rack Criticality Analysis, J. M. Moose, May 1992

11. R. W. Westfall and J. H. Knight, "SCALE System Cross-Section Validation with Shipping Cask Critical Experiments", ANS Transactions, Vol. 33, p. 368, November 1979

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

13. Criticality Analysis of Callaway Spent Fuel Racks with IFBA Fuel, November 1989, M. W. Fecteau, et al

14. Callaway Plant Final Safety Analysis Report

15. Calculation NFDC 95-014, Callaway Region 1 Spent Fuel Rack Analysis - KENO-Va Methodology, J. M. Moose, August 1995