A.10 FUEL BASKET SYSTEM NUCLEAR DESIGN CRITERIA AND BASES

A.10.1 INTRODUCTION

The design criteria for the fuel basket system are as follows:

a. In determination of subcritical limits, the k_{eff} calculated for the most reactive credible conditions shall be less than 0.95 at the 95% confidence level.

b. The initial k_∞ value of fuel to be stored without restrictions other than on the k_∞ value shall not exceed a rod lattice k_∞ of:

   1.37 for 15 x15 PWR fuel bundles (< 8.55 in.^{2})
   1.41 for 14 x 14 PWR fuel bundles (< 7.80 in.^{2})
   1.40 for 7 x 7 or 8 x 8 BWR fuel bundles
   1.38 for 10 x 10 BWR fuel bundles (< 5.65 in.^{2})

c. The k_∞ limit for BWR fuel shall be based on the initial design value of k_∞ (cold, clean fuel) as determined by the fuel designer.

d. The reactivity limit for specification PWR fuel shall be based on the initial cold, clean k_∞, including the poisoning effect of any stainless steel cladding, as determined by the fuel designer or utility customer.

e. For PWR fuel having k_∞ values in excess of the limits for unrestricted storage, the fuel shall have undergone sufficient irradiation to reduce the reactivity to a level below the storage limit taking into account the uncertainties in the calculations of burnup effects.

The k_{eff} for the basin filled with 15 x 15 PWR fuel at k_∞ of 1.37 would be 0.933 as calculated using equations developed by Battelle (Section 5.3.5.3). A k_∞ limit of 1.37 will also allow storage of stainless steel clad fuel enriched to 4.0% U-235 for which k_∞ cold clean would be 1.353.

An additional k_∞ limit has been established for the 14 x 14 PWR fuel since the smaller bundle size results in a lower k_{eff} for a given value of k. A k_∞ limit of 1.41 was established for this fuel since k_{eff} for the basin if filled with fuel at this k_∞ value would be approximately 0.920 at the 95% confidence level.

The rod lattice k_∞ limit of 1.40 for 7 x 7 or 8 x 7 BWR fuel was left unchanged from the original basis for the MFRP to avoid unnecessary changes. The basis for determining k_∞ for BWR fuel (criterion c) considers only cold, clean fuel to avoid the complexity of assessing the reduction in maximum k_∞ value caused by the burnable poison in the fuel. The cold, clean rod lattice k_∞ limit of 1.40 covers any 7 x 7 or 8 x 8 BWR fuel that might be stored in the fuel storage facilities at Morris Operation (GE-MO).

These design criteria result in limiting the administrative control of fuel receipt largely to fuel identification and evaluation of the cold, clean rod lattice k_∞. The need for determination of the effects of irradiation on the k_∞ value of fuel to be stored should be very infrequent.

The design bases for the fuel basket system are as follows:

a. Criticality evaluations are based on the physical dimensions of specific fuel designs using the largest assembly widths and considering the length to be infinite.

b. The initial U-235 enrichment corresponding to various values of k_∞ was calculated.

c. The poisoning effect of the stainless steel (iron 74%, chromium 18%, nickel 8%, manganese neglected) in the storage basket was included in the criticality evaluation.

d. Fuel centerline location within the storage tube was assumed to be that giving the maximum system reactivity and fuel was assumed to be oriented with the horizontal axes in square array and parallel to the basket axes.

e. The principal criticality calculations were made using a water temperature of 20 °C since the codes employed for the calculations had been most extensively validated at this temperature.

A.10.2 FUEL BASKET SYSTEM - NUCLEAR DESIGN ANALYSIS

The nuclear design analysis was performed by Battelle Pacific Northwest Laboratories[1] using the preceding design criteria and bases and EGGNIT, GAMTEC-11, and KENO-II Monte Carlo computer codes.

Results of the calculations of critical systems to provide validation for the KENO-II code show the code to be slightly conservative (approximately 1.75%). Fuel characteristics are shown in Table A.10-1. The critical systems and calculated results are summarized in Table A.10-2.

TABLE A.10-1
PHYSICAL CHARACTERISTICS OF REPRESENTATIVE LWR FUEL ASSEMBLIES

	1	2	3	4	5	6	7	8	9
Reactor Type	BWR	BWR	BWR	PWR	PWR	PWR	PWR	PWR	PWR
Fuel Designer	GE	GE	GE	B&W	CE	W	W	W	W
Active Fuel Length (in.)	144	144	144	144	137	120	122	144	144
Nominal Envelope (in.)	$(5.438)^2$	$(5.438)^2$	$(5.47)^2$	$(8.536)^2$	$(8.18)^2$	$(7.763)^2$	$(8.426)^2$	$(7.763)^2$	$(8.426)^2$
Rod Array	7x7	7x7	8x8	15x15	14x14	14x14	15x15	14x14	15x15
Rod Pitch (in.)	0.738	0.738	0.640	0.568	0.580	0.556	0.563	0.566	0.563
Rod o.d. (in.)	0.570	0.563	0.493	0.430	0.440	0.422	0.422	0.422	0.422
Clad Material	Zirc-2	Zirc-2	Zirc-2	Zirc-4	Zirc-4	SS	SS	Zirc-4	Zirc-4
Clad Thickness (in.)	0.0355	0.032	0.034	0.0265	0.026	0.0165	0.0165	0.0243	0.0243
Pellet o.d (in.)	0.488	0.487	0.416	0.370	0.3795	0.3835	0.3835	0.3659	0.3659
Radial Gap (in.)	0.0055	0.006	0.0045	0.0035	0.0043	0.0028	0.0028	0.0038	0.0038
H_2O/UO_2 Vol Ratio	1.5476	1.5874	1.691	1.650	1.630	1.4675	1.533	1.717	1.684
Poison Material	Gd_2O_3	Gd_2O_3	Gd_2O_3						

Summarized below are the results of calculations used in establishing the bases for the fuel basket designs.

a. k_{eff} = 0.889 for an infinite system of PWR fuel bundles having the physical dimensions indicated in Column 4 of Table A.10-1, an initial enrichment of 2.6% U-235 (fuel rod lattice k_∞ = approximately 1.33) and in a close-packed square array of full-length, 12 in., Schedule 5, stainless steel pipe canisters at 20 °C water temperature.

b. k_{eff} = 0.774 for an infinite system of BWR fuel assemblies having physical dimensions indicated in Column 2 of Table A.10-1, an initial enrichment of 2.6% U-235 (fuel rod lattice k_∞ = approximately 1.34) and in a close-packed square array of full-length, 8 in., Schedule 5, stainless steel pipe canisters at 20 °C water temperature.

c. For an infinite system of PWR fuel assemblies in four-element fuel baskets, consisting of four 12 in., Schedule 5 pipes in close-packed square array, located on 26.25 in. centers, the effect of fuel assembly location within the pipe canister did not have a significant effect on the system reactivity (ΔK <0.3 of the standard deviation of the calculational method for array reactivity).

d. For infinite systems of PWR fuel baskets as defined in c above, the following relationships among enrichment, fuel lattice k_∞ and system k_{eff} were calculated:

Enrichment (% U-235)	Lattice k_∞	System keff
1.625	1.2003	0.788 ± 0.006
1.920	1.2504	0.824 ± 0.006
2.295	1.2993	0.864 ± 0.005
2.825	1.3500	0.912 ± 0.006

e. For an infinite system of BWR fuel assemblies in nine-element fuel baskets, consisting of nine 8 in., Schedule 10 pipes in close-packed square array, located on 26.25 in. centers, it was calculated that locating the eight peripheral bundles as close to the central bundle as possible resulted in a maximum increase in k_{eff} of 4.5% over that for fuel at the centerlines for fuel with a lattice k_∞ in the range 1.20 to 1.40.

f. For an infinite system of BWR baskets as defined in e. above, the following relationships between enrichment, fuel lattice k_∞ and system k_{eff} were calculated:

Enrichment (% U-235)	Lattice k_∞	System k_{eff}
1.570	1.2001	0.652 ± 0.005
1.850	1.2500	0.688 ± 0.006
2.210	1.2994	0.732 ± 0.006
3.420	1.3996	0.792 ± 0.007

g. Effects of burnup (fissile material depletion and long-lived fission product buildup) were calculated for BWR and PWR fuels using the LEOPARD code.

A detailed nuclear safety evaluation was made which includes:

- Validation of the correlation between initial U-235 enrichment and rod lattice k_∞ which has been made using the EGGNIT code.

- Correlation of rod lattice k_∞ with bundle array k_∞ (at the reactor bundle lattice pitch). For PWR fuel arrays this difference is very small as the additional water layer at the fuel bundle boundary is approximately 1/16 in. For BWR fuel arrays the effects are somewhat greater as the water layer at the fuel bundle boundary is approximately 0.75 in. Since the safety margins for BWR fuel storage arrays are substantial, the effect does not significantly change the safety of the system.

- Extension of the array calculations to k_∞ of 1.40 for BWR fuel and 1.35 for PWR fuel.

- Evaluation of the effect of elevated fuel and water temperatures.

Additional KENO-II calculations were made to evaluate k_{eff} for PWR arrays at k_∞ (cold) of 1.35 and for temperatures of 20 °C, 50 °C, and 115 °C. It was concluded that temperature does not significantly affect the fuel reactivity.

For BWR fuel containing burnable poison (Gd_2O_3), the value of k_∞ (cold) rises from approximately 1.15 to < 1.25 and declines to < 1.20 by the end of one cycle of irradiation. Thus the presence of poison in the BWR fuel adds to the safety margins in the event of early discharge of the fuel.

Nuclear design analysis for the square tube BWR storage basket was performed by GE[2] to demonstrate the k_{eff} is maintained less than 0.95 with the new square tube geometry. The results of these analyses show that for the worst case abnormal storage condition the maximum k_∞ of 0.836 which is considerably less than the allowed limit of 0.9 k_{eff}.

A.10.3 REFERENCES

1. BPNL, Basin Criticality Safety for MFRP Project-1 Fuel Bundle Storage Baskets, May 1975. (Appendix B.5)

2. GE, Criticality Safety Analysis for Square Tube Fuel Storage Baskets at Morris Operation, May 1987. (Appendix B.15)