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Use of Burnup credit as a Safety Factor in Handling of NIST Fuel Assemblies in the L Basin of SRS

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Summary

Burnup credit was recently used for the first time in criticality safety analysis to support the handling of the National Institute of Standards and Technology spent fuel assemblies in the L Basin of Savannah River Site. Previous criticality safety analyses were based on the fissile content of fresh, unirradiated fuel assemblies, resulting in handling of a group of 10 or less fuel assemblies at a time. Using burnup credit, it was demonstrated that an isolated configuration of up to 14 NIST fuel assemblies, the maximum number of fuel assemblies in a full basket, submerged in a concrete-lined, water-filled pool is subcritical, resulting in several administrative controls being modified or eliminated without compromising safety.

Introduction

The NIST fuel assembly contains highly enriched (~ 93%) U_3O_8 dispersed in curved aluminum fuel plates as depicted in Figure 1. Each fuel assembly consists of 17 curved fuel plates and 2 dummy aluminum plates. Specific details on the fuel plates and assemblies are provided in Table 1 [1].

The NIST fuel assemblies are used in a 20-Megawatt research reactor with a core cycle period of 38 days and a refueling frequency of once every four cycles. The decrease in fissile inventory for each fuel assembly is estimated using the power generated by that assembly and a fissile consumption factor of 1.28 g ^{235}U/MWD. This methodology takes into account the small amount of power that is generated by consumption of ^{238}U.

The average ^{235}U burnup for fuel assemblies shipped to SRS is generally about 60 wt. % of the original ^{235}U present in the fresh, unirradiated fuel. It should be noted that the “burnup credit” referred to in this document is defined as only the negative reactivity credit due to the decrease in the ^{235}U inventory and does not take into account the negative reactivity credit due to the poisoning effect of the fission products or the actinide buildup during irradiation.

A fuel basket contains 7 positions. Two fuel assemblies may be stacked in a given basket position (for a total of 14 fuel assemblies in a basket). All basket handling operations are performed under water. Due to the geometric configuration of the basket, a basket loaded with 14 fresh, unirradiated fuel assemblies remains subcritical when submerged in water. However, dropping of a fuel basket that contains 14 fresh, unirradiated fuel assemblies and subsequent release and accumulation of all 14 fuel assemblies in an idealized configuration at the bottom of the storage pool may result in criticality.

Previous criticality safety analyses, using the isotopic compositions of the fresh, unirradiated fuel, demonstrated that 10 NIST fuel assemblies, utilizing conservative geometric configurations submerged in a concrete-lined, water-filled pool, are subcritical. Based on those analyses, the fuel assemblies were removed from the fuel baskets received at SRS and handled in batches of no more than 10 assemblies. It was desired to eliminate the removal of fuel assemblies from baskets and to handle full baskets of fuel. This document demonstrates, using partial credit for burnup, that all geometric configurations of 14 NIST irradiated fuel assemblies submerged in a concrete-lined, water-filled pool are subcritical, thus allowing the movement of a full basket of fuel.

Table 1. NIST Fuel Parameters

Fuel type	U_3O_8
Active length of the fuel plate (cm)	27.94
Width of the fuel plate (cm)	6.1341
Thickness of the fuel plate (cm)	0.0508
Dispersing material	Al
Dispersing material weight per fuel plate (g)	19.1
Cladding material	Al
Cladding thickness (cm)	0.038
Weigh of total uranium per fuel plate (g)	11.0 ± 0.3
Weigh of ^{235}U per fuel plate (g)	10.3 ± 0.3
Nominal total fuel weigh per fuel plate (g)	32.2
Number of fuel plates per assembly	17
Number of dummy plates per assembly	2
Overall width of the assembly (cm)	7.62
Overall thickness of the assembly (cm)	8.5547

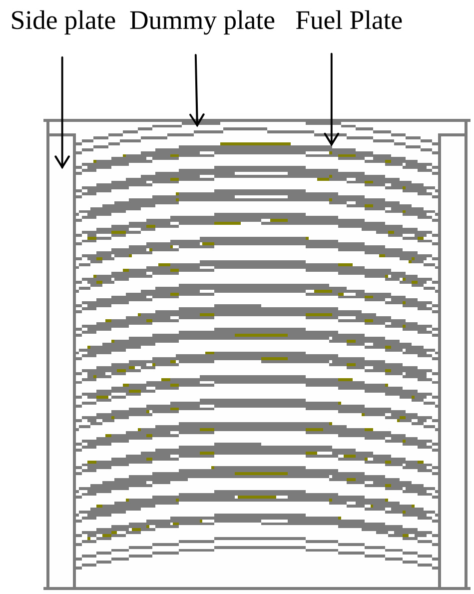

Figure 1. NIST Fuel Assembly

Discussion and Results

Fourteen NIST fuel assemblies were modeled in a planar array in four rows as depicted in Figure 2, with the top and bottom rows turned 90 degrees to minimize the system leakage. The fuel assembly was modeled explicitly, which accurately accounts for distinct regions and geometry, and preserves physical dimensions of the fuel, clad, and moderator regions within the fuel assembly. The array of fuel assemblies was reflected from two adjacent sides and the bottom by a minimum 2 ft of concrete and from the other two sides and the top by a minimum 2 ft of water. The interstitial moderation between the fuel plates and fuel assemblies was water.

The MCNP 4C [2] results using the ENDF/B-V cross section library for several burnup values of 0, 20, 30 and 40 wt% ^{235}U presented in Figure 3 indicate that a burnup of about 35% is required for the basket handling operations to be subcritical. These burnup values were modeled by simply reducing the wt. % of the ^{235}U in the fresh, unirradiated fuel plates (i.e., the fraction of ^{235}U that was depleted to produce power), while keeping other constituents unchanged. Presence of the generated ^{236}U in the irradiated fuel was conservatively neglected as calculations demonstrated that the presence of ^{236}U in the fuel has a negative effect on the reactivity of the system. The presence of fission products and other actinides, generated during irradiation, was also neglected.

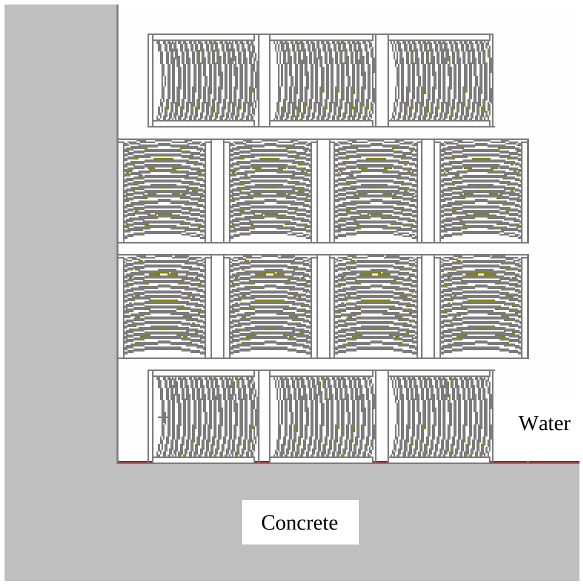

Figure 2. Idealized Fuel Assemblies Configuration (Plan View)

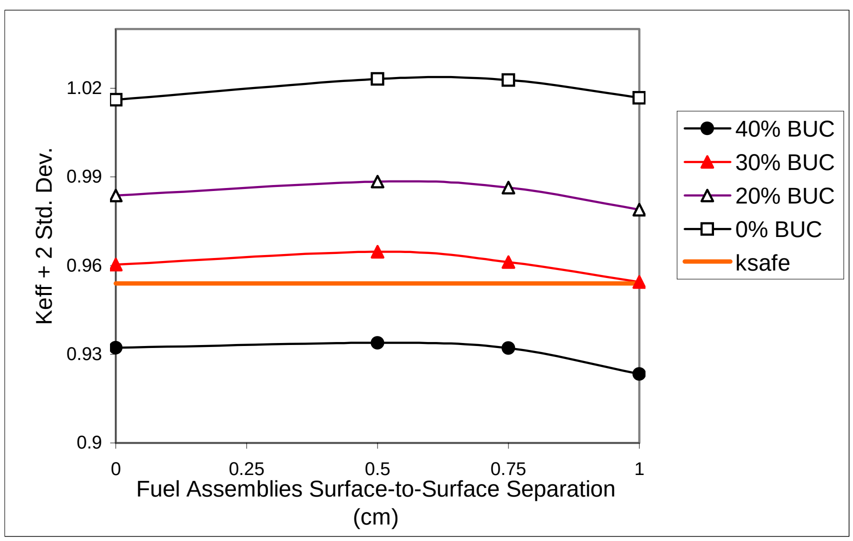

Figure 3. Effect of Burnup Credit on Reactivity of 14 Fuel Assemblies

Eleven batches of the NIST spent fuel assemblies shipped to SRS were dissolved in H-canyon between 1978 and 1987 for recovery of ^{235}U. The post-irradiation total uranium and ^{235}U estimated using burnup data and the recovered total uranium and ^{235}U for each dissolver batch are presented in Table 2. The results indicate a fairly good agreement between the NIST-estimated values and the recovered total uranium and ^{235}U.

The uncertainty associated with the total uranium and ^{235}U estimated using burnup data is estimated as +/- 5 wt. %. The combined uncertainty associated with the dissolution process is estimated as +/- 3 wt. %. Thus, a bounding uncertainty of 14% (based on the worst data point in Table 2) was applied to all uranium values estimated using burnup data before credit could be taken for ^{235}U burnup.

Table 2. Summary of NIST Fuel Assembly Dissolution at SRS

Post-Irradiation Data			**Dissolver Tank Data**		**Percent Recovered**	
Dissolver Batch #	Total U (g)	U-235 (g)	Total U (g)	U-235 (g)	Total U %	U-235 %
YVA-7	3709.0	2733.0	3966.0	3008.0	106.9	110.1
YVA-8	3723.0	2748.0	3980.0	3025.0	106.9	110.1
YVA-9	2992.3	2218.3	3114.9	2335.0	104.1	105.3
YVA-10	2873.3	2079.0	2998.3	2226.0	104.4	107.1
YVA-11	3149.3	2399.4	3122.5	2387.3	99.1	99.5
YVA-12	3180.3	2436.6	3127.6	2396.0	98.3	98.3
YVA-13	3393.9	2476.8	3434.7	2498.6	101.2	100.9
YVA-14	3236.0	2238.0	3357.7	2362.1	104.0	105.5
YVA-15	3243.0	2246.4	3348.7	2355.0	103.3	104.8
YVA-16	3132.8	2118.2	3277.0	2257.7	104.6	106.6
YVA-17	3130.8	2118.2	3310.7	2281.6	105.7	107.7

Conclusions

The NIST fuel basket handling operations are subcritical provided all fuel assemblies have been determined to have at least 40% burnup including the 14% uncertainty as discussed above. Since the fuel basket handling operations comply with the double contingency principle, the risk of a criticality is extremely small. As mentioned above, all fuel basket handling operations are performed under water. As such, in the highly unlikely event of a criticality, the dose received by the personnel in the vicinity of the pool would be minimal.

References:

1. Thomas, J. E., “Appendix A: NIST [National Inst. Of Standards and Technology],“ (DOESRAAD-99-003, Revision 0), SFS-FID-990258, #10048, Westinghouse Savannah River Company, Aiken, S.C 29808, July 27, 1999.

2. White, M. et al., “Compilation of WSMS MCNP 4C Validation”, WSMS-CRT-01-0082, Westinghouse Savannah River Company, Aiken, SC 29808, September 2001.