APPENDIX II

UNITED STATES
NUCLEAR REGULATORY COMMISSION
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SUBJECT: CRITICALITY SAFETY EVALUATION OF A LOADED CANISTER DROPPING ITS CONTENTS ONTO A SIMILAR LOADED CANISTER IN A MAXIMUM VOLUME STORAGE UNIT

1. Introduction and Summary

As agreed in our conference phone call with Phil Grant and John Thomas on Friday, October 18, 1985, I have analyzed the criticality aspects of the accidental dropping of the contents of a loaded canister onto a similar loaded stored canister. The analysis indicates that for the loading limitations per canister, maximum storage volume per canister available and 4350 ppm boron in water, such an accident poses no criticality hazard and under very conservative assumptions (discussed below), the keff shutdown range is between 32% (max) to 13% (min). A total of six KENO Monte Carlo (123 gps) cases were analyzed and form the basis of the above conclusion. Results are given in Table 2. The computer input-output for these cases are on file in Transportation Certification Branch, NMSS.

2. Problem Definition

The concern of the subject accident scenario is the criticality state of a stored loaded canister when surrounded by the dropped contents of a similar canister. The stored canister resides in a parallelipiped borated (4350 ppm) water region of dimensions 18 inches by 18 inches by 14 feet - a volume of 892,000 cc.

3. Problem Solution: Assumptions and Methods

The approach in solving the above problem was to assume all canister contents to have a maximum payload of dry 900 kg $U(3)O_2$ pellets - this nominal value is 4-1/2% higher than the greatest payload (861 kg - total) for a knock-out canister.

To understand the detailed approach taken (described below) in solving the problem, the following criticality observations are reviewed. They were established in previous studies.

a. The as-built pellet is the form and geometry of the fuel to affect the optimum Vol fuel to Vol water ratio (V_F/V_W) both for unborated water and borated water.

b. Unborated water; maximum reactivity exists for fuel as pellet for V_F/V_W = 30/70, water is more important than fuel.

c. Borated water; maximum reactivity for fuel pellet shifts to V_F/V_W = 60/40 over the boration of 2500 ppm to 4500 ppm boron. Fuel is more important than the borated water. But the ratio goes from 58/42 to 62/38 over the boration range showing the small dependence on ppm; we have thus assumed an average value of 60/40.

d. Since the above ratios (30/70 and 60/40) represent optimum values and further increase of fuel into the system would decrease reactivity, small uranium slurry volume and/or uranium fines in the moderator region give a crude-first approximation of reactivity reduction. This is not exactly correct since introducing fuel in the moderator region shifts the optimum value. This has been neglected and is considered a second order effect on the assumption the system spectrum remains constant and the shift is small.

With the above as background, Table 1 can be constructed showing how many canister-full contents can be accommodated in the water storage paralleliped of 892,000 cc total volume. The canister contents are assumed to be 900 kg UO_2 at density 10 grams/cc. No canister structural material or canister poison material is considered present in the storage volume.

TABLE 1

Number of Canister Contents in Storage Volume	$\frac{\text{Volume } UO_2}{\text{Volume } H_2O}$	V_F/V_W
1	90,000 cc UO_2 802,000 cc H_2O	.112
2	180,000 cc UO_2 712,000 cc H_2O	.253
3	270,000 cc UO_2 622,000 cc H_2O	$.434 \approx \frac{30}{70}(=.428)$
4	360,000 cc UO_2 532,000 cc H_2O	.678
5	450,000 cc UO_2 442,000 cc H_2O	1.020
6	540,000 cc UO_2 352,000 cc H_2O	$1.538 \approx \frac{60}{40}(=1.500)$

This Table 1 shows that it will take about six canister contents to approach the optimum 60/40 ratio for borated systems and about only three canister contents to approach the optimum 30/70 for unborated systems.

The criticality analysis of the cases specified in Table 2 were modeled as cells as a discrete pellet region surrounded by its associated moderator close-fitting into the 18" x 18" cross-sectional area. This gave a UO_2 mass loading of 2764 kg (vs 2700 = 3 x 900) for the 30/70 ratio and 5678 kg UO_2 (vs 5400 = 6 x 900) for the 60/40 ratio due to the arithmetical discrepencies of fitting prescribed volume fractions into a fixed region. The 30/70 case is very slightly non-conservative, whereas, the 60/40 is quite conservative since more fuel is a more reactive situation here.

4. Discussion of Results and Conservatisms

Comparison of Cases 1 and 4 show that keff will decrease by 0.14 for the unborated case by increasing the fuel by a factor of 2 in line with maximum reactivity for the 30/70 mixture. For the borated cases, a comparison of Cases 2 and 5 and Cases 3 and 6, an increase in keff of 0.14 and 0.19 results respectively by increasing the fuel by a factor of 2 in line with maximum reactivity for the 60/40 mixture.

Case 6 represents approximately six canister-fulls filling the storage volume at the most reactive mixture 60/40 for 4350 ppm boron in the storage water. If one considers the canister poisons and structural materials as well as the core (canister contents) material to contain control-rod poisons, fixed poisons, core structure material, fission products and lower average core enrichment, all the tabulated keffs of Table 2 can be decreased by at least 0.10. Since only 2 canister contents represent the accident conditions, subcriticality is assured by a large margin.

In addition, Case 7 represents a 14 foot deep infinite slab of Case 6 contents with a resulting keff of 1.085.

Case 3 of Table 2 rerun as an infinite system in the X-Y-Z direction, gave a k_{∞} of 0.8021.

Case 7 of Table 2 rerun as an infinite system in the X-Y-Z direction, gave a k_{∞} of 1.095.

TABLE 2

KENO K_{eff}'s for an 18 inch x 18 inch x 14 feet Parallelepiped Canister Storage Volume Containing Most Reactive $U(3)O_2$-H_2O Mixture
(for boron concentrations of zero, 3000 ppm and 4350 ppm in water)

KENO Case No.	PPM Boron	Vfuel/Vwater	keff(a)(b)	Contents of Storage Volume (c) (18"x18"x168"=31.5ft^3=8.92x10^{5}cm^3)
				2764 kg $U(3)O_2$; 618 kg H_2O
1	0	30/70	1.239	zero gms boron
2	3000	30/70	0.775	1893 gms boron
3	4350	30/70	0.677	2746 gms boron
				5678 kg $U(3)O_2$; 362 kg H_2O
4	0	60/40	1.099	zero gms boron
5	3000	60/40	0.918	1113 gms boron
6	4350	60/40	0.871	1614 gms boron
			K-INF(X-Y)	5678 kg $U(3)O_2$; 362 kg H_2O
7	4350	60/40	1.085 (d)	1614 gms boron

(a) to within ±0.003 for 1 std. dev.

(b) all cases (except No. 7) reflected by 1 foot all around appropriate borated-water reflector.

(c) storage volume does not contain any structural (internal and external) canister materials or canister poisons.

(d) reflected top and bottom, Z direction by 1 foot of borated water.

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