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DP-MS-75-89

Conf-751101--43

SUBCRITICAL MASS LIMITS FOR THE T-INSERT

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A Paper for Presentation at the
1975 Winter Meeting of the American Nuclear Society
San Francisco, California
November 16-21, 1975

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The Savannah River Laboratory supplies the Savannah River Operations Office of the U. S. Energy Research and Development Administration with criticality safety analyses for inclusion in Safety Analysis Reports for Packaging. Safe limits were derived for Class III shipments of ^{235}U, ^{239}Pu, and ^{233}U in the T-insert within the ANL T-2 cask. The cross section of the cask is shown in Slide 1. The cask has a 6.063-inch-diameter cavity enclosed by lead 8 inches thick and clad with steel. The insert is 5-inch Schedule 40 stainless steel. No control is to be exercised over the configuration of the fissile material. The most restrictive of the conditions that must be satisfied for a Class III shipment is the requirement that the cask be subcritical when flooded internally and externally with water.

Mass limits for the cask were calculated by ANISN with S_4 quadrature. Hansen-Roach cross sections were used, supplemented

* The information contained in this article was developed during the course of work under Contract No. AT(07-2)-1 with the U. S. Energy Research and Development Administration.

by some with the same group structure from other sources. To establish the bias in the method, calculations of k_{eff} were compared with appropriate critical experiments with aqueous solutions of ^{233}U, ^{235}U, and Pu and with HFIR experiments in which the core was reflected by steel, lead, and water.

Inconsistencies were observed in the reported data for aqueous solutions. For UO_2F_2 solutions, the specific volume of solute was derived from the formula of Johnson and Kraus as shown in Slide 2. A study of available data for $UO_2(NO_3)_2$ and $Pu(NO_3)_4$ solutions led to the specific volumes shown in Slide 3. For $^{235}UO_2F_2$ solutions, specific volumes calculated with the Johnson and Kraus formula gave $H/^{235}U$ ratios differing slightly from those reported by the experimenters as shown in Slide 4.

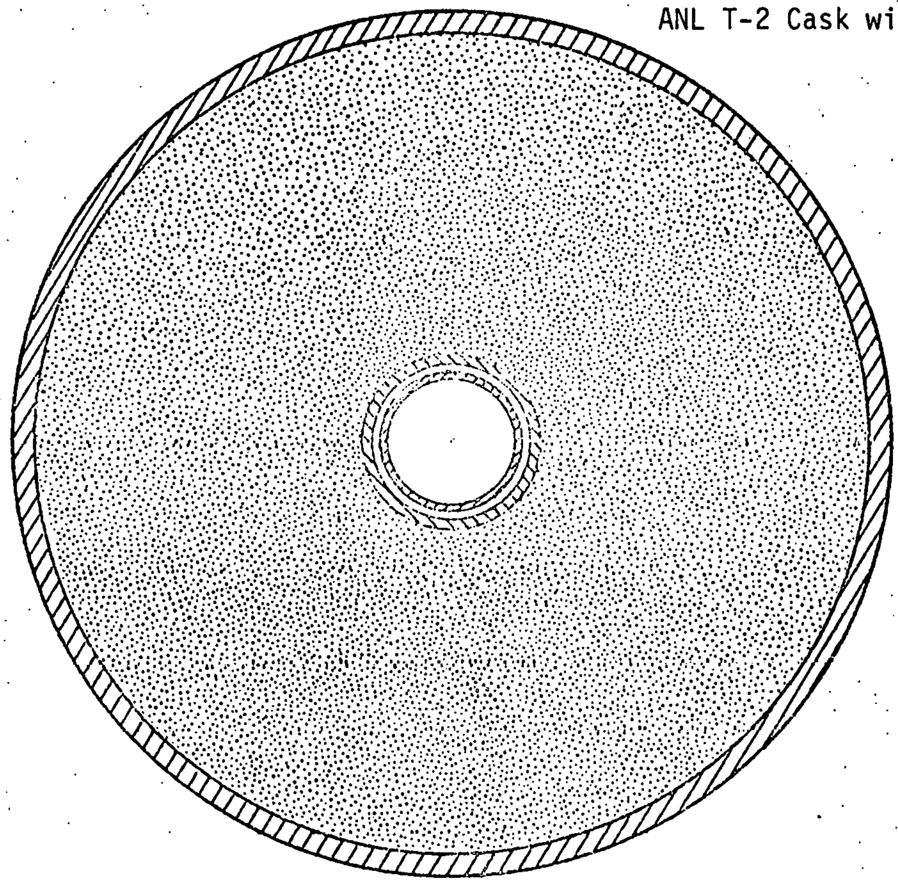
Both S_{16} and S_4 calculations of k_{eff} were made for the $^{235}UO_2F_2$ solutions. A significant bias between the calculated and reported k_{eff}'s was found at high concentrations as shown in Slide 5. The bias depends on the person making the calculation and on the derivation of the solution properties. Only S_4 calculations were made for $Pu(NO_3)_4$ solutions. Here the bias at high concentration is in the opposite direction as shown in Slide 6 (the values in parentheses were derived from reported composition data). The derivation of solution composition has a large effect at the higher concentration.

To investigate the bias associated with calculations for a lead and steel reflector, correlations were made with experiments in which the HFIR core was surrounded by various thicknesses of lead and steel. Three cross section sets were available for lead. The first was a set generated at Oak Ridge and was furnished with the KENO code. The other two [Lazarus (L) and Aerojet (A)] were obtained from Los Alamos. As shown in Slide 7, all three give conservative results, but the Lazarus set shows the least bias.

Limits for the T-insert were computed with allowance for the bias found in correlations with solution experiments and with further allowance for calculational uncertainty as indicated in Slide 8.

Slide 1

ANL T-2 Cask with T-Insert



Slide 2

UO_2F_2 Solutions

$$1/d = 1/d_0 + aF_2 + bF_2^2$$

d_0 = density of H_2O F_2 = weight fraction of UO_2F_2

T, °C	a	b
25	-0.9120	0.0567
30	-0.9126	0.0569

$$v = 1/d_0 + \frac{ac - \sqrt{(1-ac)^2 + 4bc^2/d_0}}{2c}$$

v = apparent specific volume of UO_2F_2

c = concentration, g UO_2F_2/cm^3

Slide 3

$UO_2(NO_3)_2$ and $Pu(NO_3)_4$ Solutions

	Specific Volume, cm^3/g	
Molarity	UO_3	PuO_2
0	0.038	-0.038
0.5	0.092	0.010
1.0	0.120	0.027
1.5	0.135	0.035
≥2.0	0.142	0.038

Slide 4

Critical H_2O Reflected Spheres of $^{235}UO_2F_2$ Solution

^{235}U, g/ℓ	$H/^{235}U$ Formula	$H/^{235}U$ Reported	Radium, cm
696.4	35.8		11.52
518.4	49.7		11.52
348.8	76.2	76.1	11.52
213.3	126.7	126.5	11.80
102.1	270.3	269.8	13.21
53.0	523.7	515.1	15.96
21.9	1274.0	1270.0	27.90

Slide 5

k_{eff} Calculated for $^{235}UO_2F_2$ Solutions

^{235}U, g/ℓ	S_{16} Formula	S_{16} Reported	S_4 Adj.	S_4 D.W.M.	S_6 J.W.W.
696.4	0.9799				
518.4	0.9836				
348.8	0.9793	0.9788	0.9860	0.9961	0.995
213.3	0.9746	0.9711	0.9780	0.9904	0.988
102.1	0.9826	0.9784	0.9842	0.9955	0.994
53.0	0.9929	0.9983	1.0025	1.0117	1.006
21.9	1.0035	1.0062	1.0074	1.0123	1.008

Slide 6

Critical H_2O Reflected Spheres of $Pu(NO_3)_4$ Solutions

Pu, g/ℓ	NO_3^-, g/ℓ	$H/^{239}Pu$		k_{eff} (S_4)	
435	372	54.3	(56.2)	1.0145	(1.0304)
295	303	83.3	(84.9)	1.0183	(1.0278)
268.7	346	89.9	(90.9)	1.0091	(1.0146)
140	284	178.5		1.0033	
132	281	189.6		1.0016	
126	262	200.2		1.0032	
119	245	213.5		1.0038	
100	230	255.8		0.9977	
74.5	105	359.9		0.9986	
73	86	369.7		1.0000	

Slide 7

Correlation with HFIR Experiments

	"Experimental"		Δλ, calc.		
Wall	k_{eff}	Δλ, cm	Oak Ridge	L	A
None	1.000	0	0		
1/4 in. Fe	0.965	-2.0	-1.07		
3/4 in. Fe	0.960	-2.3	-1.61		
2 in. Fe*	0.976	-1.4	-0.35		
6-1/4 in. Fe*	1.012	0.8	2.41		
3/4 in. Fe + 4 in. Pb	1.013	0.9	2.06	1.50	1.84
3/4 in. Fe + 6 in. Pb*	1.021	1.4	3.00	2.31	2.76
3/4 in. Fe + 8 in. Pb*	1.028	1.9	3.68	2.89	3.43

* Effect of surrounding 360° of core estimated

Slide 8

Calculation of Cask Limits

Compute k_{eff} for Infinite Flooded Cask by S_4

Determine λ from B^2 at k_{eff}

Apply λ to height and diameter and determine minimum mass with allowance for bias and with 0.02 allowed for uncertainty

	Limits		
	^{233}U	^{235}U	^{239}Pu
g	640	2200	2900
g/cm	15.0	30.2	31.3