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REANALYSIS OF IDEALIZED PLUTONIUM
DISSOLVERS AND THE "ALWAYS SAFE" CONDITIONS

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INTRODUCTION

In criticality safety analysis, it often becomes convenient to have available for reference critical mass information for generalized systems. In 1963, a report was published by Messrs. W. A. Reardon and C. F. Czerniejewski which dealt with minimum critical mass calculations for a fully water-reflected idealized (spherical) plutonium dissolver system⁽¹⁾. The report provides data on minimum critical masses, critical volumes, etc., for an idealized three-region system representing plutonium-239 metal dissolving into solution. With the improved computer code calculation techniques now available, a study was undertaken to update the original results. The calculations were performed under the same general conditions as in the original document, the primary difference being the use of the DTF-IV transport theory code with GAMTEC II code cross sections in lieu of the S-X² transport theory code and LAMS-2453 cross sections^(2,3). In addition, the diffusion theory code HFN replaced the 9-Zoom diffusion theory code used for the homogeneous system in the original calculations⁽⁴⁾. Plutonium-water solutions were used instead of plutonium oxide-water solution in the earlier work. This last change, however, has no significant effect on the calculations for the plutonium solution concentrations used. Because of significant differences, both the original data and the updated results are included in Figure 1, 2, and 3.

DISCUSSION

General Description

The idealized plutonium dissolver system consists basically of three concentric spheres. The innermost region (core) contains alpha phase ²³⁹Pu metal ($\rho = 19.6$ grams per cubic centimeter). Region II encircles the Pu metal core with an "idealized" Pu-H₂O solution with a plutonium concentration which is varied over a range of 20 grams per liter - 1,000 grams per liter. This system is then surrounded by 15 centimeters* of water, thus giving it full water reflection.

* 1963 calculations used 14 cm of water.

$$R_3 - R_2 = 15 \text{ cm}^*$$

Calculational Methods

The one-dimensional, multigroup, multiregion transport theory code DTF-IV was used to generate all tabulated results except for the homogeneous case ($R_1 = 0$) for which the one-dimensional, multigroup, multiregion diffusion theory code IIFN was used. In both cases the 18-energy-group cross sections were generated by the GAMTEC II code. Most calculations used an angular detail order of S_4 although some S_8 calculations were performed for comparison. A specific metal core mass was selected and critical solution annulus sizes were determined for various plutonium solution concentrations. (R_1 being fixed, R_2 was determined for various solution concentrations in Region II.) A k-effective accuracy limit of 0.0001 was used for most cases, although some calculations were performed with an accuracy limit of 0.00001. In some cases, because convergence problems arose (with large core masses and high concentration solutions), the critical size was determined graphically from calculated individual k-effective values (R_1 and R_2 fixed) as well as by critical searches on the metal core radius (R_1) with the solution annulus fixed in width. No specific reasons were determined for the convergence difficulty, although it appeared to be a problem with S_4 approximation, the number of mesh points used, and the accuracy of the radius input guesses.

* 1963 calculations used 14 cm of water.

Results

Table I gives a listing of some of the calculations that were made. Figure 1 represents the total minimum critical mass (Pu metal + Pu in solution) versus the total minimum critical volume ($V_t = 4/3 \pi R_2^3$) relationships. The curve drawn tangent to each individual case curve defines the "always safe" region, (located below the tangential). (More accurately, this envelope is the "always critical" relationship, with the envelope of the "always safe" region being displaced enough to allow for various calculational inaccuracies.) In comparison to the current calculations, the 1963 version of the "always safe" region tends to be somewhat conservative for the 4-kilogram core and nonconservative (unsafe) for cores less than that. The disagreement of the 4-kilogram case curve alters the shape of the "always safe" tangential significantly. The reason for the difference is not known, but the current calculations should be more accurate.

Figure 2 gives a better representation of what is actually happening to the total critical mass as the plutonium solution concentration increases. The agreement between the earlier work and the updated values appears to be relatively good except for the homogeneous case and the 4-kilogram core case. Some decrease in critical mass for small cores surrounded by high-density solution can be seen. The decrease is less obvious in Figure 2 than in Figure 1 since the Figure 1 graph effectively compounds the effect. However, the comparison of these two graphs shows that the envelope graphed in Figure 1 is very sensitive to what appear to be minor corrections in Figure 2.

Figure 3 represents the results of a special case involving a constant total volume (5.0 liters). In this system a 3-kilogram total mass would be critical for solution concentrations ranging from 38 to 360 grams of plutonium per liter. Below 38 grams per liter and above 360 grams per liter the 3-kilogram mass would be subcritical. The three data curves in Figure 3 represent (1) DTF-IV results, (2) the 1963 Figure III results, and (3) the interpolated results obtained using data taken from Figures I and II of the 1963 document. It does not appear as though the original Figures II and III are in agreement. The cause of the discrepancy was not determined.

It should be understood that the 1963 data shown were taken directly from the graphs and not from the original calculations. Such data is therefore subject to any original graphing errors plus any errors associated with reading the graphs.

TABLE I

DTF-IV* Zone Radius (R_2) Search data (for Figures 1 and 2)

Core Size (kg)	Soln. Conc. g Pu/l	R_2 Crit. Sph. Rad. (cm)	Total Vol. (l)	R_1 Metal Vol. (l)	Soln. Vol. (l)	Soln. Mass (kg)	Total Mass (kg)
3	20	12.4938	8.1691	.15306	8.0160	.1603	3.1603
3	30	10.8691	5.3786	.15306	5.2255	.1568	3.1568
3	50	9.7695	3.9058	.15306	3.7527	.1876	3.1876
3	70	9.3274	3.3992	.15306	3.2461	.2272	3.2272
3	150	8.8972	2.9502	.15306	2.7971	.4196	3.4196
3	300	8.5357	2.6050	.15306	2.4519	.7356	3.7356
3	600	8.3444	2.4337	.15306	2.2807	1.3684	4.3684

DTF-IV Zone Radius (R_1) Search data to calculate critical core mass (for Figure 3)

3.5221	20	10.6078	5.0	.1797	4.8202	.0964	3.6185
3.0713	30	10.6078	5.0	.1567	4.8433	.1453	3.2167
2.5049	50	10.6078	5.0	.1278	4.8722	.2436	2.7485
2.1638	70	10.6078	5.0	.1104	4.8896	.3423	2.5061
1.6993	150	10.6078	5.0	.0867	4.9133	.7370	2.4363
1.3426	300	10.6078	5.0	.0685	4.9315	1.4795	2.8221
1.0212	600	10.6078	5.0	.0521	4.9479	2.9687	3.9899

* R_2 critical size search calculations were performed for core masses of 1 kg, 2 kg, 3 kg, 4 kg, 4.5 kg, and 5 kg.

TABLE I (Contd)

HFN^{**} Zone Radius (R_2) Search data - homogeneous case ($R_1 = 0$)

Core Size (kg)	Soln. Conc. g Pu/l	R_2 Crit SpH Rad. (cm)	Total Vol. (l)	R_1 Metal Vol. (l)	Soln. Vol. (l)	Soln. Mass (kg)	Total Mass (kg)
0	20	18.7277	27.513	0	27.513	.5503	.5503
0	50	13.6523	10.659	0	10.659	.5329	.5329
0	150	12.0433	7.3169	0	7.3169	1.0975	1.0975
0	300	11.6564	6.6341	0	6.6341	1.9902	1.9902
0	600	11.3400	6.1084	0	6.1084	3.6650	3.6650

^{**} For the homogeneous case calculations were made at solution concentrations of 20, 30, 50, 70, 150, 200, 300, and 600 g/l.

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