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3.4. THE POISONING EFFECT OF COPPER LATTICES IN AQUEOUS SOLUTIONS OF ENRICHED URANYL OXYFLUORIDE

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The use of metallic copper in the design of some uranium processing plant equipment has established a need for information on the effects, from a nuclear safety standpoint, of copper placed in or near uranium solutions. Accordingly, a series of experiments to measure the poisoning effect of lattices of copper tubes and rods on an aqueous solution of uranyl fluoride was performed.

The solution used in these experiments was 93.2% U^{235}-enriched UO_2F_2 in water, at a concentration of 0.4693 g of U^{235} per cubic centimeter of solution, corresponding to an $H:U^{235}$ atomic ratio of 52.6. It was contained in a 10-in.-dia aluminum cylinder, which for most experiments was surrounded by a ¼-in.-thick copper shell, except for the top and bottom. With the exception of one case, the cylinder was reflected with water on the sides and bottom. In several experiments the copper tubes and rods were held in a stainless steel basket consisting of six ⅜-in.-dia by 6-ft-long rods equally spaced on a 9.5-in.-dia ring and attached to a perforated bottom plate. For most of the experiments, however, the copper was loaded directly into the containing vessel with edges in contact, forming a pseudo-triangular pattern. Using tubes having various diameters and wall thicknesses and placing small tubes inside larger tubes enabled the volume percentage of metal to be varied considerably.

The results of the experiments are given in Table 3.4.1, and typical curves showing the critical solution height as a function of the volume percentage of metal are plotted in Fig. 3.4.1. It can be seen that, for the case in which solution only was inside the cylinder, displacing a portion of the water reflector with the copper shell increased the critical solution height from 6.55 to 6.96 in. For the case in which the cylinder contained 27.7 vol % of copper, displacing a portion of the water reflector with the copper shell increased the solution critical height from 21.3 in. to 58.7 in. Inserting the stainless steel basket in the otherwise unpoisoned solution increased the critical height from 6.96 in. to 7.33 in., the copper

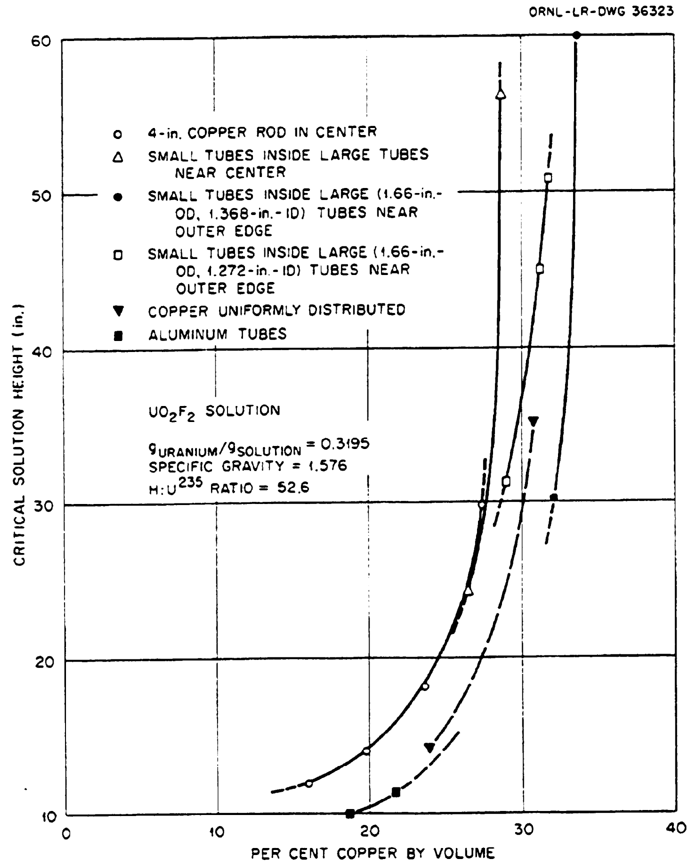

Fig. 3.4.1. Critical Height of a Reflected 10-in.-dia Aluminum Cylinder Containing a Copper-Poisoned Aqueous Solution of 93.2% U^{235}-Enriched UO_2F_2 as a Function of Copper Content.

Table 3.4.1. Critical Parameters of a 10-in.-dia Aluminum Cylinder Containing an Aqueous Solution of 93.2% U^{235}-Enriched UO_2F_2 Poisoned with Copper or Aluminum Tubes or Rods

Solution concentration: 0.3195 g of U per g of solution; 0.4693 g of U^{235} per cc of solution
$H:U^{235}$ atomic ratio: 52.6
Solution specific gravity: 1.576

Number of Tubes or Rods	Tube or Rod Dimensions (in.): Inside Diameter	Tube or Rod Dimensions (in.): Outside Diameter	Metal Content (vol %)	Critical Conditions: Solution Height (in.)	Critical Conditions: Mass (kg of U^{235})	Description of Assembly
				H_2O Reflector Only		
				6.55	3.96	Contained solution only
				Copper Tubes and Rods; 1/4-in.-thick Copper Shell Plus H_2O Reflector		
				6.96	4.21	Contained solution only
12	1.933	2.375	23.9	14.2	6.53	Tubes uniformly distributed
1	1.272	1.66				
12	1.933	2.375	37.6	60.2 (NC)[a]		12 small tubes inside large tubes; one small tube outside
13	1.272	1.66				
12	1.933	2.375				2.375- and 1.66-in. tubes uniformly distributed; smaller tubes successively placed in one another and uniformly distributed between large tubes
2	1.368	1.66				
2	0.822	1.05	30.8	35.2	14.7	
17	0.495	0.675				
18		0.25				
12	1.933	2.375				Essentially same as preceding except one 2.375-in. tube near center filled with successively smaller tubes
3	1.368	1.66				
3	0.822	1.05	30.3	59.3 (NC)		
8	0.495	0.675				
15		0.25				
26	1.272	1.66	29.5	31.3	13.3	Tubes uniformly distributed
26	1.272	1.66	30.7	60.4	25.3	Small tubes inside large tubes near center
2	0.736	1.05				
26	1.272	1.66	31.2	45.0	18.7	Small tubes inside large tubes 120° apart on outer edge
3	0.736	1.05				
26	1.272	1.66	31.8	50.8	20.9	Small tubes inside large tubes 90° apart on outer edge
4	0.736	1.05				
26	1.272	1.66	31.8	50.5	20.8	Two small tubes inside large tubes; two small tubes outside; all on outer edge
4	0.736	1.05				
26	1.368	1.66	23.0	14.5	6.75	Tubes uniformly distributed
26	1.368	1.66	23.0	58.4 (NC)		Tubes uniformly distributed; copper reflector only
26	1.368	1.66	27.4	24.2	10.8	Five small tubes inside large tubes near center; one small tube outside
6	0.736	1.05				
26	1.368	1.66	28.7	56.2	24.2	Small tubes inside large tubes near center
10	0.736	1.05				

Table 3.4.1 (continued)

Number of Tubes or Rods	Tube or Rod Dimensions (in.)		Metal Content (vol %)	Critical Conditions		Description of Assembly
	Inside Diameter	Outside Diameter		Solution Height (in.)	Mass (kg of U^{235})	
			Copper Tubes and Rods; $\frac{1}{4}$-in.-thick Copper Shell Plus H_2O Reflector			
26 16	1.368 0.736	1.66 1.05	32.1	30.2	12.4	Small tubes inside large tubes near outer edge
26 19	1.368 0.736	1.66 1.05	33.7	60[b]	24.1	Small tubes inside large tubes around outer edge
			Copper Tubes Contained in Stainless Steel Basket;[c] $\frac{1}{4}$-in.-thick Copper Shell Plus H_2O Reflector			
				7.33	4.69	Contained only stainless steel basket plus solution
60	0.822	1.05	25.6	22.2	9.98	Tubes uniformly distributed
60 10	0.822 0.495	1.05 0.675	27.7	58.7	25.7	Ten small tubes inside large tubes near center
			Copper Tubes Contained in Stainless Steel Basket;[c] H_2O Reflector Only			
60	0.822	1.05	25.6	15.5	6.97	Tubes uniformly distributed
60 7	0.822 0.495	1.05 0.675	27.1	19.2	8.46	Seven small tubes inside large tubes near center
60 10	0.822 0.495	1.05 0.675	27.7	21.3	9.31	Ten small tubes inside large tubes near center
			4-in.-OD Copper Rod Plus Tubes Held in Stainless Steel Basket;[c] $\frac{1}{4}$-in. Copper Plus H_2O Reflector			
1		4.0	16.0	11.9	6.39	Single rod in center
1 2	 1.933	4.0 2.375	19.8	14.0	6.79	Two tubes adjacent to copper rod on adjacent sides
1 4	 1.933	4.0 2.375	23.6	18.1	8.36	Small tubes placed around center rod
1 6	 1.933	4.0 2.375	27.4	29.8	15.6	Small tubes placed around center rod
1 6 2	 1.933 1.272	4.0 2.375 1.66	29.7	60 (NC)		Small tubes placed around center rod
			Aluminum Tubes; $\frac{1}{4}$-in.-thick Copper Shell Plus H_2O Reflector			
7 9	2.062 1.590	2.375 1.875	18.7	9.88	4.86	Tubes uniformly distributed
7 12	2.062 1.590	2.375 1.875	21.7	11.3	5.35	Tubes uniformly distributed

[a]NC = not critical.

[b]This assembly was not critical, but the monitoring instruments indicated that removal of one small rod would have been more than sufficient to make the assembly critical.

[c]The calculations of critical volumes in these assemblies include the volume occupied by the basket; hence the volumes recorded are slightly high.

shell displacing part of the water reflector in both cases.

In some experiments the copper placement was varied in steps radially from the center. It was observed that the metal was more effective in positions near the center, a 4-in.-dia rod at the center having the greatest effect. It was also observed that for a given volume fraction the smaller-diameter tubes had a greater effect than the larger ones.

An indication of the relative effects of displacement of solution and poisoning by the copper was obtained by substituting aluminum tubes for copper in two experiments, since aluminum has a very low absorption cross section. Comparison of aluminum data with corresponding copper data where the tube sizes and distributions are similar indicates that displacement of solution is more important than the neutron absorption effect. This is clearly seen by comparison of the curves in Fig. 3.4.1.