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3.6. CRITICAL PARAMETERS FOR 20-in.-dia STAINLESS STEEL CYLINDERS CONTAINING AQUEOUS SOLUTIONS OF U^{235} POISONED WITH PYREX GLASS

J. K. Fox   L. W. Gilley

The Nuclear Safety Group at the Y-12 Plant has suggested that Pyrex glass, nominally containing 4 wt % boron, might be a suitable poisoning material for ensuring nuclear safety in large vessels containing aqueous solutions of U^{235}-enriched uranium. An appropriate quantity of glass pipe contained in the storage vessels would prevent the achievement of criticality, even with optimum solution concentrations. Accordingly, a series of experiments has been performed to determine the volume per cent of glass necessary to assure subcritical conditions in both water-reflected and unreflected 20-in.-dia stainless steel cylinders containing aqueous solutions of U^{235}-enriched uranyl fluoride and uranyl nitrate.

Various diameters of Pyrex glass pipe were used, either in 3-ft lengths with their axes vertical to form lattices, or as short pieces (Raschig rings) randomly placed within the vessel to a height of 3 ft. For ease of handling, both the lattices and the randomly assembled arrays were contained in a stainless steel wire basket which fitted into the cylindrical experimental vessel. The results of all experiments are shown in Tables 3.6.1 and 3.6.2.

In a preliminary series of experiments, lattices of 1.5-in.-dia Pyrex pipe coated with a $\frac{1}{16}$-in. thickness of Unichrome, a polyvinyl chloride plastic, were used. The fuel solution was 93.2% U^{235}-enriched UO_2F_2 with an $H:U^{235}$ atomic ratio of 99.3, which is somewhat higher than the optimum ratio for minimum critical volumes. The resulting data are shown as Part A in Table 3.6.1. The volume fraction of glass plus coating required for poisoning was higher than that for the uncoated pipe used in subsequent experiments owing to the lesser poisoning effect of the Unichrome coating. Part A of Table 3.6.1 also shows the effect of replacing the UO_2F_2 solution with a $UO_2(NO_3)_2$ solution, which has a lower $H:U^{235}$ atomic ratio. The effect of substituting a cadmium-lined stainless steel cross for the pipe arrays in the UO_2F_2 solution was also determined.

Lattices of uncoated pipes of three different diameters were used with an 87.4% U^{235}-enriched $UO_2(NO_3)_2$ solution having an $H:U^{235}$ atomic ratio of 81.4. This concentration is very near that for minimum critical volume of nitrate solutions. Data from this solution are given in Part B of Table 3.6.1, and the critical height as a function of glass content is plotted in Fig. 3.6.1. The observed scatter in the data is believed to be due to an effect of the three diameters of pipe used. The curves indicate that for a system reflected with water on the sides and bottom, 15 vol % of glass, as 2-in.-dia pipe, would be sufficient to effectively poison a 20-in.-dia cylinder 3 ft long. For unreflected assemblies, 12 vol % would be required with 2-in.-dia pipes and 14 vol % required with 3-in.-dia pipes.

Parts C and D of Table 3.6.1 show the effect of two successive increases in the $H:U^{235}$ atomic ratio for 87.4% U^{235}-enriched $UO_2(NO_3)_2$ solutions. At an $H:U^{235}$ ratio of 141 the increased moderation increased the critical height of an unreflected cylinder containing 7.80 vol % of 2-in.-dia pipes from 16.7 in. to above 36 in., while the critical height of a reflected cylinder was increased from 9.75 in. to 12.5 in. For the same pipe assembly, a change in the $H:U^{235}$ ratio to 276 made the reflected 20-in.-dia cylinder subcritical.

The thickness of fuel above the top of the 36-in.-high Pyrex pipe assembly required for criticality is noted in the last column of Table 3.6.1. Comparison of these data with the clean critical height gives an indication of the neutron multiplication within the assembly. For example, the data in Part B show that an unreflected cylinder containing thirty-four 2-in.-dia pipes was not critical until the solution reached a height of 40.8 in., which was 4.8 in. above the top of the pipe assembly. This may be compared with a clean critical height for an unreflected system of ~5.5 in.

The results of experiments using Pyrex Raschig rings (1.469 in. OD by 1.28 in. ID by 1.56 in. long) in random arrays are presented in Table 3.6.2. Since a more homogeneous distribution of the boron poison resulted, the rings were more effective than any of the pipes used, a glass content of only 11 vol % being required to effectively poison the 20-in.-dia reflected cylinder. The data indicate that the effect of larger rings (2.375 in. OD by 2 in. ID by 2.375 in. long) is approximately the same as that of a pipe array occupying the same volume.

Table 3.6.1. Critical Parameters of Enriched Fuel Solutions Poisoned with Pyrex (~4 wt % Boron) Glass Pipe Lattices

Diameter of Pyrex Pipe (in.)	Number of Pipes	Center-to-Center Pipe Spacing (in.)	Glass Content (vol %)[a]	Reflector Condition[b]	Critical Values: Solution Height (in.)	Critical Values: Mass (kg of U^{235})	Remarks
A. Pipe Coated with $\frac{1}{16}$-in. Unichrome; 93.2% U^{235}-Enriched UO_2F_2 Fuel Solution; $H:U^{235} = 99.3$							
$1\frac{1}{2}$	49	2.1	35.0	Reflected	*c*	*c*	No source neutron multiplication
$1\frac{1}{2}$	19	3.75	13.5	Bare	9.55	11.5	
$1\frac{1}{2}$	19	3.25	13.5	Bare	14.5	17.4	More free space on edges of this array than on above array
$1\frac{1}{2}$	19	3.25	13.5	Reflected	7.80	9.38	
$1\frac{1}{2}$	31	2.75	22.1	Bare	*c*	*c*	
$1\frac{1}{2}$	31	2.75	22.1	Reflected	16.3	17.6	
$1\frac{1}{2}$	31	2.75	22.1	Reflected	18.0	20.7	Fuel solution changed to solution in B below
				Bare	8.87	12.2	Cadmium cross substituted for Pyrex pipes[d]
B. Uncoated Pipe; 87.4% U^{235}-Enriched $UO_2(NO_3)_2$ Fuel Solution; $H:U^{235} = 81.4$							
$1\frac{1}{2}$	31	2.75	9.78	Reflected	12.7	16.9	
$1\frac{1}{2}$	31	2.75	9.78	Bare	26.6	35.6	
$1\frac{1}{2}$	53	2.13	16.7	Reflected	*c*	*c*	Critical when solution was 4.1 in. above top of pipe
2	34	2.68	13.95	Reflected	30.1	38.3	Closely packed
2	34	2.68	13.95	Bare	*c*	*c*	Critical when solution was 4.8 in. above top of pipe
2	19	3.00	7.80	Bare	16.7	22.9	
2	19	3.00	7.80	Reflected	9.75	13.3	Glass pipes arranged in an ~14-in.-dia central region of the cylinder
2	23	3.00	9.45	Reflected	11.6	15.5	
2	23	3.00	9.45	Bare	24.3	32.5	

Table 3.6.1 (continued)

Diameter of Pyrex Pipe (in.)	Number of Pipes	Center-to-Center Pipe Spacing (in.)	Glass Content (vol %)[a]	Reflector Condition[b]	Critical Values: Solution Height (in.)	Critical Values: Mass (kg of U^{235})	Remarks
B. Uncoated Pipe; 87.4% U^{235}-Enriched $UO_2(NO_3)_2$ Fuel Solution; $H:U^{235} = 81.4$							
2	28	2.68	11.5	Reflected	13.6	17.8	Closely packed except on edges
2	28	2.68	11.5	Bare	*c*	*c*	Critical when solution was 3.4 in. above top of pipe
3	16	3.78	11.34	Reflected	12.5	16.4	Closely packed
3	16	3.78	11.34	Bare	23.4	30.7	
			None	Reflected	4.98	7.33	Clean critical
			None	Bare	5.97	8.85	Clean critical
C. Uncoated Pipe; 87.4% U^{235}-Enriched $UO_2(NO_3)_2$ Fuel Solution; $H:U^{235} = 141$							
2	19	3.0	7.80	Bare	*c*	*c*	Critical when solution was $\sim$0.6 in. above top of pipe
2	19	3.0	7.80	Reflected	12.5	10.28	
			None	Reflected	5.19	4.62	Clean critical
			None	Bare	6.15	5.45	Clean critical
D. Uncoated Pipe; 87.4% U^{235}-Enriched $UO_2(NO_3)_2$ Fuel Solution; $H:U^{235} = 276$							
2	19	3.0	7.80	Reflected	*c*	*c*	Critical when solution was 1.3 in. above top of pipe
			None	Reflected	5.41	2.53	Clean Critical
			None	Bare	6.60	3.11	Clean Critical

[a] Values include volume of the Unichrome coating when used.

[b] No top reflector in any of the experiments.

[c] Not critical when solution was at the level of the top of the pipe (36 in.).

[d] Glass replaced by 28-mil-thick cadmium-lined stainless steel cross 19.5 in. wide.

Table 3.6.2. Critical Parameters of Enriched Fuel Solutions Poisoned with Pyrex (~4 wt % Boron) Glass Raschig Rings in Random Arrays

Fuel solution: 87.4% U^{235}-enriched $UO_2(NO_3)_2$
$H:U^{235}$ atomic ratio: 81.4

Raschig Ring Dimensions			Glass Content (vol %)	Reflector Condition*	Critical Values		Remarks
Outside Diameter (in.)	Inside Diameter (in.)	Length (in.)			Solution Height (in.)	Mass (kg of U^{235})	
1.469	1.28	1.56	10.97	Reflected	Not critical		Critical when solution was 1.0 in. above top of rings
2.375	2.00	2.375	13.3	Reflected	19.6	25.1	
2.375	2.00	2.375	13.3	Bare	Not critical		Critical when solution was 4.0 in. above top of rings

*No top reflector in any of the experiments.

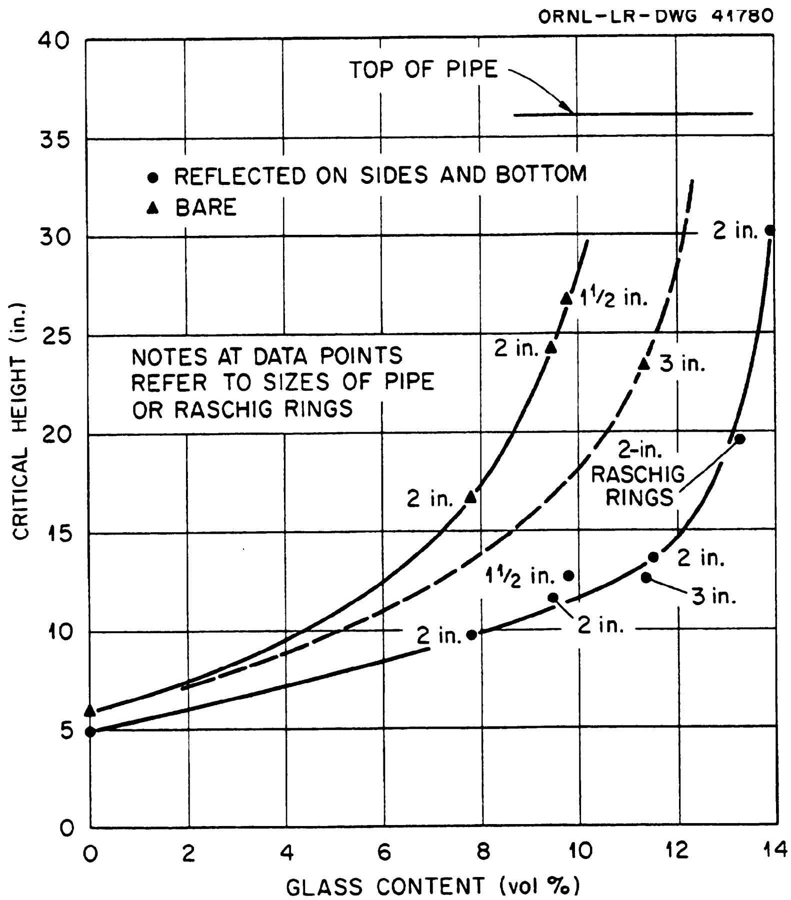

Fig. 3.6.1. Critical Heights, as a Function of the Pyrex Content, of Bare and Reflected 20-in.-dia Stainless Steel Cylinders Containing a Pyrex-Poisoned Aqueous Solution of 87.4% U^{235}-Enriched $UO_2(NO_3)_2$.