# REFERENCE 129

**L. W. GILLEY AND DIXON CALLIHAN, "NUCLEAR SAFETY TESTS ON A PROPOSED BALL MILL," OAK RIDGE NATIONAL LABORATORY REPORT ORNL-CF-54-9-89 (SEPTEMBER 1954).**

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SUBJECT: Nuclear Safety Tests on a Proposed Ball Mill

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# NUCLEAR SAFETY TESTS ON A PROPOSED BALL MILL

These experiments were conducted in an attempt to evaluate the nuclear hazards of a ball mill for enriched uranium, using steel balls, which has been proposed for one of the steps in a production schedule. The mill could be approximated by a 15" diameter cylindrical vessel using approximately 1" diameter steel rods as a poison. Accordingly, a series of critical experiments was run, using uranyl fluoride solution, in a 15" diameter stainless steel reactor which was effectively infinitely reflected with ordinary water on the bottom and sides to a height equal to the critical fuel height. The experimental variable was the number and spacing of the steel rods.

## Experimental Materials

Fuel: The fuel used was 93.2% enriched U-235 in a uranyl fluoride aqueous solution. The uranium concentration was 0.25613 gm of uranium per gram of solution and the specific gravity was 1.4201 at about 25°C corresponding to a hydrogen to U-235 atomic ratio of 73.0.

Reactor: The reactor was a 15" diameter stainless steel cylinder with a 3" solution feed line leading into the bottom. A 1/2" thick aluminum plate supported by legs 1/2" long rested on the bottom of the cylinder to support the steel rods. Concentric with the 3" feed line was a 1" reentrant stainless steel tube in which a neutron source could be located at the level of the bottom of the reactor.

Rods: Available for these experiments were 121 steel rods 7/8" in diameter and 8' long coated with about 0.01" of Heresite. Also available were a number of identical rods except they were coated with Unichrome about 0.04" thick.

Spacer Plates: In these experiments two sets of plates, 1/4" thick, were used to hold the steel rods in a hexagonal lattice. One set of plates, made of plastic, had ninety-one 1" diameter holes drilled in a hexagonal pattern with a center to center spacing of approximately 1.35" and the other set, of aluminum, had 151 holes also 1" in diameter but with a center to center spacing of approximately 1.11".

Coating Materials: Chemical analyses of the corrosion resistant coatings applied to the steel rods showed no significant amount of metallic impurity, the maximum found being 10 ppm of boron. The Unichrome, however, being a polyvinyl chloride contained about

30% chlorine by weight. Heresite, having a phenolic base, was shown to contain no chlorine and is believed to be free of other non-metallic neutron poisons.

Results and Summary

The critical height of the $UO_2F_2$ solution in the cylinder was measured as a function of the number of steel rods in an endeavor to establish the minimum number which would cause the cylinder to be sub-critical when effectively infinitely long. The results are given in the table as experiments A-H, inclusive, and in the figure where the critical height and critical mass are plotted as a function of the steel content. There was no observed source neutron multiplication with 139* rods and 20.3 kg U-235 loaded and the curves are drawn asymptotic to this abscissa. It will be noted that the rods are spaced farther apart in the loadings with fewer rods in order to distribute the poison more or less uniformly over the cylinder.

An evaluation of the additional poison introduced by the chlorine in the relatively thick coatings of Unichrome was made by comparing the critical heights of two arrays in which the proportion of differently coated rods was altered. In one array of 121 rods, experiment I, the center ones were coated with Heresite and the critical height was 53.5 cm. Replacing the seven most central rods (5.8% of the total) with ones coated with Unichrome in experiment J increased the critical height to 55.4 cm or by 3.5%. The Unichrome coated rods uniformly distributed in three earlier experiments had the effect of increasing the critical height a few percent.

Since only two sets of spacer plates were available to define the dimensions of the hexagonal pattern of the rods there were, in most cases, vacant places in the pattern. In the experiments on which the graph is based, these vacancies were distributed approximately uniformly over the area of the 15" diameter core. Comparisons were made of the importance of the location of these empty spaces by noting the critical heights in three experiments in which the total number of rods was the same. In one, K, seven rods were removed from the center and placed at the periphery, in another, I, the distribution was reversed and in the third,D, the central and six spaces on a circle mid-way along a radius were empty. The critical heights were, respectively, 36.7 cm, 53.3 cm and 42.7 cm. These results emphasize the importance of the location of the poison and illustrate, in the practical application being considered, the undesirability of "piling-up" of the balls around the periphery of the mill.

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* Since only 121 Heresite coated rods were available this array contained 18 rods covered with Unichrome which were distributed uniformly over the core. Similarly, other arrays of more than 121 rods contained some coated with Unichrome.

It should be pointed out that the displacement of the $UO_2F_2$ solution by the steel rods, in addition to the neutron absorption, contributes significantly to the loss in reactivity. In an earlier experiment[1] the distribution of 106 empty aluminum tubes, 1" in diameter over a cylinder 15" in diameter, containing $UO_2(NO_3)_2$ solution of about the moderation of these tests, increased the critical height by an estimated factor of four and more than doubled the critical mass. It was not possible to make the array with the tubes critical but the estimated increases are conservative.

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1. Callihan, D., et. al., K-643, June 30, 1950.

| Exp. | Number* Rods | Rod Spacing Center to Center | Solution** Height | Total Core Volume | Core Composition Volume Percent Steel | Rods*** | Solution | Mass U-235 | Comments |
|---|---|---|---|---|---|---|---|---|---|
| A | 0 | - | 10.8 cm | 12.3 L | 0.0 | 0.0 | 100.0 | 4.1 kg | |
| B | 31 | 3.43 cm | 13.0 | 14.8 | 10.5 | 11.1 | 88.9 | 4.3 | |
| C | 91 | 3.43 | 22.5 | 25.6 | 30.9 | 32.6 | 67.4 | 5.8 | |
| D | 121 | 2.82 | 42.7 | 48.7 | 41.1 | 43.2 | 56.8 | 9.3 | |
| E | 127 | 2.82 | 50.3 | 57.3 | 43.2 | 45.8 | 54.2 | 10.4 | |
| F | 136 | 2.82 | 95.4 | 108.8 | 46.3 | 49.2 | 50.8 | 18.5 | |
| G | 139 | 2.82 | 107.8 | 122.9 | 47.2 | 50.5 | 49.5 | 20.3 | Not critical, no apparent source neutron multiplication. |
| H | 145 | 2.82 | 110.8 | 126.3 | 49.3 | 52.2 | 47.8 | 20.2 | |
| I | 121 | 2.82 | 53.5 | 61.0 | 41.1 | 43.3 | 56.7 | 11.6 | Heresite covered rods at center. |
| J | 121 | 2.82 | 55.4 | 63.2 | 41.1 | 43.6 | 56.4 | 11.9 | Unichrome covered rods at center. |
| K | 121 | 2.82 | 36.7 | 41.8 | 41.1 | 43.2 | 56.8 | 7.9 | No rods at center |

* Diameter of uncoated rods 0.875" = 2.22 cm
Area of uncoated rods 3.87 $cm^2$
Area of Unichrome coated rods 4.67 $cm^2$
Area of Heresite coated rods 4.08 $cm^2$

** $UO_2F_2$ solution analysis: 0.256 gm U/gm; Specific gravity 1.42 at 25°C; H:U-235 = 73

*** Including coating material.