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MEASURED CADMIUM BURNUP IN C REACTOR HCR'S

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May 3, 1961

MEASURED CADMIUM BURNUP IN C REACTOR HCR'S

INTRODUCTION

C Reactor horizontal control rods were originally designed to have 32 feet of poison, made of 64 six inch "cans" each consisting of two concentric cylinders sealed at each end and the annular space between them filled with boron carbide powder. It was discovered before startup that under irradiation the neutron, alpha reaction in the boron could cause a pressure buildup and rupture of the sealed section. As an expediency cylinders wrapped with 72 mils thick cadmium metal were substituted for the boron "cans" and the pressure buildup problem was eliminated.

However, since for a unit volume, natural cadmium contains fewer high cross-section nuclei than natural boron, the lifetime of one of these cadmium rods in Hanford flux levels is limited. Five of the original 15 cadmium rods were replaced in 1957 with boron rods of improved design. The primary purpose of this document is to present

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the results of a study to evaluate the extent of burnout in the remaining ten cadmium rods and their present rate of burnout so that replacement can be scheduled before these rods start losing significant reactivity poisoning effectiveness.

SUMMARY AND CONCLUSION

The results of this study show that the cadmium in a portion of the number 7 HCR should have been nearly 100 per cent burned out by about January 1, 1961. This result has been fairly well confirmed by recent operational experience at C Reactor which indicate that the rod has lost considerable strength over the past three months. The following table presents the percentage of the cadmium 113 which has been calculated to have been burned out up to the end of 1960. This amount of burnout is applicable to the last 100 or so inches of the tips of these rods since a large share of their use during normal operation has been as short rods; i.e., only a portion of the rod has been inserted in the reactor. Also the rods probably were irradiated in a 10-20 per cent lower flux level. However, this much conservatism should be used to compensate for inaccuracies in the method.

For the original number two rod which was replaced in 1957, the predicted burnout of ^{113}Cd is 85 per cent, analysis of the sample from the rod shows 82.2 per cent burnout. The remaining cadmium rods and their calculated burnout as of January 1, 1961, is as follows:

<u>Rod</u>	<u>% Burnout (Calculated)</u>
1	88
3	77
4	48
6	90
7	100
9	73
10	48
12	80
13	98
15	77

At current power levels, burnout for rods that are used during equilibrium is about 3 per cent per month assuming 80 per cent operating efficiency.

The analysis was performed using neutron transmission measurements of a sample of one of the rods replaced in 1957 (number 2 rod), to determine the actual burnout.^{/1/} Then, by analyzing comparative operating exposure histories, the burnout of the remaining ten HCR's was calculated. This empirical method also confirmed the validity of a theoretical method for calculating the burnout, thus providing a reliable technique for calculating the boron burnout of the existing horizontal control rods in all Hanford reactors.

Cadmium 113 Burnout Measurement

In 1957, five of the original cadmium rods were replaced with boron-containing half-rods. The rod from position number two was moved to a special cave where it could safely be stored and examined at a later date.

^{/1/} R. E. Odgaard, "Measurement of ^{113}Cd Burnout in a Reactor Control Rod,"
HW-68753 dated 3-7-61

In the summer of 1960 a section of the rod about three feet from the tip end, was cut out using a long handled hack saw. (Radiation readings of about 20 r/hr at one foot were encountered.) The section was transferred to the 105 C storage basin where the cadmium was removed. The two concentric cylinders of cadmium (each 0.036 inches thick) were flattened and 2"x2" samples were sandwiched between two pieces of aluminum for handling ease. Neutron transmission measurements were then made by Physics Research personnel of Hanford Labs, to determine the isotopic concentration of Cd113 remaining in the irradiated samples. The results indicate that the outer cylinder contained no Cd113 within the precision of the measurement; the inner cylinder contained 36.6 $\pm$ 0.5 per cent of the Cd113 content of natural cadmium. Thus, the total Cd113 burnout in the two samples was 82.2 $\pm$.35 per cent. The burnout of the other rods was determined from in-pile exposure comparisons with the measured rod. Since rods are normally used in symmetric top-to-bottom pairs the burnout of the bottom rods was considered equal to the burnout of the corresponding top rods whose exposure history was examined in detail.

Method for Calculating Burnout

The absorption of neutrons by a control rod is related to its effect on this local multiplication factor or, stated simply, the reduction of k in the region of control. Since the depression of k throughout the reactor is uniform, to find the neutron absorption rate the average neutron generation rate in the control region must be known. The following discussion shows how the average neutron flux per region was approximated.

The basic assumption employed was that the number of neutrons absorbed per second equal local reactivity strength in excess k times the total number of neutrons formed in the local cell per second.

The maximum heat generated is ~ 2 kw per cm of tube at a reactor power level of 1600 MW. Since the tubes are located in square lattices 21.27 cm on a side, the liberation of heat per unit volume of the pile is at a rate of about 4.35 watts/cm³. Each fission liberates about 200 mev of heat and about 2.2 neutrons, or an average yield of 90 mev per neutron formed. Consequently since the average heat generation rate is 4.35 watts per cm³ the neutron generation rate is found by the following conversion:

$$1 \text{ watt sec} = 0.625 \times 10^{13} \text{ mev},$$

so,

$$\frac{4.35 \text{ watts/cm}^3 \times 0.625 \times 10^{13} \text{ mev/watt sec}}{90 \text{ mev/neutron}} = 0.302 \times 10^{13} \text{ neutrons/cm}^3 \text{ sec.}$$

The total volume of a 1 cm thick slab of the control region for one rod is 1 cm x 127.6 cm x 159.5 cm or 2035 x 10⁴ cm³. Therefore the number of thermal neutrons entering this control region 1 cm thick in one second is:

$$159.5 \text{ cm} \times 127.6 \text{ cm} \times 1 \text{ cm} \times 0.302 \times 10^{13} \text{ neutrons/cm}^3 \text{ sec} = 6.146 \times 10^{15} \text{ neutrons/sec.}$$

From HW-63080, the local control strength for a C Reactor control rod is given as 72.4 μ b. Using a conversion factor of 1 μ b = 61.8 c-mk, the rod absorbs the fraction 72.4 x 61.8(10)⁻⁵ or 0.04474 of the neutrons produced in a control region. Therefore, the rate of neutron absorption for the rod is 6.146 x 10¹⁵ x 0.04474 = .275 x 10¹⁵ neutrons/sec per centimeter of length. The length of a time a rod has

been subjected to a neutron flux of this magnitude is approximated by summing up the total production while the rod was in the reactor. This production divided by the 1600 MW level for which the above analysis was performed, yields the number of days of continuous operation it would take to submit the rod to the irradiation it has received. Note that only the extreme tip end would necessarily achieve this exposure since the remainder of the rod would often be out of the reactor.

Example:

Number 2 rod was inserted while a total of about $1.17(10)^6$ MWD of production was made; at a pile level of 1600 MW, 733.5 days of continuous operation would be equivalent. This represents a burnout of

$$733.5 \text{ days} \times 86,400 \text{ sec/day} \times 2.75 \times 10^{14} = 1.743 \times 10^{22} \text{ Cd}^{113} \text{ atoms per centimeter of rod length.}$$

The total number of Cd^{113} nuclei in 1 Cm of rod length is simply

$$N = \frac{\rho \times N_0 \times V \times b}{A}$$

Where:

$$\begin{aligned} \rho &= \text{Density of cadmium} = 8.642 \\ N_0 &= \text{Avogadro's number} = 6.02 \times 10^{23} \\ V &= \text{cm}^3 \text{ of Cd per cm length} = 3.592 \text{ cm}^3 \\ b &= \% \text{ of Cd}^{113} \text{ in Cd metal} = 12.34\% \\ A &= \text{Atomic weight} = 112.41 \end{aligned}$$

Therefore:

$$N = 2.051 \times 10^{22} \text{ nuclei.}$$

The burnout is then

$$\frac{1.743 \times 10^{22}}{2.051 \times 10^{22}} = 85\%$$

which agrees very closely with the measured burnout of 82.2 per cent.

This calculation should predict burnout higher than it really is since the rod is assumed to be entirely in a region of maximum power and assumes that all captures in the rod are in the cadmium 113. Furthermore, it is desirable that the calculation be conservative in this direction.

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R. A. Chitwood

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