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SUBJECT: EFFECT OF CORE CORROSION SAMPLE ASSEMBLY ON
HRT CRITICAL CONCENTRATION

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SUMMARY

An estimate has been made of the critical fuel concentration in the HRT, taking into account the effect of the core corrosion sample assembly. The estimate is based on a number of previous calculations of critical concentration in an unpoisoned reactor and one calculation of critical concentration as a function of poison level. The makeup of the first core corrosion sample assembly was used in calculating equivalent neutron poisoning effects.

Figure 1 shows the estimated critical concentration as a function of temperature with the corrosion sample assembly in place. At 280°C, the assembly raises the critical concentration by 0.6 g U-235/kg D₂O. This effect is equivalent to a uniformly distributed poison equal to 4.1% of the fission cross section. The equivalent poison is greater at lower temperatures, where the uranium concentration is lower.

CRITICAL CONCENTRATION IN THE CLEAN REACTOR

The critical concentration in the HRT in the absence of neutron poisons has been calculated a number of times by various methods and using slightly different values for nuclear constants. These calculations have been evaluated, and their results compared to arrive at an estimate of the critical concentration in a "clean" HRT with a D₂O reflector.

In 1954, Edlund and Wood first calculated critical concentrations using a harmonics method with an age-Yukawa kernel.¹ Results of their calculation for the case of a D₂O reflector are shown in Fig. 2.

Later (June, 1956), Nestor calculated critical concentrations for the clean D₂O-reflected reactor, using the most recent nuclear data then available in a two-group, two-region method.² His results are also given in Fig. 2.

In March, 1956, Kasten and Nestor calculated the critical concentration for the clean reactor at one temperature, 280°C. By a two-group calculation they obtained a critical concentration of 6.7 g U-235/kg D₂O.³ However, they estimated that about 20-30% of the fissions could be caused by neutrons of above thermal energy, and that this would result in a critical concentration about 3.5-9.5% higher than given by the two-group calculation.

Evidence that the two-group calculation may give low values for the critical concentration in the HRT is furnished by some other calculations by Nestor. He calculated critical concentrations in U-235-fueled reactors with thorium blankets by the two-group, two-region method and also by "Eyewash," a 27-group, 4-region calculation carried out on the Univac.⁴ For a core the size of the HRT, the critical concentration by the "Eyewash" calculation was about 17% higher than that by the two-group method. This was for 1000 g Th/liter in the blanket. In the case of the HRT with a

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D₂O reflector, the critical concentration will be lower, epithermal fissions will not be so important, and the two-group results should be more accurate.

Based on the foregoing information, values for the critical concentration in the HRT with a D₂O reflector and no poisons were obtained by multiplying the concentrations given in CF-56-6-123 by 1.065 to approximate the probable effect of epithermal fissions.

EFFECT OF POISON LEVEL ON CRITICAL CONCENTRATION

Figure 3 gives a curve for the fractional increase in critical concentration as a function of poison level for the D₂O-reflected reactor at 280°C. This was taken from the report by Kasten and Nestor.³ The poison level is the evenly-distributed macroscopic poison cross section divided by the macroscopic fission cross section.

VOLUMES OF METALS AND NEUTRON CROSS SECTION OF CORROSION SAMPLE ASSEMBLY

The core corrosion sample assembly is shown on ORNL drawing D-25625a. In the first assembly to be installed, in the core itself there will be 14 zirconium (Zr-2 and Zr-Nb) specimens, 7 titanium and one specimen of 347 stainless steel.⁵ The volumes of each type of metal in the core are summarized in Table 1. Volumes do not include portions of the assembly in the outlet pipe above the spherical part of the core vessel.

Table 1

Volumes of Metals in Core Corrosion Sample Assembly

Item	Material	Number	Total Volume cm ³
Specimen	Zirconium	14	46.3
Specimen	347 S.S.	1	3.3
Specimen	Titanium	7	23.3
Web-Welded Assembly	Titanium	1	174.5
Specimen Holder	Titanium	12	47.9
Lock Screw	Titanium	24	17.4
Specimen Guide	Titanium	12	3.9

Table 2 lists the total volumes, macroscopic absorption cross sections and total neutron absorption target areas for each type of material in the assembly. Neutron cross sections are evaluated at 0.048 ev, which corresponds to kT at 280°C. Composition of stainless steel, type 347, is taken from the Reactor Handbook.⁶ Microscopic cross sections are from the AEC Neutron Cross Sections.⁷

Table 2
Quantities Affecting Neutron Absorption
in Core Corrosion Sample Assembly

Material	Cross Section (0.048 ev) Σ_a, cm^{-1}	Volume V, cm^3	Target Area (0.048 ev) $V\Sigma_a, \text{cm}^2$
Zirconium	0.0055	46.3	0.3
Stainless	0.178	3.3	0.6
Titanium	0.23	267.0	<u>61.4</u>
			62.3

The neutron absorption of the same assembly is localized, rather than being evenly distributed throughout the core. Therefore, in order to use Fig. 3, it is first necessary to calculate the macroscopic cross section of an evenly-distributed poison which would have an equivalent effect. By inspection of the assembly drawing, a good approximation is to say that the neutron target area of the assembly is evenly distributed along a line extending 67 cm downward from the top of the core and passing through the center of the core. The statistical weight of absorber in this configuration, calculated from flux distributions for the unperturbed reactor, is 1.3 times as great as that for absorber uniformly distributed throughout the core. The macroscopic cross section of a uniformly-distributed poison equivalent to the sample assembly is equal to the equivalent target area divided by the core volume.

$$\Sigma_p (0.048 \text{ ev}) = \frac{1.3 \times 62.3}{2.92 \times 10^5} = 2.8 \times 10^{-4} \text{ cm}^{-1}$$

POISON FRACTION AND CRITICAL CONCENTRATIONS

The poison fraction is defined as the ratio of poison cross section to the fission cross section. At 0.048 ev, σ_P for U-235 is 397 b (really the kT cross section of an equivalent $1/v$ absorber) and

$$\Sigma_P, \text{ cm}^{-1} = 1.02 \times 10^{-3} C,$$

where C is the U-235 concentration in g/liter. Thus the poison level, in percent, is

$$P, \% = \frac{2.8 \times 10^{-4}}{1.02 \times 10^{-3} C} \times 100 = \frac{27}{C}.$$

Because σ_P and the poison cross sections all vary in about the same manner with neutron energy, the above relation is accurate enough at energies other than 0.048 ev or temperatures other than 280°C. This relation between the U-235 concentration and the equivalent poison of the sample assembly is plotted in Fig. 4.

Also plotted in Fig. 4 is a set of curves for the critical concentration, in g U-235/liter, as a function of poison fraction at a number of temperatures. Critical concentrations, in g U-235/kg D₂O, were obtained from Fig. 3, and the concentration for a clean reactor. The concentration in g/liter was then found by multiplying by the D₂O density at each temperature.

The intersections of the family of curves and the curve of P vs C give the critical concentrations, in g/liter, with the sample assembly installed. These concentrations, converted to g U-235/kg D₂O, are shown in Fig. 1.

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