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CHANGE IN CRITICAL CONCENTRATION IN A CYLINDRICAL REACTOR DUE TO A LONGITUDINAL HOLE

This report discusses the change in critical concentration due to axial holes of various diameters in a right circular cylinder containing heavy water and pure U^{233} or U^{235} . The cylinder is 8 ft high and 8 ft in diameter. The longitudinal holes were 0.8 ft, 1 ft and 2 ft in diameter. This geometry is intended to represent an aqueous homogeneous reactor with a central void due to rotating flow of the fluid through the core. As the problem of neutron streaming in such holes is rather difficult to treat, the approach chosen here was to find an upper and a lower bound for the critical concentration. The highest fuel concentration would occur if the hole were completely "black" to neutrons, and the lowest would correspond to the hole being a perfect reflector. The "black" hole case was represented by the boundary condition that the flux vanish at an extrapolated radius inside the hole; the complete reflection assumption was treated by taking the net current at the inside radius to be zero. The critical equations which result are as follows:

$$\text{Perfect Reflector: } J_1(\alpha \tilde{R}_1) Y_0(\alpha R_0) - J_0(\alpha \tilde{R}_1) Y_1(\alpha R_0) = 0 \quad (1)$$

$$\text{"Black Hole": } J_0(\alpha \tilde{R}_1) Y_0(\alpha \tilde{R}_0) - J_0(\alpha R_0) Y_0(\alpha \tilde{R}_1) = 0 \quad (2)$$

where the radii are identified on Fig. 1. (The Bessel Function notation employed by Sherwood and Reed³ is used here.)

Fig. 1

The radial buckling term α is related to the material buckling by the equations:

$$\alpha^2 + \left(\frac{\pi}{H}\right)^2 = \mu^2 \quad (3)$$

$$\mu^2 = -\frac{1}{2} \left(\frac{1}{\tau} + \frac{1}{L^2} \right) + \sqrt{\left[\frac{1}{2} \left(\frac{1}{\tau} + \frac{1}{L^2} \right) \right]^2 + (k-1) \frac{1}{\tau L^2}} \quad (4)$$

Thus, given the true and extrapolated reactor dimensions, the lowest values of α which satisfy equations (1) and (2) may be found.¹ From (3), μ^2 may be calculated, and the critical concentration may then be obtained using (4). An Oracle code was prepared to carry out all computations. (The machine computation of the roots of (1) and (2) may well prove useful for work in other fields.)

The results of the calculations are tabulated below:

TABLE I

Reactor Temperature: 250°C

Inside Radius, ft	Critical Concentration g U-233 per liter		Critical Concentration g U-235 per liter	
	Perfect Reflector	Black Hole	Perfect Reflector	Black Hole
0	0.50	-	0.55	-
0.4	0.52	0.80	0.56	0.87
0.5	0.53	0.85	0.57	0.93
1.0	0.57	1.17	0.62	1.29

Two conclusions may be drawn from these results. First, the collapse of the void in a rotating fluid reactor could result in large reactivity additions. Second, the fuel inventory increase due to the presence of the void is no more than about twofold in the most extreme case cited above.

The correct critical concentration is probably closer to the perfect reflector model than the "black hole" model, at least for the smallest hole size. Investigation of this point would require considerable further analysis, not warranted at this time. Reference (2) cited below may prove useful to those interested in further work along these lines.

REFERENCES

1. Jahnke, E. and F. Emde, "Funktionentafeln," 4th Ed., pp 206-207, Dover Publications, N. Y. (1945). (Note: Jahnke and Emde denotes the Bessel Function of the second kind, Y_n , by N_p .)
2. Critoph, E. and R. M. Pearce, "The Reactivity Effect Due to Neutron Streaming in an Empty Tube," J. Nuclear Energy 1, pp 445-459 (1957).
3. Sherwood, T. K., and C. E. Reed, "Applied Mathematics in Chemical Engineering," 1st Ed. pp 198-211, McGraw-Hill Book Company, Inc. (1939).

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gcb