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SUBJECT: Effect of Slurry Settling on Reactivity in a One-Region Thorium Breeder Reactor

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EFFECT OF SLURRY SETTLING ON REACTIVITY IN A ONE-REGION THORIUM BREEDER REACTOR

Summary

The effect of uniform slurry settling on reactivity in one-region thorium breeder reactors of economic interest was investigated. The fuel considered was a mixed slurry of UO_2 and ThO_2 suspended in D_2O.

It was found that when settling occurred, thermal reactors of possible economic interest (10 to 12 ft diameter containing 200 to 300 g Th/liter) became subcritical.

Introduction

The one-region reactor operating with a mixed slurry (UO_3-ThO_2-D_2O) is an attractive possibility for the production of electric power. One presupposed disadvantage was the possibility of a dangerous reactivity increase if rapid settling of the slurry occurred. Obviously, settling would cause a rather large reactivity increase if the fuel were ThO_2 suspended in a UO_2SO_4 solution. For a mixed slurry, however, the fissile material settles along with the fertile material and it seemed probable (for some conditions) that the decrease in resonance escape probability and increase in radial leakage would compensate for the D_2O reflector formed at the top.

Two-group calculations were made to determine the order of reactivity change with uniform settling for reactor conditions in the range of economic interest[1] (10 - 12 ft diameter; 200 - 300 g Th/liter). For calculation purposes the reactor was considered an optimum cylinder (height = 1.847 x radius) since a relatively simple solution was possible for this geometry. The spherical geometry requires a two-dimensional relaxation method which involves considerable labor to get a particular solution. It was felt that for the reactor sizes considered, the cylindrical geometry results would be applicable to the spherical geometry case.

Method

For the case of the unsettled reactor, the critical equation is that given by Glasstone and Edlund[2] for bare homogeneous reactors.

When settling occurs, the problem becomes one involving a cylinder with a D_2O reflector on only one end. The two-group, two-region method of solution as outlined by Glasstone and Edlund[2] was used. The pertinent parts of the solution are shown below.

With the application of the perimeter boundary conditions, the flux solutions are:

$$\phi_{1c} = J_o\left(\frac{2.405\ r}{R + e}\right)\left[A \sin \beta z + C \sinh \alpha z\right]$$

$$\phi_{2c} = J_o\left(\frac{2.405\ r}{R + e}\right)\left[S_1 A \sin \beta z + S_2 C \sinh \alpha a\right]$$

$$\phi_{1b} = J_o\left(\frac{2.405\ r}{R + e}\right)\left[F \sinh \gamma (H + e - z)\right]$$

$$\phi_{2b} = J_o\left(\frac{2.405\ r}{R + e}\right)\left[G \sinh \rho (H + e - z) + F S_3 \sinh \gamma (H + e - z)\right]$$

where β, α, γ and ρ satisfy the relations

$$\left(\frac{2.405}{R + e}\right)^2 + \beta^2 = \mu^2$$

$$-\left(\frac{2.405}{R + e}\right)^2 + \alpha^2 = \nu^2$$

$$-\left(\frac{2.405}{R + e}\right)^2 + \gamma^2 = \mathcal{K}_{1b}^2$$

[redacted]

$$-\frac{2.405}{R + e}^{2} + \rho^2 = \mathcal{H}_{2b}^{2}$$

and μ^2, ν^2, $\mathcal{H}_{1b}^2$ and $\mathcal{H}_{2b}^2$ are given by Glasstone and Edlund.[2] Subscripts 1 and 2 refer to fast and thermal flux respectively and subscripts c and b refer to fuel region and reflector region respectively.

Applying the interface boundary conditions to these solutions yields the following equations:

$$A \sin \beta a + C \sinh \alpha a - F \sinh \gamma (H + e - a) = 0$$

$$A S_1 \sin \beta a + C S_2 \sinh \alpha a - F S_3 \sinh \gamma (H + e - a) - G \sinh \rho (H+e-a) = 0$$

$$A\beta \cos \beta a + C\alpha \cosh \alpha a + F\left(\frac{D_{1b}}{D_{1c}}\right) \gamma \cosh \gamma (H + e - a) = 0$$

$$A S_1 \beta \cosh \alpha a + C S_2 \alpha \cosh \alpha a + F\left(\frac{D_{2b}}{D_{2c}}\right) S_3 \gamma \cosh \gamma (H + e - a) +$$

$$+ G\left(\frac{D_{2b}}{D_{1b}}\right) \rho \cosh \rho (H + e - a) = 0$$

For a consistent set of solutions to this homogeneous set of equations, the determinant of the coefficients must be zero; hence the critical determinant, or critical equation for this case is

$$\begin{vmatrix} \sin \beta a & \sinh \alpha a & -\sinh \gamma (H+e-a) & 0 \\ S_1 \sin \beta a & S_2 \sinh \alpha a & -S_3 \sinh \gamma (H+e-a) & -\sinh \rho (H+e-a) \\ \beta \cos \beta a & \alpha \cosh \alpha a & \left(\frac{D_{1b}}{D_{1c}}\right) \gamma \cosh \gamma (H+e-a) & 0 \\ S_1 \beta \cos \beta a & S_2 \alpha \cosh \alpha a & \left(\frac{D_{2b}}{D_{2c}}\right) S_3 \gamma \cosh \gamma (H+e-a) & \left(\frac{D_{2b}}{D_{2c}}\right) \rho \cosh \rho (H+e-a) \end{vmatrix} = 0$$

where

A, C, F and G = arbitrary constants

a = height of settled region + extrapolation distance, cm

[redacted]

D = diffusion coefficient, cm

e = extrapolation distance, (15 cm used in all cases), cm

H = height of reactor, cm

R = radius of reactor, cm

S_1, S_2, S_3 = coupling coefficients as given by Glasstone and Edlund.[2]

z = distance along axis from point of zero flux.

The nuclear constants used were those given in ORNL-1810. Higher isotopes were not considered since this effect can be lumped in with the poisons.

Results

The main results of this study are shown plotted in Figure 1. It is evident that supercriticality by thermal neutrons cannot occur for the cases studied.

The effect of uniform settling is less pronounced as the reactor diameter and poisons are increased and as the thorium concentration is decreased. Calculations made for 3-in settling in a 20-ft reactor indicates that a slight supercriticality occurs when operating with 200 g Th/liter. Therefore, it appears that under certain conditions, which are not of interest, there is a possibility of supercriticality occurring with settling.

For maximum possible settling there is still a question as to the effect of resonance and fast fissions on criticality. However, it does not seem probable that the large decrease in reactivity could be overcome by this means.

References

1) Claiborne, H. C. and M. Tobias, "Thorium Breeder Reactor Studies," ORNL-1810, to be published.

2) Glasstone, S. and M. C. Edlund, Elements of Nuclear Reactor Theory, Chapter VIII.

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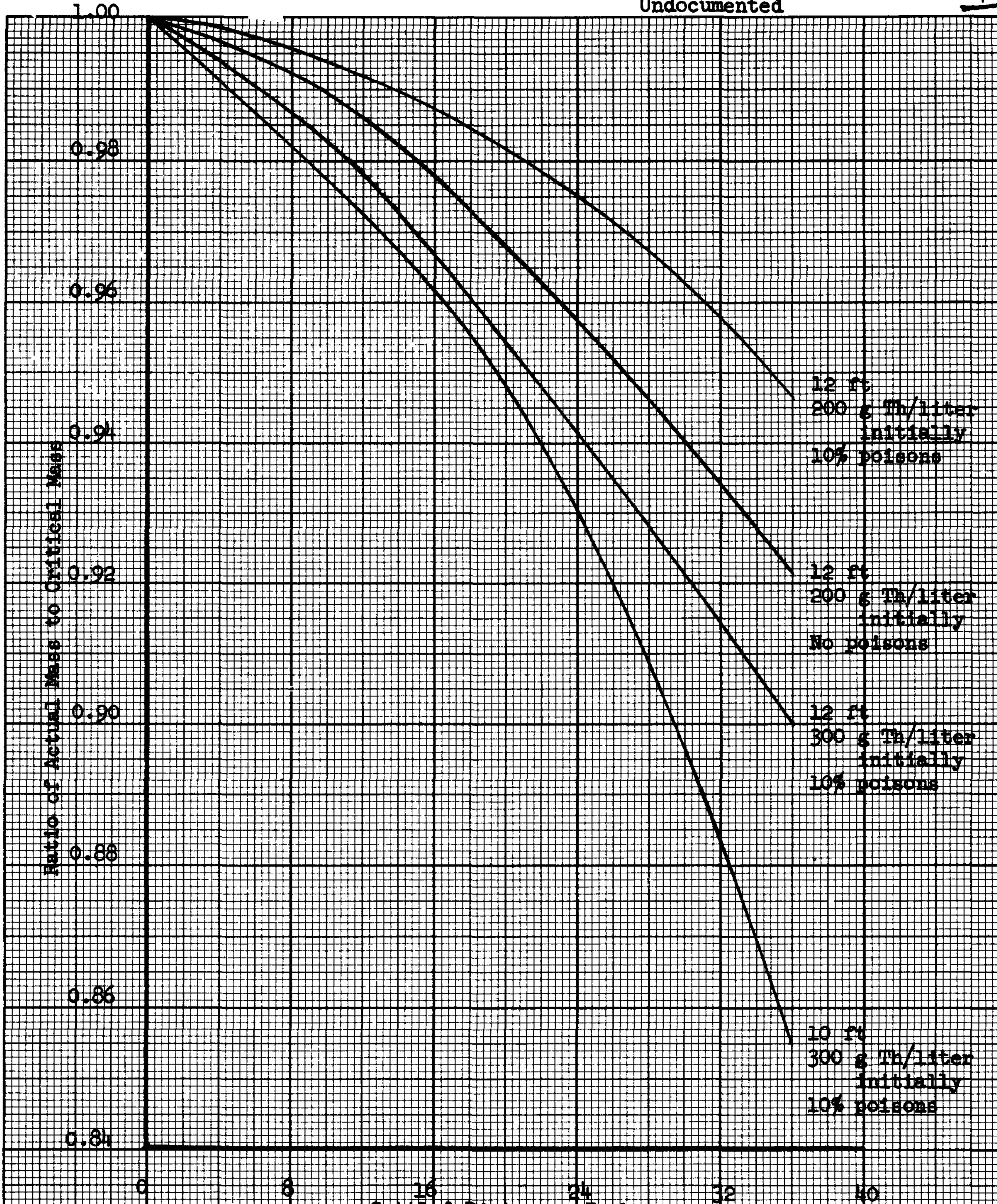

Figure 1

EFFECT OF SETTLING ON REACTIVITY