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SUBJECT: Neutron Losses to Pa^{233} in the Aqueous Homogeneous Breeder Reactor

TO: Listed Distribution

FROM: J. W. Miller and L. G. Alexander

ABSTRACT

Neutron losses to Pa^{233} in the blanket of the AHBR were computed and compared for two cases: (1) concentration of Pa^{233} is maintained uniform by continuous mixing, (2) batches of fertile material are shifted periodically from high- to low-flux regions of blanket. It was found that, if the fertile material is cycled through three radial positions in three days, the loss of neutrons to Pa^{233} is no more than one per cent greater than if it is mixed continuously.

DISCLAIMER

Time Dependent Differential Equations. - The time dependent differential equation for the concentration of Pa at radius r and time t is given by Eq. 1.

$$\frac{dN_{13}(r,t)}{dt} = \int_u \sigma_{02}(u)\ \phi(r,u)\ N_{02}\ du - \int_u [\lambda + \sigma_{13}(u)\ \phi(r,u)]\ N_{13}(r,t)\ du \quad (1)$$

where:

$N_{13}(r,t)$ = the atomic concentration of Pa^{233} at radius r and time t, atoms/cm^3,

$\sigma_{02}(u)$ = the microscopic capture cross-section of thorium at lethargy u, cm^2,

$\phi(r,u)$ = the neutron flux at radius r per unit lethargy u, neutron-cm/cm^3-sec-unit lethargy,

N_{02} = the concentration of thorium in the blanket, atoms/cm^3,

λ = the decay constant for Pa^{233}, sec^{-1},

$\sigma_{13}(u)$ = the microscopic absorption cross-section of Pa^{233} at lethargy, u cm^2.

The relative neutron flux (n-cm/cm^3-neutron born) as a function of position and lethargy may be obtained by solving the group diffusion equations, and the absolute flux is readily obtained when the power is specified. The integration of the product of cross-section and flux over lethargy may then be immediately performed. This integration will henceforth be denoted as

$$\overline{\sigma\phi(r)} = \int_{u=o}^{\infty} \sigma(u)\ \phi(r,u)\ du.$$

Losses for Batchwise Mixing. - The initial condition for the blanket is that at the beginning of a cycle the concentration of Pa^{233} in a given ring is uniform and equal to the mean concentration of the same batch in the preceding ring at the end of the previous cycle, see Table I.

Introduction

The thermal breeder reactor evaluation program, TBREP has evaluated several thermal breeder reactor concepts, one of which was an aqueous homogeneous breeder reactor (AHBR) having a thorium oxide pellet blanket (Fig. 1) processed batchwise.[1]

The blanket is divided into 20 sectors containing ThO_2 pellets. The pellets in each sector are shifted daily from one blanket ring to the next. The nuclear calculations for this blanket were performed using the IBM-704 program ERC-5,[2] which assumes that the Pa^{233} contained in the blanket is distributed uniformly, corresponding to a blanket continuously mixed. Actually, since the neutron flux falls off rapidly, the mean Pa^{233} content is higher in the inner blanket ring than in the other two rings. The purpose of this report is to compute the ratio of neutron losses to Pa^{233} in a blanket mixed periodically to the neutron losses to Pa^{233} when the blanket is continuously mixed.

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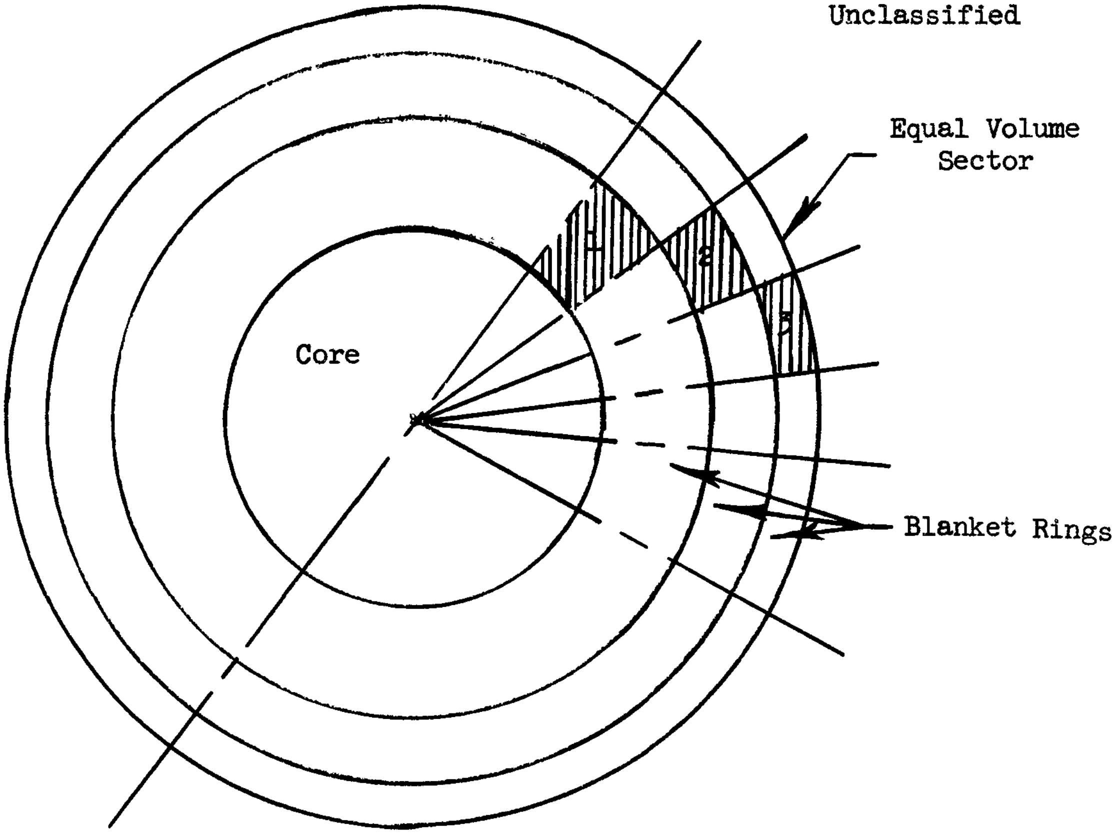

Fig. 1 Aqueous Homogeneous Breeder Reactor Blanket

The shifting within each blanket sector occurs in the sequence 1, 2, 3, 1 . . . .

Table I. Formulae for Initial Concentration of Pa in Specified Region

Region	1	2	3
Initial Pa concentration	$L \int_{r_3}^{r_3+\Delta r_3} \frac{N_{13}^{3}(r,t_R)\ 2\pi r dr}{V_3}$	$L \int_{r_1}^{r_1+\Delta r_1} \frac{N_{13}^{1}(r,t_R)\ 2\pi r dr}{V_1}$	$L \int_{r_2}^{r_2+\Delta r_2} \frac{N_{13}^{2}(r,t_R)\ 2\pi r dr}{V_2}$

where: t_R is the residence time in each ring, V is the volume of a ring, Δr is thickness of a given ring, and L is the length of the reactor.

Using these initial conditions, Eq. 1 may now be integrated.

$$N_{13}(r,t) = \frac{\sigma_{02}\ \phi(r)\ N_{02}}{\overline{\lambda+\sigma_{13}\ \phi(r)}} \left[1 - e^{-[\overline{\lambda+\sigma_{13}\ \phi(r)}]\ t}\right] +$$

$$+ N_{13}^{i}(t=0)\ e^{-[\overline{\lambda+\sigma_{13}\ \phi(r)}]\ t} \qquad (2)$$

During the residence time, t_R, the losses to Pa^{233} will be

$$C = L \int_{t=0}^{t=t_R} \int_{r_1}^{r_3+\Delta r_3} N_{13}(r,t)\ \overline{\sigma_{13}\ \phi(r)}\ 2\pi r dr\ dt. \qquad (3)$$

Losses for Continuous Mixing

For continuous mixing, $N_{13}(r,t)$ is independent of r and the equation of continuity then becomes

$$\frac{dN_{13}^{*}}{dt}(V_1+V_2+V_3) = \int_{r_1}^{r_3+\Delta r_3} \overline{\sigma_{02}\ \phi(r)}\ N_{02}\ 2\pi r L dr - \int_{r_1}^{r_3+\Delta r_3} (\overline{\lambda+\sigma_{13}\ \phi(r)})\ N_{13}^{*}\ 2\pi r L dr. \qquad (4)$$

Where the star refers to the fact that N_{13} is uniform throughout the blanket. Since N_{13}^{*} is constant at equilibrium, $dN_{13}^{*}/dt=0$, and equation 4 can be solved for N_{13}^{*}.

$$N^*_{13} = \frac{\int_{r_1}^{r_3+\Delta r_3} N_{02}\, \overline{\sigma_{02}\phi(r)}\, 2\pi r L dr}{\int_{r_1}^{r_3+\Delta r_3} (\lambda + \overline{\sigma_{13}\phi(r)})\, 2\pi r L dr} \tag{5}$$

During time period, t_R, the losses to Pa^{233} for the case of continuous mixing becomes:

$$C^* = N^*_{13} \int_{t=0}^{t_R} \int_{r_1}^{r_3+\Delta r_3} \overline{\sigma_{13}\phi(r)}\, 2\pi L r dr\, dt \quad . \tag{6}$$

The quantity $\frac{C-C^*}{C^*}$ is the fractional increase of neutron losses to Pa^{233} at finite residence times relative to the loss incurred with rapid continuous mixing. This fractional increase in neutron losses has been computed numerically using the IBM-704 program PLSB-1. The results are plotted in Fig. 2 as a function of residence time in the blanket with the reactor operating at a power level of 910 Mwt.

From Fig. 2 it can be seen that the neutron losses to Pa^{233} can be held to about 1% of the losses calculated by ERC-5 by shifting the thorium in the blanket from one ring to the next every third day.

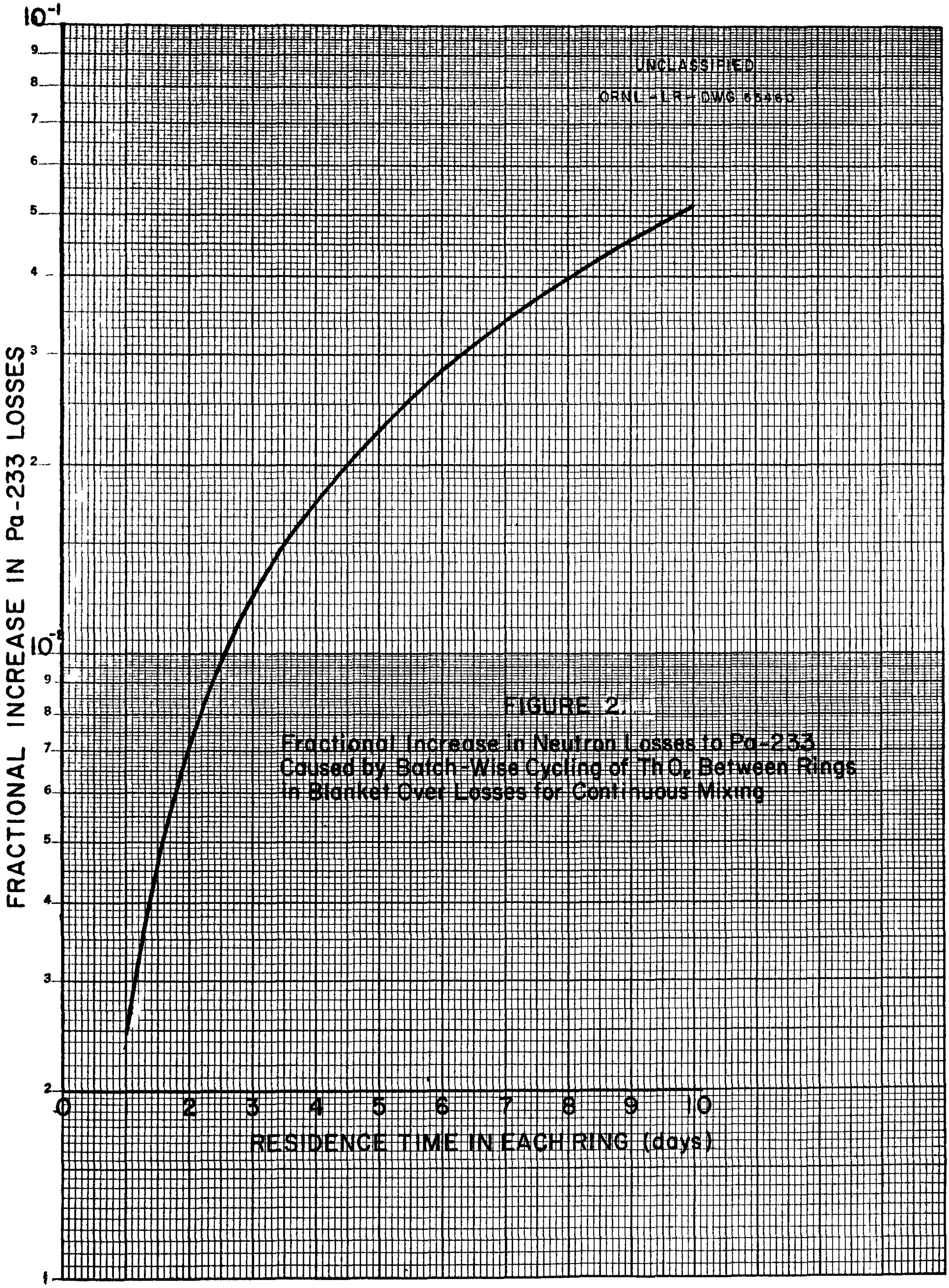

FIGURE 2.

Fractional Increase in Neutron Losses to Pa-233 Caused by Batch-Wise Cycling of ThO_2 Between Rings in Blanket Over Losses for Continuous Mixing

References

1. L. G. Alexander, et al, Preliminary Report on Thermal Breeder Reactor Evaluation, ORNL-CF-60-7-1 (July 1, 1960).

2. L. G. Alexander, ERC-5 Program for Computing the Equilibrium States of Two-Region, Thorium Breeder Reactors, ORNL-CF-60-10-87 (Oct. 20, 1960).

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