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CALCULATION OF RATE OF POISON BUILDUP IN BERYLLIUM
REFLECTOR IN MTR

by

W. L. Morris

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763-1

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INTRODUCTION

Mr. J. Evans has suggested that the reaction of fast neutrons on Be^9 nuclei might result in the production of additional absorption cross section in the beryllium reflector of the MTR. The specific process is the following:

Since He^3 is returned to H^3 by the (n, p) reaction, it may be inferred that the poison will increase linearly with time. Since, also, the absorption cross section of He^3 is about 5000 barns and that of Li^6 is about 910 barns, it will be seen that the rate of poison increase may be of consequence. It is the purpose of this report to make a quantitative investigation of the behavior of this poison.

The reactivity changes due to the buildup of Li^6 in the MTR were considered by H. L. McMurry and J. W. Webster in IDO-16017-PPCo; however, they did not consider the transformation of Li^6 to H^3 and thence to He^3 . Up to about two months of operation at 30 megawatts, poison concentration as computed by Messrs. McMurry and Webster is in essential agreement with the computations presented here; but after that time, the poison concentration continues to increase rather than attaining the equilibrium which would be inferred if the $\text{Li}^6 \rightarrow \text{H}^3 \rightarrow \text{He}^3$ reaction could be ignored. This report includes consideration of this later reaction and carries out the computation of the poison concentration in the first centimeter of the beryllium reflector to ten years of operation at 30 megawatts.

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763-2

DERIVATION OF EQUATIONS

We will let	N_1	=	number of beryllium ⁹ nuclei per cm ³
	N_2	=	number of lithium ⁶ nuclei per cm ³
	N_3	=	number of tritium nuclei per cm ³
	N_4	=	number of helium ³ nuclei per cm ³
	λ	=	decay constant of tritium
		=	$2.05 \times 10^{-9} \text{ sec}^{-1}$
	φ_f	=	fast flux
	φ_s	=	slow flux
	σ_1	=	cross section of Be ⁹ to (n, α) reaction
		=	0.05 b
	σ_2	=	thermal neutron cross section of Li ⁶ $\doteq$ 910 b
	σ_4	=	thermal neutron cross section of He ³ $\doteq$ 5000 b

We will assume N_1 constant over the period with which we shall be concerned. Precisely, it requires about 10 years for N_1 to be reduced 1 per cent.

The system of differential equations then is

$$\frac{dN_2}{dt} = N_1 \varphi_f \sigma_1 - \varphi_s \sigma_2 N_2$$

$$\frac{dN_3}{dt} = N_2 \varphi_s \sigma_2 - N_3 \lambda + N_4 \varphi_s \sigma_4$$

$$\frac{dN_4}{dt} = N_3 \lambda - N_4 \varphi_s \sigma_4$$

The solutions of these equations are:

$$N_2 = \frac{N_1 \varphi_f \sigma_1}{\varphi_s \sigma_2} (1 - e^{-\varphi_s \sigma_2 t})$$

$$N_3 = N_1 \varphi_f \sigma_1 e^{-\varphi_s \sigma_2 t} \left[\frac{\varphi_s (\sigma_4 - \sigma_2)}{\varphi_s \sigma_2 \{ \varphi_s (\sigma_4 - \sigma_2) + \lambda \}} \right]$$

$$+ N_1 \varphi_f \sigma_1 \lambda e^{-(\varphi_s \sigma_4 + \lambda)t} \left[\frac{1}{\varphi_s \sigma_2 \{ \varphi_s (\sigma_4 - \sigma_2) + \lambda \}} - \frac{1}{(\varphi_s \sigma_4 + \lambda)^2} \right]$$

$$+ \frac{N_1 \varphi_f \sigma_1 \varphi_s \sigma_4 t}{\lambda + \varphi_s \sigma_4} + \frac{N_1 \varphi_f \sigma_1 \lambda}{(\lambda + \varphi_s \sigma_4)^2}$$

$$N_4 = N_1 \varphi_f \sigma_1 \lambda \left[\frac{e^{-\varphi_s \sigma_2 t}}{\varphi_s \sigma_2 \{ \varphi_s (\sigma_4 - \sigma_2) + \lambda \}} + \frac{t - \frac{1}{\lambda + \varphi_s \sigma_4}}{\lambda + \varphi_s \sigma_4} \right]$$

$$- N_1 \varphi_f \sigma_1 \lambda e^{-(\lambda + \varphi_s \sigma_4)t} \left[\frac{1}{\varphi_s \sigma_2 \{ \varphi_s (\sigma_4 - \sigma_2) + \lambda \}} - \frac{1}{(\lambda + \varphi_s \sigma_4)^2} \right]$$

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763-4

The poison at any time in cm^2/cm^3 is given by

$$\begin{aligned}\delta \Sigma_a &= N_2 \sigma_2 + N_4 \sigma_4 \\ &= \frac{N_1 \phi_f \sigma_1}{\phi_s} (1 - e^{-\phi_s \sigma_2 t}) \\ &\quad + \sigma_4 N_1 \phi_f \sigma_1 \lambda \left[\frac{e^{-\phi_s \sigma_2 t}}{\phi_s \sigma_2 \{ \phi_s (\sigma_4 - \sigma_2) + \lambda \}} + \frac{t - \frac{1}{\lambda + \phi_s \sigma_4}}{\lambda + \phi_s \sigma_4} \right] \\ &\quad - \sigma_4 N_1 \phi_f \sigma_1 \lambda e^{-(\lambda + \phi_s \sigma_4)t} \left[\frac{1}{\phi_s \sigma_2 \{ \phi_s (\sigma_4 - \sigma_2) + \lambda \}} - \frac{1}{(\lambda + \phi_s \sigma_4)^2} \right]\end{aligned}$$

The calculation of this as a function of time is rendered systematic by placing

$$A = \lambda + \phi_s \sigma_4$$

$$B = \phi_s \sigma_2 (\phi_s \{ \sigma_4 - \sigma_2 \} + \lambda)$$

$$C = \lambda \sigma_4$$

Then

$$\begin{aligned}\delta \Sigma_a &= N_1 \phi_f \sigma_1 \left[\frac{1}{\phi_s} + e^{-\phi_s \sigma_2 t} \left(\frac{C}{B} - \frac{1}{\phi_s} \right) \right] \\ &\quad - N_1 \phi_f \sigma_1 C e^{-A t} \left[\frac{1}{B} - \frac{1}{A^2} \right] \\ &\quad + \frac{N_1 \phi_f \sigma_1 C}{A} \left[t - \frac{1}{A} \right]\end{aligned}$$

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762 - 5

Considering the first centimeter of beryllium, we can take

$$\varphi_f = 7 \times 10^{13}$$

$$\varphi_s = 2 \times 10^{14}$$

$$\sigma_2 = 910 \text{ b}$$

$$\sigma_4 = 5000 \text{ b}$$

$$\lambda = \frac{.693}{12.46 \text{ y}} = 0.0556 \text{ y}^{-1}$$

$$= 1.76 \times 10^{-9} \text{ sec}^{-1}$$

$$A = 1.002 \times 10^{-6}$$

$$B = 1.491 \times 10^{-13}$$

$$C = 8.81 \times 10^{-30}$$

$$\delta Z_a = 10^{-3} [1.7173 - 1.70 e^{-1.82 \times 10^{-7} t} - 0.0173 e^{-1.002 \times 10^{-6} t} + 3.024 \times 10^{-9} t]$$

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763-6

If we let T designate time in years, this expression becomes

$$\delta \Sigma_a = 10^{-3} [1.7173 - 1.70 e^{-5.75T} - 0.0173 e^{-31.6T} + 0.0959T]$$

The growth of this poison may be calculated readily and the results of such calculations are shown in Figures I and 2.

The effect on reactivity of the MTR will be relatively small. On a basis of the work of H. L. McMurry and J. W. Webster, it may be estimated to be about one-half of 1 per cent at 6 months and about 0.8 of 1 per cent at 10 years.

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763 7

$\delta \Sigma_a$
 $\ln \frac{\text{cm}^2}{\text{cm}^3}$
 $\times 10^3$

Fig. 1
 Buildup of Poison in Beryllium

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