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PREDICTED SLURRY ACTIVATION IN HRE-3

E. H. Gift

SUMMARY

The gamma and beta activity of the proposed HRE-3 slurry for blanket operation at 10 Mw has been estimated. The sources of activity were found to be fission-product decay and protactinium-233 decay. The estimated gamma activity of the slurry is plotted in Figure 1 which shows the Pa²³³ gammas, four energy groups of fission products, and the total gamma activity for a nearly infinite irradiation time. For the same conditions, the estimated beta activity of the slurry is plotted in Figure 2, showing the Pa²³³ betas, the fission product decay betas, and the total beta activity.

The dose rates that could be expected from the HRE-3 slurry are shown in Table I, below, as a function of time after shut down.

Table I

Dose Rates from HRE-3 Slurry*

Time After Shut Down (days)	Dose Rate (r/hr)
0	566
10	127
365	4.4

* At six feet from an infinitely long 1-1/2 inch stainless steel pipe filled with 1000 g Th/Kg D₂O slurry after infinite operation of the HRE-3 at 10 Mw blanket power level.

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DISCUSSION

The activity of the slurry in the HRE-3 is expected to come from two major sources: the fission product activity from U^{233} fissions, and the neutron absorption products of Th^{232} . All other activities should be negligible. It is assumed that the blanket power (P) is a constant at 10 Mw, the volume of the slurry system (V) is 14,500 liters, and the blanket U^{233} concentration is constant at 3 g U^{233} /liter slurry. From BNL-325, $\sigma_f^{23} = 533$ barns at $298^\circ K$, so that a U^{233} concentration of 3 g U^{233} /liter slurry at $553^\circ K$ has a macroscopic cross section (Σ_f^{23}) equal to $2.668 \times 10^{-3} \text{ cm}^{-1}$. The average thermal flux is then:

$$\phi = \frac{3.1 \times 10^{16} P}{\Sigma_f^{23} V} = 7.95 \times 10^{12} \text{ n/sec-cm}^2. \quad (1)$$

The gamma activity of U^{235} fission products has been investigated by a number of experimenters^{1,2,3,4}. The data used is that of J. O. Blomeke¹, which divides the fission product gammas into four energy groups. The Blomeke data was calculated on the ORACLE using the best-known values of the nuclear constants and fission yields. It is considered to be very complete, since the computations were performed for the approximately 300 known fission products as functions of power level, irradiation time, and decay time. The calculations are for U^{235} fission rather than U^{233} , but it is expected that the differences between the two, especially for long periods of reactor operation, will be small and the U^{235} data will be applicable.

This data is plotted in Figure 1 in four gamma energy groups for the fission product decay gammas, and in Figure 2 for the fission product decay betas.

In comparing the data from the literature, it was observed that the total gamma energy at any time was different for each of the several sources of information. Table II was constructed which lists the total fission product decay gamma heat generation rates of the HRE-3 slurry as predicted from the various sources of data. It may be noted that the rates differ by as much as a factor of three.

Table II

Fission Product Gamma Heat Generation Rate
Mev/sec-cm²

t-sec	ORNL-2127	Kay-Wigner	ORNL CF-54-4-62	NDA-27-39	Borst-Wheeler
1.8×10^3	—	2.73×10^{10}	—	1.61×10^{10}	2.97×10^{10}
1.73×10^4	2.97×10^{10}	1.73×10^{10}	1.18×10^{10}	1.12×10^{10}	1.69×10^{10}
8.64×10^4	2.77×10^{10}	1.26×10^{10}	1.00×10^{10}	9.15×10^9	1.27×10^{10}
8.64×10^5	8.87×10^9	7.93×10^9	8.85×10^9	6.03×10^9	8.81×10^9
1.73×10^6	6.36×10^9	6.90×10^9	7.13×10^9	3.36×10^9	7.22×10^9
4.32×10^6	3.76×10^9	5.75×10^9	4.62×10^9	1.74×10^9	5.10×10^9
8.64×10^6	1.73×10^9	5.00×10^9	3.25×10^9	1.07×10^9	3.72×10^9
8.64×10^7	1.43×10^8	3.16×10^9	—	5.24×10^6	8.92×10^8

For the actual slurry activation, the only reaction of interest is:

The Th^{232} (n,2n) reaction which leads to U^{232} was investigated and for the times considered in this report found to be negligible.

The buildup of Th^{233} and Pa^{233} can be represented by the equations:

$$\frac{dN^{03}}{dt} = \sum_a^{02} \phi \cdot \sigma^{03} N^{03} - \lambda^{03} N^{03} \quad (2)$$

$$\frac{dN^{13}}{dt} = \lambda^{03} N^{03} - \sigma^{13} N^{13} \phi - \lambda^{13} N^{13} \quad (3)$$

Since the half-lives of both of these isotopes are short (33.3 minutes for Th^{233} and 27.4 day for Pa^{233}) as compared with the total exposure time of 10^8 sec (3.2 years), both isotopes should be at their equilibrium activity levels. Thus, at 10^8 sec:

$$N^{03} = \frac{\sum_a^{02} \phi}{\sigma^{03} \phi + \lambda^{03}}$$

$$N^{13} = \frac{\lambda^{03} N^{03}}{\sigma^{13} \phi + \lambda^{13}}$$

The thorium concentration used in this calculation is 1000 g Th/Kg D_2O (for use with other concentrations see Appendix I), and the thermal activation cross-sections are $\sigma^{02} = 7.0$ barns, $\sigma^{03} = 1400$ barns, and $\sigma^{13} = 40$ barns. Using these values the equilibrium isotope concentrations are:

$$N^{03} = 1.439 \times 10^{14} \text{ atoms/cm}^3$$

$$N^{13} = 2.44 \times 10^{17} \text{ atoms/cm}^2$$

The rate of gamma or beta-energy emission from these isotopes, as a function of time after irradiation, is:

$$E \lambda N(t) = E \lambda N_0 e^{-\lambda t} \quad (4)$$

where E = gamma or beta energy, Mev .

Equation (4) is shown plotted on Figure 1 for the Pa^{233} gammas and on Figure 2 for the Pa^{233} betas. The activity of Th^{233} is not shown since it is insignificant after the first few minutes.

--- The total gamma energy release rate due to the Pa^{233} and the fission-product decay are also totaled in Figure 1. The total beta energy release is plotted on Figure 2.

BETA ACTIVITY OF THE HRE-3 SLURRY VS. TIME AFTER SHUTDOWN

Figure 1

GAMMA ACTIVITY OF HRE-3 SLURRY VS. TIME AFTER SHUTDOWN

Figure 2

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APPENDIX I

The activity curves presented in this report are valid only for the 1000 g Th/Kg D₂O thorium concentration. Activities due to the fission product decay will not be changed with changes of thorium concentration, but the Pa²³³ activity will change quite markedly. The following table presents factors by which the Pa²³³ activity of the curves may be multiplied when the thorium concentration is other than 1000 g Th/Kg D₂O.

Table III

Thorium Concentration g Th/Kg D ₂ O	Multiplying Factor
500	0.523
700	0.721
1000	1.000
1200	1.198
1350	1.299
1500	1.442

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