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MEMORANDUM

To: R. H. Beaton

From: M. Garbrecht and P. R. Gillette

ACTIVITY OF FISSION PRODUCTS

This report compares the activity and disintegration energy of fission products from metal under two conditions of exposure:

- (a) 200 megawatt-days integrated exposure over a period of 180 days, followed by 90 days cooling.
- (b) 400 megawatt-days integrated exposure over a period of 360 days, followed by 90 days cooling.

The total activity and energy released is given in Table I.

TABLE ITOTAL FISSION ACTIVITY

	<u>Curies/ton</u>	<u>Bwatts/ton</u>	<u>dwatts/ton</u>	<u>total watts/ton</u>
180 d irradiation	15.24×10^4	275	276	651
360 d irradiation	18.78×10^4	325	326	711

Table II gives the activity and energy for each isotope considered. Only those isotopes which had an activity of greater than one curie/ton after 30 days cooling were included.

It will be noted that the activities for short lived daughters of long-lived isotopes are reported since the activity of the daughter will continue for the life of the parent isotope and will follow the parent through chemical separation.

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272-1

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The equations used to determine the activity in curies/ton are:

$$A = k(1 - e^{-\lambda_a t_1} - e^{-\lambda_b t_2})$$

$$B = k \left\{ \left[(1 - e^{-\lambda_a t_1} - \frac{\lambda_b}{\lambda_a - \lambda_b} (e^{-\lambda_a t_1} - e^{-\lambda_b t_2})) e^{-\lambda_b t_2} + \frac{\lambda_b}{\lambda_a - \lambda_b} (1 - e^{-\lambda_a t_1}) - e^{-\lambda_b t_2} - e^{-\lambda_a t_2} \right] \right\}$$

where A = activity in curies/ton from parent isotope

B = activity in curies/ton from daughter isotope

$$\lambda = \frac{.693}{\text{half life}} = \text{decay constant}$$

(λ_a refers to parent isotope, λ_b to daughter isotope)

t_1 = irradiation time

t_2 = cooling time

$$k = \frac{\text{rate of production}}{\text{disintegration/sec/curie}}$$

$$\text{Rate of production} = \text{fission yield} \times \frac{\text{Fissions/sec}}{\text{ton}}$$

$$\frac{\text{Fissions/sec}}{\text{ton}} = \frac{\text{megawatts/ton}}{\text{megawatts fission/sec}}$$

$$\text{Megawatts/ton} = \frac{\text{MWD/ton}}{\text{day exposure}}$$

$$\frac{\text{Megawatts}}{\text{Fission/sec}} = \frac{\text{Mev}}{\text{Fission}} \times \frac{\text{joules}}{\text{ev}}$$

$$k = \frac{\text{Fission yield}}{\text{disintegration/sec/curie}} \times \frac{\text{MWD/ton/day exposure}}{\text{Mev fission} \times \text{joules/ev}}$$

Substituting numerical values:

$$k = \frac{\text{fission yield}}{3.7 \times 10^{10} \text{ disintegrations/sec/curie}} \times \frac{2.0 \text{ megawatts/ton}}{82 \text{ Mev} \times 1.6 \times 10^{-13} \text{ joules/ev}}$$

$$k = \text{fission yield} \times 1.05 \times 10^6$$

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- 3 -

The equation used to determine δ watts/ton and β watts/ton is:

$$\delta \text{ watts/ton} = \text{curies/ton} \times \text{disintegrations/sec/curie} \times \text{joules/ev} \\ \times \text{average energy (ev)}$$

$$\delta \text{ watts/ton} = \text{curies/ton} \times 3.7 \times 10^{10} \times 1.6 \times 10^{-10} \\ \times 10^3 \times \bar{\epsilon} \text{ energy (MeV)}$$

$$= 5.92 \times 10^{-3} \times \text{curies/ton} \times \bar{\epsilon} \text{ energy (MeV)}.$$

If the average β energy = 0.4 x maximum β energy,

then:

$$\beta \text{ watts/ton} = 0.4 \times 5.92 \times 10^{-3} \times \text{curies/ton} \times \text{max } \beta \text{ energy (MeV)}$$

$$= 2.63 \times 10^{-3} \times \text{curies/ton} \times \text{max } \beta \text{ energy (MeV)}$$

The fission yields were taken from the Project Handbook, Chapter III D 11 (page 5) "Fission Yields of Fissionable Materials" by N. Sugarman, dated March 1, 1945. Fission yield percentages were taken from figures for U^{235} which are equivalent within experimental error to yields of slow neutron piles (that is, the effect on percentage yields of the contributions from U^{238} and Pu^{239} fission is negligible.) Values for half lives, maximum β energies, $\bar{\epsilon}$ energies, and the disintegration schemes were taken from the "Chart of Nuclear Species" by F. G. A. Stone, Seaborg and Sullivan, dated April 1947.

It is assumed that the β energy will be completely absorbed in the solution and its container. The fraction of the $\bar{\epsilon}$ energy which will be absorbed will depend on the concentration of the solution, and the size, shape, and composition of the container.

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272-3

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TABLE 11 - FISSION ACTIVITY BREAKDOWN

Isotope	Half-life	Curies, Ton	10 ⁻⁴ B _{eff} fraction		B _{eff} fraction		Total Activity	
			180 d	360 d	180 d	360 d	180 d	360 d
U-235	7.13 y	1.735	1.385	45.2	45.2	---	45.2	45.2
U-238	4.47 y	1.0665	1.173	1.1	1.800	---	1.06	1.892
U-238	4.47 y	1.0665	1.173	3.400	6.800	---	3.400	6.800
Th-232	14.1 y	1.80	1.99	64.0	70.8	---	64.0	70.8
Pa-233	47 d	1.87	3.13	11.62	16.10	63.10	33.20	81.02
U-233	159 d	1.85	3.11	---	---	20.3	30.2	26.3
Th-231	25.5 d	2.01	3.43	10.44	12.38	130.2	154.0	140.44
Ra-226	1600 y	1.78	1.78	8.48	8.92	25.6	25.6	31.08
Rn-222	3.8 d	---	---	---	---	---	---	---
Ra-226	1600 y	1.10	1.206	---	---	---	---	---
Rn-222	3.8 d	1.120	1.300	12.8	21.90	4.4	7.56	17.2
Ac-227	21.8 y	1.004	1.201	12.0	---	---	---	12.61
Th-231	25.5 d	1.0022	1.0022	1.0022	1.0022	1.0022	1.0022	1.0022
Pa-231	32.7 y	1.0048	1.040	1.067	---	---	1.040	1.067
Th-231	25.5 d	1.0152	1.0152	---	---	1.0774	1.0500	1.0774
Th-231	25.5 d	1.0152	1.0152	1.213	1.274	---	1.213	1.274
Th-231	25.5 d	1.058	1.058	---	---	1.337	1.343	1.337
Th-231	25.5 d	1.058	1.058	2.424	2.472	1.660	1.660	4.104
Th-231	25.5 d	1.00114	1.0162	1.0162	1.038	1.038	1.042	1.0412
Th-231	25.5 d	1.115	1.126	1.41	1.214	1.405	2.30	1.853
Pa-231	13.7 y	1.040	1.040	1.26	1.26	1.48	1.48	2.44
Pa-231	13.7 y	1.0522	1.070	1.70	1.70	4.53	4.53	6.20
Ce-140	28.5 y	1.803	1.803	1.12	1.20	5.85	6.07	13.08
Pr-141	13.7 y	1.335	1.335	---	---	---	---	1.335
Co-144	19.2 y	1.33	3.23	11.24	18.40	---	---	11.24
Pr-141	13.7 y	1.33	3.23	37.0	180.0	12.0	20.0	102.0
Eu-152	12.8 y	1.040	1.097	1.206	1.047	1.024	1.048	1.0440
Eu-152	12.8 y	1.003	1.003	1.003	1.003	1.014	1.014	1.014

* The existence of 30 d Rn and 111 d Sb is reported in Table 1 of "Decay Chains and Yields" report. It is not clear if these isotopes are not listed in more recent tables.

END

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