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AEC RESEARCH AND DEVELOPMENT REPORT

RADIATION PROPERTIES OF CALIFORNIUM - 252

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ABSTRACT

The radiation properties of californium (~72 wt % ^{252}Cf) produced by thermal neutron bombardment of transplutonium isotopes are presented. The gamma and neutron radiations associated with this material were converted to dose rate, for evaluation by isotope users.

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INTRODUCTION

Small but practical quantities of californium-252 will soon be produced by thermal neutron bombardment of transplutonium isotopes. Anticipating the availability of californium-252, research groups are becoming increasingly interested in its properties.(1) The radiation properties, based on literature data, have been calculated and summarized.

SUMMARY

When plutonium-242 targets are irradiated in a nuclear reactor, a mixture of californium isotopes is obtained. The radiation properties of this californium mixture (~72 wt % ^{252}Cf) are similar to the properties of pure ^{252}Cf.

The neutron production rate from one gram of ^{252}Cf produced as the oxide is 2.4×10^{12} neutrons/sec, which corresponds to a neutron dose rate of 284 rad/hr and 2400 rem/hr at one meter.

The gamma production rate (exclusive of internal conversion X-rays) is 1.3×10^{13} photons/(sec)(gram), which corresponds to an unshielded dose rate of 140 rad/hr. Since the RBE* for gammas is 1, then this also corresponds to 140 rem/hr at 1 meter from 1 gram.

* Relative Biological Effectiveness

DISCUSSION

GENERAL NUCLEAR PROPERTIES OF CALIFORNIUM ISOTOPES

The general nuclear properties of the californium isotopes are presented in Table I.

TABLE I

General Nuclear Properties of Californium Isotopes

Isotope	Spontaneous Fission Half-Life	Neutrons Per Fission of Pure Isotope	Alpha or Beta Decay Half-Life	Specific Activity of Pure Isotope, curies/gram
^{249}Cf	1.5×10^{9} y[2]	3[a]	360 y[2]	4
^{250}Cf	$(1.73 \pm 0.06) \times 10^{4}$ y[2]	3[a]	11 y[2]	1.31×10^{2}
^{251}Cf	-	-	~1500 y[2]	0.95
^{252}Cf	85.5 ± 0.5 y[2]	3.80 ± 0.035[4]	2.646 ± 0.004 y[5]	5.37×10^{2}
^{253}Cf	-	-	18 ± 3 d[6]	2.87×10^{4}
^{254}Cf	61.9 ± 1.1 d[2]	3.9 ± 0.14[2]	-	-

(a) Estimated from Reference 3.

CALIFORNIUM PRODUCTION

Quantities of californium produced in the high flux isotope reactor at Oak Ridge National Laboratory will contain a calculated isotopic distribution as shown in Table II.

TABLE II

Composition of Californium Product[a]

Isotope	Mass Abundance, wt %
^{249}Cf	0.49
^{250}Cf	19.7
^{251}Cf	7.2
^{252}Cf	72.
^{253}Cf	0.18
^{254}Cf	0.003

(a) Computed at 90 days after removal from the reactor.

The Effect of the Isotopic Composition

All isotopes other than ^{252}Cf listed in Table II contribute only 2% of the total dose rate from the mixture. Since ^{252}Cf contributes 98% of the dose rate, the remainder of this report includes only data on ^{252}Cf.

ALPHA ACTIVITY OF ^{252}Cf

The relative abundance and energies of the alpha particles emitted from ^{252}Cf are listed in Table III.

TABLE III

Alpha Radiation from ^{252}Cf(6)

Energy, Mev	Alpha Particles Per Disintegration of ^{252}Cf	Energy Per Disintegration, Mev
5.969	~0.002	0.01
6.069	~0.155	0.94
6.112	0.845	5.16
	Total	6.11

GAMMA ACTIVITY OF ^{252}Cf

The gamma activity of ^{252}Cf consists of gamma rays from

- The alpha decay process
- Prompt spontaneous fission
- Fission products continuously produced by the spontaneous fission

Gamma radiations from each of these sources are described in the following sections.

Gamma Rays from Alpha Decay

Gamma rays reported for the decay of ^{252}Cf are listed in Table IV.

TABLE IV

Gamma Rays from ^{252}Cf Decay[7]

Energy, Mev	Abundance, photons/(sec)(g of nuclide)
0.043	2.78×10^9
0.100	2.0×10^9

Prompt Gamma Rays from Spontaneous Fission

The energy and abundance of prompt gamma rays from spontaneous fission are listed in Table V.

Gamma Rays from Equilibrium Fission Products

The fission products formed from spontaneous fission approach equilibrium within a few hours after separation. Equilibrium fission product gamma activities are listed in Table V.

TABLE V

Gamma Rays from Spontaneous Fission of ^{252}Cf

Energy, Mev	Abundance[7], photons/(sec)(g of nuclide)		
	Prompt Gammas	Equilibrium Fission Product Gammas	Total
0 - 0.5	3.3×10^{12}	1.3×10^{12}	4.6×10^{12}
0.5 - 1.0	1.7×10^{12}	4.0×10^{12}	5.7×10^{12}
1.0 - 1.5	7.7×10^{11}	9.1×10^{11}	1.7×10^{12}
1.5 - 2.0	4.2×10^{11}	3.5×10^{11}	7.7×10^{11}
2.0 - 2.5	2.2×10^{11}		2.2×10^{11}
2.5 - 3.0	1.1×10^{11}		1.1×10^{11}
3.0 - 3.5	5.6×10^{10}		5.6×10^{10}
3.5 - 4.0	3.0×10^{10}		3.0×10^{10}
4.0 - 4.5	1.7×10^{10}		1.7×10^{10}
4.5 - 5.0	8.2×10^9		8.2×10^9
5.0 - 5.5	4.9×10^9		4.9×10^9
5.5 - 6.0	1.8×10^9		1.8×10^9
6.0 - 6.5	1.0×10^9		1.0×10^9

X-rays

Although relatively high in abundance, X-rays produced are very low in energy (most <40 kev) and are not included in this report.

Gamma Dose Rate

Decay gamma rays are insignificant (~0.1% of those produced in the first energy group), compared with those produced by the spontaneous fission process. The totals listed in Table V represent the total gamma rays present. These source strengths are converted to dose rate at one meter, from one gram by assuming the source acted as a point isotropic source. The results of these calculations are shown in Table VI.

TABLE VI

Total Gamma Dose Rate from ^{252}Cf

Energy, Mev	Photons/(cm²)(sec) / g at 1 meter	Conversion Factor[a], Photons/(cm²)(sec) / rad/hr	Dose Rate, rad/hr / g at 1 meter
0 - 0.5	3.7×10^{7}	2.2×10^{6}	1.7×10^{1}
0.5 - 1.0	4.5×10^{7}	7.4×10^{5}	6.1×10^{1}
1.0 - 1.5	1.4×10^{7}	4.7×10^{5}	3.0×10^{1}
1.5 - 2.0	6.1×10^{6}	3.7×10^{5}	1.6×10^{1}
2.0 - 2.5	1.8×10^{6}	3.1×10^{5}	5.8×10^{0}
2.5 - 3.0	8.8×10^{5}	2.7×10^{5}	3.3×10^{0}
3.0 - 3.5	4.5×10^{5}	2.4×10^{5}	1.9×10^{0}
3.5 - 4.0	2.4×10^{5}	2.2×10^{5}	1.1×10^{0}
4.0 - 4.5	1.4×10^{5}	2.0×10^{5}	7.0×10^{-1}
4.5 - 5.0	6.5×10^{4}	1.9×10^{5}	3.4×10^{-1}
5.0 - 5.5	3.9×10^{4}	1.7×10^{5}	2.3×10^{-1}
5.5 - 6.0	1.4×10^{4}	1.6×10^{5}	8.7×10^{-2}
6.0 - 6.5	8.0×10^{3}	1.5×10^{5}	5.3×10^{-2}
		TOTAL	1.4×10^{2}

(a) From plot of data given in Reference 8.

BETA ACTIVITY OF ^{252}Cf

No beta radiation has been reported from the decay process. The beta radiation associated with the equilibrium fission products during spontaneous fission are easily absorbed, and are not included in this report. The contribution to dose rate from this isotope at a distance greater than a few centimeters will be very small.

NEUTRON ACTIVITY OF ^{252}Cf

The neutron radiation from ^{252}Cf consists principally of neutrons from spontaneous fission. A second source of neutrons is the α,n neutrons from the reaction of alpha particles with light elements. Table VII lists the neutrons present from spontaneous fission, and from the α,n reaction with oxygen.

TABLE VII

Neutrons from ^{252}Cf

Energy, Mev	Neutrons/(sec)(g of nuclide)[7] Spontaneous Fission	α,n Reaction with Oxygen	Total
0 - 0.5	2.8×10^{11}	2.4×10^{3}	2.8×10^{11}
0.5 - 1.0	3.7×10^{11}	7.4×10^{3}	3.7×10^{11}
1.0 - 2.0	7.6×10^{11}	2.8×10^{5}	7.6×10^{11}
2.0 - 3.0	4.6×10^{11}	1.3×10^{6}	4.6×10^{11}
3.0 - 4.0	2.8×10^{11}	1.4×10^{6}	2.8×10^{11}
4.0 - 5.0	1.6×10^{11}	2.6×10^{5}	1.6×10^{11}
5.0 - 6.0	5.6×10^{10}		5.6×10^{10}
6.0 - 7.0	4.0×10^{10}		4.0×10^{10}
7.0 - 8.0	1.3×10^{10}		1.3×10^{10}
8.0 -10.0	9.9×10^{9}		9.9×10^{9}
10.0 -13.0	2.2×10^{9}		2.2×10^{9}
		TOTAL	2.4×10^{12}

Neutron Dose Rate

Neutrons from the α,n reaction with oxygen are insignificant as compared with those from spontaneous fission. The totals listed in Table VII were converted to dose rate at one meter from one gram by assuming the source acted as a point isotropic source. The results of these calculations are shown in Table VIII.

TABLE VIII

Neutron Dose Rate from ^{252}Cf

Energy, Mev	n/(cm²)(sec) / g at 1 meter	Conversion Factor[a], rad/hr / n(cm²)(sec)	Dose Rate, rad/hr / g at 1 meter	Conversion Factor[a], rem/hr / n(cm²)(sec)	Dose Rate, rem/hr / g at 1 meter
0 - 0.5	2.2×10^6	5.8×10^{-6}	1.3×10^1	5.0×10^{-5}	1.1×10^2
0.5 - 1.0	2.9×10^6	1.2×10^{-5}	3.5×10^1	1.2×10^{-4}	3.5×10^2
1.0 - 2.0	6.1×10^6	1.5×10^{-5}	9.1×10^1	1.4×10^{-4}	8.5×10^2
2.0 - 3.0	3.7×10^6	1.6×10^{-5}	5.9×10^1	1.3×10^{-4}	4.8×10^2
3.0 - 4.0	2.2×10^6	1.7×10^{-5}	3.7×10^1	1.3×10^{-4}	2.9×10^2
4.0 - 5.0	1.3×10^6	2.0×10^{-5}	2.6×10^1	1.3×10^{-4}	1.7×10^2
5.0 - 6.0	4.5×10^5	2.3×10^{-5}	1.0×10^1	1.4×10^{-4}	6.3×10^1
6.0 - 7.0	3.2×10^5	2.5×10^{-5}	8.0×10^0	1.5×10^{-4}	4.8×10^1
7.0 - 8.0	1.0×10^5	2.5×10^{-5}	2.5×10^0	1.5×10^{-4}	1.5×10^1
8.0 - 10.0	7.9×10^4	2.6×10^{-5}	2.1×10^0	1.5×10^{-4}	1.2×10^1
10.0 - 13.0	1.8×10^4	2.5×10^{-5}	4.5×10^{-1}	1.5×10^{-4}	2.7×10^0
		TOTAL	284 rad/hr	TOTAL	2,400 rem-hr

(a) From plotted Snyder and Neufeld data reported in Reference 9.

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