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Transuranium Processing Plant Semiannual Report of Production, Status, and Plans for Period Ending December 31, 1975

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Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
Price: Printed Copy \$4.00; Microfiche \$2.25

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ORNL-5146
Dist. Category UC-4

Contract No. W-7405-eng-26

CHEMICAL TECHNOLOGY DIVISION

TRANSURANIUM PROCESSING PLANT SEMIANNUAL REPORT OF
PRODUCTION, STATUS, AND PLANS FOR PERIOD ENDING DECEMBER 31, 1975

L. J. King, J. E. Bigelow, and E. D. Collins

Date Published: October 1976

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SUMMARY

This is the sixteenth report in a series that is being issued semi-annually to inform the heavy-element community of the status and future production plans of the Transuranium Element Production Program at ORNL.

Between July 1, 1975, and December 31, 1975, we (1) performed maintenance at TRU for a period of three months, (2) prepared 295 g of curium oxide (enough for approximately 26 HFIR targets), (3) separated 100 mg of high-purity ^{248}Cm from ^{252}Cf that had been purified during earlier periods, (4) fabricated 11 HFIR targets, and (5) made 28 product shipments.

During the next 18 months, we plan to process three groups of HFIR targets, from which we expect to recover totals of 67 mg of ^{249}Bk , 780 mg of ^{252}Cf , 2.9 mg of ^{253}Es (in a mixture of isotopes), 320 μg of high-purity ^{253}Es , and 2.3 μg of ^{257}Fm . Additionally, we expect to complete purification of the 100 mg of high-purity ^{248}Cm separated during this report period and to obtain (by the end of 1977) an additional 50 mg from purified californium now in storage. No plans have been made to process any of the remaining SRP Pu-Al tubes or to irradiate any plutonium targets in the HFIR; thus we do not expect to recover any ^{244}Pu .

We have made no changes in the chemical processing flowsheets normally used at TRU during this report period. However, three equipment racks were replaced (with two new racks) during this time. In Cubicle 6, the equipment replaced was that used to decontaminate the transplutonium elements from rare earth fission products and to separate curium from the heavier elements by means of the LiCl-based anion-exchange process. In Cubicle 5, we replaced the equipment used to separate the transcurium elements by high-pressure ion exchange and to purify berkelium by batch solvent extraction.

Two neutron sources were fabricated, bringing the total fabricated to 79. One source that had been used in a completed project was returned to the TRU inventory and is available for reissue. Three sources, for which no further use was foreseen, were processed to isolate and recover the ingrown ^{248}Cm and the residual ^{252}Cf .

As a special project, we prepared eight pellets, each containing 100 μg of high-purity ^{248}Cm , for irradiation in HFIR to study the production of ^{250}Cm .

The values that we are currently using for transuranium element decay data and for cross-section data in planning irradiation-processing cycles, calculating production forecasts, and assaying products are tabulated in the Appendix.

1. INTRODUCTION

This is the sixteenth report in a series that is being issued semi-annually to inform the heavy-element community of the status and the future production plans of the Transuranium Element Production Program at ORNL. The objective of these reports is to provide information that will enable users of the products to obtain maximum service from the production facilities at ORNL. Production plans and schedules are sharply defined only for the short term; long-range plans can be markedly influenced by feedback from researchers and other users of transuranium elements.

TRU operations during this report period are summarized, and the amounts of materials recovered and shipped are listed. Proposed processing schedules and anticipated yields of various products in the near future are outlined. Revisions made to plant equipment are described. The original and current contents (^{252}Cf and ^{248}Cm) of all neutron sources that have been made at TRU, as well as the individuals to whom these sources are currently loaned, are tabulated. A special project to irradiate ^{248}Cm is described. Values of nuclear parameters which were used as input data for the calculations of production rates for transuranium elements, along with a listing of the parameters which were used to calculate the specific activities of the isotopes that are of interest to TRU, are included in the Appendix.

Previous reports in this series are:

- (1) For period ending June 30, 1968 — ORNL-4376.
- (2) For period ending December 31, 1968 — ORNL-4428.
- (3) For period ending June 30, 1969 — ORNL-4447.
- (4) For period ending December 31, 1969 — ORNL-4540.
- (5) For period ending June 30, 1970 — ORNL-4588.
- (6) For period ending December 31, 1970 — ORNL-4666.
- (7) For period ending June 30, 1971 — ORNL-4718.
- (8) For period ending December 31, 1971 — ORNL-4767.
- (9) For period ending June 30, 1972 — ORNL-4833.
- (10) For period ending December 31, 1972 — ORNL-4884.
- (11) For period ending June 30, 1973 — ORNL-4921.
- (12) For period ending December 31, 1973 — ORNL-4965.
- (13) For period ending June 30, 1974 — ORNL-4991.
- (14) For period ending December 31, 1974 — ORNL-5034.
- (15) For period ending June 30, 1975 — ORNL-5084.

2. PROCESSING SUMMARY AND PRODUCTION ESTIMATE

The isotopic concentrations of the various transuranium elements are not constant but are functions of irradiation histories and decay times. We have selected one isotope of each element to use in making material balances for the isotopic mixtures normally handled in TRU. Except in special instances, ^{242}Pu , ^{243}Am , ^{244}Cm , ^{249}Bk , ^{252}Cf , and ^{253}Es are the isotopes used for tracing the corresponding elements. Throughout this report section, we are discussing mixtures of isotopes unless we indicate otherwise.

2.1 Processing Summary

Between July 1, 1975, and December 31, 1975, we suspended chemical processing operations for a 3-month period in order to perform in-cell maintenance. Before starting the maintenance, we purified two batches of curium product solution and converted the curium to the oxide form for use in HFIR targets. A total of 295 g of curium oxide was obtained; this amount is enough for preparation of approximately 26 HFIR targets. The curium had been recovered at TRU during earlier periods from the processing of tubes and slugs irradiated at the Savannah River Plant as part of the Californium-I (Cf-I) campaign--an irradiation and processing campaign designed to obtain ^{252}Cf for use in the ^{252}Cf market evaluation program being sponsored by the ERDA Division of Nuclear Fuel Cycle and Production (NFCP).

Also, during this report period:

- (1) We separated approximately 100 mg of high-purity ^{248}Cm from 100 mg of ^{252}Cf that had been purified during earlier periods.
- (2) We fabricated 11 HFIR targets from three batches of actinide oxide (predominantly curium oxide), each of which had been prepared by the resin loading--calcination technique.¹ The compositions of the curium in these targets are summarized in Table 2.1.
- (3) We made 28 product shipments. The recipients and the amounts of nuclides for each shipment are listed in Table 2.2.

Table 2.1. Summary of HFIR targets fabricated in the Transuranium Processing Plant during the period July 1, 1975 - December 31, 1975

Source of curium	Campaign 43B ¹	Campaign 48	Campaign 49
No. of targets fabricated	4	2 ²	5
Avg. actinide content, g/target	9.2	8.0	9.7
<u>Isotope</u>	<u>Atom % (neglecting impurities)</u>		
²⁴⁰ Pu	1.050	1.312	0.581
²⁴³ Am	1.740	1.778	2.054
²⁴⁴ Cm	58.48	46.16	42.69
²⁴⁵ Cm	0.992	0.529	0.470
²⁴⁶ Cm	33.93	43.62	46.62
²⁴⁷ Cm	1.080	1.239	1.301
²⁴⁸ Cm	2.72	5.36	6.28

¹The curium in Campaign 43B was a combination of the curium recovered during Campaigns 37, 38, and 40. In each of Campaigns 37 and 38, three SRP Pu-Al tubes were processed at TRU, and in Campaign 40, 48, and 49, HFIR targets were processed.

²Each of the Campaign 48 targets contained 1 special pellet containing ²⁴⁸Cm. After irradiation, the special pellets will be removed from the targets and processed as a special project to study the production of ²⁵⁰Cm (see section 5.1 of this report).

2.2 Irradiation and Processing Proposals

The level of TRU operations to produce transcurium elements is expected to continue at the rate of two processing campaigns per year. A long-term projection of the capability of the TRU-HFIR complex to produce the "yardstick" isotope ²⁵²Cf was described in a previous report in this series.² Table 2.3 outlines the estimated production of transcurium elements from a series of likely processing campaigns which are scheduled through June 1977. Estimates for the remainder of 1977 and for 1978 are projections based on current trends.

Table 2.2. Distribution of heavy elements from the Transuranium Processing Plant during the period July 1, 1975 - December 31, 1975

Major Nuclide	Date	TRU file No.	Shipped to:	
			Individual	Site
Curium-243 (56%), mg				
0.0005	7-24-75	797	N. Cohen	NYU-Tuxedo
<u>5.28</u>	9-26-75	811	J. J. Thompson	Lovelace
5.2805				
Curium-248 (97%), mg				
6.42	10-10-75	818	R. G. Haire	ORNL
0.963	10-10-75	819	Product Support	ORNL
6.42	10-14-75	814	W. T. Carnall	ANL
6.42	10-14-75	815	N. M. Edelstein	LBL
<u>6.42</u>	10-14-75	816	R. W. Hoff	LLL
26.643				
Berkelium-249, mg				
5.2	8-05-75	807	R. G. Haire	ORNL
0.0018	8-12-75	802	Isotopes Sales	ORNL
5.2	8-12-75	803	W. T. Carnall	ANL
5.2	8-12-75	805	N. M. Edelstein	LBL
5.2	8-12-75	806	R. W. Hoff	LLL
<u>0.001</u>	9-30-75	813	Isotopes Sales	ORNL
20.8028				
Californium-249, mg				
0.50	8-11-75	808	Isotopes Sales	ORNL
Californium-252, mg				
0.000149	7-18-75	788	Isotopes Sales	ORNL
0.001	7-25-75	782	Isotopes Sales	ORNL
37.087	8-06-75	800	A. R. Boulogne	SRL
0.006	9-02-75	780	Iso. Res. Matl. Lab.	ORNL
0.015(NSD-91)	9-30-75	809	G. W. Knobelock	LASL
0.010	11-07-75	820	G. W. Knobelock	LASL
0.016	11-19-75	781	Iso. Res. Matl. Lab.	ORNL
<u>2.620(NS-86)</u>	12-04-75	719	V. Spiegel	NBS
39.755149				
Einsteinium-253, μ g				
468	7-07-75	793	W. T. Carnall	ANL
6	8-08-75	798	F. P. Hungate	PNL
<u>39</u>	8-12-75	794	G. A. Keyworth, III	LASL
513				

Table 2.2. (continued)

Major Nuclide	Date	TRU file No.	Shipped to:	
			Individual	Site
Einsteinium-253 (milked), μg				
85	8-04-75	799	R. G. Haire	ORNL
<u>11.5</u>	8-05-75	801	R. W. Hoff	LLL
96.5				
Fermium-257, pg				
0.7	7-11-75	796	W. T. Carnall	ANL

Table 2.3. Estimated future production of transcurium elements

Period	Processing campaign	Products of campaigns				²⁵² Cf production ^b		Date products available
		²⁴⁹ Bk (mg)	²⁵² Cf (mg)	²⁵³ Es ^a (μg)	²⁵⁷ Fm (pg)	During the period (mg)	Cumul. (mg)	
Through December 1975							1674 ^b	
January-June 1976	10 Cf-I Cm-HFIR Targets	22	260	1000(110)	0.8	260	1934	February 1976
July-December 1976	{ 4 Cf-I Cm-HFIR Targets 7 TRU Cm-HFIR Targets }	22	260	1000(110)	0.8	260	2194	October 1976
January-June 1977	{ 7 Cf-I Cm-HFIR Targets 5 TRU Cm-HFIR Targets }	23	260	900(100)	0.7	260	2454	March 1977
July-December 1977						260	2714	
1978						520	3234	

^a Amounts from initial separation. Amounts "milked" from californium product fraction after decay period are given in parentheses.

^b Californium produced in SRP irradiations is not included in production totals. A total of 720 mg was recovered from 164 SRP slugs and 21 SRP tubes processed between November 1970 and January 1973.

2.3 Estimates of the Availability of Transuranium Elements

The amounts of transcurium elements expected from each campaign are shown in Table 2.3. During the next 18 months, we expect to recover a total of 67 mg of ^{249}Bk , 780 mg of ^{252}Cf , 2.9 mg of ^{253}Es (in a mixture of isotopes), 320 μg of high-purity ^{253}Es , and 2.3 μg of ^{257}Fm . These estimates were made by means of a method described in a previous report in this series which requires the use of assumed values for chemical yields and recovery times for each of the transplutonium elements that are separated at TRU.³ The assumed values are based on past performance data, and the most recently revised values are listed in Table 2.4 of ref. 4.

Plutonium, americium, and curium that are separated from the transcurium elements during the processing of irradiated targets are generally considered to be intermediate feed materials. However, two isotopes of these elements, ^{244}Pu and ^{248}Cm , which are valuable research materials, are frequently recovered. Within the next 18 months, we do not plan to process any of the remaining Cf-I materials irradiated at SRP or to irradiate any plutonium targets in the HFIR; thus we do not expect to recover any ^{244}Pu .

On December 31, 1975, TRU had an inventory of purified californium in several batches, which contained totals of 537 mg of ^{252}Cf and 142 mg of ^{248}Cm . Each batch will be processed at an appropriate time to separate the californium and curium. The resulting curium is considered to be high-purity ^{248}Cm (typical isotopic composition is 97% ^{248}Cm and 3% ^{246}Cm). The ^{246}Cm "impurity" is produced by the decay of ^{250}Cf that is present in the californium. We expect to obtain 50 mg of high-purity ^{248}Cm in February 1976, 50 mg in May 1976, 50 mg in September 1976, and an additional 100 mg during 1977.

3. PROCESSES AND EQUIPMENT

We have made no changes in the chemical processing flowsheets normally used at TRU during this report period. The condition of chemical processing equipment at TRU is generally good, and the equipment is continually maintained.

When replacements are necessary, modifications are usually included to provide improved capability and performance.

During this time, we replaced the equipment rack in Cubicle 6 containing equipment for decontamination of the transplutonium actinides from rare-earth fission products and for separation of curium from the heavier elements by means of the LiCl-based anion-exchange process. The old rack had been in service for a period of 7 years and had been used to process actinide solutions containing more than 1.3 kg of ^{244}Cm and 2.3 g of ^{252}Cf .

Also, we replaced the equipment in Cubicle 5 which has been used for (1) separation of the transcurium elements by means of high-pressure ion exchange and (2) purification of ^{249}Bk by means of a batch solvent extraction (Berkex). By eliminating obsolete, multipurpose vessels and piping, we were able to fit the new equipment onto a single rack. The new rack contains a pressure-pot feed system that should be more reliable than a pump for transferring radioactive solutions to both the loading column and the capsules used for storage and shipping of ^{252}Cf . A pump will still be used for the transfer of nonradioactive eluent solutions.

4. CALIFORNIUM NEUTRON SOURCES

Some of the californium recovered at TRU is incorporated into neutron sources, which are subsequently loaned to researchers. Data for all of the neutron sources that have been fabricated at TRU are listed in Table 4.1. Most of the sources were fabricated into one of the four standard models illustrated in Fig. 4.1 of ref. 5 and are designated in the table by a three-letter prefix. Nonstandard sources are designated simply NS-. The three-letter prefix indicates whether the source is singly or doubly encapsulated and whether it is fabricated from type 304L stainless steel or Zircaloy-2. The characteristics of standard source capsules are listed in Table 4.2 of ref. 5.

4.1 Sources Fabricated During July-December 1975

Two sources, NSD-91 and NS-86, were fabricated during this report period. NS-86 was prepared in a nonstandard form specified by the user.

Table 4.1. Data for neutron sources prepared at TRU

Source	Date of calibration	^{252}Cf Content at calibration (μg)	Content as of 12/31/75		On loan to:	
			^{252}Cf (μg)	^{248}Cm (μg)	Individual	Site
NS-1 ^a	8-28-68	316	46	b	K. L. Swinth	PNL
NS-2	8-23-68	254	37	b	c	
NS-3	5-13-69	~90	~16	b	G. I. Gleason	ORAU
NS-4	7-09-69	883	162	688	C. F. Masters	LASL
NS-5 ^d	8-14-69	946	178	733	F. B. Simpson	ANC
NS-6	11-21-69	747	151	569	R. W. Hoff	LLL
NS-7	1-21-70	788	167	593	e	
NS-8	12-17-69	1839	378	1393	H. Berger	ANL
NSD-9	4-17-70	1720	386	1272	N. D. Wogman	PNL
NSS-10	3-11-70	113	25	b	J. P. Balagna	LASL
NS-11	3-10-70	8	2	b	R. R. Fullwood	LASL
NSS-12	6-30-70	1868	442	1360	R. W. Hoff	LLL
NSD-13	3-19-71	4649	1327	3168	H. O. Menlove	LASL
NSS-14	6-29-70	4615	1091	3361	D. C. Stewart	ANL
NS-15 ^d	6-25-70	931	219	679	F. B. Simpson	ANC
NSD-16	10-08-70	1657	(438)	(1291)	When processed on 12-08-75	
NSS-17	8-31-71	4886	1570	3162	L. W. Dahlke	Sandia-Livermore
NS-18 ^d	6-24-70	962	227	701	F. B. Simpson	ANC
NSS-19	6-26-70	493	116	359	J. E. Bigelow	ORNL-TRU
NSD-20	7-01-70	630	149	459	J. E. Powell	Sandia-NM
NSS-21	10-21-70	18	5	b	F. Cross	PNL
NS-22	9-10-70	13	3	b	J. E. Bigelow	ORNL-TRU
NSD-24	10-15-70	6	2	b	J. E. Rushton	ORNL
NS-25	11-09-70	58	15	b	F. J. Muckenthaler	ORNL
NSD-26	2-11-71	14	4	b	H. O. Menlove	LASL
NSD-27	1-29-71	2528	697	1746	L. C. Nelson, Jr.	New Brunswick
NSD-28	2-12-71	11	3	b	E. E. Hicks	Rocky Flats
NSD-29	9-10-71	11393	3687	7349	S. G. Snow	Y-12
NSD-30	3-31-71	879	253	597	e	
NZD-31	11-23-71	1733	591	1089	J. L. White	HEDL
NZD-32	11-23-71	1800	(616)	(1166)	When processed on 12-08-75	
NZD-33	11-23-71	1888	(649)	(1229)	When processed on 12-08-75	
NZD-34	11-23-71	1924	657	1209	W. G. Spear	HEDL
NZD-35	11-23-71	1904	650	1196	e	
NS-36 ^d	3-23-71	2070	593	1409	F. B. Simpson	ANC
NSD-37	9-04-71	9838	3170	6359	R. W. Perkins	PNL
NSD-38	6-16-71	102	31	b	H. O. Menlove	LASL
NS-39	11-07-71	942	318	595	V. Spiegel	NBS
NSD-40	4-27-72	1154	440	680	e	
NSD-41	11-08-71	5117	1728	3232	C. J. Emert	BAPL
NSD-42	11-02-71	4434	1491	2807	C. J. Emert	BAPL
NSD-43	4-20-72	4839	1838	2862	C. J. Emert	BAPL
NZD-44	5-15-72	10731	4149	6277	F. B. Simpson	ANC

Table 4.1. (continued)

Source	Date of calibration	²⁵² Cf Content at calibration (μ g)	Content as of 12/31/75		On loan to:	
			²⁵² Cf (μ g)	²⁴⁸ Cm (μ g)	Individual	Site
NSD-45	8-18-71	1776	565	1155	K. L. Swinth	PNL
NSD-46	4-23-72	629	239	372	H. O. Menlove	LASL
NSD-47	7-14-71	200	62	132	P. L. Johnson	Mound
NSD-48	7-14-71	194	60	128	J. E. Rushton	ORNL
NSD-49	7-14-71	199	62	131	f	
NS-50	8-23-71	138	44	90	S. G. Carpenter	ANL-NRTS
NSD-51	11-02-71	365	123	231	e	
NSD-52	9-02-71	280	90	181	E. D. Clayton	PNL
NSD-53	10-25-71	1051	351	667	L. J. Esch	KAPL
NS-54	1-19-73	3187	1473	1634	V. Spiegel	NBS
NSD-55	4-19-72	4	2	b	L. J. Esch	KAPL
NSD-56	4-19-72	121	46	72	L. J. Esch	KAPL
NSD-57	4-14-72	973	368	577	e	
NZD-58	5-15-72	11003	4254	6436	F. B. Simpson	ANC
NS-59	7-13-72	53	21	b	G. E. Hanson	LASL
NSD-60	4-11-72	20	8	b	F. F. Haywood	ORNL-DOSAR
NSD-61	1-19-73	5225	2415	2680	L. J. Esch	KAPL
NSS-62	3-27-73	3755	1821	1844	J. E. Bigelow	ORNL-TRU
NSD-63	4-21-72	847	322	501	H. O. Menlove	LASL
NSD-64	7-19-73	193	102	87	H. O. Menlove	LASL
NS-65	7-09-73	114	60	52	L. Green	BAPL
NSD-66	8-02-73	3449	1833	1541	J. E. Powell	Sandia-NM
NSD-73	9-11-73	13545	7410	5850	G. I. Gleason	ORAU
NSD-74	9-11-73	4416	2416	1907	G. I. Gleason	ORAU
NS-75	10-01-73	1919	1065	814	R. J. Kloepping	LLL
NSD-76	3-09-74	434	270	156	P. L. Johnson	Mound
NSD-77	3-09-74	433	269	156	P. L. Johnson	Mound
NSD-78	3-09-74	429	267	155	P. L. Johnson	Mound
NS-79	10-02-74	1650	1191	438	V. Spiegel	NBS
NSD-80	6-03-74	5966	3947	1925	C. J. Emert	BAPL
NSD-81	6-03-74	6364	4210	2054	C. J. Emert	BAPL
NS-86	11-17-75	2620	2539	78	V. Spiegel	NBS
NSD-89	4-23-75	12687	10589	2000	J. E. Powell	Sandia-NM
NZS-90	1-16-75	0.87	<1	b	J. R. Smith	ANC
NSD-91	9-26-75	15	14	b	f	
SR-Cf-167 ^g	5-26-71	3975	1191	2655	e	

^aThis source is encapsulated in aluminum.

^bThis source is not suitable for recovery of ²⁴⁸Cm.

^cThis source being held for use at ANL.

^dThis source is encapsulated in Type 405 stainless steel.

^eThis source is held at ORNL and is available for reissue.

^fThis source being held for use at KAPL.

^gThis source was fabricated at TRU in standard Savannah River SR-Cf-100 series hardware.

4.2 Sources Returned

An increasing number of neutron sources are being returned when the projects for which they were requested are completed or when replacement sources are ordered to make up for decay of the ^{252}Cf . The returned sources are available for reassignment until the appropriate time for reprocessing to recover the ingrown ^{248}Cm . Seven sources that contain from 37 to 1191 μg of ^{252}Cf are now in this category and are so designated in Table 4.1. An additional three sources have been reloaded but have not yet been shipped. Source NSD-40 was returned to TRU during this period and is available for reissue.

4.3 Sources Reprocessed

Many sources now contain significant amounts of ^{248}Cm , as noted in Table 4.1. When no further use can be foreseen for these sources, they will be dissolved and chemically processed to isolate and recover the elements. Three sources, NSD-16, NZD-32, and NZD-33, were processed during this report period.

5. SPECIAL PROJECTS

The primary functions of TRU are: (1) to fabricate targets for irradiation in the HFIR to produce transuranium elements, and (2) to isolate and purify transuranium elements for use by research workers. However, the facilities that are available⁶ are also used for a variety of other purposes such as nonroutine production, special preparations, and special irradiations in HFIR; in each case, a unique service can be provided to assist a research program at ORNL or another site. The following special project was undertaken during the current report period.

5.1 Irradiation of ^{248}Cm

A small portion of high-purity ^{248}Cm was selected for a series of test irradiations to study the production of ^{250}Cm . For this purpose, a

particular batch of high-purity ^{248}Cm on hand is especially valuable because the initial concentration of ^{250}Cm can be determined by calculation from the parent californium sample and the known decay period. The calculated concentration of ^{250}Cm is 1.47 ppm. This value is below the level of detection of mass spectrometer measurement (which is estimated to be 3 ppm) but is high enough to affect the calculated value for the ^{250}Cm cross section which is to be determined from the results of this experiment.

The ^{248}Cm was loaded into eight pellets, each containing approximately 100 μg , by means of a procedure that is similar to that used for preparing ^{249}Bk pellets for irradiation.⁷ Two special HFIR targets (T-79 and T-80), each containing two of the ^{248}Cm pellets, were fabricated. In each case, one pellet was located at a position corresponding to the reactor mid-plane; the other was situated about eight inches lower, corresponding to a region of the reactor in which the flux is about one-half that of the mid-plane. The first target will be irradiated for one reactor cycle and the second for two. After irradiation, the pellets will be dissolved and processed to measure the amount of ^{250}Cm produced.

Two other HFIR targets (T-81 and T-82) were also fabricated as part of this experiment. Each of these targets contained one ^{248}Cm pellet at a position corresponding to the reactor mid-plane, and the remaining space was filled with standard curium pellets. These two targets will be irradiated for about four to eight reactor cycles (the exact time will be determined after examining results from the irradiation of T-79 and T-80).

The two remaining ^{248}Cm pellets were stored and will be used for possible supplemental testing.

6. REFERENCES

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5. L. J. King, J. E. Bigelow, and E. D. Collins, Transuranium Processing Plant Semiannual Report of Production, Status, and Plans for Period Ending June 30, 1973, ORNL-4921, pp. 14-15.
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12. Y. A. Ellis, Nucl. Data Sheets 6, 539 (1971) (A = 237).
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14. Y. A. Ellis, Nucl. Data Sheets 6, 621 (1971) (A = 241).

7. APPENDIX

We have traditionally used the Appendix in this series of semiannual reports to tabulate decay data and cross-section data of interest to the transplutonium community. In the first few issues, rapid changes occurred as a result of the publication of much new data. Sometimes, by virtue of personal contacts with some of the investigators, we were able to incorporate new data in our tables even before formal publication. In more recent issues, the press of other work has prevented us from revising the tables; as a result, they are no longer current. In the meantime, the Nuclear Data Project at ORNL has issued revised and updated Nuclear Data Sheets⁸⁻¹⁴ which cover the mass region of interest ($A > 237$), and which are considered the definitive source of all types of nuclear data relating to decay modes, half-lives, etc. However, because these Appendix tables have proven to be a convenient reference to us at TRU, we will continue to publish them with each issue. It is our expectation that, as time permits, we will bring the decay data in these tables in line with the latest revisions of the Nuclear Data Sheets.

7.1 Decay Data

Table A-1 is a list of all nuclides of interest to the Transplutonium Element Production Program (i.e., all that can be produced by neutron bombardment of ^{238}U). The list includes values for half-lives and branching ratios or partial decay half-lives, along with literature references where available. In many cases, the half-life of an isotope was determined by relating that isotope's half-life to the half-life of some other reference isotope. In a few of these cases, a newer value has been accepted for the half-life of the reference isotope, and the values of the half-lives that were dependent upon it have been recalculated. Such cases are footnoted because the half-life value in our table no longer agrees with the value given in the reference. However, we did use the relationship given in the referenced work.

Table A-1. Half-life values^a for isotopes of transuranium elements

Nuclide	Total Half-Life	Partial Half-Life for α Decay	Branching Ratios	Partial Half-Life for Spontaneous Fission	Neutrons per Fission	References ^b
²³⁷ Np		$(2.14 \pm 0.01) \times 10^6$ y		$>10^{18}$ y	2.00 ^d	60Br12, 61Dr04
²³⁸ Np	2.10 \pm 0.01 d					50Fr53
²³⁹ Np	2.359 \pm 0.010 d					59Co93
²⁴⁰ Np	63 \pm 2 m					60Le03
^{240m} Np	7.3 \pm 0.3 m					48Hy61
²⁴¹ Np	16 m					60Le03
^{241m} Np	3.4 h					60Le03
²³⁸ Pu	87.404 \pm 0.041 y			$(5 \pm 0.6) \times 10^{10}$ y	2.33 \pm 0.08	61Dr04, 68Jo15, 56Hi01
²³⁹ Pu		$(2.4413 \pm 0.003) \times 10^4$ y		5.5×10^{15} y	2.24 ^d	52Se67, 59Ma26
²⁴⁰ Pu		6580 \pm 40 y		$(1.340 \pm 0.015) \times 10^{11}$ y	2.177 \pm 0.009	51In03, 62Wa13, 68Bo54
²⁴¹ Pu	14.98 \pm 0.33 y	$(5.72 \pm 0.1) \times 10^5$ y				68Ca19, 60Br15
²⁴² Pu		$(3.869 \pm 0.016) \times 10^5$ y		$(7.45 \pm 0.17) \times 10^{10}$ y	2.166 \pm 0.009	63Ma50, 69Be06, 68Bo54
²⁴³ Pu	4.955 \pm 0.003 h					68Di09
²⁴⁴ Pu		$(8.28 \pm 0.10) \times 10^7$ y		$(6.55 \pm 0.32) \times 10^{10}$ y	2.84 ^d	66Fi07, 69Be06
²⁴⁵ Pu	10.6 \pm 0.4 h					56Bu92
²⁴⁶ Pu	10.85 \pm 0.02 d					56Ho23
²⁴¹ Am		432.7 \pm 0.7 y		$(2.3 \pm 0.8) \times 10^{14}$ y	2.48 ^d	61Dr04, 670e01
²⁴² Am	16.01 \pm 0.02 h		EC/B = 0.19			53Ke38
^{242m} Am	144 \pm 7 y	$(2.92 \pm 0.15) \times 10^4$ y				59Ba21 ^c
²⁴³ Am		7370 \pm 40 y				68Br22
²⁴⁴ Am	10.1 \pm 0.1 h					62Va08
^{244m} Am	26 m					54Ga24
²⁴⁵ Am	2.07 \pm 0.02 h					56Bu92
²⁴⁶ Am	25.0 \pm 0.2 m					55En16
^{246m} Am	40 \pm 7 m					670r02
²⁴⁷ Am	24 \pm 3 m					670r02
²⁴² Cm	162.7 \pm 0.1 d			7.2×10^6 y	2.65 \pm 0.09	51Ha87, 57Pe52, 56Hi01
²⁴³ Cm		32 y				57As70
²⁴⁴ Cm	18.099 \pm 0.015 y		α /SF = $(7.43 \pm 0.01) \times 10^5$		2.84 \pm 0.09	65Me02, 68Be26, 56Hi01
²⁴⁵ Cm		8265 \pm 180 y				69Me01
²⁴⁶ Cm		4655 \pm 40 y	α /SF = 3822 \pm 10		3.08 ^d	69Me01, 71Mc19
²⁴⁷ Cm		$(1.56 \pm 0.05) \times 10^7$ y				71Fi01
²⁴⁸ Cm		$(3.703 \pm 0.032) \times 10^5$ y		$(4.115 \pm 0.034) \times 10^6$ y	3.32 ^d	71Mc19
²⁴⁹ Cm	64 \pm 3 m					58Ea06
²⁵⁰ Cm				$(1.74 \pm 0.24) \times 10^4$ y	3.56 ^d	66RG01

Table A-1. (continued)

Nuclide	Total Half-Life	Partial Half-Life for α Decay	Branching Ratios	Partial Half-Life for Spontaneous Fission	Neutrons per Fission	References ^b
249Bk	314 \pm 8 d		$\alpha/\beta = (1.45 \pm 0.08) \times 10^{-5}$	$(1.87 \pm 0.09) \times 10^9$ y	3.72 \pm 0.16	57Ea01, 69Mi08, 64Py02
250Bk	3.222 \pm 0.005 h					59Va02
251Bk	57 \pm 1.7 m					66RG04
249Cf		352 \pm 6 y	$\alpha/\text{SF} = (1.992 \pm 0.040) \times 10^8$		3.44 ^d	69Me01, 69Mi08
250Cf		13.08 \pm 0.09 y	$\alpha/\text{SF} = 1260 \pm 40$		3.56 ^d	63Ph01, 69Me01
251Cf		900 \pm 50 y				69Me01
252Cf	2.646 \pm 0.004 y		$\alpha/\text{SF} = 31.3 \pm 0.2$		3.796 \pm 0.031	65Me02, 68Wh04
253Cf	17.812 \pm 0.082 d		$\alpha/\beta = (3.1 \pm 0.4) \times 10^{-3}$			69Dr02, 66RG01
254Cf	60.5 \pm 0.2 d		$\alpha/\text{SF} = (3.10 \pm 0.16) \times 10^{-3}$		3.90 \pm 0.14	63Ph01, 64Py02, 68Be21
255Cf	1.5 \pm 0.5 h					70Lo19
253Es	20.467 \pm 0.024 d		$\alpha/\text{SF} = (1.15 \pm 0.03) \times 10^7$		3.92 ^d	65Me02, 69Dr02
254Es	276 d			$>2.5 \times 10^7$ y	4.04 ^d	67Fi03, 67Un01
254mEs	39.3 \pm 0.2 h		$\beta/\alpha = 382 \pm 30$ E.C./ $\beta = 0.00078 \pm 0.00006$			62Un01, 63Ph01
255Es	39.8 \pm 1.2 d		$\alpha/\beta = 0.0866 \pm 0.0043$ $\beta/\text{SF} = (2.22 \pm 0.10) \times 10^4$		4.16 ^d	66RG01, 67Fi03
256Es	25 \pm 3 m					68Lo11
254Fm	3.24 \pm 0.01 h		$\alpha/\text{SF} = 1695 \pm 8$		4.05 \pm 0.19	56Jo09, 67Fi03, 56Ch83
255Fm	20.07 \pm 0.07 h		$\text{SF}/\alpha = (2.4 \pm 1.1) \times 10^{-7}$		4.16 ^d	63Ph01, 64As01
256Fm	2.62 \pm 0.03 h		$\sim 100\%$ SF		4.27 ^d	68Ho13
257Fm	94 \pm 10 d					66RG01
258Fm	380 \pm 60 μ s		$\sim 100\%$ SF			71Hu03

^aThe half-life values used in this table were being used at TRU at the end of the report period.

^bReferences are decoded in Table A-2.

^cPublished values are adjusted for ²⁴¹Am half-life of 432.7 y.

^dValue estimated by linear interpolation of the values for ²⁴⁴Cm and ²⁵²Cf, based on nuclidic mass.

The references used in Table A-1 are decoded in Table A-2. The system of references is that used in the Nuclear Data Sheets. Table A-3 lists derived data, such as specific activities, along with information concerning the hazard associated with handling these nuclides.

7.2 Neutron Cross-Section Data

The values of neutron cross sections used to compute transmutations in HFIR target irradiations are listed in Table A-4. This table shows six parameters describing the neutron interactions. The first is the thermal-neutron capture cross section, σ_{2200}^c , and the third is the neutron capture resonance integral, RI. The second parameter, C, is a constant that is a function of the target geometry; it is used to estimate the resonance self-shielding effect. The effective capture cross section, σ_{eff}^c , would be:

$$\sigma_{\text{eff}}^c = \sigma_{2200}^c + \frac{\phi_{\text{res}}}{\phi_{2200}} \sqrt{\frac{\text{RI}}{1 + \text{CN}}},$$

where N is the number of grams of the particular nuclide in one target rod, ϕ_{res} is the average flux per unit lethargy width in the resonance region, and ϕ_{2200} is the equivalent flux of 2200-m/sec neutrons that would give the same reaction rate with a 1/v absorber as would the actual reactor flux. In the HFIR, the ratio $\phi_{\text{res}}/\phi_{2200}$ ranges from 0.042 to 0.051. The effective cross section for fission is computed by a similar relationship among the last three parameters.

These cross sections are to be regarded as a self-consistent set whereby one can compute overall transmutation effects and as a set of arbitrary constants to be used to obtain the best fit to our data. Hopefully, these numbers and the cross sections experimentally measured on pure isotopes will agree; however, we will not allow the possibility of a discrepancy to confine us.

It should be pointed out that ^{244c}Am is a fictitious isotope which is used to simplify the calculation of the main transmutation chain involving ^{244}Am . The properties of ^{244c}Am were calculated from the properties of the

Table A-2. References for Table A-1

Code	Reference	Code	Reference
48Hy01	E. K. Hyde, M. H. Studier, and W. M. Manning, ANL-4143 (April 15, 1948) and ANL-4182 (August 4, 1948).	63Ma50	L. Z. Malkin, I. D. Alkhozov, A. S. Krivokhatskii, and K. A. Petrzhak, <i>At. Energ. (USSR)</i> , 15 , 158-159 (1963).
50Fr53	N. S. Freedman, A. H. Jaffey, and F. Wagner, Jr., <i>Phys. Rev.</i> , 79 , 410-411 (1950).	63Ph01	L. Phillips, R. Gatti, R. Brandt, and S. G. Thompson, <i>J. Inorg. Nucl. Chem.</i> , 25 , 1085-1087 (1963).
51Ha87	G. C. Hanna, B. G. Harvey, N. Moss, and P. R. Tunncliffe, <i>Phys. Rev.</i> , 81 , 466-467 (1951).	64As01	F. Asaro, S. Bjrnholm, and I. Perlman, <i>Phys. Rev.</i> , 133 , B291-B300 (1964).
51In03	M. G. Inghram, D. C. Hess, P. R. Fields, and G. L. Pyle, <i>Phys. Rev.</i> , 83 , 1250 (1951).	64Py02	R. V. Pyle, Unpublished results as reported in E. K. Hyde, "Fission Phenomena," Prentice Hall, Inc. (1964).
52Se67	L. Segrè, <i>Phys. Rev.</i> , 86 , 21-28 (1952).	65Me02	D. Metta, H. Diamond, R. F. Barnes, J. Milsted, J. Gray, Jr., D. J. Henderson, and C. M. Stevens, <i>J. Inorg. Nucl. Chem.</i> , 27 , 33-35 (1965).
53Ke38	T. K. Keenan, R. A. Penneman, and B. B. McInteer, <i>J. Chem. Phys.</i> , 21 , 1802-1803 (1953).	66Fi07	P. R. Fields, A. M. Friedman, J. Milsted, J. Lerner, C. M. Stevens, D. Metta, and W. K. Sabine, <i>Nature</i> , 212 , 131 (1966).
54Ch24	A. Ghiorso, S. G. Thompson, G. R. Choppin, and B. G. Harvey, <i>Phys. Rev.</i> , 94 , 1081 (1954).	66RG01	Combined Radiochemistry Group, LRL, LASL, and ANL, <i>Phys. Rev.</i> , 148 , No. 3, 1192-1198 (1966).
55En16	D. Engelkemeir, P. R. Fields, T. Fried, G. L. Pyle, C. M. Stevens, L. B. Asprey, C. I. Browne, H. Louise Smith, and R. W. Spence, <i>J. Inorg. Nucl. Chem.</i> , 1 , 345-351 (1955).	66RG04	Argonne Heavy Element Group (unpublished data).
56Bu92	J. P. Butler, T. A. Eastwood, T. L. Collins, M. L. Jones, F. M. Rourke, and R. P. Schuman, <i>Phys. Rev.</i> , 103 , 634 (1956).	67Fi03	P. R. Fields, H. Diamond, A. M. Friedman, J. Milsted, J. L. Lerner, R. F. Barnes, R. K. Sjolom, D. N. Metta, and E. P. Horwitz, <i>Nucl. Phys.</i> , A96 , 440-448 (1967).
56Ch83	G. R. Choppin, B. G. Harvey, D. A. Hicks, J. Ise, Jr., and R. V. Pyle, <i>Phys. Rev.</i> , 102 , 766 (1956).	67Oe01	F. L. Oetting and S. R. Gunn, <i>J. Inorg. Nucl. Chem.</i> , 29 , 2659-2664 (1967).
56Hi01	D. A. Hicks, J. Ise, Jr., and R. V. Pyle, <i>Phys. Rev.</i> , 101 , 1016-1020 (1956).	67Or02	C. J. Orth, W. R. Daniels, B. H. Erkkila, F. O. Lawrence, and D. C. Hoffman, <i>Phys. Rev. Letters</i> , 19 , No. 3, 128-131 (1967).
56Ho23	D. C. Hoffman and C. I. Browne, <i>J. Inorg. Nucl. Chem.</i> , 2 , 209 (1956).	67Un01	J. Unik, private communication to P. Fields (1967).
56Jo09	M. Jones, R. P. Schuman, J. P. Butler, G. Cowper, T. A. Eastwood, and H. G. Jackson, <i>Phys. Rev.</i> , 102 , 203-207 (1956).	68Be21	C. E. Bemis, Jr. and J. Halperin, <i>Nucl. Phys.</i> , A121 , 433-439 (1968).
57As70	F. Asaro, S. G. Thompson, F. S. Stephens, Jr., and I. Perlman, <i>Bull. Am. Phys. Soc.</i> , 8 , 393 (1957).	68Be26	W. C. Bentley, <i>J. Inorg. Nucl. Chem.</i> , 30 , 2007-2009 (1968).
57Ea01	T. A. Eastwood, J. P. Butler, M. J. Cabell, H. G. Jackson, R. P. Schuman, F. M. Rourke, and T. L. Collins, <i>Phys. Rev.</i> , 107 , 1635-1638 (1957).	68Bo54	J. W. Boldeman, <i>J. Nucl. Energy</i> , 22 , 63-72 (1968).
57Pe52	R. A. Penneman, L. H. Treiman, and B. Bevan, as reported by D. C. Hoffman, G. P. Ford, and F. O. Lawrence, <i>J. Inorg. Nucl. Chem.</i> , 5 , 6-11 (1957).	68Br22	L. C. Brown and R. C. Propst, <i>J. Inorg. Nucl. Chem.</i> , 30 , 2591-2594 (1968).
58Ea06	T. A. Eastwood and R. P. Schuman, <i>J. Inorg. Nucl. Chem.</i> , 6 , 261-262 (1958).	68Ca19	M. J. Cabell, <i>J. Inorg. Nucl. Chem.</i> , 30 , 2583-2589 (1968).
59Ba21	R. F. Barnes, D. J. Henderson, A. L. Harkness, and H. Diamond, <i>J. Inorg. Nucl. Chem.</i> , 9 , 105-107 (1959).	68Di09	H. Diamond, J. J. Hines, R. K. Sjolom, R. F. Barnes, D. N. Metta, J. L. Lerner, and P. R. Fields, <i>J. Inorg. Nucl. Chem.</i> , 30 , 2553-2559 (1968).
59Co93	D. Cohen, J. C. Sullivan, and A. J. Zielen, <i>J. Inorg. Nucl. Chem.</i> , 11 , 159-161 (1959).	68Ho13	R. W. Hoff, J. E. Evans, E. K. Hulet, R. J. Dupzyk, and B. J. Qualheim, <i>Nucl. Phys.</i> , A115 , 225-233 (1968).
59Ma26	T. L. Markin, <i>J. Inorg. Nucl. Chem.</i> , 9 , 320-322 (1959).	68Jo15	K. C. Jordan, MLM-1443, 11-30 (1968).
59Va02	S. E. Vandenbosch, H. Diamond, R. K. Sjolom, and P. R. Fields, <i>Phys. Rev.</i> , 115 , 115-121 (1959).	68Lo11	R. W. Loughheed, private communication to J. E. Bigelow (1968).
60Br12	F. P. Brauer, R. W. Stromatt, J. D. Ludwick, F. P. Roberts, and W. L. Lyon, <i>J. Inorg. Nucl. Chem.</i> , 12 , 234-235 (1960).	68Wh04	P. H. White and E. J. Axton, <i>J. Nucl. Energy</i> , 22 , 73-77 (1968).
60Br15	F. Brown, G. G. George, D. E. Green, and D. E. Watt, <i>J. Inorg. Nucl. Chem.</i> , 13 , 192-195 (1960).	69Be06	C. E. Bemis, Jr., J. Halperin, and R. Eby, <i>J. Inorg. Nucl. Chem.</i> , 31 , 599-604 (1969).
60Le03	R. M. Lessler and M. C. Michel, <i>Phys. Rev.</i> , 118 , 263-264 (1960).	69Dr02	R. E. Drushel, J. Halperin, and C. E. Bemis, Jr., ORNL-4437, 28-29 (1969).
61Dr04	V. A. Druin, V. P. Pereygin, and G. I. Khlebnikov, <i>Sov. Phys. JETP</i> , 13 , 913-914 (1961).	69Me01	D. N. Metta, H. Diamond, and F. R. Kelly, <i>J. Inorg. Nucl. Chem.</i> , 31 , 1245-1250 (1969).
62Un01	J. Unik, P. Day, and S. Vandenbosch, <i>Nucl. Phys.</i> , 36 , 284-304 (1962).	69Mi08	J. Milsted, E. P. Horwitz, A. M. Friedman, and D. N. Metta, <i>J. Inorg. Nucl. Chem.</i> , 31 , 1561-1569 (1969).
62Va08	S. E. Vandenbosch and P. Day, <i>Nucl. Phys.</i> , 30 , 177-190 (1962).	70Lo19	R. W. Loughheed, J. E. Evans, and E. K. Hulet, private communication to J. E. Bigelow (1970).
62Wa13	D. E. Watt, F. J. Bannister, J. B. Laidler, and F. Brown, <i>Phys. Rev.</i> , 126 , 264-265 (1962).	71Fi01	P. R. Fields, I. Ahmad, A. M. Friedman, J. Lerner, and D. N. Metta, <i>Nucl. Phys.</i> , A160 , 460-470 (1971).
		71Hu03	E. K. Hulet, J. F. Wild, R. W. Loughheed, J. E. Evans, B. J. Qualheim, M. Nurmia, and A. Ghiorso, <i>Phys. Rev. Letters</i> , 26 , 523 (1971).
		71Mc19	J. E. McCracken, J. R. Stokely, R. D. Baybarz, C. E. Bemis, Jr., and R. Eby, <i>J. Inorg. Nucl. Chem.</i> , 33 , 3251-3259 (1971).

Table A-3. Properties^a of transuranium nuclides

Nuclide	Half-Life	Energies of Prin. Emissions (MeV)		Specific Activity				(Neutrons min ⁻¹ mg ⁻¹)	Hazard ^b		
		α	β	(Ci/g)	(W/g)	(α cpm/mg ^c)	(8 dpm/mg)		MPC _a (40) (μCi/cm ³)	Body Burden (μCi) (μg)	
²³⁷ Np	2.14 x 10 ⁶ y	4.78		7.07 x 10 ⁻⁴	2.07 x 10 ⁻⁵	8.01 x 10 ⁵		<7 x 10 ⁻⁶	4 x 10 ⁻¹²	0.06	84.9
²³⁸ Np	2.10 d		0.25 1.24	2.61 x 10 ⁵	1.27 x 10 ³			5.80 x 10 ¹⁴			
²³⁹ Np	2.359 d		0.332 0.427	2.32 x 10 ⁵	5.86 x 10 ²			5.14 x 10 ¹⁴	7 x 10 ⁻⁷	30	1.29 x 10 ⁻⁴
²⁴⁰ Np	63 m		0.89	1.24 x 10 ⁷	1.03 x 10 ⁵			2.76 x 10 ¹⁶			
^{240m} Np	7.3 m		2.18 1.6	1.07 x 10 ⁸	5.33 x 10 ⁵			2.38 x 10 ¹⁷			
²⁴¹ Np	16 m			4.86 x 10 ⁷				1.08 x 10 ¹⁷			
^{241m} Np	3.4 h			3.82 x 10 ⁶				8.49 x 10 ¹⁵			
²³⁸ Pu	87.404 y	5.49		17.2	0.570	1.94 x 10 ¹⁰		155	2 x 10 ⁻¹²	0.04	2.32 x 10 ⁻³
²³⁹ Pu	2.4413 x 10 ⁴ y	5.15		6.13 x 10 ⁻²	1.913 x 10 ⁻³	6.94 x 10 ⁷		1.35 x 10 ⁻³	2 x 10 ⁻¹²	0.04	0.653
²⁴⁰ Pu	6580 y	5.16		0.227	7.097 x 10 ⁻³	2.57 x 10 ⁸		53.7	2 x 10 ⁻¹²	0.04	0.176
²⁴¹ Pu	14.98 y	4.9	0.02	99.1	4.06 x 10 ⁻³	2.94 x 10 ⁶	2.20 x 10 ¹¹		9 x 10 ⁻¹¹	0.9	9.08 x 10 ⁻³
²⁴² Pu	3.869 x 10 ⁵ y	4.90		3.82 x 10 ⁻³	1.13 x 10 ⁻⁴	4.32 x 10 ⁶		95.3	2 x 10 ⁻¹²	0.05	13.1
²⁴³ Pu	4.955 h		0.49 0.58	2.60 x 10 ⁶	3.34 x 10 ³			5.78 x 10 ¹⁵	2 x 10 ⁻⁶	7.0	2.69 x 10 ⁻⁶
²⁴⁴ Pu	8.28 x 10 ⁷ y	4.587		1.77 x 10 ⁻⁵	4.93 x 10 ⁻⁷	2.00 x 10 ⁴		141	2 x 10 ⁻¹²	0.04	2.26 x 10 ³
²⁴⁵ Pu	10.6 h			1.21 x 10 ⁶				2.68 x 10 ¹⁵	2 x 10 ⁻⁷	3.0	2.48 x 10 ⁻⁶
²⁴⁶ Pu	10.85 d		0.15	4.91 x 10 ⁴	66.9			1.09 x 10 ¹⁴			
²⁴¹ Am	432.7 y	5.48		3.43	0.1145	3.88 x 10 ⁹		3.55 x 10 ⁻²	6 x 10 ⁻¹²	0.1	0.0292
²⁴² Am	16.01 h		0.63 0.67	8.11 x 10 ⁵	2.08 x 10 ³			1.80 x 10 ^{15d}	4 x 10 ⁻⁸	0.06	7.39 x 10 ⁻⁸
^{242m} Am	144 y	5.207	1.T.	10.3	3.08 x 10 ⁻²	5.53 x 10 ⁷	2.28 x 10 ^{10e}		6 x 10 ⁻¹²	0.07	6.80 x 10 ⁻³
²⁴³ Am	7370 y	5.27		0.200	6.42 x 10 ⁻³	2.26 x 10 ⁸			6 x 10 ⁻¹²	0.05	0.25
²⁴⁴ Am	10.1 h		0.387	1.27 x 10 ⁶	8.74 x 10 ³			2.82 x 10 ¹⁵			
^{244m} Am	26 m		1.5	2.96 x 10 ⁷	8.98 x 10 ⁴			6.58 x 10 ^{16f}	4 x 10 ⁻⁶	0.2	6.76 x 10 ⁻⁹
²⁴⁵ Am	2.07 h		0.91	6.17 x 10 ⁶	1.20 x 10 ⁴			1.37 x 10 ¹⁶			
²⁴⁶ Am	25.0 m		1.31	3.06 x 10 ⁷	2.48 x 10 ⁵			6.79 x 10 ¹⁶			
^{246m} Am	40 m			1.91 x 10 ⁷				4.24 x 10 ¹⁶			
²⁴⁷ Am	24 m			3.17 x 10 ⁷				7.04 x 10 ¹⁶			
²⁴² Cm	162.7 d	6.11		3.32 x 10 ³	122	3.76 x 10 ¹²		1.21 x 10 ⁶	1 x 10 ⁻¹⁰	0.05	1.51 x 10 ⁻⁵
²⁴³ Cm	32 y	5.79		45.9	1.677	5.20 x 10 ¹⁰	3.27 x 10 ⁸		6 x 10 ⁻¹²	0.09	1.96 x 10 ⁻³
²⁴⁴ Cm	18.099 y	5.81		80.94	2.832	9.16 x 10 ¹⁰		6.87 x 10 ⁵	9 x 10 ⁻¹²	0.1	1.24 x 10 ⁻³
²⁴⁵ Cm	8265 y	5.36		0.177	5.89 x 10 ⁻³	2.00 x 10 ⁸			5 x 10 ⁻¹²	0.04	0.226
²⁴⁶ Cm	4655 y	5.39		0.312	1.01 x 10 ⁻²	3.52 x 10 ⁸		5.58 x 10 ⁵	5 x 10 ⁻¹²	0.05	0.160
²⁴⁷ Cm	1.56 x 10 ⁷ y	4.87		9.28 x 10 ⁻⁵	2.94 x 10 ⁻⁶	1.05 x 10 ⁵			5 x 10 ⁻¹²	0.04	431
²⁴⁸ Cm	3.397 x 10 ⁵ y	5.05		4.24 x 10 ⁻³	5.34 x 10 ⁻⁴	4.39 x 10 ⁶		2.58 x 10 ⁶	6 x 10 ⁻¹³	0.005	1.18
²⁴⁹ Cm	64 m		0.9	1.18 x 10 ⁷	2.06 x 10 ⁴		2.62 x 10 ¹⁶		1 x 10 ⁻⁵	1.0	8.47 x 10 ⁻⁸
²⁵⁰ Cm	1.74 x 10 ⁴ y			8.20 x 10 ⁻²	~0.1			6.49 x 10 ⁸			

Table A-3. (continued)

Nuclide	Half-Life	Energies of Prin. Emissions (MeV)		Specific Activity				Hazard ^b			
		α	β	(Ci/g)	(W/g)	(α cpm/mg ^c)	(β dpm/mg)	(Neutrons min ⁻¹ mg ⁻¹)	MPC ^a (40)		Body Burden (μg)
									(μCi/cm ³)	(μCi)	
²⁴⁹ Bk	314 d	5.4	0.125	1.67 x 10 ³	0.358	2.74 x 10 ⁷	3.71 x 10 ¹²	6.34 x 10 ³	9 x 10 ⁻¹⁰	0.7	4.19 x 10 ⁻⁴
²⁵⁰ Bk	3,222 h		0.23	3.89 x 10 ⁶		2.75 x 10 ⁴		8.62 x 10 ¹⁵	1 x 10 ⁻⁷	0.05	1.29 x 10 ⁻⁸
²⁵¹ Bk	57 m			1.32 x 10 ⁷				2.92 x 10 ¹⁶			
²⁴⁹ Cf	352 y	5.81		4.08	0.152	4.62 x 10 ⁹		156	2 x 10 ⁻¹²	0.04	9.80 x 10 ⁻³
²⁵⁰ Cf	13.08 y	6.03		109	4.06	1.23 x 10 ¹¹		6.85 x 10 ⁸	5 x 10 ⁻¹²	0.04	3.70 x 10 ⁻⁴
²⁵¹ Cf	900 y			1.59		5.79 x 10 ⁻²		1.78 x 10 ⁹	2 x 10 ⁻¹²	0.04	2.50 x 10 ⁻²
²⁵² Cf	2,646 y	6.11		536	39.0	5.88 x 10 ¹¹		1.40 x 10 ¹¹	6 x 10 ⁻¹²	0.01	1.87 x 10 ⁻⁵
²⁵³ Cf	17,812 d	5.98	0.27	2.90 x 10 ⁴	13.89	1.02 x 10 ¹¹	6.41 x 10 ¹³		8 x 10 ⁻¹⁰	0.04	1.40 x 10 ⁻⁶
²⁵⁴ Cf	60.5 d	5.84		8.49 x 10 ³	1.06 x 10 ⁴	2.89 x 10 ¹⁰		7.35 x 10 ¹³	5 x 10 ⁻¹²	0.0007	8.24 x 10 ⁻⁸
²⁵⁵ Cf	1.5 h			~8 x 10 ⁶							
²⁵³ Es	20,467 d	6.63		2.52 x 10 ⁴	1.01 x 10 ³	2.86 x 10 ¹³		1.91 x 10 ⁷	6 x 10 ⁻¹⁰	0.04	1.59 x 10 ⁻⁶
²⁵⁴ Es	276 d	6.42		1.86 x 10 ³	71.9	2.11 x 10 ¹²		<5.04 x 10 ⁵	2 x 10 ⁻¹¹	0.02	1.08 x 10 ⁻⁵
^{254m} Es	39.3 h		0.48	3.14 x 10 ⁵	1.18 x 10 ³		6.97 x 10 ¹⁴		5 x 10 ⁻⁹	0.02	6.37 x 10 ⁻⁸
²⁵⁵ Es	39.8 d			1.29 x 10 ⁴			2.86 x 10 ¹³	4.92 x 10 ⁹	4 x 10 ⁻¹⁰	0.04	3.10 x 10 ⁻⁶
²⁵⁶ Es	25 m			2.94 x 10 ⁷			6.52 x 10 ¹⁶				
²⁵⁴ Fm	3.24 h	7.20		3.81 x 10 ⁶	1.68 x 10 ⁵	4.31 x 10 ¹⁵		2.02 x 10 ¹³	6 x 10 ⁻⁸	0.02	5.25 x 10 ⁻⁹
²⁵⁵ Fm	20.07 h	7.03		6.13 x 10 ⁵	2.79 x 10 ⁴	6.94 x 10 ¹⁴		1.36 x 10 ⁹	1 x 10 ⁻⁸	0.04	6.53 x 10 ⁻⁸
²⁵⁶ Fm	2.62 h			4.67 x 10 ⁶	5.85 x 10 ⁶			4.43 x 10 ¹⁶	2 x 10 ⁻⁹	0.0008	1.71 x 10 ⁻¹⁰
²⁵⁷ Fm	94 d			5.41 x 10 ³	~200	6.12 x 10 ¹²					
²⁵⁸ Fm	380 μs			1.15 x 10 ¹¹							

^aThe values for properties included in this table are those in use at TRU at the end of the report period.

^bFrom ICRP Publication 2, "Report of Committee II on Permissible Dose for Internal Radiation" (1959) and ICRP Publication 6, "Recommendations of the International Commission on Radiological Protection" (1964).

^cCounting geometry, 51%.

^d²⁴²Am decays by β emission (84%) and orbital capture (16%).

^e^{242m}Am decays almost entirely by isomeric transition to the 16-hr ground state, ²⁴²Am.

^f^{244m}Am decays primarily by β emission, but 0.039% decays by electron capture to ²⁴⁴Pu.

Table A-4. Neutron cross sections used to compute transmutations in HFIR target irradiations

Nuclide	Half-Life	Capture			Fission		
		2200-m/s Cross Section (barns)	Resonance Self-Shielding Constant	Resonance Integral (barns)	2200-m/s Cross Section (barns)	Resonance Self-Shielding Constant	Resonance Integral (barns)
²³⁸ Pu	87.404 y	560	0	150	16.5	0	25
²³⁹ Pu	2.4413 x 10 ⁴ y	265.7	0	195	742.4	0	324
²⁴⁰ Pu	6580 y	290	0	8453	0.05	0	0
²⁴¹ Pu	14.98 y	360	0	166	1011	0	541
²⁴² Pu	3.869 x 10 ⁵ y	19.5	6.20	1280	0	0	0
²⁴³ Pu	4.955 h	80	0	0	210	0	0
²⁴⁴ Pu	8.28 x 10 ⁷ y	1.6	0	0	0	0	0
²⁴⁵ Pu	10.6 h	277	0	0	0	0	0
²⁴⁶ Pu	10.85 d	0	0	0	0	0	0
²⁴³ Am	7370 y	105	0	1500	0	0	0
²⁴⁴ Am	10.1 h	0	0	0	2300	0	0
^{244m} Am	26 m	0	0	0	0	0	0
^{244c} Am ^a	49 m	0	0	0	1128	0	0
²⁴⁵ Am	2.07 h	0	0	0	0	0	0
²⁴⁶ Am	25.0 m	0	0	0	0	0	0
²⁴⁴ Cm	18.099 y	10.0	4.0	650	1.2	4.0	12.5
²⁴⁵ Cm	8265 y	343	2.4	120	1727	2.4	1140
²⁴⁶ Cm	4655 y	1.25	0	121	0	0	0
²⁴⁷ Cm	1.56 x 10 ⁷ y	60	0	500	120	0	1060
²⁴⁸ Cm	3.397 x 10 ⁵ y	3.56	2.0	170	0	0	0
²⁴⁹ Cm	64 m	2.8	0	0	50	0	0
²⁵⁰ Cm	1.74 x 10 ⁴ y	2	0	0	0	0	0
²⁴⁹ Bk	314 d	1451	2.4	1240	0	0	0
²⁵⁰ Bk	3.222 h	350	0	0	3000	0	0
²⁵¹ Bk	57 m	0	0	0	0	0	0
²⁴⁹ Cf	352 y	450	1.46	750	1690	5.8	2920
²⁵⁰ Cf	13.08 y	1900	20	11600	0	0	0
²⁵¹ Cf	900 y	2850	14	1600	3750	14	5400
²⁵² Cf	2.646 y	19.8	0	44	32	0	110
²⁵³ Cf	17.812 d	12.6	0	0	1300	0	0
²⁵⁴ Cf	60.5 d	50	0	1650	0	0	0
²⁵⁵ Cf	1.5 h	0	0	0	0	0	0
²⁵³ Es	20.467 d	345	0	0	0	0	0
²⁵⁴ Es	276 d	20	0	0	3060	0	0
^{254m} Es	39.3 h	1.26	0	0	1840	0	0
²⁵⁵ Es	39.8 d	60	0	0	0	0	0
²⁵⁶ Es	25 m	0	0	0	0	0	0
²⁵⁴ Fm	3.24 h	76	0	0	0	0	0
²⁵⁵ Fm	20.07 h	26	0	0	100	0	0
²⁵⁶ Fm	2.62 h	45	0	0	0	0	0
²⁵⁷ Fm	94 d	10	0	0	5500	0	0
²⁵⁸ Fm	380 μs	0	0	0	0	0	0

^aTo simplify calculations we use a fictitious isotope, ^{244c}Am, which combines the properties of ^{244m}Am and ²⁴⁴Am according to their relative rates of production from ²⁴³Am.

real isomers ^{244g}Am and ^{244m}Am by assuming that: (1) the number of atoms of ^{244c}Am present equals the total number of atoms of the real isomers; (2) the β decay from ^{244c}Am equals the total β decay from the real isomers; (3) the fissions from ^{244c}Am equal the total fissions from the real isomers; (4) the isomers are in equilibrium with their common parent ^{243}Am while the reactor is operating; and (5) the only significant production and removal factors are the removal of the isomers by decay and neutron absorption and the production of the isomers by transmutation from ^{243}Am . Thus,

$$(1) \quad N_c = N_g + N_m ,$$

$$(2) \quad \lambda_c N_c = \lambda_g N_g + \lambda_m N_m ,$$

$$(3) \quad \sigma_c^f N_c = \sigma_g^f N_g + \sigma_m^f N_m ,$$

$$(4) \quad \frac{dN_c}{dt} = \frac{dN_g}{dt} = \frac{dN_m}{dt} = 0, \text{ and}$$

$$(5) \quad (\lambda_i + \sigma_i^a \phi) N_i = f_i \sigma_i^c N_{243} ,$$

where superscripts f, a, and c refer to fission, neutron absorption, and neutron capture; subscript i refers to the i th isomer, c, g, or m; and f_i is the fraction of neutron captures in ^{243}Am resulting in the i th isomer, such that $f_c = f_g + f_m = 1$.

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