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TRANSURANIUM PROCESSING PLANT
SEMIANNUAL REPORT OF
PRODUCTION, STATUS, AND PLANS FOR
PERIOD ENDING DECEMBER 31, 1972

L. J. King
J. E. Bigelow
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CHEMICAL TECHNOLOGY DIVISION

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PRODUCTION, STATUS, AND PLANS FOR PERIOD ENDING DECEMBER 31, 1972

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

AUGUST 1973

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
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UNION CARBIDE CORPORATION
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U. S. ATOMIC ENERGY COMMISSION



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SUMMARY

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

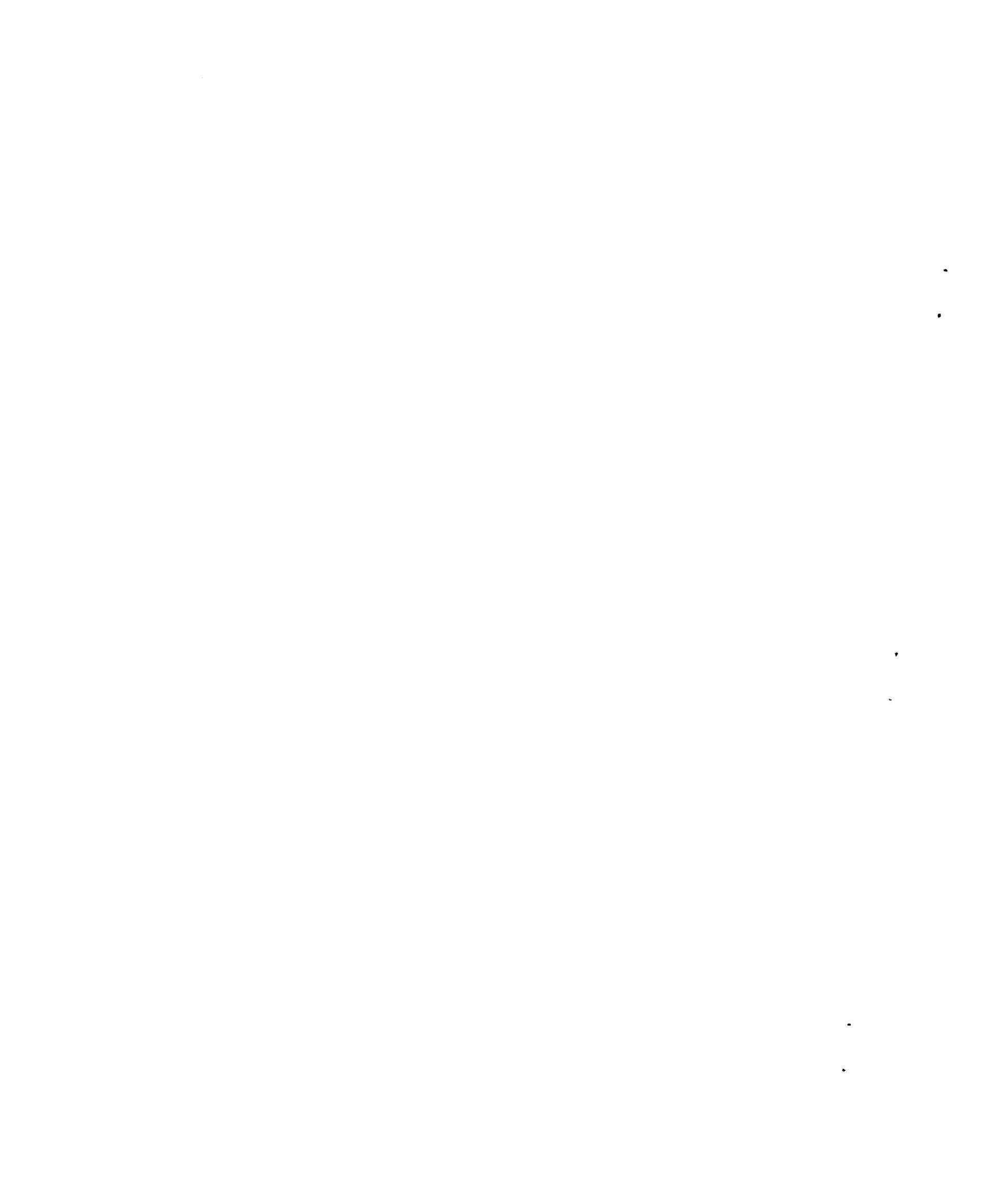
During the period July 1, 1972, through December 31, 1972, we recovered transuranium elements from three SRP Pu-Al tubes that had been irradiated at the Savannah River Plant (SRP) as a part of the Californium-I program to evaluate the commercial market for ^{252}Cf and to establish an inventory of material for sale. Products recovered are listed in Table 2.1 on p. 3. Also, 15 mg of ^{248}Cm and 1.0 μg of ^{254}Es , both of high isotopic purity, were recovered from materials previously processed. Thirty-six shipments were made from TRU during the period; recipients and the amounts of nuclides are listed in Table 2.2 on pp. 4 and 5. Thirteen HFIR targets, each containing 7 to 10 g of actinides (predominantly curium) were fabricated.

During the next 18 months, we expect to recover a total of 875 mg of ^{252}Cf : 300 mg from 24 TRU-HFIR targets, 500 mg from 30 SRP Cm-HFIR targets, and 75 mg from 3 SRP reactor tubes. Totals of 73 mg of ^{249}Bk and 4.0 mg of ^{253}Es are expected to be recovered from these targets and tubes. Also, we expect to obtain 1.8 g of ^{244}Pu , 50 mg of ^{248}Cm , and 1.8 μg of ^{254}Es from previously processed materials and from some materials for which processing is planned.

We made laboratory studies during this period to increase our knowledge of the behavior of impurities in the high-pressure ion exchange process during purification and encapsulation of californium products.

Three neutron sources were fabricated, bringing the total fabricated to 60.

In special projects, three ^{253}Es rabbits and one ^{257}Fm rabbit were encapsulated, irradiated, and shipped to ANL.



1. INTRODUCTION

This is the tenth report in a series that is being issued semiannually 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 definitely established only for the short term; long-range plans can be (and are) markedly influenced by feedback from researchers and other users of transuranium elements.

TRU operations during the report period are summarized. Quantities of materials that were recovered and shipped are specified, and proposed processing schedules and anticipated yields of various products are presented. Modifications to the equipment and processes used at TRU 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 have been loaned, are tabulated. Special projects, which utilized the facilities that are available at TRU, are 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.

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. Thus, we usually trace curium by the isotope ^{244}Cm . Except in special instances, ^{242}Pu , ^{243}Am , ^{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 when we do not stipulate "isotopically pure."

2.1 Processing Summary

During the period July 1, 1972, through December 31, 1972, chemical processing operations were suspended for about three months so that maintenance could be performed at TRU. Following the maintenance operations, one major campaign was made to recover the transuranium elements from three Pu-Al tubes that had been irradiated at the Savannah River Plant (SRP) as part of the Californium-I program to evaluate the commercial market for ^{252}Cf and to establish an inventory of material for sale. Products recovered are listed in Table 2.1.

Two special-interest isotopes, ^{248}Cm and ^{254}Es , were recovered from materials previously processed. The 92 mg of ^{252}Cf , which had been recovered from Californium-I material and stored for use as a "cow",¹ was "milked" in September 1972 and 15 mg of "isotopically pure" ^{248}Cm was obtained. Due to the presence of ^{250}Cf in the cow, the curium actually contained about 3% ^{246}Cm . The einsteinium product recovered from processing six SRP reactor tubes in TRU Campaigns 32 and 33² was stored until November 1972, approximately one year after the tubes had been discharged from the reactor; the ^{253}Es had decayed during that time and we recovered 1.0 μg of high-purity ^{254}Es .

Thirty-six shipments were made during this period; recipients and the amounts of nuclides are listed in Table 2.2. Seven of the shipments consisted of materials that had been previously shipped but had been returned for reirradiation, reprocessing, or reassignment.

Table 2.1. Amounts of Materials Recovered in the Major Campaign
in the Transuranium Processing Plant During the Period
July 1 1972, Through December 31, 1972

		Campaign 37
Completion date		December
Material processed		3 SRP Pu-Al Tubes
Amounts recovered		
^{242}Pu , g		3.05
^{243}Am , g ^a		1.96
^{244}Cm , g ^a		68.5
^{249}Bk , mg		8.5
^{252}Cf , mg		73.3
^{253}Es , μg ^b		None
^{257}Fm , pg		None

^aAmericium and curium are not usually separated from each other.

^bRecovery of about 1 μg of ^{254}Es is expected.

Thirteen HFIR targets were fabricated from actinide oxide formed by the resin loading--calcination technique³ and are now being irradiated in the HFIR. Isotopic distribution of the curium in the targets was within the range of 63 to 68% ^{244}Cm , 26 to 30% ^{246}Cm , and 2.0 to 2.5% ^{248}Cm . Each target contained 7 to 10 g of actinides, predominantly curium, in the form of actinide oxide-aluminum pellets that were pressed to 80% of theoretical density.

Table 2.2. Distribution of Heavy Elements from the
Transuranium Processing Plant During the Period
July 1, 1972 - December 31, 1972

Major Nuclide	Date	TRU File No.	Shipped To:	
			Individual	Site
Plutonium-242, g				
0.058	11-03-72	570	W. T. Carnall	ANL
Plutonium-244 (25%), g				
6.16	10-18-72	551	Isotopes Separation	ORNL
Curium-243 (55%), mg				
1.25	12-19-72	573	M. M. Abraham	ORNL
Curium-244, g				
48.82	9-13-72	562	T. B. Bowden	SRP
36.12	9-22-72	563	T. B. Bowden	SRP
48.01	10-02-72	564	T. B. Bowden	SRP
48.12	10-11-72	565	T. B. Bowden	SRP
<u>181.07</u>				
Curium-247 (30%), mg				
0.42	10-10-72	544	M. M. Abraham	ORNL
Curium-248 (97%), mg				
15.0	10-09-72	545	R. W. Benjamin	SRL
Berkelium-249, mg				
3.5	10-20-72	546	W. T. Carnall	ANL
1.75	10-20-72	547	J. R. Peterson	ORNL
0.65 ^a	10-20-72	533	L. B. Asprey	LASL
<u>5.25</u>				
Californium-249, mg (isotopically pure)				
1.97 ^a	10-24-72	533	L. B. Asprey	LASL
0.58	10-31-72	569	W. T. Carnall	ANL
<u>0.58</u>				

Table 2.2 (continued)

Table 2.2 (continued)

Major Nuclide	Date	TRU File No.	Shipped To:	
			Individual	Site
Californium-252, mg				
0.012	7-07-72	532	Isotopes Sales	ORNL
0.054 (NS-59)	7-21-72	521	J. D. Orndoff	LASL
0.021 (Special isotopic mixture)	8-02-72	567	C. E. Bemis	ORNL
0.00016	8-11-72	538	J. T. Mihalcz	Y-12
0.015	8-11-72	539	Isotopes Sales	ORNL
0.020 (NSD-60) ^b	8-15-72	555	F. F. Haywood	ORNL
34.71	8-28-72	560	A. R. Boulogne	SRL
0.006	9-07-72	540	Isotopes Sales	ORNL
0.071	9-26-72	548	J. A. Harris	LBL
13.32	9-26-72	549	R. W. Hoff	LLL
0.02	10-13-72	542	Isotopes Sales	ORNL
35.39	10-13-72	566	A. R. Boulogne	SRL
34.09	10-20-72	561	A. R. Boulogne	SRL
25.17	11-09-72	571	A. R. Boulogne	SRL
0.013	11-10-72	572	Isotopes Sales	ORNL
0.006	12-15-72	541	Isotopes Sales	ORNL
<u>142.89816</u>				
Einsteinium-253, µg				
12 (irradiated) ^c	7-11-72	534	H. Diamond	ANL
7 (irradiated) ^c	7-31-72	535	H. Diamond	ANL
Einsteinium-253, µg (isotopically pure)				
43	7-17-72	536	R. D. Baybarz	ORNL
<u>5 (irradiated)^d</u>	9-05-72	550	H. Diamond	ANL
Einsteinium-254, µg				
1.0	11-22-72	559	C. W. Reich	ANC
Fermium-257, pg				
0.05 (irradiated) ^e	10-17-72	568	R. K. Sjoblom	ANL

^aThis shipment consists of material returned from LASL for processing. It was not included in the total.

^bThis source had been previously shipped to another user. The current contents are shown but are not included in the total.

^cThis shipment consists of material previously shipped as No. 518; it was not included in the total.

^dThis shipment consists of material previously shipped as No. 536; it was not included in the total.

^eThis shipment consists of material previously shipped as No. 526; it was not included in the total.

2.2 Irradiation and Processing Proposals

The amounts of transcurium elements that will be produced at TRU during the next few years will depend on: (1) the needs of researchers for various isotopes, (2) the needs for ^{252}Cf in the Production and Materials Management (PMM) Divisions's market evaluation and sales program, and (3) the capabilities of the TRU-HFIR complex to produce the required materials. The processing schedule for the next 18 months can be predicted reasonably; thereafter, production rates will depend on the quality of curium available for irradiation in the HFIR. The long-term capability of the TRU-HFIR complex to produce transuranium elements was described in a previous report⁴ in this series.

The estimated future production of transcurium elements from a series of likely processing campaigns which are scheduled through June 1974 is outlined in Table 2.3. Only one group of 3 SRP reactor tubes is included in these campaigns; we do not plan to process any of the remaining 65 tubes. We have requested approval of a proposal to irradiate additional Californium-I curium in the HFIR to increase the amounts of materials available to researchers.

2.3 Estimates of the Availability of Transuranium Elements

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 discussed below. The usual estimates of the availability of the transcurium elements during the next 18 months are also given. The amounts of transcurium elements expected from each campaign are given in Table 2.3.

2.3.1 Plutonium

The plutonium recovered from the SRP reactor tubes has a high ^{244}Pu content (25%), and will be enriched to more than 99% in this isotope in the calutrons at the Y-12 Plant. Products from the 18 SRP tubes already processed and the 3 tubes that will be processed during early 1973 are expected

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 1972							285 ^b	
January-June 1973	3 SRP Cf-I Tubes	9	75 ^b	0 ^c	0			January 1973
	12 TRU-HFIR Targets	10	120	600(120)	0.6			February 1973
	10 SRP Cm-HFIR Targets	16	200	1000(200)	1.0	320	605	March 1973
July-December 1973	10 SRP Cm-HFIR Targets	12	150	750(150)	0.75			October 1973
	6 TRU-HFIR Targets	6	80	400(80)	0.4	230	835	November 1973
January-June 1974	10 SRP Cm-HFIR Targets	12	150	750(150)	0.75			February 1974
	6 TRU-HFIR Targets	8	100	500(100)	0.5	250	1085	June 1974
July-December 1974						200		
1975						400-825 ^d		

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

^bCalifornium produced in the SRP irradiations is not included in production totals. A total of 645 mg has been recovered from 164 SRP slugs and 18 SRP tubes processed through December 1972.

^c²⁵⁴Es (~1 μg) can be recovered.

^dThe lesser amount will be produced if feed curium is limited to current TRU stock plus Curium-II curium (95% ²⁴⁴Cm). The greater amount will be produced if Californium-I curium is used as feed for the HFIR.

to yield 0.9 g of ^{244}Pu (>99%) by mid-year and an additional 0.9 g by late 1973.

2.3.2 Curium

In accordance with an agreement between the Physical Research and PMM Divisions, we plan to maintain 90 to 100 mg of purified ^{252}Cf from Californium-I material for use as a "cow" which can be "milked" periodically to obtain "isotopically pure" ^{248}Cm . Additional amounts of ^{248}Cm will become available from other purified californium. We expect to obtain 25 mg of ^{248}Cm in August 1973 and an additional 25 mg in February 1974.

2.3.3 Berkelium

We find that the amount of ^{249}Bk produced in HFIR targets is about 8% of the ^{252}Cf production. Thus, we estimate that as much as 73 mg of ^{249}Bk could become available during the next 18 months.

2.3.4 Californium

We expect to produce 875 mg of ^{252}Cf during the next 18 months. As much as 75 mg could be recovered from 3 SRP reactor tubes, 500 mg from 30 SRP Cm-HFIR targets, and 300 mg from 24 TRU-HFIR targets.

2.3.5 Einsteinium

We expect to recover 4.0 mg of ^{253}Es in a mixture of einsteinium isotopes during the next 18 months. Also, some "second-growth" einsteinium will be recovered from the HFIR target campaigns. That is, after the mixture of einsteinium isotopes has been separated from the californium, the californium will be stored about 1 month to allow ^{253}Es to grow in from the decay of ^{253}Cf ; then, this isotopically pure ^{253}Es will be recovered. The amounts of both mixed einsteinium and isotopically pure ^{253}Es expected from each campaign are given in Table 2.3.

Einsteinium recovered from processing SRP reactor tubes contains a relatively small amount of ^{253}Es because of the long cooling time. However, high-purity ^{254}Es can be recovered if the ^{253}Es is allowed to decay for at

least 9 months after reactor discharge. During the spring of 1973, we expect to recover a total of 1.8 μg of ^{254}Es from three tubes that were processed previously (TRU Campaign 37) and from three tubes that will be processed in early 1973.

2.3.6 Fermium

The amount of ^{257}Fm recovered from the processing of HFIR targets is about 0.5 pg per 100 mg of ^{252}Cf recovered. Thus, we estimate that ~ 4.0 pg will become available during the next 18 months.

3. PROCESSES AND EQUIPMENT

The major effort of the maintenance program at TRU during this report period involved replacement of four key piping systems. Four of the six tubing bundles that connect processing equipment in the cubicles to tanks in the cell pits were replaced because many of the pipes had developed leaks or plugs during the heavy processing load of the previous three years. There was no replacement of major chemical process equipment.

The flowsheets used at TRU remain unchanged; however, laboratory studies were made this period to increase our knowledge of the behavior of impurities in the high-pressure ion exchange process during purification and encapsulation of californium products. Use of the high-pressure ion exchange process for the initial separation of the transcurium elements and use of a second cycle of the process to purify the californium, primarily from ^{244}Cm , have been described in previous reports.⁵⁻⁷ The goal of the current laboratory studies was to determine which impurities would contaminate the californium fraction, if, by some unforeseen circumstance, such impurities were present in the feed to the purification column. Gadolinium and neodymium were used in the studies as "markers" for californium and americium, respectively. Eight ionic impurities — Fe^{3+} , Al^{3+} , Cr^{3+} , Ni^{2+} , Mg^{2+} , Ca^{2+} , Ba^{2+} , and Pb^{2+} — were tested; of these, only Ca^{2+} was found to elute in the region of Cf^{3+} .

4. CALIFORNIUM NEUTRON SOURCES

Much 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. Those that are standard models, NSS (single encapsulation) and NSD (double encapsulation), are indicated in the table. A "standard" source is one which has been fabricated in the form shown in Fig. 4.1 of ref. 8 and has been catalogued by the AEC Directorate of Licensing. Thus far, only sources fabricated from type 304L stainless steel have been catalogued. The characteristics of standard sources are listed in Table 4.2 of ref. 8.

4.1 Sources Fabricated During July-December 1972

Three sources were fabricated during this report period. One of these, NSS-62, is a standard TRU source with a single encapsulation of type 304L stainless steel. Sources NS-54 and NS-59 were fabricated in nonstandard forms specified by the users. Also during this period, source NSS-60 was returned to TRU for a second encapsulation; the source, now designated as NSD-60, was reassigned to a new user.

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 available are also used for a variety of other purposes such as nonroutine productions, 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.

Table 4.1. Data for Neutron Sources Prepared at TRU

Source	Date of Calibration	^{252}Cf Content at Calibration (μg)	^{252}Cf Content as of 12-31-72 (μg)	^{248}Cm Content as of 12-31-72 (μg)	On Loan To:	
					Individual	Site
NS-1 ^a	8-28-68	316	101	b	K. L. Swinth	PNL
NS-2	8-23-68	254	81	b	J. E. Powell	Sandia-NM
NS-3	5-13-69	~90	~35	b	G. I. Gleason	ORAU
NS-4	7-09-69	883	355	504	C. F. Masters	LASL
NS-5 ^c	8-14-69	946	390	530	F. B. Simpson	ANC
NS-6	11-21-69	747	331	397	R. W. Hoff	LLL
NS-7	1-21-70	788	365	404	T. F. Handley	ORNL
NS-8	12-17-69	1839	830	962	H. Berger	ANL
NSD-9	4-17-70	1720	846	833	N. D. Wogman	PNL
NSS-10	3-11-70	113	54	b	J. P. Balagna	LASL
NS-11	3-10-70	8	4	b	R. R. Fullwood	LASL
NSS-12	6-30-70	1868	969	857	R. W. Hoff	LLL
NSD-13	3-19-71	4649	2910	1658	H. O. Menlove	LASL
NSS-14	6-29-70	4615	2393	2119	D. C. Stewart	ANL
NS-15 ^c	6-25-70	931	481	429	F. B. Simpson	ANC
NSD-16	10-08-70	1657	924	699	R. Yoshimura	Sandia-NM
NSS-17	8-31-71	4886	3443	1376	L. W. Dahlke	Sandia-Liv.
NS-18 ^c	6-24-70	962	497	443	F. B. Simpson	ANC
NSS-19	6-26-70	493	255	227	J. E. Bigelow	ORNL-TRU
NSD-20	7-01-70	630	327	289	J. E. Bigelow	ORNL-TRU
NSS-21	10-21-70	18	10	b	F. Cross	PNL
NS-22	9-10-70	13	7	b	J. E. Bigelow	ORNL-TRU
NSD-24	10-15-70	8	5	b	J. B. Davidson	ORNL
NS-25	11-09-70	58	32	b	F. J. Muckenthaler	ORNL
NSD-26	2-11-71	14	9	b	H. O. Menlove	LASL
NSD-27	1-29-71	2467	1491	931	J. E. Powell	Sandia-NM
NSD-28	2-12-71	11	7	b	E. E. Hicks	Rocky Flats
NSD-29	9-10-71	11393	8086	3153	J. D. White	Y-12
NSD-30	3-31-71	879	555	309	F. F. Haywood	ORNL
NZD-31	11-23-71	1756	1314	421	C. N. Jackson, Jr.	WADCO
NZD-32	11-23-71	1800	1347	432	C. N. Jackson, Jr.	WADCO
NZD-33	11-23-71	1888	1413	453	C. N. Jackson, Jr.	WADCO
NZD-34	11-23-71	1924	1440	462	C. N. Jackson, Jr.	WADCO
NZD-35	11-23-71	1904	1425	457	C. N. Jackson, Jr.	WADCO
NS-36 ^c	3-23-71	2070	1300	735	F. B. Simpson	ANC
NSD-37	9-04-71	9838	6953	2751	R. W. Perkins	PNL
NSD-38	6-16-71	102	68	b	H. O. Menlove	LASL
NS-39	11-07-71	942	697	234	V. Spiegel	NBS
NSD-40	4-27-72	1161	971	180	E. B. Darden	ORNL-Biology

Table 4.1 (continued)

Source	Date of Calibration	^{252}Cf Content at Calibration (μg)	^{252}Cf Content as of 12-31-72 (μg)	^{248}Cm Content as of 12-31-72 (μg)	On Loan To:	
					Individual	Site
NSD-41	11-08-71	5117	3789	1266	C. J. Emert	BAPL
NSD-42	11-02-71	4434	3269	1111	C. J. Emert	BAPL
NSD-43	4-20-72	4839	4031	771	C. J. Emert	BAPL
NZD-44	5-15-72	10731	9099	1556	F. B. Simpson	ANC
NSD-45	8-18-71	1776	1240	511	K. L. Swinth	PNL
NSD-46	4-23-72	629	525	99	H. O. Menlove	LASL
NSD-47	7-14-71	200	136	61	P. L. Johnson	Mound
NSD-48	7-14-71	194	132	59	P. L. Johnson	Mound
NSD-49	7-14-71	199	135	61	P. L. Johnson	Mound
NS-50	8-23-71	138	97	39	S. G. Carpenter	ANL-NRTS
NSD-51	11-02-71	365	269	91	L. C. Nelson, Jr.	New Brunswick
NSD-52	9-02-71	280	198	79	E. D. Clayton	PNL
NSD-53	10-25-71	1051	770	268	L. J. Esch	KAPL
NS-54	12-14-72	3265	3225	38	J. E. Bigelow	ORNL
NSD-55	4-19-72	4	3	b	L. J. Esch	KAPL
NSD-56	4-19-72	121	101	19	L. J. Esch	KAPL
NSD-57	4-14-72	973	807	158	J. E. Bigelow	ORNL-TRU
NZD-58	5-15-72	11003	9330	1596	F. B. Simpson	ANC
NS-59	7-13-72	53	47	b	J. T. Mihalcz	Y-12
NSD-60	4-11-72	20	17	b	J. S. Cheka	ORNL
SR-Cf-167 ^d	5-26-71	3975	2613	1299	G. I. Gleason	OAU

^aThis source is encapsulated in aluminum.

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

^cThis source is encapsulated in type 405 stainless steel.

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

5.1 Rabbits Containing ^{253}Es

Three rabbits containing isotopically pure ^{253}Es were encapsulated, irradiated, and sent to H. Diamond at Argonne National Laboratory. These rabbits were used in studying the energy-level structure of ^{250}Bk , α decay product of $^{254\text{m}}\text{Es}$, with a branching ratio of 0.33%.

5.2 Rabbit Containing ^{257}Fm

A quartz ampul prepared at Argonne National Laboratory, which contained 0.05 pg of ^{257}Fm (approximately 1×10^8 atoms), was encapsulated in aluminum, irradiated for 3 hr in the HFIR, and then sent to R. Sjoblom at ANL. The purpose of this experiment was to confirm, by radiochemical techniques, some of the ^{257}Fm fission product yields that have already been measured instrumentally.

6. REFERENCES

1. 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, 1972, ORNL-4833, p. 9.
2. Ibid., p. 3.
3. W. D. Burch, J. E. Bigelow, and L. J. King, Transuranium Processing Plant Semiannual Report of Production, Status, and Plans for Period Ending December 31, 1971, ORNL-4767, pp. 13-14.
4. Ibid., pp. 8-11.
5. W. D. Burch, J. E. Bigelow, and L. J. King, Transuranium Processing Plant Semiannual Report of Production, Status, and Plans for Period Ending June 30, 1968, ORNL-4376, pp. 25-27.
6. King, Bigelow, and Collins, op. cit., p. 13.
7. R. D. Baybarz, J. B. Knauer, and P. B. Orr, Final Isolation and Purification of the Transplutonium Elements from the Twelve Campaigns Conducted at TRU During the Period August 1967-December 1971, ORNL-4672 (April 1973).
8. W. D. Burch, J. E. Bigelow, and L. J. King, Transuranium Processing Plant Semiannual Report of Production, Status, and Plans for Period Ending June 30, 1971, ORNL-4718, pp. 13-14.
9. C. M. Lederer, J. M. Hollander, and I. Pearlman, Table of Isotopes, 6th ed., Wiley, New York, 1967.
10. A. H. Wapstra, "Actinide Fingerprints," Actinides Rev. 1, 39-53 (1967).

7. APPENDIX

We have tabulated the decay data and the cross-section data that we use in planning irradiation-processing cycles, calculating production forecasts, and assaying products. The tables will be reproduced completely in each of these semiannual reports, and changes made since the preceding report will be indicated. We wish to state clearly that these data merely represent numbers being used in our calculations and that the data are presented on a "best efforts" basis. Although the information is intended to be definitive, it has not been checked and cross-checked sufficiently to be considered "publishable."

The Transplutonium Element Production Program is now making nuclides available in increasing abundance and purity; therefore, in the next few years, we anticipate a burgeoning literature concerning nuclear constants for the transuranium nuclides. However, since we need such data at the present time, it will not be feasible for us to wait until highly reliable sources, such as Lederer⁹ and Wapstra,¹⁰ can publish data that have been fully evaluated.

We welcome telephone calls to point out errors or indicate additional sources of information. Please contact John Bigelow, FTS 615-483-1872 or, by commercial telephone service, 615-483-8611, ext. 3-1872.

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/ β = 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					67Or02
²⁴⁷ Am	24 \pm 3 m					67Or02
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
²⁴⁹ Bk	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
²⁵⁰ Bk	3.222 \pm 0.005 h					59Va02
²⁵¹ Bk	57 \pm 1.7 m					66RG04
²⁴⁹ Cf		352 \pm 6 y	$\alpha/\text{SF} = (1.992 \pm 0.040) \times 10^8$		3.44 ^d	69Me01, 69Mi08
²⁵⁰ Cf		13.08 \pm 0.09 y	$\alpha/\text{SF} = 1260 \pm 40$		3.56 ^d	63Ph01, 69Me01
²⁵¹ Cf		900 \pm 50 y				69Me01
²⁵² Cf	2.646 \pm 0.004 y		$\alpha/\text{SF} = 31.3 \pm 0.2$		3.796 \pm 0.031	65Me02, 68Wh04
²⁵³ Cf	17.812 \pm 0.082 d		$\alpha/\beta = (3.1 \pm 0.4) \times 10^{-3}$			69Dr02, 66RG01
²⁵⁴ Cf	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
²⁵⁵ Cf	1.5 \pm 0.5 h					70Lo19
²⁵³ Es	20.467 \pm 0.024 d		$\alpha/\text{SF} = (1.15 \pm 0.03) \times 10^7$		3.92 ^d	65Me02, 69Dr02
²⁵⁴ Es	276 d			$>2.5 \times 10^7$ y	4.04 ^d	67Fi03, 67Un01
^{254m} Es	39.3 \pm 0.2 h		$\beta/\alpha = 382 \pm 30$ E.C./ $\beta = 0.00078 \pm 0.00006$			62Un01, 63Ph01
²⁵⁵ Es	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
²⁵⁶ Es	25 \pm 3 m					68Lo11
²⁵⁴ Fm	3.24 \pm 0.01 h		$\alpha/\text{SF} = 1695 \pm 8$		4.05 \pm 0.19	56Jo09, 67Fi03, 56Ch83
²⁵⁵ Fm	20.07 \pm 0.07 h		$\text{SF}/\alpha = (2.4 \pm 1.1) \times 10^{-7}$		4.16 ^d	63Ph01, 64As01
²⁵⁶ Fm	2.62 \pm 0.03 h		$\sim 100\%$ SF		4.27 ^d	68Ho13
²⁵⁷ Fm	94 \pm 10 d					66RG01
²⁵⁸ Fm	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 by the Nuclear Data Project here at ORNL in their widely distributed "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:

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

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
48Hyb1	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	M. 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. Tunnicliffe, <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).
54Gh24	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. E. 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. Sjoblom, 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).	670e01	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).	670r02	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. Sjoblom, 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. Sjoblom, and P. R. Fields, <i>Phys. Rev.</i> , 115 , 115-121 (1959).	68Lo11	R. W. Lougheed, 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. Perehygin, 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. Lougheed, 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. Lougheed, 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				Hazard ^b			
		α	β	(Ci/g)	(W/g)	(α cpm/mg ^c)	(β dpm/mg)	(Neutrons min ⁻¹ mg ⁻¹)	MPC _a (40) (μ Ci/cm ³)	Body Burden (μ Ci) (μ g)	
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	1.1	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 ⁹			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) (μCi/cm ³)	Body Burden (μCi) (μg)	
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		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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