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TRANSURANIUM PROCESSING PLANT
SEMIANNUAL REPORT OF PRODUCTION,
STATUS, AND PLANS FOR
PERIOD ENDING JUNE 30, 1972

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



OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION • FOR THE U.S. ATOMIC ENERGY COMMISSION

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

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SUMMARY

This is the ninth 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.

During the period January 1, 1972, through June 30, 1972, we recovered transuranium elements from 19 irradiated HFIR targets and from 6 reactor 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. We purified 200 g of Californium-I curium and converted it to oxide for use in HFIR targets. We also purified 170 g of Californium-I curium and converted it to oxide for shipment to SRP. In addition, we combined the plutonium recovered from processing 15 SRP reactor tubes, then purified the resulting product, converted it to oxide, and packaged oxide containing 24 g of plutonium (25% ^{244}Pu) for shipment to the Y-12 Plant to be enriched in the calutrons to more than 99% ^{244}Pu . We made 66 shipments from TRU during the period; recipients and the amounts of nuclides are listed in Table 2.2 on p. 4. Thirteen HFIR targets, each containing approximately 10 g of actinide metal, were fabricated. Eleven of these targets were prepared from Californium-I curium (30% ^{246}Cm).

During the next 18 months, we expect to recover 260 mg of ^{252}Cf from the processing of 18 TRU-HFIR targets, and 580 mg of ^{252}Cf from the processing of 5 SRP reactor tubes and 30 SRP Cm-HFIR targets. A total of 69 mg of ^{249}Bk and 3.6 mg of ^{253}Es could be recovered from these campaigns. Also, we expect to obtain 2 g of ^{244}Pu , 30 mg of ^{248}Cm , and 2.5 μg of ^{254}Es from previously processed materials and from some materials for which processing is planned.

We compared the processing steps used for SRP reactor tubes with those used for HFIR targets. Fewer steps are required for HFIR targets because (1) there is no valuable plutonium to be recovered, and (2) less decontamination of curium from both radiochemical and chemical impurities is necessary. Some of the products recovered from the tubes are different from those recovered from HFIR targets; thus, there are corresponding differences in the

product purification steps required. During the processing of the SRP tubes, the presence of excessive aluminum in the process solutions caused difficulties; however, this problem was eliminated by using a feed pretreatment step for the LiCl-based anion exchange.

Nine neutron sources were fabricated during this period, bringing the total fabricated to date to 57.

The facilities that can be used for special projects are described. These facilities include the target fabrication cells and the laboratory hot-cell caves at TRU, cubicle 3 of the TURF Californium Facility, an alpha-contained glove-box facility at TURF, and a source decontamination facility at TRU.

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 ninth 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. Facilities for special processing, fabrication, and irradiation programs 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. 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.

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 January 1, 1972, through June 30, 1972, we recovered transuranium elements from 19 irradiated HFIR targets and from 6 reactor 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. Four major campaigns were made: two to process the 6 SRP reactor tubes, and two to process the HFIR targets. Products recovered are listed in Table 2.1.

A fifth campaign was made to purify and convert 200 g of Californium-I curium to the oxide form for use in HFIR targets. In a sixth campaign, we purified, converted to oxide, and packaged for shipment to SRP, 170 g of curium that had been recovered previously from the processing of 164 SRP reactor slugs.^{1,2}

The plutonium recovered from the six SRP reactor tubes processed during this report period was combined with the plutonium recovered from nine tubes which had been processed previously,³ and the composited material was then purified; subsequently, 24 g of plutonium (25% ^{244}Pu) was converted to oxide and prepared for shipment to the Y-12 Plant to be enriched in the calutrons to more than 99% ^{244}Pu .

Sixty-six shipments were made during this period; recipients and the amounts of nuclides are listed in Table 2.2. Ten of the shipments (all of the ^{245}Cm , ^{246}Cm , ^{247}Cm , and ^{248}Cm ; ^{252}Cf neutron sources NSS-19, NSD-20, and NSD-30; and one shipment of ^{253}Es) were transshipments of materials previously shipped.

Table 2.1. Amounts of Materials Recovered in Major Campaigns in the Transuranium Processing Plant
During the Period January 1, 1972, Through June 30, 1972

	Campaign No.				Total	
	31	32	33	35	HFIR-TRU	SRP
Completion date	February	March	April	June		
Material processed	9 TRU-HFIR Cm targets	3 SRP Pu-Al tubes	3 SRP Pu-Al tubes	10 TRU-HFIR Cm targets		
Amounts recovered						
^{242}Pu , g	None	2.8	3.2	None	None	6.0
^{243}Am , g ^a	0.3	1.2	1.3	0.3	0.6	2.5
^{244}Cm , g ^a	16.5	56	69	28.1	44.6	125
^{249}Bk , mg	9.6	7.8	13.6	7.9	17.5	21.4
^{252}Cf , mg	83	66	88	66	149	154
^{253}Es , μg	467	27	18	312	779	45
^{257}Fm , atoms ^b	1×10^9	3×10^7	3×10^7	6×10^8	1.6×10^9	6×10^7

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

^bEstimated.

Table 2.2. Distribution of Heavy Elements from the Transuranium Processing Plant During the Period January 1 – June 30, 1972

Major Nuclide	Date	TRU File No.	Shipped To	
			Individual	Site
Americium-243, g				
12 ^a	1-04-72	398	F. J. Zellely	PNL
<u>200^a</u>	1-07-72	-	R. A. Penneman	LASL
212				
Curium-243, µg				
0.02 ^a	2-08-72	471	I. M. Fisenne	HASL
Curium-244, g				
91.16	6-16-72	529	T. B. Bowden	SRP
Curium-245, mg				
0.05	1-04-72	467	K. F. Flynn	ANL
<u>1.64</u>	4-04-72	469	R. W. Hoff	LLL
1.69				
Curium-246, mg				
0.3	1-04-72	468	C. E. Bemis	ORNL-TRL
<u>0.012^b</u>	5-23-72	511	D. M. Barton	LASL
0.3				
Curium-247, mg				
0.075	4-04-72	470	R. W. Hoff	LLL
Curium-248 (97%), mg				
2.01 ^c	1-25-72	501	R. W. Hoff	LLL
Berkelium-249, mg				
3.18	2-01-72	412	J. A. Harris	LBL
5.30	2-01-72	413	R. W. Hoff	LLL
5.30	2-01-72	414	P. R. Fields	ANL
5.30	2-01-72	417	R. D. Baybarz	ORNL
0.035	2-04-72	476	J. P. Herring	PNL
3.5	5-12-72	416	M. A. Wakat	SRL
8.5	5-23-72	481	M. M. Abraham	ORNL
2.1	5-26-72	415	R. A. Penneman	LASL
8.5	5-26-72	479	W. T. Carnall	ANL

Table 2.2 (continued)

Major Nuclide	Date	TRU File No.	Shipped To	
			Individual	Site
Berkelium-249, mg (continued)				
5.0	5-26-72	480	R. W. Hoff	LLL
0.02	5-26-72	512	F. J. Zelle	PNL
<u>46.735</u>				
Californium-249 (isotopically pure), mg				
1.0	1-04-72	418	R. A. Penneman	LASL
1.05	5-31-72	517	R. G. Haire	ORNL
0.37	6-02-72	513	W. T. Carnall	ANL
0.32	6-02-72	514	J. A. Harris	LBL
0.37	6-02-72	515	R. W. Hoff	LLL
1.05	6-02-72	516	R. A. Penneman	LASL
<u>4.16</u>				
Californium-252, mg				
0.010	1-31-72	502	Isotopes Sales	ORNL
0.018	2-07-72	506	Isotopes Sales	ORNL
28.70	2-11-72	503	A. R. Boulogne	SRL
27.77	4-03-72	507	A. R. Boulogne	SRL
0.0042 (NSD-55)	4-27-72	500	L. J. Esch	KAPL
0.119 (NSD-56)	4-27-72	500	L. J. Esch	KAPL
4.77 (NSD-43)	4-27-72	505	C. J. Emert	BAPL
0.619 (NSD-46)	4-28-72	442	H. O. Menlove	LASL
1.14 (NSD-40)	5-05-72	396	E. B. Darden	ORNL-Biology
0.643 (NSD-30) ^d	5-10-72	510	F. F. Haywood	ORNL-DOSAR
10.57 (NZD-44)	5-15-72	440	F. B. Simpson	ANL
10.84 (NZD-58)	5-15-72	440	F. B. Simpson	ANL
1.04	5-15-72	497	R. W. Hoff	LLL
33.65	5-23-72	509	A. R. Boulogne	SRL
0.295 (NSS-19) ^d	5-23-72	509	A. R. Boulogne	SRL
0.382 (NSD-20) ^d	5-23-72	509	A. R. Boulogne	SRL
0.012	6-06-72	522	Isotopes Sales	ORNL
0.020 (NSS-60)	6-08-72	523	J. S. Cheka	ORNL
0.012	6-22-72	528	Isotopes Sales	ORNL
37.98	6-27-72	530	A. R. Boulogne	SRL
<u>157.2742</u>				
Einsteinium-253, µg				
184	2-15-72	484	R. D. Baybarz	ORNL
71	2-18-72	482	P. R. Fields	ANL
118	2-18-72	483	R. W. Hoff	LLL

Table 2.2 (continued)

Major Nuclide	Date	TRU File No.	Shipped To	
			Individual	Site
Einsteinium-253, μg (continued)				
12	2-18-72	485	J. P. Herring	PNL
50 ^e	2-23-72	486	M. A. Wakat	SRL
5	4-06-72	508	R. D. Baybarz	ORNL
152	6-09-72	518	W. T. Carnall	ANL
85	6-09-72	519	R. W. Hoff	LLL
40	6-13-72	520	R. D. Baybarz	ORNL
<u>667</u>				
Einsteinium-253 (isotopically pure), μg				
71	3-27-72	487	P. R. Fields	ANL
3	3-27-72	488	J. A. Harris	LBL
<u>74</u>				
Einsteinium-254, μg				
0.081	1-18-72	489	P. R. Fields	ANL
0.081	1-18-72	490	J. A. Harris	LBL
0.081	1-18-72	491	R. W. Hoff	LLL
1.5	6-20-72	496	R. W. Hoff	LLL
0.17	6-20-72	527	W. T. Carnall	ANL
<u>1.913</u>				
Fermium-257, atoms				
$\sim 1 \times 10^9$	3-16-72	492	D. C. Hoffman	LASL
$\sim 1 \times 10^8$	6-16-72	525	J. A. Harris	LBL
$\sim 3 \times 10^8$	6-16-72	526	W. T. Carnall	ANL
<u>$\sim 1.4 \times 10^9$</u>				

^aThese shipments were prepared by the ORNL Isotopes Division.

^bThis shipment contained material previously shipped as No. 468; it was not included in the total.

^cThis shipment contained material previously shipped as No. 404; it was not included in the total.

^dThese sources had been previously shipped to other users. The current contents are shown but are not included in the total.

^eThis shipment contained material previously shipped as No. 484; it was not included in the total.

Thirteen HFIR targets were fabricated using actinide oxide formed by the resin loading--calcination technique,³ and are now being irradiated in the HFIR. Each target contained approximately 10 g of actinide metal in the form of actinide oxide--aluminum pellets that were pressed to 80% of the theoretical density of the pellet core. Eleven of the targets were prepared from Californium-I curium (approximately 30% ²⁴⁶Cm). Of the two targets prepared from TRU curium, one contained 10 g of curium (33% ²⁴⁶Cm) and the other contained 0.5 g of ²⁴⁰Pu--²⁴³Am and 9 g of curium (21% ²⁴⁶Cm).

2.2 Irradiation and Processing Proposals

The amounts of transcurium elements that will be produced at TRU during the next few years will depend upon: (1) the needs of researchers for various isotopes, (2) the needs for ²⁵²Cf in the Production and Materials Management (PMM) Division'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 the previous report³ in this series.

The estimated future production of transcurium elements from a series of likely processing campaigns which are scheduled through December 1973 is outlined in Table 2.3. Two groups of TRU-HFIR targets will be processed. Also, we have firm plans to process five SRP reactor tubes during the fall of 1972, and two groups of ten curium targets, prepared from Californium-I material and irradiated in the HFIR, during the spring of 1973. We do not plan to process any of the remaining 66 SRP reactor tubes. We have requested approval of a proposal to irradiate an additional 100 g of Californium-I curium in the HFIR to increase the amounts of materials available to researchers. Irradiation of this quantity of curium would produce 12 mg of ²⁴⁹Bk, 150 mg of ²⁵²Cf, 750 μg of ²⁵³Es in mixed einsteinium isotopes, and 150 μg of isotopically pure ²⁵³Es. Products from this proposed irradiation would become available in December 1973.

Table 2.3. Estimated Future Production of Transcurium Elements

Period	Processing Campaign	Products of Campaigns			252Cf Production ^b		Date Products Available
		249Bk (mg)	252Cf (mg)	253Es ^a (μg)	During the Period (mg)	Cumul. (mg)	
Through June 1972						285 ^b	
July-December 1972	5 SRP Cf-I tubes	12	120 ^b	0 ^c	0	285	December 1972
January-June 1973	12 TRU-HFIR targets	14	180	900(180)			February 1973
	10 SRP Cm-HFIR targets	13	160	800(160)			March 1973
	10 SRP Cm-HFIR targets	12	150	750(150)	490	775	May 1973
July-December 1973	6 TRU-HFIR targets	6	80	400(80)			August 1973
	10 SRP Cm-HFIR targets	12	150	750(150)	230	1005	December 1973
1974						300-750 ^d	
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 570 mg has been recovered from 164 SRP slugs and 15 SRP tubes processed through June 1972.

^c254Es (~1.0 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 higher amount will be produced if Californium-I curium is used as feed for the HFIR.

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.

2.3.1 Plutonium

The plutonium recovered from the processing of 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 15 SRP tubes already processed and the 5 tubes that will be processed during the fall of 1972 are expected to yield 0.6 g of ^{244}Pu (>99%) by December 1972, plus additional 0.6-g quantities during each half of 1973.

2.3.2 Curium

In accordance with an agreement between the Physical Research and PMM Divisions, we purified and stored 92 mg of ^{252}Cf from Californium-I material in February 1972 for use as a "cow" from which isotopically pure ^{248}Cm can be "milked." We plan to maintain the ^{252}Cf content at 90 to 100 mg so that about 10 mg of ^{248}Cm will be available every six months. During September 1972, we expect to obtain 12 to 15 mg of ^{248}Cm from the "cow" and from other purified californium which will be available for "milking" at that time.

2.3.3 Berkelium

We find that the amount of ^{249}Bk produced in HFIR targets is about 8% of the ^{252}Cf production (instead of 10% as was previously estimated). On this basis, as much as 69 mg of ^{249}Bk could become available during the next 18 months. Incremental amounts are listed in Table 2.3.

2.3.4 Californium

We could produce up to 840 mg of ^{252}Cf during the next 18 months. As much as 580 mg could be recovered from Californium-I materials; about 260 mg can be recovered from TRU-HFIR targets. The amount expected from each campaign is given in Table 2.3.

2.3.5 Einsteinium

We could recover 3.6 mg of ^{253}Es in a mixture of einsteinium isotopes during the next 18 months. Also, some "second-growth" einsteinium can 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 second-growth ^{253}Es , which will be isotopically pure, will be recovered. The amounts of both mixed einsteinium and isotopically pure ^{253}Es expected from each campaign are given in Table 2.3.

The 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 about 9 months after reactor discharge. We expect to recover 1.5 μg of ^{254}Es during the last half of 1972 from six tubes that were processed previously, plus 1 μg during the first half of 1973 from five tubes that will be processed in the fall of 1972.

2.3.6 Fermium

We find that the amount of ^{257}Fm recovered from the processing of HFIR targets is about 1.0×10^7 atoms of ^{257}Fm per milligram of ^{252}Cf recovered (instead of 1.5×10^7 atoms as previously estimated). On this basis, about 7×10^9 atoms could become available during the next 18 months: 1.8×10^9 atoms in February 1973 from 12 TRU-HFIR targets, 1.6×10^9 atoms in March 1973 from 10 SRP Cm-HFIR targets, 1.5×10^9 atoms in May 1973 from 10 SRP Cm-HFIR targets, 8×10^8 atoms in August 1973 from 6 TRU-HFIR targets, and 1.5×10^9 atoms in December 1973 from 10 SRP Cm-HFIR targets.

3. PROCESSES AND EQUIPMENT

Figure 3.1 compares the steps used in processing SRP reactor tubes with those used in processing HFIR targets. These steps have been used and described previously. Fewer steps are required for HFIR targets because: (1) there is no valuable plutonium to be recovered from the Pubex extract, and (2) the extra decontamination of curium from fission products, obtained in the Tramex batch extraction, is not needed. The specifications for material suitable for fabrication of HFIR targets and irradiation in HFIR are less stringent with regard to radiochemical and chemical impurities.

Some of the steps required in the purification of products recovered from SRP tubes (Fig. 3.2) are different from those used for purifying products from HFIR targets (Fig. 3.3). The tubes contain valuable plutonium, which must be decontaminated from radiochemical impurities so that it can be enriched in ^{244}Pu in the calutrons at the Y-12 Plant. Very little fermium and ^{253}Es are found in the tubes because of the long cooling time; however, high-purity ^{254}Es can be recovered if the ^{253}Es is allowed to decay for about 9 months after reactor discharge. When the curium is to be returned to SRP for reirradiation, curium oxide is produced by calcining curium oxalate; but, when the curium is to be reirradiated in HFIR, curium oxide microspheres are prepared by the resin loading--calcination technique.³

Some new equipment and procedures, which are necessary for processing the tubes, were described in the previous report in this series;³ some of the major problems initially encountered were also discussed. One of the problems stemmed from aluminum that was present in the acidic dissolver solutions. The aluminum caused various difficulties in all of the succeeding process steps; the most troublesome of these was the precipitation of aluminum from feed solution for the LiCl-based anion exchange step. We eliminated this problem by using a pretreatment step in which a small volume of adjusted feed solution (12 M LiCl--0.1 M HCl) was prepared, filtered to remove insoluble material (primarily aluminum but also including other insolubles such as

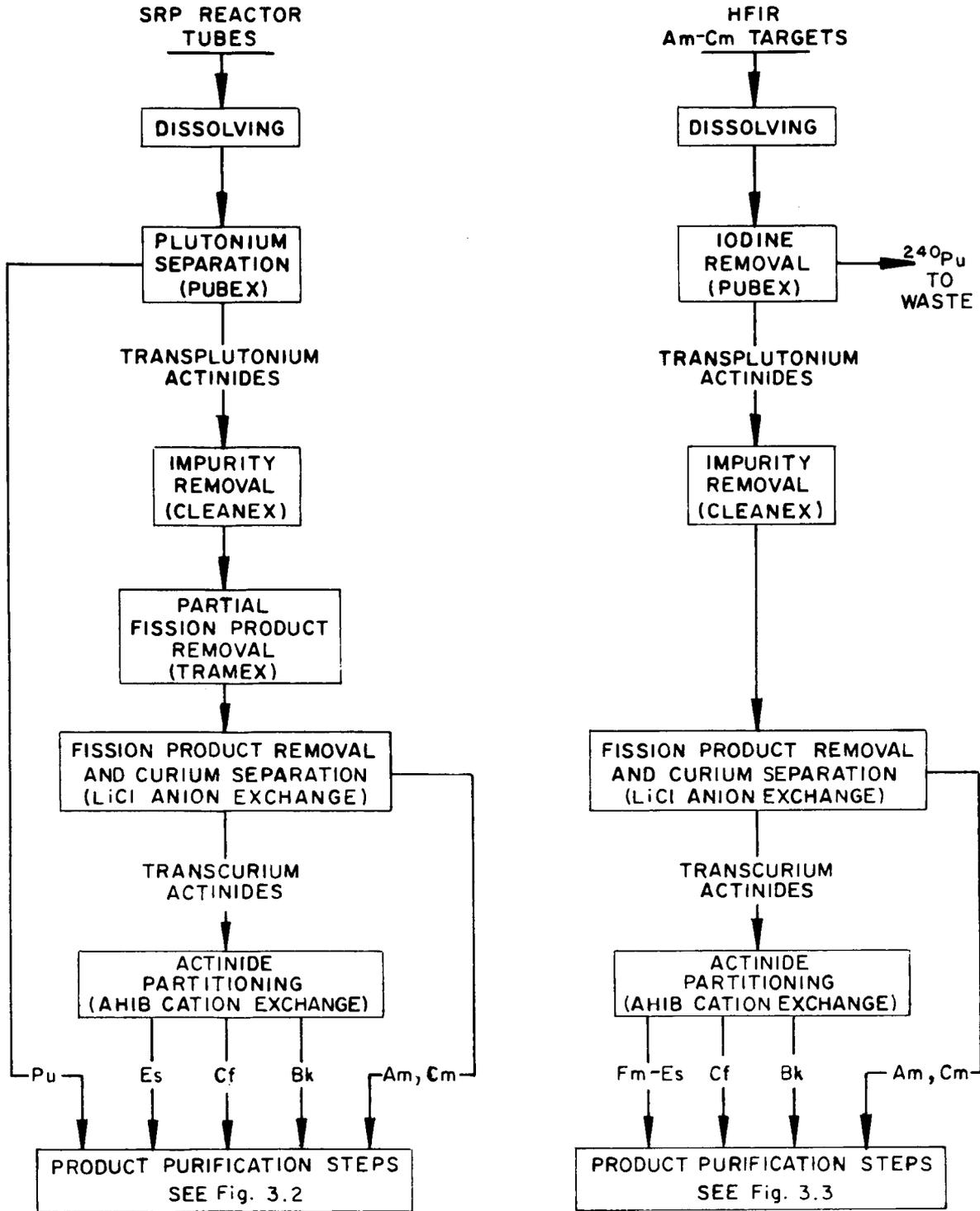


Fig. 3.1. Processing Steps Used for Transuranium Element Production.

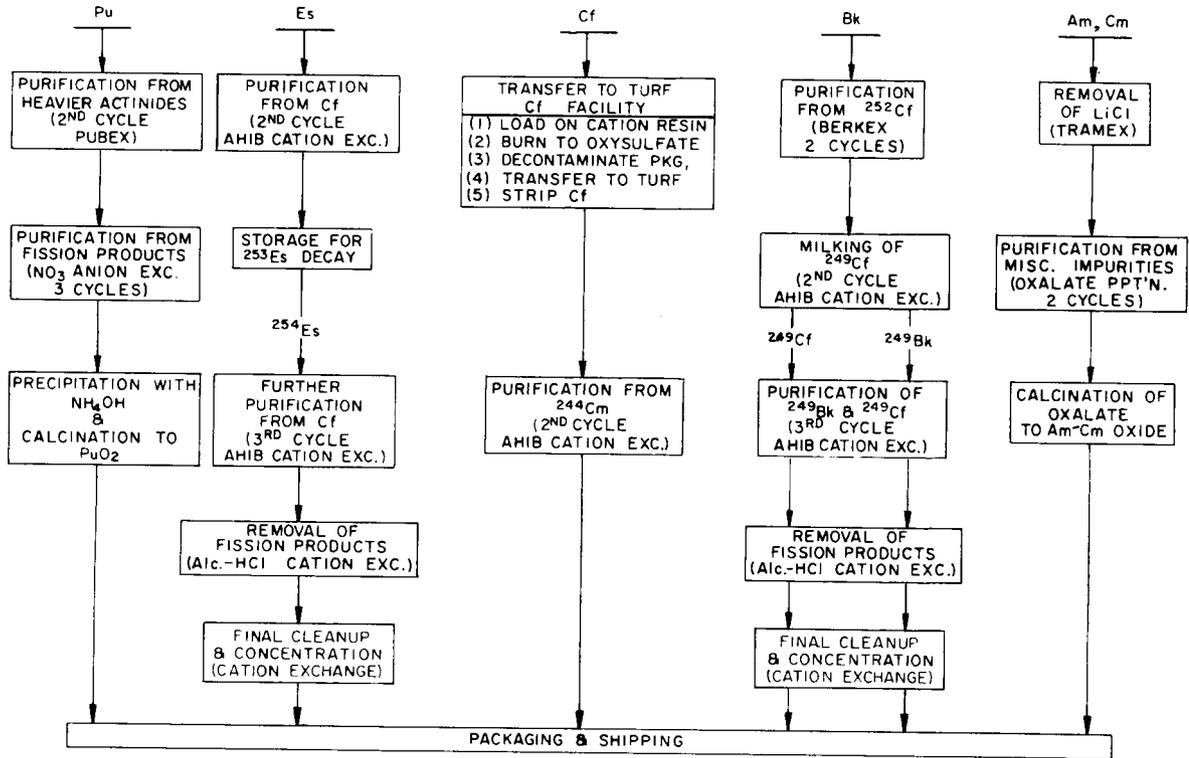


Fig. 3.2. Purification of Products Recovered from SRP Reactor Tubes.

sodium and zirconium), and finally diluted to a larger volume of 12 M LiCl to ensure complete solubility of the remaining impurities.

4. NEUTRON SOURCES

Much of the californium recovered at TRU is incorporated into 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 (singly encapsulated) and NSD (doubly encapsulated), are indicated in the table. A "standard" source is one which has been fabricated in the form shown in Fig. 4.1 of ref. 2 and has been cataloged by the AEC Division of Materials Licensing. Thus far, only sources fabricated from type 304L stainless steel have been cataloged. The characteristics of standard sources are listed in Table 4.2 of ref. 2.

4.1 Sources Fabricated During January-June 1972

Nine sources were fabricated during this report period. Six of these, NSD-40, -43, -46, -55, -56, and -57 are standard TRU sources doubly encapsulated in type 304L stainless steel. One, NSS-60, is only singly encapsulated. Sources NZD-44 and -58 were fabricated in standard TRU form but are doubly encapsulated in Zircaloy-2.

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 6-30-72 (μg)	^{248}Cm Content as of 6-30-72 (μg)	On Loan To	
					Individual	Site
NS-1 ^a	8-28-68	311	114	b	K. L. Swinth	PNL
NS-2	8-23-68	250	91	b	J. E. Powell	Sandia-NM
NS-3	5-13-69	~90	~40	b	H. W. Dickson	ORAU
NS-4	7-09-69	870	399	449	C. F. Masters	LASL
NS-5 ^c	8-14-69	932	439	470	F. B. Simpson	ANC
NS-6	11-21-69	736	372	347	R. W. Hoff	LLL
NS-7	1-21-70	776	410	349	T. F. Handley	ORNL
NS-8	12-17-69	1811	932	838	H. Berger	ANL
NSD-9	4-17-70	1694	951	709	N. D. Wogman	PNL
NSS-10	3-11-70	111	61	b	J. P. Balagna	LASL
NS-11	3-10-70	8	4	b	R. R. Fullwood	LASL
NSS-12	6-30-70	1840	1089	716	R. W. Hoff	LLL
NSD-13	3-19-71	4578	3270	1247	H. O. Menlove	LASL
NSS-14	6-29-70	4545	2689	1770	D. C. Stewart	ANL
NS-15 ^c	6-25-70	917	541	359	F. B. Simpson	ANC
NSD-16	10-08-70	1632	1038	566	R. Yoshimura	Sandia-NM
NSS-17	8-31-71	4812	3869	899	L. W. Dahlke	Sandia-Liv.
NS-18 ^c	6-24-70	947	558	371	F. B. Simpson	ANC
NSS-19	6-26-70	486	287	190	J. E. Bigelow	ORNL-TRU
NSD-20	7-01-70	620	367	241	J. E. Bigelow	ORNL-TRU
NSS-21	10-21-70	18	12	b	F. Cross	PNL
NS-22	9-10-70	13	8	b	J. E. Bigelow	ORNL-TRU
NSD-24	10-15-70	8	5	b	J. B. Davidson	ORNL
NS-25	11-09-70	57	37	b	F. J. Muckenthaler	ORNL
NSD-26	2-11-71	14	10	b	H. O. Menlove	LASL
NSD-27	1-29-71	2430	1676	719	J. E. Powell	Sandia-NM
NSD-28	2-12-71	11	8	b	E. E. Hicks	Rocky Flats
NSD-29	9-10-71	11220	9087	2035	E. M. Murray	Y-12
NSD-30	3-31-71	866	624	231	F. F. Haywood	ORNL
NZD-31	11-23-71	1729	1477	241	C. N. Jackson, Jr.	WADCO
NZD-32	11-23-71	1773	1514	247	C. N. Jackson, Jr.	WADCO
NZD-33	11-23-71	1859	1588	259	C. N. Jackson, Jr.	WADCO
NZD-34	11-23-71	1895	1618	264	C. N. Jackson, Jr.	WADCO
NZD-35	11-23-71	1875	1601	261	C. N. Jackson, Jr.	WADCO
NS-36 ^c	3-23-71	2039	1459	553	F. B. Simpson	ANC
NSD-37	9-04-71	9689	7813	1789	R. W. Perkins	PNL
NSD-38	6-16-71	100	76	b	H. O. Menlove	LASL
NS-39	11-07-71	928	783	138	V. Spiegel	NBS
NSD-40	4-27-72	1143	1092	49	E. B. Darden	ORNL-Biology

Table 4.1. (continued)

Source	Date of Calibration	^{252}Cf Content at Calibration (μg)	^{252}Cf Content as of 6-30-72 (μg)	^{248}Cm Content as of 6-30-72 (μg)	On Loan To	
					Individual	Site
NSD-41	11-08-71	5039	4257	745	C. J. Emert	BAPL
NSD-42	11-02-71	4367	3674	661	C. J. Emert	BAPL
NSD-43	4-20-72	4766	4530	225	C. J. Emert	BAPL
NZD-44	5-15-72	10568	10225	328	F. B. Simpson	ANC
NSD-45	8-18-71	1749	1393	339	K. L. Swinth	PNL
NSD-46	4-23-72	619	590	28	H. O. Menlove	LASL
NSD-47	7-14-71	197	153	42	P. L. Johnson	Mound
NSD-48	7-14-71	191	148	41	P. L. Johnson	Mound
NSD-49	7-14-71	196	152	42	P. L. Johnson	Mound
NS-50	8-23-71	136	109	26	S. G. Carpenter	ANL-NRTS
NSD-51	11-02-71	359	302	54	L. C. Nelson, Jr.	New Brunswick
NSD-52	9-02-71	276	222	51	E. D. Clayton	PNL
NSD-53	10-25-71	1035	866	161	L. J. Esch	KAPL
NSD-55	4-19-72	4	4	b	L. J. Esch	KAPL
NSD-56	4-19-72	119	113	6	L. J. Esch	KAPL
NSD-57	4-14-72	958	907	49	J. E. Bigelow	ORNL-TRU
NZD-58	5-15-72	10836	10484	336	F. B. Simpson	ANC
NSS-60	4-11-72	20	19	b	J. S. Cheka	ORNL
SR-Cf-167 ^d	5-26-71	3915	2936	933	H. W. Dickson	ORAU

^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.

The facilities include the target fabrication cells at TRU, the TRU laboratory hot-cell caves A and B⁴ (Fig. 5.1), the TURF californium facility^{4,5} (Fig. 5.2), an alpha-contained glove-box facility at TURF (Fig. 5.3), and a source decontamination facility at TRU (Fig. 5.4). Transfers of small rabbits, containing HFIR-irradiated materials, from the HFIR pool to cave B at TRU can be made via a hydraulic rabbit transfer system.⁵ The TRU building is adjacent to both the HFIR and TURF buildings. Transfers of ²⁵²Cf or other radioactive materials can be made in either direction between TRU and TURF via a pneumatic rabbit transfer system.⁶ Terminals of this system are located in cubicle 3 of cell G at TURF and in the source decontamination facility at TRU.

The target fabrication cells at TRU are used primarily for preparation of HFIR targets, which normally contain recycle materials (americium and curium) but sometimes contain special materials such as ²⁴²Pu, ²⁴⁸Cm, or ²⁵²Cf. The TRU cells contain equipment for all of the remote fabrication steps required; these steps were described in the first report in this series.⁷

The laboratory hot-cell caves at TRU are normally used for final product purification of berkelium, einsteinium, and fermium. Each cave contains equipment for ion exchange and high-pressure extraction chromatography. Cave A also contains equipment for solvent extraction operations.

Cubicle 3 of the californium facility in cell G and the glove-box facility at TURF are used primarily for the fabrication of actinide sources (usually contained in stainless steel but occasionally in Zircaloy-2 or aluminum) and aluminum-clad HFIR rabbits. Each of these facilities contains a hydraulically operated 10-ton pellet press, a welding apparatus for making fusion welds using the gas tungsten-arc process, and a helium leak-detector apparatus.

The source decontamination facility at TRU is a small, portable, water-shielded cell located above the target chute at cell 1. This cell provides an interface between the facilities as well as with off-site carriers, where packages may be decontaminated before transfer or shipment. Ultrasonic cleaning equipment, along with manual cleaning via master-slave manipulators, is used here.

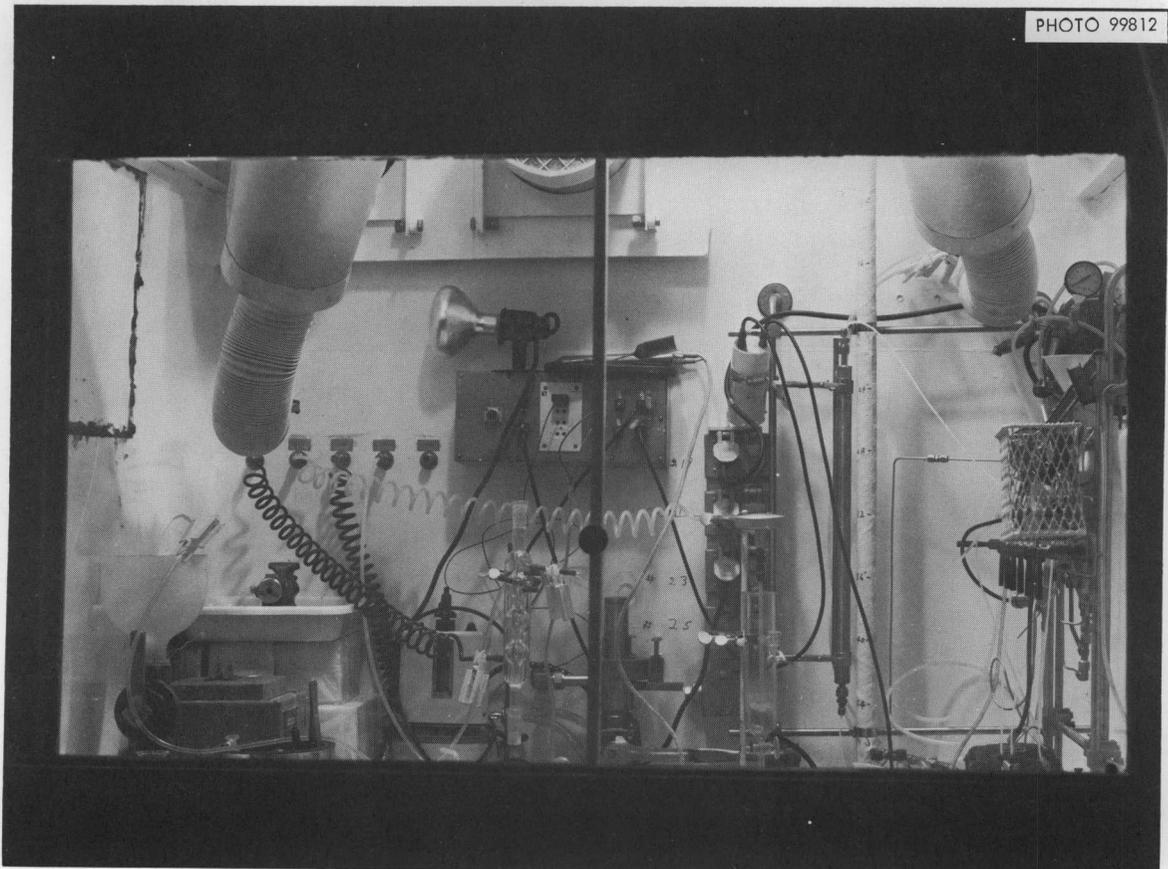


Fig. 5.1. TRU Laboratory Hot-Cell Cave B.

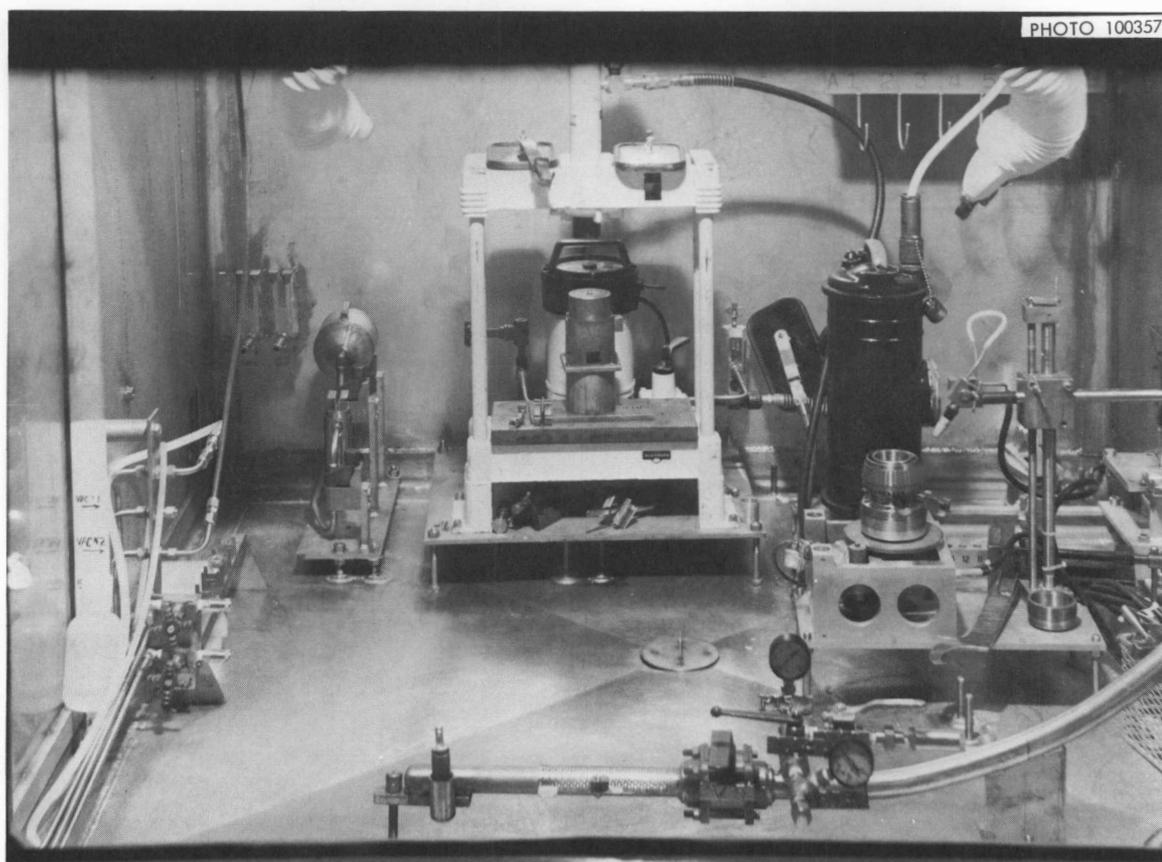


Fig. 5.2. Cubicle 3 of the TURF Californium Facility.

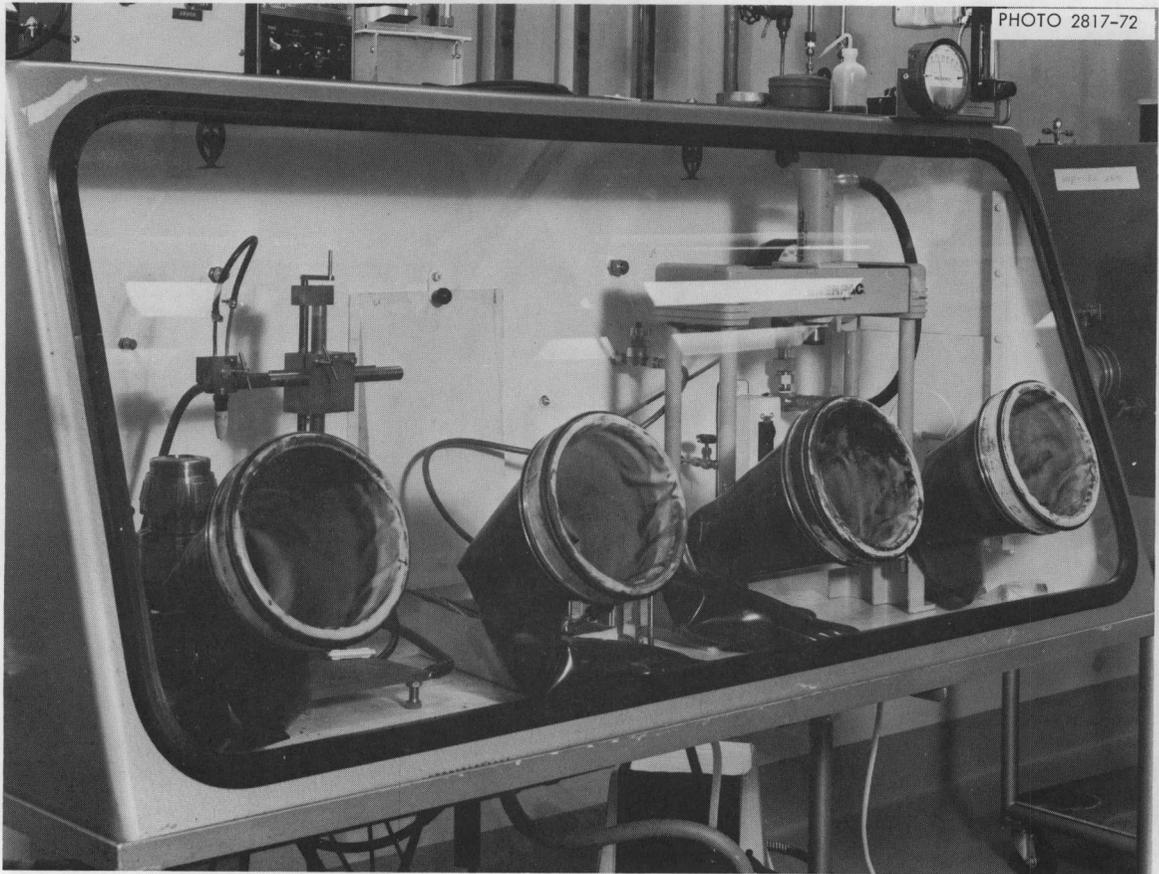


Fig. 5.3. Alpha Glove-Box Facility at TURF for Special Projects.

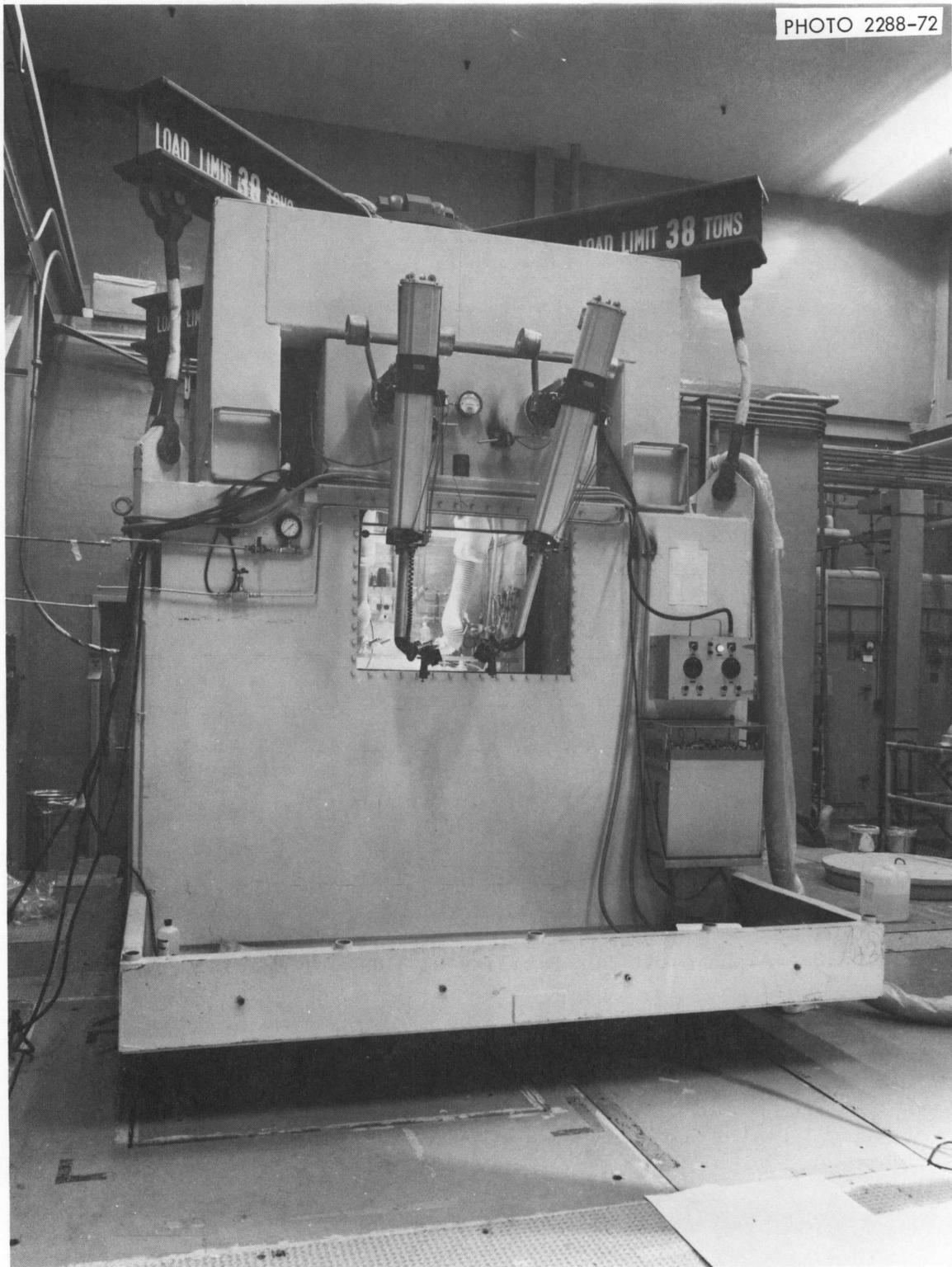


Fig. 5.4. Source Decontamination Facility at TRU.

6. REFERENCES

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2. 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.
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.
4. 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.
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, 1970, ORNL-4588.
6. Chem. Technol. Div. Ann. Progr. Rept. March 31, 1971, ORNL-4682, p. 116.
7. 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.
8. C. M. Lederer, J. M. Hollander, and I. Pearlman, Table of Isotopes, 6th ed., Wiley, New York, 1967.
9. 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 Lederer⁸ and Wapstra,⁹ 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 ²³⁸U). 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

Underlines indicate new values since the previous report.

Nuclide	Total Half-Life	Partial Half-Life for a 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 ± 0.01 d					50Fr53
²³⁹ Np	2.359 ± 0.010 d					59Co93
²⁴⁰ Np	63 ± 2 m					60Le03
^{240m} Np	7.3 ± 0.3 m					48Hy61
²⁴¹ Np	16 m					60Le03
^{241m} Np	3.4 h					60Le03
²³⁸ Pu	87.404 ± 0.041 y			$(5 \pm 0.6) \times 10^{10}$ y	2.33 ± 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 ± 40 y		$(1.340 \pm 0.015) \times 10^{11}$ y	<u>2.177 ± 0.009</u>	51In03, 62Wa13, <u>68Bo54</u>
²⁴¹ Pu	14.98 ± 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	<u>2.166 ± 0.009</u>	63Ma50, 69Be06, <u>68Bo54</u>
²⁴³ Pu	4.955 ± 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	66F107, 69Be06
²⁴⁵ Pu	10.6 ± 0.4 h					56Bu92
²⁴⁶ Pu	10.85 ± 0.02 d					56Ho23
²⁴¹ Am		432.7 ± 0.7 y		$(2.3 \pm 0.8) \times 10^{14}$ y	2.48 ^d	61Dr04, 670e01
²⁴² Am	16.01 ± 0.02 h		EC/β = 0.19			53Ke38
^{242m} Am	144 ± 7 y	$(2.92 \pm 0.15) \times 10^4$ y				59Ba21 ^c
²⁴³ Am		7370 ± 40 y				68Br22
²⁴⁴ Am	10.1 ± 0.1 h					62Va08
^{244m} Am	26 m					54Ga24
²⁴⁵ Am	2.07 ± 0.02 h					56Bu92
²⁴⁶ Am	25.0 ± 0.2 m					55En16
^{246m} Am	40 ± 7 m					670r02
²⁴⁷ Am	24 ± 3 m					670r02
²⁴² Cm	162.7 ± 0.1 d			7.2×10^6 y	2.65 ± 0.09	51Ha87, 57Pe52, 56Hi01
²⁴³ Cm		32 y				57As70
²⁴⁴ Cm	18.099 ± 0.015 y		$\alpha/SF = (7.43 \pm 0.01) \times 10^5$		2.84 ± 0.09	65Me02, 68Be26, 56Hi01
²⁴⁵ Cm		8265 ± 180 y				69Me01
²⁴⁶ Cm		<u>4655 ± 40 y</u>	$\alpha/SF = 3822 \pm 10$		3.08 ^d	69Me01, <u>71Mc19</u>
²⁴⁷ Cm		<u>$(1.56 \pm 0.05) \times 10^7$ y</u>				<u>71Fi01</u>
²⁴⁸ Cm		<u>$(3.703 \pm 0.032) \times 10^5$ y</u>		<u>$(4.115 \pm 0.034) \times 10^6$ y</u>	3.32 ^d	<u>71Mc19</u>
²⁴⁹ Cm	64 ± 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		$\alpha/B = (1.45 \pm 0.08) \times 10^{-5}$	$(1.87 \pm 0.09) \times 10^9$ 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	$\alpha/SF = (1.992 \pm 0.040) \times 10^8$		3.44 ^d	69Me01, 69Mi08
²⁵⁰ Cf		13.08 \pm 0.09 y	$\alpha/SF = 1260 \pm 40$		3.56 ^d	63Ph01, 69Me01
²⁵¹ Cf		900 \pm 50 y				69Me01
²⁵² Cf	2.646 \pm 0.004 y		$\alpha/SF = 31.3 \pm 0.2$		3.796 \pm 0.031	65Me02, 68Wh04
²⁵³ Cf	17.812 \pm 0.082 d		$\alpha/B = (3.1 \pm 0.4) \times 10^{-3}$			69Dr02, 66RG01
²⁵⁴ Cf	60.5 \pm 0.2 d		$\alpha/SF = (3.10 \pm 0.16) \times 10^{-3}$		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		$\alpha/SF = (1.15 \pm 0.03) \times 10^7$		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		$B/\alpha = 382 \pm 30$ E.C./ $\beta = 0.00078 \pm 0.00006$			62Un01, 63Ph01
²⁵⁵ Es	39.8 \pm 1.2 d		$\alpha/B = 0.0866 \pm 0.0043$ $B/SF = (2.22 \pm 0.10) \times 10^4$		4.16 ^d	66RG01, 67Fi03
²⁵⁶ Es	25 \pm 3 m					68Lo11
²⁵⁴ Fm	3.24 \pm 0.01 h		$\alpha/SF = 1695 \pm 8$		4.05 \pm 0.19	56Jo09, 67Fi03, 56Ch83
²⁵⁵ Fm	20.07 \pm 0.07 h		$SF/\alpha = (2.4 \pm 1.1) \times 10^{-7}$		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, and the third is the neutron capture resonance integral. The second parameter 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, $\sigma_{\text{eff}}^{\text{c}}$, would be:

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

where σ_{2200}^{c} is the thermal-neutron capture cross section, 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. 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 ^{244}cAm is a fictitious isotope which is used to simplify the calculation of the main transmutation chain involving ^{244}Am . The properties of ^{244}cAm were calculated from the properties of the

Table A-2. References for Table A-1

Code	Reference	Code	Reference
48Hy61	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, <u>At. Energ. (USSR)</u> , 15 , 158-159 (1965).
50Fr53	M. S. Freedman, A. H. Jaffey, and F. Wagner, Jr., <u>Phys. Rev.</u> , 79 , 410-411 (1950).	63Ph01	L. Phillips, R. Gatti, R. Brandt, and S. G. Thompson, <u>J. Inorg. Nucl. Chem.</u> , 25 , 1085-1087 (1965).
51Ha87	G. C. Hanna, B. G. Harvey, N. Moss, and P. R. Tunncliffe, <u>Phys. Rev.</u> , 81 , 466-467 (1951).	64As01	F. Asaro, S. Bjornholm, and I. Perlman, <u>Phys. Rev.</u> , 133 , B291-B300 (1964).
51In03	M. G. Inghram, D. C. Hess, P. R. Fields, and G. L. Pyle, <u>Phys. Rev.</u> , 83 , 1250 (1951).	64Py02	R. V. Pyle, Unpublished results as reported in E. K. Hyde, "Fission Phenomena," Prentice Hall, Inc. (1964).
52Se67	E. Segrè, <u>Phys. Rev.</u> , 86 , 21-28 (1952).	65Me02	D. Metta, H. Diamond, R. F. Barnes, J. Milsted, J. Gray, Jr., D. J. Henderson, and C. M. Stevens, <u>J. Inorg. Nucl. Chem.</u> , 27 , 33-35 (1965).
53Ke38	T. K. Keenan, R. A. Penneman, and B. B. McInteer, <u>J. Chem. Phys.</u> , 21 , 1802-1803 (1953).	66F107	P. R. Fields, A. M. Friedman, J. Milsted, J. Lerner, C. M. Stevens, D. Metta, and W. K. Sabine, <u>Nature</u> , 212 , 131 (1966).
54Gh24	A. Ghiorso, S. G. Thompson, G. R. Choppin, and B. G. Harvey, <u>Phys. Rev.</u> , 94 , 1081 (1954).	66RG01	Combined Radiochemistry Group, LRL, LAsL, and ANL, <u>Phys. Rev.</u> , 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, <u>J. Inorg. Nucl. Chem.</u> , 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, <u>Phys. Rev.</u> , 103 , 634 (1956).	67F103	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, <u>Nucl. Phys.</u> , A96 , 440-448 (1967).
56Ch83	G. R. Choppin, B. G. Harvey, D. A. Hicks, J. Ise, Jr., and R. V. Pyle, <u>Phys. Rev.</u> , 102 , 766 (1956).	67Oe01	F. L. Oetting and S. R. Gunn, <u>J. Inorg. Nucl. Chem.</u> , 29 , 2659-2664 (1967).
56Hi01	D. A. Hicks, J. Ise, Jr., and R. V. Pyle, <u>Phys. Rev.</u> , 101 , 1016-1020 (1956).	67Or02	C. J. Orth, W. R. Daniels, B. H. Erkila, F. O. Lawrence, and D. C. Hoffman, <u>Phys. Rev. Letters</u> , 19 , No. 3, 128-131 (1967).
56Ho23	D. C. Hoffman and C. I. Browne, <u>J. Inorg. Nucl. Chem.</u> , 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, <u>Phys. Rev.</u> , 102 , 203-207 (1956).	68Be21	C. E. Bemis, Jr. and J. Halperin, <u>Nucl. Phys.</u> , A121 , 433-439 (1968).
57As70	F. Asaro, S. G. Thompson, F. S. Stephens, Jr., and I. Perlman, <u>Bull. Am. Phys. Soc.</u> , 8 , 393 (1957).	68Be26	W. C. Bentley, <u>J. Inorg. Nucl. Chem.</u> , 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, <u>Phys. Rev.</u> , 107 , 1635-1638 (1957).	68Bo54	J. W. Boldeman, <u>J. Nucl. Energy</u> , 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, <u>J. Inorg. Nucl. Chem.</u> , 5 , 6-11 (1957).	68Br22	L. C. Brown and R. C. Propst, <u>J. Inorg. Nucl. Chem.</u> , 30 , 2591-2594 (1968).
58Ea06	T. A. Eastwood and R. P. Schuman, <u>J. Inorg. Nucl. Chem.</u> , 6 , 261-262 (1958).	68Ca19	M. J. Cabell, <u>J. Inorg. Nucl. Chem.</u> , 30 , 2583-2589 (1968).
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59Va02	S. E. Vandenbosch, H. Diamond, R. K. Sjoblom, and P. R. Fields, <u>Phys. Rev.</u> , 115 , 115-121 (1959).	68Lo11	R. W. Loughheed, private communication to J. E. Bigelow (1968).
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60Br15	F. Brown, G. G. George, D. E. Green, and D. E. Watt, <u>J. Inorg. Nucl. Chem.</u> , 13 , 192-195 (1960).	69Be06	C. E. Bemis, Jr., J. Halperin, and R. Eby, <u>J. Inorg. Nucl. Chem.</u> , 31 , 599-604 (1969).
60Le03	R. M. Lessler and M. C. Michel, <u>Phys. Rev.</u> , 118 , 263-264 (1960).	69Dr02	R. E. Drushel, J. Halperin, and C. E. Bemis, Jr., ORNL-4437, 28-29 (1969).
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Table A-3. Properties^a of Transuranium Nuclides

Underlines indicate new values since the previous report.

Nuclide	Half-Life	Energies of Prin. Emissions (MeV)		Specific Activity				MPC ^a (40)		Hazard ^b	
		α	β	(Ci/g)	(W/g)	(α cpm/mg ^c)	(β dpm/mg)	(Neutrons min ⁻¹ mg ⁻¹)	(μ Ci/cm ³)	Body Burden	(μ Ci)
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 ⁵		5.80 x 10 ¹⁴				
²³⁹ Np	2.359 d		0.332 0.427	2.52 x 10 ⁵	5.86 x 10 ²		5.14 x 10 ¹⁴		<u>7 x 10⁻⁷</u>	50	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	<u>0.653</u>
²⁴⁰ Pu	6580 y	5.16		0.227	7.097 x 10 ⁻³	2.57 x 10 ⁸		<u>53.7</u>	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		<u>95.3</u>	2 x 10 ⁻¹²	0.05	<u>13.1</u>
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	<u>7.0</u>	<u>2.69 x 10⁻⁶</u>
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	<u>2.26 x 10³</u>
²⁴⁵ Pu	10.6 h			1.21 x 10 ⁶			2.68 x 10 ¹⁵		2 x 10 ⁻⁷	3.0	<u>2.48 x 10⁻⁶</u>
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	I.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	<u>0.2</u>	<u>6.76 x 10⁻⁹</u>
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		3.52 x 10 ³	122	3.76 x 10 ¹²		1.21 x 10 ⁶	1 x 10 ⁻¹⁰	0.05	<u>1.51 x 10⁻⁵</u>
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	<u>5.81</u>		80.94	2.852	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	<u>0.226</u>
²⁴⁶ Cm	<u>4655 y</u>	<u>5.39</u>		<u>0.312</u>	1.01 x 10 ⁻²	<u>3.52 x 10⁸</u>		<u>5.58 x 10⁵</u>	5 x 10 ⁻¹²	0.05	<u>0.160</u>
²⁴⁷ Cm	<u>1.56 x 10⁷ y</u>	<u>4.87</u>		<u>9.28 x 10⁻⁵</u>	2.94 x 10 ⁻⁶	<u>1.05 x 10⁵</u>			5 x 10 ⁻¹²	0.04	<u>431</u>
²⁴⁸ Cm	<u>3.397 x 10⁵ y</u>	5.05		<u>4.24 x 10⁻³</u>	<u>5.34 x 10⁻⁴</u>	<u>4.39 x 10⁶</u>		<u>2.58 x 10⁶</u>	6 x 10 ⁻¹³	<u>0.005</u>	<u>1.18</u>
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	<u>8.47 x 10⁻⁸</u>
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) (μ Ci/cm ³)	Body Burden (μ Ci)	Burden (μ g)
²⁴⁹ Bk	314 d	5.4	0.125	1.67×10^3	0.358	2.74×10^7	3.71×10^{12}	6.34×10^3	9×10^{-10}	0.7	4.19×10^{-4}
²⁵⁰ Bk	3,222 h		0.23	3.89×10^6	2.75×10^4		8.62×10^{15}		1×10^{-7}	<u>0.05</u>	<u>1.29×10^{-8}</u>
²⁵¹ Bk	57 m			1.32×10^7			2.92×10^{16}				
²⁴⁹ Cf	352 y	5.81		4.08	0.152	4.62×10^9		156	2×10^{-12}	0.04	<u>9.80×10^{-3}</u>
²⁵⁰ Cf	13.08 y	6.03		109	4.06	1.23×10^{11}		6.85×10^8	5×10^{-12}	0.04	3.70×10^{-4}
²⁵¹ Cf	900 y			1.59	5.79×10^{-2}	1.78×10^9			2×10^{-12}	0.04	2.50×10^{-2}
²⁵² Cf	2.646 y	6.11		536	39.0	5.88×10^{11}		1.40×10^{11}	6×10^{-12}	0.01	1.87×10^{-5}
²⁵³ Cf	17.812 d	5.98	0.27	2.90×10^4	13.89	1.02×10^{11}	6.41×10^{13}		8×10^{-10}	0.04	1.40×10^{-6}
²⁵⁴ Cf	60.5 d	5.84		8.49×10^3	1.06×10^4	2.89×10^{10}		7.35×10^{13}	5×10^{-12}	<u>0.0007</u>	<u>8.24×10^{-8}</u>
²⁵⁵ Cf	1.5 h			8×10^6							
²⁵³ Es	20.467 d	6.63		2.52×10^4	1.01×10^3	2.86×10^{13}		1.91×10^7	6×10^{-10}	0.04	1.59×10^{-6}
²⁵⁴ Es	276 d	6.42		1.86×10^3	71.9	2.11×10^{12}		$<5.04 \times 10^5$	2×10^{-11}	0.02	1.08×10^{-5}
^{254m} Es	39.3 h		0.48	3.14×10^5	1.18×10^3		6.97×10^{14}		5×10^{-9}	0.02	6.37×10^{-8}
²⁵⁵ Es	39.8 d			1.29×10^4			2.86×10^{13}	4.92×10^9	4×10^{-10}	0.04	3.10×10^{-6}
²⁵⁶ Es	25 m			2.94×10^7			6.52×10^{16}				
²⁵⁴ Fm	3.24 h	7.20		3.81×10^6	1.68×10^5	4.31×10^{15}		2.02×10^{13}	6×10^{-8}	0.02	5.25×10^{-9}
²⁵⁵ Fm	20.07 h	7.03		6.13×10^5	2.79×10^4	6.94×10^{14}		1.36×10^9	1×10^{-8}	0.04	6.53×10^{-8}
²⁵⁶ Fm	2.62 h			4.67×10^6	5.85×10^6			4.43×10^{16}	2×10^{-9}	<u>0.0008</u>	<u>1.71×10^{-10}</u>
²⁵⁷ Fm	94 d			5.41×10^3	~ 200	6.12×10^{12}					
²⁵⁸ Fm	<u>380 μs</u>			1.15×10^{11}							

^aThe values for properties included in this table are those in use at IRU 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 α 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 γ emission, but 0.039% decays by electron capture to ²⁴⁴Pu.

Table A-4. Neutron Cross Sections Used to Compute Transmutations in HFIR Target Irradiations

Underlines indicate new values since the previous report.

Table A-4. Neutron Cross Sections Used to Compute Transmutations in HFIR Target Irradiations

Underlines indicate new values since the previous report.

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	2.4413×10^4 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	3.869×10^5 y	19.5	6.20	1280	0	0	0
^{243}Pu	4.955 h	80	0	0	210	0	0
^{244}Pu	8.28×10^7 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
$^{244\text{m}}\text{Am}$	26 m	0	0	0	0	0	0
$^{244\text{c}}\text{Am}^{\text{a}}$	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	<u>4655 y</u>	1.25	0	121	0	0	0
^{247}Cm	<u>1.56×10^7 y</u>	60	0	500	120	0	1060
^{248}Cm	<u>3.397×10^5 y</u>	3.56	2.0	170	0	0	0
^{249}Cm	64 m	2.8	0	0	50	0	0
^{250}Cm	1.74×10^4 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
$^{254\text{m}}\text{Es}$	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, $^{244\text{c}}\text{Am}$, which combines the properties of $^{244\text{m}}\text{Am}$ and ^{244}Am according to their relative rates of production from ^{243}Am .

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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