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TRANSURANIUM PROCESSING PLANT SEMIANNUAL REPORT OF PRODUCTION, STATUS, AND PLANS FOR PERIOD ENDING DECEMBER 31, 1970

W. D. Burch
J. E. Bigelow
L. J. King

OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

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CHEMICAL TECHNOLOGY DIVISION

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W. D. Burch, J. E. Bigelow, and L. J. King

JUNE 1971

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CONTENTS

Page

Summary v

1. Introduction. 1

2. Processing Summary and Production Estimate. 1
   2.1 Processing Summary 2
   2.2 Irradiation and Processing Proposals 6
   2.3 Estimates of the Availability of Transuranium Elements . . 8
   2.4 Rate of Production of ^{252}Cf During the Period 1973 Through 1976 10

3. Processes and Equipment 12
   3.1 Iodine Removal System. 14

4. Californium Neutron Sources 16
   4.1 Sources Fabricated During July-December 1970 16

5. Special Projects. 19
   5.1 Rabbit Containing ^{244}Pu. 19
   5.2 Rabbits Containing ^{241}Am 20

6. References. 20

7. Appendix. 21
   7.1 Decay Data 21
   7.2 Neutron Cross-Section Data 24

SUMMARY

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

During the period July 1, 1970, through December 31, 1970, we recovered 80.8 g of ^{244}Cm, 10.5 mg of ^{249}Bk, 76 mg of ^{252}Cf, 312 μg of ^{253}Es, and 10^9 atoms of ^{257}Fm as purified products from 35 reactor slugs which had been irradiated as part of the Californium-I program at the Savannah River Plant to evaluate the commercial market for ^{252}Cf. We made 55 shipments, which contained the following total amounts of nuclides: 0.5 mg of ^{244}Pu that had been isotopically enriched in a calutron and then irradiated in the HFIR prior to shipment; 0.26 g of ^{243}Am; 29 g of ^{244}Cm; 1 mg of ^{248}Cm; 851 μg of ^{249}Bk; 425 μg of isotopically pure ^{249}Cf; 23.1 mg of ^{252}Cf in a mixture of californium isotopes; 240 μg of ^{253}Es; and 9×10^8 atoms of ^{257}Fm.

Processing plans for the next 18 months are somewhat uncertain because we don't know how many SRP Californium-I reactor tubes we will be asked to process. Processing predictions were made based on 20 tubes, the maximum number that we could process without major plant revisions. On that basis, we would recover approximately 0.7 g of ^{252}Cf: 529 mg from 128 SRP Californium-I slugs and the 20 reactor tubes, and 160 mg from the processing of irradiated HFIR targets. About 74 mg of ^{249}Bk, 1 mg of ^{253}Es, and 2×10^9 atoms of ^{257}Fm will also be recovered as by-products from these campaigns.

Analysis of the future rate of production of ^{252}Cf at TRU indicates that we can produce about 0.5 g per year by irradiating curium containing 95% ^{244}Cm, or about 1.2 g per year by irradiating curium recovered from the SRP Californium-I campaigns (which contains about 24% ^{246}Cm).

The processes and equipment used for the SRP reactor slugs were generally the same as those used to process HFIR targets.

A large iodine removal unit consisting of a catalytic oxidation bed to destroy organic vapors, followed by charcoal beds for adsorbing

iodine, was installed for treating the entire vessel and cubicle off-gas system (450 cfm). During the campaign to process the 35 slugs, which contained 400 Ci of ^{131}I, about 400 mCi of the iodine was volatilized and reached the system. The average rate of release of ^{131}I was less than 6 μCi per day; system DF's were greater than 700.

Eight neutron sources were fabricated during this period; to date, 23 neutron sources have been fabricated at TRU. In special projects, 0.5 mg of ^{244}Pu was irradiated to produce ^{246}Am for gamma-ray spectroscopic studies at ANL, and 2 mg of ^{241}Am sorbed on molecular sieves was irradiated as part of a series of tests of a new technique for producing enriched isotopes of the actinide elements.

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 sixth report in a series that is being issued semi-annually to inform the heavy-element community of the status and the future production plans of the Transuranium Element Production Program at ORNL. The objective of these reports is to provide information that will enable users of the products to obtain maximum service from the production facilities at ORNL. Production plans and schedules are 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. Special processing, fabrication, and irradiation programs are described. The original and current contents of all neutron sources that have been made at TRU, as well as the person to whom each source has 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 tabulation 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.

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

We recovered 80.8 g of ^{244}Cm, 10.5 mg of ^{249}Bk, 76 mg of ^{252}Cf, 312 μg of ^{253}Es, and 10^9 atoms of ^{257}Fm as purified products from 35 reactor slugs which had been irradiated as part of the Californium-I[1] program at the Savannah River Plant (SRP) to evaluate the commercial market for ^{252}Cf.

Fifty-five shipments (Table 2.1) that were made from TRU during this period included: (1) 0.5 mg of ^{244}Pu which was irradiated in the HFIR prior to shipment; (2) 0.26 g of ^{243}Am; (3) 29 g of ^{244}Cm; (4) 1 mg of ^{248}Cm (in products containing 97% ^{248}Cm); (5) 851 μg of ^{249}Bk; (6) 425 μg of isotopically pure ^{249}Cf that had been "milked" from ^{249}Bk; (7) 23.1 mg of ^{252}Cf in a mixture of californium isotopes (∿86% ^{252}Cf); (8) 240 μg of ^{253}Es containing some ^{254}Es and ^{255}Es; (9) 0.2 μg of isotopically pure ^{253}Es; and (10) 9×10^8 atoms of ^{257}Fm.

Table 2.1. Distribution of Heavy Elements from the Transuranium Processing Plant During the Period July 1, 1970 to December 31, 1970

Major Nuclide	Date	TRU File No.	Shipped To Individual	Shipped To Site
Plutonium-244, mg				
0.5 (irradiated)	12-03-70	344	H. Diamond	ANL
0.5				
Americium-243, g				
0.25	7-30-70	315	S. J. Waligora	Lovelace
0.005	8-21-70	327	Isotope Sales	ORNL
0.001	8-24-70	329	W. J. McDowell	ORNL-CTD
0.001	9-17-70	337	J. C. Mailen	ORNL-CTD
0.257				
Curium-244, g				
0.0001	8-24-70	330	W. J. McDowell	ORNL-CTD
0.0001	9-17-70	338	J. C. Mailen	ORNL-CTD
0.46	10-01-70	323	R. G. Haire	ORNL-CTD
5.17	10-27-70	242	P. R. Fields	ANL
0.25	11-10-70	234	J. A. Harris	LRL-B
13[a]	12-21-70	125	R. W. Hoff	LRL-L
0.2[a]	12-21-70	283	J. A. Harris	LRL-B
10[a]	12-21-70	284	P. R. Fields	ANL
29.0802				
Curium-248 (97%), μg				
160	9-17-70	287	C. E. Bemis	ORNL-TRL
173	9-22-70	285	D. C. Hoffman	LASL
153	9-22-70	286	P. R. Fields	ANL
173	9-22-70	321	R. W. Hoff	LRL-L
173	9-22-70	322	J. A. Harris	LRL-B
247	11-10-70	340	A. Ghiorso	LRL-B
1079				

Table 2.1 (continued)

Major Nuclide	Date	TRU File No.	Shipped To Individual	Shipped To Site
Berkelium-249, μg				
1	7-20-70	317	W. J. McDowell	ORNL-CTD
600	11-16-70	264	R. A. Penneman	LASL
250	12-30-70	352	J. A. Harris	LRL-B
851				
Californium-249 (isotopically pure), μg				
125[b]	8-20-70	320	R. A. Penneman	LASL
60[b]	11-16-70	342	R. A. Penneman	LASL
240	12-30-70	351	J. A. Harris	LRL-B
425				
Californium-252, μg				
4830 (NS-14)	7-09-70	296	D. C. Stewart	ANL
10	7-10-70	319	Isotopes Sales	ORNL
256	7-14-70	250	C. H. Youngquist	ANL
118 (NS-10)	7-15-70	247	J. P. Balagna	LASL
10	7-15-70	292	R. A. Penneman	LASL
6550	7-31-70	297	A. R. Boulogne	SRL
980 (NS-15)	8-17-70	298	F. B. Simpson	INC
1010 (NS-18)	8-17-70	298	F. B. Simpson	INC
1800 (NS-9)	8-17-70	249	G. Rieck	PNL
1960 (NS-12)	8-17-70	294	R. W. Hoff	LRL-L
310	8-17-70	270	J. A. Harris	LRL-B
0.1	8-24-70	328	W. J. McDowell	ORNL-CTD
13 (NS-22)	9-10-70	331	O. L. Keller	ORNL-TRL
1	9-15-70	336	W. J. McDowell	ORNL-CTD
0.1	9-17-70	339	J. C. Mailen	ORNL-CTD
3420	10-19-70	314	A. R. Boulogne	SRL
1740 (NS-16)	10-29-70	299	R. Yoshimura	Sandia-NM
18 (NS-21)	10-30-70	318	F. J. Zelley	PNL
8 (NS-24)	11-09-70	333	J. B. Davidson	ORNL-I&C
10	11-10-70	341	Isotopes Sales	ORNL
5.3 (Small Sources)	11-24-70	324	H. A. Mullin	Sandia-NM
1	12-03-70	343	R. L. Folger	SRL
56 (NS-25)	12-07-70	334	F. J. Muckenthaler	ORNL
1	12-21-70	350	F. B. Simpson	INC
23107.5				

Table 2.1 (continued)

Major Nuclide	Date	TRU File No.	Shipped To Individual	Shipped To Site
Einsteinium-253, μg				
120	12-17-70	345	R. W. Hoff	LRL-L
120	12-17-70	346	P. R. Fields	ANL
240				
Einsteinium-253 (isotopically pure), μg				
0.2	7-20-70	316	W. J. McDowell	ORNL-CTD
0.2				
Fermium-257, atoms				
3×10^8	12-17-70	347	D. C. Hoffman	LASL
3×10^8	12-17-70	348	J. A. Harris	LRL-B
3×10^8	12-17-70	349	P. R. Fields	ANL
9×10^8				

[a]These shipments were prepared by ORNL Isotopes Sales. Material originated at Savannah River.

[b]From LASL's berkelium allocation.

2.2 Irradiation and Processing Proposals

The estimated amounts of transcurium elements that will be produced during the next few years is given in Table 2.2. During the period January through June 1971, we will process the remaining 128 americium-curium slugs that were irradiated as part of the Californium-I program at the Savannah River Plant (SRP). In this program, californium is being produced for use in the USAEC program to evaluate the commercial market for ^{252}Cf. Although the californium that is recovered from the slugs is primarily intended for use in the market evaluation studies, some of it will be made available to satisfy research requirements of the National Transplutonium Program of the USAEC's Research Division. Approximately 500 g of curium, assaying about 24% ^{246}Cm, will be recovered from the slugs. This curium is intended for future reirradiation at SRP to produce ^{252}Cf; however, some of it may be made available to the research program. The by-products ^{249}Bk and ^{253}Es will be allocated to researchers by the Transplutonium Committee.

Irradiation of the remaining 128 slugs was ended Nov. 8, 1970. We expect to recover about 160 g of ^{244}Cm (200 g of total curium), 8 mg of ^{249}Bk, 74 mg of ^{252}Cf, and 75 μg of ^{253}Es from the 64 slugs that will be processed by March 1971, and about 175 g of ^{244}Cm (225 g of total curium), 7 mg of ^{249}Bk, 55 mg of ^{252}Cf, and 17 μg of ^{253}Es from the 64 slugs that will be processed by May 1971.

We will then process 18 irradiated HFIR targets, from which we expect to recover 5.5 mg of ^{249}Bk, 45 mg of ^{252}Cf, and 240 μg of ^{253}Es in June 1971.

Californium was produced at SRP by irradiation of material in two forms: (1) the slugs which have been discussed above, and (2) ^{242}Pu contained in 86 tubes that are 4 in. in diameter and have active lengths of about 4 ft. We do not know how many of these tubes we will be asked to process, but we have made tentative plans to process ten during the period July through November 1971 and ten during the period January

Table 2.2. 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)	During the Period (mg)	Cumulative (mg)	
Through December 1970						73	
January - June 1971	64 SRP Cf-I slugs	8	74[b]	75			March 1971
	64 SRP Cf-I slugs	7	55[b]	17			May 1971
	13 Pu targets	1.5	16	80(15)			June 1971
	5 Cm targets	4	29	160(29)	45	118	June 1971
July - December 1971	10 SRP Cf-I tubes	20	200[b]	0[c]			November 1971
	7 Cm targets	6	50	275(50)	50	168	December 1971
January - June 1972	10 SRP Cf-I tubes	20	200[b]	0[c]			April 1972
	12 Cm targets	7	65	350(65)	65	233	June 1972
July - December 1972					∿160	∿400	
1973					∿400	∿800	
1974					∿450	∿1250	

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

[b]Californium produced in the SRP campaigns is not included in production totals.

[c]^{254}Es (∿5 μg) can be recovered.

through April 1972. We estimate that 220 g of ^{244}Cm, 20 mg of ^{249}Bk, and 200 mg of ^{252}Cf will be recovered in each of the campaigns to process ten tubes.

Processing of 7 irradiated HFIR targets in December 1971 will produce 6 mg of ^{249}Bk, 50 mg of ^{252}Cf, and 275 μg of ^{253}Es. Processing of 12 irradiated HFIR targets in June 1972 will produce 7 mg of ^{249}Bk, 65 mg of ^{252}Cf, and 350 μg of ^{253}Es.

2.3 Estimates of the Availability of Transuranium Elements

Plutonium, americium, and curium are usually considered to be intermediate feed materials rather than products. Estimates of the availability of berkelium, californium, einsteinium, and fermium during the next two years are given below.

2.3.1 Berkelium

About 74 mg of ^{249}Bk is expected to become available during the next two years: 8 mg in March 1971, 7 mg in May 1971, 5.5 mg in June 1971, 20 mg during the period July through November 1971, 6 mg in December 1971, 20 mg during the period January through April 1972, and 7 mg in June 1972.

2.3.2 Californium

Twenty-four milligrams of the ^{252}Cf that was recovered from the SRP Californium-I slugs has been assigned to the USAEC's Research Division for distribution to researchers through the Transplutonium Committee.

We expect to produce about 700 mg of ^{252}Cf contained in a mixture of californium isotopes during the next two years. About 529 mg will be recovered from SRP feed materials for the Californium-I program (74 mg in March 1971, 55 mg in May 1971, 200 mg during the period July 1971

through November 1971, and 200 mg during the period January through April 1972), and 160 mg will be recovered from HFIR targets for the Transuranium Element Production Program (45 mg in June 1971, 50 mg in December 1971, and 65 mg in June 1972).

2.3.3 Einsteinium

Our expectations for einsteinium production have been reduced since the previous report because of the early termination of irradiations in the SRP Californium-I program.

We expect to recover about 1 mg of ^{253}Es in a mixture of einsteinium isotopes during the next two years: 75 μg in March 1971, 17 μg in May 1971, 240 μg in June 1971, 275 μg in December 1971, and 350 in June 1972.

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 latter will be stored about one month to allow ^{253}Es to "grow in" from the decay of ^{253}Cf; then this second-growth ^{253}Es will be recovered. About 44 μg, 50 μg, and 65 μg of isotopically pure ^{253}Es will be "milked" from the californium that will be isolated in June 1971, December 1971, and June 1972, respectively.

2.3.4 Fermium

Each batch of californium that is recovered from the processing of HFIR targets will contain about 1.5×10^7 atoms of ^{257}Fm per milligram of ^{252}Cf. Thus, about 6.8×10^8 atoms will be available in June 1971, 7.5×10^8 atoms will be available in December 1971, and 9.8×10^8 atoms will be available in June 1972. Data that would permit us to predict the yields in the SRP reactor are not currently available; however, we estimate that the SRP-slug campaigns will produce on the order of 10^9 atoms.

2.4 Rate of Production of ^{252}Cf During the Period 1973 Through 1976

The rate at which ^{252}Cf will be produced during the period 1973 through 1976 depends upon the amount and isotopic content of the feed material (curium) that will be irradiated. It is obvious that if there is not enough feed material to keep the HFIR target island loaded to capacity, the amount of ^{252}Cf produced will be less. The way in which the isotopic content of the feed curium affects the rate of production of ^{252}Cf is less obvious. Curium-244 must be transmuted successively to ^{245}Cm, ^{246}Cm, ^{247}Cm, ^{248}Cm, and ^{249}Cm in the sequence of nuclear reactions by which ^{252}Cf is produced. Only one-fifth of the ^{245}Cm and one-third of the ^{247}Cm that is produced during irradiation is transmuted to the next heavier isotope; most of the remainder is destroyed by fission. Thus, the value of curium as a feed material is dependent upon the isotopic content.

Our present supply of curium, which contains significant amounts of ^{246}Cm and ^{248}Cm, will provide ^{252}Cf at the rates shown in the lowest curve in Fig. 2.1. The rate will increase to 0.275 g/year in 1973, then decrease because of the limited supply. By supplementing our present stock of curium with 200 g of curium (95% ^{244}Cm) per year from the Curium-II Campaign at SRP, we will be able to achieve the production rates shown in the middle curve. By 1975 the rate will reach 0.5 g of ^{252}Cf per year, which could be maintained as long as 200 g of curium containing 95% ^{244}Cm is available per year. The amounts listed in Table 2.2 were taken from this middle curve.

The production rate of ^{252}Cf at TRU would be more than doubled if we were to irradiate curium produced in the Californium-I campaign, since this curium contains about 24% ^{246}Cm and about 1% ^{248}Cm. The top curve in Fig. 2.1 shows the production rates of ^{252}Cf that would be achieved. The steady-state production rate of about 1.2 g of ^{252}Cf per year (from 200 g of curium per year) could be maintained for 10 to 15 years if all of the curium from the slugs and tubes were committed to this use.

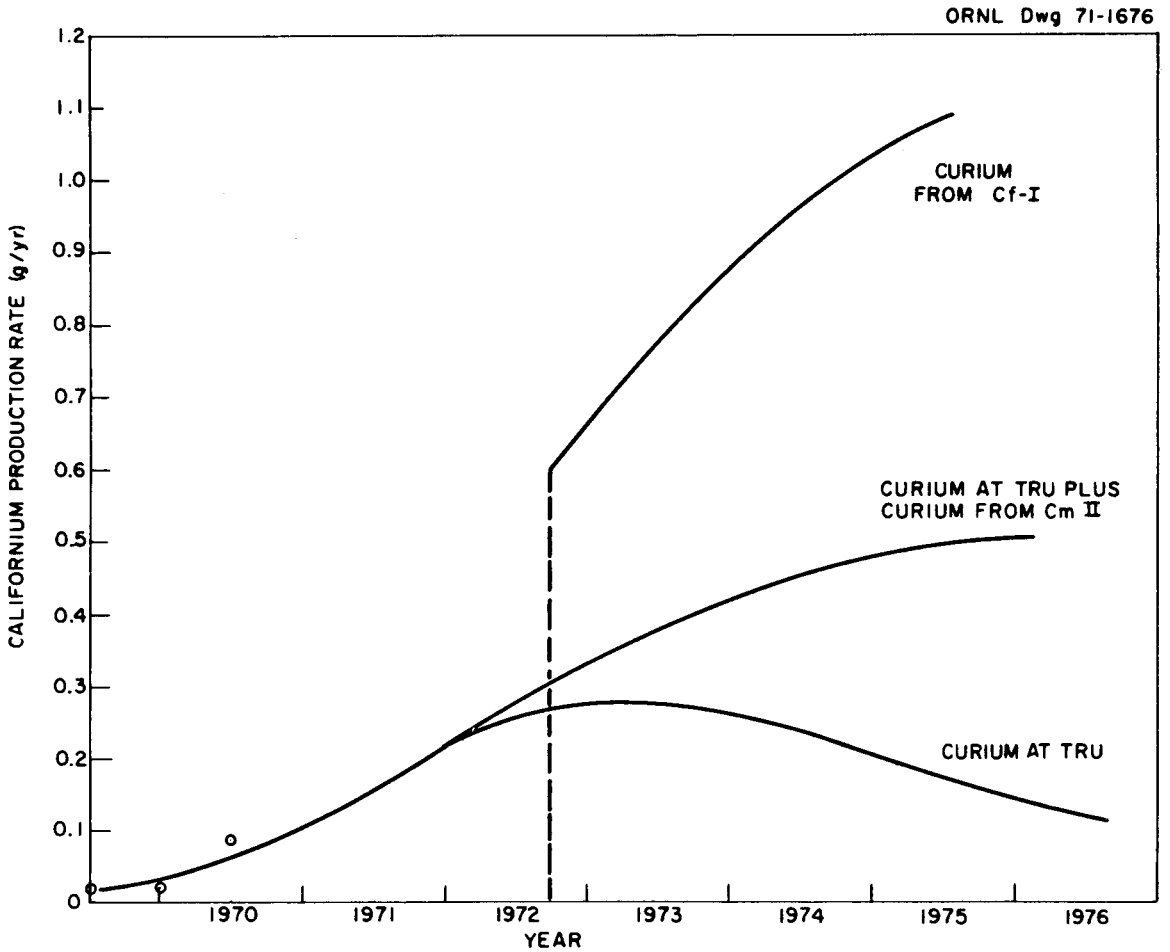

Fig. 2.1. Californium-252 Production Capability at TRU Is Dependent upon the Amount and Isotopic Content of the Available Curium.

3. PROCESSES AND EQUIPMENT

Figure 3.1 is a block diagram showing the processing steps that are required to process the SRP Californium-I slugs. These steps are: (1) the preparation of a feed solution by dissolving the irradiated SRP-reactor slugs; (2) the removal of radioiodine using the Pubex batch extraction process; (3) the decontamination of the transplutonium elements from fission products; (4) the separation of curium from the transcurium elements; (5) the separation and purification of berkelium, californium, einsteinium, and fermium; and (6) the preparation of curium oxide.

The processes and equipment used are generally the same as those used to process HFIR targets. The only step which is significantly different is the preparation of curium oxide. The oxide will be formed by calcining curium oxalate at 600°C instead of by the sol-gel process which is used for preparing oxide for recycle to the HFIR. New equipment is being fabricated for this step.

Differences which occurred during the first five processing steps listed are:

(1) The radioiodine reported almost entirely (94%) to the caustic nitrate solution used to dissolve the aluminum from the slugs. Only about 50% of the radioiodine reports to the aluminum dissolvent when HFIR targets are processed.

(2) The presence of large amounts of solids in the feed solutions hampered the planned Pubex and Tramex process steps, making it necessary to insert additional Pubex and Tramex batch extractions prior to the continuous Tramex solvent extraction step. We will install filters that have larger capacities for solids collection before the next group of slugs is processed.

(3) We processed 50 mg of ^{252}Cf in a single loading of the ion exchange column for the separation and purification of the transcurium elements, by chromatographic elution using α-hydroxyisobutyrate. Prior to this campaign, the largest amount loaded and eluted successfully in a single run was about 20 mg. In an earlier run, 35 mg was loaded on the resin column but was not eluted successfully.

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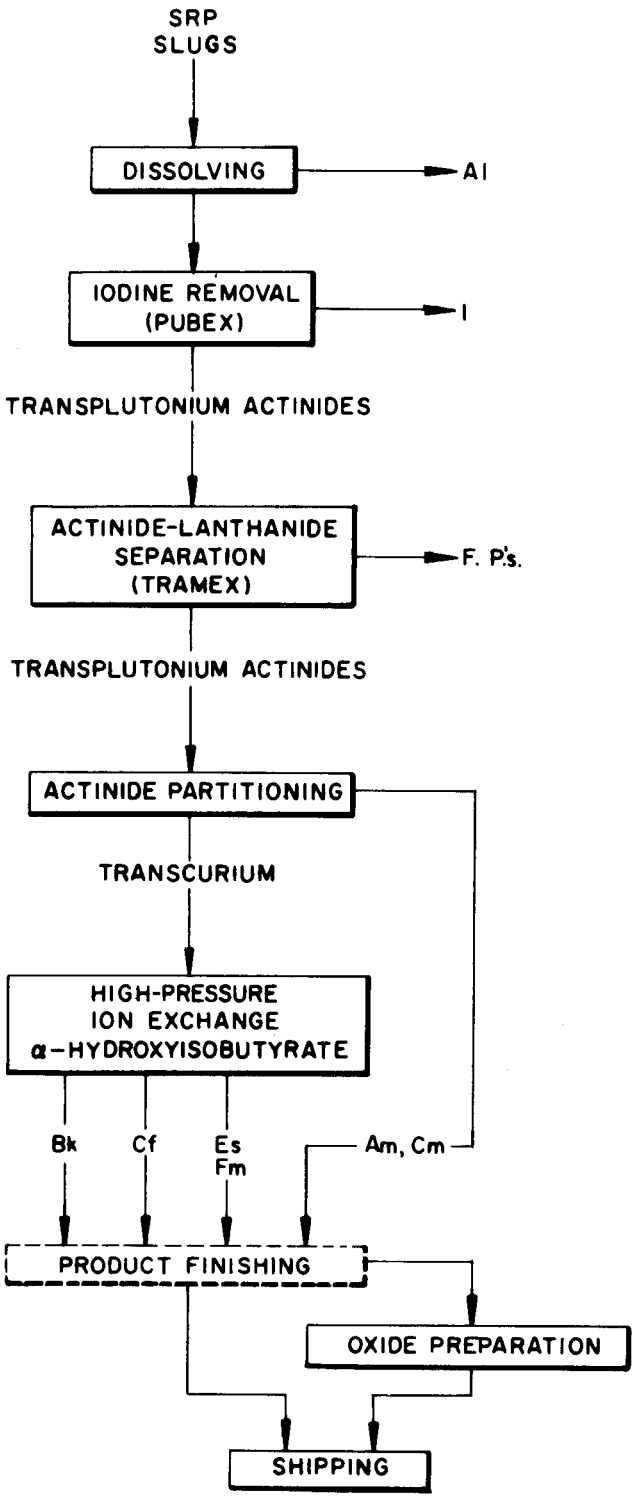

Fig. 3.1. Processing Steps Used for Transuranium Element Production.

The processing capacity of the system was increased by the installation of a small loading column in front of the existing column. The loading column is an 8-in.-long piece of 1/2-in.-diam tubing which contains about 20 ml of Dowex 50W-X8 resin. The existing column is 4 ft long (also, 1/2-in.-diam tubing). The use of the small column reduces radiation-induced damage of the resin by reducing the residence time of ^{252}Cf. When the californium is loaded onto the small column, the raffinate by-passes the large column. After the californium is loaded, the excess resin below the actinide loading must be converted to the NH_4^+ form from the H^+ form (in which it was left by the loading step). Because the loading column is small, this resin-conversion step can be accomplished in about 10 min. Converting all of the resin in the large column would require about 60 min. The 50 min of californium residence time saved by using the loading column reduces the resin damage sufficiently to permit the high loading of actinides.

3.1 Iodine Removal System

A large iodine removal unit (Fig. 3.2) consisting of a catalytic oxidation bed to destroy organic vapors, followed by charcoal beds for adsorbing iodine, has been installed for treating the entire vessel and cubicle off-gas system (450 cfm). Entering off-gas is heated to about 550°F in passing through the tubes of the primary heat exchanger (countercurrent to the exit gas from the catalytic oxidation bed). Additional electric heat is provided to maintain the catalyst (Hopcalite) bed at 650 ± 25°F. The gases from the Hopcalite bed are cooled to about 225°F in the shell side of the primary heat exchanger and then cooled further to 175 ± 25°F in a small, water-cooled exchanger. The relatively cool gases pass through two 1-in.-thick charcoal beds in series for iodine removal. The oxidation step destroys organic materials in the off-gas and thus improves the efficiency of the charcoal bed for sorption of iodine.

During this report period, 35 SRP-Californium-I slugs, which contained about 400 Ci of ^{131}I, were processed. About 400 mCi (0.1%) was

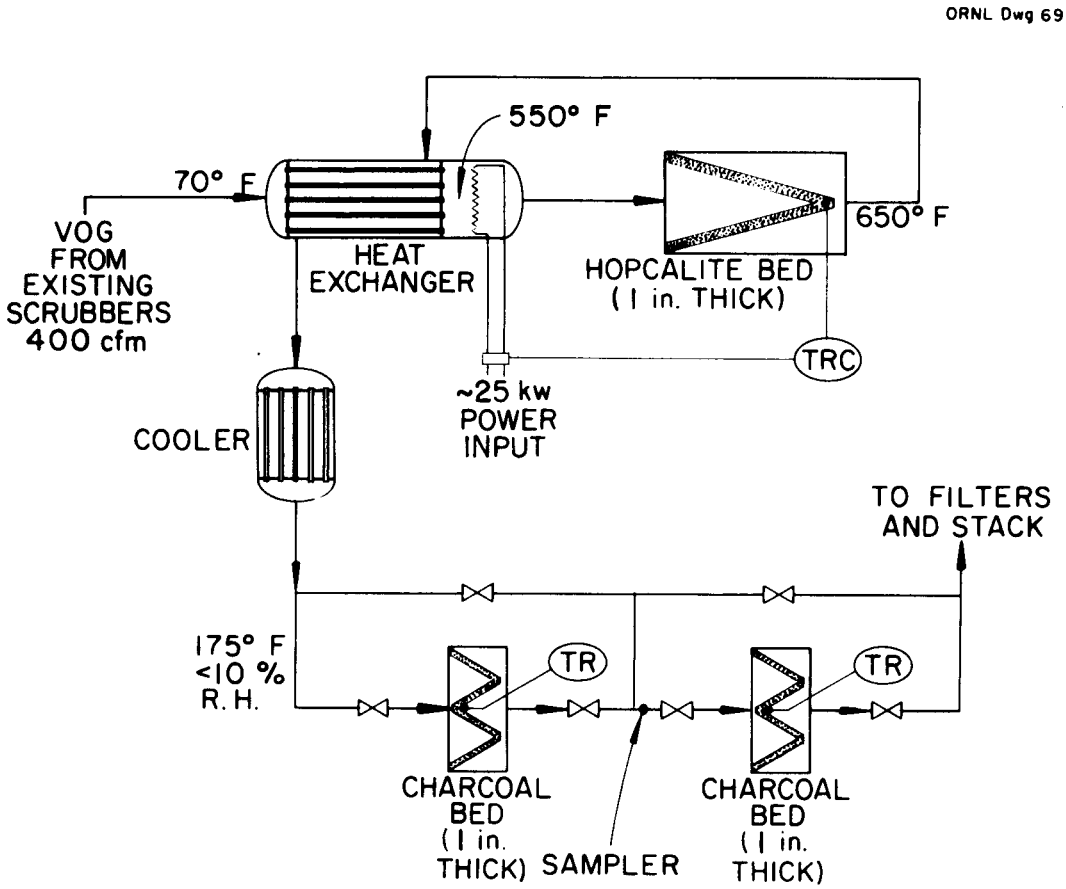

Fig. 3.2. Iodine Removal System for TRU Vessel Off-Gas.

volatilized and reached the system. The iodine release rate was generally below the limit of detection with the sampling system used. The average rate of release of ^{131}I was less than 6 μCi per day; system DF's were greater than 700. Only one outlet sample contained enough activity to yield a meaningful DF, which was 9700. The system performed well with no apparent loss in efficiency over the two-month duration of the processing campaign.

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 thus far are listed in Table 4.1. Most of them have been encapsulated in type 304L stainless steel in the typical configurations (not identical dimensions) shown in Fig. 4.1.

Recently, sources have been fabricated from californium that had been highly purified from curium in the new californium facility in TURF. This ultrapurification step makes the californium suitable for future reprocessing to recover ^{248}Cm (the alpha decay product of ^{252}Cf) that is free from ^{244}Cm contamination. The current ^{248}Cm contents of the californium sources are listed in Table 4.1.

4.1 Sources Fabricated During July-December 1970

Eight sources were fabricated during this report period. Sources NS-19, NS-20, and NS-21 are standard singly encapsulated sources, and NS-16, NS-24, and NS-26 are standard doubly encapsulated sources. Source NS-25, which is doubly encapsulated, was specially fabricated to the same external dimensions (0.75 in. in diameter by 0.87 in. high) as a lower-intensity Pu-Be source which it replaced. A more intense Pu-Be source would have been too large to fit into a special holder in the experimenter's apparatus.

Table 4.1. Data for Neutron Sources Prepared at TRU

Source (NS-)	Date of Calibration	^{252}Cf Content at Calibration (μg)	^{252}Cf Content as of 12-31-70 (μg)	^{248}Cm Content as of 12-31-70 (μg)	On Loan To Individual	On Loan To Site
1[a]	8-28-68	311	168	b	J. L. Cason	PNL
2	8-23-68	268	145	b	J. E. Powell	Sandia
3	5-13-69	∿90	∿59	b	H. E. Banta	ORAU
4	7-09-69	925	628	283	C. F. Masters	LASL
5[c]	8-14-69	992	691	287	F. B. Simpson	INC
6	11-21-69	783	586	188	R. W. Hoff	LRL-L
7	1-21-70	807	631	168	T. F. Handley	ORNL
8	12-17-69	1927	1468	438	H. Berger	ANL
9	4-17-70	1802	1497	291	N. D. Wogman	PNL
10	3-11-70	118	95	b	J. P. Balagna	LASL
11	3-10-70	8	6	b	R. R. Fullwood	LASL
12	6-30-70	1957	1715	231	R. W. Hoff	LRL-L
14	6-29-70	4833	4233	572	D. C. Stewart	ANL
15[c]	6-25-70	975	852	117	F. B. Simpson	INC
16	10-08-70	1736	1637	94	R. Yoshimura	Sandia-NM
18[c]	6-24-70	1008	880	122	F. B. Simpson	INC
19	6-26-70	469	410	56	J. E. Bigelow	ORNL-TRU
20	7-01-70	605	531	71	J. E. Bigelow	ORNL-TRU
21	10-21-70	18	17	b	F. Cross	PNL
22	9-10-70	13	12	b	W. S. Lyon	ORNL
24	10-15-70	8	8	b	J. B. Davidson	ORNL
25	11-09-70	56	54	b	F. J. Muckenthaler	ORNL
26[d]		∿10		b	J. R. Engel	ORNL

[a]This source is encapsulated in aluminum.

[b]This source is not suitable for recovery of ^{248}Cm.

[c]This source is encapsulated in type 405 stainless steel.

[d]NS-26 (about 10 μg) has not been calibrated or delivered.

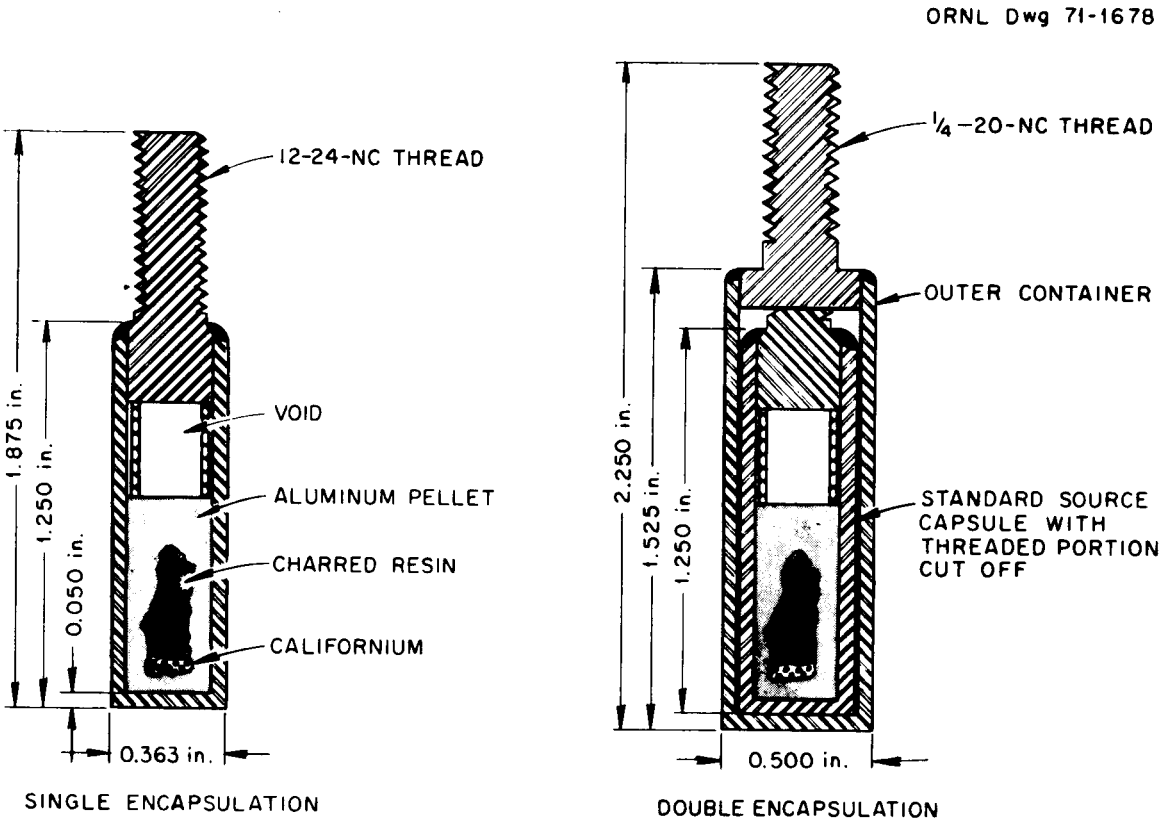

Fig. 4.1. ORNL Standard Neutron Sources Using ^{252}Cf (Stainless Steel).

Source NS-22 contains 13 μg of ^{252}Cf in a quartz bead coated with two layers of epoxy resin. It was fabricated for use in developmental work on an analytical technique involving prompt gamma-ray spectroscopy. We are developing techniques for fabricating sources of platinum and niobium for use in gamma-ray spectroscopy. These exotic materials are required to minimize the production of capture gamma rays in the source capsules, which would decrease the sensitivity of the analytical technique.

In addition to the eight sources just discussed, we made a series of four small neutron sources of the quartz-bead type for an experimenter who wanted a source of "exactly" 1 μg of ^{252}Cf. The four sources, which assayed 1.0, 1.2, 1.35, and 1.75 μg, were welded into 0.25-in.-diam by 0.5-in.-long stainless steel capsules. With this group of sources, the experimenter can select the one that best suits his needs; and, as the sources decay, he can replace a weaker source with a stronger one.

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. The facilities that are available at TRU 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.

5.1 Rabbit Containing ^{244}Pu

A rabbit containing 0.5 mg of ^{244}Pu was irradiated for H. Diamond at ANL to produce ^{246}Am. A small background of ^{246}Am was interfering with gamma-ray spectroscopic studies of ^{246m}Am produced at ANL in an accelerator. The published decay scheme of ^{246}Am was not adequate for their purposes; they needed an actual ^{246}Am standard to be run on the same instrument as the ^{246m}Am.

An old ^{244}Pu pellet, originally irradiated in our first special target in 1968 but never utilized, was incorporated into a new HFIR rabbit, which was inserted into the HFIR on November 18 for an irradiation period of approximately 25 days.

5.2 Rabbits Containing ^{241}Am

Two rabbits, each containing 1 mg of ^{241}Am sorbed on molecular sieves, were irradiated 5 min for D. O. Campbell. This was part of a series of tests of a new technique for producing enriched isotopes of the actinide elements, using the Campbell reaction.[2]

6. REFERENCES

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3. C. M. Lederer, J. M. Hollander, and I. Perlman, Table of Isotopes, 6th ed., Wiley, New York, 1967.

4. 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 Lederer[3] and Wapstra,[4] 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

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 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 ± 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	2.257 ± 0.046	51In03, 62Wa13, 56Di62
^{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	2.18 ± 0.09	63Ma50, 69Be06, 56Hi01
^{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]	66Fi07, 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, 67Oe01
^{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		$\underline{7370 \pm 40}$ y				68Br22
^{244}Am	10.1 ± 0.1 h					62Va08
^{244m}Am	26 m					54Gh24
^{245}Am	2.07 ± 0.02 h					56Bu92
^{246}Am	25.0 ± 0.2 m					55En16
^{246m}Am	40 ± 7 m					67Or02
^{247}Am	24 ± 3 m					67Or02
^{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		α/SF = $(7.43 \pm 0.01) \times 10^5$		2.84 ± 0.09	65Me02, 68Be26, 56Hi01
^{245}Cm		8265 ± 180 y				69Me01
^{246}Cm		4711 ± 22 y	α/SF = 3822 ± 10		3.08[d]	69Me01
^{247}Cm		$(1.64 \pm 0.20) \times 10^7$ y				63Fi08
^{248}Cm		$(3.84 \pm 0.04) \times 10^5$ y	α/SF = 11.0 ± 3		3.32[d]	69Me01
^{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 ± 8 d		$\alpha/\beta = (1.45 \pm 0.08) \times 10^{-5}$	$(1.87 \pm 0.09) \times 10^{9}$ y	3.72 ± 0.16	57Ea01, 69Mi08, 64Py02
^{250}Bk	3.222 ± 0.005 h					59Va02
^{251}Bk	57 ± 1.7 m					66RG04
^{249}Cf		352 ± 6 y	$\alpha/SF = (1.992 \pm 0.040) \times 10^{8}$		3.44[d]	69Me01, 69Mi08
^{250}Cf		13.08 ± 0.09 y	$\alpha/SF = 1260 \pm 40$		3.56[d]	63Ph01, 69Me01
^{251}Cf		900 ± 50 y				69Me01
^{252}Cf	2.646 ± 0.004 y		$\alpha/SF = 31.3 \pm 0.2$		3.796 ± 0.031	65Me02, 68Wh04
^{253}Cf	17.812 ± 0.082 d		$\alpha/\beta = (3.1 \pm 0.4) \times 10^{-3}$			69Dr02, 66RG01
^{254}Cf	60.5 ± 0.2 d		$\alpha/SF = (3.10 \pm 0.16) \times 10^{-3}$		3.90 ± 0.14	63Ph01, 64Py02, 68Be21
^{255}Cf	1.5 ± 0.5 h					70Lo19
^{253}Es	20.467 ± 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 ± 0.2 h		$\beta/\alpha = 382 \pm 30$ $E.C./\beta = 0.00078 \pm 0.00006$			62Un01, 63Ph01
^{255}Es	39.8 ± 1.2 d		$\alpha/\beta = 0.0866 \pm 0.0043$ $\beta/SF = (2.22 \pm 0.10) \times 10^{4}$		4.16[d]	66RG01, 67Fi03
^{256}Es	25 ± 3 m					68Lo11
^{254}Fm	3.24 ± 0.01 h		$\alpha/SF = 1695 \pm 8$		4.05 ± 0.19	56Jo09, 67Fi03, 56Ch83
^{255}Fm	20.07 ± 0.07 h		$SF/\alpha = (2.4 \pm 1.1) \times 10^{-7}$		4.16[d]	63Ph01, 64As01
^{256}Fm	2.62 ± 0.03 h		~100% SF		4.27[d]	68Ho13
^{257}Fm	94 ± 10 d					66RG01
^{258}Fm	380 ± 60 ms		~100% SF			70Hu17

[a]The half-life values used in this table were being used at TRU at the end of the report period.

[b]References are decoded in Table A-2.

[c]Published values are adjusted for ^{241}Am half-life of 432.7 y.

[d]Value estimated by linear interpolation of the values for ^{244}Cm and ^{252}Cf, based on nuclidic mass.

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.

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, σ^c_{eff}, would be:

$$\sigma^c_{eff} = \sigma^c_{2200} + \frac{\phi_{res}}{\phi_{2200}} \frac{RI}{\sqrt{1 + CN}} ,$$

where σ^c_{2200} 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.

Table A-2. References for Table A-1

Code	Reference
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58Ea06	T. A. Eastwood and R. P. Schuman, J. Inorg. Nucl. Chem., 6, 261-262 (1958).
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59Va02	S. E. Vandenbosch, H. Diamond, R. K. Sjoblom, and P. R. Fields, Phys. Rev., 115, 115-121 (1959).
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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, Nucl. Phys., A96, 440-448 (1967).
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68Br22	L. C. Brown and R. C. Propst, J. Inorg. Nucl. Chem., 30, 2591-2594 (1968).
68Ca19	M. J. Cabell, J. Inorg. Nucl. Chem., 30, 2583-2589 (1968).
68Di09	H. Diamond, J. J. Hines, R. K. Sjoblom, R. F. Barnes, D. N. Metta, J. L. Lerner, and P. R. Fields, J. Inorg. Nucl. Chem., 30, 2553-2559 (1968).
68Ho13	R. W. Hoff, J. E. Evans, E. K. Hulet, R. J. Dupzyk, and B. J. Qualheim, Nucl. Phys., A115, 225-233 (1968).
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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) α	β	Specific Activity (Ci/g)	(W/g)	(α cpm/mg[c])	(β dpm/mg)	(Neutrons min^{-1} mg^{-1})	Hazard[b] $MPC_a(40)$ ($\mu Ci/cm^3$)	Body Burden (μCi)	(μg)
^{237}Np	2.14×10^6 y	4.78		7.07×10^{-4}	2.07×10^{-5}	8.01×10^5		$<7 \times 10^{-6}$	4×10^{-12}	0.06	84.9
^{238}Np	2.10 d		0.25 1.24	2.61×10^5	1.27×10^3		5.80×10^{14}				
^{239}Np	2.359 d		0.332 0.427	2.32×10^5	5.86×10^2		5.14×10^{14}		8×10^{-7}	30	1.29×10^{-4}
^{240}Np	63 m		0.89	1.24×10^7	1.03×10^5		2.76×10^{16}				
^{240m}Np	7.3 m		2.18 1.6	1.07×10^8	5.33×10^5		2.38×10^{17}				
^{241}Np	16 m			4.86×10^7			1.08×10^{17}				
^{241m}Np	3.4 h			3.82×10^6			8.49×10^{15}				
^{238}Pu	87.404 y	5.49		17.2	0.570	1.94×10^{10}		155	2×10^{-12}	0.04	2.32×10^{-3}
^{239}Pu	2.4413×10^4 y	5.15		6.13×10^{-2}	1.913×10^{-3}	6.94×10^7		1.35×10^{-3}	2×10^{-12}	0.04	0.654
^{240}Pu	6580 y	5.16		0.227	7.097×10^{-3}	2.57×10^8		55.7	2×10^{-12}	0.04	0.176
^{241}Pu	14.98 y	4.9	0.02	99.1	4.06×10^{-3}	2.94×10^6	2.20×10^{11}		9×10^{-11}	0.9	9.08×10^{-3}
^{242}Pu	3.869×10^5 y	4.90		3.82×10^{-3}	1.13×10^{-4}	4.32×10^6		95.9	2×10^{-12}	0.05	13.0
^{243}Pu	4.955 h		0.49 0.58	2.60×10^6	3.34×10^3		5.78×10^{15}		2×10^{-6}	7.2	2.78×10^{-6}
^{244}Pu	8.28×10^7 y	4.587		1.77×10^{-5}	4.93×10^{-7}	2.00×10^4		141	2×10^{-12}	0.04	2.23×10^3
^{245}Pu	10.6 h			1.21×10^6			2.68×10^{15}		2×10^{-7}	3.0	4.03×10^5
^{246}Pu	10.85 d		0.15	4.91×10^4	66.9		1.09×10^{14}				
^{241}Am	432.7 y	5.48		3.43	0.1145	3.88×10^9		3.55×10^{-2}	6×10^{-12}	0.1	0.0292
^{242}Am	16.01 h		0.63 0.67	8.11×10^5	2.08×10^3		1.80×10^{15}[d]		4×10^{-8}	0.06	7.39×10^{-8}
^{242m}Am	144 y	5.207	I.T.	10.3	3.08×10^{-2}	5.53×10^7	2.28×10^{10}[e]		6×10^{-12}	0.07	6.80×10^{-3}
^{243}Am	7370 y	5.27		0.200	6.42×10^{-3}	2.26×10^8			6×10^{-12}	0.05	0.25
^{244}Am	10.1 h		0.387	1.27×10^6	8.74×10^3		2.82×10^{15}		2×10^{-7}	0.18	1.42×10^{-7}
^{244m}Am	26 m		1.5	2.96×10^7	8.98×10^4		6.58×10^{16}[f]		4×10^{-6}	0.18	6.08×10^{-9}
^{245}Am	2.07 h		0.91	6.17×10^6	1.20×10^4		1.37×10^{16}		3×10^{-6}	12	1.94×10^{-6}
^{246}Am	25.0 m		1.31	3.06×10^7	2.48×10^5		6.79×10^{16}				
^{246m}Am	40 m			1.91×10^7			4.24×10^{16}				
^{247}Am	24 m			3.17×10^7			7.04×10^{16}				
^{242}Cm	162.7 d	6.11		3.32×10^3	122	3.76×10^{12}		1.21×10^6	1×10^{-10}	0.05	6.27×10^{-7}
^{243}Cm	32 y	5.79		45.9	1.677	5.20×10^{10}	3.27×10^8		6×10^{-12}	0.09	1.96×10^{-3}
^{244}Cm	18.099 y	5.80		80.94	2.832	9.16×10^{10}		6.87×10^5	9×10^{-12}	0.1	1.24×10^{-3}
^{245}Cm	8265 y	5.36		0.177	5.89×10^{-3}	2.00×10^8			5×10^{-12}	0.04	0.263
^{246}Cm	4711 y	5.4		0.409	1.01×10^{-2}	3.50×10^8		5.52×10^5	5×10^{-12}	0.05	0.194
^{247}Cm	1.64×10^7 y			8.83×10^{-5}	$\sim 2.8 \times 10^{-6}$	1.00×10^5			5×10^{-12}	0.04	453
^{248}Cm	3.52×10^5 y	5.05		4.09×10^{-3}	5.32×10^{-4}	4.25×10^6		2.51×10^6	6×10^{-13}	0.01	2.91
^{249}Cm	64 m		0.9	1.18×10^7	2.06×10^4		2.62×10^{16}		8×10^{-6}	0.8	6.78×10^{-8}
^{250}Cm	1.74×10^4 y			8.20×10^{-2}	~ 0.1			6.49×10^8			
^{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}	0.04	1.03×10^{-7}
^{251}Bk	57 m			1.32×10^7			2.92×10^{16}				

Table A-3 (continued)

Nuclide	Half-Life	Energies of Prin. Emissions (MeV) α	β	Specific Activity (Ci/g)	(W/g)	(α cpm/mg[c])	(β dpm/mg)	(Neutrons $min^{-1}mg^{-1}$)	Hazard[b] $MPC_a(40)$ ($\mu Ci/cm^3$)	Body Burden (μCi)	Body Burden (μg)
^{249}Cf	352 y	5.81		4.08	0.152	4.62×10^9		156	2×10^{-12}	0.04	8.98×10^{-3}
^{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}	0.01	1.18×10^{-6}
^{255}Cf	1.5 h			$\sim 8 \times 10^6$							
^{253}Es	20.467 d	6.63		2.52×10^4	1.01×10^3	2.86×10^{13}		1.91×10^7	7×10^{-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	6×10^{-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	2×10^{-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}	0.01	2.14×10^{-9}
^{257}Fm	94 d			5.41×10^3	~200	6.12×10^{12}					
^{258}Fm	380 ms			1.15×10^{11}							

[a]The values for properties included in this table are those in use at TRU at the end of the report period.
[b]From IRCP Publication 2, "Report of Committee II on Permissible Dose for Internal Radiation (1959)" and the 1962 Supplement.
[c]Counting geometry, 51%.
[d]^{242}Am decays by β emission (84%) and orbital electron capture (16%).
[e]^{242m}Am decays almost entirely by isomeric transition to the 16-hr ground state, ^{242}Am.
[f]^{244m}Am decays primarily by β emission, but 0.039% decays by electron capture to ^{244}Pu.

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

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	24,413 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	-	166	1011	0	541
^{242}Pu	386,900 y	18.5	7.409	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	75	2.126	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	12.0	6.9	650	1.2	6.9	12.5
^{245}Cm	8265 y	340	2.4	100	1920	2.4	1140
^{246}Cm	4711 y	1.25	2.4	121	0	0	0
^{247}Cm	1.64×10^7 y	60	0	500	120	0	1060
^{248}Cm	352,000 y	5.2	1.477	250	0	0	0
^{249}Cm	64 m	2.8	0	0	50	0	0
^{250}Cm	17,400 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
^{249}Cf	352 y	450	1.46	750	1690	5.8	2920
^{250}Cf	13.08 y	1900	13.3	6670	0	0	0
^{251}Cf	900 y	2360	14	7000	3280	94	47000
^{252}Cf	2.646 y	19.8	0	44	0	0	56
^{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 ms	0	0	0	0	0	0

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

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 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) $N_c = N_g + N_m$,

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

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

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

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

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

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