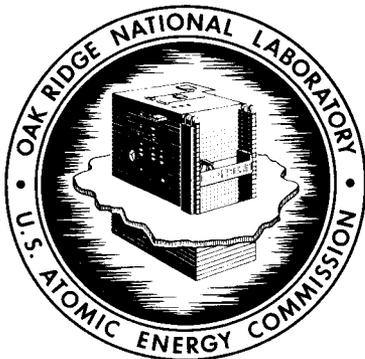


DATE ISSUED: **MAR 12 1970**

ORNL-4447 *Ycy*
UC-80 - Reactor Technology

TRANSURANIUM PROCESSING PLANT
SEMIANNUAL REPORT OF PRODUCTION,
STATUS, AND PLANS
FOR PERIOD ENDING JUNE 30, 1969

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

Printed in the United States of America. Available from Clearinghouse for Federal
Scientific and Technical Information, National Bureau of Standards,
U.S. Department of Commerce, Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

- A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

ORNL-4447

Contract No. W-7405-eng-26

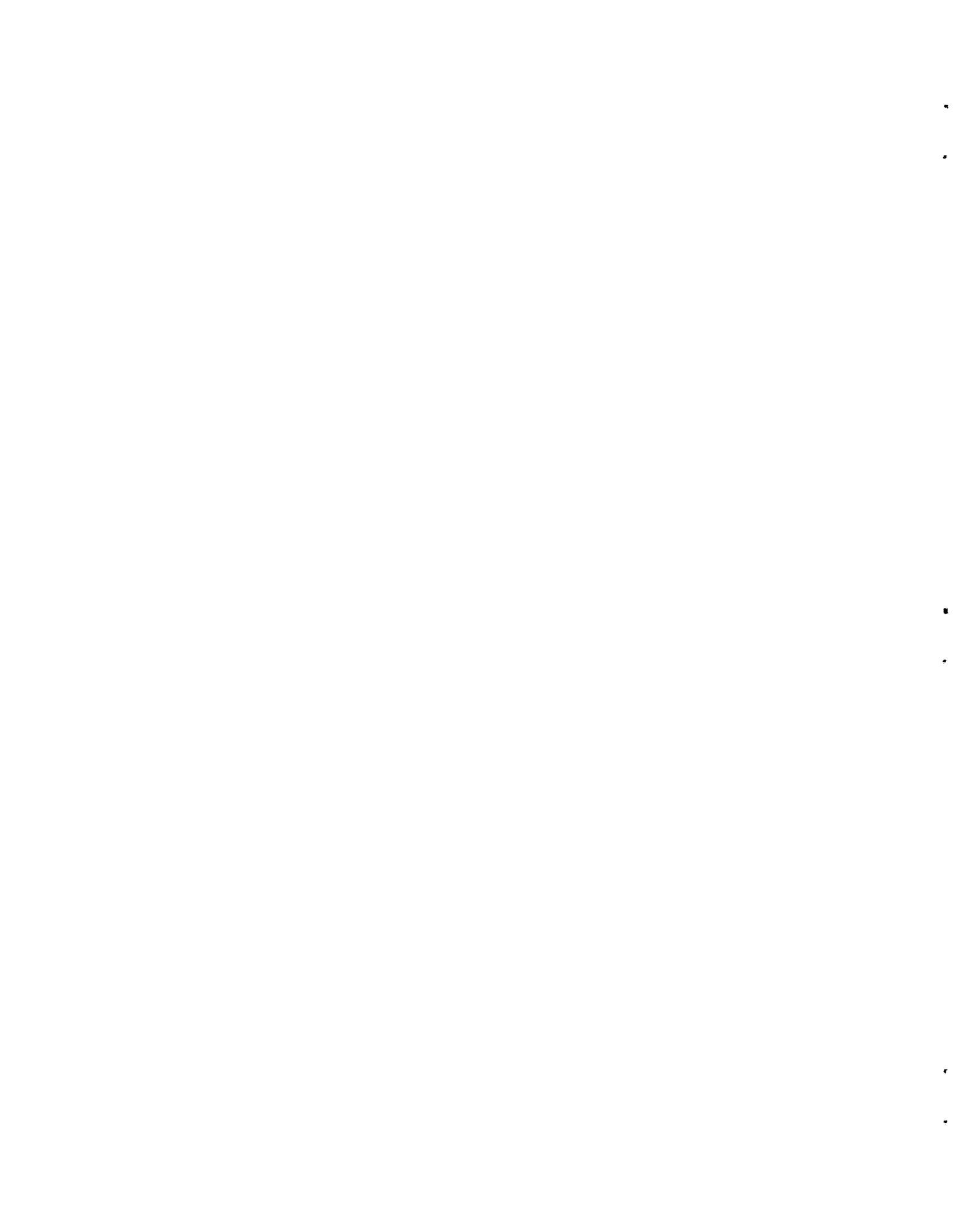
CHEMICAL TECHNOLOGY DIVISION

TRANSURANIUM PROCESSING PLANT
SEMIANNUAL REPORT OF PRODUCTION,
STATUS, AND PLANS
FOR PERIOD ENDING JUNE 30, 1969

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

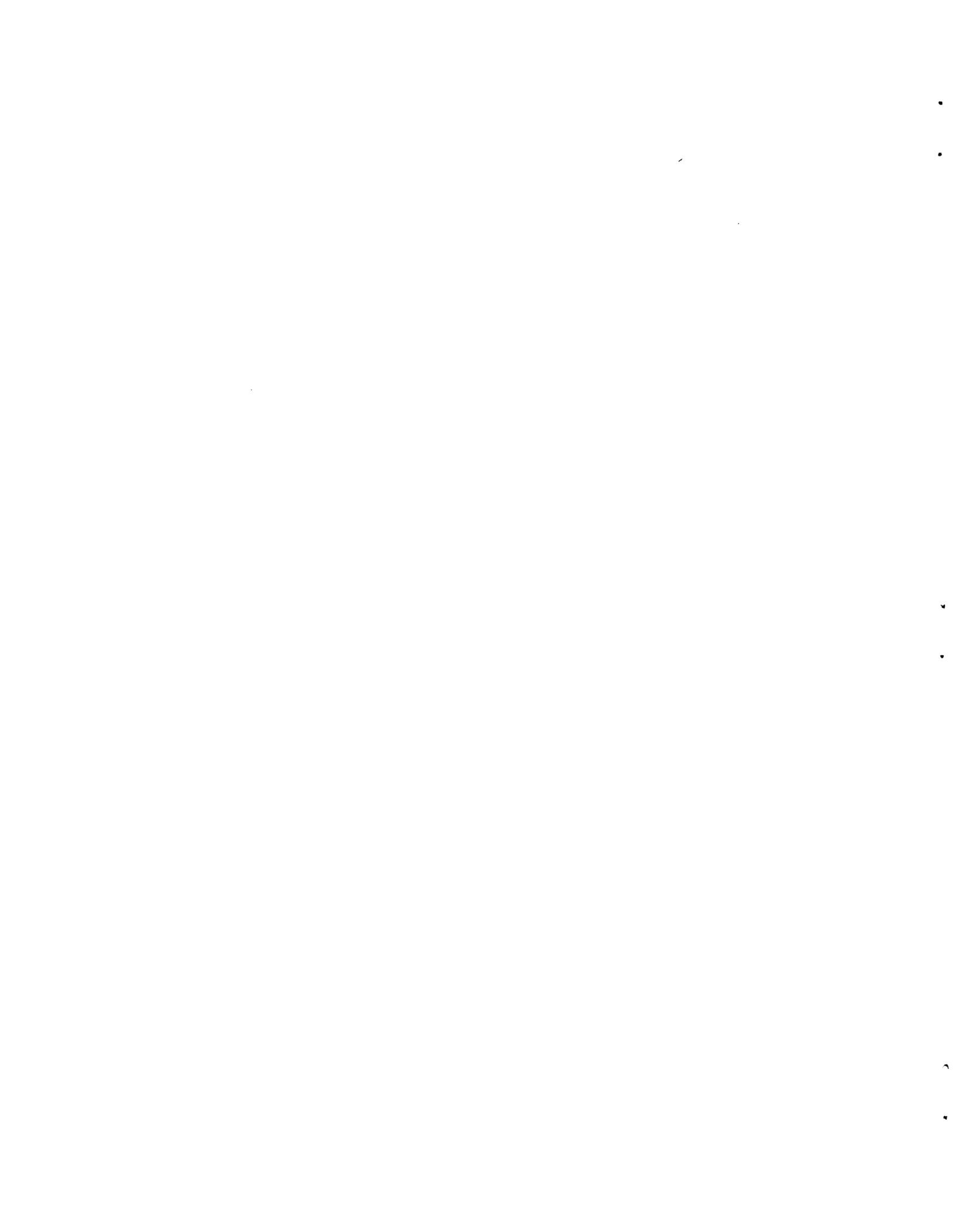
MARCH 1970

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



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
3. Processes and Equipment	9
3.1 Target Dissolution	11
3.2 Recovery of Plutonium	11
3.3 First-Cycle Solvent Extraction Process (Tramex)	11
3.4 Partitioning of Actinides	12
3.5 Separation of Transcurium Elements	12
3.6 Preparation of Actinide Oxides	12
3.7 Fabrication of Targets	15
3.8 Irradiation of ^{252}Cf to Produce ^{253}Es	15
3.9 Analysis of ^{252}Cf by Neutron Activation of Aluminum	16
3.10 Iodine in TRU	16
4. Special Projects	20
4.1 Fabrication of Special Targets	20
4.2 Einsteinium Rabbits	21
4.3 Fabrication of a Neutron Source Using Californium	21
5. References	23
6. Appendix	24



SUMMARY

This is the third 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 the 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.

The total amounts of transuranium elements processed during the period January 1, 1969, to June 30, 1969, are (approximately): 0.3 g of ^{243}Am , 17 g of ^{244}Cm , 9.2 mg of ^{252}Cf , 1.2 mg of ^{249}Bk , 86 μg of ^{253}Es , and 10^8 atoms of ^{257}Fm . We made 50 shipments, which totaled (approximately) 0.29 g of ^{242}Pu , 12 g of ^{243}Am , 4 g of ^{244}Cm , 41 μg of ^{245}Cm (75% ^{245}Cm), 21 μg of ^{247}Cm (20% ^{247}Cm), 77 μg of ^{248}Cm (90% ^{248}Cm), 750 μg of ^{249}Bk , 60 μg of isotopically pure ^{249}Cf , 600 μg of ^{252}Cf in a mixture of californium isotopes, 44 μg of ^{252}Cf that had been irradiated to 99% ^{252}Cf , 17 μg of isotopically pure ^{253}Es , 69 μg of ^{253}Es containing some ^{254}Es and ^{255}Es , and 10^8 atoms of ^{257}Fm .

We anticipate the production of about 7.8 mg of ^{249}Bk , 78 mg of ^{252}Cf , 375 μg of ^{253}Es , and 1×10^9 atoms of ^{257}Fm during the next eighteen months. We expect to produce a total of about 1 g of californium by about 1973.

The sequence of process steps currently being used at TRU is presented, and the status of each step is summarized. The steps are as follows: (1) a feed solution is prepared by dissolving irradiated targets; (2) the plutonium is recovered using a batch solvent extraction process (Pubex); (3) the transplutonium elements are decontaminated from fission products by countercurrent solvent extraction (Tramex); (4) the americium and curium are separated from the transcurium elements by ion exchange or solvent extraction; (5) the transcurium elements are separated from each other by chromatographic elution with α -hydroxyisobutyrate from a high-pressure ion exchange column; (6) the plutonium,

americium, and curium are made into oxides (in the form of microspheres), using a sol-gel technique; and (7) the microspheres are fabricated into HFIR targets, by remote means, for reirradiation to produce more transcurium elements.

Services are also available at TRU by which special materials not normally produced in main-line efforts can be prepared. Four rabbits containing ^{253}Es were prepared and irradiated in the HFIR to produce 39.3-hr $^{254\text{m}}\text{Es}$ for use at ANL in studying the energy level structure of the decay product, ^{250}Bk . A neutron source, containing 100 μg of ^{252}Cf , was fabricated for the Oak Ridge Associated Universities. This source will be used in their training program.

The values that we use 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 third report in a series^{1,2} 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 the 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.

TRU operations during the report period are summarized. Quantities of materials that were produced, processed, and shipped are specified, and proposed processing schedules and anticipated yields of various products are presented. 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. Special processing, fabrication, and irradiation programs are described.

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 usually 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

Only one major processing campaign, in which six recycle curium targets were processed, was completed during the past six months. The curium targets had been fabricated in the remote target fabrication equipment in TRU, using previously prepared americium-curium oxide powder (i.e., powder that had been prepared during developmental work on the curium sol-gel process).² Each target originally contained 4.4 g of ^{244}Cm , 0.3 g of heavier curium isotopes, and 0.8 g of ^{243}Am . The product solutions contained approximately 0.3 g of ^{243}Am , 17 g of ^{244}Cm , 1.2 mg of ^{249}Bk , 9.2 mg of ^{252}Cf , and 68 μg of ^{253}Es .

About 18 μg of einsteinium was recovered from about 2.3 mg of ^{252}Cf that had been irradiated in the HFIR hydraulic rabbit facility. Approximately 2 mg of ^{252}Cf was recovered.

Fifty shipments were made from TRU (see Table 2.1) during the past six months. The following products were included: (1) 0.29 g of ^{242}Pu ; (2) 11.86 g of ^{243}Am and 2.97 g of ^{244}Cm that had been separated and purified; (3) 1.00 g of ^{244}Cm that contained about 16% ^{246}Cm ; (4) 41 μg of ^{245}Cm ($\sim 75\%$ ^{245}Cm), 21 μg of ^{247}Cm ($\sim 20\%$ ^{247}Cm), and 77 μg of ^{248}Cm ($\sim 90\%$ ^{248}Cm) that had been isotopically enriched in the calutrons at the Y-12 Plant; (5) 750 μg of ^{249}Bk ; (6) 60 μg of ^{249}Cf (isotopically pure) that had been "milked" from ^{249}Bk ; (7) 603 μg of ^{252}Cf in a mixture of californium isotopes (75 to 80% ^{252}Cf); (8) 43.85 μg of ^{252}Cf that had been irradiated to 99% ^{252}Cf ; (9) 16.5 μg of ^{253}Es (isotopically pure) that had been "milked" from californium; (10) 68.6 μg of ^{253}Es containing some ^{254}Es and ^{255}Es ; and (11) 10^8 atoms of ^{257}Fm .

An inventory made at the end of this report period showed that we now have the following transuranium materials (exclusive of HFIR targets) on hand: 12 g of ^{242}Pu , 148 g of ^{243}Am , 184 g of ^{244}Cm , 0.3 mg of ^{249}Bk , 3.9 mg of ^{252}Cf , and 22 μg of ^{253}Es .

Table 2.1. Distribution of Heavy Elements
 from the Transuranium Processing Plant
 During the Period January 1, 1969, to June 30, 1969

Major Nuclide	Date	Shipped to	
		Individual	Site
<u>Plutonium-242, g</u>			
0.29	6-12-69	Prod. Support	ORNL-TRU
<u>0.29</u>			
<u>Americium-243, g</u>			
4.11	6-27-69	J. G. Povelites	LASL
1.07	6-27-69	R. O. Budd	PNL
6.68	6-27-69	L. K. Hurst	ANL
<u>11.86</u>			
<u>Curium-244, g</u>			
0.40	1-21-69	Prod. Support	ORNL-TRU
2.00	2-19-69	T. D. Chikalla	PNL
0.45	4-21-69	Isotopes Sales	ORNL
0.12	6-12-69	Prod. Support	ORNL-TRU
<u>2.97</u>			
<u>Curium-244 (16% ^{246}Cm content), g</u>			
1.00	6-17-69	F. B. Simpson	INC
<u>1.00</u>			
<u>Curium (isotopically enriched)</u>			
41 μg of ^{245}Cm ($\sim 75\%$ ^{245}Cm)	6-20-69	B. C. Diven	LASL
21 μg of ^{247}Cm ($\sim 20\%$ ^{247}Cm)	6-20-69	B. C. Diven	LASL
77 μg of ^{248}Cm ($\sim 90\%$ ^{248}Cm)	6-20-69	B. C. Diven	LASL

Table 2.1 (continued)

Major Nuclide	Date	Shipped to	
		Individual	Site
<u>Berkelium-249, μg</u>			
0.1	2-17-69	G. R. Choppin	Fla. St. University
130	4-07-69	P. R. Fields	ANL
130	4-07-69	T. C. Parsons	LRL-B
130	4-07-69	R. W. Hoff	LRL-L
160	4-21-69	O. L. Keller	ORNL-TRL
0.1	4-29-69	Prod. Support	ORNL-TRU
150	5-29-69	P. A. Penneman	LASL
50	6-10-69	M. L. Hyder	SRP
<u>750.2</u>			
<u>Californium-249 (isotopically pure), μg</u>			
50	5-29-69	R. A. Penneman	LASL
10	6-10-69	B. B. Cunningham	LRL-B
<u>60</u>			
<u>Californium-252, μg</u>			
10	1-07-69	Prod. Support	ORNL-TRU
260	5-06-69	J. L. Cason	PNL
10	5-08-69	Isotopes Sales	ORNL
100	5-14-69	H. E. Banta	ORAU
213	5-15-69	A. G. Evans	SRL
0.2	5-29-69	R. A. Penneman	LASL
10	6-12-69	Prod. Support	ORNL-TRU
<u>603.2</u>			

Table 2.1 (continued)

Major Nuclide	Date	Shipped to	
		Individual	Site
<u>Californium-252</u> (irradiated to 99% ^{252}Cf), μg			
2	2-11-69	C. E. Bemis	ORNL-TRL
10	3-19-69	Isotopes Sales	ORNL
0.75	4-24-69	Prod. Support	ORNL-TRU
9	4-28-69	C. E. Bemis	ORNL-TRL
1.1	6-11-69	R. L. Hahn	ORNL-TRL
1	6-11-69	M. S. Moore	LASL
20	6-11-69	Isotopes Sales	ORNL
<u>43.85</u>			
<u>Einsteinium-253</u> (isotopically pure), μg			
8	4-08-69	R. W. Hoff	LRL-L
0.01	4-09-69	C. E. Bemis	ORNL-TRL
0.5 (irradiated)	4-21-69	H. Diamond	ANL
1.5 (irradiated)	5-05-69	H. Diamond	ANL
2.5 (irradiated)	5-26-69	H. Diamond	ANL
4.0 (irradiated)	6-09-69	H. Diamond	ANL
<u>16.51</u>			
<u>Einsteinium-253, μg</u>			
2	2-26-69	T. C. Parsons	LRL-B
2	2-28-69	D. C. Hoffman	LASL
17	2-28-69	R. W. Hoff	LRL-L
17	2-28-69	P. R. Fields	ANL
23	3-13-69	O. L. Keller	ORNL-TRL
3.8	6-27-69	B. B. Cunningham	LRL-B
3.8	6-27-69	R. J. Silva	ORNL-TRL
<u>68.6</u>			
<u>Fermium-257, atoms</u>			
$\sim 1 \times 10^8$	2-28-69	E. K. Hulet	LRL-L

2.2 Irradiation and Processing Proposals

The estimated future production rates of transcurium elements are given in Table 2.2. The estimate of californium production is based on the assumption that 80% of all of the curium isotopes that are recovered during each processing campaign are recycled to the HFIR for transcurium element production. The other 20% is assumed to constitute product shipments (which include, in some cases, mass separation in the calutrons to concentrate heavy isotopes) and processing losses.

Seven irradiated plutonium targets will be processed in September 1969. We expect to recover 3.7 g of ^{242}Pu , 1.6 g of ^{243}Am , 19 g of ^{244}Cm (23 g of total curium), 1.1 mg of ^{249}Bk , 11 mg of ^{252}Cf , and 50 μg of ^{253}Es from these targets.

In February 1970 we will process fourteen irradiated plutonium targets to recover 100 μg of ^{253}Es for use as accelerator target material. This material will be used to produce unusual isotopes. Recovery of about 4 g of ^{242}Pu , 2 g of ^{243}Am , 30 g of ^{244}Cm , 2.2 mg of ^{249}Bk , and 22 mg of ^{252}Cf is anticipated.

Two second-cycle curium targets that will be processed in May 1970 are expected to produce 4 g of curium (26% ^{246}Cm and 2.2% ^{248}Cm), 0.7 mg of ^{249}Bk , 7 mg of ^{252}Cf , and 35 μg of ^{253}Es .

We plan to process three irradiated plutonium targets in July 1970, ten irradiated plutonium targets in November 1970, and four second-cycle curium targets and one third-cycle curium target in December 1970. The first three plutonium targets will contain 0.5 g of ^{242}Pu , 0.3 g of ^{243}Am , and 6 g of ^{244}Cm ; the second group of plutonium targets (i.e., ten targets) will contain 25 g of ^{242}Pu , 9 g of ^{243}Am , and 37 g of ^{244}Cm . Because of differences in irradiation periods, both of these groups of targets will contain the same amounts of transcurium elements: 0.3 mg of ^{249}Bk , 3 mg of ^{252}Cf , and 15 μg of ^{253}Es .

The four second-cycle curium targets will contain 16 g of curium (24.4% ^{246}Cm and 2.1% ^{248}Cm), 2.5 mg of ^{249}Bk , 25 mg of ^{252}Cf , and 125 μg of ^{253}Es . The third-cycle curium target will contain 2.5 g of curium (23% ^{246}Cm and 3.3% ^{248}Cm) 0.7 mg of ^{249}Bk , 7 mg of ^{252}Cf , and 35 μg of ^{253}Es .

Table 2.2. Estimated Future Production of Transcurium Elements

Period	Processing Campaign	Products of Campaigns			²⁵² Cf Production		Date Products Available
		²⁴⁹ Bk (mg)	²⁵² Cf ^a (mg)	²⁵³ Es ^b (μg)	Period (mg)	Cumulative (mg)	
Through June 1969						20	
July - December 1969	7 Pu targets	1.1	11	50(10)	11	31	October 1969
January - June 1970	14 Pu targets	2.2	22	100(20)	29	60	February 1970 May 1970
	2 Cm targets (second cycle)	0.7	7	35(7)			
July - December 1970	3 Pu targets	0.3	3	15(3)	38	98	July 1970 November 1970 December 1970 December 1970
	10 Pu targets	0.3	3	15(3)			
	4 Cm targets (second cycle)	2.5	25	125(25)			
	1 Cm target (third cycle)	0.7	7	35(7)			
1971					~150	~250	
1972					~300	~500	
1973					~450	~1000	
1974					~600	~1500	

^aPresent policy is to reirradiate all californium to burn out heavier isotopes so that isotopically pure ²⁴⁸Cm can be recovered. Handling and irradiation losses will reduce listed amounts by about 20%.

^bThe first number shown indicates the amount obtained in the initial separation. The amount "milked" from the californium product fraction after decay period is given in parentheses.

2.3 Estimates of the Availability of Transuranium Elements

Although plutonium, americium, and curium are usually considered to be intermediate feed materials rather than products, we have purified and distributed isotopes of these elements (primarily ^{242}Pu , ^{243}Am , and ^{244}Cm). We also expect to provide small quantities of the heavy curium isotopes, ^{246}Cm , ^{247}Cm , and ^{248}Cm , for experimental work. However, these isotopes are very fertile feed materials for the production of transcurium elements, and the production rate of transcurium elements would be drastically reduced if a large fraction of the available heavy curium isotopes were removed from the production line.

2.3.1 Berkelium

About 7.8 mg of ^{249}Bk will become available during the next 18 months: 1.1 mg in October 1969, 2.2 mg in February 1970, 0.7 mg in May 1970, 0.3 mg in July 1970, 0.3 mg in November 1970, and 3.2 mg in December 1970.

2.3.2 Californium

We expect to produce 78 mg of ^{252}Cf contained in a mixture of californium isotopes (about 80% ^{252}Cf) during the next 18 months: 11 mg in October 1969, 22 mg in February 1970, 7 mg in May 1970, 3 mg in July 1970, 3 mg in November 1970, and 32 mg in December 1970.

The production of isotopically pure ^{249}Cf by "milking" ^{249}Bk is not anticipated in the next 18 months because we expect to ship all of the berkelium as soon as it becomes available.

2.3.3 Einsteinium

We expect to recover 50 μg of ^{253}Es (about 0.3% of ^{254}Es and 0.06% ^{255}Es) in October 1969, 100 μg in February 1970, 35 μg in May 1970, 15 μg in July 1970, 15 μg in November 1970, and 160 μg in December 1970.

After the mixture of einsteinium isotopes has been separated from it, the purified californium will be stored to allow ^{253}Es to "grow in" from the decay of ^{253}Cf . This second-growth ^{253}Es will then be recovered. About 10, 20, 7, 3, 3, and 32 μg of isotopically pure ^{253}Es will be "milked" from the californium that will be isolated in October 1969, February 1970, May 1970, July 1970, November 1970, and December 1970, respectively.

2.3.4 Fermium

Each batch of recovered californium will contain about 1.5×10^7 atoms of ^{257}Fm per milligram of ^{252}Cf . Thus, about 1.7×10^8 atoms will be available in October 1969, 3.3×10^8 atoms in February 1970, 1×10^8 atoms in July 1970, 4.5×10^7 atoms in July 1970, 4.5×10^7 atoms in November 1970, and 4.8×10^8 atoms in December 1970.

3. PROCESSES AND EQUIPMENT

The processes and equipment that are used in TRU are constantly being modified as our knowledge increases. These modifications range from trivial changes (i.e., changing the concentration of a process stream) to significant ones (i.e., using a completely new process to perform one of the processing steps).

Figure 3.1 is a block diagram showing the processing steps that are required for transuranium element production. These steps are: (1) the preparation of a feed solution by dissolving irradiated targets; (2) the recovery of plutonium; (3) the decontamination of the transplutonium elements from fission products; (4) the separation of americium and curium from the transcurium elements; (5) the separation and purification of berkelium, californium, einsteinium, and fermium; (6) the preparation of americium-curium oxide microspheres; and (7) the fabrication of targets to be irradiated in the HFIR.

ORNL DWG 69-8356

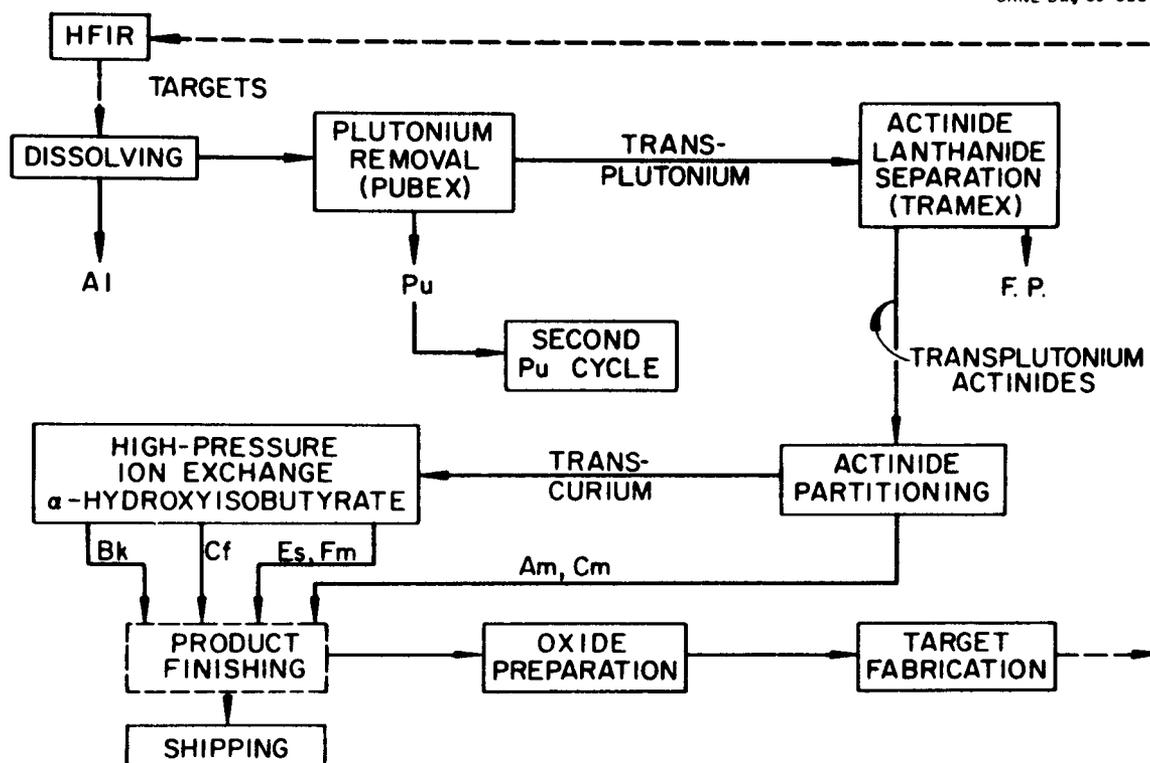


Fig. 3.1. Processing Steps Used for Transuranium Element Production.

3.1 Target Dissolution

We succeeded in increasing, by a factor of 10, the rate at which the caustic-nitrate dejacketing solution was pumped from the dissolver, T-70, by using a larger filter and by reducing the concentration of NaOH and NaNO₃ by a factor of 2. We now use 3 M NaOH--1.5 M NaNO₃ as the caustic dejacketing solution. Laboratory tests have shown that this solution has adequate capacity for dissolving aluminum, is less dense, and, most importantly, is much less viscous than the 6 M NaOH--3 M NaNO₃ solution used previously.

Six recycle curium targets, each of which originally contained 4.4 g of ²⁴⁴Cm, 0.3 g of heavier curium isotopes, and 0.8 g of ²⁴³Am were dissolved during this reporting period.

3.2 Recovery of Plutonium

No changes have been made in the Pubex batch solvent extraction process. However, we did use it for an unusual purpose during the current reporting period. The six curium targets that were processed within this period did not contain any valuable plutonium. Therefore, the Pubex processing step was used simply to remove radioiodine from the feed solution prior to Tramex solvent extraction. Iodine reports almost quantitatively to the solvent in the Pubex process. The tanks used for performing the Pubex extraction are vented through an off-gas treatment system (see Sect. 3.10) that removes iodine, but the equipment for subsequent processing steps is vented to the main VOG header in such a manner that the treatment system is bypassed.

3.3 First-Cycle Solvent Extraction Process (Tramex)

The Tramex solvent extraction process has not been modified since the previous report.

3.4 Partitioning of Actinides

Permanent metal equipment (tantalum) was installed and used for the LiCl-based anion exchange process for separating the transcurium elements from americium and curium. All the product cuts were made, based on in-line alpha monitoring of the column effluent and on neutron and gamma scans of the resin column. Such indications as the green color from nickel during its elution and the red glow from the curium band on the column were not needed.

3.5 Separation of Transcurium Elements

To date, no modifications have been made in the procedures that are used to separate and purify the transcurium elements.

3.6 Preparation of Actinide Oxides

Most of the americium and curium recovered from irradiated targets is incorporated into recycle targets (in the form of americium-curium oxides in pressed aluminum pellets), which are subsequently irradiated in the HFIR to produce transcurium elements. We are developing a sol-gel process for preparing the oxides and have produced 10 g of oxide (6.8 g of ^{244}Cm) that was suitable for incorporation into targets. However, product yields have been low (40 to 60%), and it has been necessary to grind the oxide to obtain the desired particle size distribution. Out-of-cell studies have indicated that some equipment modifications will improve both the product yield and the particle size distribution.

The process involves treatment of the americium-curium product, from either the LiCl-based anion exchange process or the Hepex solvent extraction process, by oxalate precipitation to remove lithium. This purified material is converted to a feed that is 0.1 M in HNO_3 and 0.1 M in actinides. The feed solution is added to an 8 M NH_4OH solution to form a precipitate that is washed, using a fluidized-bed technique, and is concentrated and digested to form a sol. The sol is then converted to gel particles by agitation, in the presence of

a drying solvent, in a stirred pot. The gel particles are calcined at 1150°C to give oxide particles, which are sized (and ground if necessary) and incorporated into targets.

Feed Preparation. - Oxalate precipitation involves concentrating a solution containing from 10 to 20 g of actinides to a volume of 2 to 3 liters and adjusting the acid concentration to 1 M, using NH_4OH . One liter of 0.8 M oxalic acid is added at the rate of about 100 ml/min to the stirred solution, and then water is added to give a final volume of 4 liters. The resultant slurry, which is about 0.5 M in acid--0.2 M $\text{C}_2\text{H}_2\text{O}_4$, is digested at 45°C for 20 min and then cooled to about 25°C. The actinide oxalate precipitate is collected on a medium-frit glass filter and washed, using 0.5 liter of 0.5 M HNO_3 --0.2 M $\text{C}_2\text{H}_2\text{O}_4$. The filter is kept flooded to prevent destruction of the oxalate precipitate by radiation heating. The solids on the filter are dissolved in a small volume of concentrated HNO_3 . If additional purification is required, the process is repeated, beginning with the partial neutralization using NH_4OH .

After the final oxalate precipitation step, the oxalate is destroyed by adding H_2O_2 continuously to the boiling acid solution over a period of several hours.

Feed Adjustment. - Although nitric acid with a concentration of 4 M or greater is required to dissolve the oxalate precipitate, the acid concentration that is desired for the sol-forming step is only 0.1 M. Therefore, the excess acid is removed by precipitating the actinides using NH_4OH , collecting the precipitate on a filter, and washing it with water to remove most of the NH_4NO_3 and excess NH_4OH . The precipitate is then dissolved in 0.1 M HNO_3 to give a feed solution that is about 0.1 M in actinides.

Sol Preparation. - The feed is added to 8 M NH_4OH , which is agitated vigorously, in a conical vessel. The resulting precipitate of americium and curium hydroxides is fluidized and washed continuously with water. The washed precipitate is allowed to settle, the supernate is removed, and the remaining slurry is concentrated and digested to form about 100 ml of sol.

During the recent production runs, about 10 to 20% of the actinides was lost (to rework) during the washing step, and the washing effluent was usually cloudy. This is a major variance from the results of the process development runs in which the washing effluent was sparkling clear and product losses were about 3%. We have been unable to account for this difference in behavior.

The sols that were formed in subsequent processing were reasonably stable and showed satisfactory characteristics during concentration.

Formation of Microspheres. - The equipment rack that was installed in-cell contained a countercurrent, solvent drying column with a two-fluid nozzle for use in forming gel microspheres from the sol. Similar equipment had been used successfully during process development; however, we were not able to obtain satisfactory yields of gel microspheres in-cell because of excessive coalescence or clustering. Because there are several important process variables that would require extensive investigation, we were not able to immediately pinpoint the cause of the difficulty.

We switched to a stirred-pot technique, after making preliminary studies with rare earth sols. The change was made because we were having trouble with the countercurrent column and because the use of a stirred pot eliminated the need to transfer the concentrated sol to a head tank (for feeding the countercurrent column). This change prevented a possible product loss. In the stirred-pot technique, the drying solvent (50% isoamyl alcohol--50% 2-ethylhexanol) is added to the sol in the conical vessel in which the sol is formed. Then the mixture is stirred to form gel particles. About one-half of the feed to the sol-forming step is recovered as usable oxide after grinding. The rest is recovered for rework. This technique is attractive since continued stirring results in usable products even when poor operation (sticking to the walls or large particle formation) is obtained initially.

We have been making laboratory studies, using rare earth sols, to find the combination of mixing parameters (agitator size and location, mixing speed, and the use of baffles) that will give us better particle size distribution and higher product yields.

3.7 Fabrication of Targets

Ten ordinary HFIR targets and two special targets (Sect. 4.1) were fabricated during this report period. Each of the ordinary targets contained 11.32 g of PuO_2 (approximately 9.7 g of ^{242}Pu) in 35 PuO_2 -aluminum pellets pressed to 80% of the theoretical density of the pellet core.

Eleven targets (rabbits) were fabricated for irradiation in the HFIR hydraulic rabbit facility; one contained ^{249}Bk , six contained ^{253}Es (Sect. 4.2), and four contained ^{252}Cf .

3.8 Irradiation of ^{252}Cf to Produce ^{253}Es

Seven californium rabbits were irradiated and processed during this reporting period. One rabbit, which contained 10 μg of ^{252}Cf , was irradiated 8 days in the HFIR hydraulic rabbit facility to provide additional information on the cross sections of californium. The information obtained from this rabbit, in conjunction with the data from an earlier rabbit irradiated for 3 days, confirmed that the activation cross section of ^{252}Cf (σ_c) was 20 barns. It also shows that the total destruction cross section of ^{253}Cf (σ_a) is on the order of 1300 barns (mainly fission), suggesting that the half-life of ^{253}Cf in the rabbit facility is 2.14 days. Since the conditions of fabrication precluded a precise assay of ^{252}Cf loss, the absorption cross section of ^{252}Cf was not measured.

Approximately 18 μg of ^{253}Es was recovered from the irradiation of about 2.3 mg of ^{252}Cf in the HFIR hydraulic rabbit facility. About 2 mg of ^{252}Cf was recovered. The californium was impregnated in cerium oxide microspheres in two heavily loaded rabbits (1 to 1.5 mg of ^{252}Cf each) that were irradiated a total of 10 days (four irradiation periods, each of which was separated by 10 to 18 days to allow for ^{253}Cf to decay to ^{253}Es without undergoing fission).

3.9 Analysis of ^{252}Cf by Neutron Activation of Aluminum

The aluminum discs used for neutron activation analysis² become contaminated during manipulations in the cell bank. Contamination by most radionuclides would be unimportant at the high energy (2.75 Mev) level at which the ^{24}Na is detected; however, we have discovered that ^{252}Cf is an important source of contamination in this respect since the γ -rays produced in spontaneous fission form a continuum that causes a significant rise in the background in the vicinity of the 2.75-Mev peak. Now that we are aware of this, we can guard against future difficulties by measuring the amount of californium contamination on each disc by neutron counting and then correcting the gamma decay rate for the californium-produced gamma emission.

3.10 Iodine in TRU

It is desirable to process irradiated targets very soon after they are removed from the HFIR in order to recover the maximum possible amount of ^{253}Es , which has a half-life of 20 days. The major obstacle to the processing of short-cooled targets is the presence of about 200 Ci of ^{131}I in each target when it is discharged from the reactor. We have attempted to trap radioiodine by using beds of KI-impregnated charcoal. However, organic solvents in the off-gas streams quickly poison the charcoal against iodine retention.

Significant amounts of ^{131}I have been present in five processing campaigns. After the fourth campaign, at the start of which the targets contained 360 Ci of ^{131}I , we still had not developed satisfactory iodine control measures. Although we had not released large quantities to the atmosphere, we had been constantly faced with the possibility that some inadvertent release would force us to suspend operations at least temporarily. Such an incident would have resulted in a complete loss of the einsteinium by decay.

The process steps that had been shown to cause iodine to be released were: (1) transfer of aged caustic dejacketing waste solutions within the plant, (2) boiling of iodine-bearing acid solutions during target dissolution and Pubex feed adjustment, and (3) air sparging to contact the phases during the Pubex batch extraction step. Since the transplutonium-element product fraction from the Pubex step was found to contain only a few tenths of one percent of the iodine, we have not investigated the behavior of iodine in subsequent processing steps.

The highly radioactive caustic-nitrate waste solutions were found to contain volatile forms of iodine--especially after being stored for a few weeks. This is contrary to the behavior observed for non-radioactive caustic solutions, in which iodine is found only in the nonvolatile iodide and iodate forms.

In the most recent processing campaign, sodium hypochlorite (NaOCl) was added to the waste caustic solutions to oxidize the iodine to the nonvolatile iodate or periodate forms. This treatment proved to be so effective that we were unable to volatilize iodine from some of the solution during a test of the off-gas treatment system. This can be contrasted with our experience in an earlier campaign in which, after an equivalent aging period (i.e., about 3 weeks), almost 10% of the contained iodine was released from some dejacketing waste by merely pumping it from one tank to another.

Modifications were made in plant piping to permit all process and waste solutions containing significant amounts of radioiodine to be handled and stored in tanks that were vented through the condensate collection system serving the dissolver and the seven process evaporators. Thus, most of the iodine-bearing off-gas was confined to a 3-cfm stream instead of being dispersed throughout the 350-cfm vessel off-gas (VOG) stream. An experimental iodine-removal system, consisting of a caustic scrubber (to remove acid vapors), a heater, a bed of Hopcalite* (to convert organics to CO_2 and H_2O , and to protect the charcoal trap from organics), a cooler, and a charcoal trap, was placed in the 3-cfm off-gas stream.

*Hopcalite is an oxidation catalyst consisting of a CuO-MnO_2 mixture that has been treated to give a large surface area. It is a proprietary material of the Mine Safety Appliance Company.

A few tests indicated that Hopcalite would decompose organic vapors present in the TRU off-gas at 300 to 350°C. Previous attempts to trap radioiodine, using beds of KI-impregnated charcoal, had been unsuccessful because organic solvents, which are used in various processing steps, were transported to off-gas streams in amounts that quickly poisoned the beds against iodine retention. We did not study Hopcalite exhaustively; no other catalysts were tested.

The process for removing iodine from the condensate system off-gas is shown in Fig. 3.2. After the off-gas is scrubbed to remove HCl vapors, it is heated electrically and passed to the bed of catalyst, which is maintained at 650°F (350°C). The effluent from the catalyst is cooled, passed through a 7-in.-thick bed of KI-impregnated charcoal, and then added to the main vessel off-gas. The charcoal bed is operated at about 120°F (50°C).

During the 7 weeks required to process the six recycle curium targets (see Sect. 2.1), which contained a total of 400 Ci of ^{131}I at the beginning of the campaign, 300 mCi of iodine was released to the environment. (In the previous campaign, which consisted of targets containing a comparable amount of ^{131}I at the beginning of processing, 2 Ci was released.) Of a total of 2.5 Ci of ^{131}I routed to the iodine removal system, only 6 mCi was discharged; the remainder of the 300 mCi that was released to the atmosphere resulted from the handling of solutions in parts of the plant not protected by the iodine removal system. Decontamination factors for ^{131}I varied from 100 to 10^4 across the iodine removal system and averaged 400.

These results indicate that, in future processing, we can expect to maintain an iodine DF of 10^3 to 10^4 . This is certainly satisfactory for processing short-cooled targets. We are now investigating a larger system for installation in the total vessel and cubicle off-gas system (350 cfm).

ORNL-DWG 69-583A

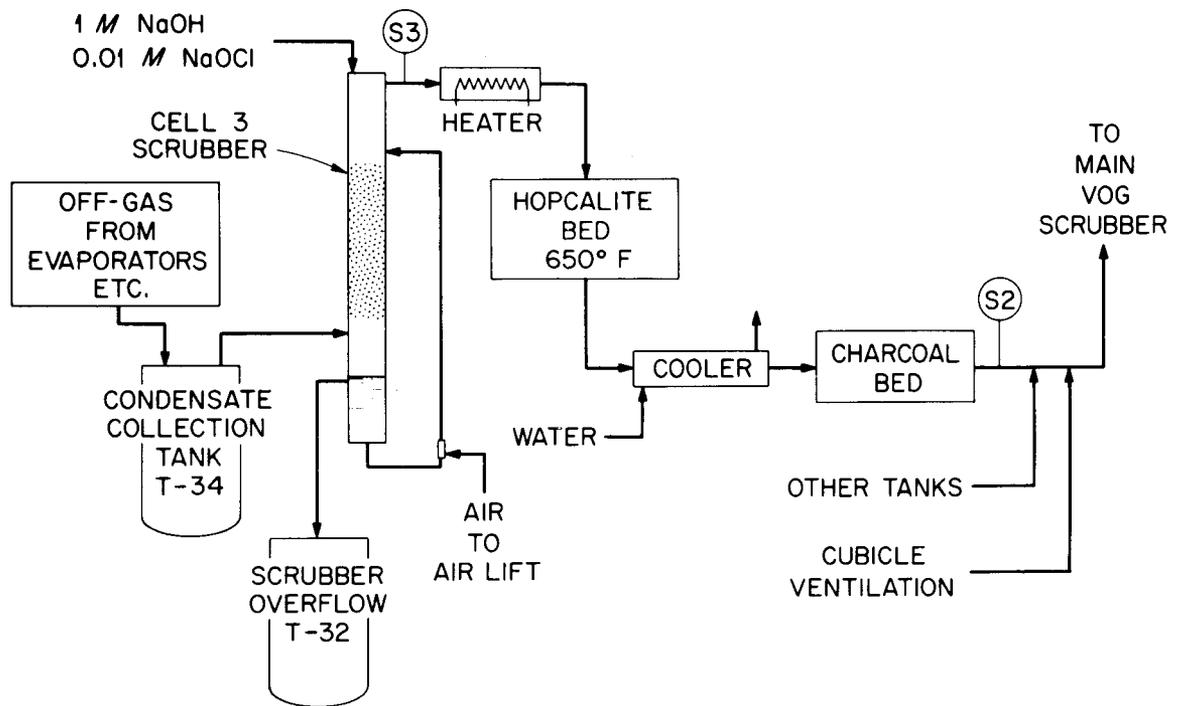


Fig. 3.2. Iodine-Removal Process for the Condensate-Collection System Off-Gas.

4. SPECIAL PROJECTS

Projects that are being carried out by various groups at ORNL and at other sites require the services available at TRU for the preparation of special materials that are not normally produced in main-line efforts. The phases of these projects involving activities at TRU are reported here; the end results of the research are reported elsewhere.

4.1 Fabrication of Special Targets

We fabricated a special target (ST-4) containing six different special-purpose materials (listed below) in addition to 19 ^{244}Cm pellets that were to be irradiated to produce transuranium elements. The special materials were as follows:

1. One curium pellet identical to the 19 ^{244}Cm pellets that were to be irradiated to produce transuranium elements. This pellet was isolated from the others to facilitate analysis for cross-section measurement.

2. One pellet containing 10 μg of ^{252}Cf for measurement of steady-state ratios of heavy californium isotopes. Comparison of the data obtained from this pellet with data from similar pellets irradiated in other target positions will provide an evaluation of the effects of flux spectrum on cross sections.

3. One pellet containing 285 mg of ^{242}Pu . This material is free of ^{244}Pu and will be used to study cross sections leading to ^{244}Pu production.

4. Two special containers, called Phoenix capsules, containing a total of 150 μg of ^{248}Cm that was supplied by C. E. Bemis, Chemistry Division, ORNL. Phoenix capsules are Zircaloy-2 containers with screwed closures; each holds a quartz ampul. The ^{248}Cm was irradiated to produce ^{250}Cm and also to purify the ^{248}Cm by burning out lower isotopes. Our objective was to recover the Phoenix capsules

intact after the target was irradiated and to load them into new, special targets for further irradiation. The capsules will be irradiated in four or five targets successively. This method is being employed because the ^{248}Cm must be irradiated for a very long time and the use of an entire target position for such a small quantity of target material does not seem warranted.

5. Five flux monitors.

6. Two packages containing aluminum specimens for study by the Mechanical Properties Group of the Metals and Ceramics Division.

After target ST-4 was irradiated for five cycles in the HFIR, the Phoenix capsules were recovered and placed in special target ST-5; 19 curium pellets, one ^{242}Pu pellet, one ^{252}Cf pellet, and 5 flux monitor assemblies were also included in this target.

4.2 Einsteinium Rabbits

A series of four einsteinium rabbits (originally containing 0.5 to 2.5 μg of ^{253}Es) were fabricated, irradiated, and delivered to H. Diamond at ANL for use in studying the energy level structure of the decay product, ^{250}Bk . The einsteinium was encapsulated in quartz vials (instead of pressed aluminum pellets), which were enclosed in the aluminum rabbit tube. The induced radiation in the ultrapure quartz is substantially less than that which we have experienced with aluminum pellets. This lower radiation level allows us to use a lighter carrier for the shipment to ANL and permits shipment from the Knoxville airport instead from Atlanta.

Two rabbits containing 0.2 μg ^{253}Es were fabricated for use at ORNL to measure cross sections.

4.3 Fabrication of a Neutron Source Using Californium

A neutron source (NS-3) containing 100 μg of ^{252}Cf in a welded, stainless steel capsule was fabricated for the Oak Ridge Associated Universities for use in their training program. In the new technique that was used to fabricate the source, an aluminum pellet liner

having a porous aluminum bottom was filled with ion exchange resin. A tubing fitting was attached to the pellet liner, using a special aluminum insert to support the walls, and a solution of californium was pumped through the pellet liner. The californium was sorbed on the resin, which was later thermally decomposed to a carbonaceous mass that was sealed into the pellet by the usual pellet pressing technique.

5. REFERENCES

1. 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.
2. 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, 1968, ORNL-4428.
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).

6. 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 Lederer³ 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.

6.1 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

Table A-1. Half-Life Values^a for Isotopes of Transuranium Elements
Underlines indicate new values since the previous report.

Nuclide	Total Half-Life	Reference ^b	Partial Half-Life for Spontaneous Fission	Reference ^b
²³⁷ Np	$(2.14 \pm 0.01) \times 10^6$ y	60Br12	$>10^{18}$ y	61Dr4
²³⁸ Np	2.10 ± 0.01 d	50F53		
²³⁹ Np	2.359 ± 0.010 d	59C93		
²⁴⁰ Np	63 ± 2 m	60Le3		
^{240m} Np	7.3 ± 0.3 m	48H61		
²⁴¹ Np	16 m	60Le3		
^{241m} Np	3.4 h	60Le3		
²³⁸ Pu	87.404 ± 0.041 y	68Jo15	$(5 \pm 0.6) \times 10^{10}$ y	61Dr4
²³⁹ Pu	24.413 ± 30 y	59M126	5.5×10^{15} y	52S67
²⁴⁰ Pu	6580 ± 40 y	51I13	$(1.340 \pm 0.015) \times 10^{11}$ y	62Wal3
²⁴¹ Pu	14.98 ± 0.33 y	68Ca19		
²⁴² Pu	$(3.869 \pm 0.016) \times 10^5$ y	69Be06	$(7.45 \pm 0.17) \times 10^{10}$ y	63Ma50
²⁴³ Pu	4.955 ± 0.003 h	68Di09		
²⁴⁴ Pu	$(8.28 \pm 0.10) \times 10^7$ y	69Be06	$(6.55 \pm 0.32) \times 10^{10}$ y	66F107
²⁴⁵ Pu	10.6 ± 0.4 h	56B92		
²⁴⁶ Pu	10.85 ± 0.02 d	56H23		
²⁴¹ Am	432.7 ± 0.7 y	67Oe01	$(2.3 \pm 0.8) \times 10^{14}$ y	61Dr4
²⁴² Am	16.01 ± 0.02 h	53K38		
^{242m} Am	144 ± 7 y	59B221 ^c		
²⁴³ Am	7340 ± 50 y			
²⁴⁴ Am	10.1 ± 0.1 h	62Va8		
^{244m} Am	26 m	54G24		
²⁴⁵ Am	2.07 ± 0.02 h	56B92		
²⁴⁶ Am	25.0 ± 0.2 m	55E16		
^{246m} Am	40 ± 7 m	67Or02		
²⁴⁷ Am	24 ± 3 m	67Or02		
²⁴² Cm	162.7 ± 0.1 d	57P52	7.2×10^6 y	51H87
²⁴³ Cm	32 y	57A70		
²⁴⁴ Cm	18.099 ± 0.015 y	68Be26	$(1.346 \pm 0.006) \times 10^7$ y	65Me02
²⁴⁵ Cm	<u>8265 ± 180 y</u>	69Me01		
²⁴⁶ Cm	<u>4711 ± 22 y</u>	69Me01	<u>$(1.80 \pm 0.01) \times 10^7$ y</u>	69Me01
²⁴⁷ Cm	$(1.64 \pm 0.20) \times 10^7$ y	63F108		
²⁴⁸ Cm	<u>$(3.52 \pm 0.14) \times 10^5$ y</u>	69Me01	<u>$(4.22 \pm 0.12) \times 10^6$ y</u>	69Me01
²⁴⁹ Cm	64 ± 3 m	58E06		
²⁵⁰ Cm	$(1.74 \pm 0.24) \times 10^4$ y	66RG01	$(1.74 \pm 0.24) \times 10^4$ y	66RG01
²⁴⁹ Bk	314 ± 8 d	57E01	$>1.4 \times 10^9$ y	57E01
²⁵⁰ Bk	3.222 ± 0.005 h	59V02		
²⁵¹ Bk	57 ± 1.7 m	66RG04		

Table A-1 (continued)

Nuclide	Total Half-Life	Reference ^b	Partial Half-Life for Spontaneous Fission	Reference ^b
²⁴⁹ Cf	<u>352 ± 6 y</u>	69Me01	4.5×10^8 y	57E01
²⁵⁰ Cf	<u>13.06 ± 0.09 y</u>	69Me01	$(1.73 \pm 0.06) \times 10^4$ y	63Ph01
²⁵¹ Cf	<u>900 ± 50 y</u>	69Me01		
²⁵² Cf	2.646 ± 0.004 y	65Me02	85.5 ± 0.5 y	65Me02
²⁵³ Cf	<u>17.812 ± 0.082 d</u>	69Dr02		
²⁵⁴ Cf	60.5 ± 0.2 d	63Ph01	60.5 ± 0.2 d	63Ph01
²⁵³ Es	<u>20.467 ± 0.024 d</u>	69Dr02	$(6.3 \pm 0.2) \times 10^5$ y	65Me02
²⁵⁴ Es	276 d	67Un01	$> 2.5 \times 10^7$ y	67F103
^{254m} Es	39.3 ± 0.2 h	62Un1		
²⁵⁵ Es	39.8 ± 1.2 d	66RG01	2440 ± 140 y	67F103
²⁵⁶ Es	25 ± 3 m	68Lo11		
²⁵⁴ Fm	3.24 ± 0.01 h	56J09	228 ± 1 d	67F103
²⁵⁵ Fm	20.07 ± 0.07 h	64As01	$(1.0 \pm 0.6) \times 10^4$ y	63Ph01
²⁵⁶ Fm	2.62 ± 0.03 h	68Ho13	2.62 ± 0.03 h	68Ho13
²⁵⁷ Fm	94 ± 10 d	66RG01		

^aThe half-life values used in this table were being used at TRU on July 1, 1969.

^bReferences are decoded in Table A-2.

^cPublished value was adjusted for ²⁴¹Am half-life of 432.7 y.

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.

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.

6.2 Neutron Cross-Section Data

The values of neutron cross sections used to compute transmutions 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:

$$\sigma_{\text{eff}}^{\text{c}} = \sigma_{2000}^{\text{c}} + \frac{\phi_{\text{res}}}{\phi_{2200}} \frac{\text{RI}}{\sqrt{1 + \text{CN}}},$$

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.

Table A-2. References for Table A-1.

Code	Reference	Code	Reference
48H61	E. K. Hyde, M. H. Studier, and W. M. Manning, ANL-4143 (April 15, 1948) and ANL-4182 (August 4, 1948).	62Un1	J. Unik, P. Day, and S. Vandenbosch, <u>Nucl. Phys.</u> , <u>36</u> , 284-304 (1962).
50F53	M. S. Freedman, A. H. Jaffey, and F. Wagner, Jr., <u>Phys. Rev.</u> , <u>79</u> , 410-411 (1950).	62Va8	S. E. Vandenbosch and P. Day, <u>Nucl. Phys.</u> , <u>30</u> , 177-190 (1962).
51H87	G. C. Hanna, B. G. Harvey, N. Moss, and P. R. Tunncliffe, <u>Phys. Rev.</u> , <u>81</u> , 466-467 (1951).	62Wa13	D. E. Watt, F. J. Bannister, J. B. Laidler, and F. Brown, <u>Phys. Rev.</u> , <u>126</u> , 264-265 (1962).
51I13	M. G. Inghram, D. C. Hess, P. R. Fields, and G. L. Pyle, <u>Phys. Rev.</u> , <u>83</u> , 1250 (1951).	63F108	P. R. Fields, A. M. Friedman, J. Lerner, D. Metta, and R. Sjoblom, <u>Phys. Rev.</u> , <u>131</u> , 1249-1250 (1963).
52S67	E. Segrè, <u>Phys. Rev.</u> , <u>86</u> , 21-28 (1952).	63Ma50	L. Z. Malkin, I. D. Alkhozov, A. S. Krivokhataki, and K. A. Petrzhak, <u>At. Energ. (USSR)</u> , <u>15</u> , 158-159 (1963).
53K38	T. K. Keenan, R. A. Penneman, and B. B. McInteer, <u>J. Chem. Phys.</u> , <u>21</u> , 1802-1803 (1953).	63Ph01	L. Phillips, R. Gatti, R. Brandt, and S. G. Thompson, <u>J. Inorg. Nucl. Chem.</u> , <u>25</u> , 1085-1087 (1963).
54G24	A. Chiorso, S. G. Thompson, G. R. Choppin, and B. G. Harvey, <u>Phys. Rev.</u> , <u>94</u> , 1081 (1954).	64As01	F. Asaro, S. Bjornholm, and I. Perlman, <u>Phys. Rev.</u> , <u>133</u> , B291-B300 (1964).
55E16	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> , <u>1</u> , 345-351 (1955).	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> , <u>27</u> , 33-35 (1965).
56B92	J. P. Butler, T. A. Eastwood, T. L. Collins, M. E. Jones, F. M. Rourke, and R. P. Schuman, <u>Phys. Rev.</u> , <u>103</u> , 634 (1956).	66F107	P. R. Fields, A. M. Friedman, J. Milsted, J. Lerner, C. M. Stevens, D. Metta, and W. K. Sabine, <u>Nature</u> , <u>212</u> , 131 (1966).
56H23	D. C. Hoffman and C. I. Browne, <u>J. Inorg. Nucl. Chem.</u> , <u>2</u> , 209 (1956).	66RG01	Combined Radiochemistry Group, LRL, LASL, and ANL, <u>Phys. Rev.</u> , <u>148</u> , No. 3, 1192-1198 (1966).
56J09	M. Jones, R. P. Schuman, J. P. Butler, G. Cowper, T. A. Eastwood, and H. G. Jackson, <u>Phys. Rev.</u> , <u>102</u> , 203-207 (1956).	66RG04	Argonne Heavy Element Group (unpublished data).
57A70	F. Asaro, S. G. Thompson, F. S. Stephens, Jr., and I. Perlman, <u>Bull. Am. Phys. Soc.</u> , <u>8</u> , 393 (1957).	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> , <u>A96</u> , 440-448 (1967).
57E01	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> , <u>107</u> , 1635-1638 (1957).	67Oe01	F. L. Oetting and S. R. Gunn, <u>J. Inorg. Nucl. Chem.</u> , <u>29</u> , 2659-64 (1967).
57P52	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> , <u>2</u> , 6-11 (1957).	67Or02	C. J. Orth, W. R. Daniels, B. H. Erkkila, F. O. Lawrence, and D. C. Hoffman, <u>Phys. Rev. Letters</u> , <u>19</u> , No. 3, 128-131 (1967).
58E06	T. A. Eastwood and R. P. Schuman, <u>J. Inorg. Nucl. Chem.</u> , <u>6</u> , 261-262 (1958).	67Un01	J. Unik, private communication to P. Fields (1967).
59B221	R. F. Barnes, D. J. Henderson, A. L. Harkness, and H. Diamond, <u>J. Inorg. Nucl. Chem.</u> , <u>2</u> , 105-107 (1959).	68Be26	W. C. Bentley, <u>J. Inorg. Nucl. Chem.</u> , <u>30</u> , 2007-9 (1968).
59C93	D. Cohen, J. C. Sullivan, and A. J. Zielen, <u>J. Inorg. Nucl. Chem.</u> , <u>11</u> , 159-161 (1959).	68Ca19	M. J. Cabell, <u>J. Inorg. Nucl. Chem.</u> , <u>30</u> , 2583-9 (1968).
59M126	T. L. Markin, <u>J. Inorg. Nucl. Chem.</u> , <u>2</u> , 320-322 (1959).	68D109	H. Diamond, J. J. Hines, R. K. Sjoblom, R. F. Barnes, D. N. Metta, J. L. Lerner, and P. R. Fields, <u>J. Inorg. Nucl. Chem.</u> , <u>30</u> , 2553-9 (1968).
59V02	S. E. Vandenbosch, H. Diamond, R. K. Sjoblom, and P. R. Fields, <u>Phys. Rev.</u> , <u>115</u> , 115-121 (1959).	68Ho13	R. W. Hoff, J. E. Evans, E. K. Hulet, R. J. Dupzyk, and B. J. Qualheim, <u>Nucl. Phys.</u> , <u>A112</u> , 225-33 (1968).
60Br12	F. P. Brauer, R. W. Stromatt, J. D. Ludwick, F. P. Roberts, and W. L. Lyon, <u>J. Inorg. Nucl. Chem.</u> , <u>12</u> , 234-235 (1960).	68Jo15	K. C. Jordan, <u>MM-1443</u> , 11-30 (1968).
60Le3	R. M. Lessler and M. C. Michel, <u>Phys. Rev.</u> , <u>118</u> , 263-264 (1960).	68Lo11	R. W. Loughheed, private communication to J. E. Bigelow (1968).
61Dr4	V. A. Druin, V. P. Pereygin, and G. I. Khlebnikov, <u>Sov. Phys. JETP</u> , <u>13</u> , 913-914 (1961).	69Be06	C. E. Bemis, Jr., J. Halperin, and R. Eby, <u>J. Inorg. Nucl. Chem.</u> , <u>31</u> , 599-604 (1969).
		69Dr02	R. E. Drushel, J. Halperin, and C. E. Bemis, Jr. To be published.
		69Me01	D. N. Metta, H. Diamond, and F. R. Kelly, <u>J. Inorg. Nucl. Chem.</u> , <u>31</u> , 1245-1250 (1969).

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				Hazard ^b			
		α	β	(Ci/g)	(w/g)	(α cpm/mg ^c)	(β dpm/mg)	(Neutrons min ⁻¹ mg ⁻¹)	MPC _a (40)	Body Burden	
									(μCi/cm ³)	(μCi)	(μg)
²³⁷ Np	2.14 x 10 ⁶ y	4.78		7.07 x 10 ⁻⁴	2.07 x 10 ⁻⁵	8.01 x 10 ⁵			4 x 10 ⁻¹²	0.06	84.9
²³⁸ Np	2.10 d		0.25 1.24	2.61 x 10 ⁵	1.27 x 10 ³		5.80 x 10 ¹⁴				
²³⁹ Np	2.359 d		0.332 0.427	2.32 x 10 ⁵	5.86 x 10 ²		5.14 x 10 ¹⁴		8 x 10 ⁻⁷	30	1.29 x 10 ⁻⁴
²⁴⁰ Np	63 m		0.89	1.24 x 10 ⁷	1.03 x 10 ⁵		2.76 x 10 ¹⁶				
^{240m} Np	7.3 m		2.18 1.6	1.07 x 10 ⁸	5.33 x 10 ⁵		2.38 x 10 ¹⁷				
²⁴¹ Np	16 m			4.86 x 10 ⁷			1.08 x 10 ¹⁷				
^{241m} Np	3.4 h			3.82 x 10 ⁶			8.49 x 10 ¹⁵				
²³⁸ Pu	87.404 y	5.49		17.2	0.570	1.94 x 10 ¹⁰		<u>155</u>	2 x 10 ⁻¹²	0.04	2.32 x 10 ⁻³
²³⁹ Pu	24,413 y	5.15		6.13 x 10 ⁻²	1.913 x 10 ⁻³	6.94 x 10 ⁷			2 x 10 ⁻¹²	0.04	0.654
²⁴⁰ Pu	<u>6580 y</u>	5.16		0.227	<u>7.097 x 10⁻³</u>	2.57 x 10 ⁸		<u>55.7</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>95.9</u>	2 x 10 ⁻¹²	0.05	13.0
²⁴³ Pu	4.955 h		0.49 0.58	2.60 x 10 ⁶	3.34 x 10 ³		5.78 x 10 ¹⁵		2 x 10 ⁻⁶	7.2	2.78 x 10 ⁻⁶
²⁴⁴ Pu	8.28 x 10 ⁷ y	4.587		1.77 x 10 ⁻⁵	4.93 x 10 ⁻⁷	2.00 x 10 ⁴		374	2 x 10 ⁻¹²	0.04	2.23 x 10 ³
²⁴⁵ Pu	10.6 h			1.21 x 10 ⁶			2.68 x 10 ¹⁵		2 x 10 ⁻⁷	3.0	4.03 x 10 ⁵
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		0.04	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	7340 y	5.27		0.200	6.45 x 10 ⁻³	2.27 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		2 x 10 ⁻⁷	0.18	1.42 x 10 ⁻⁷
^{244m} Am	26 m		1.5	2.96 x 10 ⁷	8.98 x 10 ⁴		6.58 x 10 ^{16f}		4 x 10 ⁻⁶	0.18	6.08 x 10 ⁻⁹
²⁴⁵ Am	2.07 h		0.91	6.17 x 10 ⁶	1.20 x 10 ⁴		1.37 x 10 ¹⁶		3 x 10 ⁻⁶	12	1.94 x 10 ⁻⁶
²⁴⁶ Am	25.0 m		1.31	3.06 x 10 ⁷	2.48 x 10 ⁵		6.79 x 10 ¹⁶				
^{246m} Am	40 m			1.91 x 10 ⁷			4.24 x 10 ¹⁶				
²⁴⁷ Am	24 m			3.17 x 10 ⁷			7.04 x 10 ¹⁶				
²⁴² Cm	162.7 d	6.11		3.32 x 10 ³	122	3.76 x 10 ¹²		1.21 x 10 ⁶	1 x 10 ⁻¹⁰	0.05	6.27 x 10 ⁻⁷
²⁴³ Cm	32 y	5.79		45.9	1.677	5.20 x 10 ¹⁰	3.27 x 10 ⁸		6 x 10 ⁻¹²	0.09	1.96 x 10 ⁻³
²⁴⁴ Cm	18.099 y	5.80		80.94	2.832	9.16 x 10 ¹⁰		<u>6.86 x 10⁵</u>	9 x 10 ⁻¹²	0.1	1.24 x 10 ⁻³
²⁴⁵ Cm	<u>8265 y</u>	5.36		<u>0.177</u>	<u>5.89 x 10⁻³</u>	<u>2.00 x 10⁸</u>			5 x 10 ⁻¹²	0.04	0.263
²⁴⁶ Cm	<u>4711 y</u>	5.4		<u>0.309</u>	<u>1.01 x 10⁻²</u>	<u>3.50 x 10⁸</u>		<u>5.43 x 10⁵</u>	5 x 10 ⁻¹²	0.05	0.194
²⁴⁷ Cm	1.64 x 10 ⁷ y			8.83 x 10 ⁻⁵	2.8 x 10 ⁻⁶	1.00 x 10 ⁵			5 x 10 ⁻¹²	0.04	453
²⁴⁸ Cm	<u>3.52 x 10⁵ y</u>	5.05		<u>4.09 x 10⁻³</u>	<u>5.32 x 10⁻⁴</u>	<u>4.25 x 10⁶</u>		<u>2.44 x 10⁶</u>	6 x 10 ⁻¹³	0.01	2.91
²⁴⁹ Cm	64 m		0.9	1.18 x 10 ⁷	2.06 x 10 ⁴		2.62 x 10 ¹⁶		8 x 10 ⁻⁶	0.8	6.78 x 10 ⁻⁸
²⁵⁰ Cm	1.74 x 10 ⁴ y			8.20 x 10 ⁻²	0.1			6.50 x 10 ⁸			
²⁴⁹ Bk	314 d	5.4	0.125	1.67 x 10 ³	0.258	4.16 x 10 ⁷	3.71 x 10 ¹²	<u>8.5 x 10³</u>	9 x 10 ⁻¹⁰	0.7	419
²⁵⁰ Bk	3.222 h		0.23	3.89 x 10 ⁶	2.75 x 10 ⁴		8.62 x 10 ¹⁵		1 x 10 ⁻⁷	0.04	1.03 x 10 ⁻⁷
²⁵¹ Bk	57 m			1.32 x 10 ⁷			2.92 x 10 ¹⁶				

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) (uCi/cm ³)	Body Burden (uCi) (ug)
²⁴⁹ Cf	352 y	5.81		4.08	0.152	4.62 x 10 ⁹		2 x 10 ³	2 x 10 ⁻¹²	0.04 8.98 x 10 ⁻³
²⁵⁰ Cf	13.08 y	6.03		109	4.06	1.23 x 10 ¹¹		2.12 x 10 ⁸	5 x 10 ⁻¹²	0.04 3.70 x 10 ⁻⁴
²⁵¹ Cf	900 y			1.59	5.79 x 10 ⁻²	1.78 x 10 ⁹			2 x 10 ⁻¹²	0.04 2.50 x 10 ⁻²
²⁵² Cf	2.646 y	6.11		536	39.0	5.88 x 10 ¹¹		1.41 x 10 ¹¹	2 x 10 ⁻¹¹	0.04 7.46 x 10 ⁻⁵
²⁵³ Cf	17.812 d		0.27	2.90 x 10 ⁴	13.89		6.42 x 10 ¹³		8 x 10 ⁻¹⁰	0.04 1.40 x 10 ⁻⁶
²⁵⁴ Cf	60.5 d	5.84		8.51 x 10 ³	1.06 x 10 ⁴			7.35 x 10 ¹³	5 x 10 ⁻¹²	0.01 1.18 x 10 ⁻⁶
²⁵³ Es	20.467 d	6.63		2.52 x 10 ⁴	1.01 x 10 ³	2.86 x 10 ¹³		1.95 x 10 ⁷	7 x 10 ⁻¹⁰	0.04 1.59 x 10 ⁻⁶
²⁵⁴ Es	276 d	6.42		1.86 x 10 ³	71.9	2.11 x 10 ¹²		8.39 x 10 ⁷	2 x 10 ⁻¹¹	0.02 1.08 x 10 ⁻⁵
^{254m} Es	39.3 h		0.48	3.14 x 10 ⁵	1.18 x 10 ³		6.97 x 10 ¹⁴		5 x 10 ⁻⁹	0.02 6.37 x 10 ⁻⁸
²⁵⁵ Es	39.8 d			1.29 x 10 ⁴			2.86 x 10 ¹³		6 x 10 ⁻¹⁰	0.04 3.10 x 10 ⁻⁶
²⁵⁶ Es	25 m			2.94 x 10 ⁷			6.52 x 10 ¹⁶			
²⁵⁴ Fm	3.24 h	7.20		3.81 x 10 ⁶	1.68 x 10 ⁵	4.31 x 10 ¹⁵		2.03 x 10 ¹¹	6 x 10 ⁻⁸	0.02 5.25 x 10 ⁻⁹
²⁵⁵ Fm	20.07 h	7.03		6.13 x 10 ⁵	2.79 x 10 ⁴	6.94 x 10 ¹⁴		1.29 x 10 ⁹	2 x 10 ⁻⁸	0.04 6.53 x 10 ⁻⁸
²⁵⁶ Fm	2.62 h			4.67 x 10 ⁶	5.85 x 10 ⁶			4.31 x 10 ¹⁶	2 x 10 ⁻⁹	0.01 2.14 x 10 ⁻⁹
²⁵⁷ Fm	94 d			5.41 x 10 ³	~200	6.12 x 10 ¹²				

^aThe values for properties included in this table are those in use at TRU on July 1, 1969.

^bFrom IRCP Publication 2, "Report of Committee II on Permissible Dose for Internal Radiation (1959)" and the 1962 Supplement.

^cCounting geometry, 51%.

^d²⁴²Am 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, ²⁴²Am.

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

Table A-4. Neutron Cross Sections Used to
Compute Transmutations in HFIR Target Irradiation (July 1, 1969)

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	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	0	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 x 10 ⁷ y	1.6	0	0	0	0	0
^{245}Pu	10.6 h	277	0	0	0	0	0
^{246}Pu	10.85 d	0	0	0	0	0	0
^{243}Am	7340 y	75	2.126	1500	0	0	0
$^{244}\text{Cm}^{\text{a}}$	27.3 m	0	0	0	130	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	6.9	650	2.7	6.9	72
^{245}Cm	<u>8265 y</u>	445.3	1.4	90	1544	1.4	600
^{246}Cm	<u>4711 y</u>	5	0.866	170	0	0	0
^{247}Cm	1.64 x 10 ⁷ y	77.63	0	200	281.33	0	1000
^{248}Cm	<u>352,000 y</u>	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	1706	0	1850	553.5	0	0
^{250}Bk	3.222 h	350	0	0	960	0	0
^{249}Cf	<u>352 y</u>	300	0	0	1735	0	0
^{250}Cf	<u>13.08 y</u>	2000	0	0	0	0	0
^{251}Cf	<u>900 y</u>	1948	0	0	5126	0	0
^{252}Cf	2.646 y	19.8	0	44	0	0	0
^{253}Cf	<u>17.812 d</u>	12.6	0	0	1300	0	0
^{254}Cf	60.5 d	75	0	1650	0	0	0
^{253}Es	<u>20,467 d</u>	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	20	0	0	0	0	0
^{257}Fm	94 d	10	0	0	100	0	0

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

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 $^{244\text{C}}\text{Am}$ is a fictitious isotope that combines the properties of $^{244\text{m}}\text{Am}$ and $^{244\text{g}}\text{Am}$ according to their relative rates of production from ^{243}Am . The use of this isotope simplifies the calculations of the main transmutation chain involving ^{244}Am .

INTERNAL DISTRIBUTION

1. Biology Library
- 2-4. Central Research Library
- 5-6. ORNL - Y-12 Technical Library
- 7-41. Laboratory Records Department
42. Laboratory Records, ORNL R.C.
43. R. D. Ackley
44. R. E. Adams
45. E. D. Arnold
46. R. Baldock
47. R. D. Baybarz
48. C. E. Bemis
49. M. Bender
50. J. E. Bigelow
51. R. E. Blanco
52. G. E. Boyd
53. R. E. Brooksbank
54. K. B. Brown
55. P. E. Brown
56. F. R. Bruce
57. G. D. Brunton
58. W. D. Burch
59. S. R. Buxton
60. A. E. Cameron
61. W. H. Carr
62. J. M. Chandler
63. F. R. Chattin
64. J. M. Chilton
65. J. W. Cleland
66. H. E. Cochran
67. C. F. Coleman
68. E. D. Collins
69. J. H. Cooper
70. B. L. Corbett
71. L. T. Corbin
72. D. A. Costanzo
73. R. A. Costner, Jr.
74. J. A. Cox
75. S. J. Cromer (K-25)
76. F. L. Culler, Jr.
77. F. L. Daley
78. M. D. Danford
79. J. S. Drury
80. R. E. Eby
81. W. W. Evans
82. L. G. Farrar
83. D. E. Ferguson
84. J. R. Flanary
85. H. E. Goeller
86. H. B. Graham
87. L. A. Haack
88. R. G. Haire
89. J. Halperin
90. F. E. Harrington
91. R. F. Hibbs
92. M. R. Hill
93. J. D. Hoeschele
94. C. A. Horton
95. F. T. Howard
96. F. A. Kappelmann
97. O. L. Keller
98. M. T. Kelley
99. E. E. Ketchen
100. L. J. King
101. R. E. Leuze
102. K. H. Lin
103. M. H. Lloyd
104. A. L. Lotts
105. L. O. Love
106. H. G. MacPherson
107. E. J. Manthos
108. W. R. Martin
109. J. L. Matherne
110. R. W. McClung
111. R. V. McCord
112. J. R. McWherter
113. H. C. Meyer
114. F. L. Moore
115. J. P. Nichols
116. P. B. Orr
117. D. B. Owsley
118. J. R. Parrott
119. F. L. Peishel
120. S. A. Reynolds
121. J. C. Richter
122. S. J. Rimshaw
123. J. T. Roberts
124. T. H. Row
125. A. D. Ryon
126. R. D. Seagren
127. C. L. Shepherd
128. R. C. Shipwash
129. E. M. Shuford
130. T. M. Sims

- | | |
|-----------------------|----------------------------------|
| 131. M. J. Skinner | 142. R. C. Weir |
| 132. Martha Stewart | 143. M. E. Whatley |
| 133. B. J. Strader | 144. J. C. White |
| 134. D. A. Sundberg | 145. R. G. Wymer |
| 135. O. K. Tallent | 146. O. O. Yarbrow |
| 136. W. E. Unger | 147. J. P. Young |
| 137. J. E. Van Cleve | 148. P. H. Emmett (consultant) |
| 138. V. C. A. Vaughen | 149. J. J. Katz (consultant) |
| 139. C. E. Waddell | 150. J. L. Margrave (consultant) |
| 140. B. S. Weaver | 151. E. A. Mason (consultant) |
| 141. A. M. Weinberg | 152. R. B. Richards (consultant) |

EXTERNAL DISTRIBUTION

153. F. P. Baranowski, U. S. Atomic Energy Commission, Washington, D.C.
 154. A. R. Boulogne, Savannah River Laboratory, Aiken, South Carolina
 155. R. O. Budd, Battelle-Northwest Laboratory, Richland, Washington
 156. H. Diamond, Argonne National Laboratory, Argonne, Illinois
 157. R. W. Dodson, Brookhaven National Laboratory, Upton, L.I., N.Y.
 158. W. K. Eister, U. S. Atomic Energy Commission, Washington, D.C.
 159. P. R. Fields, Argonne National Laboratory, Argonne, Illinois
 160. R. L. Folger, Savannah River Laboratory, Aiken, South Carolina
 161. A. Ghiorso, Lawrence Radiation Laboratory, Berkeley, California
 162. D. T. Goldman, National Bureau of Standards, Washington, D.C.
 163. R. W. Hoff, Lawrence Radiation Laboratory, Livermore, California
 164. E. K. Hulet, Lawrence Radiation Laboratory, Livermore, California
 165. M. L. Hyder, Savannah River Laboratory, Aiken, South Carolina
 166. C. H. Ice, Savannah River Laboratory, Aiken, South Carolina
 167. T. R. Jones, U. S. Atomic Energy Commission, Washington, D.C.
 168. R. D. Kelsch, Savannah River Laboratory, Aiken, South Carolina
 169. R. M. Latimer, Lawrence Radiation Laboratory, Berkeley, California
 170. J. N. Maddox, U. S. Atomic Energy Commission, Washington, D.C.
 171. L. H. Meyer, Savannah River Laboratory, Aiken, South Carolina
 172. M. S. Moore, Los Alamos Scientific Laboratory, Los Alamos, N.M.
 173. T. C. Parsons, Lawrence Radiation Laboratory, Berkeley, California
 174. R. A. Penneman, Los Alamos Scientific Laboratory, Los Alamos, N.M.
 175. A. R. Prince, Brookhaven National Laboratory, Upton, L.I., N. Y.
 176. D. M. Richman, U.S. Atomic Energy Commission, Washington, D.C.
 177. B. C. Rusche, Savannah River Laboratory, Aiken, South Carolina
 178. W. D. Sandberg, U.S. Atomic Energy Commission, SRO, Aiken, S.C.
 179. N. Stetson, U.S. Atomic Energy Commission, SRO, Aiken, S.C.
 180. J. A. Swartout, Union Carbide Corporation, New York, N.Y.
 181. A. Van Dyken, U.S. Atomic Energy Commission, Washington, D.C.
 182. Laboratory and University Division, AEC, ORO
 183-398. Given distribution as shown in TID-4500 under Reactor Technology category (25 copies - CFSTI)