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Stable Isotope Inventory Requirements and Enrichment Capabilities

W. A. Bell
J. G. Tracy

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OPERATIONS DIVISION

STABLE ISOTOPE INVENTORY REQUIREMENTS AND ENRICHMENT CAPABILITIES

W. A. Bell
J. G. Tracy

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STABLE ISOTOPE INVENTORY REQUIREMENTS AND ENRICHMENT CAPABILITIES

W. A. Bell

J. G. Tracy

I. INTRODUCTION

The electromagnetic isotope enrichment program established in 1945 has since then continued to provide enriched stable, actinide, and selected radioactive isotopes. These unique materials used in research and medicine and for industrial applications are made available throughout the world by direct sales and/or on a loan basis. In recent years, the primary effort of the program has been directed toward providing enriched stable isotopes necessary to replenish the sales inventory. This document presents a summary of the stable isotope sales requirements and the capabilities of the electromagnetic isotope separators for providing the quantity and quality of enriched products to meet those needs. Special enrichment and actinide separations or Research Materials Collection (loan program) needs are not addressed.

II. SEPARATORS

Two types of separators (calutrons) are utilized for the enrichment of stable isotopes to maintain the sales inventory. The first is the 180° focusing machine, and the second is a 255° double-focusing, inhomogeneous magnetic field separator. Both machines are capable of multi-milliampere beam current and can resolve all the isotopes of an element simultaneously. The 255° machine has a higher mass dispersion and resolution, but has a correspondingly less beam throughput. In practice, both types of separators are necessary to meet the requirements of the user community.

III. COLLECTIONS AND ENRICHMENT

Enrichment of the isotopes of each element is unique, depending on atomic weight and physical and chemical characteristics. Table 1 presents typical enrichment and collection capabilities for the isotopes of each element. Since the dispersion at the collector varies inversely as the square root of the mass, it sometimes is necessary to use more than one type collector for elements having isotopes with atomic weights greater than 100. The collection rate listed in Column 3 in Table 1 is summarized from Appendix A and has been adjusted for pocket retention and percent innage.

IV. INVENTORY REQUIREMENTS

Tank times required to replace material distributed through annual sales and maintain inventory equilibrium are given in Table 2. These data were derived from the average annual sales (Appendix B) and the collection rates given in Table 1. The total tank hours (90,728) required to maintain inventory equilibrium represent approximately 16 calutron-years operating on a 5-day/week, 24-hour/day basis.

Table 1. Calutron capabilities

Element-Isotope	Abundance (Atom %)		Collection Rate (mg/Tank hr)	
	Natural	Enriched	Collector I	Collector II
Antimony-121	57.25	>99	28.0	
Antimony-123	42.75	>99	29.4	
Barium-130	0.101	35-60	0.085	0.085
Barium-132	0.097	20-50	0.137	0.137
Barium-134	2.42	80-85	2.06	
Barium-135	6.59	>93		4.11
Barium-136	7.81	>92	8.11	
Barium-137	11.32	>89		10.2
Barium-138	71.66	>99	45.1	
Bromine-79	50.54	>98	10.6	
Bromine-81	49.46	>98	9.31	
Cadmium-106	1.215	80-91	1.11	1.11
Cadmium-108	0.875	>69	1.01	1.01
Cadmium-110	12.39	>96	10.0	
Cadmium-111	12.75	>95		9.41
Cadmium-112	24.07	>97	18.7	
Cadmium-113	12.26	>96		9.34
Cadmium-114	28.86	>98	20.8	
Cadmium-116	7.58	>98	5.59	5.59
Calcium-40	96.97	>99.9	54.9	
Calcium-42	0.64	>93	0.438	
Calcium-43	0.145	>79	0.110	
Calcium-44	2.06	>98.5	1.67	
Calcium-46	0.0033	>43	0.0055	
Calcium-48	0.185	>97	0.156	

Table 1. Calutron capabilities (continued)

Element-Isotope	Abundance (Atom %)		Collection Rate (mg/Tank hr)	
	Natural	Enriched	Collector I	Collector II
Cerium-136	0.193	35-50	0.099	
Cerium-138	0.25	>25	0.263	
Cerium-140	88.48	>99.5	26.6	
Cerium-142	11.07	>92	2.98	
Chlorine-35	75.53	>99	10.6	
Chlorine-37	24.47	>98	2.86	
Chromium-50	4.31	>95	2.23	
Chromium-52	83.76	>99.7	46.4	
Chromium-53	9.55	>96	5.10	
Chromium-54	2.38	>94	0.925	
Copper-63	69.09	>99.8	59.1	
Copper-65	30.91	>99.6	25.8	
Dysprosium-156	0.052	21-34	0.034	0.034
Dysprosium-158	0.090	>20	0.053	0.053
Dysprosium-160	2.294	69-85	1.64	
Dysprosium-161	18.88	90-96		11.2
Dysprosium-162	25.53	92-96	14.7	
Dysprosium-163	24.97	93-97		12.6
Dysprosium-164	28.18	>98	14.0	
Erbium-162	0.136	>27	0.174	0.174
Erbium-164	1.56	>73	0.941	0.941
Erbium-166	33.41	>96	19.0	
Erbium-167	22.94	>91		13.4
Erbium-168	27.07	>95	15.0	
Erbium-170	14.88	>95	8.38	8.38
Europium-151	47.82	>92	18.7	
Europium-153	52.18	94-98	18.5	

Table 1. Calutron capabilities (continued)

Element-Isotope	Abundance (Atom %)		Collection Rate (mg/Tank hr)	
	Natural	Enriched	Collector I	Collector II
Gadolinium-152	0.20	32-51	0.166	0.166
Gadolinium-154	2.15	>66	1.41	
Gadolinium-155	14.73	>90		4.71
Gadolinium-156	20.47	93-99	6.76	
Gadolinium-157	15.86	>90		6.87
Gadolinium-158	24.87	>95	8.22	
Gadolinium-160	21.90	95-98	8.39	8.39
Gallium-69	60.4	>99	24.2	
Gallium-71	39.6	>99	13.3	
Germanium-70	20.52	>98	6.45	
Germanium-72	27.43	>97	10.4	
Germanium-73	7.76	>94	2.53	
Germanium-74	36.54	>98	13.6	
Germanium-76	7.76	>92	1.90	
Hafnium-174	0.18	7-19	0.057	0.057
Hafnium-176	5.20	64-72	0.742	
Hafnium-177	18.50	86-91		3.83
Hafnium-178	27.14	91-94	7.05	
Hafnium-179	13.75	81-87		3.60
Hafnium-180	35.24	>93	7.36	
Indium-113	4.28	>96	2.29	
Indium-115	95.72	>99.99	55.6	
Iridium-191	37.3	98.17	8.72	
Iridium-193	62.7	99.45	17.4	
Iron-54	5.82	>96	3.67	
Iron-56	91.66	>99.9	69.4	
Iron-57	2.19	86-90	1.70	
Iron-58	0.33	65-76	0.235	

Table 1. Calutron capabilities (continued)

Element-Isotope	Abundance (Atom %)		Collection Rate (mg/Tank hr)	
	Natural	Enriched	Collector I	Collector II
Lanthanum-138	0.089	>7	0.353	
Lanthanum-139	99.911	99.99	29.7	
Lead-204	1.48	>70	2.11	2.11
Lead-206	23.60	>99	26.3	
Lead-207	22.6	>92		26.4
Lead-208	52.3	>98	61.2	
Lutetium-175	97.41	>99.9	44.2	
Lutetium-176	2.59	70-75	1.16	
Magnesium-24	78.70	>99.9	31.4	
Magnesium-25	10.13	>97	4.49	
Magnesium-26	11.17	>99	4.87	
Mercury-196	0.146	31-48	0.068	
Mercury-198	10.02	85-96		0.416
Mercury-199	16.84	85-91	1.16	
Mercury-200	23.13	>95		1.74
Mercury-201	13.22	>92	1.02	
Mercury-202	29.80	>96		2.06
Mercury-204	6.85	90-98	0.475	
Molybdenum-92	15.84	>97	15.3	
Molybdenum-94	9.04	>91	10.0	
Molybdenum-95	15.72	>96	15.5	
Molybdenum-96	16.53	>96	18.0	
Molybdenum-97	9.46	>92	9.41	
Molybdenum-98	23.78	>96	22.7	
Molybdenum-100	9.63	>97	8.52	

Table 1. Calutron capabilities (continued)

Element-Isotope	Abundance (Atom %)		Collection Rate (mg/Tank hr)	
	Natural	Enriched	Collector I	Collector II
Neodymium-142	27.11	>92	13.2	
Neodymium-143	12.17	>91		6.30
Neodymium-144	23.85	>97	11.8	
Neodymium-145	8.30	>89		4.47
Neodymium-146	17.22	>97	8.30	
Neodymium-148	5.73	>94	2.90	2.90
Neodymium-150	5.62	>96	2.56	2.56
Nickel-58	67.88	>99.9	97.5	
Nickel-60	26.23	>99	41.0	
Nickel-61	1.19	88-93	1.71	
Nickel-62	3.66	>96	5.32	
Nickel-64	1.08	92-96	1.29	
Osmium-184	0.018	5.45	0.023	0.023
Osmium-186	1.59	>61	0.203	
Osmium-187	1.64	>70		0.457
Osmium-188	13.30	>94	2.35	
Osmium-189	16.10	>94		2.86
Osmium-190	26.40	>95	5.49	
Osmium-192	41.00	>95	7.18	7.18
Palladium-102	0.96	>69	0.481	0.481
Palladium-104	10.97	>95	5.28	
Palladium-105	22.23	>97		9.95
Palladium-106	27.33	>98	12.0	
Palladium-108	26.71	>98	12.9	12.9
Palladium-110	11.81	>96	5.27	5.27

Table 1. Calutron capabilities (continued)

Element-Isotope	Abundance (Atom %)		Collection Rate (mg/Tank hr)	
	Natural	Enriched	Collector I	Collector II
Platinum-190	0.0127	>4	0.049	0.049
Platinum-192	0.78	>57	0.230	0.230
Platinum-194	32.9	>97	11.5	
Platinum-195	33.8	>97		10.7
Platinum-196	25.3	>97	8.22	
Platinum-198	7.21	>95	2.13	2.13
Potassium-39	93.10	>99.9	14.8	
Potassium-40	0.012	78-87	0.008	
Potassium-41	6.88	>98	0.820	
Rhenium-185	37.07	>96	17.1	
Rhenium-187	62.93	>99.2	32.0	
Rubidium-85	72.15	>99.7	30.6	
Rubidium-87	27.85	98	12.8	
Ruthenium-96	5.51	98	0.659	
Ruthenium-98	1.87	>89	0.201	
Ruthenium-99	12.72	>98	1.64	
Ruthenium-100	12.62	>97	1.50	
Ruthenium-101	17.07	>97	1.87	
Ruthenium-102	31.61	>99	3.18	
Ruthenium-104	18.58	>99	2.37	
Samarium-144	3.09	85-96	2.76	2.76
Samarium-147	14.97	>98		12.8
Samarium-148	11.24	>96	10.1	
Samarium-149	13.83	>97		11.4
Samarium-150	7.44	>95	6.15	
Samarium-152	26.72	>98	24.1	24.1
Samarium-154	22.71	>98	18.8	18.8

Table 1. Calutron capabilities (continued)

Element-Isotope	Abundance (Atom %)		Collection Rate (mg/Tank hr)	
	Natural	Enriched	Collector I	Collector II
Selenium-74	0.87	55-77	0.120	
Selenium-76	9.02	>96	2.27	
Selenium-77	7.58	91-94	1.98	
Selenium-78	23.52	>97	5.87	
Selenium-80	49.82	>99	13.2	
Selenium-82	9.19	>96	1.83	
Silicon-28	92.21	>99.8	35.1	
Silicon-29	4.70	>95	1.32	
Silicon-30	3.09	>94	0.920	
Silver-107	51.35	>98	22.8	
Silver-109	48.65	>99	21.2	
Strontium-84	0.56	>80	0.534	
Strontium-86	9.86	>95	10.5	
Strontium-87	7.02	87-93	7.43	
Strontium-88	82.56	>99.8	78.9	
Sulfur-32	95.0	>99.8	47.8	
Sulfur-33	0.760	48-90	0.174	
Sulfur-34	4.22	94-98	1.52	
Sulfur-36	0.0136	15-35	0.001	
Tantalum-180	0.0123	4.10	2.44	
Tellurium-120	0.089	>51	0.081	0.081
Tellurium-122	2.46	>96		1.52
Tellurium-123	0.87	76-89	0.692	
Tellurium-124	4.61	94-97		4.10
Tellurium-125	6.99	>95	7.18	
Tellurium-126	18.71	>98		13.0
Tellurium-128	31.79	>99	26.3	26.3
Tellurium-130	34.49	>99	25.6	25.6

Table 1. Calutron capabilities (continued)

Element-Isotope	Abundance (Atom %)		Collection Rate (mg/Tank hr)	
	Natural	Enriched	Collector I	Collector II
Thallium-203	29.50	>95	47.3	
Thallium-205	70.50	>98	110.0	
Tin-112	0.96	68-80	0.520	0.520
Tin-114	0.66	>61	0.343	
Tin-115	0.35	>32		0.239
Tin-116	14.30	>95	9.34	
Tin-117	7.61	>89		5.51
Tin-118	24.03	>97	15.0	
Tin-119	8.58	>84		5.58
Tin-120	32.85	>98	23.8	
Tin-122	4.72	>92	2.88	2.88
Tin-124	5.94	>94	3.56	3.56
Titanium-46	7.93	>81	3.89	
Titanium-47	7.28	>80	3.81	
Titanium-48	73.94	>99	37.4	
Titanium-49	5.51	68-81	2.36	
Titanium-50	5.34	67-83	2.27	
Tungsten-180	0.135	>8	1.53	1.53
Tungsten-182	26.41	>94		34.7
Tungsten-183	14.4	>81	23.1	
Tungsten-184	30.64	>94		40.1
Tungsten-186	24.41	>97	37.0	37.0
Vanadium-50	0.24	36	0.044	

Table 1. Calutron capabilities (continued)

Element-Isotope	Abundance (Atom %)		Collection Rate (mg/Tank hr)	
	Natural	Enriched	Collector I	Collector II
Ytterbium-168	0.135	13-24	0.260	0.260
Ytterbium-170	3.03	>78	1.90	
Ytterbium-171	14.31	>95		8.80
Ytterbium-172	21.82	>97	12.0	
Ytterbium-173	16.13	>92		9.40
Ytterbium-174	31.84	>98	18.3	
Ytterbium-176	12.73	>96	6.63	6.63
Zinc-64	48.89	>99.8	25.8	
Zinc-66	27.81	>98	21.3	
Zinc-67	4.11	89-93	2.48	
Zinc-68	18.57	97-99	15.8	
Zinc-70	0.62	65-86	0.346	
Zirconium-90	51.46	97-99	12.7	
Zirconium-91	11.23	88-94		2.37
Zirconium-92	17.11	>98	3.76	
Zirconium-94	17.40	>98	3.70	3.70
Zirconium-96	2.80	>95	0.343	0.343

Table 2. Tank hours required to replace annual sales

Element-Isotope	Inventory 12/31/84 (mg)	Avg. Sales (1980-84) (mg/yr)	Tank Hours for Annual Sales Replacememt		TOTAL
			Collector I	Collector II	
Antimony-121	0	534	19		
Antimony-123	538	919	31		31
Barium-130	682	53	624	624	624
Barium-132	192	47	343	343	
Barium-134	0	43[a]	21		
Barium-135	3,700	1,041		253	
Barium-136	401	1,075[a]	133		
Barium-137	500	551		54	
Barium-138	4,909	2,878	64		
Bromine-79	0	1,702	161		161
Bromine-81	0	919	99		
Cadmium-106	352	189	170	170	
Cadmium-108	0	83	82	82	
Cadmium-110	7,733	2,158[a]	216		
Cadmium-111	1,860	2,056		219	
Cadmium-112	45,964	43,139	2,307		2,307
Cadmium-113	0	2,053[a]		220	220
Cadmium-114	45,569	4,620	222		
Cadmium-116	5,208	1,447	259	259	

Table 2. Tank hours required to replace annual sales (continued)

Element-Isotope	Inventory 12/31/84 (mg)	Avg. Sales (1980-84) (mg/yr)	Tank Hours for Annual Sales Replacememt		TOTAL
			Collector I	Collector II	
Calcium-40	66,549	4,090	75		
Calcium-42	2,386	991	2,263		
Calcium-43	540	38	346		
Calcium-44	5,771	2,683	1,607		
Calcium-46	0	37	6,727		6,727
Calcium-48	1,811	979	6,276		
Cerium-136	930	3	31		
Cerium-138	172				
Cerium-140	28,412	18,534	697		697
Cerium-142	501	544	183		
Chlorine-35	8,604	3,189	301		301
Chlorine-37	11,623	642	225		
Chromium-50	9,473	2,453	1,100		
Chromium-52	7,260	1,073	23		
Chromium-53	3,314	862	169		
Chromium-54	2,735	1,225	1,325		1,325
Copper-63	52,138	32,924	557		557
Copper-65	54,440	14,313	555		

Table 2. Tank hours required to replace annual sales (continued)

Element-Isotope	Inventory 12/31/84 (mg)	Avg. Sales (1980-84) (mg/yr)	Tank Hours for Annual Sales Replacememt		TOTAL
			Collector I	Collector II	
Dysprosium-156	0	27[a]	794	794	
Dysprosium-158	163	62	1,170	1,170	1,170
Dysprosium-160	744	707	431		
Dysprosium-161	85	2,507		224	
Dysprosium-162	973	4,998	340		
Dysprosium-163	1,476	2,220		176	
Dysprosium-164	584	7,310	522		
Erbium-162	0	31[a]	178	178	
Erbium-164	584	97	103	103	
Erbium-166	4,000	2,355	124		
Erbium-167	588	3,070		229	229
Erbium-168	4,149	3,396	227		227
Erbium-170	3,943	2,901	346	346	
Europium-151	0	1,909	102		
Europium-153	1	2,987	162		162

Table 2. Tank hours required to replace annual sales (continued)

Element-Isotope	Inventory 12/31/84 (mg)	Avg. Sales (1980-84) (mg/yr)	Tank Hours for Annual Sales Replacemement		TOTAL
			Collector I	Collector II	
Gadolinium-152	2	233[a]	1,404	1,404	
Gadolinium-154	1,187	271	192		
Gadolinium-155	4,757	314		67	
Gadolinium-156	3,289	1,985	294		
Gadolinium-157	457	416		61	
Gadolinium-158	3,216	1,342	163		
Gadolinium-160	96	13,087	1,560	1,560	1,560
Gallium-69	3,579	1,736	72		
Gallium-71	417	1,796	135		135
Germanium-70	9,617	2,401[a]	372		
Germanium-72	17,180	1,297[a]	125		
Germanium-73	8,242	241	95		
Germanium-74	12,039	6,225	458		458
Germanium-76	4,180	588	310		
Hafnium-174	144	3	53	53	
Hafnium-176	692	84	113		113
Hafnium-177	1,109	464[a]		121	
Hafnium-178	2,315	333	47		
Hafnium-179	1,483	583		162	162
Hafnium-180	3,928	776	106		

Table 2. Tank hours required to replace annual sales (continued)

Element-Isotope	Inventory 12/31/84 (mg)	Avg. Sales (1980-84) (mg/yr)	Tank Hours for Annual Sales Replacememt		TOTAL
			Collector I	Collector II	
Indium-113	0	70	31		31
Indium-115	988	278[a]	5		
Iridium-191	3,060	838[a]	96		96
Iridium-193	15,687	1,000[a]	58		
Iron-54	400	6,610	1,801		
Iron-56	402	30,998	447		
Iron-57	11	6,507	3,828		
Iron-58	8	1,624[a]	6,911		6,911
Lanthanum-138	346	60	170		170
Lanthanum-139	4,896	20	1		
Lead-204	15,502	143[a]	68	68	
Lead-206	20,586	3,708	141		
Lead-207	90,223	7,194		273	273
Lead-208	511,888	47,954[a]	784		784
Lutetium-175	1,866	344	8		
Lutetium-176	0	1,192[a]	1,028		1,028

Table 2. Tank hours required to replace annual sales (continued)

Element-Isotope	Inventory 12/31/84 (mg)	Avg. Sales (1980-84) (mg/yr)	Tank Hours for Annual Sales Replacememt		
			Collector I	Collector II	TOTAL
Magnesium-24	3,356	5,329	170		
Magnesium-25	0	2,917	650		650
Magnesium-26	335	1,762[a]	362		
Mercury-196	659	21	309		
Mercury-198	795	151[a]		363	363
Mercury-199	1,937	205[a]	177		
Mercury-200	1,892	157[a]		91	
Mercury-201	328	396[a]	388		
Mercury-202	2,616	173[a]		84	
Mercury-204	6,494	395[a]	832		832
Molybdenum-92	5,523	2,597	170		
Molybdenum-94	881	1,570	157		
Molybdenum-95	8,459	16,170	1,043		1,043
Molybdenum-96	5,732	4,745	264		
Molybdenum-97	1,477	2,547	271		
Molybdenum-98	118,017	1,594	70		
Molybdenum-100	9,806	5,234[a]	614		

Table 2. Tank hours required to replace annual sales (continued)

Element-Isotope	Inventory 12/31/84 (mg)	Avg. Sales (1980-84) (mg/yr)	Tank Hours for Annual Sales Replacememt		TOTAL
			Collector I	Collector II	
Neodymium-142	8,757	1,357	103		
Neodymium-143	4,445	996		158	
Neodymium-144	1,448	2,407	204		
Neodymium-145	1,779	1,653		370	
Neodymium-146	3,321	2,074	250		
Neodymium-148	3,636	1,115	385	385	
Neodymium-150	1,502	2,036	795	795	795
Nickel-58	4,018	152,113	535		
Nickel-60	12,731	52,129	1,272		
Nickel-61	3,670	443	259		
Nickel-62	9,220	8,449	1,588		1,588
Nickel-64	44	1,422	1,102		
Osmium-184	34	1	44	44	
Osmium-186	91	24	119		
Osmium-187	513	31		68	
Osmium-188	733	388	165		
Osmium-189	190	398		140	140
Osmium-190	8,960	1,471[a]	268		268
Osmium-192	3,512	987	138	138	

Table 2. Tank hours required to replace annual sales (continued)

Element-Isotope	Inventory 12/31/84 (mg)	Avg. Sales (1980-84) (mg/yr)	Tank Hours for Annual Sales Replacemement		TOTAL
			Collector I	Collector II	
Palladium-102	0	143[a]	298	298	298
Palladium-104	8,001	421	80		
Palladium-105	12,703	757[a]		76	76
Palladium-106	16,202	510	43		
Palladium-108	13,714	1,553[a]	120	120	
Palladium-110	7,320	492[a]	94	94	
Platinum-190	37	14[a]	286	286	
Platinum-192	278	72	313	313	313
Platinum-194	3,238	366[a]	32		
Platinum-195	2,934	670		63	63
Platinum-196	3,471	444[a]	54		
Platinum-198	2,295	542[a]	255	255	
Potassium-39	1,103	1,405	95		
Potassium-40	0	47[a]	5,875		5,875
Potassium-41	0	519[a]	633		
Rhenium-185	0	1,709	100		100
Rhenium-187	216	802	25		

Table 2. Tank hours required to replace annual sales (continued)

Element-Isotope	Inventory 12/31/84 (mg)	Avg. Sales (1980-84) (mg/yr)	Tank Hours for Annual Sales Replacememt		TOTAL
			Collector I	Collector II	
Rubidium-85	2	2,353	77		
Rubidium-87	2,272	5,230	409		409
Ruthenium-96	1,757	410[a]	622		
Ruthenium-98	809	20[a]	100		
Ruthenium-99	5,841	312[a]	190		
Ruthenium-100	4,971	312[a]	208		
Ruthenium-101	6,816	1,246[a]	666		666
Ruthenium-102	11,216	835[a]	263		
Ruthenium-104	9,322	875[a]	369		
Samarium-144	57	1,098[a]	40	40	
Samarium-147	0	2,469		193	
Samarium-148	7,201	1,432	142		
Samarium-149	5,137	1,912		168	
Samarium-150	2,510	1,947	317		
Samarium-152	3,194	11,677	485	485	
Samarium-154	4,301	19,899	1,058	1,058	1,058

Table 2. Tank hours required to replace annual sales (continued)

Element-Isotope	Inventory 12/31/84 (mg)	Avg. Sales (1980-84) (mg/yr)	Tank Hours for Annual Sales Replacemement		TOTAL
			Collector I	Collector II	
Selenium-74	1,731	205	1,708		1,708
Selenium-76	2,329	1,247	549		
Selenium-77	269	420	212		
Selenium-78	76	423	72		
Selenium-80	480	1,995	151		
Selenium-82	2,541	605	331		
Silicon-28	1,276	1,867	53		
Silicon-29	10	3,672	2,782		2,782
Silicon-30	12	1,885[a]	2,049		
Silver-107	2,581	8,819	387		387
Silver-109	7,363	7,467	352		
Strontium-84	1,878	508	951		951
Strontium-86	1,980	2,551	243		
Strontium-87	10,036	1,662	224		
Strontium-88	18,939	20,893	265		
Sulfur-32	3,988	1,055	22		
Sulfur-33	56	342	1,966		1,966
Sulfur-34	894	1,004[a]	661		
Sulfur-36	17	15	15,000		

Table 2. Tank hours required to replace annual sales (continued)

Element-Isotope	Inventory 12/31/84 (mg)	Avg. Sales (1980-84) (mg/yr)	Tank Hours for Annual Sales Replacememt		TOTAL
			Collector I	Collector II	
Tantalum-180	1	8	4		4
Tellurium-120	39	16	196	196	
Tellurium-122	20,572	497		327	
Tellurium-123	1,680	264	382		382
Tellurium-124	112,106	35,470		8,651	8,651
Tellurium-125	4,301	1,690	236		
Tellurium-126	6,338	3,033		234	
Tellurium-128	6,369	8,109	309	309	
Tellurium-130	26,019	9,133	357	357	
Thallium-203	988,364	723,558	15,298		15,298
Thallium-205	13,812	2,979	3		
Tin-112	5,931	1,948	3,746	3,746	
Tin-114	239	221	645		
Tin-115	651	8		34	
Tin-116	5,241	2,450	263		
Tin-117	5,263	12,513		2,271	
Tin-118	10,841	4,265	285		

Table 2. Tank hours required to replace annual sales (continued)

Element-Isotope	Inventory 12/31/84 (mg)	Avg. Sales (1980-84) (mg/yr)	Tank Hours for Annual Sales Replacememt		TOTAL
			Collector I	Collector II	
Tin-119	1,700	6,904		1,238	
Tin-120	513	4,244	179		
Tin-122	2,157	2,345	815	815	
Tin-124	649	14,184	3,985	3,985	3,985
Titanium-46	0	2,113	544		
Titanium-47	151	2,041	536		
Titanium-48	1,453	2,710	73		
Titanium-49	0	2,167	919		919
Titanium-50	0	729	322		
Tungsten-180	508	28	19	19	
Tungsten-182	3,341	1,096		32	32
Tungsten-183	0	992[a]	43		43
Tungsten-184	3,861	931[a]		24	
Tungsten-186	1,326	2,130	58	58	
Vanadium-50	24	7[a]	160		160

Table 2. Tank hours required to replace annual sales (continued)

Element-Isotope	Inventory 12/31/84 (mg)	Avg. Sales (1980-84) (mg/yr)	Tank Hours for Annual Sales Replacememt		TOTAL
			Collector I	Collector II	
Ytterbium-168	2,306	747	2,873	2,873	2,873
Ytterbium-170	1,257	225	119		
Ytterbium-171	8,969	1,549		176	
Ytterbium-172	7,612	649	54		
Ytterbium-173	4,839	879		94	
Ytterbium-174	6,525	1,465	80		
Ytterbium-176	5,501	2,947	445	445	
Zinc-64	7,949	3,541	137		
Zinc-66	20,137	3,956	186		
Zinc-67	11,292	3,341	1,347		
Zinc-68	56,263	143,358	9,074		9,074
Zinc-70	2,648	602	1,740		
Zirconium-90	1,938	4,947	390		390
Zirconium-91	4,811	301		127	127
Zirconium-92	929	731	195		
Zirconium-94	213	873	236	236	
Zirconium-96	1,705	62	181	181	
				GRAND TOTAL HR:	**90,728**

a. Sales data limited due to low inventory.

APPENDICES

APPENDIX A

Table A-1. Collection rates of isotopes*

Element Isotope	Natural Abundance (%)	Series	Total Product to Receiver (mg/Innage hr)	Innage (%)	Retention (%)	Pocket Recovery (mg/Tank hr)	Collection Rate (mg/Tank hr)	
							Collector I	Collector II
Antimony-121	57.25	IC	147.7	74.0	44.7	28.0	28.0	
Antimony-123	42.75				63.0	29.4	29.4	
Barium-130	0.101	OJ	97.8	80.4	107.0	0.085	0.085	0.085
Barium-132	0.097				180.0	0.137	0.137	0.137
Barium-134	2.42				108.0	2.06	2.06	0
Barium-135	6.59				79.3	4.11	0	4.11
Barium-136	7.81				132.0	8.11	8.11	0
Barium-137	11.32				115.0	10.2	0	10.2
Barium-138	71.66				80.0	45.1	45.1	0
Bromine-79	50.52	OR	46.0	63.9	71.7	10.6	10.6	
Bromine-81	49.48				64.0	9.31	9.31	
Cadmium-106	1.215	PQ	135.4	85.2	79.5	1.11	1.11	1.11
Cadmium-108	0.875				99.9	1.01	1.01	1.01
Cadmium-110	12.39				70.0	10.0	10.0	0
Cadmium-111	12.75				64.0	9.41	0	9.41
Cadmium-112	24.07				67.4	18.7	18.7	0
Cadmium-113	12.26				66.0	9.34	0	9.34
Cadmium-114	28.86				62.5	20.8	20.8	0
Cadmium-116	7.57				64.0	5.59	5.59	5.59

Table A-1. Collection rates of isotopes* (continued)

Element Isotope	Natural Abundance (%)	Series	Total Product to Receiver (mg/Innage hr)	Innage (%)	Retention (%)	Pocket Recovery (mg/Tank hr)	Collection Rate (mg/Tank hr) Collector I	Collector II
Calcium-40	96.97	NI & NX	142.8	79.3	50.0	54.9	54.9	
Calcium-42	0.64				60.4	0.438	0.438	
Calcium-43	0.145				67.2	0.110	0.110	
Calcium-44	2.06				71.7	1.67	1.67	
Calcium-46	0.0033				146.5	0.0055	0.0055	
Calcium-48	0.185				74.5	0.156	0.156	
Cerium-136	0.193	OP	50.1	64.5	158.0	0.099	0.099	
Cerium-138	0.25				325.0	0.263	0.263	
Cerium-140	88.48				93.1	26.6	26.6	
Cerium-142	11.07				83.2	2.98	2.98	
Chlorine-35	75.53	QC	31.3	60.2	74.7	10.6	10.6	
Chlorine-37	24.47				62.0	2.86	2.86	
Chromium-50	4.31	OO	83.2	73.8	84.4	2.23	2.23	
Chromium-52	83.76				90.3	46.4	46.4	
Chromium-53	9.55				87.0	5.10	5.10	
Chromium-54	2.38				63.3	0.925	0.925	
Copper-63	69.1	NR	123.9	86.3	80.0	59.1	59.1	
Copper-65	30.9				78.0	25.8	25.8	

Table A-1. Collection rates of isotopes* (continued)

Element Isotope	Natural Abundance (%)	Series	Total Product to Receiver (mg/Innage hr)	Innage (%)	Retention (%)	Pocket Recovery (mg/Tank hr)	Collection Rate (mg/Tank hr) Collector I	Collection Rate (mg/Tank hr) Collector II
Dysprosium-156	0.052	OB[1]	73.9	77.4	115.0	0.034	0.034	0.034
Dysprosium-158	0.090				103.0	0.053	0.053	0.053
Dysprosium-160	2.294				125.0	1.64	1.64	0
Dysprosium-161	18.88				104.0	11.2	0	11.2
Dysprosium-162	25.53				101.0	14.7	14.7	0
Dysprosium-163	24.97				88.4	12.6	0	12.6
Dysprosium-164	28.18				87.0	14.0	14.0	0
Erbium-162	0.136	OG[1]	76.7	77.9	214.0	0.174	0.174	0.174
Erbium-164	1.56				101.0	0.941	0.941	0.941
Erbium-166	33.41				95.1	19.0	19.0	0
Erbium-167	22.94				97.6	13.4	0	13.4
Erbium-168	27.07				93.0	15.0	15.0	0
Erbium-170	14.88				94.2	8.38	8.38	8.38
Europium-151	47.77	MO	60.4	70.6	92.0	18.7	18.7	
Europium-153	52.23				83.1	18.5	18.5	
Gadolinium-152	0.20	OY[2]	66.2	71.3	176.0	0.166	0.166	0.166
Gadolinium-154	2.15				139.0	1.41	1.41	0
Gadolinium-155	14.73				67.8	4.71	0	4.71

Table A-1. Collection rates of isotopes* (continued)

Element Isotope	Natural Abundance (%)	Series	Total Product to Receiver (mg/Innage hr)	Innage (%)	Retention (%)	Pocket Recovery (mg/Tank hr)	Collection Rate (mg/Tank hr)	
							Collector I	Collector II
Gadolinium-156	20.47				70.0	6.76	6.76	0
Gadolinium-157	15.86				91.8	6.87	0	6.87
Gadolinium-158	24.87				70.0	8.22	8.22	0
Gadolinium-160	21.90				81.2	8.39	8.39	8.39
Gallium-69	60.20	PB	67.6	82.6	72.0	24.2	24.2	
Gallium-71	39.80				59.7	13.3	13.3	
Germanium-70	20.55	QD	55.5	89.2	63.4	6.45	6.45	
Germanium-72	27.37				76.4	10.4	10.4	
Germanium-73	7.67				66.6	2.53	2.53	
Germanium-74	36.74				74.6	13.6	13.6	
Germanium-76	7.67				50.0	1.90	1.90	
Hafnium-174	0.18	PD[2]	45.0	71.3	98.5	0.057	0.057	0.057
Hafnium-176	5.15				44.9	0.742	0.742	0
Hafnium-177	18.39				65.0	3.83	0	3.83
Hafnium-178	27.08				81.2	7.05	7.05	0
Hafnium-179	13.78				81.3	3.60	0	3.60
Hafnium-180	35.44				64.7	7.36	7.36	0

Table A-1. Collection rates of isotopes* (continued)

Element Isotope	Natural Abundance (%)	Series	Total Product to Receiver (mg/Innage hr)	Innage (%)	Retention (%)	Pocket Recovery (mg/Tank hr)	Collection Rate (mg/Tank hr)	
							Collector I	Collector II
Indium-113	4.23	JO	73.1	90.1	82.2	2.29	2.29	
Indium-115	95.77				88.1	55.6	55.6	
Iridium-191	37.30	RD	56.7	49.2	83.8	8.72	8.72	
Iridium-193	62.70				99.6	17.4	17.4	
Iron-54	5.84	QG	96.9	80.0	81.1	3.67	3.67	
Iron-56	91.68				97.6	69.4	69.4	
Iron-57	2.17				101.1	1.70	1.70	
Iron-58	0.31				97.8	0.235	0.235	
Lanthanum-138	0.089	LC	44.8	82.8	1,069.0	0.353	0.353	
Lanthanum-139	99.911				80.0	29.7	29.7	
Lead-204	1.48	NH	143.3	91.5	108.7	2.11	2.11	2.11
Lead-206	23.6				85.0	26.3	26.3	0
Lead-207	22.6				89.0	26.4	0	26.4
Lead-208	52.3				89.2	61.2	61.2	0
Lutetium-175	97.40	KS	66.0	76.8	89.5	44.2	44.2	
Lutetium-176	2.60				88.2	1.16	1.16	

Table A-1. Collection rates of isotopes* (continued)

Element Isotope	Natural Abundance (%)	Series	Total Product to Receiver (mg/Innage hr)	Innage (%)	Retention (%)	Pocket Recovery (mg/Tank hr)	Collection Rate (mg/Tank hr)	
							Collector I	Collector II
Magnesium-24	78.60	OD	64.8	78.0	79.0	31.4	31.4	
Magnesium-25	10.11				87.8	4.49	4.49	
Magnesium-26	11.29				85.4	4.87	4.87	
Mercury-196	0.15	NW & ON	35.2	65.6	195.0	0.068	0.068	0
Mercury-198	10.02				18.0	0.416	0	0.416
Mercury-199	16.84				30.0	1.16	1.16	0
Mercury-200	23.13				32.6	1.74	0	1.74
Mercury-201	13.22				33.5	1.02	1.02	0
Mercury-202	29.80				30.0	2.06	0	2.06
Mercury-204	6.85				30.0	0.475	0.475	0
Molybdenum-92	15.86	PK	142.3	76.0	89.0	15.3	15.3	
Molybdenum-94	9.12				101.5	10.0	10.0	
Molybdenum-95	15.70				91.2	15.5	15.5	
Molybdenum-96	16.50				100.7	18.0	18.0	
Molybdenum-97	9.45				92.1	9.41	9.41	
Molybdenum-98	23.75				88.4	22.7	22.7	
Molybdenum-100	9.62				81.9	8.52	8.52	

Table A-1. Collection rates of isotopes* (continued)

Element Isotope	Natural Abundance (%)	Series	Total Product to Receiver (mg/Innage hr)	Innage (%)	Retention (%)	Pocket Recovery (mg/Tank hr)	Collection Rate (mg/Tank hr)	
							Collector I	Collector II
Neodymium-142	27.11	OU[1]	72.6	74.8	89.4	13.2	13.2	0
Neodymium-143	12.17				95.3	6.30	0	6.30
Neodymium-144	23.85				91.4	11.8	11.8	0
Neodymium-145	8.30				99.2	4.47	0	4.47
Neodymium-146	17.22				88.8	8.30	8.30	0
Neodymium-148	5.73				93.1	2.90	2.90	2.90
Neodymium-150	5.62				84.0	2.56	2.56	2.56
Nickel-58	67.76	QN[3]	256.3	66.8	84.0	97.5	97.5	
Nickel-60	26.16				91.5	41.0	41.0	
Nickel-61	1.25				79.9	1.71	1.71	
Nickel-62	3.66				84.9	5.32	5.32	
Nickel-64	1.16				65.0	1.29	1.29	
Osmium-184	0.018	RB	83.0	32.9	476.0	0.023	0.023	0.023
Osmium-186	1.59				46.7	0.203	0.203	0
Osmium-187	1.64				102.0	0.457	0	0.457
Osmium-188	13.30				64.8	2.35	2.35	0
Osmium-189	16.10				65.0	2.86	0	2.86
Osmium-190	26.40				76.2	5.49	5.49	0
Osmium-192	41.0				64.1	7.18	7.18	7.18

Table A-1. Collection rates of isotopes* (continued)

Element Isotope	Natural Abundance (%)	Series	Total Product to Receiver (mg/Innage hr)	Innage (%)	Retention (%)	Pocket Recovery (mg/Tank hr)	Collection Rate (mg/Tank hr)	
							Collector I	Collector II
Palladium-102	0.96	PR	90.2	67.8	82.0	0.481	0.481	0.481
Palladium-104	10.97				78.8	5.28	5.28	0
Palladium-105	22.23				73.2	9.95	0	9.95
Palladium-106	27.33				71.8	12.0	12.0	0
Palladium-108	26.71				78.8	12.9	12.9	12.9
Palladium-110	11.81				73.0	5.27	5.27	5.27
Platinum-190	0.012	RC	71.3	51.8	1,097.0	0.049	0.049	0.049
Platinum-192	0.78				79.8	0.230	0.230	0.230
Platinum-194	32.80				95.1	11.5	11.5	0
Platinum-195	33.70				86.4	10.7	0	10.7
Platinum-196	25.40				87.6	8.22	8.22	0
Platinum-198	7.23				79.8	2.13	2.13	2.13
Potassium-39	93.08	KI	28.5	85.2	65.3	14.8	14.8	
Potassium-40	0.0119				277.0	0.008	0.008	
Potassium-41	6.91				48.9	0.820	0.820	
Rhenium-185	37.07	OS	92.1	68.0	73.5	17.1	17.1	
Rhenium-187	62.93				81.3	32.0	32.0	
Rubidium-85	72.15	PP	67.5	85.2	73.7	30.6	30.6	
Rubidium-87	27.85				79.9	12.8	12.8	

Table A-1. Collection rates of isotopes* (continued)

Element Isotope	Natural Abundance (%)	Series	Total Product to Receiver (mg/Innage hr)	Innage (%)	Retention (%)	Pocket Recovery (mg/Tank hr)	Collection Rate (mg/Tank hr) Collector I	Collector II
Ruthenium-96	5.47	RH	41.0	44.2	66.5	0.659	0.659	
Ruthenium-98	1.84				62.9	0.210	0.201	
Ruthenium-99	12.77				70.7	1.64	1.64	
Ruthenium-100	12.56				65.8	1.50	1.50	
Ruthenium-101	17.10				60.2	1.87	1.87	
Ruthenium-102	31.70				55.3	3.18	3.18	
Ruthenium-104	18.56				70.3	2.37	2.37	
Samarium-144	3.16	NU[1]	118.3	77.2	95.5	2.76	2.76	2.76
Samarium-147	15.07				92.8	12.8	0	12.8
Samarium-148	11.27				98.2	10.1	10.1	0
Samarium-149	13.84				90.3	11.4	0	11.4
Samarium-150	7.47				90.2	6.15	6.15	0
Samarium-152	26.63				98.9	24.1	24.1	24.1
Samarium-154	22.53				91.2	18.8	18.8	18.8
Selenium-74	0.87	PH	31.5	88.8	49.5	0.120	0.120	
Selenium-76	9.02				89.8	2.27	2.27	
Selenium-77	7.58				93.4	1.98	1.98	
Selenium-78	23.52				89.3	5.87	5.87	
Selenium-80	49.82				94.7	13.2	13.2	
Selenium-82	9.19				71.3	1.83	1.83	

Table A-1. Collection rates of isotopes* (continued)

Element Isotope	Natural Abundance (%)	Series	Total Product to Receiver (mg/Innage hr)	Innage (%)	Retention (%)	Pocket Recovery (mg/Tank hr)	Collection Rate (mg/Tank hr) Collector I	Collector II
Silicon-28	92.27	LW	62.6	78.0	77.8	35.1	35.1	
Silicon-29	4.68				57.6	1.32	1.32	
Silicon-30	3.05				61.8	0.920	0.920	
Silver-107	51.35	NP	76.8	80.1	72.3	22.8	22.8	
Silver-109	48.65				70.8	21.2	21.2	
Strontium-84	0.56	MS	142.0	80.1	83.8	0.534	0.534	
Strontium-86	9.86				93.7	10.5	10.5	
Strontium-87	7.02				93.1	7.43	7.43	
Strontium-88	82.56				84.0	78.9	78.9	
Sulfur-32	95.06	NV	87.3	67.2	85.7	47.8	47.8	
Sulfur-33	0.74				40.0	0.174	0.174	
Sulfur-34	4.18				62.0	1.52	1.52	
Sulfur-36	0.016				10.0	0.001	0.001	
Tantalum-180	0.012	KX	65.7	76.5	40,506.0	2.44	2.44	
Tellurium-120	0.089	QX[2]	133.7	79.5	85.6	0.081	0.081	0.081
Tellurium-122	2.46				58.1	1.52	0	1.52
Tellurium-123	0.87				74.8	0.692	0.692	0
Tellurium-124	4.61				83.7	4.10	0	4.10

Table A-1. Collection rates of isotopes* (continued)

Element Isotope	Natural Abundance (%)	Series	Total Product to Receiver (mg/Innage hr)	Innage (%)	Retention (%)	Pocket Recovery (mg/Tank hr)	Collection Rate (mg/Tank hr)	
							Collector I	Collector II
Tellurium-125	6.99				96.6	7.18	7.18	0
Tellurium-126	18.71				65.4	13.0	0	13.0
Tellurium-128	31.79				77.8	26.3	26.3	26.3
Tellurium-130	34.49				69.8	25.6	25.6	25.6
Thallium-203	29.50	QW	222.6	97.4	74.0	47.3	47.3	
Thallium-205	70.50				72.0	110.0	110.0	
Tin-112	0.95	OT	97.4	79.2	71.0	0.520	0.520	0.520
Tin-114	0.65				68.4	0.343	0.343	0
Tin-115	0.34				91.1	0.239	0	0.239
Tin-116	14.24				85.0	9.34	9.34	0
Tin-117	7.57				94.3	5.51	0	5.51
Tin-118	24.01				81.2	15.0	15.0	0
Tin-119	8.58				84.3	5.58	0	5.58
Tin-120	32.97				93.5	23.8	23.80	0
Tin-122	4.71				79.2	2.88	2.88	2.88
Tin-124	5.98				77.2	3.56	3.56	3.56
Titanium-46	7.95	MN	77.5	87.5	72.2	3.89	3.89	
Titanium-47	7.75				72.4	3.81	3.81	
Titanium-48	73.45				75.0	37.4	37.4	

Table A-1. Collection rates of isotopes* (continued)

Element Isotope	Natural Abundance (%)	Series	Total Product to Receiver (mg/Innage hr)	Innage (%)	Retention (%)	Pocket Recovery (mg/Tank hr)	Collection Rate (mg/Tank hr)	
							Collector I	Collector II
Titanium-49	5.51				63.2	2.36	2.36	
Titanium-50	5.34				62.8	2.27	2.27	
Tungsten-180	0.135	MT	218.8	70.6	733.0	1.53	1.53	1.53
Tungsten-182	26.40				85.0	34.7	0	34.7
Tungsten-183	14.40				104.0	23.1	23.1	0
Tungsten-184	30.6				84.8	40.1	0	40.1
Tungsten-186	28.4				84.4	37.0	37.0	37.0
Vanadium-50	0.24	IT	43.2	71.8	54.8	0.44	0.44	
Ytterbium-168	0.14	QV	88.4	69.3	303.0	0.260	0.260	0.260
Ytterbium-170	3.03				102.0	1.90	1.90	0
Ytterbium-171	14.31				100.0	8.80	0	8.80
Ytterbium-172	21.82				90.0	12.0	12.0	0
Ytterbium-173	16.13				95.0	9.40	0	9.40
Ytterbium-174	31.84				94.0	18.3	18.3	0
Ytterbium-176	12.73				85.0	6.63	6.63	6.63
Zinc-64	48.89	QU	134.8	75.6	51.8	25.8	0.258	
Zinc-66	27.82				75.2	21.3	21.3	
Zinc-67	4.14				58.7	2.48	2.48	

Table A-1. Collection rates of isotopes*

Element Isotope	Natural Abundance (%)	Series	Total Product to Receiver (mg/Innage hr)	Innage (%)	Retention (%)	Pocket Recovery (mg/Tank hr)	Collection Rate (mg/Tank hr)	
							Collector I	Collector II
Zinc-68	18.54				83.5	15.8	15.8	
Zinc-70	0.617				78.8	0.495	0.495	
Zirconium-90	51.46	PN	33.9	76.3	95.2	12.7	12.7	0
Zirconium-91	11.23				81.5	2.37	0	2.37
Zirconium-92	17.11				85.0	3.76	3.76	0
Zirconium-94	17.40				82.2	3.70	3.70	3.70
Zirconium-96	2.80				47.3	0.343	0.343	0.343

* Total product to receiver: (Average total ion current)(0.0373)(Atomic weight of element); Pocket recovery: (Total product to receiver)(Natural abundance)(% Innage)(% Retention); % Retention: (Recovered weight)(Estimated weight).

1. Separations in both 180° and 255° machine.
2. Separation in 255° machine.
3. Two-arc equipment.

APPENDIX B

Table B-1. Average sales per year in milligrams (1980-1984)

Element-Isotope	1980	1981	1982	1983	1984	Total	Average
Antimony-121	1,096	36	1,244	0	294	2,670	534
Antimony-123	886	180	1,924	388	1,219	4,597	919
Barium-130	110	14	85	50	5	264	53
Barium-132	203	10	20	0	1	234	47
Barium-134[a]	30	121	0	0	64	215	43
Barium-135	2,280	2,084	297	210	332	5,203	1,041
Barium-136[a]	4,436	440	500	0	0	5,376	1,075
Barium-137	2,000	300	265	0	190	2,755	551
Barium-138	9,490	1,558	2,000	1,340	0	14,388	2,878
Bromine-79	2,593	1,386	1,828	102	2,600	8,509	1,702
Bromine-81	2,030	1,325	920	0	320	4,595	919
Cadmium-106	240	350	283	72	0	945	189
Cadmium-108	80	18	143	175	0	416	83
Cadmium-110[a]	9,770	380	334	6	300	10,790	2,158
Cadmium-111	3,697	3,501	2,650	93	339	10,280	2,056
Cadmium-112	36,242	11,730	8,452	78,300	81,000	215,724	43,145
Cadmium-113[a]	7,676	2,326	0	0	263	10,265	2,053
Cadmium-114	4,345	4,200	3,332	7,000	4,222	23,099	4,620
Cadmium-116	1,680	2,642	1,982	930	0	7,234	1,447

Table B-1. Average sales per year in milligrams (1980-1984) (continued)

Element-Isotope	1980	1981	1982	1983	1984	Total	Average
Calcium-40	5,330	4,191	4,514	2,600	3,813	20,448	4,090
Calcium-42	1,026	544	1,673	655	1,058	4,956	991
Calcium-43	71	22	67	10	20	190	38
Calcium-44	4,530	704	2,223	3,379	2,580	1,316	2,683
Calcium-46	8	42	15	7	111	183	37
Calcium-48	465	444	1,652	1,095	1,237	4,893	979
Cerium-136	0	4	4	5	0	13	3
Cerium-138	0	0	0	0	0	0	0
Cerium-140	11,520	8,905	55,796	15,950	500	92,671	18,534
Cerium-142	949	193	1,065	354	160	2,721	544
Chlorine-35	4,572	5,325	1,545	950	3,550	15,942	3,189
Chlorine-37	440	233	170	250	2,117	3,210	642
Chromium-50	2,124	1,900	2,229	2,980	3,033	12,266	2,453
Chromium-52	1,400	1,295	1,800	600	271	5,366	1,073
Chromium-53	2,125	324	1,270	540	50	4,309	862
Chromium-54	390	5,082	535	0	120	6,127	1,225
Copper-63	76,683	-17,136	14,861	27,733	12,418	131,659*	32,924
Copper-65	27,290	10,733	11,649	8,742	13,153	71,567	14,313

Table B-1. Average sales per year in milligrams (1980-1984) (continued)

Element-Isotope	1980	1981	1982	1983	1984	Total	Average
Dysprosium-156[a]	0	85	10	26	12	133	27
Dysprosium-158	-395	0	83	150	16	249*	62
Dysprosium-160	1,650	1,085	27	673	100	3,535	707
Dysprosium-161	5,932	2,255	3,105	453	790	12,535	2,507
Dysprosium-162	1,940	10,722	7,320	333	4,674	24,989	4,998
Dysprosium-163	3,750	1,725	2,050	3,035	540	11,100	2,220
Dysprosium-164	8,335	2,980	16,350	8,790	95	36,550	7,310
Erbium-162[a]	0	100	5	0	50	155	31
Erbium-164	280	50	152	0	0	482	97
Erbium-166	1,639	3,350	4,295	2,315	175	11,774	2,355
Erbium-167	9,600	755	2,356	1,776	861	15,348	3,070
Erbium-168	8,500	1,600	3,085	1,655	2,140	16,980	3,396
Erbium-170	3,370	7,445	925	419	2,345	14,504	2,901
Europium-151	1,176	1,227	1,455	723	4,964	9,545	1,909
Europium-153	2,041	6,642	961	1,465	3,825	14,934	2,987
Gadolinium-152[a]	160	320	38	229	416	1,163	233
Gadolinium-154	25	550	550	45	183	1,353	271
Gadolinium-155	493	305	322	270	180	1,570	314

Table B-1. Average sales per year in milligrams (1980-1984) (continued)

Element-Isotope	1980	1981	1982	1983	1984	Total	Average
Gadolinium-156	8,025	1,327	535	20	20	9,927	1,985
Gadolinium-157	656	750	451	25	200	2,082	416
Gadolinium-158	3,911	1,600	75	410	712	6,708	1,342
Gadolinium-160	5,392	42,170	4,155	6,262	7,456	65,435	13,087
Gallium-69	713	2,300	3,300	1,550	817	8,680	1,736
Gallium-71	1,600	2,160	4,245	315	659	8,979	1,796
Germanium-70[a]	10,610	1,396	0	0	0	12,006	2,401
Germanium-72[a]	1,610	4,300	436	0	140	6,486	1,297
Germanium-73	140	238	463	16	347	1,204	241
Germanium-74	12,260	7,163	6,699	3,000	2,002	31,124	6,225
Germanium-76	1,460	330	940	11	200	2,941	588
Hafnium-174	10	1	2	0	0	13	3
Hafnium-176	50	64	307	0	0	421	84
Hafnium-177[a]	547	270	800	86	619	2,322	464
Hafnium-178	550	201	150	674	91	1,666	333
Hafnium-179	522	421	1,079	260	635	2,917	583
Hafnium-180	315	379	884	1,670	630	3,878	776

Table B-1. Average sales per year in milligrams (1980-1984) (continued)

Element-Isotope	1980	1981	1982	1983	1984	Total	Average
Indium-113	50	4	124	60	110	348	70
Indium-115[a]	0	190	1,200	0	0	1,390	278
Iridium-191[a]	850	2,651	177	0	510	4,188	838
Iridium-193[a]	850	3,719	32	0	400	5,001	1,000
Iron-54	11,743	6,155	5,900	4,524	4,730	33,052	6,610
Iron-56	15,610	30,320	33,860	36,111	39,089	154,990	30,998
Iron-57	6,093	6,564	10,152	5,216	4,509	32,534	6,507
Iron-58[a]	848	210	5,425	1,606	30	8,119	1,624
Lanthanum-138	47	33	28	186	5	299	60
Lanthanum-139	0	0	100	0	0	100	20
Lead-204[a]	306	0	155	139	115	715	143
Lead-206	1,609	12,043	2,603	1,180	1,106	18,541	3,708
Lead-207	8,875	10,701	6,150	8,814	1,430	35,970	7,194
Lead-208[a]	100,331	25,017	19,847	80,777	13,796	239,768	47,954
Lutetium-175	283	500	200	482	255	1,720	344
Lutetium-176[a]	2,385	0	0	0	0	2,385	1,192

Table B-1. Average sales per year in milligrams (1980-1984) (continued)

Element-Isotope	1980	1981	1982	1983	1984	Total	Average
Magnesium-24	3,433	4,967	2,900	3,340	12,004	26,644	5,329
Magnesium-25	2,160	2,126	6,193	1,600	2,504	14,583	2,917
Magnesium-26[a]	2,595	4,810	0	300	1,103	8,808	1,762
Mercury-196	36	2	30	25	13	106	21
Mercury-198[a]	195	130	278	9	142	754	151
Mercury-199[a]	125	184	537	10	171	1,027	205
Mercury-200[a]	363	272	100	0	50	785	157
Mercury-201[a]	93	120	366	-244	1,003	1,582*	396
Mercury-202[a]	120	363	290	10	80	863	173
Mercury-204[a]	1,583	0	0	0	391	1,974	395
Molybdenum-92	2,785	1,691	4,833	1,900	1,777	12,986	2,597
Molybdenum-94	1,925	1,281	900	1,540	2,204	7,850	1,570
Molybdenum-95	7,566	3,492	4,450	5,423	59,918	80,849	16,170
Molybdenum-96	4,137	5,440	8,626	2,920	2,600	23,723	4,745
Molybdenum-97	5,300	1,277	2,372	930	2,951	12,736	2,547
Molybdenum-98	2,120	1,250	2,000	500	2,100	7,970	1,594
Molybdenum-100[a]	1,800	1,588	5,360	2,220	15,200	26,168	5,234

Table B-1. Average sales per year in milligrams (1980-1984) (continued)

Element-Isotope	1980	1981	1982	1983	1984	Total	Average
Neodymium-142	1,567	1,110	748	404	2,966	6,785	1,357
Neodymium-143	1,503	3,150	120	205	0	4,978	996
Neodymium-144	227	1,975	840	5,233	3,762	12,037	2,407
Neodymium-145	2,705	852	4,214	100	392	8,263	1,653
Neodymium-146	2,840	845	1,122	3,899	1,666	10,372	2,074
Neodymium-148	1,155	3,550	454	20	395	5,570	1,115
Neodymium-150	1,975	3,250	1,278	3,032	643	10,178	2,036
Nickel-58	25,339	59,770	14,543	20,905	140,010	260,567	52,113
Nickel-60	80,949	66,703	90,279	2,740	19,975	260,646	52,129
Nickel-61	526	222	671	454	342	2,215	443
Nickel-62	2,600	3,547	15,151	10,224	10,723	42,245	8,449
Nickel-64	689	1,715	2,261	702	1,743	7,110	1,422
Osmium-184	0	1	2	0	0	3	1
Osmium-186	0	69	0	0	52	121	24
Osmium-187	50	53	0	25	27	155	31
Osmium-188	150	480	1,296	0	16	1,942	388
Osmium-189	451	270	357	100	812	1,990	398
Osmium-190[a]	673	5,275	0	0	1,406	7,354	1,471
Osmium-192	2,322	393	0	1,238	984	4,937	987

Table B-1. Average sales per year in milligrams (1980-1984) (continued)

Element-Isotope	1980	1981	1982	1983	1984	Total	Average
Palladium-102[a]	0	27	0	50	637	714	143
Palladium-104	500	831	161	0	614	2,106	421
Palladium-105[a]	3,462	0	200	21	100	3,783	757
Palladium-106	1,220	760	148	260	164	2,552	510
Palladium-108[a]	4,506	2,077	421	181	580	7,765	1,553
Palladium-110[a]	1,367	0	72	70	949	2,458	492
Platinum-190[a]	0	0	5	60	4	69	14
Platinum-192	0	0	128	0	229	357	72
Platinum-194[a]	44	0	0	0	1,784	1,828	366
Platinum-195	2,074	100	100	22	1,056	3,352	670
Platinum-196[a]	1,077	170	0	30	942	2,219	444
Platinum-198[a]	1,320	202	112	100	975	2,709	542
Potassium-39	235	1,087	2,037	1,333	2,333	7,025	1,405
Potassium-40[a]	69	59	13	0	0	141	47
Potassium-41[a]	781	543	628	119	5	2,076	519
Rhenium-185	583	3,485	1,006	0	53	5,127	1,709
Rhenium-187	1,352	1,277	580	0	0	3,209	802
Rubidium-85	3,030	3,503	1,465	1,716	2,049	11,763	2,353
Rubidium-87	8,285	4,085	4,489	2,886	6,407	26,152	5,230

Table B-1. Average sales per year in milligrams (1980-1984) (continued)

Element-Isotope	1980	1981	1982	1983	1984	Total	Average
Ruthenium-96[a]	0	0	0	0	410	410	410
Ruthenium-98[a]	0	0	0	0	20	20	20
Ruthenium-99[a]	225	0	0	0	400	625	321
Ruthenium-100[a]	256	0	0	24	600	624	312
Ruthenium-101[a]	0	850	0	14	1,629	2,493	1,246
Ruthenium-102[a]	516	0	0	0	1,155	1,671	835
Ruthenium-104[a]	652	1,584	93	0	1,169	3,498	875
Samarium-144[a]	2,311	1,075	145	20	1,940	5,491	1,098
Samarium-147	1,750	3,650	3,805	2,591	550	12,346	2,469
Samarium-148	1,292	2,200	1,201	1,135	1,330	7,158	1,432
Samarium-149	4,000	2,831	1,431	755	545	9,562	1,912
Samarium-150	3,697	1,631	3,509	700	200	9,737	1,947
Samarium-152	44,675	-15,022	10,37	10,337	2,023	58,385	11,677
Samarium-154	12,894	31,493	5,086	47,291	2,730	99,494	19,899
Selenium-74	234	165	255	284	86	1,024	205
Selenium-76	730	470	1,184	3,155	695	6,234	1,247
Selenium-77	332	570	470	485	244	2,101	420
Selenium-78	350	235	360	745	424	2,114	423
Selenium-80	7,556	480	671	299	971	9,977	1,995
Selenium-82	40	105	729	1,546	-792	2,420	605

Table B-1. Average sales per year in milligrams (1980-1984) (continued)

Element-Isotope	1980	1981	1982	1983	1984	Total	Average
Silicon-28	1,624	2,100	437	3,753	1,420	9,334	1,867
Silicon-29	2,422	6,065	5,618	1,500	2,756	18,361	3,672
Silicon-30[a]	2,584	3,595	1,367	1,335	544	9,425	1,885
Silver-107	17,025	8,905	8,875	3,650	5,639	44,094	8,819
Silver-109	23,283	578	9,614	2,833	1,029	37,337	7,467
Strontium-84	1,520	401	242	185	193	2,541	508
Strontium-86	2,313	2,200	2,875	3,200	2,165	12,753	2,551
Strontium-87	2,100	0	2,688	3,222	300	8,310	1,662
Strontium-88	4,720	2,800	37,424	38,250	21,270	104,464	20,893
Sulfur-32	1,210	500	565	1,000	2,000	5,275	1,055
Sulfur-33	363	287	244	357	458	1,709	342
Sulfur-34[a]	1,016	940	2,080	943	40	5,019	1,004
Sulfur-36	0	0	76	0	0	76	15
Tantalum-180	2	17	6	0	0	25	8
Tellurium-120	3	0	0	50	25	78	16
Tellurium-122	520	203	1,410	55	298	2,486	497
Tellurium-123	200	70	100	90	858	1,318	264
Tellurium-124	19,875	38,682	61,630	46,185	10,975	177,347	35,470

Table B-1. Average sales per year in milligrams (1980-1984) (continued)

Element-Isotope	1980	1981	1982	1983	1984	Total	Average
Tellurium-125	300	1,822	373	5,475	480	8,450	1,690
Tellurium-126	2,365	3,049	3,419	3,732	2,600	15,165	3,033
Tellurium-128	6,999	3,300	12,881	9,078	8,287	40,545	8,109
Tellurium-130	10,713	9,400	16,226	5,275	4,052	45,666	9,133
Thallium-203	708,176	1,242.842	799,710	655,408	211,655	3,617,791	723,558
Thallium-205	5,000	1,410	3,833	0	4,651	14,894	2,979
Tin-112	3,079	2,821	430	2,361	1,050	9,741	1,948
Tin-114	70	20	140	160	714	1,104	221
Tin-115	0	21	14	0	5	40	8
Tin-116	5,098	3,369	442	1,620	1,720	12,249	2,450
Tin-117	-57,068	2,867	945	980	707	62,567	12,513
Tin-118	7,779	1,108	7,213	2,487	2,736	21,323	4,265
Tin-119	6,944	7,978	5,854	5,783	7,961	34,520	6,904
Tin-120	3,015	5,881	2,730	4,295	5,300	21,221	4,244
Tin-122	1,200	2,341	3,666	343	4,175	11,725	2,345
Tin-124	8,900	4,503	50,965	4,562	1,989	70,919	14,184
Titanium-46	3,685	2,295	149	210	0	6,339	2,113
Titanium-47	5,874	200	450	1,370	270	8,164	2,041
Titanium-48	1,883	1,120	4,728	3,107	2,714	13,552	2,710

Table B-1. Average sales per year in milligrams (1980-1984) (continued)

Element-Isotope	1980	1981	1982	1983	1984	Total	Average
Titanium-49	5,322	924	130	0	124	6,500	2,167
Titanium-50	879	782	700	126	0	2,187	729
Tungsten-180	0	0	125	0	11	136	28
Tungsten-182	884	1,929	850	2,300	400	5,479	1,096
Tungsten-183[a]	1,150	950	875	0	0	2,975	992
Tungsten-184[a]	1,169	250	1,150	1,386	700	4,655	931
Tungsten-186	4,500	3,900	800	1,047	400	10,647	2,130
Vanadium-50[a]	1	3	23	0	10	36	7
Ytterbium-168	500	1,299	286	757	890	3,732	747
Ytterbium-170	150	0	250	625	100	1,125	225
Ytterbium-171	3,162	2,535	1,292	310	445	7,744	1,549
Ytterbium-172	555	1,270	200	620	600	3,245	649
Ytterbium-173	995	500	1,025	1,711	165	4,396	879
Ytterbium-174	1,800	3,605	0	995	925	7,325	1,465
Ytterbium-176	3,317	3,525	2,590	700	4,600	14,732	2,947
Zinc-64	5,720	6,020	2,003	1,061	2,900	17,704	3,541
Zinc-66	2,627	5,360	7,794	3,847	150	19,778	3,956
Zinc-67	4,754	4,319	4,405	1,969	1,257	16,704	3,341

Table B-1. Average sales per year in milligrams (1980-1984) (continued)

Element-Isotope	1980	1981	1982	1983	1984	Total	Average
Zinc-68	118,481	119,175	142,303	82,370	254,460	716,789	143,358
Zinc-70	1,057	1,000	396	185	373	3,011	602
Zirconium-90	10,805	3,658	6,271	3,000	1,002	24,736	4,947
Zirconium-91	480	44	325	16	637	1,502	301
Zirconium-92	60	470	301	1,160	420	3,653	731
Zirconium-94	554	685	2,288	695	140	4,362	873
Zirconium-96	98	0	80	92	40	310	62

*Does not include negative (-) sales. Negative values result from inventory adjustments and are not included in calculations.

a. Sales data limited due to low inventory.

NOTE: Data obtained from ORNL/TM-7214, -7764, -8302, -8704, and -8979.

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