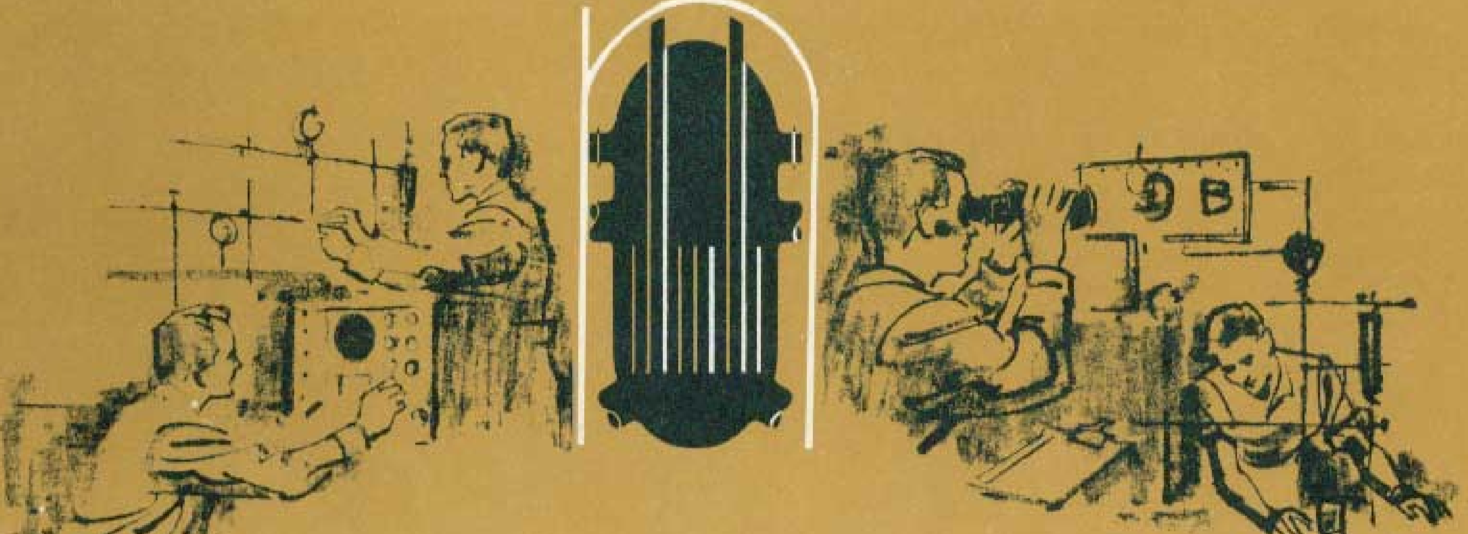
NUMEC®

1966



Nuclear Materials and Equipment Corporation
Apollo, Pennsylvania 15613
U.S.A.

NUMEC® Products and Services

FUEL MATERIALS
Bulk and fabricated
Uranium, plutonium and thorium
Metals, alloys and compounds

MODERATING MATERIALS
Beryllium oxide
Hydrides of zirconium, yttrium and niobium

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Preparation and fabrication

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Isotopic heat sources
Neutron sources
Alpha sources
Beta and gamma sources

CRYSTAL BAR
Hafnium and zirconium

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Spherical metal powders
Brazing alloys
Powder metallurgy parts
Controlled porosity shapes

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Thermionic converters

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Automatic weight, density and dimensional inspection devices (Densitron®)
Crush strength apparatus
Surface area and density apparatus
Nuclear moisture-density gauges

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Derivative polorographic instruments (Polaroscan®)
Constant potential coulometric titrator
Surface area and density apparatus
Pyro-hydrolysis tubes
Neutron irradiator-howitzer (Neutron Pac®)
Gamma irradiators

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Cathodic vacuum etchers
Vacuum evaporators
Combination vacuum etcher-evaporators
Remotized vacuum etcher and evaporators

METAL WORKING SERVICES
Melting and casting
Rolling
Pressing and compaction
Swaging
Extrusion
Vacuum annealing and out-gassing
Brazing and welding

COATING
Monolayer
angular pa

CEMENTA
High densit

SCRAP RE
Reprocessin
Recovery o

LABORAT
Instrumenta
Materials r
Radiochemi
Powder ch
Corrosion t
Physical te
Hot Labora

DECONTA
Equipment
Clothing

RADIOPR
Equipment
Architect-e
Industrial s
Process de

CONSULTING SERVICE
Materials
Health Physics
Decontamination
Radioisotope application
Radioprocessing application
Personnel training

ARCHITECTURAL AND ENGINEERING SERVICE
Chemical processing facilities
Radiation processing facilities
Radioprocessing facilities

Y

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CONTENTS

NUMEC®
1966

DATA CONCERNING THE ELEMENTARY PARTICLES THAT COMBINE TO BUILD UP ALL THE ATOMS OF THE PERIODIC SYSTEM OF ELEMENTS

NAME AND SYMBOL	CHARGE	MASS	ENERGY	ATOMIC* WEIGHT	NUMBER	DIAMETER
Positive + Negative — Neutral O	absolute e. s. u.	gram	mc^2 ergs	relative $C^{12} = 12$	one gram	cm
NEUTRON, η	O	1.67470×10^{-24}	1.5052×10^{-3}	1.008661	5.9712×10^{23}	2.8×10^{-13}
ELECTRON, $\beta -$	-4.8029×10^{-10}	9.1083×10^{-28}	8.186×10^{-7}	5.4858×10^{-4}	1.0979×10^{27}	2.8×10^{-13}
PROTON, ρ	$+4.8029 \times 10^{-10}$	1.67239×10^{-24}	1.5031×10^{-3}	1.007273	5.9795×10^{23}	2.8×10^{-13}
POSITRON, $\beta +$	$+4.8029 \times 10^{-10}$	9.1083×10^{-28}	8.186×10^{-7}	5.4858×10^{-4}	1.0979×10^{27}	2.8×10^{-13}

*Atomic weights, as indicated in the Numec data section, are based upon $C^{12} = 12$.

DIAMETER

cm

2.8
× 10-13

2.8
× 10-13

2.8
× 10-13

2.8
× 10-13

ALPHABETICAL LIST OF THE ELEMENTS

At. No.	Name of Element	Sym.	At. Wt.	At. No.	Name of Element	Sym.	At. Wt.	At. No.	Name of Element	Sym.	At. Wt.
89	Actinium	Ac	227	79	Gold	Au	196.967	59	Praseodymium	Pr	140.907
13	Aluminum	Al	26.9815	72	Hafnium	Hf	178.49	61	Promethium	Pm	145*
95	Americium	Am	243*	2	Helium	He	4.0026	91	Protactinium	Pa	231*
51	Antimony	Sb	121.75	67	Holmium	Ho	164.930	88	Radium	Ra	226*
18	Argon	A	39.948	1	Hydrogen	H	1.00797	86	Radon	Rn	222*
33	Arsenic	As	74.9216	49	Indium	In	114.82	75	Rhenium	Re	186.2
85	Astatine	At	210*	53	Iodine	I	126.9044	45	Rhodium	Rh	102.905
56	Barium	Ba	137.34	77	Iridium	Ir	192.2	37	Rubidium	Rb	85.47
97	Berkelium	Bk	247*	26	Iron	Fe	55.847	44	Ruthenium	Ru	101.07
4	Beryllium	Be	9.0122	36	Krypton	Kr	83.80	62	Samarium	Sm	150.35
83	Bismuth	Bi	208.980	57	Lanthanum	La	138.91	21	Scandium	Sc	44.956
5	Boron	B	10.811	103	Lawrencium	Lw	257*	34	Selenium	Se	78.96
35	Bromine	Br	79.909	82	Lead	Pb	207.19	14	Silicon	Si	28.086
48	Cadmium	Cd	112.40	3	Lithium	Li	6.939	47	Silver	Ag	107.870
20	Calcium	Ca	40.08	71	Lutetium	Lu	174.97	11	Sodium	Na	22.9898
98	Californium	Cf	249*	12	Magnesium	Mg	24.312	38	Strontium	Sr	87.62
6	Carbon	C	12.01115	25	Manganese	Mn	54.9380	16	Sulfur	S	32.064
58	Cerium	Ce	140.12	101	Mendelevium	Md	256*	73	Tantalum	Ta	180.948
55	Cesium	Cs	132.905	80	Mercury	Hg	200.59	43	Technetium	Tc	99*
17	Chlorine	Cl	35.453	42	Molybdenum	Mo	95.94	52	Tellurium	Te	127.60
24	Chromium	Cr	51.996	60	Neodymium	Nd	144.24	65	Terbium	Tb	158.924
27	Cobalt	Co	58.9332	10	Neon	Ne	20.183	81	Thallium	Tl	204.37
29	Copper	Cu	63.54	93	Neptunium	Np	237*	90	Thorium	Th	232.038
96	Curium	Cm	248*	28	Nickel	Ni	58.71	69	Thulium	Tm	168.934
66	Dysprosium	Dy	162.50	41	Niobium	Nb	92.906	50	Tin	Sn	118.69
99	Einsteinium	E	254*	7	Nitrogen	N	14.0067	22	Titanium	Ti	47.90
68	Erbium	Er	167.26	102	Nobelium	No	254*	74	Tungsten	W	183.85
63	Europium	Eu	151.96	76	Osmium	Os	190.2	92	Uranium	U	238.03
100	Fermium	Fm	253*	8	Oxygen	O	15.9994	23	Vanadium	V	50.942
9	Fluorine	F	18.9984	46	Palladium	Pd	106.4	54	Xenon	Xe	131.30
87	Francium	Fr	223*	15	Phosphorus.	P	30.9738	70	Ytterbium	Yb	173.04
64	Gadolinium	Gd	157.25	78	Platinum	Pt	195.09	39	Yttrium	Y	88.905
31	Gallium	Ga	69.72	94	Plutonium	Pu	242*	30	Zinc	Zn	65.37
32	Germanium	Ge	72.59	84	Polonium	Po	209*	40	Zirconium	Zr	91.22
				19	Potassium	K	39.102				

*Mass number of the most staple isotope.

"Atomic weights are based on C^{12}"

SELECTED PROPERTIES OF THE ELEMENTS

	1	2	3	4	5	6	7	8	9	10	11	12	13
PERIOD ↓	Atomic No. Z	Symbol	Average thermal neutron absorption cross section barns*	Density @ 20°C except as noted g/cc	Modulus of elasticity (tension) × 10^6 psi	Electrical resistivity microhm/cm.	Latent heat of fusion cal./g	Specific heat cal./g/°C 20°C	Coefficient of linear thermal expansivity × 10^{-6}/°C 20°C	Thermal conductivity cal./cm.²/cm/°C/sec 20°C	Melting point °C	Boiling point °C	Atomic No. Z
1	1	H	0.33	.00008988			15.0	3.45		4.061×10^{-4}	-259.4	-252.5	1
	2	He	0.007	.0001785				1.25		3.32×10^{-4}	>-272.2	-268.6	2
2	3	Li	71.	0.534		8.55(0°)	104.2	0.79	56.	0.17	179.	'1317.	3
	4	Be	0.010	1.848	40.-44.	4.0(20°)	260.	.45	11.6	.35	1278. ±5	2970.	4
	5	B	755.	2.34	64.	1.8×10^{12}(0°)		0.309	8.3		2300.	2550.	5
	6	C	0.0037	1.9-2.3	0.7	1375.(0°)		0.165	0.6-4.3	0.057	3550.	4827.	6
	7	N	1.9	0.0012506			6.2	0.247		0.600×10^{-4}	-209.86	-195.8	7
	8	O	<0.0002	0.001429			3.3	0.218		0.590×10^{-4}	-218.4	-183.07	8
	9	F	0.009	0.001696			10.1	0.18			-219.62	-188.14	9
	10	Ne	<1.	0.00089990						1.1×10^{-4}	-248.67	-245.92	10
3	11	Na	0.53	0.971^{20}		4.2(0°)	27.5	0.295	71.	0.32	97.81 ±03	883.	11
	12	Mg	0.069	1.738	5.77	4.45(20°)	89.	0.245	26.	0.38	651.	1107.	12
	13	Al	0.24	2.702	9.0	2.6548(20°)	94.6	0.215	23.9	0.53	659.7	2057.	13
	14	Si	0.16	2.33^{25}	16.	10^{3}(0°)	432.	0.162	2.8-7.3	0.20	1410.	2355.	14
	15	P	0.20	$2.07\text{-}1.957^{20}$		10^{17}(11°)	5.0	0.177	125.		44.1 ±01	280.	15
	16	S	0.52	2.07		2×10^{23}(20°)	9.3	0.175	64.	6.31×10^{-4}	112.8—119.0	444.6	16
	17	Cl	34.	0.003214			21.6	0.116		0.172×10^{-4}	-100.98	-34.6	17
	18	A	0.66	0.001784			6.7	0.125		0.406×10^{-4}	-189.2	-185.7	18
4	19	K	2.1	0.862		6.15(0°)	14.5	0.177	83.	0.24	63.65	774.	19
	20	Ca	0.44	1.55	3.2-3.8	3.91(0°)	52.0	0.149	22.	0.3	845. ±3	1487.	20
	21	Sc	24.	2.992		61.0(22°)	84.5	0.134			1539.	2727.	21
	22	Ti	5.8	4.507	16.8	80.(0°)	104.(est)	0.124	8.41		1675.	3260.	22
	23	V	5.00	$6.01^{18.7}$	18.-20.	24.8-26.0(20°)		0.120	8.3	0.074	1890. ±10	÷ 3000.	23
	24	Cr	3.1	7.18-7.20	36.	12.9(0°)	96.	0.11	6.2	0.16	1890.	2482.	24
	25	Mn	13.2	7.24-7.44	23.	185.(23°)	64.	0.115	22.		1244. ±3	2097.	25
	26	Fe	2.6	7.874	28.5	9.71(20°)	65.	0.11	11.7	0.18	1555.	3500.	26
	27	Co	38.	8.85	30.	6.24(20°)	58.4	0.099	13.8	0.165	1495.	2900.	27

*Thermal neutron absorption cross section (2200 m/s) barns
BNL-325, Second Edition and Supplement No. 1.

	11	12	13
al vity ^{2}/ sec	Melting point °C	Boiling point °C	Atomic No. Z
10^{-4}	−259.4	−252.5	1
$)^{-4}$	>−272.2	−268.6	2
	179.	ˆ1317.	3
	1278. ±5	2970.	4
	2300.	2550.	5
	3550.	4827.	6
10^{-4}	−209.86	−195.8	7
10^{-4}	−218.4	−183.07	8
	−219.62	−188.14	9
^{4}	−248.67	−245.92	10
	97.81 ±03	883.	11
	651.	1107.	12
	659.7	2057.	13
	1410.	2355.	14
	44.1 ±01	280.	15
$^{-4}$	112.8—119.0	444.6	16
0^{-4}	−100.98	−34.6	17
0^{-4}	−189.2	−185.7	18
	63.65	774.	19
	845. ±3	1487.	20
	1539.	2727.	21
	1675.	3260.	22
	1890. ±10	≑ 3000.	23
	1890.	2482.	24
	1244. ±3	2097.	25
	1555.	3500.	26
	1495.	2900.	27

SELECTED PROPERTIES OF THE ELEMENTS

	1	2	3	4	5	6	7	8	9	10	11	12	13
PERIOD	Atomic No. Z	Symbol	Average thermal neutron absorption cross section barns*	Density @ 20°C except as noted g/cc	Modulus of elasticity (tension) × 10^6 psi	Electrical resistivity microhm/cm	Latent heat of fusion cal./g	Specific heat cal./g/°C 20°C	Coefficient of linear thermal expansivity × 10^{-6}/°C 20°C	Thermal conductivity cal./cm.²/cm/°C/sec 20°C	Melting point °C	Boiling point °C	Atomic No. Z
	28	Ni	4.6	8.902^{25}	30.	6.84(20°)	74.	0.105	13.3	0.22	1453.	2732.	28
	29	Cu	3.8	8.96	16.	1.673(20°)	50.6	0.092	16.5	0.94	1083.0 ±0.1	2595.	29
	30	Zn	1.1	7.133^{25}	12.	5.916(20°)	24.09	0.0915	39.7	0.27	419.4	907.	30
	31	Ga	2.8	5.907		17.4(20°)	19.2	0.079	18.	0.07-0.09	29.78	2403.	31
	32	Ge	2.5	5.323^{25}		46 × 10^6(22°)		0.073	5.75	0.14	937.4	2830.	32
	33	As	4.3	5.727^{14}		33.3(20°)	88.5	0.082	4.7		814(at 36 atm)	615.	33
	34	Se	12.	4.79	8.4	12.0 (0°)	16.4	0.084	37.	7-18 × 10^{-4}	217.	684.9 ±1	34
	35	Br	6.7	3.12			16.2	0.070			-7.2	58.78	35
	36	Kr	31	0.003743						0.21 × 10^{-4}	-156.6	-152.30	36
5	37	Rb	0.73	1.532		12.5(20°)	6.5	0.080	90.		38.89	688.	37
	38	Sr	1.2	2.60		23.(20°)	25.	0.176			769	1384.	38
	39	Y	1.3	4.45	17.0	29.0(25°)	46.0	0.071		0.035	1495 ±5	2927.	39
	40	Zr	0.18	6.53	13.7	40.0(20°)	60 (est)	0.066	5.	0.211	1852 ±2	3578.	40
	41	Nb	1.2	8.57	15.0^{25}	12.5(0°)	69.0	0.065	7.1	0.125	2468 ±10	4927.	41
	42	Mo	2.7	10.22	50.	5.2(0°)	70 (est)	0.066	4.9	0.35	2610	5560.	42
	43	Tc	22.	11.50							2200 ±50		43
	44	Ru	2.6	12.41	60.	7.6(0°)		0.057	9.1		2250.	3900.	44
	45	Rh	150.	12.41	42.	4.51(20°)		0.059	8.3	0.21	1960 ±3	3727 ±100	45
	46	Pd	8.	12.02	17.	10.8(20°)	34.2	0.058	11.8	0.17	1552.	2927.	46
	47	Ag	63.	10.50^{20}	11.	1.59(20°)	25.	0.056	19.7	0.975	960.8	2212.	47
	48	Cd	2450.	8.65	8.	6.83(0°)	13.2	0.055	29.8	0.22	320.9	765.	48
	49	In	190.	7.31		8.37(20°)	6.8	0.057	33.	0.057	156.61	2000 ±10	49
	50	Sn	.62	5.75 (1)	6.	11.0(0°)	14.5	0.054	23.	0.16	231.89	2270.	50
	51	Sb	5.7	6.684^{25}	11.3	39.0 (0°)	38.3	0.049	8.5-10.8	0.045	630.5	1380.	51
	52	Te	4.7	6.24	6.	4.36 × 10^5(25°)	32.0	0.047	16.8	0.014	449.5 ±0.3	989.8 ±3.8	52

*Thermal neutron absorption cross section (2200 m/s) barns BNL-325, Second Edition and Supplement No. 1.

SELECTED PROPERTIES OF THE ELEMENTS

PERIOD	1	2	3	4	5	6	7	8	9	10	11	12	13
	Atomic No. Z	Symbol	Average thermal neutron absorption cross section barns*	Density @ 20°C except as noted g/cc	Modulus of elasticity (tension) $\times 10^6$ psi	Electrical resistivity microhm/cm.	Latent heat of fusion cal./g	Specific heat cal./g/°C 20°C	Coefficient of linear thermal expansivity $\times 10^{-6}$/°C 20°C	Thermal conductivity cal./cm.²/cm/°C/sec 20°C	Melting point °C	Boiling point °C	Atomic No. Z
	53	I	7.0	4.93		1.3×10^{15}(20°)	14.2	0.052	93.	10.4×10^{-4}	113.5	184.35	53
	54	Xe	35.	0.005887						1.24×10^{-4}	111.9	-107.1±3	54
6	55	Cs	28.	1.873		20 (20°)	3.8	0.048	97.		28.52	690.	55
	56	Ba	1.2	3.51				0.068			725.	1140.	56
	57	La	8.9	5.98-6.186		5.70(25°)	17.3	0.048	5.0	0.033	920.	3469.	57
	58	Ce	0.73	6.67-8.23		75.0(25°)	8.6	0.045	8.	0.026	795.	3468.	58
	59	Pr	11.3	6.782		68.(25°)	11.8	0.046	4.	0.028	935.	3127.	59
	60	Nd	46.	6.80-7.004		64.0(25°)	11.8	0.045	6.	0.031	1024.	3027.	60
	61	Pm									1035.	2730.	61
	62	Sm	5600	7.536	8.0	88.(25°)		0.043			1072.	1900.	62
	63	Eu	4300	5.259		90.0(25°)	16.9	0.040	26.		826.	1439.	63
	64	Gd	46,000	7.9895	8-14	140.5(25°)	16.4	0.071	4	0.021	1312.	÷3000.	64
	65	Tb	46	8.272			23.6	0.044	7.0		1356. ±50	2800.	65
	66	Dy	950	8.537	10-14	57.0(25°)	26.4	0.041	9.0	0.024	1407.	2600.	66
	67	Ho	65	8.803	11.0	87.0(25°)		0.039			146	2600.	67
	68	Er	173	9.051		107.0(25°)	24.6	0.040	9.0	0.023	1497.	2900.	68
	69	Tm	127	9.332		79.0(25°)	26.0	0.038			1545.	1727.	69
	70	Yb	37	6.977		29.0(25°)	12.7	0.035	25.		824. ±5	1427.	70
	71	Lu	112	9.7872		79.0(25°)	26.4	0.037			1652.	3327.	71
	72	Hf	105	13.29	20.	35.1(25°)		0.035	5.9		2150.	5400.	72
	73	Ta	21	16.6	27.	12.45(25°)	38.0	0.034	6.5	0.13	2996.	5425±100	73
	74	W	19.2	19.3	50.	5.65(27°)	44.	0.032	4.6	0.397	3410. ±20	5927.	74
	75	Re	86.	21.02	66.7	19.3(20°)		0.033	6.7	.17	3180.	5627.	75
	76	Os	15.3	22.57	80.	9.5(20°)		0.031	4.6		3000. ±10	5000.	76
	77	Ir	440.	22.42^{17}	75.	5.3(20°)		0.031	6.8	0.14	2410.	4527±100	77
	78	Pt	8.8	21.45	21.	10.6(20°)	27.	0.032	8.9	0.17	1769.	3827±100	78
	79	Au	98.8	19.32	12.	2.35(20°)	16.1	0.031	14.2	0.71	1063.	2966.	79

*Thermal neutron absorption cross section (2200 m/s) barns
BNL-325, Second Edition and Supplement No. 1.

0	11	12	13
rmal ıctivity 'cm.²/ / sec)°C	Melting point °C	Boiling point °C	Atomic No. Z
$\times 10^{-4}$	113.5	184.35	53
$\times 10^{-4}$	111.9	−107.1 ± 3	54
	28.52	690.	55
	725.	1140.	56
33	920.	3469.	57
26	795.	3468.	58
28	935.	3127.	59
31	1024.	3027.	60
	1035.	2730.	61
	1072.	1900.	62
	826.	1439.	63
21	1312.	÷ 3000.	64
	1356. ± 50	2800.	65
24	1407.	2600.	66
	146	2600.	67
23	1497.	2900.	68
	1545.	1727.	69
	824. ± 5	1427.	70
	1652.	3327.	71
	2150.	5400.	72
3	2996.	5425 ± 100	73
97	3410. ± 20	5927.	74
7	3180.	5627.	75
	3000. ± 10	5000.	76
	2410.	4527 ± 100	77
	1769.	3827 ± 100	78
1	1063.	2966.	79

SELECTED PROPERTIES OF THE ELEMENTS

	1	2	3	4	5	6	7	8	9	10	11	12	13
PERIOD ↓	Atomic No. Z	Symbol	Average thermal neutron absorption cross section barns*	Density @ 20°C except as noted g/cc	Modulus of elasticity (tension) $\times 10^{6}$ psi	Electrical resistivity microhm/cm.	Latent heat of fusion cal./g	Specific heat cal./g/°C 20°C	Coefficient of linear thermal expansivity $\times 10^{-6}$/°C 20°C	Thermal conductivity cal./cm.²/cm./°C/sec 20°C	Melting point °C	Boiling point °C	Atomic No. Z
	80	Hg	380.	13.546		98.4 (50°)	2.7	0.033		0.0201	−38.87	356.58	80
	81	Tl	3.4	11.85		18.0 (0°)	5.04	0.031	28.	0.093	303.5	1457 ± 10	81
	82	Pb	0.17	11.35	2.6	20.648(20°)	6.3	0.031	29.3	0.083	327.5	1744.	82
	83	Bi	0.034	9.747	4.6	106.8(0°)	12.5	0.029	13.3	0.020	271.3 ± 0.1	1560 ± 5	83
	84	Po		9.32		42.					254.	962.	84
	85	At											85
	86	Rn		0.000973							−71.	−61.8	86
7	87	Fr											87
	88	Ra	20.	÷ 5.							700.	1737.	88
	89	Ac	510.								1050. ± 50	÷ 3000.	89
	90	Th	7.56	11.66	7.-10.	13.0(0°)	19.82	0.034	12.5	0.090	1700.	÷ 4000.	90
	91	Pa	260.	15.37									91
	92	U	7.68	18.95	24.0	30.	11.3	0.028		0.064	1132.3 ± 0.8	3818.	92
	93	Np		18.0-20.45							640 ± 1		93
	94	Pu		19.84^{25}	14.0	145.4(107°)	3.3	0.033	48.4	0.020	630.5 ± 2	3235 ± 19	94
	95	Am		11.7		143.					> 800.	2600.	95
	96	Cm		÷ 7.									96
	97	Bk											97
	98	Cf											98
	99	Es											99
	100	Fm											100
	101	Md											101
	102	No											102
	103	Lw											103
	104												104
	105												105
	106												106

*Thermal neutron absorption cross section (2200 m/s) barns BNL-325, Second Edition and Supplement No. 1.

FISSION REACTIONS

Energy released E (Mev), prompt neutrons ν, ratio values of delayed to prompt neutrons β, per thermal fission

	Total Energy of light fragments	Total Energy of heavy fragments	Total Energy of γ rays	Total Energy of fission neutron	Total Energy of beta rays	Total Energy	ν	β
U^{233}	97	66	14	5	9	191	2.51	0.0026
U^{235}	98	67	15	4.9	9	194	2.47	0.0064
Pu^{239}	100	72	14	5.8	9	201	2.91	0.0021

BREEDING PROCESSES

$$U^{238} + n = U^{239} + \gamma \,;\; U^{239} \xrightarrow{\text{23 min.}} Np^{239} + \beta- \,;\; Np^{239} \xrightarrow{\text{2.3 days}} Pu^{239} + \beta-$$

$$Th^{232} + n = Th^{233} + \gamma \,;\; Th^{233} \xrightarrow{\text{23 min.}} Pa^{233} + \beta- \,;\; Pa^{233} \xrightarrow{\text{27.4 days}} U^{233} + \beta-$$

THERMONUCLEAR REACTIONS

$$\begin{tikzcd} & T + P + 4.0 \text{ Mev} \\ D + D \arrow[ur] \arrow[dr] & \\ & He^{3} + n + 3.2 \text{ Mev} \end{tikzcd}$$

$$D + T = He^{4} + n + 17.6 \text{ Mev}$$

ıermal fission

β

0.0026

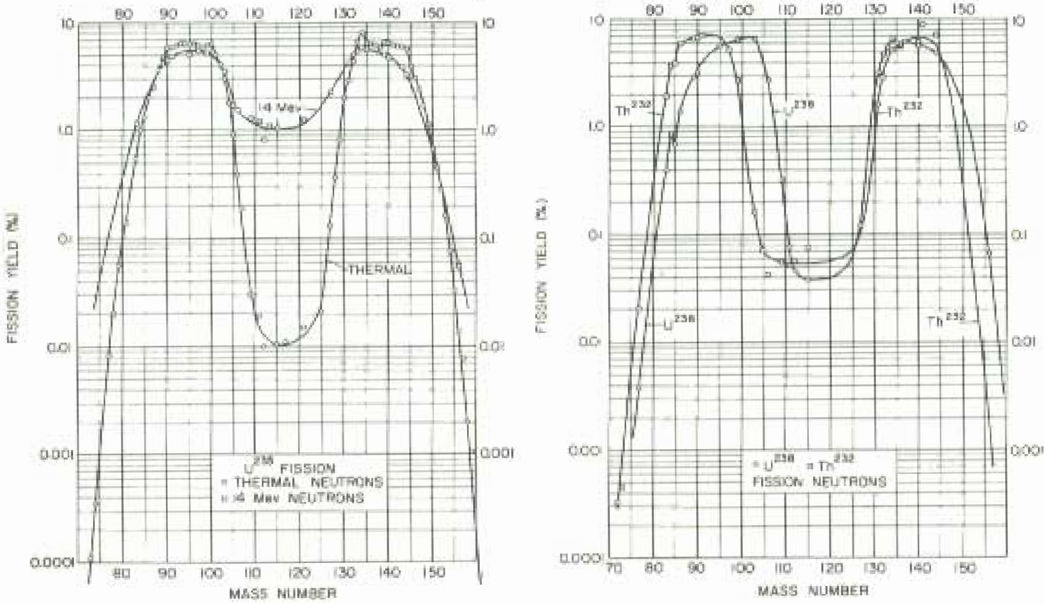
0.0064

0.0021

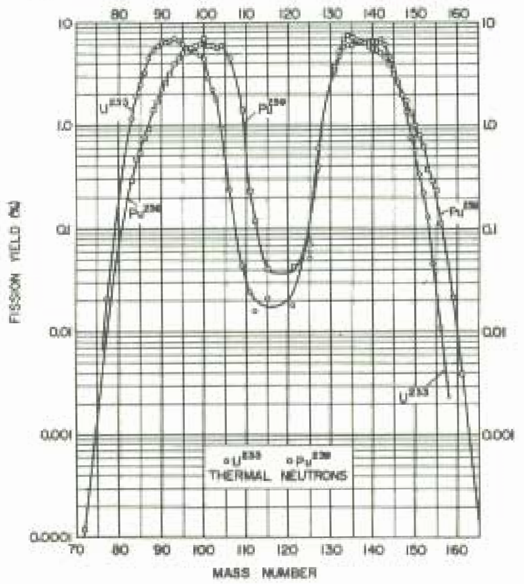
FISSION FRAGMENTS

FISSION YIELD (%) yield vs. mass number for thermal fission

Mass Distribution of U^{235}, U^{238} and Th^{232} Fission Products



U^{233}, Pu^{239} Fission-Product Distribution



From S. Katcoff, Brookhaven National Laboratory, Nucleonics—Nov. 1960

FUNDAMENTAL PHYSICAL CONSTANTS

Symbol	Quantity	Value
$a_0 = \eta^2/me^2$	First Bohr Radius	$5.291659 \pm 0.000026 \times 10^{-9}$cm
$1/\alpha = \eta c/e^2$	Fine Structure Constant	137.0389 ± 0.000006
c	Velocity of Light	$2.997925 \pm 0.000002 \times 10^{10}$cm sec^{-1}
ϵ	Base of Natural Logarithms	2.7182818
e	Electronic Charge	$4.80296 \pm 0.00006 \times 10^{-10}$esu
e^2		$1.43989 \pm 0.00006 \times 10^{-7}$ev cm
e/c		$1.602095 \pm 0.000022 \times 10^{-20}$emu
e/m	Charge to Mass Ratio of the Electron	$5.272741 \pm 0.000015 \times 10^{17}$esu gm^{-1}
e/mc		1.75889×10^{7}emu gm^{-1}
$F = Ne/c$	Faraday Constant (Phys. Scale)	9648.73 ± 0.04 emu gm^{-1} mole^{-1}
γp	Gyromagnetic Ratio of Proton, corrected for Diamagnetism	2.675192 ± 0.000007 radians sec^{-1} gauss^{-1}
h	Planck's Constant	$6.62554 \pm 0.00015 \times 10^{-27}$ erg sec
$\eta = h/2\pi$		$1.05449 \pm 0.00003 \times 10^{-27}$ erg sec
h/e		$1.379469 \pm 0.000013 \times 10^{-17}$ erg sec esu^{-1}

PREFIXES FOR UNITS ADOPTED BY NBS

February 1963

The National Bureau of Standards has accepted the recommendations of the International Committee on Weights and Measures, adopting the following new prefixes for denoting multiples and sub-multiples of units:

Order	Prefix	Symbol	Pronunciation	Order	Prefix	Symbol	Pronunciation
10^{12}	tera	T	ter'a	10^{-2}	centi	c	sen'ti
10^{9}	giga	G	ji'ga	10^{-3}	milli	m	mil'i
10^{6}	mega	M	meg'a	10^{-6}	micro	μ	mi'kro
10^{3}	kilo	k	kil'a	10^{-12}	pico	p	pe'co
10^{2}	hecto	h	hek'to	10^{-15}	femto	f	fem'to
10	deka	da	dek'a	10^{-18}	atto	a	at'to
10^{-1}	deci	d	des'i				

m

:m sec^{-1}

J

:m

emu

ɜsu gm^{-1}

ɔle^{-1}

s sec^{-1} $gauss^{-1}$

g sec

g sec

erg sec esu^{-1}

tee on Weights

nits:

Pronunciation

sen'ti

mil'i

mi'kro

pe'co

fem'to

at'to

RADIOISOTOPE DEFINITIONS

Carrier-Free (CF) — A carrier-free radioisotope of an element is one in which all the atoms of the element that are present are atoms of this radioisotope. However, this ideal is usually only approached; carrier-free is used to mean **no added carrier.**

Concentration — Concentration is the solution concentration of the radioactivity and is usual expressed as millicuries per milliliter (mc/ml), millicuries per gram (mc/g), or millicuries per milligram (mc/mg.).

Cross Section — The neutron activation cross section is a measure of the probability of interaction between a target nucleus and neutrons to produce a specified radioactive nuclide and is usually expressed in barns ($1 \text{ barn} = 10^{-24} \text{ cm}^2$). The values ordinarily listed in cross section tables are the isotopic cross sections; that is, they are applicable only to the particular isotope under consideration. The activation cross section used in calculating the production of a specified radioisotope from the normal element is obtained by multiplying the isotopic cross section by the isotopic abundance.

Some neutrons are absorbed to produce other radionuclides or stable nuclides in the same element; the total absorption cross sections may be found in references such as "Neutron Cross Sections," a compilation of the Atomic Energy Commission Neutron Cross Sections Advisory Group, BNL-325 (July 1, 1958), or "Nuclear Data," a compilation of the National Bureau of Standards Nuclear Data Group, NBS Circular 499 (September 1, 1955).

Curie — A curie is that quantity of a radioisotope required to supply 3.7×10^{10} disintegrations per second (d/sec). When there is an indeterminate mixture of radioisotopes and an absolute measurement cannot be made, a curie is taken as 3.7×10^{10} beta counts/sec, estimated by standard counting procedures and corrected only for counting geometry. One one-thousandth of a curie (3.7×10^7 d/sec) is termed 1 millicurie (mc). One one-millionth of a curie (3.7×10^4 d/sec) is termed 1 microcurie (c).

Electron Capture (EC) — Electron capture is a mode of radioactive decay involving the capture of an orbital electron by its nucleus. Capture from a particular electron shell is designated as K-electron capture or L-electron capture.

Half-Life — The half-life of a radioisotope, one of the fundamental characteristics used to identify a particular radioactive species, is the time required for one-half the atoms to decay.

Isomeric Transition (IT) — Isomeric transition is the process by which a nuclide decays to an isomeric nuclide (one of the same mass number and atomic number) of lower energy. Isomeric transitions proceed by gamma ray and/or by internal conversion electron emission.

Million Electron Volts (Mev) — The energies of radiations listed herein, unless otherwise indicated, are Mev units.

Purity — Purity, as is radiochemical purity, that is, the relative freedom from other radioelements contributing contamination activities. In this respect, daughter activity and activity from radioisotopes of the same element are not considered impurities. For example, the presence of Sb^{124} in Sb^{122} would not be considered in calculating the purity of the Sb^{122}. The approximate amount of such isotopes present, however, is usually given with each shipment.

Radioactive Decay — Radioactive decay is a probability process, and the rate of decay is proportional to the number of radioactive atoms present at any time.

rhm — The abbreviation for 1 roentgen per hour at 1 meter is rhm.

Roentgen — Roentgen is defined by the Radiological Congress (Chicago, 1937) as: "The quantity of X or gamma radiation such that the associated corpuscular emission per 0.001293 g of air (= 1 cc, STP) produces, in air, ions carrying 1 electrostatic unit of quantity of electricity of either sign." A roentgen is equivalent to 1.61×10^{12} ion pairs per gram of air or the absorption of 83.8 ergs of energy per gram of air. One one-thousandth of a roentgen is termed 1 milliroentgen (mr).

Roentgen Equivalent Physical (rep) — The quantity of ionizing radiation required to produce an energy absorption of 93 ergs per gram of tissue is defined as rep.

Specific Activity — Specific activity is taken as the amount of radioactive isotope present per unit weight of total element and is usually expressed in curies or millicuries per gram.

Standard Temperature and Pressure (STP) — STP is a temperature of 0°C and a pressure of 760 mm Hg.

METHODS OF RADIOISOTOPE PRODUCTION

Radioisotopes are produced in a nuclear reactor by several different processes. Those processes that produce appreciable quantities of radioisotopes are described below.

1. (η,γ) **Process.**— In the (η,γ) process, which is most common, a neutron is captured by a target atom, and a gamma photon is emitted immediately. Since no change of the atomic number (charge on the nucleus) occurs, the element remains the same as the target material. The radioelement cannot be separated chemically unless a recoil collection is made, as in the Szilard-Chalmers process. The (η,γ) reaction is primarily a thermal-neutron (low-energy) reaction. For example:

$$_{11}Na^{23} + \eta \longrightarrow {}_{11}Na^{24} - \gamma$$

A radioisotope produced by this method sometimes decays by beta emission to a radioactive daughter with a different atomic number. The daughter can be separated chemically to obtain high specific activity material. For example:

$$_{32}Ge^{76} + \eta \longrightarrow {}_{32}Ge^{77} + \gamma$$

$$_{32}Ge^{77} \xrightarrow[(12\ h)]{\beta\longrightarrow} {}_{33}As^{77}$$

2. (η,ρ) **Process.**— In the (η,ρ) process, which requires neutrons of higher-than-thermal energies, a neutron enters a target nucleus with sufficient energy to cause a proton to be released. The atomic number is reduced by 1, and the affected atom is transmuted into a different element, which can be separated chemically from the target material. Through the chemical separation, high-specific-activity material can be obtained. For example:

$$_{14}S^{32} - \eta \longrightarrow {}_{15}P^{32} + \rho$$

3. (η,α) **Process.**— The (η,α) process, like the (η,ρ) process, requires high-energy neutrons. In the (η,α) process, a neutron of very high energy enters a target atom and causes an alpha particle to be emitted. The atomic number of the target atom is reduced by 2, and a chemical separation is possible. By means of chemical separation, high-specific-activity material can be obtained. For example:

$$_{13}Al^{27} + \eta \longrightarrow {}_{11}Na^{24} + \alpha$$

4. Fission.— In the fission process most of the fragments of uranium atoms which have undergone fission are radioactive atoms ranging from atomic number 30 through atomic number 64. They can be concentrated chemically for high specific activities, but, since several isotopes of any one element are often produced, the isotopic purity will not necessarily be as high as that of radioisotopes produced by (η,ρ) and (η,α) reactions. The isotopic purity will depend somewhat upon the length of time that the uranium was exposed to neutrons and upon the elapsed time between removal from the reactor and the chemical separation.

ACTIVITY PRODUCTION CALCULATION

The basic equation used in calculating activity yields is

$$A = N f \sigma S$$

where A is the activity in disintegrations per second, N is the number of atoms of the target nuclide, f is the neutron flux per square centimeter per second, σ is the activation cross section for the reaction in square centimeters per atom, and S is the saturation factor $(1—e^{-\lambda t})$, which is the ratio of the amount of the activity produced in time t to that produced in infinite time. The decay constant, λ, is related to the half-life of the radionuclide produced ($\lambda = 0.693/\text{half-life}$). Hence $S = (1—e^{-0.693t/T})$, where T = half-life. The activity in disintegrations per second, A, may be converted to millicuries by dividing by 3.7×10^7 d/sec/mc.

A typical example in the application of this equation is given below for calculating the millicuries of Na^{24} activity produced in an irradiation time of seven days. The stable nuclide Na^{23} is 100% abundant; the activation cross section for the (η,γ) reaction is 0.6 ± 0.2 barn; the half-life of Na^{24} is 15.06 hr; and the target material is 0.6 g of Na_2CO_3 (0.26 g of Na). The saturation factor, $S(1—e^{-\lambda t})$, is 1.0 for a seven-day irradiation of a nuclide with a 15-hr half-life. The neutron flux used is 5×10^{11} neutrons/cm²/sec. The number of atoms, N, is Avogadro's number (6.02×10^{23}) times the weight of sodium (in grams) in the target divided by the gram atomic weight of the sodium atom, 23.

$$Na^{24} = \frac{(6.02 \times 10^{23})(5 \times 10^{11})(0.6 \times 10^{-24})(1)(1)(0.26)}{(23)(3.70 \times 10^7)} = 55.2 \text{ mc}$$

The specific activity of sodium is $\frac{55.2 \text{ mc}}{0.26 \text{ g}}$

= 212 mc per gram of sodium.

In cases where t is not very large compared with T, the saturation factor may be obtained by referring to page 13.

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is 5×10^{11} neutrons/cm²/
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atom, 23.

$\frac{)(1)(0.26)}{} = 55.2$ mc

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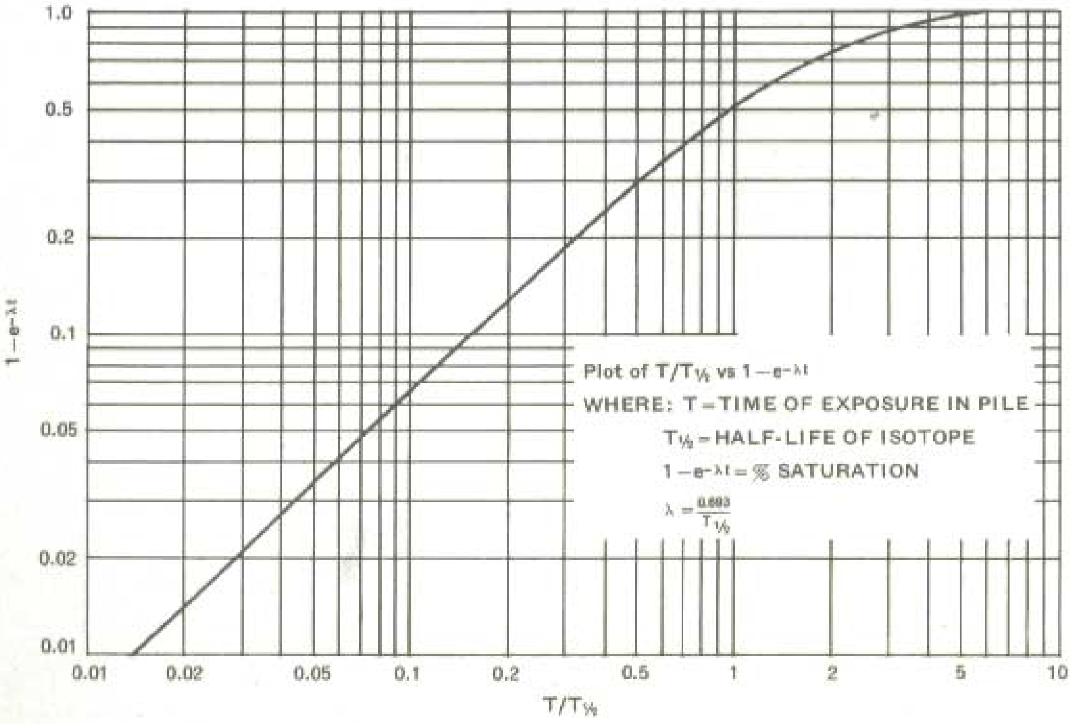
DECAY OF A RADIOELEMENT

Half-Lives	F*	Half-Lives	F*	Half-Lives	F*	Half-Lives	F*
0.00	1.000	0.70	0.616	1.65	0.319	3.20	0.109
0.02	0.986	0.75	0.595	1.70	0.308	3.30	0.102
0.04	0.973	0.80	0.574	1.75	0.297	3.40	0.095
0.06	0.959	0.85	0.555	1.80	0.287	3.50	0.088
0.08	0.946	0.90	0.535	1.85	0.277	3.60	0.083
0.10	0.933	0.95	0.518	1.90	0.268	3.70	0.077
0.12	0.920	1.00	0.500	1.95	0.259	3.80	0.072
0.14	0.908	1.05	0.483	2.00	0.250	3.90	0.067
0.16	0.895	1.10	0.467	2.10	0.233	4.00	0.063
0.18	0.883	1.15	0.451	2.20	0.218	4.10	0.058
0.20	0.871	1.20	0.435	2.30	0.203	4.20	0.054
0.25	0.841	1.25	0.421	2.40	0.189	4.30	0.051
0.30	0.812	1.30	0.406	2.50	0.177	4.40	0.047
0.35	0.785	1.35	0.393	2.60	0.165	4.50	0.044
0.40	0.758	1.40	0.379	2.70	0.154	4.60	0.041
0.45	0.732	1.45	0.367	2.80	0.144	4.70	0.039
0.50	0.707	1.50	0.354	2.90	0.134	4.80	0.036
0.55	0.683	1.55	0.342	3.00	0.125	4.90	0.034
0.60	0.660	1.60	0.330	3.10	0.117	5.00	0.031
0.65	0.638						

*F = fraction remaining.



EXEMPT QUANTITIES OF RADIOISOTOPES

Exempt quantities of radioisotopes are available under general license and do not require a specific AEC license for procurement and possession. Exempt quantities are shown in Title 10, Part 31 of the Federal Register.

Exempt Quantities of Byproduct material	Column No. I Not as a sealed source (micro-curies)	Column No. II As a sealed source (micro-curies)
Antimony (Sb 124)	1	10
Arsenic 76 (As 76)	10	10
Arsenic 77 (As 77)	10	10
Barium 140—Lanthanum 140 (Ba-La 140)	1	10
Beryllium (Be 7)	50	50
Cadmium 109—Silver 109 (Cd-Ag 109)	10	10
Calcium 45 (Ca 45)	10	10
Carbon 14 (C 14)	50	50
Cerium 144—Praseodymium (Ce-Pr 114)	1	10
Cesium—Barium 137 (Ce-Ba 137)	1	10
Chlorine 36 (Cl 36)	1	10
Chromium 51 (Cr 51)	50	50
Cobalt 60 (Co 60)	1	10
Copper 64 (Cu 64)	50	50
Europium 154 (Eu 154)	1	10
Fluorine 18	50	50
Gallium 72 (Ga 72)	10	10
Germanium 71 (Ge 71)	50	50
Gold 198 (Au 198)	10	10
Gold 199 (Au 199)	10	10
Hydrogen 3 (Tritium) (H 3)	250	250
Indium 114 (In 114)	1	10
Iodine 131 (I 131)	10	10
Iridium 192 (Ir 192)	10	10
Iron 55 (Fe 55)	50	50
Iron 59 (Fe 59)	1	10
Lanthanum 140 (La 140)	10	10
Manganese 52 (Mn 52)	1	10
Manganese 56 (Mn 56)	50	50
Molybdenum 99 (Mo 99)	10	10
Nickel 59 (Ni 59)	1	10
Nickel 63 (Ni 63)	1	10
Niobium 95 (Nb 95)	10	10
Palladium 109 (Pd 109)	10	10
Palladium 103—Rhodium 103 (Pd-Rh 103)	50	50
Phosphorus 32 (P 32)	10	10
Polonium 210 (Po 210)	0.1	1
Potassium 42 (K 42)	10	10
Praseodymium 143 (Pr 143)	10	10
Promethium 147 (Pm 147)	10	10
Rhenium 186 (Re 186)	10	10
Rhodium 105 (Rh 105)	10	10
Rubidium 86 (Rb 86)	10	10
Ruthenium 106—Rhodium 106 (Ru-Rh 106)	1	10
Samarium 153 (Sm 153)	10	10
Scandium 46 (Sc 46)	1	10
Silver 105 (Ag 105)	1	10
Silver 111 (Ag 111)	10	10
Sodium 22 (Na 22)	10	10
Sodium 24 (Na 24)	10	10
Strontium 89 (Sr 89)	1	10
Strontium 90—Yttrium 90 (Sr-Y-90)	0.1	1
Sulfur 35 (S 35)	50	50
Tantalum 182 (Ta 182)	10	10
Technetium 96 (Tc 96)	1	10
Technetium 99 (Tc 99)	1	10
Tellurium 127 (Te 127)	10	10
Tellurium 129 (Te 129)	1	10
Thallium 204 (Tl 204)	50	50
Tin 113 (Sn 113)	10	10
Tungsten 185 (W 185)	10	10
Vanadium 48 (V 48)	1	10
Yttrium 90 (Y 90)	1	10
Yttrium 91 (Y 91)	1	10
Zinc 65 (Zn 65)	10	10
Beta and/or gamma emitting by-product material not listed above	1	10

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0	50
0	10
0.1	1
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0	10
0	10
0	10
0	10
0	10
1	10
0	10
1	10
1	10
0	10
0	10
0	10
1	10
0.1	1
0	50
0	10
1	10
1	10
0	10
1	10
0	50
0	10
0	10
1	10
1	10
1	10
0	10
1	10

RADIOISOTOPES FOR HEAT SOURCES

Isotope (in order of decreasing half-life)	Compound	Radiation	Watts per gram of compound	Density of compound gm/cm³	Power density thermal watts per cm³	Shielding thickness of uranium per 100 watt source to produce .1 rads/hr. at 100 cm. cm	Half-life years	Cost $/thermal watt	Curies per thermal watt	Power after 2 years/initial power	Power after 5 years/initial power
Americium, ^{241} Am	Metal	α	.1	11.7	1.17	Minor	458.	$1,820	30	.997	.992
Plutonium, ^{238} Pu	PuO_2	α	.39	10.0	3.9(a)	Minor	89.	894	30	.985	.961
Uranium, ^{232} U	UO_2	α,γ	3.3	10.0	33.0	Heavy	74.	350	26	.981	.954
Cesium, ^{137} Cs	Borasilicate	β,γ	.0774	3.1	.24	8.4	30±.3	109(21$^{(b)}$)	207	.955	.892
Strontium, ^{90} Sr	SrO	β,γ	.334	4.5	1.5	4.4	27.7	111(19$^{(b)}$)	150	.951	.884
Strontium, ^{90} Sr	$SrTiO_3$	β,γ	.223	3.7	.825	4.4	27.7	111(19$^{(b)}$)	150	.951	.884
Curium, ^{244} Cm	Cm_2O_3	α,γ,η	2.5	9.0	22.5	Neutron Shield	18.4	357	30	.927	.828
Cobalt, ^{60} Co	Metal	β,γ	5.52	8.7	48	9.5	5.24	33	65	.767	.516
Thallium, ^{204} Tl	Tl_2O_3	β	.12	9.0	1.08	Minor	4.	100	640	.707	.419
Prometheum, ^{147} Pm	Pm_2O_3	β	.324	6.6	2.03	Low	2.6	4,260(91$^{(b)}$)	2,770	.586	.263
Thorium, ^{228} Th	ThO_2	α,γ	141.	9.	1,270	Heavy	1.9	40	24	.482	.161
Cerium, ^{144} Ce	CeO_2	β,γ	3.48	7.0	21.9	9.	.78	135(1.00$^{(b)}$)	124	.169	.0116
Curium, ^{242} Cm	Cm_2O_3	α,γ,η	44.1	9.	397	Neutron Shield	.445	17	28	.044	.00041
Polonium, ^{210} Po	Metal	α	134.	9.3	1,210	Minor	.38	20	32	.026	.00011
Thulium, ^{170} Tm	Tm_2O_3	β	1.03	7.7	7.9	Minor	.35	10	385	.019	.00005

(a) Does not include void volume. (b) Hanford Isotope Plant Proposal

References:

1. Oak Ridge National Laboratory Radio and Stable Isotopes Catalog, April 1963.
2. The Fission Products, by C. A. Rohrmann, Hanford Laboratories, May 1964.
3. Isotope Power Data Sheets compiled by S. J. Rimshaw, Oak Ridge, Tennessee.

THORIUM MATERIALS CONVERSION TABLE

	Mol. Wt.*	Th	ThO_2	(TNT)	ThC	ThC_2	$ThCl_4$
Th Metal	232.00	1.000	0.879	0.420	0.951	0.906	0.621
ThO_2 (Thorium Dioxide)	264.00	1.138	1.000	0.478	1.082	1.031	0.706
$Th(No_3)_4 \cdot 4H_2O$ [Thorium Nitrate Tetrahydrate (TNT)]	552.08	2.380	2.091	1.000	2.263	2.156	1.477
ThC (Thorium Carbide)	244.01	1.052	0.924	0.442	1.000	0.953	0.653
ThC_2 (Thorium Dicarbide)	256.02	1.104	0.970	0.464	1.049	1.000	0.685
$ThCl_4$ (Thorium Tetrachloride)	373.81	1.611	1.416	0.677	1.532	1.460	1.000

Example: 100# of ThO_2 × 0.879 = 87.9# of Th Metal obtained from ThO_2.
*Based on $C^{12} = 12$.

THORIUM DIOXIDE (ThO_2)— PERCENT THEORETICAL DENSITY (% T. D.) AND EQUIVALENT GRAMS PER CUBIC CENTIMETER (g/cc).*

% T.D.	g/cc	% T.D.	g/cc	% T.D.	g/cc	% T.D.	g/cc	% T.D.	g/cc	% T.D.	g/cc	% T.D.	g/cc	% T.D.	g/cc
83.0	8.333	85.0	8.534	87.0	8.735	89.0	8.936	91.0	9.136	93.0	9.337	95.0	9.538	97.0	9.739
2	8.353	2	8.554	2	8.755	2	8.956	2	9.156	2	9.357	2	9.558	2	9.759
4	8.373	4	8.574	4	8.775	4	8.976	4	9.177	4	9.377	4	9.578	4	9.779
6	8.393	6	8.594	6	8.795	6	8.996	6	9.197	6	9.397	6	9.598	6	9.799
8	8.414	8	8.614	8	8.815	8	9.016	8	9.217	8	9.418	8	9.618	8	9.819
84.0	8.434	86.0	8.634	88.0	8.835	90.0	9.036	92.0	9.237	94.0	9.438	96.0	9.638	98.0	9.839
2	8.454	2	8.654	2	8.855	2	9.056	2	9.257	2	9.458	2	9.658	2	9.859
4	8.474	4	8.675	4	8.875	4	9.076	4	9.277	4	9.478	4	9.679	4	9.879
6	8.494	6	8.695	6	8.895	6	9.096	6	9.297	6	9.498	6	9.699	6	9.899
8	8.514	8	8.715	8	8.916	8	9.116	8	9.317	8	9.518	8	9.719	8	9.919

*Based on TD = 10.04 g/cc.

ThC	ThC_2	$ThCl_4$
0.951	0.906	0.621
1.082	1.031	0.706
2.263	2.156	1.477
1.000	0.953	0.653
1.049	1.000	0.685
1.532	1.460	1.000

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cc	% T.D.	g/cc	% T.D.	g/cc
137	95.0	9.538	97.0	9.739
157	2	9.558	2	9.759
177	4	9.578	4	9.779
197	6	9.598	6	9.799
118	8	9.618	8	9.819
138	96.0	9.638	98.0	9.839
158	2	9.658	2	9.859
178	4	9.679	4	9.879
198	6	9.699	6	9.899
118	8	9.719	8	9.919

PLUTONIUM MATERIALS CONVERSION TABLE (Pu Composition 93% Pu^{239}, 7% Pu^{240})

	Mol. Wt.*	Pu	PuO_2	$PuCl_3$	PuF_3	PuF_4	PuC	PuN	$Pu(SO_4)_2$	(PuSH)
Pu Metal	239.13	1.000	0.882	0.692	0.808	0.759	0.952	0.945	0.555	0.475
PuO_2 (Plutonium Dioxide)	271.13	1.134	1.000	0.785	0.916	0.860	1.080	1.071	0.629	0.539
$PuCl_3$ (Plutonium Trichloride)	345.49	1.445	1.274	1.000	1.167	1.096	1.376	1.365	0.801	0.687
PuF_3 (Plutonium Trifloride)	296.12	1.238	1.092	0.857	1.000	0.940	1.179	1.170	0.687	0.588
PuF_4 (Plutonium Tetrafloride)	315.12	1.318	1.162	0.912	1.064	1.000	1.235	1.245	0.731	0.626
PuC (Plutonium Carbide)	251.14	1.050	0.926	0.727	0.848	0.797	1.000	0.992	0.582	0.499
PuN (Plutonium Nitride)	253.14	1.059	0.934	0.733	0.855	0.803	1.008	1.000	0.587	0.503
$Pu(SO_4)_2$ (Plutonium Sulfate)	431.21	1.803	1.590	1.248	1.456	1.368	1.717	1.703	1.000	0.857
$Pu(SO_4)_2$ $4H_2O$ [Plutonium Sulfate Tetrahydrate (PuSH)]	503.25	2.105	1.856	1.457	1.699	1.597	2.004	1.988	1.167	1.000

Example: 100# of $PuCl_3$ × 0.692 = 69.2# of Pu metal obtained from $PuCl_3$.
*Based on $C^{12} = 12$.

PLUTONIUM DIOXIDE (PuO_2)— PERCENT THEORETICAL DENSITY (% T. D.) AND EQUIVALENT GRAMS PER CUBIC CENTIMETER (g/cc).*

% T.D.	g/cc	% T.D.	g/cc	% T.D.	g/cc	% T.D.	g/cc	% T.D.	g/cc	% T.D.	g/cc	% T.D.	g/cc	% T.D.	g/cc
83.0	9.516	85.0	9.745	87.0	9.975	89.0	10.204	91.0	10.433	93.0	10.662	95.0	10.892	97.0	11.121
2	9.539	2	9.768	2	9.997	2	10.227	2	10.456	2	10.685	2	10.915	2	11.144
4	9.562	4	9.791	4	10.020	4	10.250	4	10.479	4	10.708	4	10.938	4	11.167
6	9.585	6	9.814	6	10.043	6	10.273	6	10.502	6	10.731	6	10.961	6	11.190
8	9.608	8	9.837	8	10.066	8	10.296	8	10.525	8	10.754	8	10.983	8	11.213
84.0	9.631	86.0	9.860	88.0	10.089	90.0	10.319	92.0	10.548	94.0	10.777	96.0	11.006	98.0	11.236
2	9.654	2	9.883	2	10.112	2	10.341	2	10.571	2	10.800	2	11.029	2	11.259
4	9.676	4	9.906	4	10.135	4	10.364	4	10.594	4	10.822	4	11.052	4	11.282
6	9.699	6	9.929	6	10.158	6	10.387	6	10.617	6	10.846	6	11.075	6	11.304
8	9.722	8	9.952	8	10.181	8	10.410	8	10.640	8	10.869	8	11.098	8	11.327

*Based on TD = 11.465 g/cc.

URANIUM MATERIALS CONVERSION TABLE

	Mol.* Wt.	U	UO_2	UO_3	U_3O_8	UF_4	UF_6	(UNH)	UC	UC_2	UN	(USH)
U Metal	238.03	1.000	0.881	0.832	0.848	0.758	0.676	0.474	0.952	0.908	0.944	0.567
UO_2 (Brown Oxide)	270.03	1.134	1.000	0.944	0.962	0.860	0.767	0.538	1.080	1.030	1.071	0.643
UO_3 (Orange Oxide)	286.03	1.202	1.059	1.000	1.019	0.911	0.813	0.570	1.144	1.091	1.135	0.681
U_3O_8 (Black Oxide)	842.09	1.179	1.040	0.981	1.000	0.894	0.797	0.559	1.123	1.071	1.114	0.668
UF_4 (Green Salt)	314.02	1.319	1.163	1.098	1.119	1.000	0.892	0.625	1.256	1.198	1.246	0.747
UF_6 (U Hexafluoride)	352.02	1.479	1.304	1.231	1.254	1.121	1.000	0.701	1.408	1.343	1.397	0.838
$UO_2(NO_3)_2 \cdot 6H_2O$ [Uranyl Nitrate (UNH)]	502.13	2.110	1.860	1.756	1.789	1.599	1.426	1.000	2.008	1.916	1.992	1.195
UC (U Monocarbide)	250.04	1.050	0.926	0.874	0.891	0.796	0.710	0.498	1.000	0.954	0.992	0.595
UC_2 (U Dicarbide)	262.05	1.101	0.970	0.916	0.934	0.834	0.744	0.522	1.048	1.000	1.040	0.624
UN (U Nitride)	252.04	1.059	0.933	0.881	0.898	0.803	0.716	0.502	1.008	0.962	1.000	0.600
$UO_2SO_4 \cdot 3H_2O$ [Uranyl Sulfate (USH)]	420.14	1.765	1.556	1.469	1.497	1.338	1.194	0.837	1.680	1.603	1.667	1.000

*Based on $C^{12} = 12$

URANIUM DIOXIDE (UO_2) — PERCENT THEORETICAL DENSITY (% T. D.) AND EQUIVALENT GRAMS PER CUBIC CENTIMETER (g/cc).*

(Normal Enrichment)

% T.D.	g/cc	% T.D.	g/cc	% T.D.	g/cc	% T.D.	g/cc	% T.D.	g/cc	% T.D.	g/cc	% T.D.	g/cc	% T.D.	g/cc
91.0	9.974	92.0	10.083	93.0	10.193	94.0	10.302	95.0	10.412	96.0	10.522	97.0	10.631	98.0	10.741
1	985	1	094	1	204	1	313	1	423	1	533	1	642	1	752
2	996	2	105	2	215	2	324	2	434	2	544	2	653	2	763
3	10.006	3	116	3	226	3	335	3	445	3	554	3	664	3	774
4	017	4	127	4	237	4	346	4	456	4	565	4	675	4	785
5	028	5	138	5	248	5	357	5	467	5	576	5	686	5	796
6	039	6	149	6	259	6	368	6	478	6	587	6	697	6	806
7	050	7	160	7	270	7	379	7	489	7	598	7	708	7	817
8	061	8	171	8	280	8	390	8	500	8	609	8	719	8	828
9	072	9	182	9	291	9	401	9	511	9	620	9	730	9	839

*Based on TD = 10.960 g/cc

UC	UC_2	UN	(USH)
0.952	0.908	0.944	0.567
1.080	1.030	1.071	0.643
1.144	1.091	1.135	0.681
1.123	1.071	1.114	0.668
1.256	1.198	1.246	0.747
1.408	1.343	1.397	0.838
2.008	1.916	1.992	1.195
1.000	0.954	0.992	0.595
1.048	1.000	1.040	0.624
1.008	0.962	1.000	0.600
1.680	1.603	1.667	1.000

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'cc	% T.D.	g/cc	% T.D.	g/cc
22	97.0	10.631	98.0	10.741
33	1	642	1	752
44	2	653	2	763
54	3	664	3	774
65	4	675	4	785
76	5	686	5	796
87	6	697	6	806
98	7	708	7	817
09	8	719	8	828
20	9	730	9	839

BASE CHARGES FOR ENRICHED URANIUM AS UF_6

Uranium enriched in U-235 is distributed to licensees in the form of UF_6. It is shipped as a solid under pressure in steel cylinders. It is available in all enrichments from normal (0.711 weight per cent U-235) to approximately 95 weight per cent U-235.

The base charges for enriched uranium as UF_6 are as follows:

Assay (weight fraction U-235)	Base charge ($ per Kg U)	Assay (weight fraction U-235)	Base charge ($ per Kg U)
0.0075	$ 26.50	0.050	$ 479.40
0.0080	30.50	0.055	536.80
0.0085	34.70	0.060	594.50
0.0090	38.90	0.07	710.50
0.0095	43.30	0.08	827.00
0.0100	47.70	0.09	944.00
0.011	56.80	0.10	1,062.00
0.012	66.10	0.12	1,298.00
0.013	75.70	0.14	1,535.50
0.014	85.40	0.16	1,774.00
0.015	95.30	0.18	2,013.00
0.016	105.30	0.20	2,252.00
0.017	115.50	0.25	2,853.00
0.018	125.70	0.30	3,456.00
0.019	136.10	0.35	4,060.00
0.020	146.50	0.40	4,666.00
0.022	167.60	0.50	5,882.00
0.024	189.00	0.60	7,103.00
0.026	210.60	0.70	8,329.00
0.028	232.40	0.80	9,562.00
0.030	254.30	0.85	10,183.00
0.032	276.40	0.90	10,808.00
0.034	298.60	0.92	11,061.00
0.036	320.90	0.93	11,188.00
0.038	343.30	0.94	11,315.00
0.040	365.80	0.96	11,597.00
0.045	422.40	0.98	12,389.00

Base charges for enriched uranium of assays not specifically listed will be determined by linear interpolation between the nearest listed assays. When the assay of enriched material is less than 0.0075 the base charge will be determined by linear interpolation between the base charge for 0.0075 material and a value of $23.50 per Kg U of normal uranium (0.00711 weight fraction U-235) in the form of UF_6.

BASE CHARGES FOR DEPLETED URANIUM AS UF_6

For depleted uranium as UF_6, without specified assay, the base charge is $2.50 per Kg of contained U. For specifically requested assays the base charges are as follows:

Assay (weight fraction U-235)	Base charge ($ per Kg U)
0.0022	$3.00
0.0038	3.00
0.0040	3.70
0.0042	4.60
0.0044	5.60
0.0046	6.65
0.0048	7.75
0.0050	8.90
0.0052	10.10
0.0054	11.35
0.0056	12.65
0.0058	13.95
0.0060	15.35
0.0065	18.90
0.0070	22.60

Base charges for depleted uranium of assays not specifically listed will be determined by linear interpolation between the nearest listed assays. When the assay of depleted materials is greater than 0.0070, the base charge will be determined by linear interpolation between the base charge for 0.0070 material and a value of $23.50 per Kg U for normal uranium (0.00711 weight fraction U-235) in the form of UF_6.

USE CHARGES FOR SPECIAL NUCLEAR MATERIAL

Title to all special nuclear material remains with the United States Government. Special nuclear material is leased to licensees on an annual use charge of 4¾ percent of its value as determined from the appropriate schedule of charges.

The use charge, based on the UF_6 value of the material, commences on the date the material is diverted from Commission production channels; it continues either until (1) the material, or part of it, is returned to the Commission, at which time the licensee is credited for the value of the material returned, less any charges for processing to specification, and makes settlement; or until (2) the licensee declares that all or some part of the material has been burned, lost, or otherwise consumed — and the licensee makes payment. Oak Ridge, Tenn., is the FOB point for distribution and return of UF_6.

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AEC CHARGES FOR CONVERSION OF U_3O_8 TO UF_6

Recovered uranium bearing materials are usually returned to the AEC in the form of U_3O_8 for conversion to UF_6. AEC charges for this service are as follows:

Materials of up to 5% enrichment	$ 5.60 per Kg contained U
Materials of more than 5% enrichment	$32.00 per Kg contained U

In addition, cost allowance should also be made for processing losses of 1.6 grams per Kg of U returned as well as 20 days use charges per Kg of U returned.

NOTE: Reference, USAEC-TID-4020, Revision 1, September 1961

AEC WITHDRAWAL AND CERTIFICATION CHARGES FOR UF_6

Charges for withdrawing and packaging UF_6 into individual containers are given in Column 1. If a single order is packaged into more than one container of the same type, the samples which are taken for determination of the properties may sometimes be composited into a single analytical lot. If this is done, the charges given in Column II are appropriate for all cylinders from which samples are so composited, excepting the first one of each lot. The maximum number of cylinders from which samples may be composited is given in Column III. Unless specifically requested otherwise, the AEC will composite to the maximum extent possible.

WITHDRAWAL AND PACKAGING CHARGES

Cylinder type	Column I, single cylinder or first cylinder in composite, analytical lot ($ per cylinder)	Column II, remaining cylinders in composite, analytical lot ($ per cylinder)	Column III, maximum number of cylinders per composite, analytical lot
10-ton	850	Not composited	
2.5-ton	375	235	3
12-inch (MD)	150	70	6
8-inch [1]	143	63	6
5-inch	135	55	6
4-inch	115	Not composited	
Harshaw bomb	58	Not composited	
2-inch	58	Not composited	
Hoke tube	29	Not composited	

[1] 8-inch cylinders are used only for assays of 0.0375 to 0.125 weight fraction U-235 inclusive.

SPECIAL CERTIFICATION CHARGES

Property or condition to be certified	Charge (per cylinder)
A. Total Pressure	$ 7
B. Spectrographic Impurities	158
C. Bromine and Chlorine	36
D. Freezing-point Depression	14
E. Non-volatile Matter	36
F. Boron-equivalent Cross Section	36
G. Molybdenum, Vanadium, Chromium, and Tungsten (Molybdenum only, $29)	65
H. Fission-product and U-237 Gamma Activity	28
I. Fission-product Beta Activity	22
J. Plutonium Content	22
Total	$424

LOADING LIMITS ON AEC UF_6 CYLINDERS (1)

Assay (weight fraction U-235)	Maximum quantity per cylinder, pound UF_6				
	10-ton	2.5-ton	12-inch (MD)	8-inch	5-inch
0.0095 or less	21,000	4,800	450	Not used	55
Above 0.0095 to 0.0100	0	4,800	450	Not used	55
Above 0.0100 to 0.0110	0	4,417	450	Not used	55
Above 0.0110 to 0.0120	0	2,445	450	Not used	55
Above 0.0120 to 0.0125	0	1,800	450	Not used	55
Above 0.0125 to 0.0375	0	0	450	Not used	55
Above 0.0375 to 0.125	0	0	0	250	55
Above 0.125	0	0	0	0	55

(1) Cylinders loaded to these limits may require special precautions in storage and shipment to avoid the possibility of nuclear interaction with adjacent cylinders or with moderators and reflectors other than water. The loading limit on a 4-inch cylinder is 11 pounds, on a bomb is 4.8 pounds, on a 2-inch cylinder is 3.3 pounds and on a Hoke tube is 1.5 grams at all enrichments.

AEC CHARGES FOR CONTAINED PLUTONIUM ISOTOPES

Pu-239 plus Pu-241

The AEC has established base charges for material of standard isotopic assays. Charges for plutonium nitrate distributed by lease after July 1, 1963 are $43 per gram of the contained plutonium isotopes Pu-239 plus Pu-241.

Reduced base charges are applicable in cases in which the AEC has determined that the use of such material will produce technical and economic data of sufficient interest in the AEC program and the lessee has agreed to extend to the AEC access to such data and appropriate patent rights. Under these conditions, plutonium nitrate charges are $10 per gram of the contained plutonium isotopes Pu-239 plus Pu-241.

The total charge for conversion of plutonium nitrate to metal is $1.50 per gram of plutonium metal distributed, plus use charges and a charge for loss of an amount of plutonium during conversion equal to 1.0 percent of plutonium metal distributed multiplied by the base charges set forth above. A special charge is also made by the AEC for packaging plutonium into suitable containers; these charges are not refunded upon return of leased material.

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AEC CHARGES FOR URANIUM ENRICHED IN U-233

Effective July 1, 1963, the AEC established base charges for material of standard isotopic assays. Charges for uranyl nitrate containing uranium enriched in U-233 are $82 per gram of contained U-233. Base charges, however, are subject to adjustments for the isotopic assay which follows.

(1) Calculate a weight fraction equal to the ratio of the weight of U-235 plus U-233 to the total weight of uranium. For that weight fraction, find the charge per gram of U-235 from the schedule of base charges in effect for uranium enriched in U-235. (If the weight fraction exceeds 0.90, use the charge for 0.90.) Take that charge as the base charge per gram of U-235 in the mixture and 82/12 of that charge as the base charge per gram of U-233 in the mixture. (The ratio of 82/12 is the ratio of charges for highly enriched U-233 and U-235, prior to the deduction given in (2) below.)

(2) Make the following deduction in dollars per gram of total uranium, depending on the assay of the U-232 isotope. (This deduction will cover estimated handling costs to the AEC when leased uranium is returned after irradiation with an increased U-232 assay.)

Parts of U-232 per million parts of total uranium	**Deduction in dollars per gram of total uranium**
0	0.50
10	0.65
20	0.75
40	0.95
60	1.10
80	1.25
100	1.40
200	1.85
400	2.05
600	2.20
800	2.30
1000	2.35
1500 and above	2.50

Reduced base charges are applicable only in cases in which the AEC has determined that the use of such material will produce technical and economic data of sufficient interest in the AEC program and the lessee has agreed to extend to the AEC access to such data and appropriate patent rights. Under these conditions, the base charge for uranyl nitrate containing uranium enriched in U-233 is $14 per gram of contained U-233, subject to adjustments of isotopic assays given above except that the ratio of 85/12 shall be replaced by the ratio of 14/12.

In addition to base charges, there are special charges by the AEC for packaging uranium containing U-233 into suitable containers. These charges are not refunded upon return of leased materials.

NEUTRON SOURCE DATA

	1	2	3	4	5	7	10	20	30	32.4	Curies
Pu:Be neutron sources	16	32	48	64	80	112	160				**Grams of Pu**
Pu half-life: (24,400 years)	1.8x10^6	3.6x10^6	5.4x10^6	7.2x10^6	9.0x10^6	1.2x10^7	1.8x10^7				**Strength Neutrons/sec.**
Am:Be neutron sources	.3	.6	.9	1.2	1.5	2.1	3.0	6.0	9.0	10.0	**Grams of Am**
Am half-life: (458.1 years)	2.2x10^6	4.4x10^6	6.6x10^6	8.8x10^6	1.1x10^7	1.5x10^7	2.2x10^7	4.4x10^7	6.6x10^7	7.1x10^7	**Strength Neutrons/sec.**

NOTE: A brochure describing NUMEC's complete line of neutron, alpha, beta and gamma sources is available upon request.

AMERICIUM-241

The primary use of americium-241 is in neutron radiation sources. Recent AEC removal of the 10 gram limit on americium will permit filling industrial requirements for americium neutron sources which are now chiefly used for well logging.

Salient characteristics of americium-241 are:

Half-Life: 458.1 years
Specific Activity: 3.24 curies/gram
Alpha Radiation: 5.44 and 5.48 Mev (98%)
Gamma Radiation: 60 Kev (34%)

The AEC base charge for this radioisotope is $1500 per gram.

NEPTUNIUM-237

The principal use of neptunium-237 is as a component of neutron detection instruments. The AEC base charge for this radioisotope is $500 per gram.

	30	32.4	Curies
			Grams of Pu
			Strength Neutrons/sec.
	9.0	10.0	Grams of Am
07	6.6x10^7	7.1x10^7	Strength Neutrons/sec.

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TYLER STANDARD SCREEN SCALE SIEVES

In the following table the Tyler Standard Screen Scale Sieves Series has been expanded to include intermediate sieves for closer sizing which gives a ratio of the fourth root of two or 1.189 between openings in successive sieves.

Tyler Standard Screen Scale Sieves and U.S. Sieves can be used interchangeably.

Tyler Standard Screens Scale $\sqrt{2}$ Openings in inches	For Closer Sizing Ratios $\sqrt[4]{2}$ Openings in inches	Mesh	Diameter of wire, Decimal of an inch	U.S. Series Equivalent (Fine Series)	
				MICRON Designation	Number
3			.207		
2			.192		
1.5			.162		
1.050	1.050		.148		
	.883		.135		
.742	.742		.135		
	.624		.120		
.525	.525		.105		
	.441		.105		
.371	.371		.092		
	.312	2½	.088		
.263	.263	3	.070		
	.221	3½	.065	5660	3½
.185	.185	4	.065	4760	4
	.156	5	.044	4000	5
.131	.131	6	.036	3360	6
	.110	7	.0328	2830	7
.093	.093	8	.032	2380	8
	.078	9	.033	2000	10
.065	.065	10	.035	1680	12
	.055	12	.028	1410	14
.046	.046	14	.025	1190	16
	.0390	16	.0235	1000	18
.0328	.0328	20	.0172	840	20
	.0276	24	.0141	710	25
.0232	.0232	28	.0125	590	30
	.0195	32	.0118	500	35
.0164	.0164	35	.0122	420	40
	.0138	42	.0100	350	45
.0116	.0116	48	.0092	297	50
	.0097	60	.0070	250	60
.0082	.0082	65	.0072	210	70
	.0069	80	.0056	177	80
.0058	.0058	100	.0042	149	100
	.0049	115	.0038	125	120
.0041	.0041	150	.0026	105	140
	.0035	170	.0024	88	170
.0029	.0029	200	.0021	74	200
	.0024	250	.0016	62	230
.0021	.0021	270	.0016	53	270
	.0017	325	.0014	44	325
.0015	.0015	400	.001	37	400

ENERGY CONVERSION FACTORS

	erg	joule = Watt-sec	Kilowatt-hour	cal
1 erg	1	10^{-7}	$2.78 \cdot 10^{-14}$	$2.39 \cdot 10^{-8}$
1 joule	10^{7}	1	$2.78 \cdot 10^{-7}$	$2.39 \cdot 10^{-1}$
1 kilowatt-hour	$3.6 \cdot 10^{13}$	$3.6 \cdot 10^{6}$	1	$0.86 \cdot 10^{6}$
1 cal	$4.19 \cdot 10^{7}$	4.19	$1.16 \cdot 10^{-6}$	1
1 kgm	$0.98 \cdot 10^{8}$	9.8	$2.72 \cdot 10^{-6}$	2.34
1 Electronvolt	$1.60 \cdot 10^{-12}$	$1.60 \cdot 10^{-19}$	$4.45 \cdot 10^{-26}$	$3.83 \cdot 10^{-20}$
1 Mol Electronvolt	$9.65 \cdot 10^{11}$	$9.65 \cdot 10^{4}$	$2.68 \cdot 10^{-2}$	23060
10^{-3} unit atomic mass	$1.49 \cdot 10^{-6}$	$1.49 \cdot 10^{-13}$	$4.14 \cdot 10^{-20}$	$3.56 \cdot 10^{-14}$
1 g-mass equivalent	$8.99 \cdot 10^{20}$	$8.99 \cdot 10^{13}$	$2.50 \cdot 10^{7}$	$2.15 \cdot 10^{13}$
1 Megawatt-day	$8.64 \cdot 10^{17}$	$8.64 \cdot 10^{10}$	$2.4 \cdot 10^{4}$	$2.06 \cdot 10^{10}$

al
$9 \cdot 10^{-8}$
$9 \cdot 10^{-1}$
$6 \cdot 10^{5}$
4
$\cdot 10^{-20}$
60
$\cdot 10^{-14}$
$\cdot 10^{13}$
$\cdot 10^{10}$

kgm	Electronvolt	1 Mol Electronvolt	10^{-3} unit atomic mass	g-mass equivalent	Megawatt-day
$1.02 \cdot 10^{-8}$	$0.624 \cdot 10^{12}$	$1.04 \cdot 10^{-12}$	$0.670 \cdot 10^{6}$	$1.113 \cdot 10^{-2}$	$1.16 \cdot 10^{-18}$
$1.02 \cdot 10^{-1}$	$0.624 \cdot 10^{19}$	$1.04 \cdot 10^{-5}$	$0.670 \cdot 10^{13}$	$1.113 \cdot 10^{-14}$	$1.16 \cdot 10^{-11}$
$3.67 \cdot 10^{5}$	$2.25 \cdot 10^{25}$	37.3	$2.41 \cdot 10^{19}$	$4.01 \cdot 10^{-8}$	$4.17 \cdot 10^{-5}$
$4.27 \cdot 10^{-1}$	$2.61 \cdot 10^{19}$	$4.34 \cdot 10^{-5}$	$2.81 \cdot 10^{13}$	$4.66 \cdot 10^{-14}$	$4.84 \cdot 10^{-11}$
1	$0.612 \cdot 10^{20}$	$1.02 \cdot 10^{-4}$	$0.657 \cdot 10^{14}$	$1.092 \cdot 10^{-13}$	$1.13 \cdot 10^{-10}$
$1.63 \cdot 10^{-20}$	1	$1.66 \cdot 10^{-24}$	$1.074 \cdot 10^{-6}$	$1.78 \cdot 10^{-33}$	$1.85 \cdot 10^{-30}$
$9.84 \cdot 10^{3}$	$6.03 \cdot 10^{23}$	1	$6.46 \cdot 10^{17}$	$1.074 \cdot 10^{-9}$	$1.11 \cdot 10^{-6}$
$1.52 \cdot 10^{-14}$	$0.931 \cdot 10^{6}$	$1.55 \cdot 10^{-18}$	1	$1.66 \cdot 10^{-27}$	$1.73 \cdot 10^{-24}$
$9.17 \cdot 10^{12}$	$5.61 \cdot 10^{32}$	$9.31 \cdot 10^{8}$	$6.03 \cdot 10^{26}$	1	$1.04 \cdot 10^{3}$
$8.81 \cdot 10^{9}$	$5.39 \cdot 10^{29}$	$8.99 \cdot 10^{5}$	$5.79 \cdot 10^{23}$	$9.61 \cdot 10^{-4}$	1

UNIT CONVERSION CHARTS

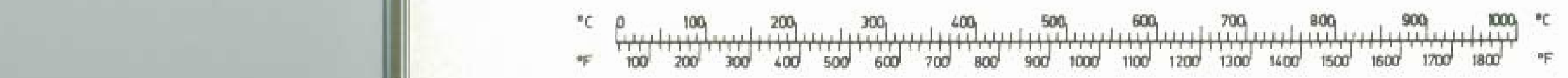
TEMPERATURE

1 °C = 1·8 °F

$n\,°C = \left(9/5\ n + 32\right)\,°F$

1 °F = 0·556 °C

$n\,°F = \left[\left(n - 32\right) \cdot 5/9\right]\,°C$



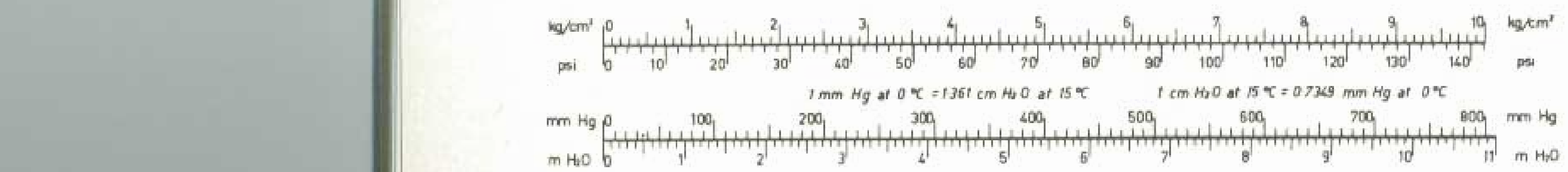
PRESSURE

1 kg/cm^2 = 14·223 psi

1 psi = 0·07031 kg/cm^2

1 mm Hg at 0 °C = 1·361 cm H_2O at 15 °C

1 cm H_2O at 15 °C = 0·7349 mm Hg at 0 °C



FLOW

1 kg/sec = 3·60 t/hr = 7936·6 lb/hr

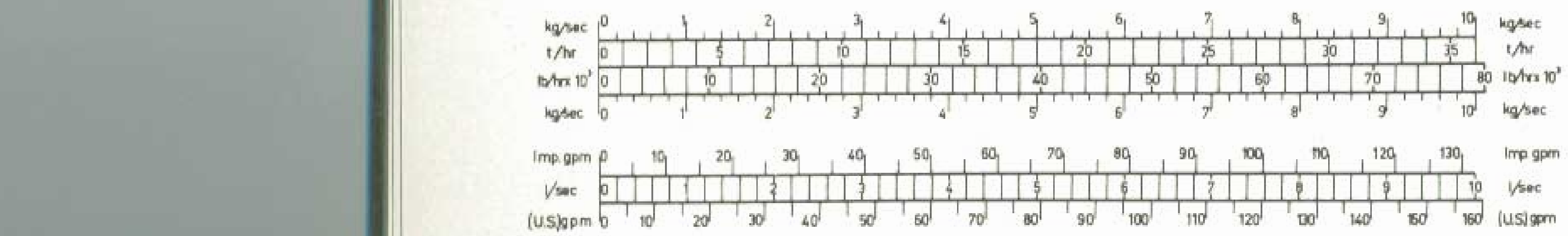
1 t/hr = 0·2778 kg/sec = 2204·6 lb/hr

1 lb/hr = 1·260 x 10^{-4} kg/sec = 4·536 x 10^{-4} t/hr

1 l/sec = 15·850 (U.S.)gpm = 13·199 Imp.gpm

1 (U.S.)gpm = 0·8327 Imp.gpm = 0·063091 l/sec

1 Imp.gpm = 1·20094 (U.S.)gpm = 0·075766 l/sec



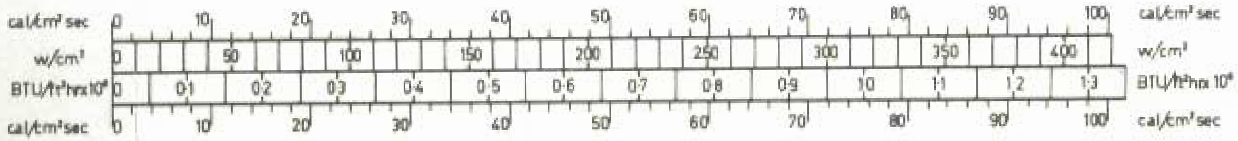
HEAT

1 kcal = 3·9683 BTU

1 BTU = 0·2520 kcal

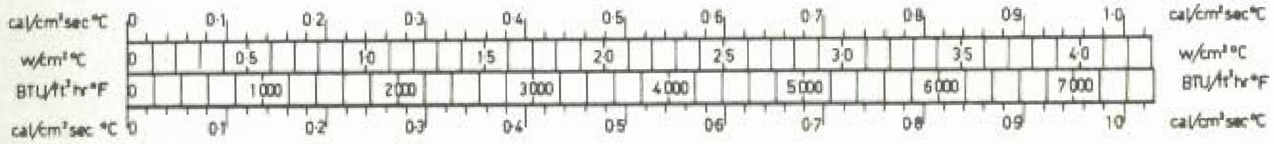
HEAT TRANSFER

1 cal/cm^{2}sec = 4·1840 w/cm^2 = 13263 BTU/ft^{2}hr
1 w/cm^2 = 0·2390 cal/cm^{2}sec = 3171 BTU/ft^{2}hr
1 BTU/ft^{2}hr = 0·754 x 10^{-4} cal/cm^{2}sec = 3·154 x 10^{-4} w/cm^2



HEAT TRANSFER COEFF.

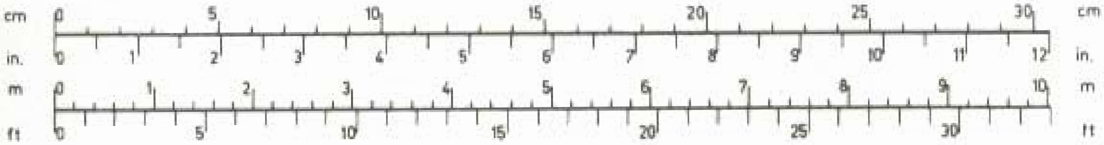
1 cal/cm^2 sec °C = 4·1833 w/cm^2 °C = 7373 5 BTU/ft^{2}hr°F
1 w/cm^2 °C = 0·239 cal/cm^2 sec °C = 1762 2 BTU/ft^{2}hr°F
1 BTU/ft^{2}hr°F = 1·3563 x 10^{-4} cal/cm^2 sec °C = 5·673 x 10^{-4} w/cm^2°C



LENGTH

1 cm = 0·3937 in
1 m = 3·28083 ft
1 km = 0·62137 mile

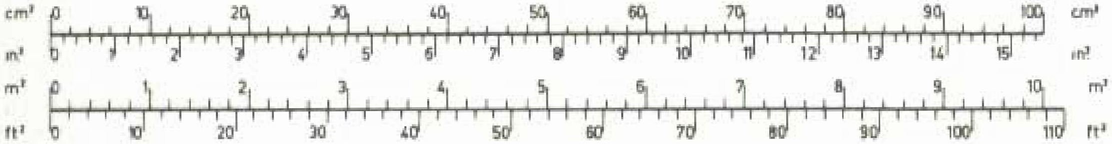
1 in. = 2·540 cm
1 ft = 0·30480 m
1 mile = 1·6093 km



AREA

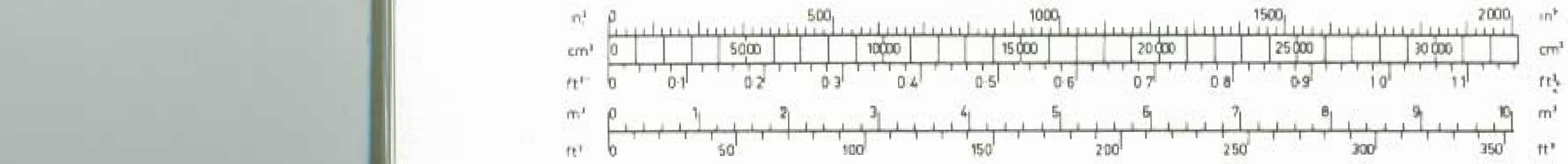
1 cm^2 = 0·1550 in^2
1 m^2 = 10·764 ft^2

1 in^2 = 6·4516 cm^2
1 ft^2 = 0·09290 m^2



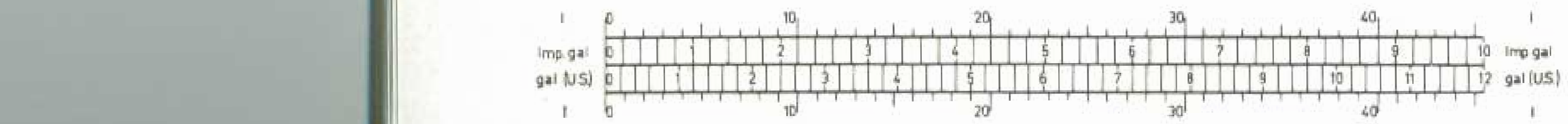
VOLUME

1 cm³ = 0·06103 in³ 1 in³ = 16·3870 cm³
1 m³ = 35·314 ft³ 1 ft³ = 0·028317 m³



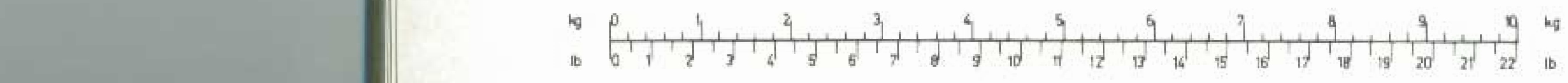
CAPACITY

1 l = 0·21998 Imp gal = 0·26417 gal (US)
1 Imp gal = 4·5460 l = 1·20094 gal (US)
1 gal (US) = 3·7854 l = 0·8327 Imp gal



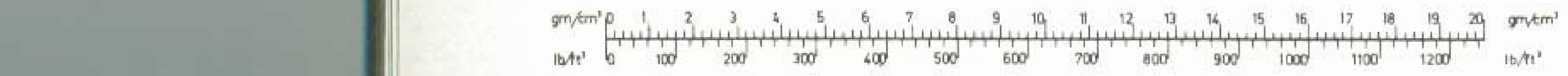
WEIGHT

1 kg = 2·2046 lb 1 lb = 0·4536 kg



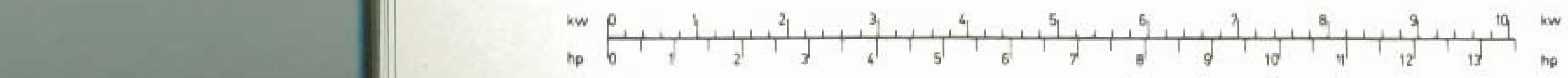
DENSITY

1 g/cm³ = 62·43 lb/ft³ 1 lb/ft³ = 0·01602 g/cm³



POWER

1 hp = 0·7457 kw 1 kw = 1·341 hp



in^3
cm^3
ft^3
m^3
ft^3

l
0 Imp gal
2 gal (US)
l

kg
lb

gm/cm^3
lb/ft^3

kw
hp

AEC OPERATIONS OFFICES

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Tel. 412-462-5000

Schenectady Naval Reactors Office
U. S. Atomic Energy Commission
P. O. Box 1069
Schenectady, N. Y. 12301
Tel. 518-393-6611

JANUARY

1966

DECEMBER

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

FEBRUARY

S	M	T	W	T	F	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28					

SUNDAY	MONDAY	TUESDAY
2	3	4
9	10	11
16	17	18
23 30	24 31	25

3	4
10	11
17	18
24 31	25

- CABLE: NUMEC-APOLLO

WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
			1 NEW YEAR'S DAY
5	6	7	8
12	13	14	15
19	20	21	22
26	27	28	29

TELEPHONE:

NUMEC

- Bulk Uranium Fuel Materials
- Refractory Metal Powder
- Nuclear Moisture Density Meters
- Metallic and Ceramic Coatings
- Equipment Decontamination and Renovation

FEBRUARY

1966

JANUARY

S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

MARCH

S	M	T	W	T	F	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

SUNDAY	MONDAY	TUESDAY
		1
6	7	8
13	14 VALENTINE DAY	15
20	21	22 WASHINGTON'S BIRTHDAY
27	28	

AY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
	1	2	3	4	5
7	8	9	10	11	12 LINCOLN'S BIRTHDAY
14 DAY	15	16	17	18	19
21	22 WASHINGTON'S BIRTHDAY	23 ASH WEDNESDAY	24	25	26
28					

NUMEC

- Bulk Plutonium Fuel Materials
- Zirconium, Zircaloy, and Hafnium Metal Powders
- Cathodic Vacuum Etchers
- Controlled Porosity Shape
- Gamma Irradiators

MARCH

1966

FEBRUARY

S	M	T	W	T	F	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28					

APRIL

S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

SUNDAY	MONDAY	TUESDAY
		1
6	7	8
13	14	15
20	21	22
27	28	29

Y	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
	1	2	3	4	5
7	8	9	10	11	12
14	15	16	17 ST. PATRICK'S DAY	18	19
21	22	23	24	25	26
28	29	30	31		

TELEPHONE:

NUMEC

- Nuclear Fuel Spherical Particles — U, Pu, Th
- Plutonium Scrap Recovery
- Alpha, Beta, and Gamma Sources
- Control Rod Materials
- Glove Box Installations

APRIL

1966

MARCH

S	M	T	W	T	F	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

MAY

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

SUNDAY	MONDAY	TUESDAY
3 PALM SUNDAY	4	5 PASSOVER—FIRST DAY
10 EASTER	11	12
17	18	19
24	25	26

AY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
				1	2
4	5 PASSOVER—FIRST DAY	6 PASSOVER—SECOND DAY	7	8 GOOD FRIDAY	9
11	12	13	14	15	16
18	19	20	21	22	23
25	26	27	28	29	30

NUMEC

- **Fabricated Nuclear Fuels—U, Pu, Th**
- **U-233 Scrap Recovery**
- **Hafnium and Zirconium Foil, Rod and Wire**
- **Thermionic Convertors**
- **Instrumental and Wet Chemical Analyses**

MAY

1966

APRIL

S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

JUNE

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

SUNDAY	MONDAY	TUESDAY
1	2	3
8 MOTHER'S DAY	9	10
15	16	17
22	23	24
29	30 MEMORIAL DAY	31

					SATURDAY
2	3	4	5	6	7
9	10	11	12	13	14
16	17	18	19	20	21
23	24	25	26	27	28
30	31				

CABLE: NUMEC-APOLLO

TELEPHONE: 412-472-8411 • TWX: 412-584-5212

NUMEC

- Nuclear Fuel Rods — U, Pu, Th
- Brazing Alloys — Zr-Be, Ni-Ti, Ni-Nb
- Derivative Polarographic Instruments
- Isotopic Heat Sources
- Corrosion Testing

JUNE

1966

MAY

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

JULY

S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

SUNDAY	MONDAY	TUESDAY
5	6	7
12	13	14 FLAG DAY
19	20	21
26	27	28

AY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
		1	2	3	4
6	7	8	9	10	11
13	14 FLAG DAY	15	16	17	18
20	21	22	23	24	25
27	28	29	30		

NUMEC

- U-233 Processing and Fabrication
- Burnable Poison Materials
- Particle Crush Strength Testers
- Thermoelectric Generators
- Radioprocess Facility Design and Construction

JULY

1966

JUNE

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

AUGUST

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

SUNDAY	MONDAY	TUESDAY
3	4 INDEPENDENCE DAY	5
10	11	12
17	18	19
24 31	25	26

Y	TUESDAY
4 E DAY	5
11	12
18	19
25	26

CABLE NUMEC APOLLO

WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
		1	2
6	7	8	9
13	14	15	16
20	21	22	23
27	28	29	30

NUMEC

- Bulk Thorium Fuels
- Fission and Metal Foils
- Surface Area and Density Apparatus — AFA-4
- Radiochemical Analyses
- Ceramic Isotopic Sources

AUGUST

1966

JULY

S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

SEPTEMBER

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	

SUNDAY	MONDAY	TUESDAY
	1	2
7	8	9
14	15	16
21	22	23
28	29	30

AY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
1	2	3	4	5	6
8	9	10	11	12	13
15	16	17	18	19	20
22	23	24	25	26	27
29	30	31			

NUMEC

- Nuclear Fuel Research and Development
- Refractory Metal Alloy Shapes
- Automatic Weight, Density, Dimension Inspection Device
- Fabricated Plutonium Metal Fuel Plates and Elements
- Metallographic Investigations

SEPTEMBER

1966

AUGUST

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

OCTOBER

S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

SUNDAY	MONDAY	TUESDAY
4	5 LABOR DAY	6
11	12	13
18	19	20
25	26	27

	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
			1	2	3
5	6	7	8	9	10
12	13	14	15 JEWISH NEW YEAR—1st DAY	16 JEWISH NEW YEAR—2nd DAY	17
19	20	21	22	23	24 YOM KIPPUR
26	27	28	29	30	

NUMEC

- Specialty Shapes — Enriched and Depleted Uranium
- Constant Potential Coulometic Titrators
- Irradiated Fuel Evaluations
- Replacement Gamma Irradiator Sources
- Vapor Deposited Coating and Cementation

OCTOBER

1966

SEPTEMBER

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	

NOVEMBER

S	M	T	W	T	F	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

SUNDAY	MONDAY	TUESDAY
2	3	4
9	10	11
16	17	18
23 30	24 31 HALLOWE'EN	25

AY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
					1
3	4	5	6	7	8
10	11	12 COLUMBUS DAY	13	14	15
17	18	19	20	21	22
24 31 EN	25	26	27	28	29

• CABLE: NUMEC APOLLO

TELEPHONE: 412-472-8411 • TWX: 412

NUMEC

- Enriched Uranium Metal Fuel Plates and Elements
- Architect, Engineering, and Construction Services
- Controlled Porosity Shapes
- Electronic Weight Balances
- Nuclear Fuel Material Analyses

NOVEMBER

1966

OCTOBER

S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
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DECEMBER

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11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

SUNDAY	MONDAY	TUESDAY
		1
6	7	8 ELECTION DAY
13	14	15
20	21	22
27	28	29

	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
	1	2	3	4	5
7	8 ELECTION DAY	9	10	11 VETERANS' DAY	12
14	15	16	17	18	19
21	22	23	24 THANKSGIVING	25	26
28	29	30			

NUMEC

- Reactive Metal Alloy Shapes
- Powder Characterizations
- Neutron Sources — Pu-Be, Am-Be, Po-Be
- Cathodic Vacuum Etchers and Evaporators
- Rolling, Extrusion, and Swaging Services

DECEMBER

1966

NOVEMBER

S	M	T	W	T	F	S
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6	7	8	9	10	11	12
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JANUARY

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29	30	31				

SUNDAY	MONDAY	TUESDAY
4	5	6
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18	19	20
25 CHRISTMAS	26	27

		WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
			1	2	3
5	6	7	8	9	10
12	13	14	15	16	17
19	20	21	22	23	24
26	27	28	29	30	31

NUMEC

- Neutron Irradiators — Howitzers
- Shipping Container Designs and Fabrication
- Hot Cell Services
- High Purity Hafnium and Zirconium Crystal Bar
- Arc, Induction Plasma, and Resistance Melting Services

JANUARY

1967

DECEMBER

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FEBRUARY

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SUNDAY	MONDAY	TUESDAY
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DAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
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30	31				

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NUMEC

- Spherical Metal Powders
- Remotized Cathodic Vacuum Etchers
- Radioisotope Source Encapsulation
- Facility Management and Operation
- Materials Research and Development

1965

JANUARY 1965

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FEBRUARY 1965

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MARCH 1965

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APRIL 1965

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MAY 1965

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JUNE 1965

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JULY 1965

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AUGUST 1965

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SEPTEMBER 1965

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OCTOBER 1965

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NOVEMBER 1965

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DECEMBER 1965

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1966

JANUARY 1966

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FEBRUARY 1966

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MARCH 1966

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MAY 1966

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JUNE 1966

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JULY 1966

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AUGUST 1966

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SEPTEMBER 1966

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OCTOBER 1966

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NOVEMBER 1966

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DECEMBER 1966

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1967

JANUARY 1967

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FEBRUARY 1967

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MARCH

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APRIL 1967

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MAY 1967

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JUNE 1967

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JULY 1967

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AUGUST 1967

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SEPTEMBER 1967

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OCTOBER 1967

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NOVEMBER 1967

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DECEMBER 1967

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1967

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RY 1967			
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1967			
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1967			
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JULY 1967

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AUGUST 1967

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SEPTEMBER 1967

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OCTOBER 1967

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NOVEMBER 1967

S	M	T	W	T	F	S
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DECEMBER 1967

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10	11	12	13	14	15	16
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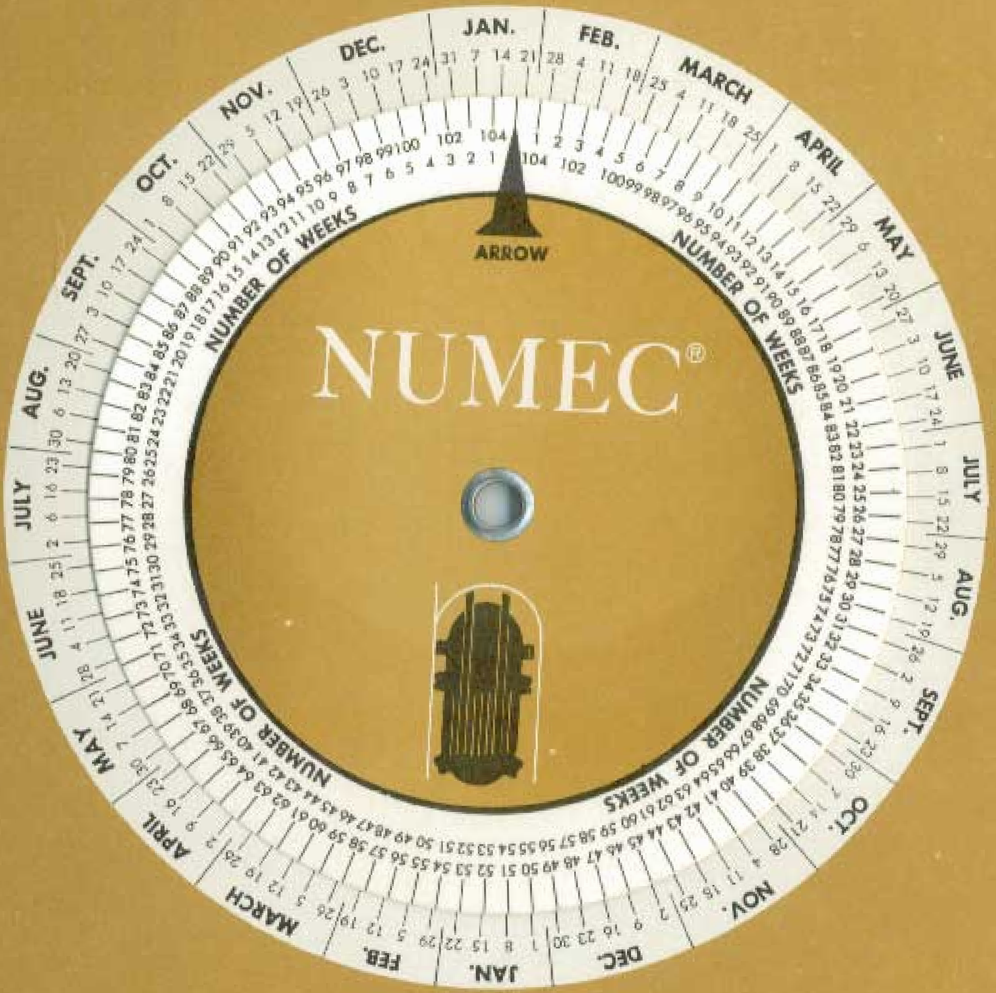
31	..	..	..	..	..	..

DATE CALCULATOR

DUE DATE
1967



DUE DATE
1966

Completion date based on desired beginning date:

1. Set arrow opposite beginning date.
2. Read clockwise on number of weeks scale to the time cycle required.
3. Read off completion date.

Beginning date based on desired completion date:

1. Set arrow opposite desired completion date.
2. Read counterclockwise on the number of weeks to the time cycle required.
3. Read off the necessary beginning date.

NUCLEAR MATERIALS AND EQUIPMENT CORPORATION, APOLLO, PA. 15613 U. S. A.
PHONE: (412) 472-8411

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