Section L
Use of RASCAL

Description

The following material is included to provide information on the capabilities and availability of the tools in the Radiological Assessment System for Consequence Analysis software (RASCAL Version 2.1) and to provide some of the flowcharts and worksheets to facilitate the use of the tools.

RASCAL contains three basic tools to assist in consequence assessment. Figure L-1 can assist in determining the appropriate tool.

- ST-DOSE model (Source Term to Dose)

  ST-DOSE computes doses starting with a source term. It allows you to estimate doses resulting from accidents at nuclear facilities. The doses are based on your specification of a source term and meteorological conditions. The plant condition source-term option performs the calculations used in Section C. The program (1) computes source terms from plant conditions, if necessary, (2) predicts radionuclide concentrations in the atmosphere and on the ground, and (3) calculates doses from the predicted concentrations.

  This program should not be used to estimate doses based on radioisotope concentrations measured in the environment. If you have concentrations measured in the environment, you should use the FM-DOSE (Field Measurement to Dose) program.

- FM-DOSE model (Field Measurement to Dose)

  FM-DOSE computes doses starting from isotopic concentrations measured in the air or on the ground. Groundshine, cloud immersion, and inhalation doses are computed. The overhead cloudshine dose is not computed. The computed doses may be viewed on the screen or printed.

  The dose computations and dose factors used in FM-DOSE are the same as those used in ST-DOSE except that the ingrowth of radioactive decay products is included in more detail in FM-DOSE.

  This program should not be used to estimate doses based on reactor conditions. If you have information about reactor conditions, you should use the ST-DOSE program.

- DECAY model

  DECAY computes the activities of radionuclides after an input time for radioactive decay and buildup. It also computes the integrated activities over that time. It uses the same algorithm as in FM-DOSE and ST-DOSE. It does not compute doses.

The use of these tools is discussed in the following documents:

- *RASCAL Version 2.1 User's Guide*, by A. L. Sjoreen, G. F. Athey, J. V. Ramsdell and T. J. McKenna, NUREG/CR-5247, Vol. 1, Rev. 2, December 1994.

- *RASCAL Version 2.1 Workbook*, by G. F. Athey, A. L. Sjoreen and T. J. McKenna, NUREG/CR-5247, Vol. 2, Rev. 2, December 1994.

- *Operations Center Information Management System (OCIMS) Operations Manual*, by HFS Inc. (This document is primarily for NRC internal use.)

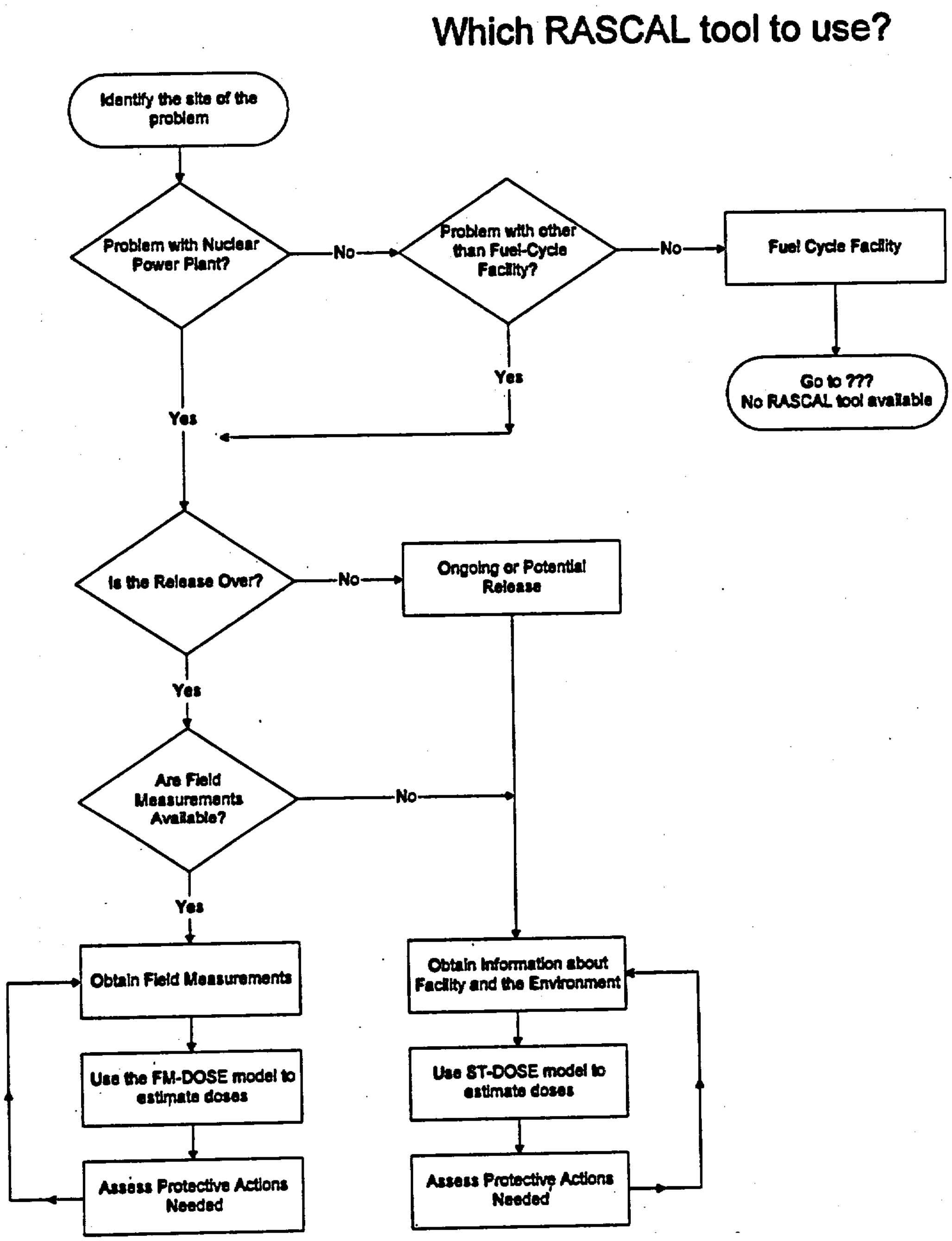
The RASCAL Version 2.1 software is available from

Energy, Science and Technology Software Center
P. O. Box 1020
Oak Ridge, TN 37831-1020
Phone: (423) 576-2606
FAX: (423) 576-2865
Internet: estsc@adonis.osti.gov

RASCAL Worksheets

The following worksheets are provided for use in collecting the information needed to run RASCAL and for summarizing results of the analyses.

Fig. L-1
Identification of appropriate RASCAL tool.



Worksheet L-1. RASCAL ST-DOSE weather data worksheet.

Site Name: ____________________ Site Code: __________

Time of Release: ____________________ Time Zone: __________

Part 1: Current Observations

Time	Wind Speed / Units	Wind Direction	Stability Class	WX (Weather)	Data Source	
					NWS	Site

Part 2: Forecast

Time	Wind Speed / Units	Wind Direction	Stability Class	Precipitation	Data Source	
					Worded	Computer

Part 3: Input for the ST-DOSE model

Time	Wind Speed / Units	Wind Direction	Stability Class	Mixing Layer Height	Precipitation Codes

Worksheet L-2. RASCAL ST-DOSE data worksheet.

Analyst(s) ______________________ **Date/Time** ____________________

Description **(Case Title, Site Name, etc.)**

____

____

____

____

Default Units: Ci (output will be in rem) *or* Bq (output will be in Sv)

Data Source: Projected *or* Actual

Effective Release Height: ________ ft or m

Source Term

See the data sheet provided by the Source Term Analyst

Sequence of Events (dates and times)

	Reactor Shutdown	Start of Release to Containment	Start of Release to Environment	End of Release	End of Exposure
Date					
Time					

Meteorological Data

See the data sheet provided by the Dispersion Analyst

Calculation Options:

Model: Plume *or* Puff

Calculate Building Wake Effects: YES *or* NO

Calculation Radius: 0–10 miles *or* 0–25 miles

Worksheet L-2. RASCAL ST-DOSE data worksheet (continued).

Guidance on which results to examine first

For these conditions:	Look at these doses first:
Reactor accidents	TEDE and Thyroid for comparison with EPA PAGs
To compare with field monitoring external dose measurements	Cloud shine dose
For accidents where inhalation lung dose may dominate (e.g. Pu)	Acute Lung Dose

Check the results of most interest

- ☐ Total Acute Bone
- ☐ Acute Lung
- ☐ Total Effective Dose Equivalent
- ☐ Thyroid
- ☐ Cloudshine
- ☐ Initial Groundshine
- ☐ 4-day Groundshine
- ☐ Acute Bone Inhalation
- ☐ Inhalation Dose CEDE
- ☐ Deposition

Worksheet L-3. RASCAL ST-DOSE source term worksheet.

Case Name ______________________________

A. User Specified Source Term—Isotopic Release Rates

Release Rate Units: ________ (prefix) **[Ci, Bq]/[sec, min, h]**

Isotope	Release Rate	Isotope	Release Rate
______	______	______	______
______	______	______	______
______	______	______	______
______	______	______	______
______	______	______	______
______	______	______	______
______	______	______	______
______	______	______	______

Prefixes

tera
giga
mega
kilo
centi
milli
micro
nano
pico

B. User Specified Source Term—Isotopic Concentrations

Release Rate: ________ **[cc, ft³, L, g]/[sec, min, h]**

Concentration Units: ________ (prefix) **[Ci, Bq]/[cc, ft³, L, g]**

Input from DECAY Calculator: No or Yes

Isotope	Concentration	Isotope	Concentration
______	______	______	______
______	______	______	______
______	______	______	______
______	______	______	______
______	______	______	______
______	______	______	______
______	______	______	______
______	______	______	______

Prefixes

tera
giga
mega
kilo
centi
milli
micro
nano
pico

C. Gross Reactor Release—Mix Specified By Analyst

Gross Release Rate: ________ **Ci/sec** *or* **Bq/sec**

Percentage of Release:

Kr, Xe:	______%	**Te, Sb:**	______%	**La, Y, Ce, Np:**	______%
I:	______%	**Ba, Sr:**	______%		
Cs:	______%	**Ru, Mo:**	______%		

Worksheet L-3. RASCAL ST-DOSE source term worksheet (continued).

D. Reactor Accident, Based on Plant Conditions (six release pathways available)

Large Dry, or Subatmospheric Containment Leakage/Failure

Core Condition: GAP RELEASE (core uncovered 15–30 min)
IN-VESSEL SEVERE CORE DAMAGE (uncovered > 30 min)
VESSEL MELT-THROUGH

Reactor Power: _____ MW(t) *or* Full Power

Containment Sprays: ON *or* OFF   Release path: FILTERED *or* UNFILTERED

Containment Leak Rate:			
	100%/h	4%/h (100%/day)	design pressure
	50%/h	1%/h	½ design pressure
	10%/h	0.5%/h	

Steam Generator Tube Rupture (Coolant)

Coolant Concentration: GAP RELEASE (core uncovered 15–30 min)
IN-VESSEL SEVERE CORE DAMAGE (uncovered > 30 min)
TYPICAL COOLANT
COOLANT WITH 100× NORMAL NON-NOBLES

SG Conditions: PARTITIONED *or* NOT PARTITIONED

Release Rate:		
	1 TUBE 35%/h; 500 gal/min	1 PUMP 3%/h; 50 gal/min
	2 TUBES 70%/h; 1000 gal/min	2 PUMPS 6%/h; 100 gal/min
		3 PUMPS 9%/h; 150 gal/min

Release is from: STEAM JET AIR EJECTOR *or* SAFETY VALVE

Ice Condenser Containment Leakage/Failure

Core Condition: GAP RELEASE (core uncovered 15–30 min)
IN-VESSEL SEVERE CORE DAMAGE (uncovered > 30 min)
VESSEL MELT-THROUGH

Reactor Power: _____ MW(t) *or* Full Power   Recirculation Fans: ON *or* OFF

Release Path: FILTERED *or* UNFILTERED   Containment Sprays: ON *or* OFF

Ice Bed Condition Before Core Damage: EXHAUSTED *or* NOT EXHAUSTED

Containment Leak Rate:			
	100%/h	4%/h (100%/day)	design pressure
	50%/h	1%/h	½ design pressure
	10%/h	0.5%/h	

Worksheet L-3. RASCAL ST-DOSE source term worksheet (continued).

Dry Well Leakage/Failure; BWR Containment

Core Condition: GAP RELEASE (core uncovered 15–30 min)
IN-VESSEL SEVERE CORE DAMAGE (uncovered > 30 min)
VESSEL MELT-THROUGH

Reactor Power: _____ MW(t) *or* Full Power

Release Path: FILTERED *or* UNFILTERED   Containment Sprays: ON *or* OFF

Dry Well Leak Rate:

100%/h	1%/h
50%/h	0.5%/h
10%/h	design pressure
4%/h (100%/day)	½ design pressure

Wet Well Leakage/Failure; BWR Containment

Core Condition: GAP RELEASE (core uncovered 15–30 min)
IN-VESSEL SEVERE CORE DAMAGE (uncovered > 30 min)
VESSEL MELT-THROUGH

Reactor Power: _____ MW(t) *or* Full Power

Wet Well: SATURATED *or* SUBCOOLED

Release Path: FILTERED *or* UNFILTERED

Wet Well Leak Rate:

100%/h	1%/h
50%/h	0.5%/h
10%/h	design pressure
4%/h (100%/day)	½ design pressure

Containment Bypass (Event V)

Core Condition: GAP RELEASE (core uncovered 15–30 min)
IN-VESSEL SEVERE CORE DAMAGE (uncovered > 30 min)
VESSEL MELT-THROUGH

Reactor Power: _____ MW(t) *or* Full Power

Release Path: FILTERED *or* UNFILTERED

Leak Rate:

100%/h	1%/h
50%/h	0.5%/h
10%/h	design pressure
4%/h (100%/day)	½ design pressure

Worksheet L-3. RASCAL ST-DOSE source term worksheet (continued).

E. Containment Monitor Reading

Location of Monitor:	PWR			
	BWR Mark I	Wet Well	*or*	Dry Well
	BWR Mark II	Wet Well	*or*	Dry Well
	BWR Mark II	Wet Well	*or*	Dry Well

Reactor Power: _____ MW(t) *or* Full Power

Monitor Reading: _____________ R/h

Containment Sprays: ON *or* OFF

Release Path: FILTERED *or* UNFILTERED

Leak Rate:	100%/h	1%/h
	50%/h	0.5%/h
	10%/h	design pressure
	4%/h (100%/day)	½ design pressure

F. Spent Fuel / Spent Fuel Pool Accident

Fuel Condition: Zircalloy File—New Batch Only
Fuel Cladding Failure—Gap Release

Reactor Power: _____ MW(t) *or* Full Power

Last batch put in pool: ______________________ (date and time)

Number of batches: _________

Sprays: ON *or* OFF

Release Path: UNFILTERED *or* FILTERED

Leak Rate:	100%/h	1%/h
	50%/h	0.5%/h
	10%/h	0.1%/h
	4%/h (100%/day)	

Worksheet L-4. RASCAL FM-DOSE model worksheet.

Case Title: ____________________

Sample Collection Date/Time: ____________

Input Units for Ground Concentrations		Input Units for Air Concentrations		Output Units for Dose	
tera	m^2	tera	m^3	tera	rem
giga	cm^2	giga	cm^3	giga	Sv
mega	ft^2	mega	L	mega	
kilo		kilo	ft^3	kilo	
centi		centi		centi	
milli		milli		milli	
micro		micro		micro	
nano		nano		nano	
pico		pico		pico	

☐ Use Ground Concentrations in Calculations		☐ Use Air Concentrations in Calculations	
Ground Surface Correction Factor: ____________			
Exposure Time (h): ____________		Exposure Time (h): ____________	
Resuspension Rate: ____________			
Reentry Delay (days): ____________			
Nuclide	Concentration	Nuclide	Concentration
____________	____________	____________	____________
____________	____________	____________	____________
____________	____________	____________	____________
____________	____________	____________	____________
____________	____________	____________	____________
____________	____________	____________	____________
____________	____________	____________	____________
____________	____________	____________	____________
____________	____________	____________	____________
____________	____________	____________	____________

Worksheet L-5. NRC consequence analysis summary.

Case Title: ____

Analyst(s): ____

Date/Time: ____
(when the analysis was done)

Summary of Results:

Attach the following as needed:

ST-DOSE Model

Model Worksheet
Source Term Worksheet
Weather Worksheet

Maximum Value Report
Model Input Summary
Computed Source Term

Graphics

FM-DOSE Model

FM-DOSE Worksheet
Model Input Summary

Early Phase Dose Report
Intermediate Phase Dose Report

Worksheet L-6. NRC consequence analysis log.

Case Title	Date/Time	Current Conditions	Analysis Requested	Comments and Results

M

SECTION M

RADIOACTIVE HALF-LIVES AND DECAY DATA

Section M
Quick Reference Guide

Section M
Radioactive Half-Lives and Decay Data

Half-Life Values

Table M-1 contains element names, chemical symbols, atomic numbers (Z), and radioactive half-lives for some selected radioisotopes. The atomic number is the number of protons in the nucleus of the atom; the number of protons defines the chemical properties of the element and thus defines the element. Radioactive half-life is the time required for one-half of the nuclei of a radioactive species to decay.

Decay Diagrams

Radioactive decay diagrams for many isotopes are shown in Fig. M-1. The isotopes are indicated in the form ^{A}X, where X is the symbol for the element and A is the atomic mass number (the number of protons plus the number of neutrons). Spontaneous fission is not indicated on the charts, although it may be the most important decay mode in terms of total energy releases for some transuranics.

Decay processes indicated on the diagrams are described below. Some relatively rare processes have been omitted.

α (alpha decay)—An atom with an atomic number Z and atomic mass number A emits an alpha particle (a ^{4}He nucleus with Z=2 and A=4), producing a daughter atom with atomic number Z−2 and mass number A−4.

β^- (β^- decay)—One of the beta decay processes in which a negative electron (β^-) and an antineutrino ($\bar{\nu}$) are emitted from the nucleus as a result of the transformation of a neutron into a proton, $n \rightarrow p + \beta^- + \bar{\nu}$. The atomic number Z increases by one, while the mass number A remains the same.

β^+ (β^+ decay)—One of the beta decay processes in which a positron (β^+) and a neutrino (ν) are emitted from the nucleus as a result of the transformation of a proton into a neutron, $p \rightarrow n + \beta^+ + \nu$. The atomic number Z decreases by one, while the mass number A remains the same.

EC (electron capture)—One of the beta decay processes in which an atomic electron is captured by the nucleus. This transforms a proton into a neutron and a neutrino is emitted, $p + e^- \rightarrow n + \nu$. As in β^+ decay, the atomic number Z decreases by one, and the mass number A remains the same.

IT (isomeric transition)—The decay of long-lived excited states of a nucleus (metastable states) to states of lower energy in the same nucleus (same atomic number and same mass number), usually accompanied by the emission of a gamma ray (γ) or an internal conversion electron. A gamma ray is composed of electromagnetic energy, roughly equal in energy to the energy difference in the two nuclear levels. In internal conversion, the energy difference between the two nuclear levels is transferred to a bound atomic electron, which is then ejected from the atom.

Table M-1. Element names, atomic numbers, and half-lives for selected radioisotopes

Element name	Symbol	Atomic number	Radioisotope[a]	Half-life[b]
Hydrogen	H	1	^{3}H	12.28 yr
Carbon	C	6	^{14}C	5.73×10^{3} yr
Sodium	Na	11	^{22}Na ^{24}Na	2.602 yr 15.00 h
Phosphorus	P	15	^{32}P ^{33}P	14.29 d 25.4 d
Sulfur	S	16	^{35}S	87.44 d
Chlorine	Cl	17	^{36}Cl	3.01×10^{5} yr
Potassium	K	19	^{40}K ^{42}K	1.277×10^{9} yr 12.36 h
Calcium	Ca	20	^{45}Ca	162.7 d
Scandium	Sc	21	^{46}Sc	83.80 d
Titanium	Ti	22	^{44}Ti	47.3 yr
Vanadium	V	23	^{48}V	15.971 d
Chromium	Cr	24	^{51}Cr	27.704 d
Manganese	Mn	25	^{54}Mn ^{56}Mn	312.7 d 2.5785 h
Iron	Fe	26	^{55}Fe ^{59}Fe	2.7 yr 44.63 d
Cobalt	Co	27	^{58}Co ^{60}Co	70.80 d 5.271 yr
Nickel	Ni	28	^{63}Ni	100.1 yr
Copper	Cu	29	^{64}Cu	12.701 h
Zinc	Zn	30	^{65}Zn	244.4 d
Gallium	Ga	31	^{68}Ga	68.0 m
Germanium	Ge	32	^{68}Ge	288 d
Selenium	Se	34	^{75}Se	119.78 d
Krypton	Kr	36	^{85}Kr ^{85m}Kr ^{87}Kr ^{88}Kr	10.72 yr 4.48 h 76.3 m 2.84 h

Table M-1. Element names, atomic numbers, and half-lives for selected radioisotopes (continued)

Element name	Symbol	Atomic number	Radioisotope[a]	Half-life[b]
Rubidium	Rb	37	^{86}Rb	18.66 d
			^{87}Rb	4.73×10^{10} yr
			^{88}Rb	17.8 m
			^{89}Rb	15.44 m
Strontium	Sr	38	^{89}Sr	50.55 d
			^{90}Sr	28.6 yr
			^{91}Sr	9.5 h
Yttrium	Y	39	^{90}Y	64.1 h
			^{90m}Y	3.19 h
			^{91}Y	58.51 d
			^{91m}Y	49.71 m
Zirconium	Zr	40	^{93}Zr	1.53×10^{6} yr
			^{95}Zr	64.02 d
			^{97}Zr	16.90 h
Niobium	Nb	41	^{94}Nb	2.03×10^{4} yr
			^{94m}Nb	6.26 m
			^{95}Nb	35.06 d
Molybdenum	Mo	42	^{99}Mo	66.02 h
Technetium	Tc	43	^{99}Tc	2.13×10^{5} yr
			^{99m}Tc	6.02 h
Ruthenium	Ru	44	^{103}Ru	39.35 d
			^{105}Ru	4.44 h
			^{106}Ru	368.2 d
Rhodium	Rr	45	^{103m}Rh	56.119 m
			^{105}Rh	35.36 h
			^{105m}Rh	45 s
			^{106}Rh	29.92 s
Silver	Ag	47	^{109m}Ag	39.6 s
			^{110}Ag	24.57 s
			^{110m}Ag	249.85 d
Cadmium	Cd	48	^{109}Cd	464 d
			^{113}Cd	9.3×10^{15} yr
			^{113m}Cd	13.7 yr
Indium	In	49	^{114}In	71.9 s
			^{114m}In	49.51 d
Tin	Sn	50	^{113}Sn	115.1 d
			^{123}Sn	129.2 d
			^{126}Sn	1.0×10^{5} yr

Table M-1. Element names, atomic numbers, and half-lives for selected radioisotopes (continued)

Element name	Symbol	Atomic number	Radioisotope[a]	Half-life[b]
Antimony	Sb	51	^{124}Sb	60.20 d
			^{126}Sb	12.4 d
			^{126m}Sb	19.0 m
			^{127}Sb	3.85 d
			^{129}Sb	4.40 h
Tellurium	Te	52	^{127}Te	9.35 h
			^{127m}Te	109 d
			^{129}Te	69.6 m
			^{129m}Te	33.6 d
			^{131}Te	25.0 m
			^{131m}Te	30 h
			^{132}Te	78.2 h
Iodine	I	53	^{125}I	60.14 d
			^{129}I	1.57×10^7 yr
			^{131}I	8.040 d
			^{132}I	2.30 h
			^{133}I	20.8 h
			^{134}I	52.6 m
			^{135}I	6.61 h
Xenon	Xe	54	^{131m}Xe	11.84 d
			^{133}Xe	5.245 d
			^{133m}Xe	2.19 d
			^{135}Xe	9.11 h
			^{135m}Xe	15.36 m
			^{138}Xe	14.13 m
Cesium	Cs	55	^{134}Cs	2.062 yr
			^{135}Cs	2.3×10^6 yr
			^{136}Cs	13.16 d
			^{137}Cs	30.17 yr
			^{138}Cs	32.2 m
Barium	Ba	56	^{133}Ba	10.5 yr
			^{135m}Ba	28.7 h
			^{137m}Ba	2.552 m
			^{140}Ba	12.789 d
Lanthanum	La	57	^{140}La	40.22 h
Cerium	Ce	58	^{141}Ce	32.50 d
			^{143}Ce	33.0 h
			^{144}Ce	284.3 d

Table M-1. Element names, atomic numbers, and half-lives for selected radioisotopes (continued)

Element name	Symbol	Atomic number	Radioisotope[a]	Half-life[b]
Praseodymium	Pr	59	^{143}Pr ^{144}Pr ^{144m}Pr	13.56 d 17.28 m 7.2 m
Neodymium	Nd	60	^{147}Nd	10.98 d
Promethium	Pm	61	^{145}Pm ^{147}Pm	17.7 yr 2.6234 yr
Samarium	Sm	62	^{147}Sm ^{151}Sm	1.069×10^{11} yr 90 yr
Europium	Eu	63	^{152}Eu ^{152m}Eu ^{154}Eu ^{155}Eu	13.6 yr 9.32 h 8.8 yr 4.96 yr
Gadolinium	Gd	64	^{153}Gd	241.6 d
Terbium	Tb	65	^{160}Tb	72.3 d
Holmium	Ho	67	^{166}Ho ^{166m}Ho	26.80 h 1.20×10^{3} yr
Thulium	Tm	69	^{170}Tm	128.6 d
Ytterbium	Yb	70	^{169}Yb	31.97 d
Hafnium	Hf	72	^{181}Hf	42.39 d
Tantalum	Ta	73	^{182}Ta	114.74 d
Tungsten	W	74	^{187}W	23.83 h
Iridium	Ir	77	^{192}Ir	74.02 d
Gold	Au	79	^{198}Au	2.696 d
Mercury	Hg	80	^{203}Hg	46.60 d
Thallium	Tl	81	^{204}Tl	3.779 yr
Lead	Pb	82	^{210}Pb	22.26 yr
Bismuth	Bi	83	^{207}Bi ^{210}Bi	33.4 yr 5.013 d
Polonium	Po	84	^{210}Po	138.378 d
Francium	Fr	87	^{223}Fr	21.8 m

Table M-1. Element names, atomic numbers, and half-lives for selected radioisotopes (continued)

	Symbol	Atomic number	Radioisotope[a]	Half-life[b]
Radon	Rn	86	^{218}Rn	0.035 s
			^{219}Rn	3.96 s
			^{220}Rn	55.61 s
			^{222}Rn	3.8235 d
Radium	Ra	88	^{226}Ra	1600 yr
			^{227}Ra	42.2 m
Actinium	Ac	89	^{227}Ac	21.773 yr
			^{228}Ac	6.13 h
Thorium	Th	90	^{227}Th	18.718 d
			^{228}Th	1.9132 yr
			^{230}Th	7.7×10^4 yr
			^{231}Th	25.52 h
			^{232}Th	1.405×10^{10} yr
Protactinium	Pa	91	^{231}Pa	3.276×10^4 yr
			^{233}Pa	27.0 d
Uranium	U	92	^{232}U	72 yr
			^{233}U	1.592×10^5 yr
			^{234}U	2.445×10^5 yr
			^{235}U	7.038×10^8 yr
			^{236}U	2.3415×10^7 yr
			^{238}U	4.468×10^9 yr
Neptunium	Np	93	^{237}Np	2.14×10^6 yr
			^{239}Np	2.355 d
Curium	Cm	96	^{242}Cm	163.2 d
			^{243}Cm	28.5 yr
			^{244}Cm	18.11 yr
			^{245}Cm	8.5×10^3 yr
Californium	Cf	98	^{252}Cf	2.639 yr

[a]The radioisotopes are listed in the form ^{A}X, where X is the symbol for the element and A is the atomic mass number. When the atomic mass number is followed by an "m," it indicates that the radioisotope is "metastable." Metastable states are excited nuclear states that have a half-life long enough to be observed.

[b]In this column, s = second, m = minute, d = day, h = hour, and yr = year.

Sources: Turner (1986), DOE/TIC-11026.

Fig. M-1
Decay diagrams for selected radioisotopes.

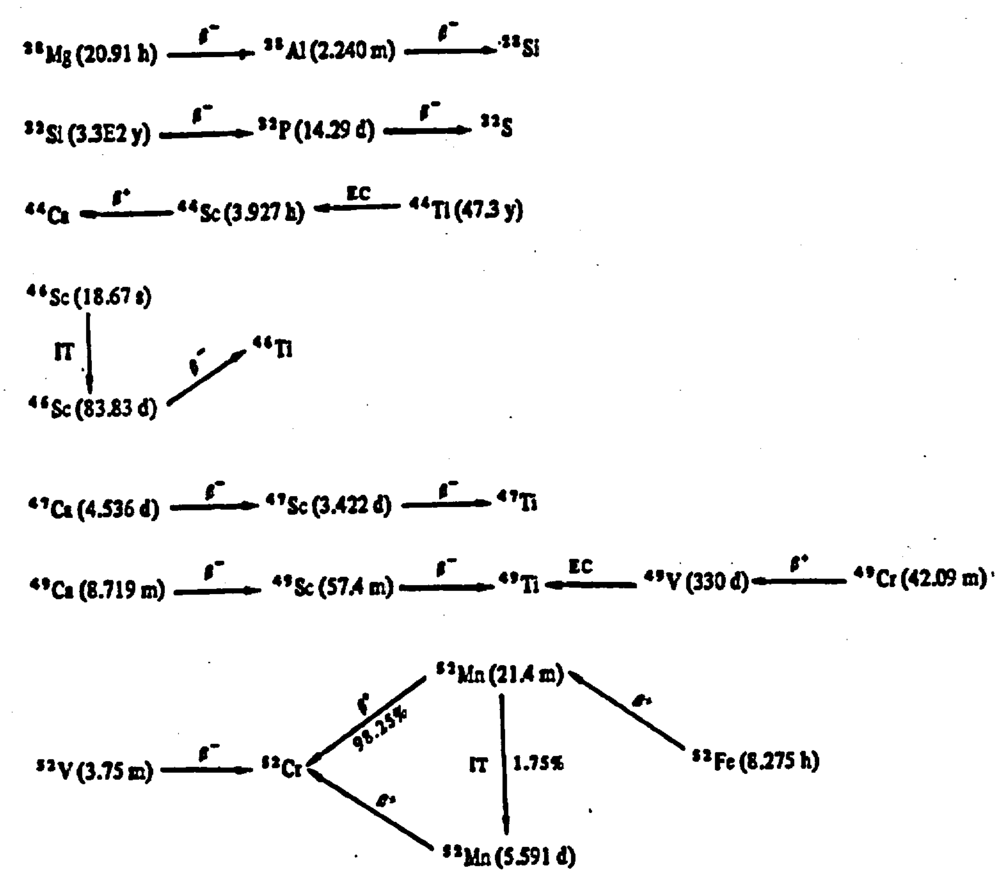


Fig. M-1
Decay diagrams for selected radioisotopes (continued).

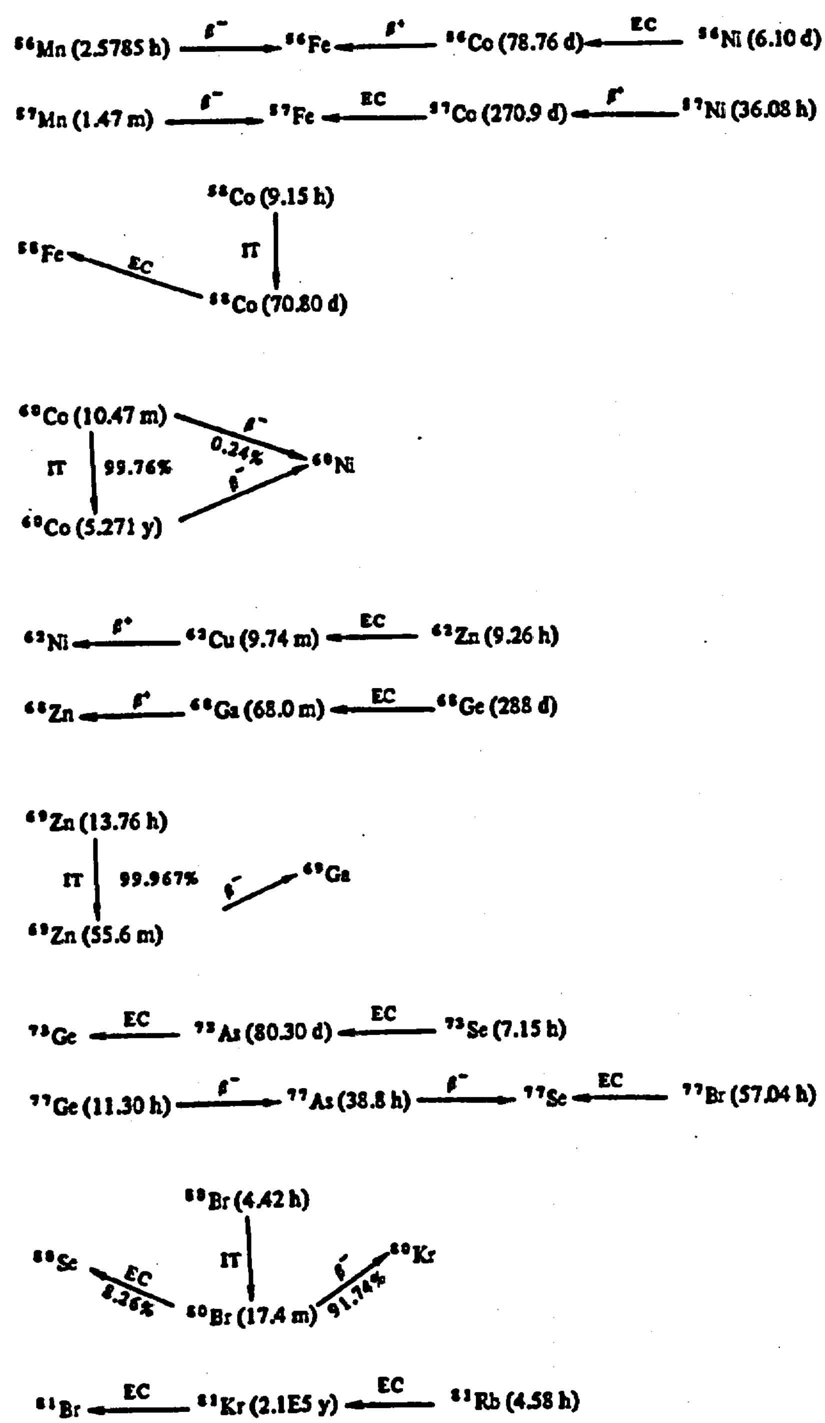


Fig. M-1
Decay diagrams for selected radioisotopes (continued).

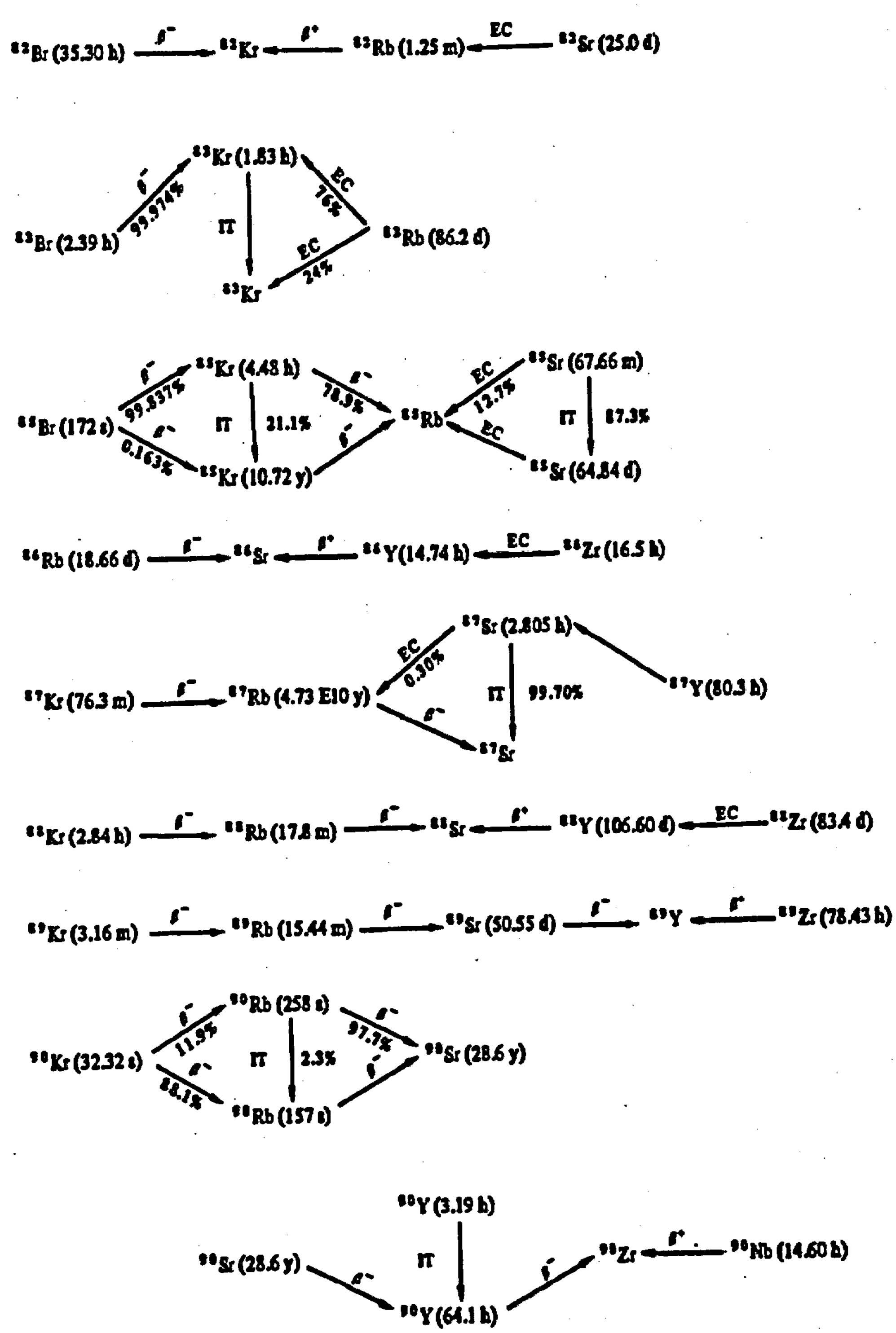


Fig. M-1
Decay diagrams for selected radioisotopes (continued).

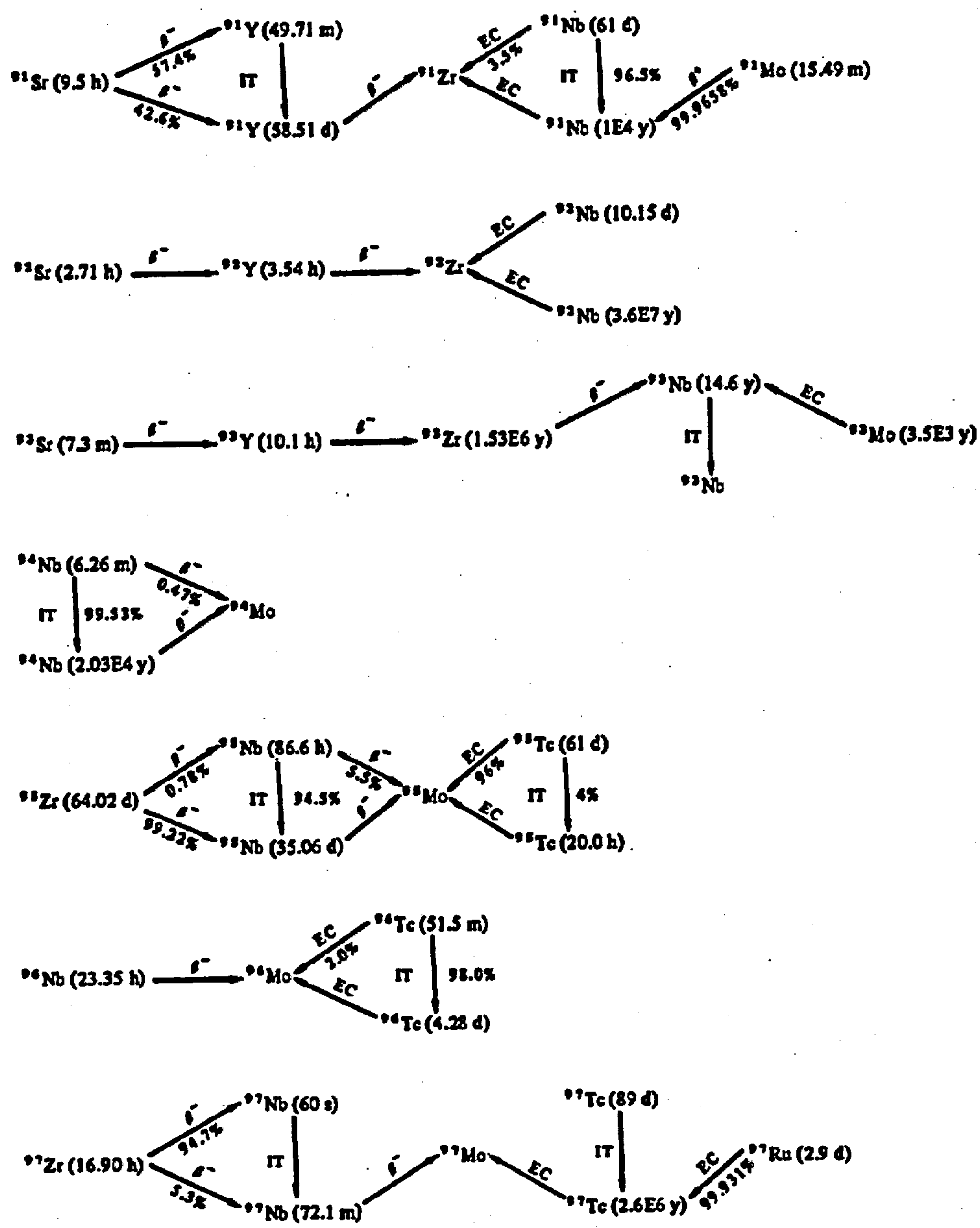


Fig. M-1
Decay diagrams for selected radioisotopes (continued).

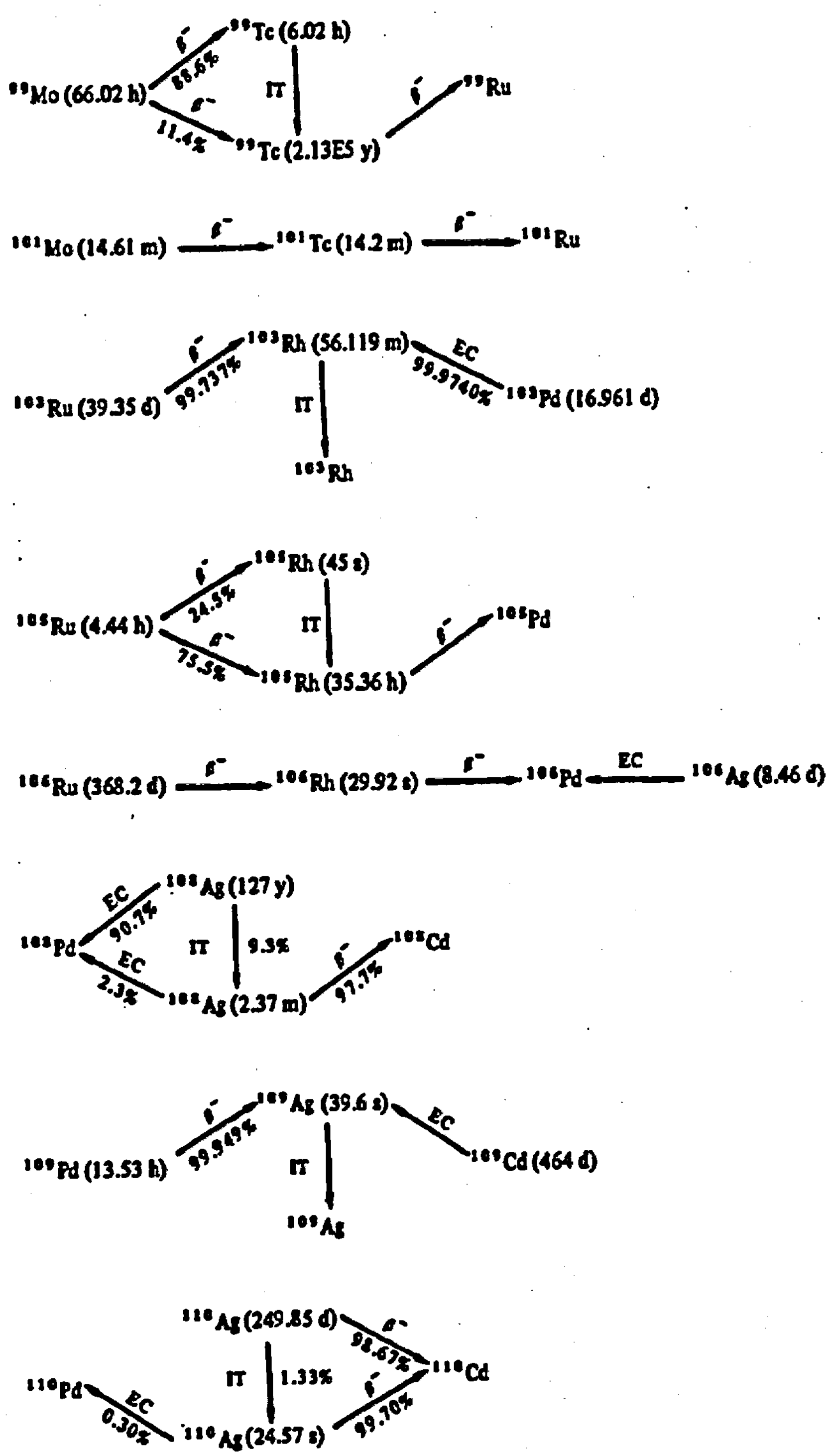


Fig. M-1
Decay diagrams for selected radioisotopes (continued).

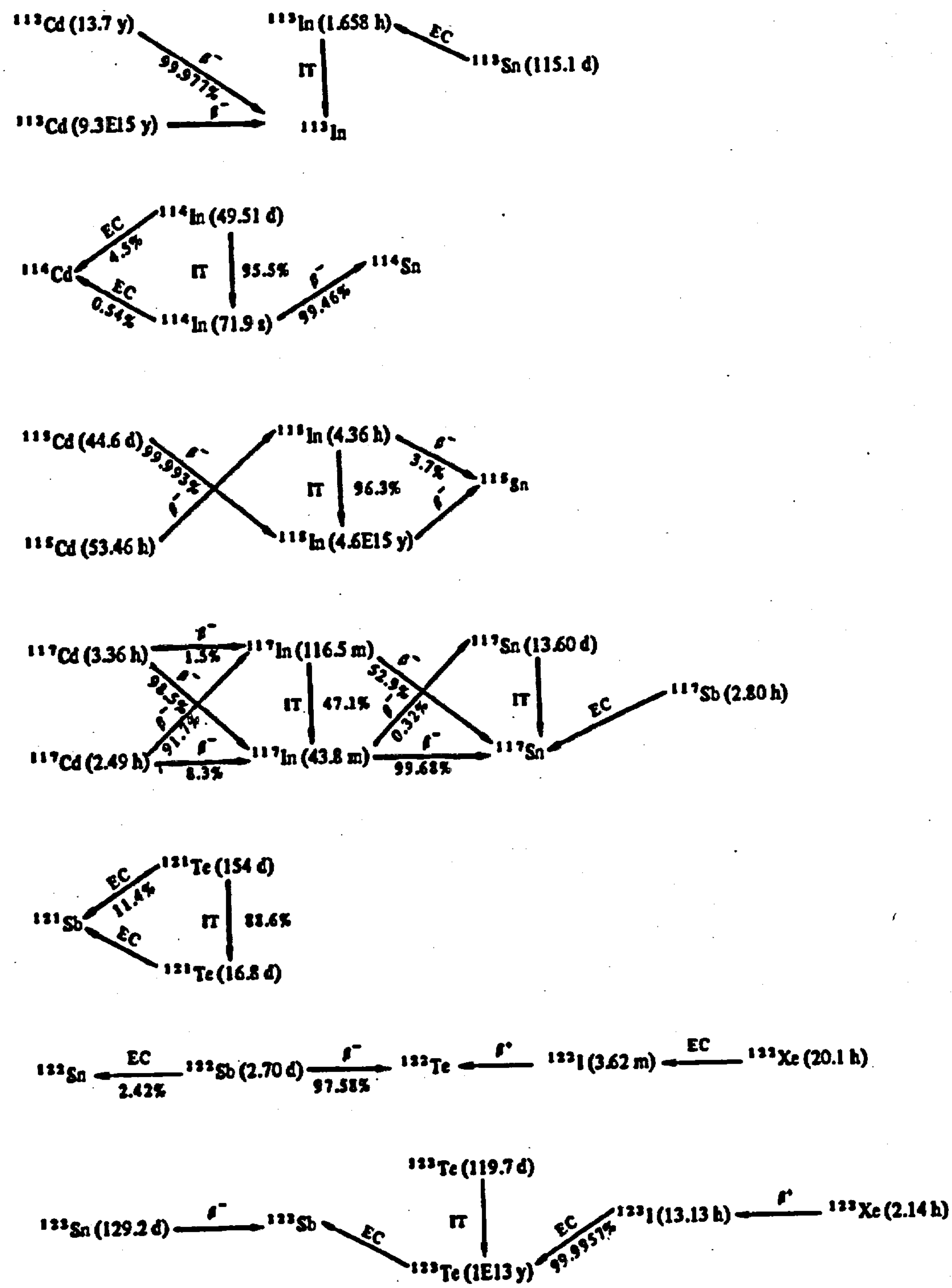


Fig. M-1
Decay diagrams for selected radioisotopes (continued).

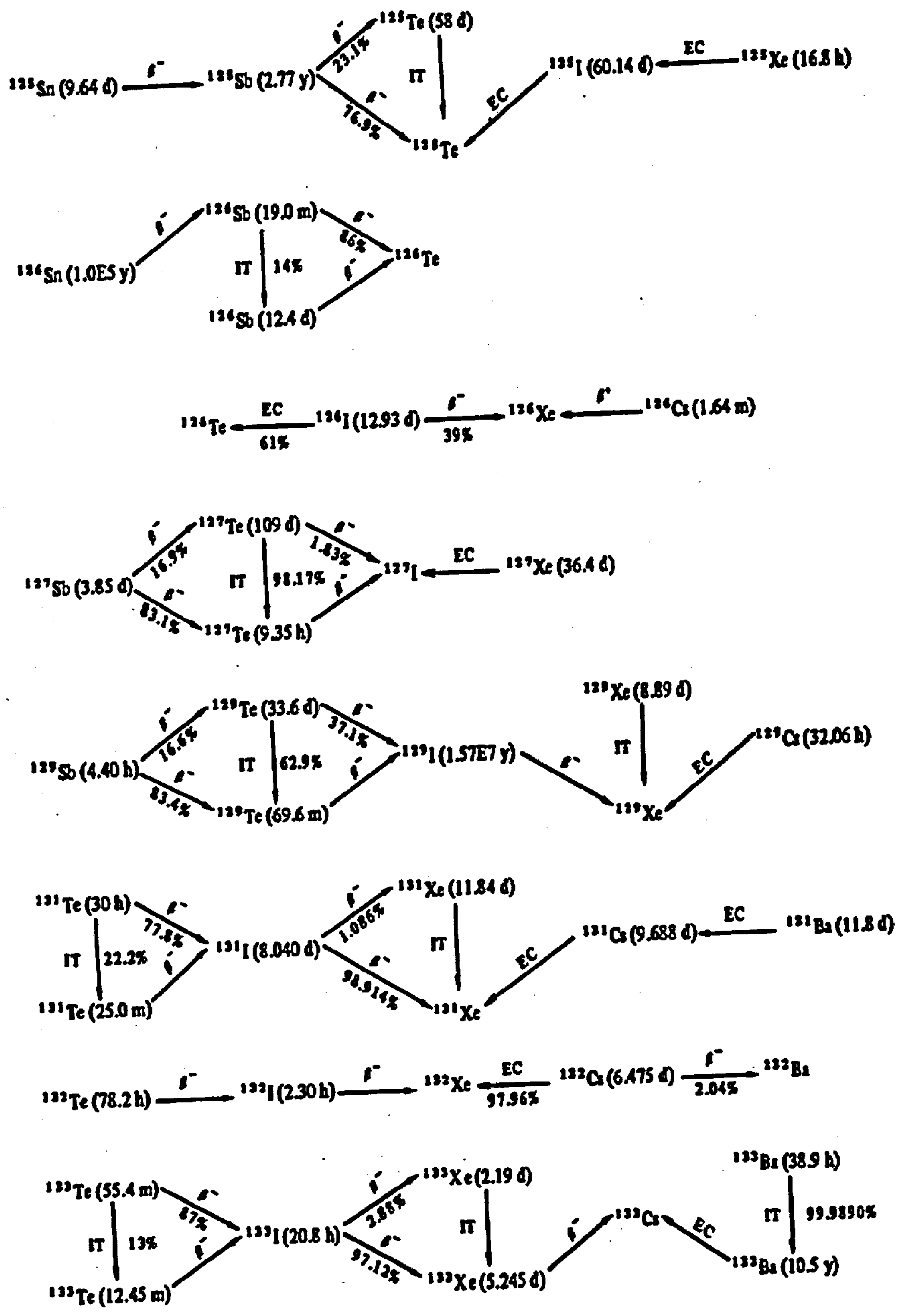


Fig. M-1
Decay diagrams for selected radioisotopes (continued).

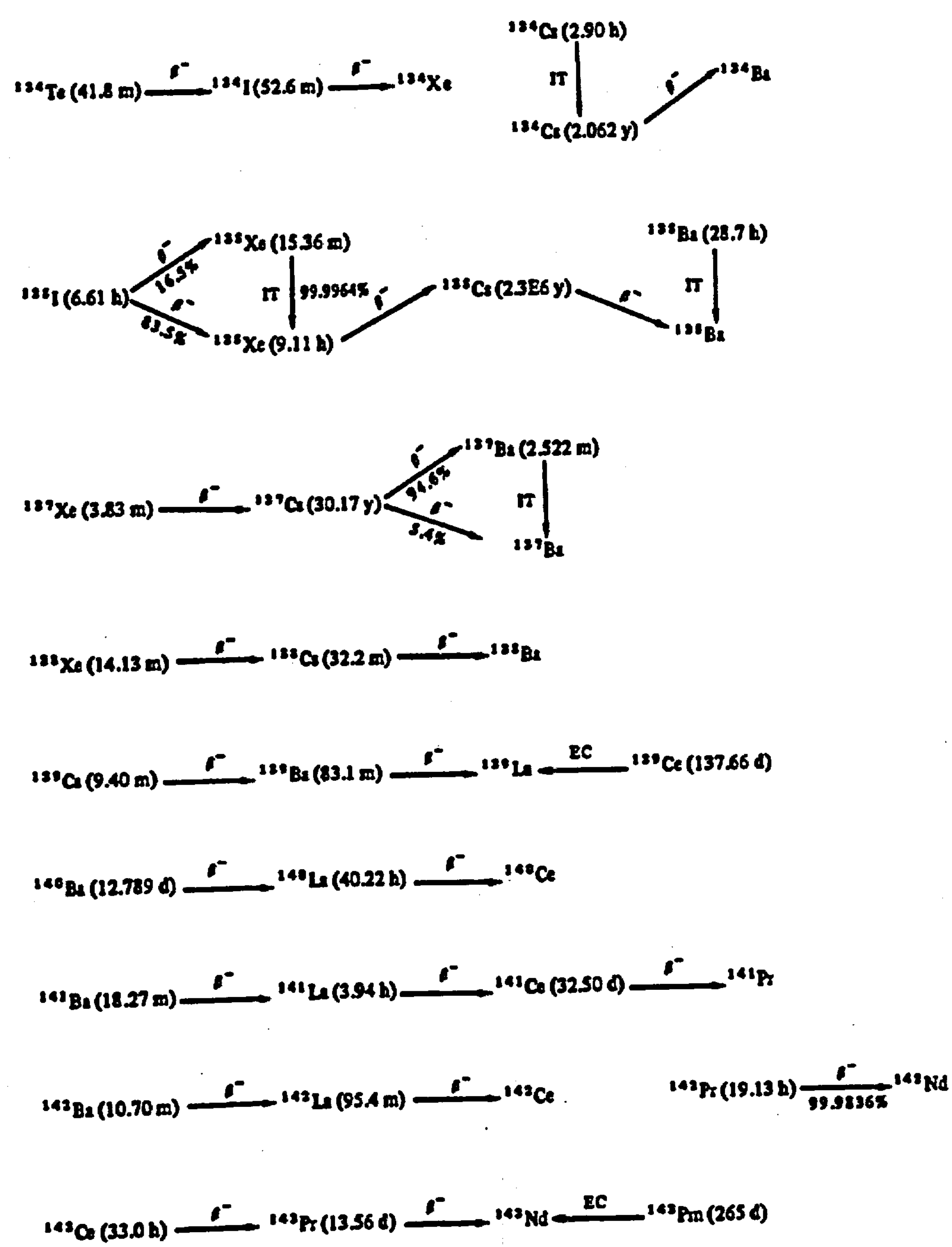


Fig. M-1
Decay diagrams for selected radioisotopes (continued).

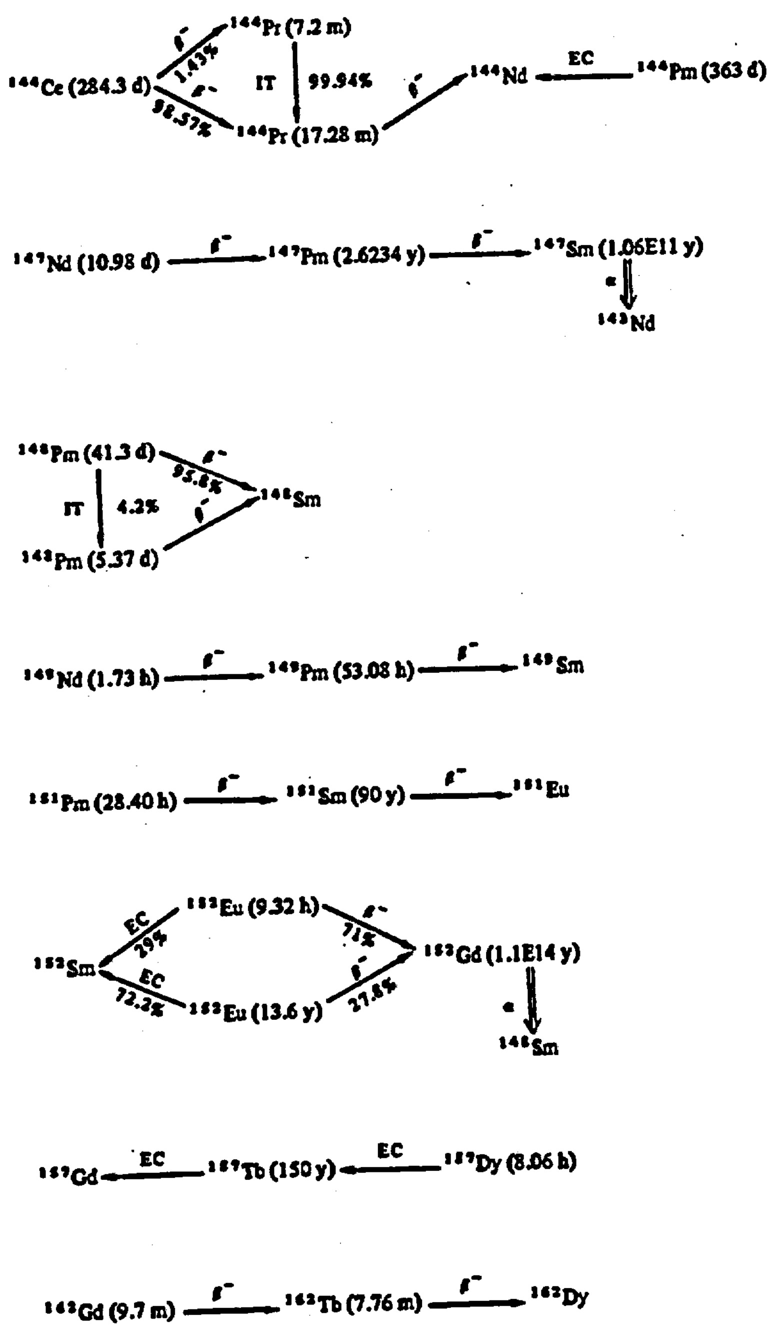


Fig. M-1
Decay diagrams for selected radioisotopes (continued).

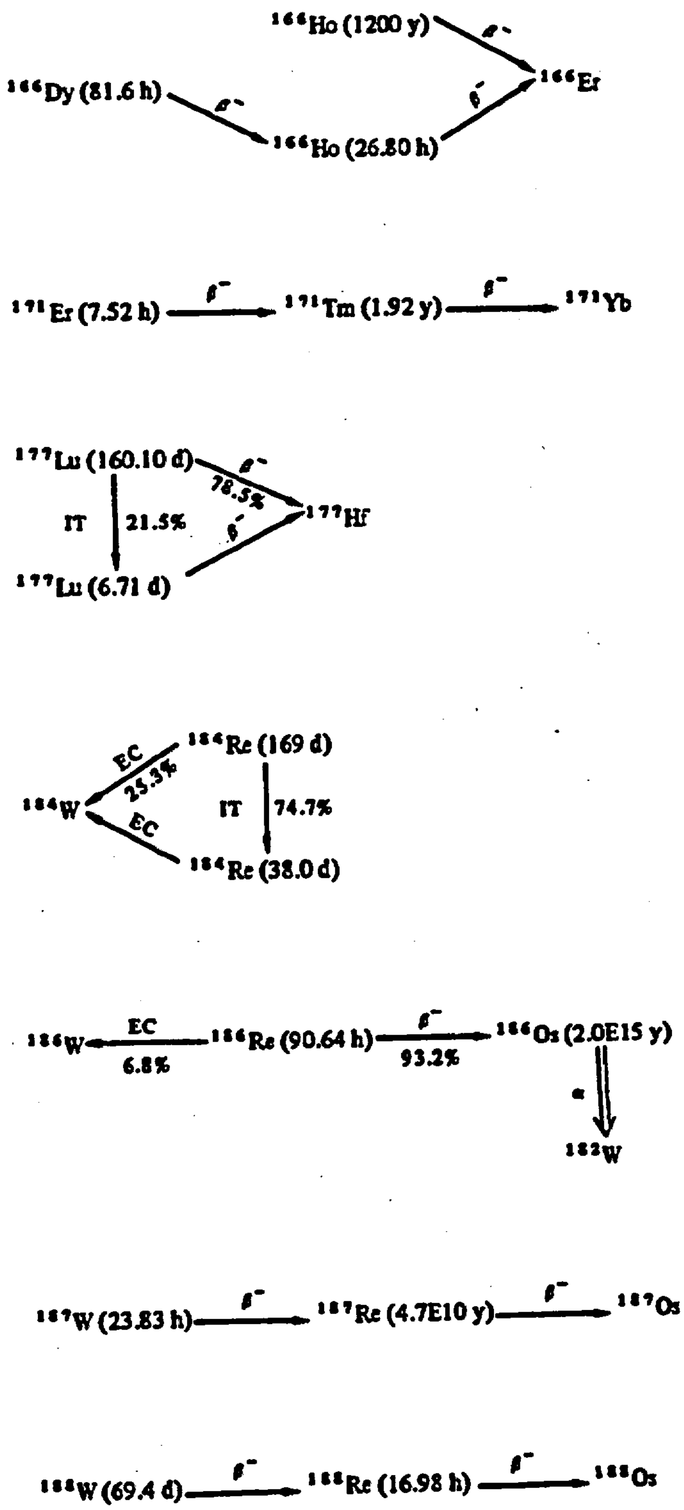


Fig. M-1

Decay diagrams for selected radioisotopes (continued).

Neptunium Series

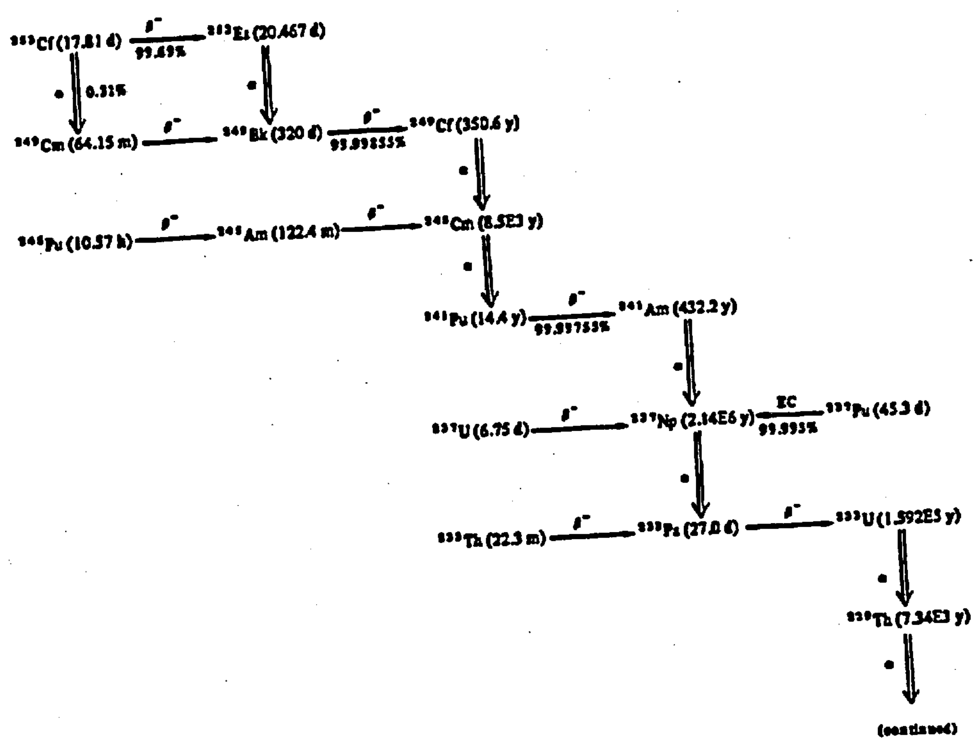


Fig. M-1
Decay diagrams for selected radioisotopes (continued).

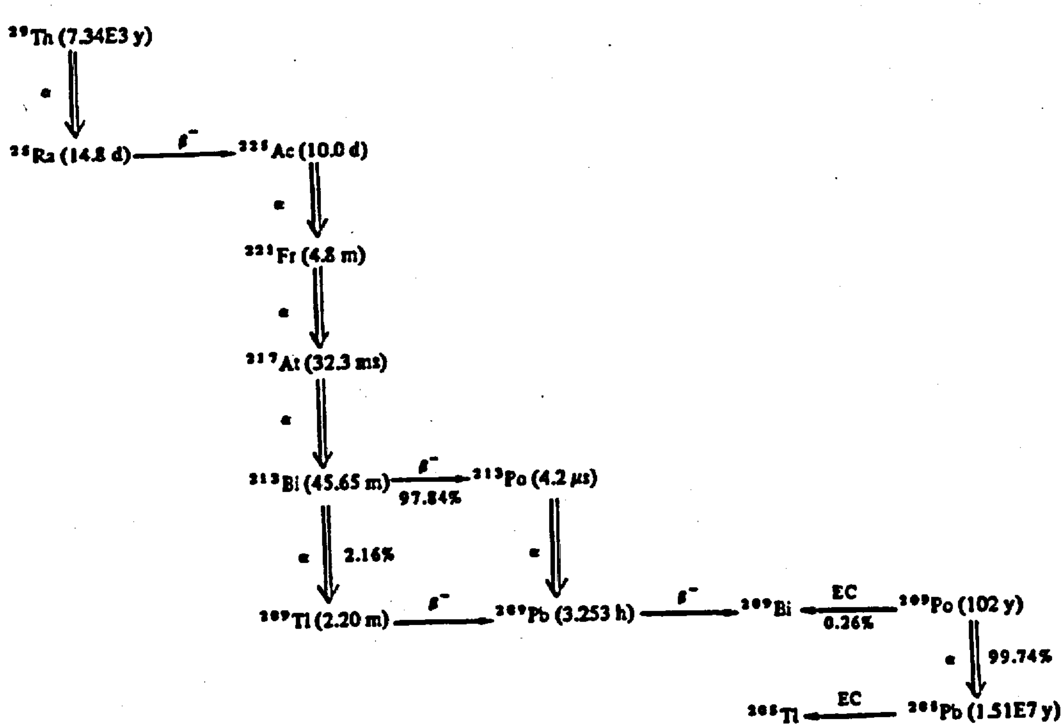


Fig. M-1
Decay diagrams for selected radioisotopes (continued).

Uranium Series

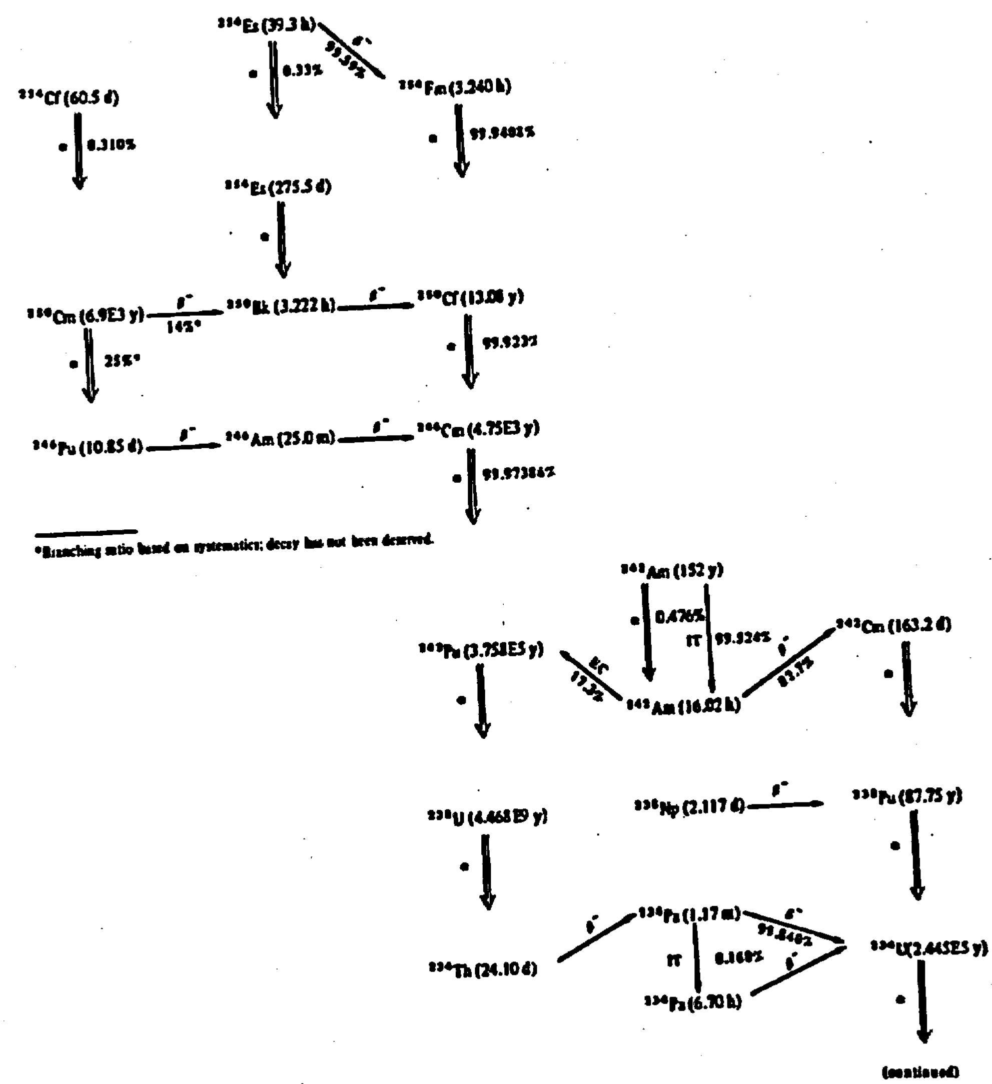


Fig. M-1
Decay diagrams for selected radioisotopes (continued).

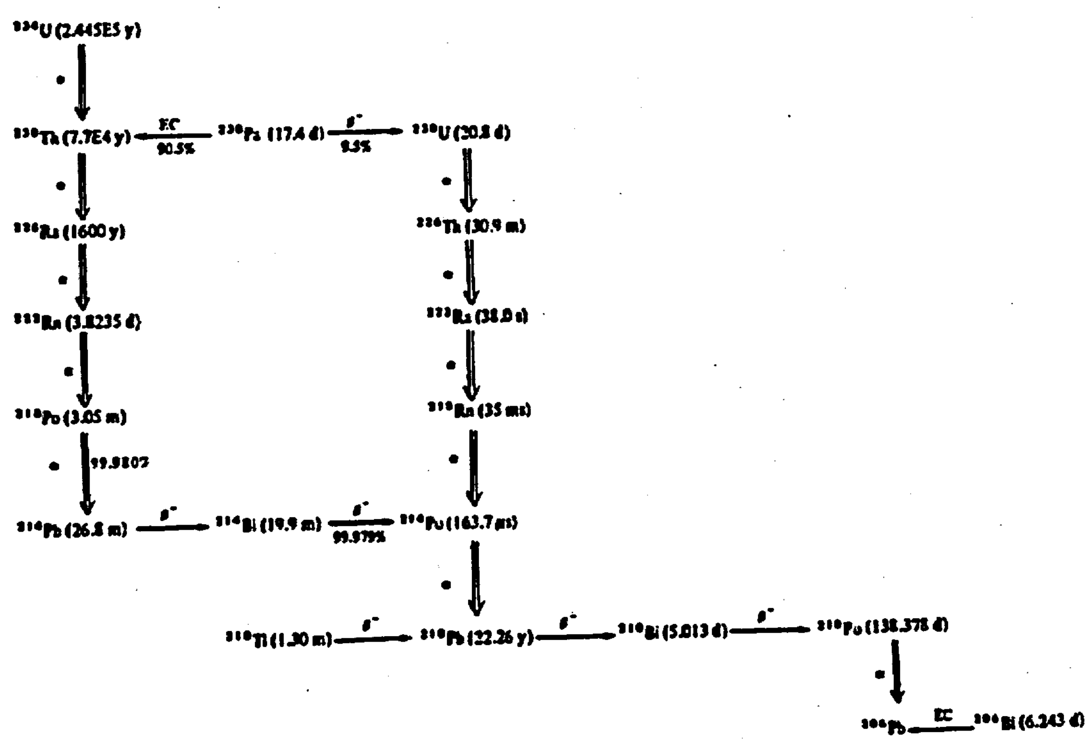


Fig. M-1
Decay diagrams for selected radioisotopes (continued).

Actinium Series

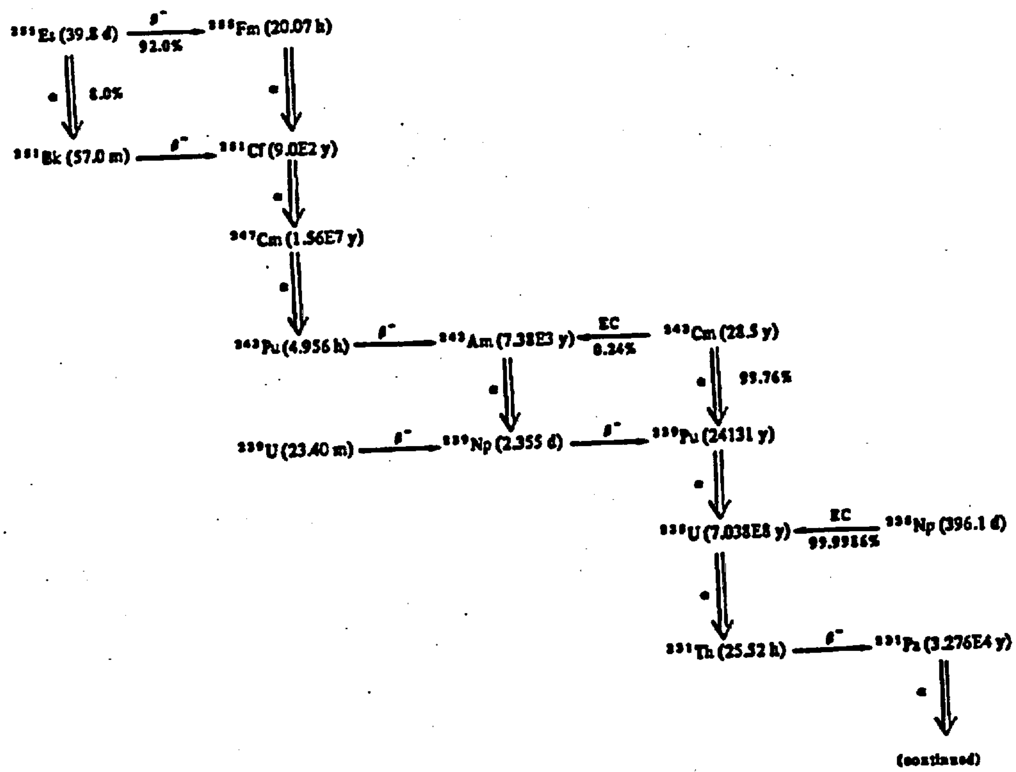


Fig. M-1
Decay diagrams for selected radioisotopes (continued).

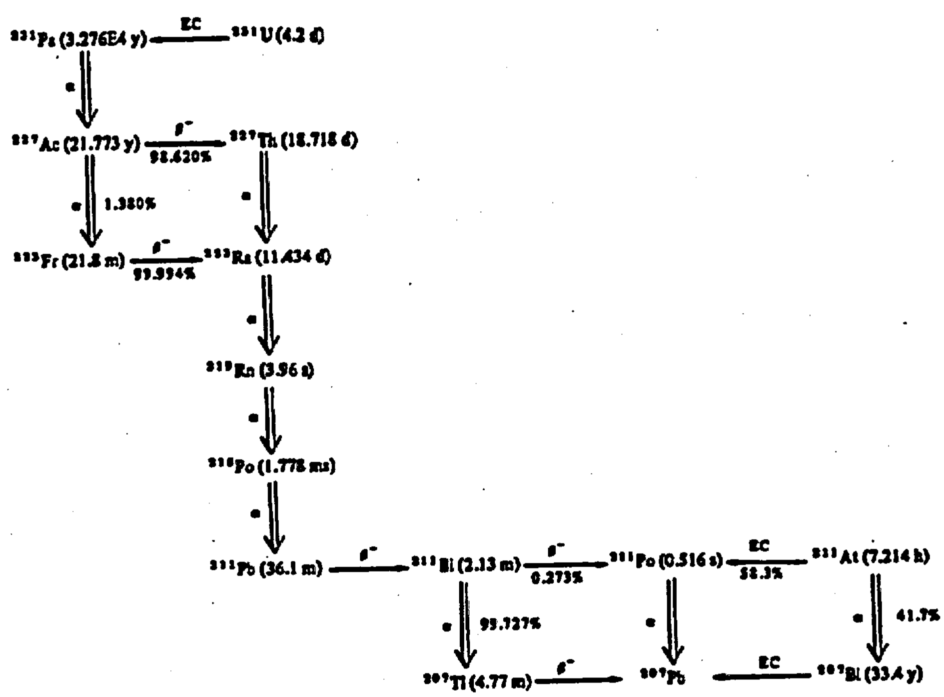


Fig. M-1
Decay diagrams for selected radioisotopes (continued).

Thorium Series

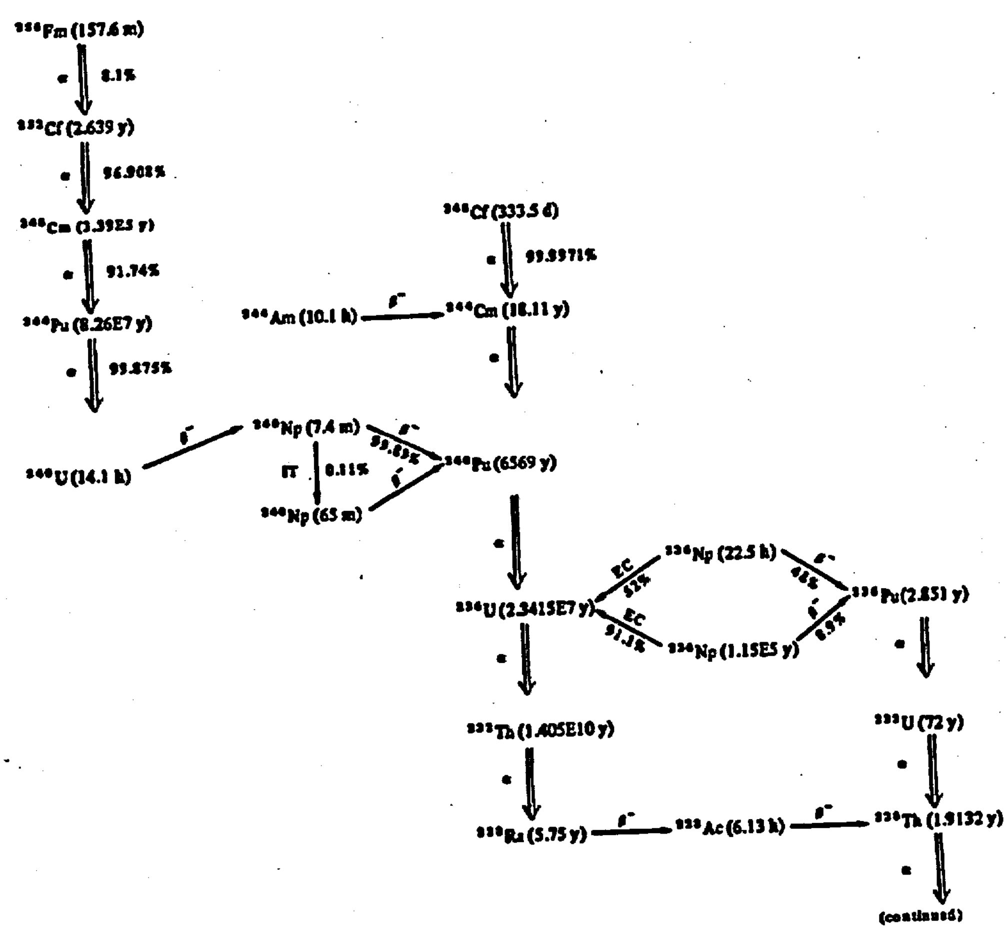
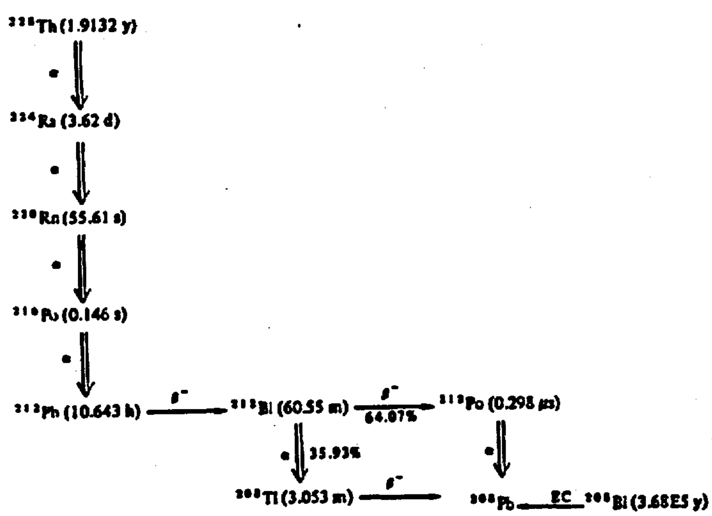


Fig. M-1
Decay diagrams for selected radioisotopes (continued).



Source: DOE/TIC-11026, pp. 49–67.

N

SECTION N

EXPONENTS, SI UNITS, AND CONVERSIONS

Section N
Quick Reference Guide

Section N
Exponents, SI Units, and Conversions

Exponents

An exponent is a symbol or number, usually written to the right of and above another symbol or number, that indicates how many times the latter number should be multiplied by itself. Exponents allow very large or very small numbers to be expressed compactly. Scientific notation is a mathematical notation in which the number is expressed as a number between 1 and 10 multiplied by a power of 10. For example, 750,000,000,000 can be written 7.5×10^{11} and 0.0000000123 is written 1.23×10^{-8}.

An alternate way of expressing the exponent, more convenient for data processing, uses the letter "E" to indicate that the number following is the exponent of 10. Using this system, 7.5×10^{11} is written 7.5E+11 and 1.23×10^{-8} is written 1.23E−08.

Operations with exponents of 10 follow the general rules for operations with exponents (*a* and *b* are positive, non-zero integers and *x* and *y* are not zero):

$$x^a x^b = x^{a+b}$$

$$(x^a)^b = x^{ab}$$

$$(xy)^a = x^a y^a$$

$$\frac{x^a}{x^b} = x^{a-b} \text{ if } a>b$$

$$\frac{x^a}{x^b} = \frac{1}{x^{b-a}} \text{ if } a<b$$

$$a^0 = 1$$

$$x^{-a} = \frac{1}{x^a}$$

$$x^{\frac{a}{b}} = \sqrt[b]{x^a}$$

(Examples: $10^2 10^3 = 10^5$, $(10^2)^3 = 10^6$, $(2 \cdot 10)^2 = 2^2 \cdot 10^2 = 4 \cdot 10^2 = 400$, $\frac{10^4}{10^2} = 10^2$, $\frac{10^2}{10^4} = \frac{1}{10^2}$, $10^0 = 1$, $10^{\frac{2}{3}} = \sqrt[3]{10^2}$.)

SI Units

The International System of Units (Le Système International d'Unités or SI) is a rationalized selection of units from the metric system. SI is a coherent system with seven base units and two supplementary units for which names, symbols, and precise definitions have been established (Table N-1). There is only one unit for each physical quantity. Other units are derived from these units by multiplication and division with no numerical factors other than unity. Some derived units have been given special names (Table N-2).

In general, SI prefixes should be used to indicate orders of magnitude, eliminating nonsignificant digits and leading zeros. This convention provides a convenient alternative to the power-of-ten notation. The prefix should generally be chosen so that the numerical value is between 0.1 and 1000. The prefix should normally be attached to the unit in the numerator, except when kilogram occurs in the denominator. Compound prefixes, juxtaposing two SI prefixes, should not be used (1 nm instead of 1 mμm). SI prefixes are found in Table N-3. (In pronunciation, the first syllable of the SI prefix is accented.)

Conversion Factors

Table N-4 contains selected conversion factors for converting from conventional to SI units. Table N-5 contains other useful conversion and equivalence factors. Equivalences between celsius and fahrenheit temperatures, activity in curies and becquerels, and dose equivalent in rem and sievert are displayed graphically in Fig. N-1. Conversions between time zones are shown in Table N-6.

Source: ASTM E 380-93.

Table N-1. Base and supplementary SI units

Base SI units			Supplementary SI units		
Quantity	Unit	Symbol	Quantity	Unit	Symbol
length	meter	m	plane		
mass	kilogram	kg	angle	radian	rad
time	second	s	solid		
electric current	ampere	A	angle	steradian	sr
thermodynamic temperature	kelvin	K			
amount of substance	mole	mol			
luminous intensity	candela	cd			

Source: ASTM E 380-93, Tables 1 and 2, p. 2.

Table N-2. Derived SI units with special names

Quantity	Unit	Symbol	Formula
frequency (of a periodic phenomenon)	hertz	Hz	1/s
force	newton	N	$kg \cdot m/s^2$
pressure, stress	pascal	Pa	N/m^2
energy, work, quantity of heat	joule	J	N·m
power, radiant flux	watt	W	J/s
quantity of electricity, electrical charge	coulomb	C	A·s
electric potential, potential difference, electromotive force	volt	V	W/A
electrical capacitance	farad	F	C/V
electrical resistance	ohm	Ω	V/A
electrical conductance	siemens	S	A/V
magnetic flux	weber	Wb	V·s
magnetic flux density	tesla	T	Wb/m^2
inductance	henry	H	Wb/A
Celsius temperature	degree Celsius	°C	°K − 274.15
luminous flux	lumen	lm	cd·sr
illuminance	lux	lx	lm/m^2
activity (of a radionuclide)	becquerel	Bq	1/s
absorbed dose	gray	Gy	J/kg
dose equivalent	sievert	Sv	J/kg

Source: ASTM E 380-93, Table 3, p. 3.

Table N-3. SI prefixes

Multiplication factor	Prefix	Symbol
1 000 000 000 000 000 000 000 000 = 10^{24}	yotta	Y
1 000 000 000 000 000 000 000 = 10^{21}	zetta	Z
1 000 000 000 000 000 000 = 10^{18}	exa	E
1 000 000 000 000 000 = 10^{15}	peta	P
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
100 = 10^{2}	hecto[a]	h
10 = 10^{1}	deka[a]	da
0.1 = 10^{-1}	deci[a]	d
0.01 = 10^{-2}	centi[a]	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	μ
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p
0.000 000 000 000 001 = 10^{-15}	femto	f
0.000 000 000 000 000 001 = 10^{-18}	atto	a
0.000 000 000 000 000 000 001 = 10^{-21}	zepto	z
0.000 000 000 000 000 000 000 001 = 10^{-24}	yocto	y

[a]Use to be avoided where practical.

Source: ASTM E 380-93, Table 5, p. 4, and NRPB 155.

Table N-4. Conversion to SI units

To convert from	Into	Multiply by
	Angle	
degree	radian (rad)	1.745329 E−02
minute	radian (rad)	2.908882 E−04
second	radian (rad)	4.848137 E−06
	Area	
acre	square meter (m^2)	4.046873 E+03
ft^2	square meter (m^2)	9.290304 E−02
hectare	square meter (m^2)	1.000000 E+04
in^2	square meter (m^2)	6.451600 E−04
mi^2 (international)	square meter (m^2)	2.589988 E+06
mi^2 (U.S. statute)	square meter (m^2)	2.589998 E+06
yd^2	square meter (m^2)	8.361274 E−01
	Energy (includes work)	
British thermal unit (Int. table)	joule (J)	1.055056 E+03
British thermal unit (mean)	joule (J)	1.05587 E+03
calorie (International table)	joule (J)	4.186800 E+00
calorie (mean)	joule (J)	4.19002 E+00
electronvolt	joule (J)	1.60219 E−19
ft · lbf	joule (J)	1.355818 E+00
kW · h	joule (J)	3.600000 E+06
therm (European Community)	joule (J)	1.05506 E+08
therm (U.S.)	joule (J)	1.054804 E+08
ton (energy equivalent-TNT)	joule (J)	4.184 E+09
W · h	joule (J)	3.600000 E+03
W · s	joule (J)	1.000000 E+00
	Force per unit length	
lbf/ft	newton per meter (N/m)	1.459390 E+01
lbf/in	newton per meter (N/m)	1.751268 E+02
	Length	
foot	meter (m)	3.048000 E−01
inch	meter (m)	2.540000 E−02
mile (international nautical)	meter (m)	1.852000 E+03
mile (U.S. nautical)	meter (m)	1.852000 E+03
mile (international)	meter (m)	1.609344 E+03
mile (U.S. statute)	meter (m)	1.609347 E+03
yard	meter (m)	9.144000 E−01
	Mass	
gram	kilogram (kg)	1.000000 E−03
ounce (avoirdupois)	kilogram (kg)	2.834952 E−02
ounce (troy or apothecary)	kilogram (kg)	3.110348 E−02
pound (lb avoirdupois)	kilogram (kg)	4.535924 E−01
pound (troy or apothecary)	kilogram (kg)	3.732417 E−01
ton (long, 2240 lb)	kilogram (kg)	1.016047 E+03
ton (metric)	kilogram (kg)	1.000000 E+03
ton (short, 2000 lb)	kilogram (kg)	9.071847 E+02
tonne	kilogram (kg)	1.000000 E+03

Table N-4. Conversion to SI units (continued)

To convert from	Into	Multiply by
	Mass per unit area	
oz/ft²	kilogram per sq meter (kg/m²)	3.051517 E−01
lb/ft²	kilogram per sq meter (kg/m²)	4.882428 E+00
	Mass per unit length	
lb/ft	kilogram per meter (kg/m)	1.488164 E+00
lb/in	kilogram per meter (kg/m)	1.785797 E+01
lb/yd	kilogram per meter (kg/m)	4.960546 E−02
	Mass per unit volume (includes density and mass capacity)	
g/cm³	kilogram per cubic meter (kg/m³)	1.000000 E+03
oz (avoirdupois)/gal (U.K. liquid)	kilogram per cubic meter (kg/m³)	6.236023 E+00
oz (avoirdupois)/gal (U.S. liquid)	kilogram per cubic meter (kg/m³)	7.489152 E+00
lb/ft³	kilogram per cubic meter (kg/m³)	1.601846 E+01
lb/in³	kilogram per cubic meter (kg/m³)	2.767990 E+04
lb/gal (U.K. liquid)	kilogram per cubic meter (kg/m³)	9.977637 E+01
lb/gal (U.S. liquid)	kilogram per cubic meter (kg/m³)	1.198264 E+02
	Power	
Btu (International table)/h	watt (W)	2.930711 E−01
Btu (International table)/s	watt (W)	1.055056 E+03
erg/s	watt (W)	1.000000 E−07
	Pressure or stress (force per unit area)	
atmosphere, standard	pascal (Pa)	1.013250 E+05
atmosphere, technical	pascal (Pa)	9.806650 E+04
bar (meteorological atmos.)	pascal (Pa)	1.000000 E+05
foot of water (39.2°F)	pascal (Pa)	2.98898 E+03
psi	pascal (Pa)	6.894757 E+03
	Radiation units	
curie	becquerel (Bq)	3.700000 E+10
rad	gray (Gy)	1.000000 E−02
rem	sievert (Sv)	1.000000 E−02
roentgen	coulomb per kilogram (C/kg)	2.580000 E−04
	Temperature	
degree Celsius	kelvin (K)	$T_K = t_{°C} + 273.15$
degree Fahrenheit	degree Celsius (°C)	$t_{°C} = (t_{°F} - 32)/1.8$
degree Fahrenheit	kelvin (K)	$T_K = (t_{°F} + 459.67)/1.8$
degree Rankine	kelvin (K)	$T_K = T_{°R}/1.8$
kelvin	degree Celsius (°C)	$t_{°C} = T_K - 273.15$
	Time	
day	second (s)	8.640000 E+04
hour	second (s)	3.600000 E+03
minute	second (s)	6.000000 E+01
year (365 days)	second (s)	3.153600 E+07

Table N-4. Conversion to SI units (continued)

To convert from	Into	Multiply by
	Velocity (includes speed)	
ft/h	meter per second (m/s)	8.466667 E−05
ft/min	meter per second (m/s)	5.080000 E−03
ft/s	meter per second (m/s)	3.048000 E−01
in/s	meter per second (m/s)	2.540000 E−02
km/h	meter per second (m/s)	2.777778 E−01
knot (international)	meter per second (m/s)	5.144444 E−01
mi/h (international)	meter per second (m/s)	4.470400 E−01
mi/h (international)	kilometer per hour (km/h)	1.609344 E+00
rpm (r/min)	radian per second (rad/s)	1.047198 E−01
	Volume (includes capacity)	
acre-foot	cubic meter (m^3)	1.233489 E+03
bushel (U.S.)	cubic meter (m^3)	3.523907 E−02
ft^3	cubic meter (m^3)	2.831685 E−02
gallon (Canadian liquid)	cubic meter (m^3)	4.546090 E−03
gallon (U.K. liquid)	cubic meter (m^3)	4.546092 E−03
gallon (U.S. dry)	cubic meter (m^3)	4.404884 E−03
gallon (U.S. liquid)	cubic meter (m^3)	3.785412 E−03
in^3	cubic meter (m^3)	1.638706 E−05
liter	cubic meter (m^3)	1.000000 E−03
ounce (U.K. fluid)	cubic meter (m^3)	2.841306 E−05
ounce (U.S. fluid)	cubic meter (m^3)	2.957353 E−05
peck (U.S.)	cubic meter (m^3)	8.809768 E−03
pint (U.S. dry)	cubic meter (m^3)	5.506105 E−04
pint (U.S. liquid)	cubic meter (m^3)	4.731765 E−04
quart (U.S. dry)	cubic meter (m^3)	1.101221 E−03
quart (U.S. liquid)	cubic meter (m^3)	9.463529 E−04
yd^3	cubic meter (m^3)	7.645549 E−01
	Volume per unit time (includes flow)	
ft^3/min	cubic meter per second (m^3/s)	4.719474 E−04
ft^3/s	cubic meter per second (m^3/s)	2.831685 E−02
yd^3/min	cubic meter per second (m^3/s)	1.274258 E−02
gallon (U.S. liquid) per day	cubic meter per second (m^3/s)	4.381264 E−08
gallon (U.S. liquid) per minute	cubic meter per second (m^3/s)	6.309020 E−05

Source: ASTM E380-93, pp. 31-38.

Table N-5. Other conversion factors

To convert from	Into	Multiply by
centimeters	inches	0.39
feet	centimeters	30.48
feet	kilometers	3.05E−04
inches	centimeters	2.54
meters	centimeters	100.00
meters	feet	3.28
meters	miles (statute)	6.21E−04
meters per seconds	miles per hour	2.24
acres	square miles	1.562E−03
square centimeters	square inches	0.15
square feet	square centimeters	929.00
square feet	square meters	~11
square inches	square centimeters	6.45
square kilometers	square centimeters	1.0E10
square kilometers	square miles	0.39
square kilometers	square meters	10^6
cubic centimeters	milliliter	1.00
cubic centimeter water	gram	~1
cubic feet	gallons (U.S. liquid)	7.48
cubic feet	quarts (U.S. liquid)	29.92
cubic feet	pounds	62.4
gallons (U.S. liquid)	cubic centimeters	3785
gallons	cubic feet	0.13
gallons	liters	3.78
gallons of water[a]	pounds	8.33
gallons per minute	cubic feet per hour	8.02
liters	cubic centimeters	1,000.00
liters	cubic feet	0.035
liters	gallons (U.S. liquid)	0.26
cubic meters	liters	1,000
pounds of water (14.7 psi, 80°F)	cubic feet	0.016
pounds of water (14.7 psi, 80°F)	cubic inches	27.68
pounds of water (14.7 psi, 80°F)	gallons	0.12
quarts (liquid)	gallons	0.25
days	seconds	86,400.00
kilograms	pounds	2.20
tons (metric)	pounds	2,205.00
kilowatts	Btu per minute	56.92
kilowatt-hours	Btu	3,413.00
pounds per square inch	megapascals	145
pounds per square inch	pascals	~7000
degrees celsius	degrees farenheit	$t_{°F} = 1.8(t_{°C}) + 32$
becquerels	curies	2.7×10^{-11}
megabecquerels	millicuries	0.027
megabecquerels	microcuries	27
millicuries	megabecquerels	37
grays	rads	100
microsieverts (µSv)	millirem (mrem)	0.1
milligrays (mGy)	millirads (mrad)	100
millirads	milligrays	0.01
millirems	microsieverts	10
milliroentgens	microcoulombs/kilogram	0.258
microcoulombs/kilogram	milliroentgens	3.88
(rem/hour)/(curie/meter^2)	(millirem/year)/(microcurie/meter^2)	0.014
rem/curie	sievert/becquerel	3.7×10^{-12}

Table N-6. Number of hours to add or subtract when converting times[a]

From	To							
	UTC/Z	Atlantic	Eastern	Central	Mountain	Pacific	Alaska	Hawaiian-Aleutian
UTC/Z[b]	0	−4	−5	−6	−7	−8	−9	−10
Atlantic	+4	0	−1	−2	−3	−4	−5	−6
Eastern	+5	+1	0	−1	−2	−3	−4	−5
Central	+6	+2	+1	0	−1	−2	−3	−4
Mountain	+7	+3	+2	+1	0	−1	−2	−3
Pacific	+8	+4	+3	+2	+1	0	−1	−2
Alaska	+9	+5	+4	+3	+2	+1	0	−1
Hawaiian-Aleutian	+10	+6	+5	+4	+3	+2	+1	0

[a]Daylight saving time (DST) status must be same at both locations. To convert from UTC to DST in any zone, subtract one less hour than indicated (assuming DST is 1 h ahead of standard time). Add one less hour to convert local DST to UTC.

[b]Universal Time Coordinated (UTC) replaced Z or Greenwich Mean Time (GMT).

Fig. N-1
Equivalences (temperature, activity, and dose equivalent)

TEMPERATURE

celsius	fahrenheit
3000°C	5432°F
2500°C	4532°F
2000°C	3632°F
1500°C	2732°F
1000°C	1832°F
800°C	1472°F
600°C	1112°F
400°C	752°F
200°C	392°F
100°C	212°F
50°C	122°F
0°C	32°F
-17.8°C	0°F

ACTIVITY

curie	becquerel
1 pCi	37 MBq
27 pCi	1 Bq
1 nCi	37 Bq
27 nCi	1 kBq
1 μCi	37 kBq
27 μCi	1 Mbq
1 mCi	37 MBq
27 mCi	1 GBq
1 Ci	37 GBq
27 Ci	1 TBq
1 kCi	37 TBq
27 kCi	1 PBq
1 MCi	37 PBq

DOSE EQUIVALENT

rem	sievert
0.1 mrem	1 μSv
1 mrem	10 μSv
10 mrem	100 μSv
100 mrem	1 mSv
500 mrem	5 mSv
1 rem	10 mSv
5 rem	50 mSv
10 rem	100 mSv
25 rem	250 mSv
50 rem	500 mSv
100 rem	1 Sv
500 rem	5 mSv
1000 rem	10 Sv

SECTION O

PUTTING RADIATION IN PERSPECTIVE FOR THE PUBLIC

Section O
Quick Reference Guide

Section O
Putting Radiation in Perspective for the Public

Radiation Doses

Figure O-1 displays the effective dose equivalent associated with various activities, thresholds, and standards. Effective dose equivalents in the 0.1 mrem to 800,000 mrem (800 rem) range are included. Notes and sources for Fig. O-1 follow the figure.

Radiation Releases

Radioactivity (in curies) released during normal reactor operation is compared to releases during the Three Mile Island and Chernobyl accidents in Table O-1.

Table O-1. Radiation releases in perspective

Release	Noble gas[a] (Ci)	Iodine (Ci)	Particulate (Ci)
Average annual reactor release (1975-1979)	1,100	0.13	
Three Mile Island reactor release (1979)	2,500,000	15	
Chernobyl accident, USSR (April 1986)[b]	260,000,000	40,000,000	60,000,000

[a]Iodine and particulate releases pose a much greater risk to the public than noble gas releases.
[b]The estimates in the USSR reports and reports based on the USSR reports consider decay from April 26 to May 6 and thus exclude the short-lived fission products. The estimates shown here include the short-lived fission products expected to be released considering the power history of the plant.

Sources: (Aver. annual) UNSCEAR, (noble gases) p. 286, (iodine) p. 295, (particulates) p. 298 ; (Three Mile Island) Rogovin (1980), p. 344; (Chernobyl) USSR, Appendix 4, p. 21.

Fig. O-1
Radiation doses in perspective.

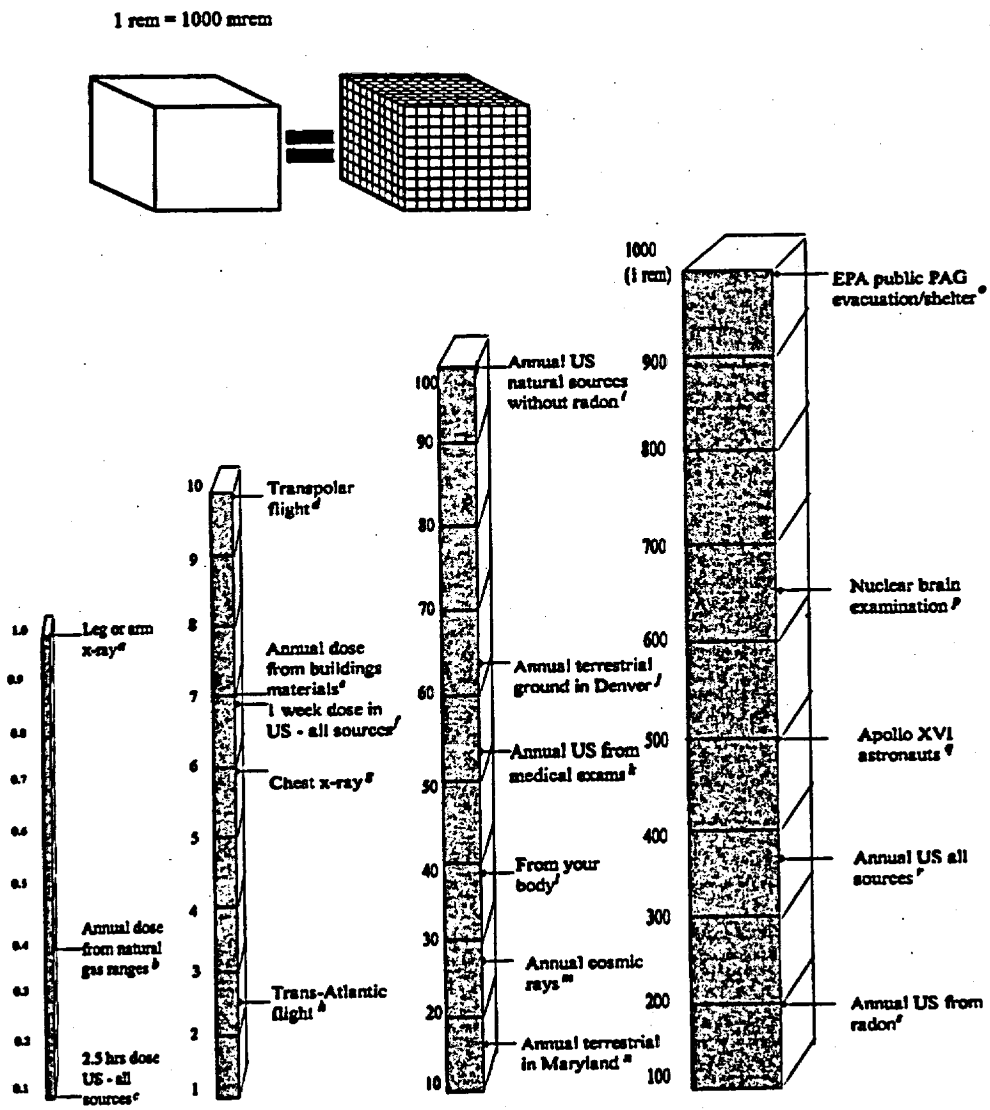
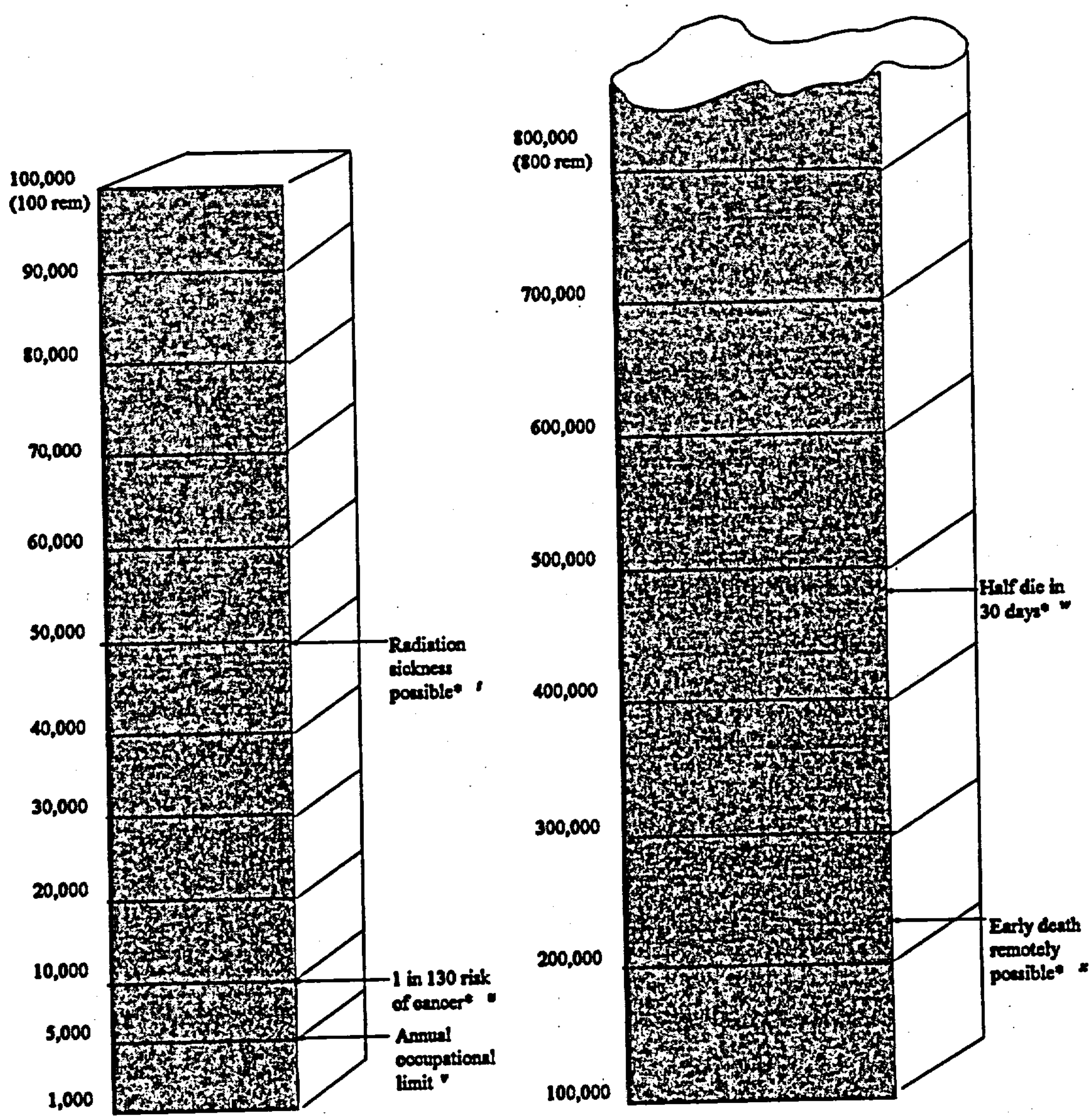


Fig. O-1
Radiation doses in perspective (continued).



* Doses received over a short time period (hours - days) at high dose rates (acute doses)

Notes for Fig. O-1.

[a]Average effective dose equivalent per diagnostic medical X-ray of extremity in 1980. *Source:* NCRP 93, p. 45.

[b]Average annual effective dose equivalent to exposed population. Average annual effective dose equivalent in U.S. population is 0.2 mrem. *Source:* NCRP 93, p. 31.

[c]Average effective dose equivalent in U.S. population in 2.5 h, derived from average annual effective dose equivalent of 360 mrem. *Source:* NCRP 93, p. 53.

[d]Calculated dose equivalent resulting from cosmic radiation during a 10-h polar flight from California to Europe. *Source:* NCRP 94, p. 21.

[e]Average annual dose equivalent to exposed population from building materials. Average annual effective dose equivalent in U.S. population is 3.6 mrem. *Source:* NCRP 93, p. 31.

[f]Average effective dose equivalent in U.S. population in 1 week, derived from average annual effective dose equivalent of 360 mrem. *Source:* NCRP 93, p. 53.

[g]Average effective dose equivalent per diagnostic medical chest X-ray in 1980. *Source:* NCRP 93, p. 45.

[h]Calculated dose equivalent due to cosmic rays from transcontinental or transatlantic flight of 5 h at 12 km altitude and mid-latitudes. *Source:* NCRP 94, p. 21.

[i]Average annual effective dose equivalent in U.S. population from natural sources, excluding radon (circa 1980-1982). *Source:* NCRP 93, p. 53.

[j]Average annual dose equivalent in Denver area from terrestrial sources. *Source:* NCRP 94, p. 89.

[k]Average annual effective dose equivalent in the U.S. population from medical examinations. Value

[r]Average annual effective dose equivalent from all sources in U.S. population (circa 1980-1982). *Source:* NCRP 93, p. 53.

[s]Average annual effective dose equivalent in U.S. population as a result of natural radon (circa 1980-1982). *Source:* NCRP 93, p. 53.

[t]Estimated threshold dose equivalent to produce vomiting after total body irradiation for brief period of time (dose rate ≥ 6 rad/h). *Source:* NUREG/CR-4214, Rev. 1, Part II, p. II-21.

[u]An instantaneous dose of 10 rad to all body organs for an average population of 100,000 men is estimated to result in an average of 770 cancers. There would be about 15,000 cancers normally expected from other causes in this group of men. The same dose is estimated to result in an average of 810 cancers in an average population of 100,000 women. There would be about 18,000 cancers from other causes normally expected in this group. [Normal cancer estimates from *Health Physics* 63(3), September 1992, p. 279.] *Source:* BEIR V, p. 172.

[v]10 CFR 20.1201.

[w]Calculated mean lethal bone marrow dose equivalent for 50% mortality for brief exposure (dose rate ≥ 100 rad/h) with supportive medical treatment. *Source:* NUREG/CR-4214, Rev. 1, Part II, p. II-39.

[x]Calculated mean threshold lethal bone marrow dose equivalent for brief exposure (dose rate ≥ 1,000 rad/h) with supportive medical treatment. *Source:* NUREG/CR-4214, Rev. 1, Part II, p. II-39.

P

SECTION P

SUMMARY OF ASSUMPTIONS

Section P
Quick Reference Guide

Section P
Assumptions

Introduction

This section describes the assumptions used in the methods in Sections A–K. Most of this information is also found in the text or footnotes, but this section compiles and summarizes the information.

Section A: Core Damage Consequence Assessment

Method A.1: Evaluation of Water Injection. Figures A-1 and A-2 show the amount of water that must be injected to remove decay heat by boiling. The curves are based on a 3000-MW(t) nuclear power plant that has been operated at constant power and then shut down instantaneously. Decay heat data are based on ANSI/ANS-5.1. If the injected water is about 80°F (27°C), the curves are within 5% for pressures 14–2500 psia (0.1–17.2 MPa). The curves are valid within 20% for injected water temperatures up to 212°F (100°C).

Method A.2: Evaluate Sub-Cooling Margin (Saturation Table). Evaluation of whether water in core is boiling using the sub-cooling margin is appropriate only in PWRs.

Method A.3: Evaluate Core Once Uncovered. Estimation of LWR core temperature is based on the assumption that the fuel in the core will heat up at 1–2°F/s (0.5–1.0°C/s) immediately after the top of an active core of a PWR is uncovered or 5–10 min after the top of an active core of a BWR is uncovered. These fuel heatup estimates are reasonable within a factor of two if the core is uncovered within a few hours of shutdown (including failure to scram) for a boil-down case (without injection).

Method A.4: Evaluate Containment Radiation. Figures A-5 through A-12 provide probable maximum readings for the containment monitors assuming

- prompt release of all the fission products in the coolant, spike, gap, or from in-vessel core melt;
- uniform mixing in the containment; and
- an unshielded monitor that can "see" most of the area shown in Fig. A-3 or A-4.

Because the mix is most likely different from that assumed in the calibration of the monitor, the actual reading at the upper end of the scale could differ by a factor of 10–100 if a shielded detector is used for the higher radiation measurements.

The action of the emergency core cooling system sprays can affect the reading on the monitors. If the sprays were on for 1–2 h, the particulates and aerosols in the containment will be washed down where the monitors cannot see them. If the sprays were off, some of the material will plateout inside containment. Although the material that plates out is not available for release, it may be seen by the monitor and result in higher readings.

The levels of damage indicated on the charts should be considered minimum levels unless there are inconsistent monitor readings. Inconsistent readings may be caused by uneven mixing in containment [e.g., steam rising to top of dome, not enough time for uniform mixing to occur (it may take hours)]. The calculations were performed using CONDOS II (NUREG/CR-2068).

Method A.5: Evaluate Coolant Concentrations. This evaluation of fission products in the coolant assumes that

- releases from the core are uniformly mixed in the coolant and
- there is no dilution from injection.

The baseline coolant concentrations are for 0.5 h after shutdown of a core that has been through at least one refueling cycle.

For a BWR, it is assumed that the release from the core is uniformly mixed in the reactor coolant system and suppression pool. If most of the core release is confined to the reactor coolant system, the concentrations in the coolant could be up to 10 times higher.

Method A.6: Evaluate Containment Hydrogen. This method uses hydrogen percentages in wet samples. If a dry (steam removed) sample concentration is used, this method may overestimate considerably the level of core damage.

This method assumes that all hydrogen is released to the containment and is completely mixed in the containment atmosphere. The curves are a function of containment size. The results of severe accident research (research supporting NUREG-1150) were examined to identify the *least* percentage of metal-water reaction associated with each core damage state. Higher percentages of metal-water reaction are possible for some accident sequences.

Section B: Classification Assessment

Method B.2: NUREG-0654 Full Guidance. Use of this method requires the assessor to have a thorough knowledge of NUREG-0654.

Section C: Reactor Accident Consequence Assessment Based on Plant Conditions

These calculations consider only the plant, release, and atmospheric conditions that have a major (greater than a factor of 10) impact on dose.

Core Conditions. Four different core conditions can be assumed. These conditions span the entire range of possible core damage states. The amount of fission products assumed to be released is approximately the mean value calculated for a range of core damage accidents. Assumed core release fractions are shown in Table C-4.

- Leakage of normal coolant following a steam generator tube rupture (SGTR) accident that does not involve core damage. Normal coolant concentrations in Tables C-2 and C-3 are based on an ANSI standard.

- Leakage of spiked coolant following an SGTR accident that does not involve core damage. Spiked coolant assumes all the non-nobles in the normal coolant increase by a factor of 100 to estimate the maximum spiking sometimes seen with rapid shutdown or depressurization of the primary system.

- A gap release assumes that the core is damaged and all fuel pins have failed, releasing the gaseous fission products contained in the fuel pin gap.

- An in-vessel core melt release assumes that the entire core has melted, releasing a mixture of isotopes believed to be representative for most core melt accidents.

Release Pathways and Conditions. Six simplified release pathways and conditions are used for two PWR containments and three BWR containments. For each containment release pathway, the mechanisms that will substantially reduce the release are considered (e.g., containment sprays). The effectiveness of the reduction mechanism used is representative for a range of assumptions. The reduction factors assumed for each reduction mechanism are listed in Table C-5. Case-specific assumptions about reduction mechanisms are located in the notes to each event tree.

- A PWR dry containment release assumes a release into the containment which leaks to the atmosphere. The effectiveness of sprays or natural processes (plate-out) can be considered.

- A BWR drywell containment release assumes a release into the containment which leaks to the atmosphere. The effectiveness of sprays or natural processes (plateout) can be considered. The majority of the release bypasses the suppression pool. In this containment, the amount of released material may be reduced if it passes through the standby gas treatment system filters.

- A PWR ice condenser containment release assumes either a single pass through the ice (because of fan failure or major containment failure) or recirculation through the ice. Credit for sprays and natural processes can also be taken. If the ice is depleted before core damage occurs, then the PWR dry containment release pathway should be used.

- A BWR wetwell containment release assumes a release through the suppression pool. If the release bypasses the suppression pool, then the BWR drywell release pathway should be used. Credit may be taken for a release through the standby gas treatment system filters.

- A PWR SGTR release assumes contaminated coolant leaks through the rupture. Steam generator partitioning can be considered as a reduction mechanism. The effectiveness of the condenser may also be considered for releases out of the steam-jet air ejector. If the primary system is dry, then the containment bypass release pathway should be used.

- A PWR/BWR containment bypass release assumes a release through a dry pathway from the primary system out of the containment. Only plateout on pipes and filtering (if established) in the release pathway can be considered.

Release Rates.The assumed release rates and resulting escape fractions are listed in Table C-6. Containment leakage rates include

- catastrophic failure (100%/h),

- failure to isolate containment (100%/day), and

- design leakage (0.5%/day).

The SGTR leakage rates used are

- failure of one tube at full pressure (500 gal/min) and

- failure of one tube at low-pressure with coolant being pushed out of the break by one charging pump (50 gal/min).

Source Term. The method for calculating the source term is summarized on p. C-13. Release reduction mechanisms are included in the calculation. NUREG-1228 contains a full description of the method. Source term assumptions in RASCAL are discussed in Appendix C of *RASCAL Version 2.1 User's Guide*, NUREG/CR-5247.

Dose Calculation. Doses at 1 mile are calculated with RASCAL 2.1 with the following assumptions:

- a ground-level release of 1-h duration,
- building wake, and
- average meteorological conditions (4 mph or 1.8 m/s, no rain, and D stability).

Transport and diffusion assumptions in the RASCAL code are discussed in Appendix D of NUREG/CR-5247.

Doses are a best estimate of the maximum total acute bone marrow dose and maximum thyroid dose (plume center line) to an individual who stayed unsheltered and unprotected at a point along the centerline of the plume for 24 h. External dose factors are from EPA-402-R-93-081. Inhalation dose factors are from NRPB-R162 and WASH-1400. Dose factors used in RASCAL are found in Appendix K of NUREG/CR-5247.

- Total acute bone dose includes 1 h of cloudshine (external exposure from immersion in passing radioactive plume), acute inhalation dose (30-day dose commitment), and 24 h of groundshine (external exposure to deposited radioactive material). Radioactive decay and in-growth are included.
- Thyroid doses are for adults from inhalation of the passing plume only.

The dose estimates should be within a factor of 10–100 *if* the plant, release height, and rain conditions are accurately represented.

Section D: Fuel Pool Damage and Consequence Assessment

These calculations consider only the fuel conditions, release, and atmospheric conditions that have a major (greater than a factor of 10) impact on dose.

Two types of damage from overheating of fuel resulting from loss of coolant in the spent fuel pool were assumed:

- Zircaloy cladding fire in recently discharged fuel and

- cladding failure with release of the fission products in the fuel pin gap (gap release). This may occur from <2 h to several days after the pool is drained. The pin is assumed to heat up before failure, releasing about 5% of the volatile fission products.

Dose Calculation. Doses at 1 mile are calculated with RASCAL 2.1 using the following assumptions:

- a ground-level release of 1-h duration,

- building wake, and

- average meteorological conditions (4 mph, no rain, and D stability).

Doses are a best estimate of the maximum total acute bone marrow dose and maximum thyroid dose to an individual who stayed unsheltered at a point along the centerline of the plume for 24 h. External dose factors are from EPA-402-R-93-081. Inhalation dose factors are from NRPB-R162 and WASH-1400. A discussion of the dose factors used in RASCAL is found in Appendix K of *RASCAL Version 2.1 User's Guide*, NUREG/CR-5247.

- Total acute bone dose includes 1 h of cloudshine (external exposure to passing radioactive plume), acute inhalation dose (30-day dose commitment), and 24 h of groundshine (external exposure to deposited radioactive material). Radioactive decay and in-growth is included.

- Thyroid doses are for adults from inhalation of the passing plume only.

The dose estimates should be within a factor of 10–100 *if* the spent fuel pool and rain conditions are accurately represented.

Section E: Uranium Hexafluoride Release Assessment

The values shown in Fig. E-1 were calculated using the default assumptions described below under Method E.1.

Method E.1: Estimation of Inhaled Soluble Uranium Intake and Hydrogen Fluoride Concentration After a Liquid UF_6 Release. The estimations in this method use the following default assumptions:

- use of a Gaussian atmospheric dispersion model for the airborne fraction;

- average meteorological conditions (D stability, 4 mph or 1.8 m/s wind speed, and no rain);

- release fractions (percentage of liquid UF_6 by weight that becomes airborne as soluble uranium or HF) of 0.34 for soluble uranium and 0.12 for HF (NUREG-1140, pp. 32, 35);
- release time (duration) of 15 min (900 s) (NUREG-1140, p. 35); and
- breathing rate of 3.3×10^{-4} m^3/s, equivalent to adult light activity (EPA-520/1-88-020, p. 10).

Method E.2: Calculation of Inhaled Soluble Uranium Intake and Hydrogen Fluoride Concentration After a UF_6 Release. A Gaussian plume model is assumed to approximate the distribution of the airborne fraction downwind. If gaseous UF_6 is released, then the assumption that 100% of the UF_6 becomes airborne and is incorporated in the plume is appropriate for the purposes of performing a rough bounding calculation. Under this assumption, the release fractions would be 0.68 for uranium and 0.23 for HF.

Method E.3: Estimation of Committed Effective Dose Equivalent Resulting From Inhaled Uranium After a Liquid UF_6. The default assumptions for Method E.1 were also used in this calculation to find the intake of soluble uranium. The specific activity used for each enrichment is given in Table E-5. The specific activity of enriched uranium may depend somewhat on the history of the material and the method of enrichment. The dose conversion factor for ^{234}U (2.7 rem/μCi) was used to give a conservative dose for the mixture.

Method E.4: Calculation of Committed Effective Dose Equivalent Resulting From Inhaled Uranium After a UF_6 Release. The assumptions used in Method E.2 were used in the calculation of the intake of soluble uranium. ^{234}U is the major contributor to specific activity of enriched UF_6. The specific activity of enriched uranium may depend somewhat on the history of the material and the method of enrichment. If a specific activity cannot be obtained, using the specific activity for ^{234}U (6.19×10^3 μCi/g) will provide an overestimate of the committed effective dose equivalent (CEDE). The dose conversion factor given for ^{234}U is used to approximate that for all isotopic mixes.

Section F: Early Phase Dose Projections

The early phase of an accident extends from the identification of a release threat until the release (or threat of the release) has ended and any areas of major contamination have been identified. The early phase normally includes up to 4 days (100 h) of exposure to deposition

Method F.1: Calculation of Activity Based On Mass. Specific activities of isotopes are in Table F-1. In this table, the specific activity of natural and depleted uranium is based on 10 CFR 20 App. B, confirmed by calculations. For enriched uranium, the is specific activity of the material is dominated by the concentration of ^{234}U because the ^{234}U concentration increases with ^{235}U enrichment and ^{234}U has a relatively high specific activity. The ^{234}U concentration relative to the ^{235}U enrichment is assumed to be 4% enrichment, 0.032% ^{234}U; 20% enrichment, 0.15% ^{234}U; and 93% enrichment, 2% ^{234}U.

Method F.2: Estimation of Activity Released by a Fire. Filtering, plateout, or other mechanisms that can reduce the release of non-nobles are *not* considered in this calculation; this method should provide a reasonable upper bound for most accidents involving radioactive material. This method is *not* valid for reactor accidents.

Method F.3: Downwind Dose Projection Based on Estimated Activity Released. Estimates and calculations in this method assume a Gaussian atmospheric dispersion model.

Dilution factors (Table F-10) are on the center line of ground-level release with a vertical dispersion limit of 1000 m; dilution factors at 0.25 mile are assumed to be dominated by building wake and are constant across all Pasquill turbulence types.

Ground concentration factors used in calculating deposition (Table F-11) were based on RASCAL calculations and include building wake. D stability was assumed. The average deposition velocity was 0.3 cm/s.

The total doses using either the quick estimate or full calculational method are assumed to be calculated as follows:

- The total acute bone dose is assumed to be the sum of the contribution of each isotope to the air immersion effective dose equivalent, the dose from 4 days exposure to deposition (including inhalation of resuspended materials), and the inhalation committed dose equivalent to the bone.

- The total acute lung dose is assumed to be the sum of the contribution of each isotope to the air immersion effective dose equivalent, the dose from 4 days exposure to deposition (including inhalation of resuspended materials), and the inhalation committed dose equivalent to the lung.

- The total effective dose equivalent is assumed to be the sum of the contribution of each isotope to the air immersion effective dose equivalent, the dose from 4 days exposure to deposition (including inhalation of resuspended materials), and the inhalation committed effective dose equivalent (CEDE).

- The thyroid dose is the committed dose equivalent to the thyroid from inhalation of the plume.

Quick estimate method. Precalculated doses from a 1-μCi release (release conversion factors) are provided for a variety of isotopes at distances of 0.25 (Table F.4) and 1 mile (Table F.5). Initial calculations can be adjusted to consider an elevated release and rain (Method F.5). The dose projections should be within a factor of 10 for a reasonable range of stability classes and wind speeds. Calculation of the release conversion factors is illustrated in the notes following Tables F-4 and F-5.

The following assumptions were used in calculating the release conversion factors:

- ground level release.
- average meteorological conditions (D stability, 4 mph or 1.8 m/s wind speed, and no rain).
- dose calculation is maximized by assuming the exposed individual remains unsheltered and unprotected at the centerline of plume pathway for the plume passage and remainder of 4-days (100 h).
- inhalation dose contribution
  - acute bone marrow and acute lung doses are from inhalation of 1-μm activity mean aerodynamic diameter aerosol with a 30-day dose commitment;
  - CEDE and thyroid dose equivalent are 50-year dose commitment using dose conversion factors from EPA-520/1-88-020;
  - inhalation doses include contributions from daughter isotopes;
  - breathing rate is for an adult performing light activity as recommended by EPA-520/1-88-020, p. 10 (breathing rate = 3.3×10^{-4} m^3/s);
  - the lung clearance class giving the highest dose was used, except for UF_6, where the D clearance class for soluble uranium was used; and
  - CEDE from inhalation of tritium was doubled to account for skin absorption.
- cloudshine dose contribution
  - air immersion dose equivalent is for a semi-infinite cloud, maximizing the dose from cloudshine; and
  - contributions from daughter isotopes are included in external doses only where noted in the tables.

- ground exposure dose contribution
  - daughters are included in external doses only where noted in the tables;
  - groundshine dose contribution includes external dose equivalent from groundshine for 4 days (1 m above ground level) and CEDE from resuspension ($R_t = 10^{-6}$, appropriate for non-arid areas) from remaining on contaminated ground for 4 days;
  - ground concentration factors (Table F-11) were 3.9×10^{-8} m^{-2} for 0.25 mile and 2.1×10^{-8} m^{-2} for 1 mile; and
  - the groundshine doses were corrected for ground roughness (ground roughness correction factor = 0.7).
- for natural and depleted uranium, it is assumed all the release is ^{238}U, and for enriched uranium it is assumed all the release is ^{234}U.

Full Calculation Method. The doses are calculated using dose conversion factors in Tables F-6 and F-7. Table F-6 also contains an exposure conversion factor to approximate a radiation meter reading at 1 m above the ground. The following assumptions were used in calculating the dose conversion factors (these calculations are shown in the notes following Tables F-6 and F-7):

- ground level release.
- no rain.
- dose calculation is maximized by assuming the exposed individual remains unsheltered and unprotected at the centerline of plume pathway for the plume passage and remainder of 4-days (100 h).
- inhalation dose contribution
  - acute bone marrow and acute lung doses are from inhalation of 1 μm activity mean aerodynamic diameter aerosol with a 30-day dose commitment
  - CEDE and thyroid dose are 50-year dose commitment using dose conversion factors from EPA-520/1-88-020;
  - inhalation doses include contributions from daughter isotopes;

  - inhalation dose conversion factors (Table F-7) provide mrem acquired from 1 h of breathing an air concentration of 1 $\mu Ci/m^3$ at a breathing rate of 1.2 m^3/h or 3.3 × 10^{-4} m^3/s (breathing rate for an adult performing light activity as recommended by EPA-520/1-88-020, p. 10);

  - the lung clearance class giving the highest dose was used, except for UF_6, where the D clearance class for soluble uranium was used; and

  - CEDE dose conversion factor for tritium was doubled to account for skin absorption.

- cloudshine dose contribution

  - daughters are included only where noted in the tables; and

  - assumes immersion in a semi-infinite cloud, maximizing the dose from cloudshine.

- ground exposure dose contribution

  - daughters are included only where noted in the tables;

  - ground exposure includes external dose equivalent from groundshine for 4 days and CEDE from resuspension from remaining on contaminated ground for 4 days;

  - two values are assumed for the resuspension factor, $R_s = 10^{-6}$ for non-arid areas and $R_s = 10^{-4}$ for arid areas;

  - groundshine doses were corrected for ground roughness (ground roughness correction factor = 0.7); and

  - external exposure rate is 1.4 times the effective dose equivalent rate from deposition.

- for natural and depleted uranium, it is assumed all the release is ^{238}U, and for enriched uranium it is assumed all the release is ^{234}U.

Method F.4: Estimation of Dose and Exposure Rate from Point Source. Dose rate and exposure rate conversion factors have been calculated using CONDOS II for various isotopes at 1 m from a point source (Table F-6). For natural and depleted uranium it is assumed all the material is ^{238}U, and for enriched uranium it is assumed all the material is ^{234}U.

The conversion factors assume no shielding. The calculations do not include build-up, so if shielding is added to the calculation, the result should be considered the *lower bound*. Half-value layers in Table F-13 are for "good geometry" where build-up is not important.

Method F.5: Adjusting 1-Mile Dose to Consider Distance, Elevation and Rain. This method requires an estimate of the total acute bone dose or inhalation thyroid dose at 1 mile from a ground-level release under average meteorological conditions (D stability, 4 mph wind speed, and no rain). Doses should be for the distances the plume has traveled, not the distance from the release source. The estimates assume a constant wind direction and should represent the maximum dose within a factor of 10 for a range of stability classes and wind speeds.

Total acute bone doses used as input should represent dose equivalent from cloudshine and acute dose equivalent from inhalation and approximately 24 h of the resulting groundshine to an adult performing normal activities with no sheltering (these are the assumptions used in Sections C and D and Method F.3). The thyroid dose should be from inhalation of the plume alone.

A ground-level release should be used unless the release is from an isolated stack more than 2.5 times higher than nearby structures or if observation indicates that it has an effective release height of 200 m or more. The elevated release case is assumed here to be 200 m or one-half of the typical nighttime mixing level.

Method F.6: Quick Long-Range Estimation. The usefulness of this method is limited. The method assumes a simple Gaussian model for an instantaneous release. There can be large variations in the estimate if the height of release is incorrect. These calculations assume a non-depositing material. With a non-depositing material, ground-level estimates will always be the more conservative and should be used.

The estimates from Fig. F-3 are much more appropriate at longer downwind distances, when the spreading of the material is comparable to the 24-h sampling time that was used to verify this approach. At plume travel times less than 1 day, the average dispersion parameters that were used are difficult to justify.

The calculations in this method assume an average elevated release to be about 1500 m above ground. Normal stack emissions are to be considered as ground-level releases.

The estimate of the maximum deposition assumes that all the material in the air is removed at that time. It is assumed that all the airborne material is available for ground deposit at each downwind time. Fractional removal requires subsequent deposition and air concentrations to be adjusted accordingly.

Section G: Early Phase Protective Action Assessment

For dose projection purposes, the early phase is assumed to last for 4 days (100 h). Doses normally include contributions from the airborne plume and from 4 days exposure to material deposited on the ground.

Section H: Intermediate Phase Protective Action Assessment

For dose projection purposes, the intermediate phase is assumed to last for 1 year.

The *FRMAC Assessment Manual* and RASCAL can be used to evaluate the projected doses needed for assessment.

Section I: Ingestion Pathway Protective Action Assessment

The HHS Protective Action Guides apply to short-term exposure from consumption of contaminated food and milk. These guides are assumed to apply to water, for which there is no guidance.

The *FRMAC Assessment Manual* can be used to evaluate the areas in which the radiological contamination levels in food need to be evaluated and to analyze food, water, and milk samples.

Section J: Use of Potassium Iodide and Thyroid Monitoring

The minimum detectable dose commitment calculated from Table J-1 assumes that all the radioiodine has reached the thyroid.

Section K: Extraordinary Nuclear Occurrence

Projected doses required for an extraordinary nuclear occurrence (Table K-1) include radiation doses from external sources as well as from radioactive material that has been taken into the body (e.g., ingestion or inhalation).

Surface contamination levels required for an extraordinary nuclear occurrence (Table K-1) are maximum levels (observed or projected) above background 8 h or more after initial deposition. Beta or gamma dose rates must be measured through no more than 7 mg/cm^2 of total absorber.

Q

SECTION Q

GLOSSARY

GLOSSARY

Absolute pressure. The total pressure of a gas system measured with respect to zero pressure.

Absorbed dose. A measure of energy deposition in any medium by all types of ionizing radiation (unit is usually rad or gray).

Activity. The number of nuclear disintegrations occurring in a given quantity of material per unit time. Becquerel and curie are the usual units for expressing activity.

Acute dose/dose equivalent. Radiation dose/dose equivalent received over a short period of time (hours-weeks), as opposed to a chronic dose.

Advisory Team for Environment, Food, and Health. A multi-agency team formed during a response to assist the NRC in preparing coordinated Federal recommendations on protective actions. The Advisory Team contains, at a minimum, representation from EPA, HHS, and USDA.

Aerosol. The suspension of very fine particles of a solid or droplets of a liquid in a gaseous medium.

Alert. The third most serious of the four NRC emergency classes. Classification as an "Alert" indicates that events are in progress or have occurred which involve an actual or potential substantial degradation of the level of safety of the plant. Any releases are expected to be limited to small fractions of the EPA Protective Action Guide exposure levels.

Alpha decay. A form of radioactive decay in which an alpha particle is emitted from the nucleus of an atom with atomic number Z and atomic mass A, leaving a daughter atom with atomic number $Z-2$ and mass number $A-4$.

Alpha particle (α). A particle consisting of two protons and two neutrons (a ^4He nucleus) emitted from the nucleus of an atom.

Alternating current (AC). An electric current that reverses direction in a circuit at regular intervals (e.g., normal household electrical service in U.S.). Alternating current is necessary to run such reactor components of the emergency core cooling system such as pumps and motor-operated valves.

Antineutrino ($\bar{\nu}$). A weakly interacting particle, with no rest mass and no charge, emitted along with an electron in β^- decay. An antineutrino is the antiparticle to the neutrino.

Atmospheric boundary layer. The lowest part of the earth's atmosphere in which considerable mixing occurs, extending from the earth's atmosphere to about 1 km (also called the mixing layer).

Atom. The smallest amount of an element retaining the characteristics of that element.

Atomic mass number (A). The sum of the number of protons plus the number of neutrons in the atom.

Atomic number (Z). The number of protons in an atom. The number of protons defines the chemical properties of the element and thus defines the element.

Atto (a). SI prefix corresponding to multiplication by 10^{-18}.

Automatic depressurization system. A system for rapidly relieving primary system pressure by dumping steam to the suppression pool in a boiling water reactor containment.

Background (radiation). Ionizing radiation normally present in the region of interest and coming from sources other than that of primary concern.

Basemat. The concrete base under the reactor containment structure.

Batch. Portion of nuclear material handled as a unit for accounting purposes. A batch of reactor fuel is usually one-third of the reactor fuel in the core, the amount typically used during refueling.

Beta decay. A family of radioactive decay processes including β^- decay, β^+ decay, and electron capture.

β^- decay. One of the beta decay processes in which an electron and an antineutrino are emitted from the nucleus as a result of the transformation of a neutron into a proton. The atomic number Z increases by one, while the mass number A remains the same.

β^+ decay. One of the beta decay processes in which a positron and a neutrino are emitted from the nucleus as a result of the transformation of a proton into a neutron. The atomic number Z decreases by one, while the mass number A remains the same.

Beta particle (β). An electron or positron emitted from the nucleus during beta decay.

Beta skin dose. Radiation dose to the skin from beta-emitters, usually from contamination on the surface of the skin or on clothing.

Boiling water reactor (BWR). A light-water reactor in which water, used as both coolant and moderator, and allowed to boil under pressure in the core to steam, which drives the turbine directly.

Bone marrow. Soft material that fills the cavity in most bones; it manufactures most of the formed elements of the blood.

British Thermal Unit (BTU). The amount of heat required to raise the temperature of 1 lb of water by 1°F.

Building wake. Distortions in the wind patterns which are caused by a building. This effect, which is most pronounced immediately downwind of a building, alters the distribution of material within an atmospheric plume released from a source at or near the building.

BWR containment drywell release. See *drywell release*.

BWR containment wetwell release. See *wetwell release*.

BWR/PWR containment bypass release. See *containment bypass release*.

Catastrophic failure. Failure of the reactor containment in a manner that releases most of the fission products in the containment into the environment in a short time.

Centerline (plume). An imaginary line drawn in the middle of the plume along its downwind travel direction with a straight-line Gaussian approximation model. The plume concentrations and deposition are assumed to be the highest along the centerline.

Centi (c). SI prefix corresponding to multiplication by 10^{-2}.

Chemical toxicity. The degree to which a material is poisonous or harmful because of its chemical nature (not because of radioactivity).

Chronic dose. Radiation dose received over a long period of time (years).

Cladding. The outer coating (usually zirconium alloy, aluminum, or stainless steel) which covers the nuclear fuel elements to prevent corrosion of the fuel and the release of fission products into the coolant.

Cloudshine. Gamma radiation from the radioactive materials in an airborne plume. In this document, the dose from cloudshine is the dose from immersion in the plume, assumed to be a semi-infinite cloud.

Coherent system of units. A system of units of measurement in which a small number of base units, defined as dimensionally independent, are used to derive all other units in the system by rules of multiplication and division with no numerical factors other than unity.

Cold leg. In a pressurized water reactor, the part of the reactor coolant system from the exit of the steam generator to the reactor vessel; in a boiling water reactor, the reactor coolant system from the feedwater containment penetration to the reactor vessel.

Combustion. A rapid chemical reaction accompanied by the evolution of light and the rapid production of heat.

Committed dose. The radiation dose resulting from radionuclides in the body over a time period following their inhalation or ingestion.

Committed dose equivalent. The total dose equivalent (averaged over a particular tissue) deposited over a time period following the intake of a radionuclide.

Committed effective dose equivalent (CEDE). The effective dose equivalent resulting from radionuclides in the body over a time period (50 years in this document) following their inhalation or ingestion.

Compound. Two or more elements chemically linked in definite proportions.

Condenser. A large heat exchanger designed to cool exhaust steam from a turbine so that it can be returned to the heat source as water. In a pressurized water reactor, the water is returned to the steam generator. In a boiling water reactor, it returns to the reactor vessel. The heat removed from the system by the condenser is transferred to a circulating water system and is exhausted to the environment, either through a cooling tower or directly into a body of water.

CONDOS II. A computer program used to compute doses from consumer products. It computes doses from radioactive objects of various geometries, including the effects of up to five layers of different shielding materials.

Containment. A gas-tight shell or other enclosure around a reactor to confine fission products that otherwise might be released to the environment.

Containment bypass release. A release from a boiling water reactor or pressurized water reactor through a dry pathway from the primary system to the outside of the containment.

Containment spray. The water system inside containment used to relieve pressure and temperature buildup by steam released (loss of coolant accident, main steam line rupture, or feedwater line rupture) in the containment structure.

Coolant. The medium, often water, used to remove heat from the reactor core to the heat sink.

Core. See *reactor core.*

Core release fraction. The fraction of each isotope in the core inventory that is assumed to be released from the core under given core conditions.

Criticality (critical). A condition in which the number of neutrons release by fission is exactly balanced by the neutrons being absorbed (by the fuel and poisons) and escaping the reactor core. A reactor is said to be "critical" when it achieves a self-sustaining nuclear chain reaction.

Critical organ. For a specific radionuclide, solubility class, and mode of intake, the organ that limited the maximum permissible concentration in air or water.

Critical pressure. The pressure of a substance at its critical temperature.

Critical safety function. Functions that must be performed during normal reactor operations and following an accident to protect the integrity of the fission product barriers and prevent the release of radioactive materials into the environment.

Critical temperature. The temperature above which a substance has no transition from the liquid to the gaseous phase; i.e., the highest pressure at which the gas can be liquified regardless of the pressure applied.

Curie (Ci). A unit of radioactivity equal to 3.7×10^{10} disintegrations per second.

Daughter isotope. Isotopes that are formed by the radioactive decay of some other isotope.

Daughter, radioactive. A radioactive isotope formed by radioactive decay.

Daylight Saving Time (DST). Time during which clocks are set ahead of standard time (usually by 1 h) to provide more daylight at the end of the working day during the late spring, summer, and early fall.

Decay, radioactive. See *radioactive decay*.

Decay heat. The heat produced by the decay of radioactive fission products after the reactor has been shut down or in spent fuel that has been removed from the reactor.

DECAY model. One of the tools in the RASCAL software that allows the user to compute the activities of radionuclides at a given time, allowing for radioactive decay and ingrowth.

Decay product(s). A radionuclide or a series of radionuclides formed by the nuclear transformation of another radionuclide which, in this context, is referred to as the parent.

Deci (d). SI prefix corresponding to multiplication by 10^{-1}.

Decontamination. The reduction or removal of radioactive contamination from a structure, area, object, or person. Decontamination may be accomplished by (1) treating the surface to remove or decrease the contamination, (2) letting the material stand so that the radioactivity is decreased as a result of natural decay, and (3) covering the contamination to shield or attenuate the radiation emitted.

Deka (da). SI prefix corresponding to multiplication by 10^{1}.

Delayed health effects. Radiation effects which appear long after the relevant exposure. The vast majority are stochastic, that is, the severity is independent of the dose and the probability is assumed to be proportional to the dose, without threshold.

Delta T. The difference in temperatures between the hot and cold legs of the reactor cooling system. "Delta T" is also used to denote temperature difference in atmospheric mixing.

Depleted uranium. Uranium from which part of the ^{235}U has been removed by the enrichment process.

Depletion. Reduction of the concentration of one or more specified isotopes in a material or one of its constituents.

Deposition. The material, such as radioactive material, deposited on the ground and other surfaces when an atmospheric plume passes over them.

Derived response level (DRL). A level of radioactivity in an environmental medium that would be expected to produce a dose equivalent equal to its corresponding Protective Action Guide.

Direct current (DC). An electric current that flows in one direction only. Direct current is used to operate essential reactor safety systems such as circuit breakers, solenoid-operated valves, and instruments and permits control of many components from remote locations.

Disintegration, radioactive. A spontaneous nuclear transformation characterized by the emission of energy and/or mass from the nucleus.

Dose commitment. See *committed dose*.

Dose conversion factor (DCF). A number that relates a dose equivalent or dose equivalent rate from a given isotope under a particular set of assumptions to an environmental measurement (the concentration of that isotope in air or to the amount of that isotope deposited on the ground). With a point source, this number represents the dose equivalent from a unit source with no shielding at 1 m distance.

Dose equivalent. The product of the absorbed dose (in rad or gray), a quality factor related to the biological effectiveness of the radiation involved and any other modifying factors. The unit of dose equivalent is rem or sievert.

Drywell. The primary containment structure in a BWR system. The drywell houses the reactor and the recirculating loop.

Drywell release. A release from the core of a boiling water reactor that enters the containment and then leaks to the environment.

Early health effects. Prompt radiation effects (observable within a short period of time) for which the severity of the effect varies with the dose and for which practical thresholds exist.

Early phase. The period at the beginning of a nuclear incident when immediate decisions for effective use of protective actions are required, and must therefore usually be based primarily on the status of the nuclear facility (or other incident site) and the prognosis for worsening conditions. This phase may last from hours to days. For the purpose of dose projection in this document, it is assumed to last for 4 days.

Effective dose equivalent (EDE). The sum of the products of the dose equivalent (H) to each organ or tissue (T) and a weighting factor (w) (i.e., $H_E = \Sigma w_T H_T$), where the weighting factor is the ratio of the risk of mortality from delayed health effects arising from irradiation of a particular organ or tissue to the total risk of mortality from delayed health effects when the whole body is irradiated uniformly to the same dose.

Effective dose equivalent conversion factor. The committed effective dose equivalent per unit intake of radionuclide.

Electron. A fundamental particle from which an atom is constructed, with a single negative electrical charge and a mass of 1/1840 atomic mass units (usually neglected in determining the mass of the atom). An electron is the antiparticle to the positron.

Electron capture. One of the beta decay processes in which an atomic electron is captured by the nucleus. This transforms a proton into a neutron and a neutrino is emitted. Like β^+ decay, the atomic number Z decreases by one, and the mass number A remains the same.

Element. A substance which cannot be broken down by ordinary chemical processes into simpler substances.

Elevated release. A release of materials to the atmosphere through a stack or opening well above ground level.

Emergency. Any unplanned situation that results in or may result in substantial injury or harm to the population or substantial damage to or loss of property.

Emergency Action Level (EAL). Observable indicators, such as instrument readings, which if exceeded initiate classification of an event and appropriate response actions.

Emergency Broadcast System (EBS). Broadcasting facilities that have been authorized by the Federal Communications Commission to operate in a controlled manner during a war, state of public peril or disaster, or other national emergency as provided by the EBS plan (will be replaced by the Emergency Alert System).

Emergency core cooling system (ECCS). An emergency system that provides for removal of residual heat from a reactor following loss of normal heat removal capability or a loss of coolant accident.

Emergency Operations Facility (EOF). A licensee facility, usually established within about 20 miles of a reactor site, to manage the licensee emergency response.

Emergency Planning Zone (EPZ). An area defined around a nuclear or other facility to facilitate offsite planning and develop a significant response base. EPZs are defined around power reactors for both the plume and ingestion exposure pathways.

Emergency Protective Action Guide. The projected dose commitment value at which responsible officials should isolate food containing radioactivity to prevent its introduction into commerce and at which the responsible officials should determine whether condemnation or another disposition is appropriate. At the emergency PAG, higher impact actions are justified because of the projected health hazards.

Emergency Response Planning Guideline-1 (ERPG-1). The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 h without experiencing other than mild, transient adverse health effects or without perceiving a clearly defined objectionable odor.

Emergency Response Planning Guideline-2 (ERPG-2). The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 h without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective actions.

Emergency Response Planning Guideline-3 (ERPG-3). The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 h without experiencing or developing life-threatening health effects.

Emergency worker. A person who performs emergency services and may be unavoidably exposed to radiation under emergency conditions (e.g., law enforcement, fire fighting, health services, animal care).

Erythema. Redness of the skin.

Escape fraction. Fraction of reactor containment volume or primary system coolant released in 1 h during an accident.

Evacuation. The urgent removal of people from an area to avoid or reduce high-level, short-term exposure to a hazard. Evacuation may be a preemptive action taken in response to a facility condition or a probably release of a hazardous material rather than an actual release.

Exa (E). SI prefix corresponding to multiplication by 10^{18}.

Executive Team (ET). The NRC headquarters team, led by the chairman or another commissioner, that directs the agency's response to significant events from the Operations Center. The Executive Team is supported by the Reactor Safety, Safeguards, Operations Support, Liaison, and Protective Measures teams.

Exposure. A measure of the ionization produced in air by X-rays or gamma radiation. It is the sum of the electrical charges on all of the ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in the air, divided by the mass of the air in the volume element. The special unit of exposure is the roentgen. In SI units, exposure is given in coulombs per kilogram (C/kg).

Exposure conversion factor. A number that relates the external exposure rate (instrument reading) in a gamma or X-ray field from a given isotope under a particular set of assumptions to the concentration of that isotope in air or to the amount of that isotope deposited on the ground. With a point source, this number represents the exposure rate from a unit source with no shielding at 1 m distance.

Exposure rate. The exposure per unit time.

Exponent. A symbol or number, usually written to the right of and above another symbol or number, that indicates how many times the latter number should be multiplied by itself.

External dose. The radiation dose resulting from radioactive materials outside the body (radiation must penetrate the skin).

External radiation. Radiation incident on a body from an external source.

Extraordinary nuclear occurrence. A radiological event which the Nuclear Regulatory Commission has determined to be an extraordinary nuclear event as defined in the Atomic Energy Act of 1954, as amended (10 CFR 140, Subpart E).

Federal Radiological Monitoring and Assessment Center (FRMAC). An operating center usually established near the scene of a radiological emergency from which the Federal field monitoring and assessment assistance is directed and coordinated.

Femto (f). SI prefix corresponding to multiplication by 10^{-15}.

Field measurement to dose model (FM-DOSE). One of the tools in the RASCAL software that allows the user to estimate doses based on isotopic concentrations of radionuclides on the ground or in the air.

Filtering. Passing a liquid or a gas through porous substance to remove constituents such as suspended matter.

Fissile. Capable of undergoing fission by interaction with thermal neutrons.

Fission. The splitting of the nucleus into at least two other nuclei and the release of a relatively large amount of energy. Two or three neutrons (and gamma rays) are usually released during this type of transformation.

Fission products. The nuclei (fission fragments) formed by the fission of heavy elements or by subsequent radioactive decay of the fission fragments.

Fissionable. Capable of undergoing fission by any process.

Flammability. Ability to be ignited and propagate a flame.

Fuel cladding. See *cladding*.

Fuel rod (fuel pin). A long, slender tube that holds fissionable material (fuel) for nuclear reactor use. Fuel rods are assembled into bundles called fuel elements or fuel assemblies, which are loaded individually into the reactor core.

Fuel cycle. The steps involved in supplying fuel for nuclear power reactors. It can include mining, milling, isotopic enrichment, fabrication of fuel elements, use in a reactor, chemical reprocessing to recover the fissionable material remaining in the spent fuel, reenrichment of the fuel material, refabrication into new fuel elements, and waste disposal.

Fuel reprocessing. The processing of reactor fuel to recover the unused fissionable material from the fission products.

Gamma (γ). Electromagnetic radiation emitted from the nucleus of the atom in gamma decay.

Gamma decay. Radioactive decay by the emission of a energetic photon (electromagnetic radiation).

Gap. The space inside a reactor fuel rod that exists between the fuel pellet and the fuel rod cladding.

Gap release. The release into containment of all the fission products in the fuel pin gap.

Gaussian plume dispersion model. A plume model based on the assumption that the concentration profiles in the crosswind direction (horizontal and vertical) are characterized by a Gaussian or normal distribution. Gaussian plume models have some important limitations: they do not deal well with complex terrain, light or calm winds, heavier-than-air gases, or materials that began as heavier-than-air and transform into neutrally buoyant gases, such as some cryogenically-stored materials.

General Emergency. The most serious of the four NRC emergency classes.. Classification as a "General Emergency" indicates that events are in progress or have occurred which involve actual or imminent substantial core degradation or melting with potential for loss of containment integrity. Releases can be reasonably expected to exceed EPA Protective Action Guide exposure levels offsite for more than the immediate site area.

Genetic effect. An effect in a descendent resulting from the modification of genetic material in a parent.

Giga (G). SI prefix corresponding to multiplication by 10^9.

Ground concentration factor. An estimate of the activity deposited as a function of distance downwind on the centerline from a ground level release. Calculation of ground concentration factors requires assumptions in meteorology and deposition velocity.

Ground level release. A release of materials to the atmosphere from a source or opening near ground level.

Ground roughness correction factor. A factor (assumed to be 0.7) in this document used to reduce the estimated dose because the radioactive material has been deposited on a rough surface which provides some shielding instead of a smooth plane.

Groundshine. Gamma radiation from radioactive materials deposited on the ground.

Half-life, biological. The time for the activity of radionuclide to diminish by a factor of a half because of biological elimination of the material.

Half-life, effective. The time for the activity of radionuclide to diminish by a factor of a half because of a combination of nuclear decay events and biological elimination of the radionuclide.

Half-life, radiological. The time for the activity of radionuclide to diminish by a factor of a half because of nuclear decay events.

Hecto (h). SI prefix corresponding to multiplication by 10^2.

Hold-up time. The time that a release of radioactive material is held in the containment structure of the reactor before it is released to the environment.

Hot. A colloquial term meaning highly radioactive.

Hot leg. In a PWR, the reactor coolant system from the reactor vessel, past the pressurizer to the entrance of the steam generator; in a BWR, the reactor coolant system from the reactor vessel to the penetration exiting containment.

Hot spot. The region in a radiation or contamination area in which the level of radiation or contamination is noticeably greater than in neighboring regions in the area.

Ice bed. Part of the passive containment system for some pressurized water reactors. During an accident, steam is directed through the ice bed to a containment compartment. The ice cools and condenses the steam, decreasing the volume and thus limiting the maximum containment pressure.

Ice condenser. See *ice bed.*

Ice condenser containment release. A release from the core of a pressurized water reactor that passes through an ice bed one or more times before leaking to the environment.

Immediately Dangerous to Life and Health (IDLH). The maximum concentration from which, in the event of respirator failure, one could escape within 30 min without a respirator and without experiencing any escape-impairing (e.g., severe eye irritation) or irreversible health effects.

Immersion. The condition of being covered completely by a liquid or a gas.

Inadequate core cooling. A condition which may occur during a reactor cooling system failure that results in a heat buildup in the core. Indications of inadequate core cooling include the first indication of saturation, core uncovery, and increase in fuel cladding temperature, finally exceeding the maximum value for normal recovery from a small loss-of-cooling accident.

Incident phase. EPA protective action guidance distinguishes three phases of an incident or accident: (1) *early phase*, (2) *intermediate phase*, and (3) *late phase*.

Indemnity agreement. A legal exception from liability damage.

Ingestion. Entry of a material (e.g., radioactive material) into the body through the mouth.

Ingrowth, radioactive. The increase in activity of a daughter radioactive isotope over time (when its half-life is longer than that of the parent).

Inhalation. The process of breathing in. Radioactive contamination in the atmosphere may enter the body by being breathed into the lungs. Some of the material will remain in the lung; some will pass into the blood stream; some will leave the lungs and be swallowed; and the remainder will be exhaled.

Inhalation dose. The committed dose (or committed dose equivalent) resulting from inhalation of radioactive materials and subsequent deposition of these radioisotopes in body tissues.

Inhalation organ dose. The committed dose equivalent to a particular organ as a result of breathing in radioactive material.

Initiating Condition (IC). A symptom or event that indicates actual or potential safety problems with a reactor, used in emergency classification systems.

Intensity. Amount of energy per unit time passing through a unit area perpendicular to the line of propagation at the point in question.

Intermediate phase. The period beginning after the incident source and releases have been brought under control and reliable environmental measurements are available for use as a basis for decisions on additional protective actions and extending until these protective actions are terminated. This phase may overlap the early and late phases and may last from weeks to many months. For the purpose of dose projection, it is assumed to last for 1 year.

Internal radiation. Radiation emitted from nuclides distributed within the body.

International System of Units (SI). Officially Le Système International d'Unités, a rationalized selection of units from the metric system. SI is a coherent system with seven base units and two supplementary units for which names, symbols, and precise definitions have been established.

In-vessel core melt. A condition during a reactor accident in which some of the cladding or reactor fuel melts as a result of overheating the fuel and remains inside the reactor vessel.

In-vessel core melt release. A release into containment from the reactor vessel which assumes the entire core has melted, releasing a representative mixture of radioisotopes.

Isobars. Nuclides which have the same atomic mass number but different atomic numbers (different elements).

Isolation failure. Failure to isolate fission products within the containment; as a result, leakage of fission products to the environment occurs.

Isomeric transition. Radioactive decay of long-lived excited states of a nucleus to states of lower energy in the same nucleus (same atomic number and same mass number), usually accompanied by the emission of a gamma ray or an internal conversion electron.

Isotopes. Nuclides of a particular element that contain the same number of protons but different numbers of neutrons.

Isotopic composition. The composition of a material in terms of the amounts of different isotopes present.

Kilo (k). SI prefix corresponding to multiplication by 10^3.

Large, dry containment release. A release from the core of a pressurized water reactor that passes into the containment before leaking to the environment.

Late phase. The period beginning when recovery actions designed to reduce radiation levels in the environment to permanently acceptable levels are commenced, and ending when all recovery actions have been completed. This period may extend from months to years (also referred to as the recovery phase.)

Light water reactor (LWR). A nuclear reactor using slightly enriched uranium as fuel and water as both moderator and coolant.

Linear energy transfer (LET). Average energy lost by ionizing radiation per unit distance of its travel through a medium. High LET is generally associated with protons, alpha particles, and neutrons, while low LET is associated with X-rays, electrons, and gamma rays.

Loss of coolant accident (LOCA). Accidents that would result in a loss of reactor coolant at a rate in excess of the capability of the reactor makeup system. The coolant losses are from breaks in the reactor coolant pressure boundary, up to and including a break equivalent in size to the double-ended rupture of the largest pipe of the reactor coolant system.

Lung clearance class (D, W, or Y). A classification scheme for inhaled material according to its clearance half-time, on the order of days, weeks, or years, from the pulmonary region of the lung to the blood and the gastrointestinal tract.

Main steam isolation valve (MSIV). The valve that closes the main steam line where it penetrates the reactor containment.

MARK I, II, III. Three different containment designs used with boiling water reactors. (Fig. A-4 contains sketches of these designs.)

Mega (M). SI prefix corresponding to multiplication by 10^6.

Metastable state. An excited nuclear state that has a half-life long enough to be observed.

Meteorology. The science dealing with the phenomena of the atmosphere, especially weather and weather conditions.

Micro (μ). SI prefix corresponding to multiplication by 10^{-6}.

Milli (m). SI prefix corresponding to multiplication by 10^{-3}.

Mitigation. A safety system or action that reduces the consequences of an event.

Mix. See *relative abundance*.

Mixing level. The height of the atmospheric boundary layer.

Model. A simplified representation of natural processes used to project expected outcomes of a set of conditions.

Moderation control (UF_6). A hydrogen-to-uranium atomic ratio of less than 0.088, which is equivalent to the purity specification of 99.5% for UF_6.

Moderator. A material used to slow neutrons in a reactor (by neutron scattering without appreciable neutron capture.)

Molecular weight. The weight of one molecule of a material, obtained by summing the atomic weights of the atoms in the molecule.

Monitoring (radiation). Periodic or continuous determination of the amount of ionizing radiation or radioactive contamination present in an occupied region, as a safety measure, for the purpose of health protection.

Nano (n). SI prefix corresponding to multiplication by 10^{-9}.

Neutron. A close combination of a proton and electron, usually treated as a single fundamental particle. A neutron is electrically neutral and has a mass of approximately one atomic mass unit.

Neutrino (ν). A weakly-interacting particle, with no rest mass and no charge, emitted along with the positron in β^+ decay or emitted as a result of electron capture. A neutrino is the antiparticle to the antineutrino.

Noble gas. A gas that is unreactive (inert) or reactive only to a limited extent with other elements (i.e., helium, neon, argon, krypton, xenon, and radon).

Nomogram. A chart representing numerical relationships.

Non-isolable. Unable to be isolated.

Non-stochastic effects. Health effects for which the severity of the effect in affected individuals varies with the dose, and for which a threshold is assumed to exist, e.g., radiation-induced cataracts or nausea.

Normal coolant release. The release into containment of the fission products found in the reactor coolant system under normal operating conditions.

Nuclear incident. An event or series of events, either deliberate or accidental, leading to the release, or potential release, into the environment of radioactive materials in sufficient quantity to warrant consideration of protective actions.

Nucleus. The central core of the atom, around which the electrons rotate in various orbits.

Nuclide. Any isotope of an atom, a nuclear species.

Offsite. The area outside the boundary of the onsite area. For emergencies at a fixed nuclear facility, "offsite" generally refers to the area beyond the facility boundary. For emergencies that do not occur at fixed nuclear facilities and for which no physical boundary exists, the circumstances of the emergency will dictate the boundary of the offsite area.

Onsite. The area within (a) the boundary established by the owner or operator of a fixed nuclear facility, (b) the area established as a National Defense Area or National Security Area, (c) the area established around a downed/ditched U.S. spacecraft, or (d) the boundary established at the time of the emergency by the State or local government with jurisdiction for a transportation accident not occurring at a fixed nuclear facility and not involving nuclear weapons.

Operating basis earthquake (OBE). The earthquake that could reasonably be expected to affect a nuclear power plant site during the operating life of the plant; it is the earthquake that produces the vibratory ground motion for which those features of the plant necessary for continued operations without undue risk to the health and safety of the public are designed to remain functional.

Parent isotope. A radioisotope, that upon nuclear disintegration, yields a specified isotope, the daughter, either directly or as a later member of a radioactive series.

Partial occupancy. The use of a building or structure for part of the period in question.

Partitioning. See *steam generator partitioning*.

Particulate. Material composed of separate and distinct particles.

Peta (P). SI prefix corresponding to multiplication by 10^{15}.

Pico (p). SI prefix corresponding to multiplication by 10^{-12}.

Plateout. Deposition of some isotopes on solid surfaces before they reach the environment.

Plume, atmospheric. The airborne "cloud" of material released to the environment, which may contain radioactive materials and may or may not be invisible. In a plume release (as opposed to a "puff release"), the release and sampling times are long compared with travel time from the source.

Poison, nuclear. A substance which, because of its ability to absorb neutrons, can reduce the ability to sustain a nuclear reaction.

Positron. A particle having the same mass as an electron with one unit of positive charge. A positron is the antiparticle to the electron.

Power-operated relief valve (PORV). A valve placed on a tank that is operated electrically, hydraulically, or pneumatically to relieve a pressure buildup inside the tank. The relief valves are set to open before the self-actuating safety valves in the tank.

Pressure vessel. See *reactor vessel.*

Pressurized water reactor (PWR). A light water reactor, in which the uranium fuel elements are cooled and moderated by water under pressure to keep it from boiling. Water heated in the reactor vessel is pumped to the steam generators to provide the heat for production of steam to drive the turbines.

Pressurizer. A tank or vessel that acts as a head tank (or surge volume) to control the pressure in a pressurized water reactor.

Preventive Protective Action Guide. The projected dose commitment value at which responsible officials should take protective actions having minimal impact to prevent or reduce the radioactive contamination of human food or animal feeds.

Projected dose. Future dose calculated for a specified time period on the basis of estimated or measured initial concentrations of radionuclides or exposure rates and in the absence of protective actions.

Projected dose commitment. The dose commitment that would be received in the future by individuals in the population group from the contaminating event if no protective action were taken.

Protective action. An activity conducted in response to an incident or potential incident to avoid or reduce radiation dose to members of the population (sometimes called a protective measure).

Protective action (ingestion). An action or measure taken to avoid most of the radiation dose that would occur from future ingestion of foods contaminated with radioactive materials.

Protective Action Guide (PAG). The projected dose commitment to individuals in the general population that warrants protective action following a release of radioactive material. Protective action would be warranted if the expected individual dose reduction is not offset by negative social, economic, or health effects. The PAG does not include the dose that has unavoidably occurred before the assessment.

Protective measure. See *protective action.*

Proton. A fundamental particle found in the nucleus or central core of the atom. The proton has a single positive charge and a mass of approximately one atomic mass unit.

PWR large, dry containment release. See *large, dry containment release.*

PWR subatmospheric containment release. See *subatmospheric containment release.*

PWR ice condenser containment release. See *ice condenser containment release.*

PWR steam generator tube rupture release. See *steam generator tube rupture release.*

Quality factor. A factor (Q) used in the determination of the radiation dose equivalent that reflects the ability of a particular type of radiation to cause radiation damage. Usual values for Q include 1 for X-rays, gamma rays, and electrons; 2.3 for thermal neutrons; 10 for fast neutrons and protons; and 20 for alpha particles.

Rad. A unit of absorbed dose that is equivalent to an energy deposition of 0.01 J/kg.

Radiation, internal. Radiation emitted from radionuclides distributed within the body.

Radiation, ionizing. Any radiation capable of displacing electrons from atoms or molecules, thereby producing ions.

Radiation, external. Radiation incident upon the body from an external source.

Radiation sickness. Nausea and vomiting that occur within a few hours after a person receives a large acute radiation dose (usually greater than 100 rem).

Radioactive decay. Transformation of an unstable substance into a more stable form, usually accompanied by the emission of charged particles and gamma rays.

Radioiodine. One or more of the radioactive isotopes of iodine.

Radioisotope. A radioactive isotope of a specific element.

Radiological Assessment System for Consequence Analysis (RASCAL). An NRC software package containing a calculational model used to assist in estimating radiological doses from reactor or fuel cycle facility accidents based on source term information or assumptions or field measurements.

Reactor (nuclear). A device in which nuclear fission may be sustained and controlled in a self-supporting nuclear reaction. The varieties are many, but all incorporate certain features, including fissionable material or fuel, a moderating material (unless the reactor is operated on fast neutrons), a reflector to conserve escaping neutrons, provisions for heat removal, measuring and controlling instruments, and protective devices.

Reactor coolant pump. One of the pumps that circulate water through the reactor core and the rest of the primary coolant system.

Reactor coolant system (RCS). The system within a nuclear reactor containing coolant material for cooling the reactor core by the transfer of heat.

Reactor core. The central portion of a nuclear reactor containing the fuel elements, moderator, neutron poison, and support structures.

Reactor vessel. A strong metal container that contains the reactor core and reactor coolant under pressure (in LWRs).

Recognition Categories. Categories of events or symptoms used to develop Emergency Action Levels in the NUMARC/NESP-007 emergency classification system. The four recognition categories are A, Abnormal Rad Levels/Radiological Effluent; F, Fission Product Barrier Degradation; H, Hazards and Other Conditions Affecting Plant Safety, and S, System Malfunction.

Reduction factor (source term). The ratio of the radioactivity available for release after reduction mechanism is considered to the radioactivity available for release before the reduction mechanism.

Reduction mechanisms. Chemical or physical mechanisms that act to reduce the amount of radioactive material that escapes to the environment during an accident.

Reentry. Temporary entry into a restricted zone under controlled conditions.

Relative abundance. The isotopic ratio of the radionuclides in a sample or deposited on the ground.

Release conversion factor (RCF). A number that relates a dose equivalent from a given isotope under a particular set of assumptions to the amount (activity) of that isotope released.

Release fraction. See *core release fraction*.

Release rate. The rate (e.g., Ci/s) at which radioactive isotopes are released.

Release pathway. A mechanism or pathway through which radioactive materials are released to the environment.

Rem. A unit of dose equivalent. The dose equivalent in rem is numerically equal to the absorbed dose in rad multiplied by the quality factor, the distribution factor, and any other necessary modifying factors.

Restricted zone. An area with controlled access from which the population has been relocated.

Reprocessing. See *fuel reprocessing*.

Resuspension. Reintroduction into the atmosphere of material originally deposited on the ground or other surfaces.

Roentgen (R). The unit of exposure which corresponds to the production of ions (of one sign) carrying a charge of 2.58×10^{-4} coulombs per kilogram (C/kg) of air.

Safe shutdown earthquake (SSE). The earthquake that is based on an evaluation of the maximum earthquake potential considering regional and local geology and seismology and specific characteristics of local subsurface material. It is the earthquake that produces the maximum vibratory ground motion for which certain structures, systems, and components of a nuclear power plant are designed to remain functional so that the plant can be brought to a safe shutdown.

Safety relief valve. A valve in a pressurized tank that opens automatically to relieve the pressure before it reaches a dangerous level.

Saturated vapor. Vapor that is sufficiently concentrated to be able to exist in equilibrium with the liquid form of the same substance.

Saturation. A condition in the atmosphere corresponding to 100% relative humidity.

Saturation temperature. The temperature at which the liquid and vapor phases are in equilibrium at some given pressure.

Scientific notation. A form of mathematical notation in which the number is expressed as a number between 1 and 10 multiplied by a power of 10.

Screening level. An exposure, dose, or contamination level, below which no further scrutiny is required.

Sheltering. An immediate protective action where people go indoors, close all doors and windows, turn off all sources of outside air, listen to radio or television for information, and remain indoors until officially notified that it is safe to go out.

Shield building. A structure surrounding the containment that provides an additional barrier against the escape of radioactive material.

Shielding. Material intended to reduce the intensity of radiation entering an area.

Short-lived daughters. Radioactive progeny of radioactive isotopes that have half-lives on the order of a few hours or less.

Shutdown time. Amount of time since the reactor has been shut down.

Site Area Emergency. The second most serious of the four NRC emergency classes. Classification as a "Site Area Emergency" indicates that events are in progress or have occurred which involve actual or likely major failures of plant functions needed for protection of the public. Any releases are not expected to exceed EPA Protective Action Guide exposure levels, except near the site boundary.

Slump. Relocation of molten reactor core during an accident.

Source term. The amount and isotopic composition of material released or the release rate, used in modeling releases of material to the environment.

Source term to dose model (ST-DOSE). One of the tools in the RASCAL software that allows the user to estimate doses based on source terms and meteorological conditions.

Specific activity. The activity per unit weight of a sample of radioactive material.

Spent fuel. Reactor fuel removed from a reactor following irradiation, or which is no longer usable because of depletion of fissile material, poison buildup, or radiation damage.

Spent fuel pool. A large pool of water used to store and cool spent fuel and other radioactive elements before they are shipped for storage or disposal.

Spent fuel pool release (BWR/PWR). Release from fuel in storage in a spent fuel pool from either a Zircoloy fire or a gap release from ruptured cladding when fuel heats up.

Spiked coolant. Reactor coolant containing increased concentrations of non-noble isotopes, sometimes seen with rapid shutdown or depressurization of primary system.

Spiked coolant release. The release into containment of 100 times the non-noble gas fission products found in the coolant.

Spontaneous fission. Radioactive decay by fission that is not induced by the addition of energy, such as bombardment with neutrons.

Spray. See *containment spray*.

Stability class. One of several atmospheric turbulence types determined by meteorological conditions such as wind speed, time of day, and amount of sunlight (e.g., Pasquill stability classes, Tables F-8 and F-9) used to indicate the intensity of mixing in the atmosphere.

Standby gas treatment system (SGTS). A system to filter and remove particulates from the air in the containment before it is released to the environment.

Steam generator. The heat exchanger used in some reactor designs to transfer heat from the primary (reactor coolant) system to the secondary (steam) system. This design permits heat exchange with little or no contamination of the secondary system equipment.

Steam generator partitioning. The presence of a water-steam interface in the steam generator. When the steam generator is partitioned, particulates are retained in the steam generator water and are not released.

Steam generator tube rupture (SGTR) release. A release from a ruptured steam generator tube releasing radioisotopes characteristic of normal (typical) coolant, spiked (non-noble fission products increased by factor of 100) coolant, or coolant contaminated by a gap release from the core or an in-vessel core melt.

Steam jet air ejector. A system in a reactor to remove noncondensable gases from the main condenser and vent them to the offgas system.

Stochastic effects. Health effects for which the probability of the effect varies with dose (e.g., radiation-induced cancer). It is generally assumed that there is no threshold below which stochastic effects do not occur.

Subatmospheric containment release. A release into a pressurized water reactor containment (normally maintained at subatmospheric pressure) that leaks to the atmosphere.

Sub-cooling margin. The amount (in a PWR) by which the saturation temperature at the given primary system pressure exceeds the coolant temperature. When the coolant temperature exceeds the saturation temperature (negative sub-cooling margin), the coolant water is boiling.

Subcritical. The reactor condition when the number of neutrons released by fission is not sufficient to achieve a self-sustaining nuclear chain reaction.

Suppression pool. A pool of water in the wet well of a BWR containment that is designed to condense steam. Steam vents to the wet well after a loss of coolant accident. Condensing the steam reduces the pressure inside the containment after an accident.

Tera (T). SI prefix corresponding to multiplication by 10^{12}.

Thermocouple. A temperature-measuring device consisting of two different metals joined together at both ends. The temperature difference across the two metals produces a thermoelectric current proportional to the difference.

Thyroid blocking. The use of stable iodine (usually in the form of potassium iodide) to block the uptake of radioactive iodine by the thyroid.

Tort. Any wrongful act, damage, or injury done willfully, negligently, or in circumstances involving strict liability, but not involving breach of contract, for which a civil suit can be brought.

Total acute bone dose (TABD). The dose to the bone marrow received in the first 24 h after the release. TABD includes the dose from immersion in the plume during plume passage, the groundshine from deposition to an adult outside, and the committed effective dose equivalent from inhalation of plume.

Total effective dose equivalent (TEDE). The sum of the effective dose equivalent from external radiation while immersed in the plume, the effective dose equivalent from 4-days exposure to deposition, the committed effective dose equivalent from inhalation for 4 days of resuspended material that was deposited on the ground, and the committed effective dose equivalent from inhalation of the material in the plume.

Transuranic elements. Artificially produced elements with atomic numbers greater than that of uranium (92).

Turbulence. Atmospheric turbulence is essentially the motion of the wind over the time scales smaller than the averaging time used to determine the mean wind. Turbulence consists of circular whirls or eddies of all possible orientations.

Ullage. The gas volume above the liquid in a container, e.g., a UF_6 cylinder.

Universal Time Coordinated (UTC). Mean solar time for the meridian at Greenwich, England, formerly known as Greenwich Mean Time (GMT) or Z time. (Eastern Standard Time is 5 hours behind UTC; Eastern Daylight Time is 4 hours behind UTC.)

Unusual Event. The least serious of the four NRC emergency classes. This classification indicates that unusual events are in progress or have occurred which indicate a potential degradation of the level of safety of the plant. No releases of radioactive material requiring offsite response or monitoring are expected unless further degradation of safety systems occurs.

Vessel melt-through release. A reactor release which assumes that the melted core melts through the reactor vessel, releasing additional fission products as the core interacts with the containment basemat concrete.

Volatile. Readily vaporizable at a relatively low temperature.

Volatile fission products. Isotopes resulting from nuclear fission that are gaseous or can easily be vaporized.

Weathering. The reduction of the amount of deposited radioactive material in the environment resulting from exposure to weather.

Weathering factor. The fraction of radioactivity remaining after being affected by average weather conditions for a specified period of time.

Wetwell. The volume of a BWR containment that holds the suppression pool.

Wetwell release. Release from a boiling water reactor that passes through a suppression pool in containment before leaking to the environment.

Yarway instrument. An instrument for water level indication that uses differential pressure through the use of an external-to-vessel variable leg and an adjacent reference leg. The term "Yarway" implies a mechanical transducer with local level readouts or transmission by capillary pressure to a remote reading, requiring no electrical power for operation.

Yocto (y). SI prefix corresponding to multiplication by 10^{-24}.

Yotta (Y). SI prefix corresponding to multiplication by 10^{24}.

Zepto (z). SI prefix corresponding to multiplication by 10^{-21}.

Zetta (Z). SI prefix corresponding to multiplication by 10^{21}.

Zircaloy. An alloy consisting of approximately 98% zirconium that is used in the cladding of fuel for light-water power reactors.

R

SECTION R

ACRONYNS AND ABBREVIATIONS

Section R
Acronyms and Abbreviations

A	atomic mass
A	ampere
A	activity of isotope
a	atto (SI prefix 10^{-18})
AC	alternating current
AIHA	American Industrial Hygiene Association
ADS	automatic depressurization system
AMN	atomic mass number
ANS	American Nuclear Society
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
α	alpha particle
@	at
Ba	barium
BEIR	Biological Effects of Ionizing Radiation
Btu	British thermal unit
Bq	becquerel
BR	breathing rate
BWR	boiling water reactor
β^+	β^+ particle (positron)
β^-	β^- particle (electron)
C	coulomb
c	centi (SI prefix 10^{-2})
°C	degrees Celsius
cc	cubic centimeter
cd	candela
CDE	committed dose equivalent
CEDE	committed effective dose equivalent
CET	core exit thermocouple
CFR	*Code of Federal Regulations*
Ci	curie
cm	centimeter
cpm	counts per minute
CR	contractor report
CRF	core release fraction
Cs	cesium

cu	cubic
χ_{HF}	hydrogen fluoride concentration
d	deci (SI prefix 10^{-1})
d	distance downwind
D_{EPg}	early phase dose equivalent from groundshine and resuspension
D_T	dose equivalent to an organ
da	deka (SI prefix 10^1)
DECAY	radioactive decay model
DC	direct current
DCF	dose conversion factor
$DCF_{E,50}$	dose conversion factor for CEDE
DCF_{IP}	dose conversion factor for immediate phase
DF	dilution factor
DF_d	dilution factor at distance, d
Dis	distance
DOC	U.S. Department of Commerce
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
DSO	Director of Site Operations (NRC)
E	exa (SI prefix 10^{18})
EAL	Emergency Action Level
EBS	Emergency Broadcast System
EC	electron capture
ECCS	emergency core cooling system
EDE	effective dose equivalent
EF	escape factor
EOF	Emergency Operations Facility
EPA	U.S. Environmental Protection Agency
EPZ	Emergency Planning Zone
ERPG	Emergency Response Planning Guideline
ET	Executive Team (NRC)
F	farad
f	femto (SI prefix 10^{-15})
°F	degrees Farenheit
FDA	Food and Drug Administration
FEMA	Federal Emergency Management Agency
FM-DOSE	field measurement to dose
FR	*Federal Register*

FRF	fire release fraction
FRMAC	Federal Radiological Monitoring and Assessment Center
FPI	fission product inventory
ft	foot/feet
G	giga (SI prefix 10^9)
g	gram
gal	gallon
GCF	ground concentration factor
GM	Geiger-Mueller
GMT	Greenwich Mean Time
Gy	gray
γ	gamma ray
H	henry
h	hecto (SI prefix 10^3)
h	hour
H_a	dose equivalent due to immersion
$H_{e,50}$	committed effective dose equivalent
H_p	effective dose equivalent from point source
H_2	hydrogen (molecular)
HF	hydrogen fluoride
H_2O	water
HHS	U.S. Department of Health and Human Services
HQ	headquarters
HVL	half value layer
Hz	hertz
I	iodine
I	exposure intensity
IAEA	International Atomic Energy Agency
IC	initiating condition
Ice	ice bed
IDLH	Immediately Dangerous to Life and Health
in.	inch
IT	isomeric transition
IU_{sol}	intake of soluable uranium
J	joule

K	kelvin
K	vertical mixing coefficient
k	kilo (SI prefix 10^3)
kg	kilogram
KI	potassium iodide
km	kilometer
lb	pound
lbf	pound force
LET	linear energy transfer
LOCA	loss of coolant accident
lm	lumen
LWR	light water reactor
lx	lux
M	mega (SI prefix 10^6)
m	milli (SI prefix 10^{-3})
m	meter
m	metastable
m^2	square meter
mg	milligram
mi	mile
min	minute
Mk	Mark
mL	milliliter
mol	mole
mph	miles per hour
mR	milliroentgen
mrad	millirad
mrem	millirem
MSIV	main steam isolation valve
MW(e)	megawatt (electric)
MW(t)	megawatt (thermal)
μ	micro (SI prefix 10^{-6})
μCi	microcurie
N	newton
n	neutron
n	nano (SI prefix 10^{-9})
NaI(Tl)	sodium iodide doped with thallium (scintillator)
NC	not calculated

NCRP	National Council on Radiation Protection and Measurements
NESP	National Environmental Studies Project (NUMARC)
NIOSH	National Institute for Occupational Safety and Health
NOAA	National Oceanic and Atmospheric Administration (DOC)
NRC	Nuclear Regulatory Commission
NUMARC	Nuclear Management and Resources Council, Inc.
NUREG	Nuclear Regulatory Commission report
NUREG/CR	U.S. Nuclear Regulatory Commission contractor report
ν	neutrino
$\bar{\nu}$	antineutrino
OBE	operating basis earthquake
OCIMS	Operations Center Information Management System (NRC)
Op	operating
ORNL	Oak Ridge National Laboratory
oz	ounce
Ω	ohm
P	pressure
P	peta (SI prefix 10^{15})
p	proton
p	pico (SI prefix 10^{-12})
Pa	pascal
PAG	Protective Action Guide
PORV	power-operated relief valve
ppm	parts per million
psi	pounds per square inch
psia	pounds per square inch absolute
psig	pounds per square inch gage
PWR	pressurized water reactor
Q	release rate of activity
Q_i	isotopic release rate
Q_T	total activity released
Q_{UF_6}	uranium hexafluoride inventory
R	roentgen
rad	radian
RASCAL	Radiological Assessment System for Consequence Analysis
RC	reactor coolant

RCF	release conversion factor
RCS	reactor coolant system
RDF	reduction factor
RF_{HF}	hydrogen fluoride release fraction
RF_{Usol}	soluble uranium release fraciton
rpm	revolutions per minute
S	siemens
s	second
SBGTS	standby gas treatment system
SGTR	steam generator tube rupture
SI	International System of Units (Le Système International d'Unités)
SpA	specific activity
sq	square
Sr	strontium
SRV	safety relief valve
SSE	safe shutdown earthquake
ST	shielding thickness
st	steradian
ST-DOSE	source term to dose
Sv	sievert
T	tesla
T	temperature
T	tera (SI prefix 10^{12})
T_{ed}	exposure duration
T_{rd}	release duration
$T_{1/2}$	radiological half-life
t_r	release duration
TABD	total acute bone (marrow) dose
TALD	total acute lung dose
Tech Specs	technical specifications
TEDE	total effective dose equivalent
TMI	Three Mile Island
TSC	Technical Support Center
U	uranium
$\bar{U}$	average wind speed
UF_6	uranium hexafluoride
UO_2F_2	uranyl fluoride

USDA	U.S. Department of Agriculture
UTC	Universal Time Coordinated
V	volt
W	watt
WB	whole body
Wb	weber
Wt	weight
Y	yotta (SI prefix 10^{24})
y	yocto (SI prefix 10^{-24})
yd	yard
yr	year
Z	atomic number
Z	Zulu (UTC)
Z	zetta (SI prefix 10^{21})
z	zepto (SI prefix 10^{-21})
Zr	zirconium

S

SECTION 5

REFERENCES

Section S
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