RADIATION HYGIENE HANDBOOK

BLATZ

McGRAW-HILL

RADIATION HYGIENE HANDBOOK

A PRACTICAL REFERENCE COVERING THE INDUSTRIAL, MEDICAL, AND RESEARCH USES OF RADIATION AND ATOMIC ENERGY WITH SPECIAL APPLICATIONS TO THE FIELDS OF HEALTH PHYSICS, INDUSTRIAL HYGIENE, AND SANITARY ENGINEERING

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FOREWORD

The scope and complexity of radiation hygiene make it a fascinating field of study for those who enjoy the challenge of scientific variety.

Here is a subject that begins with the properties of the fundamental particles and the way in which they interact with matter—especially the matter of which living things are composed. Although these interactions take place at the lowest biochemical level, they may express themselves so as to involve the entire organism and, in the case of effects on the hereditary mechanisms, the entire race.

It is in the study of the dispersion of radioactive substances in the environment that one finds the greatest degree of interplay among the many branches of science. Meteorology, soil chemistry, the hydrologic sciences, and mineral metabolism are some of the subjects which are involved to a major degree in evaluating the significance of radioactive contamination.

The ultimate objective of the radiation hygienist is to recommend effective and yet economical methods of controlling radiation hazards. This frequently requires intimate knowledge of the procedures of laboratories and industrial processes. The job of the radiation hygienist does not stop with identification of a potential hazard: it is important that he assist as well in the solution of the problem.

Radiation hygienists today are for the most part specialists of one kind or another who have acquired more general knowledge through their working relationships with specialists from other fields. Logically, the first of the workers in the field of radiation protection were physicists, many of whom were concerned originally with dosimetric aspects of radiation exposure. In recent years the ranks of this new profession have attracted chemists, geologists, engineers, meteorologists, and biologists.

The interdisciplinary characteristic of the field creates problems of definition and purpose which must soon be solved if the needs of the expanding nuclear industry are to be met. Who is a radiation hygienist (or, for that matter, what is a health physicist)? What should he know, what should he do, where do his responsibilities begin, and where do they end? As our second and third generations of scientists and engineers enter this expanding field, our definitions must be improved, our standards for professional qualification must be established, and our universities must adapt their curricula for the new requirements that the atomic age imposes.

The "Radiation Hygiene Handbook" will serve in an important way to assist science and industry to find the basic information with which radiation protection problems can be solved. For the first time, a compendium of information is available to permit the scientist and engineer to probe the many ramifications of health protection in the peaceful applications of atomic energy.

Merril Eisenbud

PREFACE

This is a new handbook to fill a new need. With the rapidly increasing use of radiation as a tool in industry, medicine, and research and the frequent appearance of radiation as an objectionable by-product in such fields as atomic energy for power and for transportation, the need for information and data to help protect workers and the public from its harmful effects is pressing.

This, the first comprehensive handbook in the field we chose to call "radiation hygiene," has been dependent upon the contributions, advice, and inspiration of many of the American leaders in this relatively new branch of science. The list of contributors, their areas of specialization, and their affiliations give some indication of the broadness of the subject.

Many different disciplines and many different philosophies are represented in this new field. On the one hand are the ultraconservatives, who believe that because of the many unknowns (particularly with regard to genetics) radioactive contamination and radiation exposures should be kept to the absolute minimum, regardless of cost. At the other extreme are those who prefer to wait for evidence of damage before instituting corrective measures.

In offering guidance to the various contributors, the editor has attempted to follow a reasonably "middle-of-the-road" philosophy as exemplified by many of the leaders in this field with which the editor has had the good fortune to be associated for many years: Shields Warren, John Bugher, G. Failla, Charles L. Dunham, Carl B. Braestrup, S. Allan Lough, William B. Harris, John H. Harley, Norton Nelson, and many others.

If any particular point of view is expressed in this handbook, it was perhaps influenced most by Merril Eisenbud, through whose leadership the AEC Health and Safety Laboratory has to a great extent set the pace in this rapidly expanding field of endeavor. To him, in particular, this book is dedicated.

Many of my former staff in the Radiation Branch of the Health and Safety Laboratory have been most generous in their advice, encouragement, and assistance, particularly Leonard R. Solon, James E. McLaughlin, Yvette Rosenberg, Pauline Castellani, and Josephine Lemma. Last, but by no means least, this formidable task could not have been completed without the infinite and loving patience of my wife Elizabeth and our family through these trying three years.

Hanson Blatz

RADIATION HYGIENE HANDBOOK

CONTENTS

Section 1

REFERENCE DATA

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Acknowledgments. Some of the material in this section is from the "Radiological Health Handbook" of the U.S. Department of Health, Education and Welfare. Dr. Kinsman, as editor of the "Radiological Health Handbook," wishes to acknowledge the assistance of his many associates at the Robert A. Taft Sanitary Engineering Center in Cincinnati, Ohio.

Tables 1-15, 1-16, and 1-17 are based, in part, on data from the "Code of Practice for the Protection of Persons Exposed to Ionizing Radiations," British Radioactive Substances Standing Advisory Committee, H.M. Stationery Office, London, England (1957).

Tables 1-18, 1-19, and 1-20 are from the recommendations of the International Commission on Radiological Protection.

REFERENCE DATA

Hanson Blatz and Simon Kinsman

Table 1-1. Alphabetical Index of Elements and Their Atomic Numbers (*Z*)

Element	Symbol	*Z*	Element	Symbol	*Z*
Actinium	Ac	89	Molybdenum	Mo	42
Aluminum	Al	13	Neodymium	Nd	60
Americium	Am	95	Neon	Ne	10
Antimony	Sb	51	Neptunium	Np	93
Argon	A	18	Nickel	Ni	28
Arsenic	As	33	Niobium *	Nb	41
Astatine	At	85	Nitrogen	N	7
Barium	Ba	56	Osmium	Os	76
Berkelium	Bk	97	Oxygen	O	8
Beryllium	Be	4	Palladium	Pd	46
Bismuth	Bi	83	Phosphorus	P	15
Boron	B	5	Platinum	Pt	78
Bromine	Br	35	Plutonium	Pu	94
Cadmium	Cd	48	Polonium	Po	84
Calcium	Ca	20	Potassium	K	19
Californium	Cf	98	Praseodymium	Pr	59
Carbon	C	6	Promethium	Pm	61
Cerium	Ce	58	Protoactinium	Pa	91
Cesium	Cs	55	Radium	Ra	88
Chlorine	Cl	17	Radon †	Rn	86
Chromium	Cr	24	Rhenium	Re	75
Cobalt	Co	27	Rhodium	Rh	45
Copper	Cu	29	Rubidium	Rb	37
Curium	Cm	96	Ruthenium	Ru	44
Dysprosium	Dy	66	Samarium	Sm	62
Erbium	Er	68	Scandium	Sc	21
Europium	Eu	63	Selenium	Se	34
Fluorine	F	9	Silicon	Si	14
Francium	Fr	87	Silver	Ag	47
Gadolinium	Gd	64	Sodium	Na	11
Gallium	Ga	31	Strontium	Sr	38
Germanium	Ge	32	Sulfur	S	16
Gold	Au	79	Tantalum	Ta	73
Hafnium	Hf	72	Technetium	Tc	43
Helium	He	2	Tellurium	Te	52
Holmium	Ho	67	Terbium	Tb	65
Hydrogen	H	1	Thallium	Tl	81
Indium	In	49	Thorium	Th	90
Iodine	I	53	Thulium	Tm	69
Iridium	Ir	77	Tin	Sn	50
Iron	Fe	26	Titanium	Ti	22
Krypton	Kr	36	Uranium	U	92
Lanthanum	La	57	Vanadium	V	23
Lead	Pb	82	Wolfram ‡	W	74
Lithium	Li	3	Xenon	Xe	54
Lutecium	Lu	71	Ytterbium	Yb	70
Magnesium	Mg	12	Yttrium	Y	39
Manganese	Mn	25	Zinc	Zn	30
Mercury	Hg	80	Zirconium	Zr	40

* Formerly columbium (Cb). † Also called radium emanation. ‡ Also called tungsten.

Table 1-2. Half-lives of Common Radioactive Elements

Element	Half-life	Element	Half-life
Th-232	1.39×10^{10} y	Y-91	58 d
U-238	4.49×10^{9} y	Sr-89	53 d
U-235	7.13×10^{8} y	Fe-59	45 d
Cl-36	3.1×10^{5} y	Cr-51	27 d
U-233	1.62×10^{5} y	Th-234	24.1 d
Ni-59	8×10^{4} y	Rb-86	18.6 d
Pu-239	2.436×10^{4} y	P-32	14.5 d
C-14	5,600 y	Ba-140	12.8 d
Ra-226	1,622 y	I-131	8.05 d
Cs-137	30 y	Au-199	3.15 d
Sr-90	28 y	Au-198	2.7 d
H-3	12.26 y	Mo-99	67 h
Co-60	5.27 y	Y-90	64 h
Tl-204	4.1 y	La-140	40 h
Fe-55	2.9 y	Br-82	35.87 h
Pm-147	2.6 y	As-76	26.8 h
Cs-134	2.3 y	Na-24	15.0 h
Ru-106	1.0 y	Ga-72	14.1 h
Ce-144	285 d	Cu-64	12.8 h
Zn-65	245 d	K-42	12.5 h
Ca-45	160 d	Mn-56	2.576 h
Po-210	138.4 d	A-41	109 m
Ta-182	112 d	Pr-144	17 m
S-35	87 d	N-16	7.4 s
W-185	74 d	Po-212	3×10^{-7} s

Table 1-3. Fundamental Constants

Name		*Value*
Avogadro's number	N_0	$= 6.025 \times 10^{23}$ molecules/g mole
Base of natural logarithms	e	$= 2.7183...$
Curie	c	$= 3.7 \times 10^{10}$ disintegrations/sec
Electron charge	e	$= 4.8 \times 10^{-10}$ statcoulomb
		$= 1.6 \times 10^{-19}$ coulomb
Energy equivalent of electron mass	mc^2	$= 0.51$ Mev
Faraday's constant	F	$= 96{,}514$ coulombs/g equivalent (physical scale)
Frequency associated with 1 ev	ν_0	$= 2.4186 \times 10^{14}$ sec^{-1}
Gravitational acceleration	g	$= 980.665$ cm/sec^2
Mass, alpha particle	m_α	$= 6.64 \times 10^{-24}$ g $= 4.002777$ mu
Mass, electron	m_e	$= 9.1066 \times 10^{-28}$ g $= 0.000548$ mu
Mass, H-atom	m_H	$= 1.67339 \times 10^{-24}$ g $= 1.008142$ mu
Mass, neutron	m_n	$= 1.6751 \times 10^{-24}$ g $= 1.008982$ mu
Mass, proton	m_p	$= 1.67248 \times 10^{-24}$ g $= 1.007594$ mu
Mass unit	mu	$= 1.66035 \times 10^{-24}$ g $= 1.0000$ mu
Microcurie	μc	$= 10^{-6}$ curie $= 3.7 \times 10^4$ disintegrations/sec
Micromicrocurie	$\mu\mu$c	$= 10^{-12}$ curie $= 3.7 \times 10^{-2}$ disintegration/sec
Millicurie	mc	$= 10^{-3}$ curie $= 3.7 \times 10^7$ disintegrations/sec
Planck's constant	h	$= 6.624 \times 10^{-27}$ erg-sec
Roentgen	r	$= 1$ esu/0.001293 g of air
Rutherford	rd	$= 10^6$ disintegrations/sec
Universal gas constant	R	$= 0.08206$ liter-atm/g-mole/°K
Velocity of light	c	$= 2.99776 \times 10^{10}$ cm/sec
Wavelength associated with 1 ev	λ_0	$= 12394.8$ A

Table 1-4. Signs and Symbols of Particular Interest in Radiation and Radioactivity

A or Å	angstrom (10^{-10} m)
A	activity (radioactivity)
A_0	activity (radioactivity), original
A_t	activity (radioactivity), at time t
b	build-up factor
c	curie
D	deuterium
d	deuteron
e	electron
I	radiation intensity
I_0	radiation intensity, initial
I_x	radiation intensity, transmitted
LD-50	median lethal dose
n	neutron
N	number of counts
N_0	number of counts, original
N_t	number of counts, at time t
h	Planck's constant
p	proton
r	roentgen
t	triton
α	alpha particle
β	beta particle
γ	gamma ray
λ	wavelength or decay constant
$\bar{\lambda}$	mean free path
u	linear absorption coefficient
σ	area (barn–cross section)

Table 1-5. Commonly Used Units

Units of radioactivity:		
$\mu\mu$c	micromicrocurie	10^{-12} curie
μc	microcurie	10^{-6} curie
c	curie	
kc	kilocurie	10^3 curies
Mc	megacurie	10^6 curies
Units of radiation:		
μr	microroentgen	10^{-6} roentgen
mr	milliroentgen	10^{-3} roentgen
r	roentgen	
The prefixes milli (m) and micro (μ) are also commonly used with the units rad, rep (obsolescent), and rem.		
Units of energy (of radiation):		
ev	electron volt	
kev	kiloelectron volt	10^3 electron volts
Mev	million electron volts	10^6 electron volts
Bev	billion electron volts	10^9 electron volts