SIXTH EDITION

PATTY'S INDUSTRIAL HYGIENE

HAZARD RECOGNITION
VOLUME I

EDITED BY
VERNON E. ROSE
BARBARA COHRSSEN

WILEY

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Sixth Edition

Volume 1
HAZARD RECOGNITION

VERNON E. ROSE
BARBARA COHRSSEN
Editors

CONTRIBUTORS
M. Berode
S. Cha
L. J. Cralley
L. V. Cralley
M. Cullen
P. Droz
D. Fishwick
J. F. Gamble
V. H. Grassian
M. Guillemin
M. Harper
R. Harris
R. Lieckfield
A. Merlo
F. Mirer
J. Pendergrass
T. M. Peters
R. Ratney
P. C. Reist
V. E. Rose
J. Singh
A. Turk
A. Wagner

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CONTRIBUTORS

Michael Berode, Ph.D., Institute for Work and Health, Lausanne, Switzerland

Samuel Cha, MS, Cha and Associates, San Gabriel, CA

Lester V. Cralley, Ph.D., CIH (Deceased)

Lewis J. Cralley, Ph.D., CIH (Deceased)

Mark R. Cullen, MD, Professor, Yale University, New Haven, CT

Pierre-Oliver Droz, Ph.D. (Deceased)

David Fishwick, MD, Co-Director, Centre for Workplace Health, Sheffield, UK

John F. Gamble, Ph.D., MA, MSPH, Exxon Biomedical Sciences, Inc., Somerset, NJ

Vicki H. Grassian, Ph.D., Director, Nanoscience and Nanotechnology Institute, University of Iowa, Iowa City, IA

Michel P. Guillemin, Ph.D., Honorary Professor, University of Lausanne, Switzerland

Martin Harper, Ph.D., CIH, Cchem, MRSC, Health Effects Laboratory Division, National Institute for Occupational Safety and Health, CDC, Morgantown, WV

Robert L. Harris, Ph.D., CIH (Retired), Chapel Hill, NC

Robert G. Lieckfield, Jr., CIH, Vice President, Clayton Group Services, Inc., Novi, MI

Angela Merlo, MD, Ph.D., Lawrenceville, NJ

Franklin E. Mirer, MD, Ph.D., Professor, Hunter College, New York, NY

John A. Pendergrass, PE, CIH (Retired), CSP, Mobile, AL

Thomas M. Peters, Ph.D., Department of Occupational and Environmental Health, College of Public Health, University of Iowa, Iowa City, IA

Ronald S. Ratney, Ph.D., CIH (Retired), Boston, MA

Parker C. Reist, ScD, PE, (Retired), Chapel Hill, NC

Vernon E. Rose, DrPH, CIH, CSP, PE, Professor Emeritus, University of Alabama at Birmingham, Franklin, TN

Jaswant Singh, Ph.D., CIH, Golden Associates, Inc., Kamuela, HI

Amos Turk, Ph.D., Professor Emeritus, The City College of New York, Danbury, CT

Andreas Wagner, CIH, Golden Associates Ltd., Mississauga, Ontario, Canada

PREFACE

Industrial hygiene is an applied science and a profession. Like other applied sciences such as medicine and engineering, it is founded on basic sciences such as biology, chemistry, mathematics, and physics. In a sense, it is a hybrid profession because within its ranks are members of other professions—chemists, engineers, biologists, physicists, physicians, nurses, and lawyers. In their professional practice, all are dedicated in one way or another to the purposes of industrial hygiene, to the anticipation, recognition, evaluation, and control of work-related health hazards. The contributors to these volumes come from these professions.

Although the term "industrial hygiene" used to describe our profession is probably of twentieth century origin, we must go further back in history for the origin of its words. The word "industry," which has a dictionary meaning "systematic labor for some useful purpose or the creation of something of value" has its English origin in the fifteenth century. For "hygiene," we must look even earlier. Hygieia, a daughter of Aesklepios who is god of medicine in Greek mythology, was responsible for the preservation of health and prevention of disease. Thus, Hygieia, when she was dealing with people who were engaged in systematic labor for some useful purpose, was practicing our profession, industrial hygiene.

Industrial Hygiene and Toxicology was originated by Frank A. Patty with publication of the first single volume in 1948. In 1958, an updated and expanded second edition was published with his guidance. A second volume, *Toxicology*, was published in 1963. Frank Patty was a pioneer in industrial hygiene; he was a teacher, practitioner, and manager. He served in 1946 as eighth President of the American Industrial Hygiene Association. To cap his professional career, he served as Director of the Division of Industrial Hygiene for the General Motors Corporation.

At the request of Frank Patty, George and Florence Clayton took over editorship of the ever-expanding *Industrial Hygiene and Toxicology* series for the third edition of Volume I, *General Principles*, published in 1978, and Volume II, *Toxicology*, published in 1981–1982. The First edition of Volume III, *Theory and Rationale of Industrial Hygiene Practice,* edited by Lewis and Lester Cralley, was published in 1979 with its second edition published in 1984. The ten-book, two-volume fourth edition of *Patty's Industrial Hygiene and Toxicology,* edited by George and Florence Clayton, was published in 1991–1994, and the third edition of Volume III, *Theory and Rationale of Industrial Hygiene Practice,* edited by Robert Harris, Lewis Cralley, and Lester Cralley, was published in 1994. With the agreement and support of George and Florence Clayton, and Lewis and Lester Cralley, Robert Harris edited the fifth edition of *Patty's Industrial Hygiene.*

It is now our privilege and honor to follow them and Frank A. Patty as the editors of the sixth edition of Industrial Hygiene volumes of *Patty's Industrial Hygiene and Toxicology.* Each of the four volumes in the sixth edition is a "stand alone" publication. Volume 1 covers chemical hazard recognition, Volume 2 addresses evaluation and control of chemical hazards, Volume 3 considers all aspects of physical and biological agents, and Volume 4 considers management and specialty areas of practice. In addition, Volume 4 contains a complete index covering all four volumes.

Industrial hygiene has been dealt with very broadly in the past editions of *Patty's Industrial Hygiene and Toxicology.* Chapters have been offered on sampling and analysis, exposure measurement and interpretation, absorption and elimination of toxic materials, instrument calibration, odors, industrial noise, ionizing and non-ionizing radiation, heat and cold stress, pressure, lighting, control of exposures, safety and health law, health surveillance, ergonomics, hazardous wastes, occupational epidemiology, and other vital areas of practice. These traditional areas continue to be covered in this latest edition. Consistent with the past history of *Patty's*, following new areas of industrial hygiene concerns and practices have been addressed: nanomaterials, infectious diseases, risk assessment, mathematical modeling, control banding, protective clothing, product stewardship, health care work settings, emergency and disaster response, management of international EH&S programs, and fire safety.

Although industrial hygiene has been practiced in one guise or another for centuries, the most systematic approaches and the most esoteric accomplishments have been made in the past 50 or 60 years—generally in the years since Frank Patty published his first book. This accelerated progress is due primarily to increased public awareness of occupational health and safety issues and need for environmental control as is evidenced by Occupational Safety and Health, Clean Air, and Clean Water legislation at both federal and state levels.

Industrial hygienists know that variability is the key to measurement and interpretation of workers' exposures. If exposures did not vary, exposure assessment could be limited to a single measurement, the results of which could be acted upon, then the matter filed away as something of no further concern. We know, however, that exposures change, and change is characteristic of the science and practice of

our profession as well. We must not only be alert to recognize new hazards, continue to evaluate new and changing stresses, and evaluate performance of exposure controls but also upgrade them from time to time. These volumes represent the theory and practice of industrial hygiene as they are understood by their chapter authors at the time of their writing. But, as observed by the Greek philosopher Heracleitus about 2500 years ago, "There is nothing permanent except change." Improvements and changes in theory and practice of industrial hygiene take place continuously and are generally reported in the professional literature. Industrial hygienists, the practitioners, the teachers, and the managers must stay abreast of the professional literature. Furthermore, when an industrial hygienist develops new knowledge, he/she has what almost amounts to an ethical obligation to share it with others in the profession.

One cannot ponder the rapid changes and advancements made in the recent decades in science and technology, and in our own profession as well, without wondering at what the next two or three decades will bring. Developments in computer technology and information processing and exchange have greatly influenced manufacturing (robotics, computer controlled machining) and the general conduct of commerce and business in the past one or two decades. It has also changed the way we can now practice the purposes of industrial hygiene. This change has accelerated with computer speeds, methods of communication and available instrumentation. The possibility for continuously monitoring and computer storage of exposures of individual workers is becoming a reality. The human genome project holds promise for prevention and cure of many diseases, including some associated with conditions of work. World population continues to increase geometrically and is expected to be about eight billion in the year 2020; with improvements in preventive health care this will be an increasingly older population. Genetic engineering and highly effective pesticides are already improving yields of agricultural commodities; if all goes well in this area, feeding the expanding human population may not be a limiting factor. Globalization of manufacturing and commerce has already begun to reduce manufacturing employment in the United States and in Europe, and to expand opportunities for expanding populations in some developing nations. The United States and the other developed nations are on their way to becoming world centers of information and innovation.

How will all of this affect the future practice of industrial hygiene? In the preface to the fourth edition of *Patty's*, George and Florence Clayton suggested that the future of industrial hygiene is limited only by the narrowness of vision of its practitioners.

We extend our appreciation to Robert Harris, editor of the fifth edition of *Patty's Industrial Hygiene* for graciously allowing us to include much of his well-written preface in this edition. In it, we saw a sweeping, but still succinct review not only of Patty's publications but also of the practice of industrial hygiene itself. His writing is as timely in 2010 as it was a decade ago.

Occupational and environmental hygiene professionals must be aware of the changes likely to take place, and develop strategies to assure the profession's full

participation in protecting the health and safety of workers and the environment of tomorrow. Our participation, locally, nationally, and globally will continue to be greatly needed in the coming years.

VERNON ROSE
Franklin, TN

BARBARA COHRSSEN
San Francisco, CA

USEFUL EQUIVALENTS AND CONVERSION FACTORS

1 kilometer = 0.6214 mile
1 meter = 3.281 feet
1 centimeter = 0.3937 inch
1 micrometer = 1/25,4000 inch = 40 microinches = 10,000 Angstrom units
1 foot = 30.48 centimeters
1 inch = 25.40 millimeters
1 square kilometer = 0.3861 square mile (U.S.)
1 square foot = 0.0929 square meter
1 square inch = 6.452 square centimeters
1 square mile (U.S.) = 2,589,998 square meters = 640 acres
1 acre = 43,560 square feet = 4047 square meters
1 cubic meter = 35.315 cubic feet
1 cubic centimeter = 0.0610 cubic inch
1 cubic foot = 28.32 liters = 0.0283 cubic meter = 7.481 gallons (U.S.)
1 cubic inch = 16.39 cubic centimeters
1 U.S. gallon = 3,7853 liters = 231 cubic inches = 0.13368 cubic foot
1 liter = 0.9081 quart (dry), 1.057 quarts (U.S., liquid)
1 cubic foot of water = 62.43 pounds (4°C)
1 U.S. gallon of water = 8.345 pounds (4°C)
1 kilogram = 2.205 pounds
1 gram = 15.43 grains
1 pound = 453.59 grams
1 ounce (avoir.) = 28.35 grams
1 gram mole of a perfect gas ≎ 24.45 liters (at 25°C and 760 mm Hg barometric pressure)
1 atmosphere = 14.7 pounds per square inch
1 foot of water pressure = 0.4335 pound per square inch
1 inch of mercury pressure = 0.4912 pound per square inch
1 dyne per square centimeter = 0.0021 pound per square foot
1 gram-calorie = 0.00397 Btu
1 Btu = 778 foot-pounds
1 Btu per minute = 12.96 foot-pounds per second
1 hp = 0.707 Btu per second = 550 foot-pounds per second
1 centimeter per second = 1.97 feet per minute ≒ 0.0224 mile per hour
1 footcandle = 1 lumen incident per square foot = 10.764 lumens incident per square meter
1 grain per cubic foot = 2.29 grams per cubic meter
1 milligram per cubic meter = 0.000437 grain per cubic foot

To convert degrees Celsius to degrees Fahrenheit: °C (9/5) + 32 = °F
To convert degrees Fahrenheit to degrees Celsius: (5/9) (°F − 32) = °C
For solutes in water: 1 mg/liter ≎ 1 ppm (by weight)
Atmospheric contamination: 1 mg/liter ≎ 1 oz/1000 cu ft (approx)
For gases or vapors in air at 25°C and 760 mm Hg pressure:
To convert mg/liter to ppm (by volume): mg/liter (24,450/mol. wt.) = ppm
To convert ppm to mg/liter: ppm (mol. wt./24,450) = mg/liter

CONVERSION TABLE FOR GASES AND VAPORS[a]

(Milligrams per liter to parts per million, and vice versa; 25°C and 760 mm Hg barometric pressure)

Molecular Weight	1 mg/liter ppm	1 ppm mg/liter	Molecular Weight	1 mg/liter ppm	1 ppm mg/liter	Molecular Weight	1 mg/liter ppm	1 ppm mg/liter
1	24,450	0.0000409	39	627	0.001595	77	318	0.00315
2	12,230	0.0000818	40	611	0.001636	78	313	0.00319
3	8,150	0.0001227	41	596	0.001677	79	309	0.00323
4	6,113	0.0001636	42	582	0.001718	80	306	0.00327
5	4,890	0.0002045	43	569	0.001759	81	302	0.00331
6	4,075	0.0002454	44	556	0.001800	82	298	0.00335
7	3,493	0.0002863	45	543	0.001840	83	295	0.00339
8	3,056	0.000327	46	532	0.001881	84	291	0.00344
9	2,717	0.000368	47	520	0.001922	85	288	0.00348
10	2,445	0.000409	48	509	0.001963	86	284	0.00352
11	2,223	0.000450	49	499	0.002004	87	281	0.00356
12	2,038	0.000491	50	489	0.002045	88	278	0.00360
13	1,881	0.000532	51	479	0.002086	89	275	0.00364
14	1,746	0.000573	52	470	0.002127	90	272	0.00368
15	1,630	0.000614	53	461	0.002168	91	269	0.00372
16	1,528	0.000654	54	453	0.002209	92	266	0.00376
17	1,438	0.000695	55	445	0.002250	93	263	0.00380
18	1,358	0.000736	56	437	0.002290	94	260	0.00384
19	1,287	0.000777	57	429	0.002331	95	257	0.00389
20	1,223	0.000818	58	422	0.002372	96	255	0.00393
21	1,164	0.000859	59	414	0.002413	97	252	0.00397
22	1,111	0.000900	60	408	0.002554	98	249.5	0.00401
23	1,063	0.000941	61	401	0.002495	99	247.0	0.00405
24	1,019	0.000982	62	394	0.00254	100	244.5	0.00409
25	978	0.001022	63	388	0.00258	101	242.1	0.00413
26	940	0.001063	64	382	0.00262	102	239.7	0.00417
27	906	0.001104	65	376	0.00266	103	237.4	0.00421
28	873	0.001145	66	370	0.00270	104	235.1	0.00425
29	843	0.001186	67	365	0.00274	105	232.9	0.00429
30	815	0.001227	68	360	0.00278	106	230.7	0.00434
31	789	0.001268	69	354	0.00282	107	228.5	0.00438
32	764	0.001309	70	349	0.00286	108	226.4	0.00442
33	741	0.001350	71	344	0.00290	109	224.3	0.00446
34	719	0.001391	72	340	0.00294	110	222.3	0.00450
35	699	0.001432	73	335	0.00299	111	220.3	0.00454
36	679	0.001472	74	330	0.00303	112	218.3	0.00458
37	661	0.001513	75	326	0.00307	113	216.4	0.00462
38	643	0.001554	76	322	0.00311	114	214.5	0.00466

CONVERSION TABLE FOR GASES AND VAPORS (*Continued*)

(Milligrams per liter to parts per million, and vice versa; 25°C and 760 mm Hg barometric pressure)

Molecular Weight	1 mg/liter ppm	1 ppm mg/liter	Molecular Weight	1 mg/liter ppm	1 ppm mg/liter	Molecular Weight	1 mg/liter ppm	! ppm mg/liter
115	212.6	0.00470	153	159.8	0.00626	191	128.0	0.00781
116	210.8	0.00474	154	158.8	0.00630	192	127.3	0.00785
117	209.0	0.00479	155	157.7	0.00634	193	126.7	0.00789
118	207.2	0.00483	156	156.7	0.00638	194	126.0	0.00793
119	205.5	0.00487	157	155.7	0.00642	195	125.4	0.00798
120	203.8	0.00491	158	154.7	0.00646	196	124.7	0.00802
121	202.1	0.00495	159	153.7	0.00650	197	124.1	0.00806
122	200.4	0.00499	160	152.8	0.00654	198	123.5	0.00810
123	198.8	0.00503	161	151.9	0.00658	199	122.9	0.00814
124	197.2	0.00507	162	150.9	0.00663	200	122.3	0.00818
125	195.6	0.00511	163	150.0	0.00667	201	121.6	0.00822
126	194.0	0.00515	164	149.1	0.00671	202	121.0	0.00826
127	192.5	0.00519	165	148.2	0.00675	203	120.4	0.00830
128	191.0	0.00524	166	147.3	0.00679	204	119.9	0.00834
129	189.5	0.00528	167	146.4	0.00683	205	119.3	0.00838
130	188.1	0.00532	168	145.5	0.00687	206	118.7	0.00843
131	186.6	0.00536	169	144.7	0.00691	207	118.1	0.00847
132	185.2	0.00540	170	143.8	0.00695	208	117.5	0.00851
133	183.8	0.00544	171	143.0	0.00699	209	117.0	0.00855
134	182.5	0.00548	172	142.2	0.00703	210	116.4	0.00859
135	181.1	0.00552	173	141.3	0.00708	211	115.9	0.00863
136	179.8	0.00556	174	140.5	0.00712	212	115.3	0.00867
137	178.5	0.00560	175	139.7	0.00716	213	114.8	0.00871
138	177.2	0.00564	176	138.9	0.00720	214	114.3	0.00875
139	175.9	0.00569	177	138.1	0.00724	215	113.7	0.00879
140	174.6	0.00573	178	137.4	0.00728	216	113.2	0.00883
141	173.4	0.00577	179	136.6	0.00732	217	112.7	0.00888
142	172.2	0.00581	180	135.8	0.00736	218	112.2	0.00892
143	171.0	0.00585	181	135.1	0.00740	219	111.6	0.00896
144	169.8	0.00589	182	134.3	0.00744	220	111.1	0.00900
145	168.6	0.00593	183	133.6	0.00748	221	110.6	0.00904
146	167.5	0.00597	184	132.9	0.00753	222	110.1	0.00908
147	166.3	0.00601	185	132.2	0.00757	223	109.6	0.00912
148	165.2	0.00605	186	131.5	0.00761	224	109.2	0.00916
149	164.1	0.00609	187	130.7	0.00765	225	108.7	0.00920
150	163.0	0.00613	188	130.1	0.00769	226	108.2	0.00924
151	161.9	0.00618	189	129.4	0.00773	227	107.7	0.00928
152	160.9	0.00622	190	128.7	0.00777	228	107.2	0.00933

CONVERSION TABLE FOR GASES AND VAPORS (*Continued*)

(*Milligrams per liter to parts per million, and vice versa; 25°C and 760 mm Hg barometric pressure*)

Molecular Weight	1 mg/liter ppm	1 ppm mg/liter	Molecular Weight	1 mg/liter ppm	1 ppm mg/liter	Molecular Weight	1 mg/liter ppm	1 ppm mg/liter
229	106.8	0.00937	253	96.6	0.01035	277	88.3	0.01133
230	106.3	0.00941	254	96.3	0.01039	278	87.9	0.01137
231	105.8	0.00945	255	95.9	0.01043	279	87.6	0.01141
232	105.4	0.00949	256	95.5	0.01047	280	87.3	0.01145
233	104.9	0.00953	257	95.1	0.01051	281	87.0	0.01149
234	104.5	0.00957	258	94.8	0.01055	282	86.7	0.01153
235	104.0	0.00961	259	94.4	0.01059	283	86.4	0.01157
236	103.6	0.00965	260	94.0	0.01063	284	86.1	0.01162
237	103.2	0.00969	261	93.7	0.01067	285	85.8	0.01166
238	102.7	0.00973	262	93.3	0.01072	286	85.5	0.01170
239	102.3	0.00978	263	93.0	0.01076	287	85.2	0.01174
240	101.9	0.00982	264	92.6	0.01080	288	84.9	0.01178
241	101.5	0.00986	265	92.3	0.01084	289	84.6	0.01182
242	101.0	0.00990	266	91.9	0.01088	290	84.3	0.01186
243	100.6	0.00994	267	91.6	0.01092	291	84.0	0.01190
244	100.2	0.00998	268	91.2	0.01096	292	83.7	0.01194
245	99.8	0.01002	269	90.9	0.01100	293	83.4	0.01198
246	99.4	0.01006	270	90.6	0.01104	294	83.2	0.01202
247	99.0	0.01010	271	90.2	0.01108	295	82.9	0.01207
248	98.6	0.01014	272	89.9	0.01112	296	82.6	0.01211
249	98.2	0.01018	273	89.6	0.01117	297	82.3	0.01215
250	97.8	0.01022	274	89.2	0.01121	298	82.0	0.01219
251	97.4	0.01027	275	88.9	0.01125	299	81.8	0.01223
252	97.0	0.01031	276	88.6	0.01129	300	81.5	0.01227

[a]A. C. Fieldner, S. H. Katz, and S. P. Kinney, "Gas Masks for Gases Met in Fighting Fires," *U.S. Bureau of Mines, Technical Paper No. 248,* 1921.

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PART I

INTRODUCTION TO INDUSTRIAL HYGIENE