INDUSTRIAL HYGIENE AND TOXICOLOGY

Second Revised Edition

FRANK A. PATTY, *Editor*

VOLUME I

GENERAL PRINCIPLES

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INDUSTRIAL HYGIENE AND TOXICOLOGY

Second Revised Edition *In Three Volumes*

VOLUME I:
General Principles

VOLUME II:
Toxicology

VOLUME III:
Industrial Environmental Analysis

PREFACE

to the Second Edition, Volume I

Major changes in emphasis in this revision are found in the subjects of Noise, Heat, Ionizing Radiation, Human Engineering and Industrial Safety, Sanitation, Air Pollution, and Illumination.

Noise and its environmental implications have assumed a degree of importance that warrants a chapter devoted exclusively to the subject.

Heat and its control have received much attention in industrial hygiene circles in recent years, and technology concerning the conditioning of air for health and comfort is much in demand. The subject is of sufficient importance to warrant four chapters dealing with the various phases of the problem, including Air Conditioning, Air Cleaning, Ventilation, and Heat Control in the Hot Industries.

With the rapidly growing application of radioisotopes and the peacetime uses of nuclear power, the recognition, evaluation, and control of *ionizing radiation* exposures and the inhalation and ingestion of radioactive gases and aerosols assume industrial importance comparable to those of other highly hazardous environmental contaminants. Industrial hygienists will find it increasingly necessary to acquire a working knowledge in radiation hygiene. Health physicists as they enter industrial work environments will find it increasingly necessary to recognize the health problems attending other physical forces—such as sound, heat, and light—chemical contaminants, and all the harmful environmental situations with which industrial employees may come in contact. Natural and irresistible forces work against clannishness and toward efficient and expedient methods of competently protecting the employees' health and safety.

Human Engineering and Industrial Safety. To develop the best possible adjustment between man and his job is a fringe interest because methods engineering and machine design must take into account certain engineering, biological, and environmental facts commonplace to the industrial hygiene discipline.

Industrial Sanitation, another fringe interest, deals with problems not inherent in the manufacturing process and needs to be drawn into sharper focus defining its relation to the field of health engineering and, therefore, a chapter to this end has been included.

Air Pollution involves industrial hygiene because the contaminants in the air of the community are the base line upon which any indoor contamination studies or control programs must be built. In many cases pollutants must be removed from air before admitting it to the plant environment. Likewise, stack

effluents frequently require cleaning up before they are acceptable to the community atmosphere. Much technology is common to both the indoor and outdoor air contamination problems.

A separate chapter is devoted to the subject of *Illumination,* a controversial field not heretofore sufficiently explored by industrial hygienists.

The objective of industrial hygiene remains the same—safeguarding the health of working people and improving work environments.

FRANK A. PATTY

February, 1958

PREFACE

to the First Edition, Volume I

Industrial hygiene has been recognized and practiced from the time of Pliny down through the ages. It is the present concept of industrial hygiene that is relatively new—the concept of anticipating and recognizing potentially harmful situations and applying engineering control measures before serious injury results. There are some who question industry's ability to control all harmful exposures; and there is quite naturally a tendency to take the easy way out of a difficulty by substituting materials of low or moderate toxicity for those of a hazardous nature. Nevertheless, where incentives such as low cost, availability, or superior properties of a hazardous material justify the provision of positive engineering controls, they can be supplied promptly.

It is said that artisans are born rather than made, but there can be no doubt that industrial hygienists must be made, and it takes years to mellow some of us with sufficient understanding so that we can use our knowledge of the basic principles of industrial hygiene to the best advantage in accomplishing our goal.

Depending somewhat upon where we acquire our academic training and initial experience in field work, we are likely to start out with the concept that industry has one purpose—to make money—and that, in following that urge, the humanitarian aspects are apt to be neglected. So it is with somewhat of a shock that some of us learn that many industries are eagerly taking the initiative in improving the work environment of their employees. Our first ideas of introducing hygiene to industry are likely to involve some means of maneuvering into a position in which our recommendations for control measures are to be accepted as commandments not to be questioned and not, upon penalty of closing up shop, to be ignored. It is only gradually that we become aware of the fact that in promoting anything to the American public a sound idea "takes" more quickly and develops faster if it is "sold" rather than presented as an ultimatum. As a people we basically resent being told bluntly that we have to do a thing: we much prefer to "discover" for ourselves that the proposed new course is correct and therefore to our advantage. Adams* expresses these ideas well in his recent book, from which I quote:

> The American is a composite of almost all races, nationalities, and classes . . . He hates a bit and bridle as heartily as does a young colt . . . There *are* dirty politicians, dirty labor leaders, dirty business men—black markets, some selfish and dirty consumers—but Americans, now 138,000,000 of them, *the American people*, are the hope of the world and of the whole future of humanity.

* J. T. Adams, *Big Business in Democracy*. Scribner's, New York, 1946.

The industrial hygienist becomes aware that salesmanship is a necessary part of his practice. The salesman will think of the "buyer's" point of view and, first of all, develop his recommendations for environmental controls with the understanding of an economist, and then stress all the advantages. He will simplify his work by taking advantage of the views of production engineers and occasionally going them one better by saving them money in the conservation of materials or in the recovery of a by-product. One cardinal rule he learns early is not to "bluff" or try to impress his audience with his superior knowledge. Some few persons have the ability to "get away with it," but the odds are against them and it is much safer to work on the same plane as our audience whether that means a step down or a jump up, and it helps to imagine one's self in the position of the man one is trying to influence.

Industrial hygiene may be defined as *the science and art of preserving health through the recognition, evaluation, and control of environmental causes and sources of illness in industry.* It resolves itself into the problem of finding factors or conditions in workplaces that may cause or contribute to the illness or serious discomfort of employees, and of devising methods and means of eliminating or controlling such conditions.

It would be a mistake to attempt to give the impression that industrial hygiene is pure science, or that it is restricted to the art of applying scientific principles: much of it involves a liberal use of common sense or what is perhaps better known as "horse sense." The job will never become monotonous or routine because the chemist, the engineer, and the physicist will keep introducing new and more or less hazardous materials and processes that require new developments for the evaluation and control of exposures attendant to their use. Neither is the job glamorous or spectacular, and much of it is hard work bordering on drudgery, but it has its compensations.

I should like to narrate an incident that, because of its fundamentality and at the same time dramatic departure from the daily routine of an industrial hygienist, may be worth describing without retouching. One of the pioneers in industrial medicine and hygiene whom most readers will recognize without further identification might have regarded this incident as an "acorn."* However, since no tangible reward or token of appreciation was either anticipated or received and the only special remuneration was the feeling of satisfaction that goes with accomplishing any job, assumed or assigned, it was considered all in the day's work.

While busily engaged at my office one morning in the industrial hygienist's favorite occupation of pouring over survey reports, I received a telephone call: "This is Dr. ——, chemist over at —— Dry Dock. Here's something I think you should know about and maybe you will want to come over and look around. We just sent a man to the hospital and we have two more who are laid up and in a serious condition. The —— was docked here just two weeks ago for repairs and conversion and out of the 2,000 men working on her, over 100 are affected with some sort of breaking out and itch and all the men are threatening to quit if we don't find out what's wrong and correct it. The boat's been in the tropics for some time and the workmen fear some tropical disease is responsible for this outbreak."

* C. P. McCord, *A Blind Hog's Acorns*. Cloud, Inc., Chicago, 1945.

Yes, I did want to look around, and within an hour was aboard the ship and observed many of the afflicted men at work. There was considerable grumbling and an abundance of dirty looks. Several men wore bandages over vesicular patches and on a few there was evidence of a generalized fine vesiculation. We went through the ship from stem to stern and forecastle to bilge. It was like a beehive: men were cutting with torches, sawing out panels, knocking off plaster, shoveling out debris and filth, scrubbing, and removing the interior furnishings preparatory to refitting the boat completely. Admittedly the ship was dirty—in fact, in some areas it was filthy—but so what! Next we went to the first-aid room to see the attendant and find out what, if any, information could be obtained there. The place was crowded with patients, and while we waited to see the attendant first-aid man we could hear the grumblings of the waiting patients, who complained of "filthy working conditions" and that, if the health department were not called in to condemn the place, everyone should quit before they became ill—that the place was "infested with fleas" and that they didn't "want any tropical fevers." Finally the harassed attendant came to us, but he had little to offer except to comment that the cases and complaints were getting more numerous and that he certainly hoped we could do something.

We had seen the situation: a once luxuriant ship, somewhat filthy in spots, an explosive outbreak of dermatitis in nearly ten per cent of the 2,000 men at work on the ship, no reported cases among the many thousands of workmen in adjacent areas of the same shipyard, and, unless something were done quickly, work on this desperately needed troop ship and possibly in the entire yard would stop.

The job looked interesting if not easy. We collected samples of everything we could get loose—plaster, upholstery, hair stuffing, sweepings, scrapings from panels and floors, and samples of the different woods and sawdusts, and returned to the laboratory. The samples were turned over to the chemists and microscopists to look for fumigants, insecticides, alkalies, and other common irritants, as well as any signs of insects or parasites. Two members of the staff were inveigled into joining me in making patch tests with some of the materials after saturating them with alcohol as a precautionary measure. While these tests were in progress a medical associate told me with an air of finality that our company had called in, as consultant, an authority on dermatology and that he planned to leave the matter entirely in the consultant's hands. When I took the story to my immediate superior he said it was very interesting, and sometime when he had more time I should "tell him all about it." I telephoned the consultant dermatologist and inquired if he had seen the cases and had any ideas of what might cause the difficulty. Yes, he had seen them, and, except for the fact that it didn't make sense, he would say that they resembled poison-ivy cases. That agreed with what we had seen on the job, but we had not seen any poison ivy! After all of the chemical and microscopic tests proved negative except for an insignificant amount of arsenic in the sweepings, there remained only the possibility that the patch tests might indicate an irritant. After 48 hours, and with all patch tests negative, the shipyard's chemist reported that there were several more cases, including an electrician working on the dock beside the boat, and that a walkout seemed imminent even though the ship was desperately needed for a troop transport.

The fact that an electrician who possibly had not been on the boat was affected gave an indication that the problem might be attacked from epidemiological approach by personally interviewing some of the afflicted men. Discussion of personal matters with employees, especially shipyard workers, is ordinarily something to be avoided, but in this instance approval of such interviews was readily obtained from all parties concerned. Aided by the chemist and two safety engineers, we went out on the job and talked to some of the affected men, including the electrician, who had never been on the suspected ship, and a security policeman, who was seriously affected and had been aboard the ship only once for a few minutes. This introduced a strong element of doubt about the ship's

being the contact source and diverted our attention to other possible sources of irritant material. It developed that nearly all cases were on the day shift. The electrician's case had been diagnosed "cable rash," but, since the characteristics of his lesions were similar to those of the other workmen, we did not waste time examining the cables with which he had been working. Instead, we investigated all the possible exposure sources where the men spent their time when they were off the ship: where they ate their lunch, where they loafed, and the route they took to and from work. We found what appeared to be some damaged oil drums in a pile on a sand lot where several men had spent their lunch hour within the shipyard grounds, but about a block away from the dock to which the boat was tied. The drums were punctured or otherwise damaged and, for the most part, were empty, but three or four contained some dark oily liquid. Close examination of these drums revealed lettering still visible on one which read *Cashew Shell Liquid!*

The cause of the epidemic had been found.

At the shipyard, management quickly announced the facts over a public address system to the workmen so that their fears would be allayed. A strike was averted, and the ship was completed ahead of schedule. Further investigation revealed that cashew shell liquid had been spilled on the dock to some extent, in the street to a considerable amount, and extensively scattered over the sand lot in question. Many of the men working at refinishing and repairing this ship had sat on the sand, or the drums themselves, during the noon hour while they ate their lunches. Others had stretched out in the sun, bare-backed, on the contaminated sand. A check into the source of the drums revealed that a cargo of 1000 drums of the liquid had arrived and been unloaded on the opposite side of this same dock about one month previously. This work had been done by an outside contractor who had dumped the damaged drums onto the unused lot.

At our suggestion, all suspicious-looking spots were covered with chlorinated lime, the dock was cleaned and scrubbed, the drums disposed of, and dirt filled in on the sand lot. The dermatitis, which by now was starting to appear in the homes of workmen, from contact with soiled clothing, quickly disappeared. My colleague, the shipyard's chemist, however, in a sincere effort to convince himself and others of the potency of the cashew liquid, became impatient at negative results obtained in 24 hours with one tiny patch test and tried four more generous patches with samples from different drums. A few days later he joined those who had been hospitalized.

This is not a medical book nor is it intended for legal reference. Its primary purpose is not to aid in the diagnosis and treatment of disease, the winning of compensation, or the refutation of false claims. If it should prove of use in such instances by making some facts more widely available, it may be presumed that the more light that can be thrown upon these phases of industrial medicine and industrial relations the better. It is hoped that much information of use in preventive medicine is included. Diagnostic signs of absorption or of early effects, in advance of injury, are eagerly sought by the progressive industrial physician, and, although time-proved and recognized tests are disappointingly few, the research-minded industrial physician will find opportunities for increasing this field of knowledge. The object of this book is to present industrial hygiene and toxicology in simple, understandable terms in sufficient detail to be of some use to all persons interested in safeguarding the health and welfare of working people and in improving the working environment. Essential requisites for the completely successful advancement of the health and safety of the breadwinning population include: (*1*) competent persons in health and safety maintenance de-

partments; (*2*) managerial interest and appreciation of the benefits to be derived from health and safety work; and (*3*) teamwork—camaraderie, and cooperative efforts among industrial hygiene, medical, and safety personnel.

The welfare of an individual workman involves not only a working environment that gives reasonable assurance of freedom from accidental injury or occupational disease, but also his mental, temperamental, and physical fitness for the work to be done. Incentive, whether in the form of tangible assets to supply the necessities and some of the pleasures of life, or some expression of interest or recognition of accomplishments, ability, and efforts may be involved indirectly, but are somewhat outside the field of industrial hygiene.

It is not possible to maintain a uniform style in a collaboration, but the collective viewpoints compensate for some variations in style. The book is liberally supplied with references for the benefit of those whose wish to pursue the subjects in greater detail.

FRANK A. PATTY

Detroit, Michigan
October, 1948

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USEFUL EQUIVALENTS AND CONVERSION FACTORS

1 kilometer = 0.6214 mile
1 meter = 3.281 feet
1 centimeter = 0.3937 inch
1 micron = 1/25,400 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 = 4,047 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 B.t.u.
1 B.t.u. = 778 foot-pounds
1 B.t.u. per minute = 12.96 foot-pounds per second
1 hp. = 0.707 B.t.u. per second = 550 foot-pounds per second
1 centimeter per second = 1.97 feet per minute = 0.0224 mile per hour
1 foot candle = 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 grains per cubic foot

To convert degrees centigrade to degrees Fahrenheit: °C. (9/5) + 32 = °F.

To convert degrees Fahrenheit to degrees centigrade: (5/9) (°F. − 32) = °C.

For solutes in water: 1 mg./liter ≎ 1 p.p.m. (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 p.p.m. (by volume): mg./liter (24,450/mol. wt.) = p.p.m.

To convert p.p.m. to mg./liter: p.p.m. (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. Mercury Barometric Pressure)

Molecular Weight	1 mg./l. p.p.m.	1 p.p.m. mg./l.	Molecular Weight	1 mg./l. p.p.m.	1 p.p.m. mg./l.	Molecular Weight	1 mg./l. p.p.m.	1 p.p.m. mg./l.
1	24,450	0.0000409	51	479	0.002086	101	242.1	0.00413
2	12,230	.0000818	52	470	.002127	102	239.7	.00417
3	8,150	.0001227	53	461	.002168	103	237.4	.00421
4	6,113	.0001636	54	453	.002209	104	235.1	.00425
5	4,890	.0002045	55	445	.002250	105	232.9	.00429
6	4,075	.0002454	56	437	.002290	106	230.7	.00434
7	3,493	.0002863	57	429	.002331	107	228.5	.00438
8	3,056	.000327	58	422	.002372	108	226.4	.00442
9	2,717	.000368	59	414	.002413	109	224.3	.00446
10	2,445	.000409	60	408	.002554	110	222.3	.00450
11	2,223	.000450	61	401	.002495	111	220.3	.00454
12	2,038	.000491	62	394	.00254	112	218.3	.00458
13	1,881	.000532	63	388	.00258	113	216.4	.00462
14	1,746	.000573	64	382	.00262	114	214.5	.00466
15	1,630	.000614	65	376	.00266	115	212.6	.00470
16	1,528	.000654	66	370	.00270	116	210.8	.00474
17	1,438	.000695	67	365	.00274	117	209.0	.00479
18	1,358	.000736	68	360	.00278	118	207.2	.00483
19	1,287	.000777	69	354	.00282	119	205.5	.00487
20	1,223	.000818	70	349	.00286	120	203.8	.00491
21	1,164	.000859	71	344	.00290	121	202.1	.00495
22	1,111	.000900	72	340	.00294	122	200.4	.00499
23	1,063	.000941	73	335	.00299	123	198.8	.00503
24	1,019	.000982	74	330	.00303	124	197.2	.00507
25	978	.001022	75	326	.00307	125	195.6	.00511
26	940	.001063	76	322	.00311	126	194.0	.00515
27	906	.001104	77	318	.00315	127	192.5	.00519
28	873	.001145	78	313	.00319	128	191.0	.00524
29	843	.001186	79	309	.00323	129	189.5	.00528
30	815	.001227	80	306	.00327	130	188.1	.00532
31	789	.001268	81	302	.00331	131	186.6	.00536
32	764	.001309	82	298	.00335	132	185.2	.00540
33	741	.001350	83	295	.00339	133	183.8	.00544
34	719	.001391	84	291	.00344	134	182.5	.00548
35	699	.001432	85	288	.00348	135	181.1	.00552
36	679	.001472	86	284	.00352	136	179.8	.00556
37	661	.001513	87	281	.00356	137	178.5	.00560
38	643	.001554	88	278	.00360	138	177.2	.00564
39	627	.001595	89	275	.00364	139	175.9	.00569
40	611	.001636	90	272	.00368	140	174.6	.00573
41	596	.001677	91	269	.00372	141	173.4	.00577
42	582	.001718	92	266	.00376	142	172.2	.00581
43	569	.001759	93	263	.00380	143	171.0	.00585
44	556	.001800	94	260	.00384	144	169.8	.00589
45	543	.001840	95	257	.00389	145	168.6	.00593
46	532	.001881	96	255	.00393	146	167.5	.00597
47	520	.001922	97	252	.00397	147	166.3	.00601
48	509	.001963	98	249.5	.00401	148	165.2	.00605
49	499	.002004	99	247.0	.00405	149	164.1	.00609
50	489	.002045	100	244.5	.00409	150	163.0	.00613

Molecular Weight	1 mg./l. p.p.m.	1 p.p.m. mg./l.	Molecular Weight	1 mg./l. p.p.m.	1 p.p.m. mg./l.	Molecular Weight	1 mg./l. p.p.m.	1 p.p.m. mg./l.
151	161.9	0.00618	201	121.6	0.00822	251	97.4	0.01027
152	160.9	.00622	202	121.0	.00826	252	97.0	.01031
153	159.8	.00626	203	120.4	.00830	253	96.6	.01035
154	158.8	.00630	204	119.9	.00834	254	96.3	.01039
155	157.7	.00634	205	119.3	.00838	255	95.9	.01043
156	156.7	.00638	206	118.7	.00843	256	95.5	.01047
157	155.7	.00642	207	118.1	.00847	257	95.1	.01051
158	154.7	.00646	208	117.5	.00851	258	94.8	.01055
159	153.7	.00650	209	117.0	.00855	259	94.4	.01059
160	152.8	.00654	210	116.4	.00859	260	94.0	.01063
161	151.9	.00658	211	115.9	.00863	261	93.7	.01067
162	150.9	.00663	212	115.3	.00867	262	93.3	.01072
163	150.0	.00667	213	114.8	.00871	263	93.0	.01076
164	149.1	.00671	214	114.3	.00875	264	92.6	.01080
165	148.2	.00675	215	113.7	.00879	265	92.3	.01084
166	147.3	.00679	216	113.2	.00883	266	91.9	.01088
167	146.4	.00683	217	112.7	.00888	267	91.6	.01092
168	145.5	.00687	218	112.2	.00892	268	91.2	.01096
169	144.7	.00691	219	111.6	.00896	269	90.9	.01100
170	143.8	.00695	220	111.1	.00900	270	90.6	.01104
171	143.0	.00699	221	110.6	.00904	271	90.2	.01108
172	142.2	.00703	222	110.1	.00908	272	89.9	.01112
173	141.3	.00708	223	109.6	.00912	273	89.6	.01117
174	140.5	.00712	224	109.2	.00916	274	89.2	.01121
175	139.7	.00716	225	108.7	.00920	275	88.9	.01125
176	138.9	.00720	226	108.2	.00924	276	88.6	.01129
177	138.1	.00724	227	107.7	.00928	277	88.3	.01133
178	137.4	.00728	228	107.2	.00933	278	87.9	.01137
179	136.6	.00732	229	106.8	.00937	279	87.6	.01141
180	135.8	.00736	230	106.3	.00941	280	87.3	.01145
181	135.1	.00740	231	105.8	.00945	281	87.0	.01149
182	134.3	.00744	232	105.4	.00949	282	86.7	.01153
183	133.6	.00748	233	104.9	.00953	283	86.4	.01157
184	132.9	.00753	234	104.5	.00957	284	86.1	.01162
185	132.2	.00757	235	104.0	.00961	285	85.8	.01166
186	131.5	.00761	236	103.6	.00965	286	85.5	.01170
187	130.7	.00765	237	103.2	.00969	287	85.2	.01174
188	130.1	.00769	238	102.7	.00973	288	84.9	.01178
189	129.4	.00773	239	102.3	.00978	289	84.6	.01182
190	128.7	.00777	240	101.9	.00982	290	84.3	.01186
191	128.0	.00781	241	101.5	.00986	291	84.0	.01190
192	127.3	.00785	242	101.0	.00990	292	83.7	.01194
193	126.7	.00789	243	100.6	.00994	293	83.4	.01198
194	126.0	.00793	244	100.2	.00998	294	83.2	.01202
195	125.4	.00798	245	99.8	.01002	295	82.9	.01207
196	124.7	.00802	246	99.4	.01006	296	82.6	.01211
197	124.1	.00806	247	99.0	.01010	297	82.3	.01215
198	123.5	.00810	248	98.6	.01014	298	82.0	.01219
199	122.9	.00814	249	98.2	.01018	299	81.8	.01223
200	122.3	.00818	250	97.8	.01022	300	81.5	.01227

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

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