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HEALTH HAZARDS IN THE FOUNDRY INDUSTRY*

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Introduction

In April, 1931, the Wisconsin Manufacturers Association, through Mr. Harold S. Falk, Chairman of the Association's committee on dust, fumes, vapors and gases, requested the Metropolitan Life Insurance Company to extend a health survey, undertaken for a group of its own policyholders, to include representative foundries in the State of Wisconsin for the purpose of determining the extent and nature of the health hazards in the industry, with the object of recommending measures for better and more sanitary working conditions.

The proposed study was discussed with Mr. F. M. Wilcox, Chairman of the Industrial Commission for the State of Wisconsin, who endorsed the Association's request that the Metropolitan Life Insurance Company undertake the survey. This request met with the approval of Mr. F. H. Ecker, President of the Metroplitan Life Insurance Company, who directed the Industrial Health Section to conduct the study.

Acknowledgment is gratefully made for the counsel and technical assistance of the following individuals in making this survey:

Dr. F. V. Meriwether, Surgeon, U. S. Public Health Service.
Dr. A. J. Lanza, Assistant Medical Director, Metropolitan Life Insurance Company.
Mr. P. A. Petrick, Laboratory Assistant, Metropolitan Life Insurance Company.

Scope and Technic of the Survey

Although a total of 41 foundries has been surveyed by the Industrial Health Section to date, twenty-one foundries were selected for this study as representative of the industry. The various types of foundries were classified in four general groups, namely:

A. Grey iron foundries;
B. Steel foundries;
C. Malleable iron foundries;
D. Non-ferrous metal foundries.

The first group (A) is represented by plants A to L inclusive. Plant J of this group manufactures both iron and steel castings, and Plant K manufactures grey iron and malleable iron castings. The former, therefore, may be classified in groups A and B, and the latter in groups A and C.

The second group (B) is represented

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by plants M to P inclusive; the third group (C) by plants Q to T inclusive; and the fourth group by plant U. Plant Q manufactures steel and malleable iron castings and may be classified in groups B and C.

The survey includes plants of all sizes and those considered good, average and poor. Therefore, the selection is representative of the industry, as far as size and plant conditions are concerned. Although physical examinations were not made, except where these were the routine of the plant, 215 X-ray examinations of the chests of workers exposed to foundry dusts were made. These workers were selected from locations where the dust concentrations were highest. Dust samples were taken at various places of employment and in the line of travel in each department. To secure a picture of working conditions and, if possible, sources of health hazards, process analyses were made, and sanitary conditions and personal service facilities were noted.

Measuring Instruments and Methods of Collecting Samples

The measuring instruments used in the survey were the foot candle meter for determining the illumination at the working levels; the sling psychrometer for measuring the dry and wet bulb temperatures; flasks for collecting gas samples which were analyzed for carbon monoxide; and the impinger and electrical precipitator for collecting dust samples.

Air samples were collected around the cupolas and in the vicinity of freshly poured molds. These were analyzed for carbon monoxide by the pyrotannic acid method, but the results of these analyses were negative.

Air sampling for dust was made with the impinger (1) method which collects the dust by aspirating the air and impinging it onto a flat surface covered by a liquid in a container; and with the electric precipitator (2), an instrument designed upon the principle of a Cottrell precipitator. Both are standard methods used in America for determining dust concentrations and particle size.

The impinger was placed in close proximity to the largest groups of workmen and at a height corresponding to the breathing level of these workers. The liquid used in the container of the impinger consisted of distilled water. The impingers were actuated by suction supplied by steam ejectors operated by compressed air. The rate of air flow, during sampling, was measured by means of a small vacuum gauge inserted into the suction line. The entire set-up, in turn, had previously been standardized against a standard wet meter. Wherever masks or respirators were worn by the workmen, a connection was made either into or under the helmet by means of rubber tubing which was connected to the impinger. Each sample collected by the impinger method represented a sample of dust from a volume of air amounting to from 50 to 100 cubic feet.

The electric precipitator was placed in a position similar to that of the impinger. The air is drawn through this instrument by means of a small rotary fan, run by a motor, the quantity being measured by a flow meter. Each sample collected by the electric precipitator represented a volume of air of from 10 to 50 cubic feet. These samples were used for determination of particle size.

Particle size measurements were made by taking microphotographs at a known magnification of the dried preparation of dust, as described by Green (3), and then enlarging the negative further by projecting the images upon a screen by means of a stereopticon. The longest diameters of the images of the dust particles were then measured upon the screen. From the results of a sufficient number of these measurements a curve was plotted of the size frequency relations on Hazens' logarithmic probability paper, the logarithms of the function measured in microns plotted as ordinates, and the probability of occurrence as abscissae (3, 4). It is a simple procedure to interpolate from these plots, which develop into straight lines, the frequency of occurrence of any sized dust particle less than 10 microns present in the particular dust under investigation.

It has been demonstrated repeatedly that no silica particles exceeding 10 microns (5) in greatest diameter enter the lung tissue, and for this reason it has been the general practice to count only dust particles under 10 microns. Figure 1 indicates that 96 per cent. of the dust particles were less than 10 microns and 55 per cent. were less than 3 microns in greatest diameter.

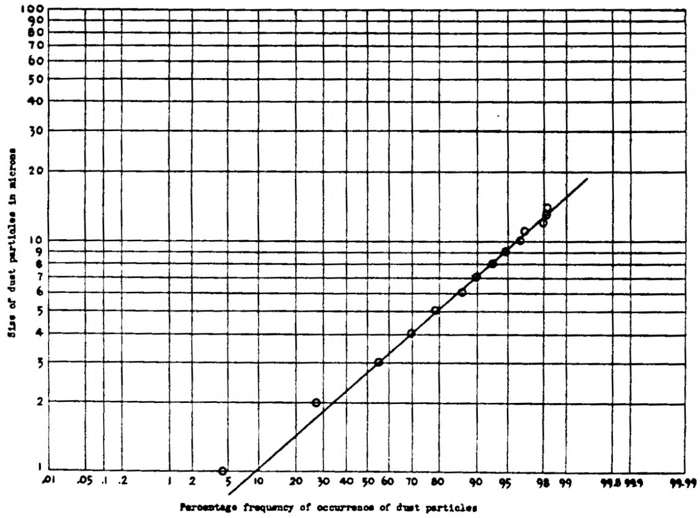

FIG. 1.—Composite Graph of General Air Samples from 12 Foundries of Which 3 are Steel, 5 Grey Iron and 4 Malleable Iron Foundries

DUST COUNTS

The reader is referred to the March

18, 1932 number of Public Health Reports (6) for a detailed description of methods for standardizing and cleaning equipment and necessary precautions for accurate work. Accurate technic is acquired only by observation and diligent work under the guidance of a qualified technician. The method of dust counting used by the United States Public Health Service is an empirical or rule-of-thumb technic devised to measure the extent of air dustiness. This method was demonstrated to be effective in the Service study of the granite industry at Barre, Vt. (7).

In 1928, one of us, J. W. F. (8), while conducting a study of the hazards of rock drilling on building and subway construction work in New York City, experienced difficulty in checking with this standard procedure of counting and after consultation with other technicians it was learned that certain modifications were introduced, such as tilting or shading the microscope mirror, thereby modifying the light. With the increase of the free silica content of the dust the difficulties in counting by the standard procedure increased. It was definitely demonstrated by experimentation that as the dust approached the pure form of free silica, the refraction approached that of the lens system of the microscope, making it difficult to focus the image clearly. Therefore, a modification of the illumination was tried by using a Plankton or fixed stop condenser, which resulted in marked improvement. A series of counts was conducted by both standard and the modified illumination, and it was found that the counts checked more consistently, but they also ran higher by the modified method than by the standard light field procedure. It was found later that this procedure of modified dark field counting is identical with the method used on the Witwatersrand in South Africa since July, 1923. The advantages of the modified dark field over the standard light field illumination are illustrated in the photographs here reproduced of identical fields using 3 micron silica, the only difference being the type of illumination (Figs. 2 and 3).

It has been demonstrated that the employment of the dark field method enables one to count readily particles of 0.5 micron in size, while with the standard light field method particles under 1.5 microns are frequently missed. Both methods were used in this study and it was found that the modified dark field method gave results consistently twice as great as the standard light field procedure. The results obtained by the standard light field method are here reported.

Foundry Buildings and Plant Processes

The general condition and appearance of foundries have been improved and they have, therefore, become more desirable places in which to work. The foundry buildings for the most part are large and high, with a great amount of window space available. Brick, stone, corrugated iron and steel are the usual materials used in construction, although a few foundries of frame construction were found.

Foundry work requires the use of ponderous machinery. Industrial railways, cranes, hoisting accessories and certain types of foundry machinery are of interest from the viewpoint of accidents, but need not be discussed in this report which is confined to the determination of health hazards.

Plant Hygiene

Illumination.—While most of the foundries studied have a large window area, thus permitting the use of natural illumination in the vicinity of the windows, the majority require some system of artificial lighting. It is recognized that an adequate supply of natural light is desirable and it could be more generally used by providing a systematic method of cleaning of windows. It was noticed that in some instances, where the windows were not cleaned for a long period, the glass had become rust-pitted and almost opaque, resulting in the transmission of very little light.

Artificial light is not always used advantageously. The use of bare lamps is to be discouraged from the standpoint of operating economy and on account of the glare, which is annoying to workers. Steel reflectors having a porcelain enamelled reflecting surface are well adapted to foundry work. Special treatment of foundry illumination is almost a necessity, owing to the darkness of the materials used, which absorb a great deal of light, and on account of the smoke, steam and dust in the air, through which the light must penetrate. A large volume of light is required and can be secured by large lamps or clusters of smaller units, hung low enough and equipped with reflectors and diffusing globes which direct the light downward in order to distribute properly the light on the work. Where bench work or machine molding is done, the general illumination

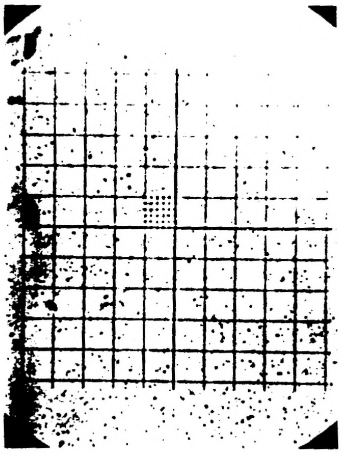

Fig. 2.—Standard Light Field

Fig. 3.—Modified Dark Field

should be reinforced with local illumination. The cleaning of these units at frequent intervals is important. The painting of the interiors of foundries with light colored paints will facilitate light distribution.

Ventilation.—The usual ventilation of foundries is by means of windows. A system of forced draft, either for general ventilation or for the ventilation of individual rooms, is used in some instances. The general ventilation is supplemented, as a rule, by ventilating hoods at specific points. The ventilation of foundries, so far as supplying pure air for breathing is concerned, is quite difficult on account of the smoke, fumes, and dust incident to foundry work. Where these can be collected and exhausted at the point of origin, the problem of their control is simplified, but unfortunately this cannot always be effectively accomplished.

Air dustiness.—The introduction of new methods, new apparatus, and new protective measures has greatly ameliorated the atmosphere in foundries. The mechanical cleaning of castings in conjunction with suitable exhausts, the use of tumbling operations and dust-tight sand blast rooms, the hydraulic washing of castings, and the provision of positive air pressure helmets for workers engaged in sand blasting are all measures designed to control the health hazards resulting from the inhalation of dust. Certain types of foundry work must be done by the older methods, particularly large castings where the production is so infrequent as not to warrant the expense of sand blast equipment, or where the size or character of their cores will not admit the use of sand blast equipment. It is a fact, however, that most of the dust incident to foundry work results from defective equipment and lack of proper maintenance.

The dusts encountered in foundries have a high free silica content, averaging between 50 per cent. and 90 per cent. free silica, which makes control of these dusts a necessity.

Dusty processes.—The health hazard from the inhalation of foundry dust results chiefly from three foundry operations:

1. *Sand conditioning and conveying.*—The conditioning of the sand which is accomplished by the addition of binders, such as flour, molasses and water in proper proportions, together with sieving, mixing and the preparation of the mold facing sand, is usually done in the central area of the foundry. The sand is carried back and forth by means of mechanical conveyors. Although by centralizing these operations, the raw materials and conditioned sand are conveyed a minimum distance, the dusts that are created are distributed throughout the entire foundry. Marked improvement, from the viewpoint of dustiness, would be noticeable were these operations to be carried out in a separate department completely isolated from the foundry proper, and a considerable amount of dust could be confined by enclosing the sand conveyors.

2. *Shake-out operations.*—These operations are usually located near the sand conditioner, but may be carried on in any convenient space in the foundry. When a sand cutter is used for sand conditioning, it is customary to shake out castings wherever poured.

Because of the hot dry sand and the mechanical means of handling castings subjected to the shaking out operations, clouds of fine silica dust are set up which penetrate the entire foundry atmosphere, thus exposing practically every worker to the dust. In foundries where heavy castings are shaken out by means of suspending the mold with a crane and applying a vibrator hammer, fewer workmen would be exposed to the dust if the operations were carried out in a separate room or, preferably, outside the foundry proper. In the case of small castings, the shaking out operation can be done over a grate attached to an exhaust or in a separate room. Where the molding is done on the foundry floor and a sand cutter is used for sand conditioning, the shaking out operation should be begun preferably at the end of the working period, thus exposing the least number of foundry workers to the resulting dust. Sufficient time would elapse for the dust to settle before the beginning of the next working day.

Cores are now effectively removed from castings by washing with high pressure streams of water inside a cabinet or outdoors. This operation eliminates the dust hazard due to hand removing and cleaning.

3. *Cleaning operations.*—Casting cleaning by means of chipping, grinding, and sand blasting is sometimes carried on in a separate department, but it is common practice to conduct these operations in the foundry proper at almost any convenient location that has the advantage of the least amount of handling. Proper hoods and exhausts for entrapping dust arising from grinding wheels, and mechanical maintenance of a good type of sand blast cabinet, together with the use of an efficient type of respirator by operators, will greatly aid in safeguarding the workers.

Harmfulness of Silica Dust

The hazard of silica dust with special reference to the lungs has long been appreciated. It has been firmly established that the inhalation of this dust results in a fibrosis of the lungs, which disease is known as "silicosis," and its presence, for some reason yet ill-defined, results in extraordinary predisposition to pulmonary tuberculosis. It should be borne in mind that silicosis develops very slowly, taking from five to fifteen and even twenty to twenty-five years to become established. This rate of progress is influenced mainly by the dosage of silica which the lungs receive and this dosage, in turn, depends upon three variables: the amount of silica in the dust, the quantity and particle size of dust in the air, and the extent of exposure. Individual idiosyncrasy might be included as a fourth variable. However, little is known of the variations in susceptibility in those exposed to dust.

In an investigation of granite cutting plants (7), conducted by the United States Public Health Service, most of the workers were found to be exposed to an average of about 60,000,000 particles of dust of less than 10 microns in greatest diameter, per cubic foot of air. The dust contained about 70 per cent. silica, of which about 35 per cent. was in the form of quartz or free silica. Under such conditions, there was an almost universal occurrence of silicosis among those exposed 20 years and longer, and a large proportion of the workers developed pulmonary tuberculosis. It was not found in this investigation that it would be necessary to eliminate all of the dust to do away with the hazard. A safe limit of between nine and twenty million particles of dust, less than 10 microns in longest diameter, per cubic foot of air could be established. The conditions of atmosphere involved in this investigation, however, are not comparable to those encountered in the foundries.

Table I gives the dust counts by plants and by processes for the various types of foundries.

These counts represent the air dustiness at a given place and for a given period during which the collecting device was in operation, and merely suggest the extent of atmospheric pollution. It must be remembered, however, that these conditions may vary during the working day period and from day to day.

The value of dust determinations lies in their employment as a measurement for the efficiency of devices and equipment designed to control dust, rather than for the purpose of establishing safe limits of air dustiness. It will be noticed that the counts listed under plant L are consistently lower than those under other grey iron foundries, and are entirely due to the progress this plant has made in controlling the dust through well designed equipment and effective exhaust systems.

A safe limit of air dustiness for foundries has never been established, but presumably on account of the high silica content of the dust the count representing a safe limit would be comparatively low and in many instances impracticable to maintain. Protection can best be afforded to foundrymen by isolating dusty processes as far as practicable; by the employment of well designed and well constructed dust-tight equipment; by the substitution, wherever possible, of mechanical cleaning for hand cleaning; by the adequate maintenance of general ventilation and local exhaust systems; by good housekeeping; and by supplying workers exposed to dust, which cannot otherwise be controlled, with adequate respiratory protective equipment. Responsibility does not end with the installation of proper facilities, but these must be adequately maintained through regular and intelligent inspection. A responsible person or persons directly under the supervision of the management should be assigned the task of inspecting equipment and supervising housekeeping conditions.

X-ray Examinations

Although certain symptoms and signs suggestive of silicosis may be found on physical examination, the diagnosis rests mainly on the X-ray film of the chest. The progress of silicosis has been classified by Lanza and Childs (9) based upon roentgen-ray findings into three stages. The appearances during the progress of the condition are so strikingly different that anyone is likely to select practically the same classification. The first stage demonstrates a beginning fibrosis; the trunk shadows are increased in density and breadth, with numerous punctate deposits of varying size along them. Second stage: in addition to the foregoing, there are found fairly symmetrical, small, circumscribed, dense areas throughout both lungs, and later larger masses accumulate. Third stage: this differs from the second stage only in the extent of lung involvement, indicated by increased numbers of deposits and more massive grouping.

There were 130 employees of the grey iron foundries selected for X-ray examinations of the chest. Of these 1 was diagnosed as second degree silicosis, 31 as first degree, 20 as doubtful for silicosis, and 78 negative for silicosis; of 62 employees in the steel foundries, 2 were diagnosed as second degree silicosis, 25 as first degree, 6 as doubtful, and 29 as negative; of 18 employees of the malleable iron foundries, 7 were diagnosed as first degree, 2 as doubtful, and 9 as negative, and of 5 employees of the non-ferrous metal foundries examined, 1 was diagnosed as first degree, 1 as doubtful, and 3 as negative.

The management of each foundry was furnished with a table setting forth a detailed description of the X-ray examination of each worker, correlated with his age, occupation, previous occupation, years of exposure, and other pertinent information indicating the extent of the health hazard. The name of the worker was omitted and a number substituted in order to avoid any discrimination.

Tables II, III, and IV give the results of the X-ray examinations by age groups, by years of exposure, and by occupations for the groups examined.

It is obvious that these tables merely indicate what may be expected and are of no statistical value because the examinations were limited to a few workers only in each group. The individual was classified either according to the department in which he worked at the time of examination or where he had spent most of his time. Many had changed from one department to another and from one plant to another during their years of employment in the foundry industry. Since only the amounts of dust collected at the time of this survey in the various departments are known, there is no way of determining the average amount of dust in the atmosphere inhaled by these people over the years of their employment. Consequently, it is not possible to correlate individual cases with definite amounts of dust exposure.

Mortality Experience Among Foundry Workers in United States and Great Britain

Although this study did not include the collection of information relative to sickness among foundrymen, the Statistical and Actuarial Departments of the Metropolitan Life Insurance Company, in a study of mortality statistics, have supplied the following evidence to show that foundry workers are subject to an unusually high incidence of respiratory diseases.

Mortality statistics both American and foreign, covering a long period of years, agree in recording high death rates for respiratory diseases for foundry workers. These studies, it must be admitted, have been far from complete, giving little indication of the specific processes responsible for the excess mortality from these causes. Nevertheless, the results have been so consistent as to leave little doubt concerning the presence of some condition

TABLE I

DUST COUNTS BY PLANTS AND PROCESSES

Grey iron foundries

PROCESSES	PLANT A	PLANT B	PLANT C	PLANT D	PLANT E	PLANT F	PLANT G	PLANT H	PLANT I	PLANT J*	PLANT K†	PLANT L
	million particles‡	million particles	million particles	million particles	million particles	million particles	million particles	million particles	million particles	million particles	million particles	million particles
1. Coremaking:												
a. Hand	9.3	2.5	1.0		4.5	1.9		5.8	24.2	10.1	5.1	3.6
b. Machine	9.4				6.1	5.7						4.3
2. Corerubbing					47.7							8.7
3. Molding:												
a. Hand bench		10.0			9.4						5.3	
b. Hand floor								10.2	5.1	35.2		
c. Machine and hand bench		11.9	4.5									
1. Sandslingers	14.5	20.3			474.6	16.6		25.4				
2. Jar and squeeze	20.3	9.5	6.0		79.7		15.7	14.5				11.16
3. Bumper									8.3			
d. Roll-over	13.0								8.8	16.4	10.3	7.9
4. Shake-out:												
a. Floor	12.2		5.0				31.2			10.6		
b. Castings suspended on crane, cleaned by hand and air hammer	11.8	8.0		6.6								
c. On continuous line casting machines	22.6	51.0			66.4			10.1				24.3
d. Traveling crane used in combination with continuous line casting machines												11.1
5. Cleaning:												
a. Chipping	4.8											11.1
b. Flexible shaft grinder		59.5		184.5								
c. Stand grinder	5.4			108.8	47.6		7.8			58.4		2.5
d. Swing grinder		65.8			158.1			49.4		9.0		4.0

1. Sand blasting cabinets		22.7										
a. From under helmet	70.7	437.5§		23.5	1,036.3	39.8			202.7	141.7	74.3	3.9
b. Operator outside cabinet				52.8	98.2							6.0
2. Rotary sand blasting	57.5						126.2					
3. Tumbler barrels	7.8											2.5
4. Blasting cabinets using steel shot												
5. Rotary blasts using steel shot			1.5									
6. Tumbler barrels using steel shot												
6. Sand reconditioning:												
a. Mechanical	37.4	23.0		263.6	22.2						23.4	
b. Sand cutters												
7. Conditioning of core sand												
8. General air sample in foundry	12.47	5.0			3.2	2.7	12.5	8.0	8.3	17.9	3.5	8.9
9. General air sample in cleaning room			7.0	76.8		3.1	23.6	10.7		15.8	10.8	
10. General air sample in core room					49.4		19.7					7.0
11. Facing mills					2,608.1	32.4		445.7	34.6			

* Plant J has both a grey iron and steel foundry; see table for steel foundries.
† Plant K has both a grey iron and malleable foundry; see table for malleable foundries.
‡ Millions of particles less than 10 microns per cubic foot of air.
§ Home-made helmet.
In some instances the counts given in the tables are averages of several samples taken at the same station within a short period of time.

TABLE I—*Continued*

Steel foundries

PROCESSES	PLANT J*	PLANT M	PLANT N	PLANT O	PLANT P	PLANT Q†
	million particles	*million particles*	*million particles*	*million particles*	*million particles*	*million particles*
1. Coremaking:						
a. Hand	12.2	14.7	8.5	4.7	5.1	1.0
b. Machine						
2. Corerubbing						
3. Molding:						
a. Hand bench	19.5	16.2			10.0	
b. Hand floor	160.2	1.3	7.3	13.8	6.5	
c. Machine and hand bench:						
1. Sandslingers						2.0
2. Jar and squeeze		9.0	33.9			
3. Bumper		9.1	13.0		11.4	
d. Roll-over				21.7		
4. Shake-out:						
a. Floor	4.3		2.1			
b. Casting suspended on crane cleaned by hand and air hammer		82.9	23.0	12.0	19.1	3.0
c. On continuous line casting machines						
d. Traveling crane used in combination with continous line casting machines						
e. Floor shaker		25.9		9.5		
5. Cleaning:						
a. Chipping				22.6		
b. Flexible shaft grinder						
c. Stand grinder		1.3	5.7	10.9		36.5
d. Swing grinder		16.9	15.0	36.2	6.5	25.5
1. Sand blasting cabinets under helmets	1,235.5	638.7	148.0	110.7	300.7	217.7
a. Operator outside cabinet						

2. Rotary sand blasting			12.8			
3. Tumbler barrels			5.5		3.2	32.0
4. Blasting cabinets using steel shot (under helmet)		5.2				
5. Rotary blasts using steel shot						
6. Tumbler barrels using steel shot						
6. Sand reconditioning:						
a. Mechanical		20.6				
b. Sandcutters						
7. Conditioning of core sand				8.1		
8. General air sample in foundry	34.3	2.95	5.1	22.3	7.9	13.0
9. General air sample in cleaning room		5.8		1.3	6.9	
10. General air sample in core room	6.4	4.5		5.2		
11. Facing mills	251.0	58.3	274.9	3.6	8.5	

* Plant J has both a grey iron and steel foundry; see table for grey iron foundries.
† Plant Q has both a steel and malleable foundry; see table for malleable foundries.

Malleable foundries. Non-ferrous metal foundries

PROCESSES	PLANT K*	PLANT Q†	PLANT R	PLANT S	PLANT T	PLANT U
	million particles	*million particles*	*million particles*	*million particles*	*million particles*	*million particles*
1. Coremaking:						
a. Hand	9.5	2.8	1.7		6.1	19.7
b. Machine				5.6		
2. Corerubbing						
3. Molding:						
a. Hand bench	44.8			10.5		
b. Hand floor			1.4			27.8
c. Machine and hand bench		3.0				
1. Sandslingers						
2. Jar and squeeze	25.8		2.2		28.4	4.6
3. Bumper				3.8		
d. Roll-over						

TABLE 1—*Concluded*

Malleable foundries. Non-ferrous metal foundries—*Concluded*

PROCESSES	PLANT K*	PLANT Q†	PLANT R	PLANT S	PLANT T	PLANT U
	million particles	*million particles*	*million particles*	*million particles*	*million particles*	*million particles*
4. Shake-out:						
a. Floor	75.4				97.0	20.8
b. Casting suspended on crane, cleaned by hand and air hammer		13.0	2.1	6.7		
c. On continuous line casting machine						
d. Traveling crane used in combination with continous line casting machines						
5. Cleaning:						
a. Chipping						
b. Flexible shaft grinder						
c. Stand grinder	13.4	10.0	1.5	8.9		5.9
d. Swing grinder						
1. Sandblasting cabinets from under helmet		12.5				
a. Operator outside cabinet						7.1
2. Rotary sandblasting	209.0		4.4	3.7		
3. Tumbler barrels	6.0	22.0			13.9	11.8
4. Blasting cabinets using steel shot						
5. Rotary blasts using steel shot						
6. Tumbler barrels using steel shot			0.8			
6. Sand reconditioning:						
a. Mechanical						
b. Sandcutters		52.5			59.4	
7. Conditioning of core sand						
8. General air sample in foundry	16.5	7.0	2.3	3.6	12.7	5.9
9. General air sample in cleaning room						17.1
10. General air sample in core room	4.3					6.7
11. Facing mills		67.5				

* Plant K has both a grey iron foundry and malleable foundry; see table for grey iron foundries.

† Plant Q has both a steel and malleable foundry; see table for steel foundries.

in the foundrymen's work which operates to produce a high incidence of respiratory affections among them. What few statistics there are on the incidence of disabling sicknesses and of the incidence of physical impairments among these workers, support the findings of the mortality investigations.

Three recent mortality investigations, made by American life insurance companies, and a report of the Registrar General of England and Wales show clearly how unfavorable is the respiratory disease mortality of foundrymen. In the following paragraphs, we shall discuss the main findings of these investigations:

Combined group mortality experience.—1922–1930 (10).—Table V was compiled from the report entitled "Combined Group Mortality Experience 1922–1930" published by the Committee on Group Mortality Investigations, July 17, 1931. The Committee analyzed the mortality records of employees of industrial concerns insured under Group Life

TABLE II

AGE GROUPS

	GREY IRON			STEEL			MALLEABLE IRON			NON-FERROUS METAL		
	Positive	Doubtful	Negative	Positive	Doubtful	Negative	Positive	Doubtful	Negative	Positive	Doubtful	Negative
years												
50 and over	11	6	13	6	1	3	1	0	2	0	0	0
40–49	14	7	29	11	3	9	0	1	0	1	1	0
30–39	7	6	22	7	0	12	3	1	2	0	0	2
20–29	0	1	13	3	2	5	0	0	1	0	0	1
Under 20	0	0	1	0	0	0	0	0	0	0	0	0
Not given	0	0	0	0	0	0	3	0	4	0	0	0
Total examined...	32	20	78	27	6	29	7	2	9	1	1	3

TABLE III

YEARS OF EXPOSURE

	GREY IRON			STEEL			MALLEABLE IRON			NON-FERROUS METAL		
	Positive	Doubtful	Negative	Positive	Doubtful	Negative	Positive	Doubtful	Negative	Positive	Doubtful	Negative
years												
15 and over	19	9	18	12	2	8	1	2	1	1	1	2
10–15	5	3	13	5	1	7	2	0	1	0	0	1
5–10	5	7	29	8	1	7	3	0	2	0	0	0
Under 5	3	1	18	2	2	7	1	0	3	0	0	0
Not given	0	0	0	0	0	0	0	0	2	0	0	0
Total examined...	32	20	78	27	6	29	7	2	9	1	1	3

Insurance contracts written by six large American and Canadian insurance companies. All employees of a particular company, regardless of occupation, are classified under but one industry.

It is more than twice that for workers in any of the industries selected for comparison. More than one-third of all the deaths among foundry workers were caused by some respiratory disease, whereas but little more than

TABLE IV

By Occupation

	Grey iron			Steel			Malleable iron			Non-ferrous metal		
	Positive	Doubtful	Negative	Positive	Doubtful	Negative	Positive	Doubtful	Negative	Positive	Doubtful	Negative
Molding	7	3	5	5	2	5	0	1	2	1	1	1
Coremaking	2	3	5	4	0	2	0	1	1	0	0	1
Pouring metal	0	0	0	0	0	1	0	0	0	0	0	0
Chipping	0	0	2	5	1	5	0	0	1	0	0	0
Sand blasting	1	2	9	2	1	1	0	0	1	0	0	1
Tumbler operators	0	1	0	0	0	0	2	0	2	0	0	0
Sand conditioning	1	0	0	0	0	0	0	0	0	0	0	0
Sand cutter	1	0	0	0	0	0	1	0	0	0	0	0
Sand mixing	0	1	0	0	0	0	0	0	0	0	0	0
Annealing	0	0	0	0	0	0	1	0	1	0	0	0
Melter (electric furnace)	0	0	0	0	0	1	0	0	0	0	0	0
Poke out	0	0	0	0	0	1	0	0	0	0	0	0
Shake-out	1	2	7	2	0	4	0	0	0	0	0	0
Grinding (swing or stand)	3	0	5	2	0	3	1	0	0	0	0	0
Steel treating	0	0	0	1	0	0	0	0	0	0	0	0
Flame cutter	0	0	0	0	0	1	0	0	0	0	0	0
Machine repairer	0	0	0	0	1	0	0	0	0	0	0	0
Foundry laborer	0	0	1	0	0	0	1	0	0	0	0	0
Cleaning mill operator	0	0	0	0	0	0	1	0	0	0	0	0
Craneman	0	1	0	2	1	4	0	0	0	0	0	0
Chainman	0	0	0	1	0	1	0	0	0	0	0	0
Welding	0	0	0	3	0	0	0	0	0	0	0	0
Cleaning room laborer	1	1	1	0	0	0	0	0	0	0	0	0
Cupola tender	1	0	2	0	0	0	0	0	0	0	0	0
Enameller	0	0	2	0	0	0	0	0	0	0	0	0
Painter	0	0	1	0	0	0	0	0	0	0	0	0
Not given	14	6	38	0	0	0	0	0	1	0	0	0
Total examined	32	20	78	27	6	29	7	2	9	1	1	3

The death rate for respiratory diseases (including all forms of tuberculosis and influenza) for iron and steel foundry workers, is shown to be about two and one-third times that for workers in all industries combined.

one-fifth of the deaths of workers in other industries were due to these causes.

Table VI is also based upon the Combined Group Mortality Experience. It presents death rates by ages for influenza, tuberculosis (all forms), and other diseases of the respiratory system, as well as for this group of causes as a whole.

TABLE V

DEATHS FROM RESPIRATORY DISEASES* PER 1,000 LIFE YEARS EXPOSED (COMBINED GROUP MORTALITY EXPERIENCE 1922–1930); ALL AGES

INDUSTRY	LIFE YEARS EXPOSED	DEATH RATE PER 1,000	PER CENT RESPIRATORY DEATHS OF TOTAL DEATHS
Steel and iron foundries	450,012	3.39	33.9
Sheet metal products (stamping and pressing)	209,196	1.42	23.0
Light metal products (tools, hardware, etc.)	1,070,598	1.65	22.7
Heavy machinery and other heavy metal products	920,024	1.53	22.1
Bituminous coal mining—underground	153,407	1.54	15.5
All industries	20,353,369	1.45	20.9

* Influenza and tuberculosis (all forms) are included.

TABLE VI

DEATHS FROM RESPIRATORY DISEASES* PER 1,000 LIFE YEARS EXPOSED (COMBINED GROUP MORTALITY EXPERIENCE 1922–1930)

(A) Steel and iron foundry employees—450,012 years of life exposed. (B) All industries—20,353,369 years of life exposed

1	2	3	4	5	6	7	8	9	10	11	12	13
CENTRAL AGE	TOTAL RESPIRATORY DISEASES*			INFLUENZA		TUBERCULOSIS (ALL FORMS)		OTHER RESPIRATORY DISEASES		PER CENT. RESPIRATORY DISEASE DEATHS OF TOTAL DEATHS		
	A	B	A/B	A	B	A	B	A	B	A	B	Per cent A/B
18	1.12	0.76	147	0.14	0.04	0.19	0.45	0.79	0.26	34.8	32.8	106
23	1.67	0.83	201	0.06	0.04	0.48	0.51	1.14	0.27	44.0	32.6	135
28	2.09	0.86	243	0.08	0.04	0.57	0.48	1.45	0.34	48.7	30.8	158
33	2.57	0.97	265	0.11	0.06	0.91	0.45	1.55	0.45	51.7	29.3	177
38	3.25	1.24	262	0.16	0.08	0.87	0.51	2.22	0.65	47.3	27.8	170
43	3.53	1.52	232	0.29	0.10	0.89	0.57	2.35	0.86	40.6	24.7	164
48	4.31	1.91	226	0.21	0.12	1.00	0.64	3.10	1.16	35.8	21.8	164
53	5.08	2.31	220	0.19	0.15	1.36	0.65	3.52	1.50	33.0	18.1	182
58	5.73	2.98	192	0.38	0.22	1.19	0.66	4.15	2.11	26.5	16.1	164
63	7.64	4.09	187	0.47	0.30	1.01	0.80	6.16	2.99	21.9	13.7	159
68	9.60	5.40	178	0.56	0.42	1.55	0.81	7.48	4.17	18.2	12.4	147
73	11.51	7.84	147	0.68	0.78	1.02	0.75	9.81	6.31	14.5	12.2	119
78 and over	15.10	12.40	122	0.79	1.19	0.79	0.77	13.51	10.44	12.7	11.5	110
All ages	3.39	1.45	234	0.18	0.10	0.83	0.54	2.38	0.82	33.9	20.9	162

* Includes tuberculosis (all forms) and influenza.

The striking fact brought out by this table is the uniformly high death rates for foundry workers for each of the respiratory diseases throughout the working period of life. Foundrymen have a rate for influenza lower than that for all workers combined only at central age 73, their rate for tuberculosis is lower only at central ages 18 and 23, while their rate for other diseases of the respiratory system is markedly in excess at all ages.

Comparing the crude death rates for all ages combined, it is found that the influenza death rate for foundrymen exceeds the average by about 80 per cent, while their rate for tuberculosis is 54 per cent in excess. Most outstanding is the high rate for other respiratory diseases (pneumonia, bronchitis, etc.) where the foundrymen's rate was nearly three times that for all workers combined. Unfortunately, deaths from pneumonia were not separately distinguished. Other studies have indicated that this disease is the leading cause of death among foundrymen. Undoubtedly this cause is largely responsible for the high rate reported in this investigation for other diseases of the respiratory system.

Evidence of the excessive mortality among foundrymen will be found in the graphic presentation of the data embodied in columns 2 and 3 of Table VI. This is crudely presented in the graph shown in Fig. 4.

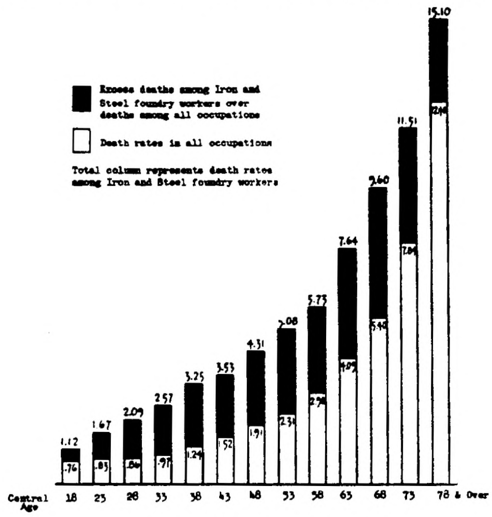

FIG. 4.—All Respiratory Diseases

Deaths per thousand life years exposed. Intercompany group mortality experience 1922–1930. Employees of steel and iron foundries 450,012 years. All occupations 20,353,369 years.

Joint occupation study—1928 (11).—This study covers persons insured in twelve large life insurance companies under Ordinary plans ($1,000 or more) during the years 1915–1926. As a measure of the effect of employment on the mortality rate, the ratio of actual to expected deaths was used. The number of deaths which would be expected to occur from respiratory diseases among the group of persons engaged in each foundry occupation, assuming that they experienced the same death rate as Standard lives, was computed. The number of expected deaths thus calculated was then compared with the number which actually occurred.

Iron and steel molders, founders, and casters, constitute the largest foundry group represented in the investigation. In fact, this is the only group reported upon which of itself had a sufficient number of deaths to give significant results. It is worthy of mention first that more deaths were recorded from pneumonia among these workers than from any other cause. Where there might have been expected twelve deaths from this cause, there were actually 38, giving a ratio of actual to expected deaths of 315 per cent. Twenty-four deaths were recorded for respiratory tuberculosis where 13 might have been expected, giving a ratio of 179 per cent., while the ratio for influenza was 216 per cent., based on 23 actual as compared with 11 expected deaths. A similar situation was found for molders, founders and casters of brass and bronze, except that the ratios in general were higher than for iron molders and deaths from tuberculosis were more numerous than from pneumonia. The number of deaths, however, were few. There were seven deaths from tuberculosis where 1.3 was expected; five from pneumonia where 1.1 was expected, and four deaths from influenza where one was expected. All the other foundry occupations showed high ratios of actual to expected deaths for each of the respiratory causes. Few deaths were recorded for each class, but taken together the results are significant.

Causes of death by occupation (12).—The occupational mortality of adult white male Industrial policyholders of the Metropolitan Life Insurance Company who died during the years 1922–1924 is reported upon in this investigation. Since the number of living policyholders in each occupation class was not known, death rates could not be calculated. The method of analysis employed was to compare the proportion of deaths due to any one cause in any one specified occupation group, with the proportion due to the same cause among all occupied white males.

Here again we find that pneumonia was the leading cause of death among foundry workers, a condition not true of any of the other 71 occupations included in the analysis. Deaths from pneumonia accounted for 15.9 per cent. of the deaths from all causes, while deaths from tuberculosis accounted for 14.6 per cent. The combined group of respiratory diseases was responsible for slightly more than one-third of all the deaths of foundrymen, compared with slightly less than one-fourth of the deaths of all occupied workers.

When differences in the age composition of the two groups were taken into account, it was determined that the proportion of deaths from pneumonia was 120 per cent. higher for foundrymen than for occupied males generally. In the same way, the proportion of deaths from influenza was found to be 82 per cent. higher, that for tuberculosis of the respiratory system 5 per cent. higher, and that for other respiratory diseases, 17 per cent. higher.

Report of the registrar-general of England and Wales—1921 (13).—Confirmation of American insurance experience is afforded by this comprehensive analysis of English population statistics covering the occupational mortality of males in England and Wales during the years 1921–1923. Three classes of foundry workers were reported upon—metal molders, iron foundry furnacemen and laborers, and brass foundry furnacemen and laborers. Standardized death rates (ages 20–65) were given for each of the important causes of death.

The foundrymen's mortality is shown to exceed that for all occupied and retired males for each of the respiratory diseases. So far as respiratory tuberculosis is concerned, the excess was slight in two of the classes, being but 7 per cent. in excess for metal molders, and 1 per cent for iron foundry furnacemen and laborers. The rate for brass foundry furnacemen and laborers, however, was more than twice that for all occupied and retired males. Brass foundry workers, curiously enough, also had the highest death rates for each of the other respiratory diseases. Their death rate for bronchitis exceeded the average by 99 per cent., that for influenza by 121 per cent., and that for pneumonia by 149 per cent. Iron foundry workers had the next highest death rates for each disease. Their excess mortality ranged from 79 per cent. for influenza to 127 per cent. for pneumonia. Metal molders had the lowest rate for each class except for tuberculosis. Their rates for non-tuberculous respiratory diseases exceeded the average by from 41 per cent. for influenza, to 72 per cent. for bronchitis.

As a protection to the employer as well as the employees, it seems advisable to select not only workers who are skilled and competent, but also those who are physically fit for the work. This can only be accomplished through a physical examination, which should include an X-ray examination when indicated. In view of the serious results frequently following long exposures in dusty atmospheres, all such men should be repeatedly re-examined so that if evidence of disease develops it can promptly be checked.

The Lead Hazard in Foundries Studied

Three of the foundries studied, J, K, and O, have brass foundries for the casting of bearing metal. Air samples taken at the breathing level of the workmen and analyzed for lead showed the concentrations given in Table VII.

Toxicity of lead.—A relatively small number of studies have been published concerning the quantitative aspects of lead poisoning. Legge and Goadby have stated as their belief that 2 mg. of lead was the lowest dose which, inhaled by a worker each day, would in the course of a year set up chronic lead poisoning. Teleky, a distinguished German industrial hygienist, is reported by Oliver as believing that a little more than a milligram per day is toxic. A recent investigation of lead poisoning in a storage battery plant by Russell et al. (14) indicates that the limit of safety under the conditions encountered in the study is an atmospheric concentration of lead dust or fumes of less than 1.5 mg. per 10 cubic meters of air.

For the purpose of such a study as the present, it is necessary to set rather arbitrarily some standard for the minimal toxic dose, and it is presumably fair to assume 1 mg. per day as the minimal toxic dose. It is assumed that a man working ten hours inhales 10 cubic meters of air. All of this air would not reach the alveoli of the lungs, but this air would be drawn into the body and some of the dust or fumes drawn with it might be swallowed if not inhaled.

Men exposed to lead should be examined at monthly intervals. An important part of the physical examination is an examination of the blood. Most of the recent research workers regard the blood and the blood forming system as the anatomical elements earliest affected by lead, and hold that by a microscopical examination of the blood of lead workers, lead absorption may be detected before symptoms develop, and when, therefore, it is possible for actual lead poisoning to be averted. Additional evidence of absorption is the presence of lead in the excreta and the appearance of a lead line in the gums. While neither the presence of lead in the urine and feces, nor the discoloration of the gums demonstrates in itself that there has been any injury to the organism, both signify that lead has been absorbed.

Damage to body tissues may become manifest in many different ways. Lead may cause the early development of arteriosclerosis (hardening of the arteries) or chronic nephritis (kidney disease), as well as other degenerative changes which bear no apparent relation to lead poisoning. There are four signs which most frequently appear during the early stage of the disease: (a) the ashen color of the skin, (b) the lead line on the gums, (c) stippling of the red blood cells, and (d) mild secondary anemia or other evidence of rapid peripheral destruction of blood, such as increased quantity of blood pigment in the plasma or of hematoporphyrin in the urine. These conditions can only be discovered by careful and frequent medical examinations of exposed individuals.

TABLE VII

	CUBIC FEET OF AIR SAMPLED	MILLIGRAMS OF LEAD PER CUBIC FOOT OF AIR	MILLIGRAMS OF LEAD PER CUBIC METER OF AIR	LEAD INTAKE IN MILLIGRAMS IN 10-HOUR DAY ON BASIS OF WORKMAN BREATHING 10 CUBIC METERS OF AIR
Plant J	24.3	0.06	2.11	21.1
Plant K	50.0	0.02	0.71	7.1
Plant O	74.5	0.04	1.41	14.1

Certain measures of hygiene are particularly important. Workmen should wear clean clothes while at work, and always keep them quite separate from those worn at other times. This requires two lockers, for if dusty clothes are hung at night where street clothes hang during the day, contamination can hardly be prevented. An excellent arrangement used by many plants consists in building locker rooms on either side of the shower room. Men are required to leave work clothing in one locker and pass into the shower room. After taking a shower they pass along to the next locker room where they dress in street clothes. Smoking or chewing tobacco, if the hands are at all dirty, involves the danger of ingestion of lead; and as food may also be contaminated in the same way, provision should be made for ample washing facilities and for eating in rooms completely removed from the lead hazard.

The physician or some representative of the company should be given authority to order the transfer of suspicious cases from hazardous positions, or to request a period of rest. Upon re-exposure great emphasis must be placed on the necessary precautions, and the factory physician should be rigorous in his supervision.

Heat, Cold and Wet Hazards

Molders are exposed to the heat of molten metal when pouring and again to the heat of the partially cooled casting on shaking out the molds.

Cranemen and those working at the cupola are exposed to excessive heat from the molten metal, and it is usually the front of the body that is exposed. Here also arises a hazard affecting the eyes due to glare of hot metal and burns from spattering.

As the foundry is of a large area with large entrance doors and, necessarily, has sources of heat unevenly distributed, drafts are set up to which the workmen are exposed. The results of a study of the effects of radiant heat on the skin are reported in Reprint No. 1370 of the U. S. Public Health Service (15). This study demonstrates the actual skin temperatures resulting from exposure to heat sources.

There are few wet hazards, except in certain foundries employing hydraulic pressure in core casting cleaning.

Protective clothing should be worn by workers so exposed.

Plant Housekeeping

Orderliness and cleanliness, in so far as practicable for the type of work, were the rule rather than the exception in the plants studied. The floors were found to be fairly level. Only occasionally were sandy hills and hollows noticed. For cleaning, safety and efficiency, concrete, wooden blocks or granite blocks are preferable, and it is easier to keep them free from excessive dust. It is important to keep the aisles clear and well maintained, and provision should be made for storing equipment and tools not in use.

Personal Service Facilities

Washing facilities.—Separate and modern washrooms are provided for the employees in most instances. In some the washing facilities are scanty and inadequate. Shower baths provided with hot and cold water were found only occasionally.

Lockers. The majority of the foundries furnish lockers of some sort, made either of wood or steel.

When employees change their street clothing in the work rooms, the want of lockers leads to the continued exposure to dust of street clothing, as well as of food and tobacco, as long as they are in the foundry. Because lockers and locker rooms are not provided, the employees in many cases wear their work clothes from their homes to the foundry and back again, and in this manner carry dust into their homes.

Water supply and drinking facilities.—In the foundries studied city water supply was available. A few of the foundries have "bubblers" or fountains. The water is cooled for use in the warm weather.

Toilets.—The toilets are all connected with a sewer system and are of a modern type. As a rule, they are adequate in number.

Clothing.—Protective clothing and foundry shoes are usually worn by the workers.

Respirators. These are provided where necessary and while a few workers use the old type of helmet, the majority use the newer positive pressure air masks. The chief criticisms to be made are:

1. Poor mechanical maintenance; either the workman does not receive sufficient air or else the face piece or hood is so worn that it does not fit properly.
2. Use of an improper type of respirator—the use of the ordinary pig snout respirator without positive air supply.
3. Positive pressure respirators not supplied with clean air.

Summary and Conclusions

This study has directed attention to the improvements noticed in foundry processes and particularly the progress made in the development of protective equipment for foundry use. It demonstrates also that the available protective equipment either is not used to advantage or is poorly maintained.

Counts of dust particles in the air taken at the breathing levels of the workers are given and indicate a relatively high dust count in practically every department of the foundry. In only two plants (C and L) of the grey iron foundries and three (R, S, and U) of the malleable foundries were the dust counts found consistently low. The dust concentration in many instances was sufficiently high to justify the assumption that workers so exposed over a period of years might readily develop silicosis. More than 56 per cent. of the samples collected exceeded ten million dust particles and nearly 10 per cent. exceeded one hundred million particles less than ten microns in greatest diameter per cubic foot of air, determined by the standard light field method. The advantages of modifying the illumination (dark field method) are discussed and the method described. Both methods were used in this study and it was found that for dusts encountered in foundries the dark field method gave results consistently twice as great as the standard light field procedure. Counts determined by the standard light field method only are listed.

The report emphasizes the harmful effects on the lungs of exposed workers from inhalation of dust and gives the results of the X-ray findings of groups of workers. Sixty-seven of the two hundred fifteen X-ray films taken were diagnosed as positive for silicosis. While advanced cases of silicosis were not found among those examined, sufficient evidence of the occurrence of the disease is presented. The prevalence of respiratory diseases, as indicated by mortality statistics, is discussed.

A section of the report is devoted to a discussion of lead dust and fumes found in a few of the foundries studied. In every instance the lead content of the air breathed by workmen exceeded the limits of safety. Recommendations regarding the control of this hazard are suggested.

Other possible health hazards, such as heat, cold, dampness, etc., have been briefly discussed. Comments regarding plant housekeeping and personal service facilities are made.

Recommendations regarding the isolation of processes, the use of approved equipment, responsibility for maintaining and inspecting equipment, the desirability of a program to insure plant cleanliness, and the protection of workers by means of proper clothing and respirators and by initial and periodical physical examinations have been submitted.

It is believed that this study justifies the conclusion that while foundry work at present may be considered a hazardous occupation, there are available well-designed equipment and protective devices which, if used and maintained, will prevent undue exposure of foundrymen to hazards injurious to health.

BIBLIOGRAPHY

1. U. S. Public Health Service, Treasury Department, Public Health Bulletin No. 144: Comparative Tests of Instruments for Determining Atmospheric Dust. Government Printing Office, Washington, D. C., January, 1925, p. 41.
2. Drinker, Philip, and Thomson, Robert M.: Determination of Suspensoids by Alternating-Current Precipitators. This Jour., June, 1925, 7, No. 6, p. 261.
3. Green, Henry: A Photomicrographic Method for the Determination of Particle Size of Paint and Rubber Pigments. Jour. Franklin Inst., November, 1921.
4. Whipple, G. C.: Vital Statistics. John Wiley & Sons, New York, 1925, p. 451.
5. Heffernan, P., and Green, A. T.: The Method of Action of Silica Dust in the Lungs. This Jour., 1928, *10*, 272.
6. U. S. Public Health Service, Treasury Department, Public Health Reports March 18, 1932, Vol. 47, No. 12: The Impinger Dust Sampling Apparatus as Used by the U. S. Public Health Service. Government Printing Office, Washington, D. C.
7. U. S. Public Health Service, Treasury Department, Public Health Bulletin No. 187: The Health of Workers in Dusty Trades, II, Exposure to Siliceous Dust (Granite Industry). Government Printing Office, Washington, D. C., July, 1929.
8. Fehnel, J. W.: III. A Study of Silica Dust in Hard Rock Drilling in New York City. This Jour., February, 1929, *11*, No. 2, p. 69.
9. Lanza, A. J., and Childs, S. B.: Miners' Consumption, A Study of 433 Cases of the Disease Among Zinc Miners in Southwestern Missouri, with a chapter on roentgen-ray findings in miners' consumption. U. S. Pub. Health Service Bulletin No. 85, Government Printing Office, Washington, D. C., January, 1917, p. 32.
10. Committee on Group Mortality Investigations, E. E. Cammack, Vice President and Actuary, Aetna Life Insurance Company, Chairman: Combined Group Mortality Experience 1922–1930, July, 1931.
11. Actuarial Society of America and Association of Life Insurance Medical Directors, N. Y. Joint Occupation Study—1928, July, 1929.
12. U. S. Bureau of Labor Statistics, Bulletin No. 507: Causes of Death by Occupation, Experience of Metropolitan Life Insurance Company Industrial Department 1922–1924. Louis I. Dublin and R. J. Vane. Government Printing Office, Washington, D. C., Feb. 1930.
13. Registrar-General England and Wales,

Decennial Supplement, 1921: Part II. Occupation Mortality, Fertility, and Infant Mortality. H. M. Stationery Office, London, 1927.

14. U. S. Public Health Service, Public Health Bulletin No. 205: Lead Poisoning in a Storage Battery Plant. Government Printing Office, Washington, D. C., 1933, p. 55.

15. U. S. Public Health Service, Reprint No. 1370 from Public Health Reports, Vol. 45, No. 18, May 2, 1930, pp. 997–1009: Effect of Radiant Energy on the Skin Temperatures of a Group of Steel Workers. Government Printing Office, Washington, D. C.