THE JOURNAL OF INDUSTRIAL HYGIENE

VOLUME X JUNE, 1928 NUMBER 6

SPRAY PAINTING HAZARDS AS DETERMINED BY THE PENNSYLVANIA AND THE NATIONAL SAFETY COUNCIL SURVEYS*

HENRY FIELD SMYTH, M.D., DR.P.H.

AND

HENRY F. SMYTH, JR., B.S. IN CH.E.

CONTENTS

*Received for publication Feb. 7, 1928.

Introduction

FROM the mechanical and production standpoints the introduction of the spray gun or air brush has proved a most important advance in many branches of industry and its use is increasing rapidly. In many types of factories today it is the only means employed for placing permanent coatings for protective or artistic effect on manufactured articles. Its use not only saves time but economizes materials and permits of artistic effects not easily obtainable in any other way and also produces better and more uniform coverage than can be had otherwise.

Since its more general use, however, there have appeared from time to time accounts of apparently serious harm to workers from the inhalation of sprayed materials, as solid particles, droplets, or vapors. The attention of the medical profession was first called to the possible danger of spray painting by Dr. Albaugh in 1915 (1), and two years later Dr. Wade Wright included one spray painter in a list of cases of lead poisoning (2). In 1922 Dr. N. C. Sharpe (3) reported the results of an investigation into the lead poisoning risk among spray operators, his studies including air sampling in the laboratory and in factories and the testing of the efficiency of various types of respirators. He recognized the danger of poisoning from fume inhalation where volatile solvents are sprayed, but reported no tests for them.

In 1924 Dr. Alice Hamilton (4) called attention to the risk of lead poisoning from spraying lead finishes, and in 1924 and 1925 the Wisconsin Industrial Commission promulgated regulations governing the use of the spray gun (5). These were objected to by some as being too drastic and by others as inadequate.

When the Pennsylvania Department of Labor and Industry desired to draft regulations governing spray coating, it decided first to endeavor to obtain more definite data than were then available as to the possible health hazards, particularly as to the risk of benzol poisoning from the spraying of lacquers. For this purpose it initiated a state-wide survey in 1925 of the entire spray coating industry, it being thought best to include the use of varnishes, shellacs, stains, paints, and even vitreous enamels. With this in view the senior author was engaged to conduct such a study in collaboration with Dr. Elizabeth Bricker of the Department. Field work was carried on by Dr. Bricker, Dr. Smyth, and H. F. Smyth, Jr., and laboratory analyses for benzol were carried out by Dr. E. F. Pike, then instructor in chemistry at the University of Penn-

sylvania. This field study included plant tests for materials in the air where spraying was in progress, air measurements, and surveys of spray equipments and exhaust ventilation, and medical examinations of spray operatives. This was supplemented by a series of tests at a spray booth erected in the laboratories of the Mechanical Engineering Department of the University of Pennsylvania, the booth being donated for this purpose by one of the prominent firms manufacturing spray painting equipment. The Pennsylvania findings have been published in Special Bulletin No. 16 of the Department of Labor and Industry (6).

Following the Pennsylvania survey the National Safety Council, through a special committee representing as far as possible all phases of the industry and all directly interested groups, instituted a supplementary study. This was aimed to include work not covered in Pennsylvania or not sufficiently covered owing to lack of opportunity. The field studies for this committee were also under Dr. Smyth's direction and the field staff included H. F. Smyth, Jr., and Dr. Pike, as well as several others. Field studies were conducted in and around Detroit, Mich.; in Toledo, Ohio; and in vitreous enameling plants in Mansfield and Cleveland, Ohio. These findings have also been published in considerable detail as a special report (7).

It is the purpose of this paper to present the findings of both surveys as a connected study of spray coating hazards and to consider them under three headings based on types of materials being sprayed: (1) lacquers and similar materials containing highly volatile and possibly toxic solvents; (2) paints and enamels in which lead, turpentine, and "mineral spirits" are the potential hazards; (3) vitreous enamels which may contain more or less lead or toxic pigments and which all do contain much silicious matter liable to produce pulmonary fibrosis. The chemical methods employed in testing for benzol are discussed in a separate section as they were the subject of considerable experimentation and gave rise to considerable controversy in both investigations (8).

Chemical Methods Employed in Determining Benzol Vapor Concentrations in Air

The methods used for this part of the work were selected and developed by Dr. Pike and the laboratory work on the determination of benzol was done by him or under his direction. Practically all the sampling in the field and at the experimental booth was done by the junior author, who is now working on improvements in the methods here described.

Three groups of air samples for benzol were taken which will be treated separately in chronologic order: (1) field samples for the Pennsylvania Department of Labor and Industry, collected during the latter half of 1925 and January, 1926, in factories scattered throughout Pennsylvania; (2) samples collected during the first half of 1926 at the experimental spray

booth set up in the Engineering Laboratories of the University of Pennsylvania; and (3) field samples for the National Safety Council collected during the summer of 1926 in factories in Detroit and Toledo.

Basic Method Selected from the Literature

At the beginning of this survey, a search of the literature was made to find some reliable method for the determination of benzol vapors in air. The ideal method desired would be capable of easy use in the field, require not more than one hour for collecting one sample, indicate with a reasonable degree of accuracy concentrations of benzol in air of from 20 parts per million by volume up, and not be interfered with by other vapors, such as alcohols, esters, and hydrocarbons, present when nitrocellulose lacquers are sprayed.

Greenburg, in the National Safety Council Benzol Studies (8), had determined benzol in air by adsorption on activated charcoal, but this method was not applicable to the present problem because of the complex mixture of vapors present. One manufacturer of lacquers had written to the Pennsylvania Department of Labor and Industry that he was using eleven volatile materials in his preparations, which of course would all be adsorbed by the charcoal to a greater or less extent.

There was not sufficient time before beginning field work to attempt to develop a new method which might be selective for benzol. Work in progress for over a year subsequent to this study, and still continuing, indicates that the development of such a method is a very complex problem. The only data which appeared to furnish a method at all satisfactory had been presented by Elliott and Dalton (9). Their work was done on the determination of benzol in benzol-alcohol-acetone vapors in air.

The procedure of Elliott and Dalton, which employed Pfeiffer's method (10), consisted briefly in nitration of the benzol vapors with subsequent reduction with stannous chloride solution, titrating the excess with iodine solution. The air containing the benzol to be determined was drawn through 15 c.c. of a mixture of equal volumes of fuming nitric acid (specific gravity 1.5) and sulphuric acid (specific gravity 1.84). The mixed acids, now containing the benzol as meta-dinitrobenzene, were heated on the water bath for fifteen minutes to complete the nitration, cooled, diluted with water, made just alkaline with 40 per cent sodium hydroxide solution, and then faintly acid with hydrochloric acid. After dilution to about 500 c.c. to prevent crystallization of sodium sulphate, the liquid was extracted with three successive portions of ether previously treated with a little sodium hydroxide solution. After separation of the ether from the watery layer, and removal of the ether by distillation, the residue was warmed on the water bath to remove any oxidation products of the alcohol and acetone present in the air sampled, and was then dissolved in 10 c.c. of alcohol. The alcoholic solution was heated with 10 c.c. of a standard stannous chloride solution for ten minutes, cooled, and the excess stannous chloride titrated with 0.1 normal iodine, using starch as an indicator. A blank was carried out

as a control. The number of parts of benzol per million of air was obtained by multiplying milligrams of benzol per liter of air sample taken by 313.

Procedure Used on Samples Collected in Pennsylvania

Field Samples

This method of Elliott and Dalton was followed for all benzol determinations in the Pennsylvania survey, with these few modifications. The nitration acid was diluted after reaching the laboratory by pouring it on ice. The ether extractions of all samples taken in the field were made by means of a continuous extraction device, employing a fixed volume of ether, continuously circulated and distilled. No ethyl alcohol was added to the dinitrobenzene before titration, in order that no other possible oxidizing agent might be present.

The scheme for taking the air sample was very simple. The line through which the air was drawn was of glass tubing, with short rubber joints. One end was placed as close to the sprayer's nose as was possible without interfering with his work. The other end was connected, as shown in Figure 1, to the absorption bottle and the aspirator, which were kept in the nearest safe place. The aspirator was graduated to read directly the volume of air drawn into the sampling line, correcting for the drop in pressure caused by the resistance of the fine bubbling tip in the absorption bottle. The sample was taken at the rate of approximately 10 liters per hour. The average sample was 7.5 liters, read to the nearest 0.1 liter. This size sample allowed one test per hour, with time for setting up the apparatus and moving it to the next point.

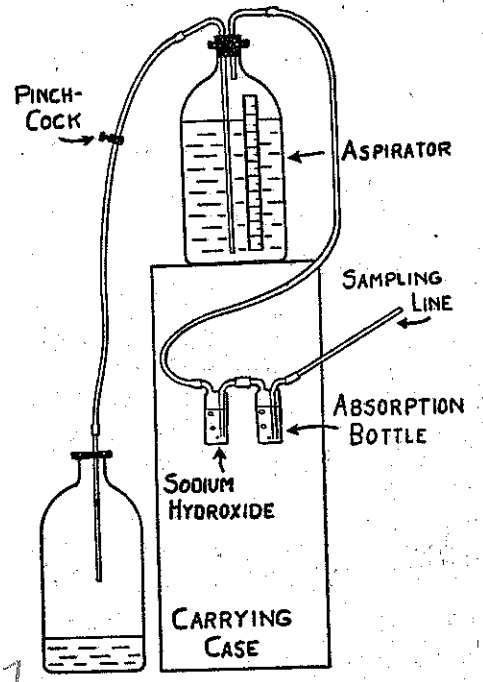

Fig. 1.—Set-up used in the field for taking air samples for benzol.

The absorption bottle used for taking samples in the field is shown in Figure 2. The entrance tube ended in a capillary tip about 0.3 mm. in diameter and about 1 mm. from the bottom of the bottle. This arrangement resulted in a well-broken stream of fine bubbles. After a sample had been passed through the bottle, it was often noticed that the acid was full of minute bubbles, which required some time to rise to the surface. The ground joint was lubricated by a small amount of vaseline, care being taken that none of it was exposed directly to the acid fumes.

Usually after a sample had been taken in the field, the acid was trans-

ferred to a glass ampule and sealed up for safe storage and transportation to the laboratory. Care was taken to

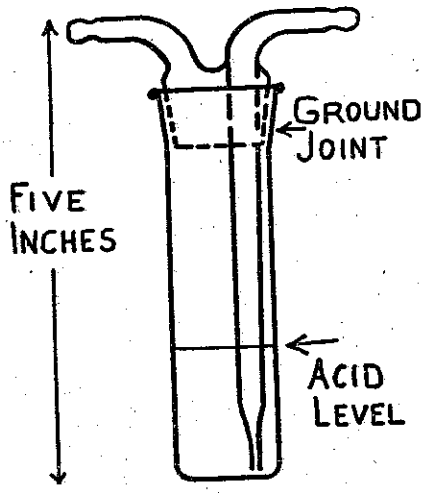

FIG. 2.—Absorption bottle used in the Pennsylvania survey.

wipe off all vaseline before the acid was poured out of the absorption bottle. The rinsing was done with a small amount of the nitration acid. When the acid was transported in the absorption bottles, the entrance and exit tubes were closed with glass beads held in rubber tubes. Blank tests showed that the slight contamination of the acid by rubber and vaseline, although it produced a yellow color, introduced no appreciable error in the determination.

During the field tests twenty blanks were run at various times to obtain values to be applied to titration results to correct for any constant errors of titration, impurities in reagents, contamination, or other source of positive error. At least one blank was run with each new batch of nitration acid. At least one was made with each changed condition in field tests, such as marked change in temperature of a[ir] at the place of sampling, or change [in] the length of time the acid was ex[-] posed to rubber or vaseline in tran[s]portation. These blanks were use[d] singly, not averaged, to correct the batch of tests to which they cor[-]responded. They were reasonably consistent, and ranged around 0.8 m[g] of benzol. At no time did the man making the titrations know which tes[ts] were blanks. They consisted of 15-c[c] portions of nitration acid kept in the absorption bottles for the same length of time as acid used for actual sam[-]pling, and treated subsequently in exactly the same way.

Tests of Accuracy of Method

Before the method for the de[-]termination of benzol was used at all two groups of tests of its accuracy were made. First, dry air was bubbled through weighed amounts of pure benzol in glass-stoppered bottles with entrance and exit tubes fused on. The loss of weight of the benzol repre[-]sented the amount taken up by the air This air was then passed through an absorption bottle containing nitra[-]tion acid, exactly the same as that to be used in the field. The amount of benzol nitrated was determined as described above. The average re[-]covery of the benzol as indicated by the titration result was 92 per cent.

Second, mixtures of 2 c.c. each of ethyl alcohol, methyl alcohol, and amyl acetate containing a small weighed amount of pure benzol were com[-]pletely volatilized by a current of dry air, which was next passed through an absorption bottle with nitration acid and the amount of benzol nitrated was determined as before. When care

was taken to expel all the alcohols and any of their oxidation products by heating on the water bath before reducing with stannous chloride, an average of 87 per cent. of the benzol originally present was recovered.

Unfortunately, owing to lack of time and of equipment, this is as far as the examination of the accuracy of the method could go before field work was started. Between field sampling and the sampling at the experimental booth there was opportunity for more thorough testing of accuracy. For this a series of samples was taken using known mixtures of air and benzol, approximating the concentrations found in field work. The mixtures were made by Yant-Frey gassing chambers (11), lent by the Pittsburgh Station of the United States Bureau of Mines.

Pure benzol, pure toluol, 50:50 and 5:95 mixtures of benzol and toluol, in concentrations of from 100 to 10,000 parts per million of air, and the distillate from one of the lacquers sprayed at the experimental booth were sampled in these devices. The compositions of the vapor mixtures as calculated from the data of the machine operation were constant to within 5 per cent. during each run. In determining the concentration of the air mixtures sampled, averages of several determinations made at intervals during the taking of each sample were used. Samples of the vapor-air mixtures were drawn from the chambers through absorption bottles exactly as field samples had been taken, and dinitrobenzene was determined in the same way as before. In addition a second series of samples was taken with 30 c.c. of nitration acid instead of 15 c.c., and at the rate of 5 liters per hour instead of 10, as was done in the field. A few of the results of these samplings of known vapor-air mixtures appear in Table 1.

TABLE 1.—RESULTS OF SAMPLING VAPOR-AIR MIXTURES OF KNOWN COMPOSITIONS, AS PREPARED BY THE YANT-FREY GASSING CHAMBERS

VAPOR PRESENT	CONCENTRATION OF VAPOR IN AIR SAMPLES[1]	CONCENTRATION OF BENZOL FOUND BY TITRATION	VAPOR REPORTED AS BENZOL
	p.p.m.	*p.p.m.*	%
Benzol	4,750	358	8
	4,350	255	6
	1,845	217	12
	622	140	23
	252	77	31
	108	77	71
Toluol	9,552	185	2
	5,050	230	5
	2,132	134	6
	557	69	12
	116	64	55

[1] Calculated from constants of the machine.

A curve was constructed from the results with pure benzol and the results previously obtained for samples taken in the field were corrected by it. The curve showed the method as used in the field to be from 10 to 60 per cent. efficient. The higher efficiencies occur at the lower concentrations, and in the range of concentrations most frequently found in the field. It was felt that the low efficiencies were due to the poor design of the absorption bottle, and in the later work this was improved considerably.

Because of the low efficiencies found in this series of samples, the high value of the titration blank, and the practice of reading the volume of air sample taken to only 0.1 liter, it was felt best not to report any field result as a numerical part per million, but to divide the results into groups lying within arbitrarily chosen ranges of concentration. These ranges, and the number of field samples in each, are given in Table 2.

TABLE 2.—RANGES OF BENZOL CONCENTRATIONS FOUND IN FIELD SAMPLES, PENNSYLVANIA SURVEY

GROUP NO.	CONCENTRATION SHOWN ON TITRATION	PROBABLE TRUE CONCENTRATION[1]	NO. OF FIELD SAMPLES
	p.p.m.	*p.p.m.*	
0	0	.....	28
1	0– 30	0– 50	28
2	31– 50	51– 100	8
3	51– 75	101– 200	12
4	76–125	201– 500	8
5	126–175	501–1,000	2
6	176–230	1,001–2,000	2
7	over 230	over 2,000	1
Total	.....	.....	89

[1] Based on curve of accuracy of the sampling method, as discussed in the text.

Many of these samples were taken where materials such as shellac and varnish, containing very little or no benzol, were being sprayed. This accounts for the large number of zero results.

Interference of Toluol.—The tests with the gassing chambers show that the method used for benzol determines toluol and presumably xylol, when they are present, with about the same efficiency as it does benzol. The search of the literature made before any work was done in this survey indicated that such would not be the case, no indication being found that toluol or xylol vapors would be nitrated by the acid mixture used, or that, if nitrated, their nitration products would be reduced by the dilute aqueous stannous chloride with only ten minutes of heating. Accordingly it had been concluded safe to use the method even when toluol was known to be present. That toluol was determined by the method may have been due to the fact that only a few milligrams of it were involved, while all references found were to work with several grams.

If it had not been for one reaction found during the examination of the accuracy of the method, doubt would have been thrown on all the results of field sampling by the interference of toluol. It was noticed that, whenever any appreciable portion of the nitration products could be assumed to have come from toluol, the slightly alkaline solution obtained just before ether extraction was deep orange or red. When the nitration products of benzol only were present, the solution at this point was water white or yellow, unless enough dinitrobenzene was present to separate as crystals and then an orange color was developed. This orange did not resemble that from a small amount of toluol nitration products. Xylol nitration products were later found to give a similar color to that given by toluol, but browner. There was no possible confusion of these colors from toluol and xylol with that from benzol nitration products. In

several hundred determinations made since these two surveys were finished, this color has developed in every case where toluol was known to be present and in no case where it was known to be absent. A further discussion of this color reaction will be given at a later date when studies now being made on improvements in the method of determining benzol are completed.

In only two of the ninety-one field tests was this color signal observed, and these indicated no benzol on titration, so that toluol, although generally present in nitrocellulose lacquers, did not interfere with the results of these surveys.

Samples Collected at Experimental Booth

The 174 air samples for benzol taken during operation of the experimental booth were treated by the procedure discussed above, with very few differences. The sampling rate was 5 liters per hour, and the size of sample was from 3 to 6 liters, depending on the solvent concentration as estimated from spraying conditions. The absorption bottle was double, consisting of two bottles such as had been used in the field sampling (see Fig. 1), fused together. In each half, 30 c.c. of nitration acid were placed. The efficiencies of this style of absorber as determined by samples taken in the gassing chambers ranged from 10 to 100 per cent., the higher efficiencies occurring in the range of concentrations found in actual use at the booth. The highest concentration found on titration of these samples was 100 parts per million, in the sample taken while spraying a lacquer containing added benzol. From the curves for the efficiency of the method, the efficiency at this concentration with this absorption bottle was 100 per cent., within the limits of accuracy of the various measurements involved. Because of this, no correction for accuracy of the method was used in this part of the work. The results were reported to the nearest 5 parts per million.

Some as yet unknown cause acted to lower the apparent benzol on titration. In 46 per cent. of the samples taken at the experimental booth the results were lower than the zero blank. These had to be reported as zero benzol.

The ether extractions of this series of tests were not made with the continuous extraction device, but with ordinary separatory funnels, using three 50-c.c. portions of ether for the extraction of some 70 c.c. of aqueous solution.

PROCEDURE USED ON SAMPLES COLLECTED IN NATIONAL SAFETY COUNCIL SURVEY

During all the Pennsylvania work the stannous chloride solution had been giving trouble and had changed its strength rapidly. It was standardized twice daily against the 0.1 normal iodine, and metallic tin was kept in the bottle with it. In spite of these precautions it lost strength on standing and was felt to be unsatisfactory. At the suggestion of Dr. Hamilton Bradshaw of the Du Pont Company, the reducing agent was changed to titanous chloride. This must be stored in dark bottles under pressure of hydrogen, and must be used in an atmosphere of carbon dioxide,

but in spite of these objections it was felt that it was more suitable than stannous chloride.

In addition to the change in reducing agent, the absorption bottle was improved. The new bottle was similar to the Milliken gas washing bottle, but of a smaller size than that of any available at the time of the Pennsylvania study. This bottle is made so that gas bubbles roll slowly up through the absorbing liquid along an extended helical passage, producing circulation of the liquid by their motion. In the model used in our work the bubbles passed some 40 cm. through acid. The bottle had a ground-in top, carrying entrance and exit tubes, and was filled to a working height by 60 c.c. of acid.

The sampling rate varied for the individual absorption bottles used, being as rapid as would still produce individual bubbles in the acid. This rate was close to 5 liters per hour. A faster rate formed a continuous mass of air in the helix, making it seem likely that much benzol vapor never came into contact with the acid at all. The average sample taken was 2.5 liters, read to the nearest 0.1 liter. This sample was adequate because of the high concentrations of benzol present during the almost continuous spraying in the automobile body factories, where the samples for this survey were taken.

The method of Elliott and Dalton, as described in detail above, was followed in general, but there were so many changes in procedure that it will be simplest to outline the entire method as used in this survey.

After reaching the laboratory, the nitration acid containing the benzol as dinitrobenzene was heated for one hour at 100°C., this time of heating having been found necessary for complete nitration by heating samples taken from the gassing chambers until complete nitration was obtained. The acid was then cooled, poured on ice and carefully neutralized with strong sodium hydroxide until slightly alkaline. The solution was then boiled gently for five minutes in order to remove aliphatic alcohols, etc., and their oxidation products. It was then made just acid with hydrochloric acid and extracted with four 50-c.c. portions of neutralized ether, using a motor driven stirrer in a large separatory funnel for mixing the ether with the aqueous solution.

The ether extract was washed with a little water, and evaporated on the water bath. The residue was heated on the water bath five minutes in order to remove the last of the oxidation products from the alcohols and esters. 5 c.c. of freshly distilled alcohol added, the volume made up to 100 c.c. with oxygen free water, and aliquot portions of this were taken for titration. Usually the average of three 25-c.c. portions was taken as the amount of benzol.

The titanous chloride titrations were made according to the methods of Knecht and Hibbert (12) and English (13). The aliquot portion of the dinitrobenzene solution was placed in a 250-c.c. wide-mouthed Erlenmeyer flask, closed with a two-hole stopper. Through one hole a constant stream of carbon dioxide from a Kipp generator was admitted and maintained throughout the titration

Through the second hole, which was for the insertion of burette tips, 25 c.c. of 40 per cent. sulphuric acid and 50 c.c. of titanous chloride solution were added and the hole was closed. The solution was boiled for five minutes, then cooled in ice water, and ferric alum solution run in until the violet color of the titanous chloride was nearly discharged. Ten c.c. of 10 per cent. ammonium thiocyanate were added and more ferric alum run in until a faint, permanent pink color was obtained.

The titanous chloride was from 0.25 to 0.3 normal and was standardized daily against aliquot portions of a solution of a weighed amount of purified dinitrobenzene in dilute alcohol. The ferric alum was 0.05 normal and was standardized against the titanous chloride. Blanks were run each day using all the reagents of the procedure, and in addition frequent blanks of nitration acid were included with the field samples in such a way that the laboratory operator did not know which they were. Eighty-five field samples were successfully completed. Several others were taken which were valueless because red fuming nitric acid was used, and it was found impossible to remove all oxides of nitrogen from the dinitrobenzene. The highest concentration of benzol found was 6,500 parts per million of air and several zero results were obtained.

Because of the high efficiency assumed for the absorption bottles used, the titration results were reported without correction except for the value of blanks. The red color referred to before as a sign of toluol did not appear at all, and so the results probably include little if any toluol reported as benzol.

Discussion

The ultimate determination in the procedure here described is that of nitro groups. The method therefore should be capable of use in the determination of any vapor forming nitro compounds with mixed nitric and sulphuric acids. It is particularly adapted to the determination of benzol vapors in the absence of toluol and xylol. It can probably be adapted for the determination of either toluol or xylol with very few changes.

On the basis of the details of the procedure (solution strengths, size of air sample, and recovery of benzol from known vapor concentrations) as used in the Pennsylvania work, the lowest concentration which the method can determine with assurance is about 10 parts of benzol per million of air. Owing to the inefficiency of the absorption bottle, however, a curve had to be used for interpretation of all results. This curve indicated 60 per cent. recovery of benzol at 100 parts per million and 11.5 per cent. at 2,000 parts per million. The modified absorber used at the Pennsylvania experimental spraying booth recovered 100 per cent. of the benzol at 100 parts per million and 20 per cent. at 2,000 parts. The uncertainty in measurement of volume of air sample taken was about 1 per cent.

On the same bases the smallest concentration which could be determined with assurance in the National Safety Council work was 40 parts per million. The difference between this and the minimum con-

centration for Pennsylvania was largely due to the fact that smaller samples were taken in the National Safety Council Survey. Here the absorber appeared so efficient as compared with the former ones that it was assumed to be nearly perfect for the concentrations sampled. The uncertainty in measurement of volume of air sample was 2 per cent.

The procedure described determines benzol by means of a compound of over twice its molecular weight (metadinitrobenzene), which is a decided advantage for small amounts. It enables a small air sample to be taken. After the air sample is passed through the nitration acid, the latter may be stored indefinitely without change, until it is convenient to make the determination. Aliphatic esters, alcohols, water vapor, and carbon dioxide do not interfere as they may when benzol is determined with adsorbents. A good indication of the presence of toluol in the air sample is given as a regular part of the procedure.

On the other hand, the method has several disadvantages. If toluol, or presumably xylol, be present in the air sampled, there is no method available by which their interference can be avoided. Also the nitration acid is awkward to transport and transfer in the field. In addition, after the samples reach the laboratory the procedure is somewhat complicated and no hope is seen of simplifying it.

There seem to be three main points where improvement is needed. (1) An efficient absorber requiring not more than 10 c.c. of nitration acid is desired. (2) A good separation of the dinitrobenzene from the corresponding toluol product is needed and (3) a separate determination of toluol when it is present. Work is being done on these points; the first two are practically solved, and will be reported shortly.

Lacquer Spraying and the Benzol Hazard

Lacquers are coming more and more into general use as coating materials and the spray gun has been largely responsible for this. The nitrocellulose lacquers came into use industrially after the war and until recently were always applied with the spray gun. In the last few years brushing lacquers are beginning to be used but they were not considered in either survey as their use was not as yet common in industry. They find their principal place in domestic practice for occasional finishing and refinishing of household articles. In addition to the only occasional exposure in their use, they are not so to contain so much highly volatile toxic solvent material as do spraying lacquers.

Lacquer Components

Lacquers as a class are quick dry and contain a number of volatile solvents and diluents. At first benzol was present in considerable amounts in most, if not all, lacquers. Table lists the answers received to a questionnaire sent out in 1925 to a group of lacquer manufacturers. It shows benzol contents admitted by the manufacturers of nine out of twenty-seven

lacquers listed. Seven out of twenty-one answers received admitted 20 per cent. of benzol and over, two up to 50 per cent. Three answers specifically stated that benzol was absent; four said that it was present but did not mention any other substances. At the time of writing, many of the spraying lacquers on the market are reasonably free from benzol.

Scope of Studies

Field studies included plant surveys, spray booth surveys and measurements, air velocity measurements, and collection of air samples for chemical determinations. Medical studies included medical and working histories of sprayers, physical examinations, blood pressure readings, and urine and blood examinations. Details of procedure and detailed findings are given in the two reports previously referred to (6) (7).

In Pennsylvania 214 establishments were visited, representing thirty-one different types of plants; 134 air measurements were taken at spraying locations and ninety-one benzol determinations made on air samples. Physical examinations of 264 persons were made, including 127 lacquer sprayers, fifteen sprayers of substitute shellac or oil stains, eighty-one paint or enamel sprayers, thirty-five varnish sprayers, and six shellac sprayers.

In the National Safety Council study twenty-nine establishments were visited—two automobile factories, four auto body plants, one custom spraying shop, eleven vitreous enamel factories, and eleven contracting painters—and 164 physical examinations of lacquer sprayers were made.

Mr. Pitt of the National Paint, Oil and Varnish Association has listed over ninety manufactured articles on which lacquer is sprayed and he refers to this as "a partial list." No attempt was made to cover the entire field of lacquer use but we endeavored rather to study those processes where lacquers were sprayed in quantity and continuously or nearly so, and, for comparison, some industries where they were used irregularly, intermittently, or in small quantities.

The statistical material was handled somewhat differently in the two studies

TABLE 3.—SOLVENTS AND DILUENTS PRESENT IN COMMERCIAL LACQUERS AS REPORTED IN ANSWERS TO QUESTIONNAIRE

LACQUER NO.[1]	BENZOL	TOLUOL	XYLOL	SOLVENT NAPHTHA, BENZINE	BUTYL ACETATE	AMYL ACETATE	ETHYL ACETATE	BUTYL ALCOHOL	AMYL ALCOHOL, FUSEL OIL	ETHYL ALCOHOL, DENATURED	ACETONE	DIETHYL CARBONATE	"OTHERS"
2	x[2]	...	...	...	x	...	...	x	...	...	...	...	...
4	...	x	x	...	x	x	x	x	...	x	...	...	...
7	...	x	x	...	x	x	x	x	...	x	...	...	...
13	x	x	...	...	x	x	x	x	x	x	...	...	...
15	x	x	x	x	x	x	x	x	x	x	x	...	...
16	x	x	x	...	x	...	x	...	...	...	...	...	...
17	...	x	x	...	...	...	...	...	...	...	...	...	...
18	x	x	x	...	x	x	x	...	...	x	x	...	...
20	x	...	...	x	x	...	x	x	...	...	...	x	...
21	...	...	...	x	...	...	...	...	...	x	...	...	x
24	...	...	...	...	...	x	...	...	x	...	...	...	...
25	x	x	x	...	x	x	...	x	...	...	...	...	...
26	x	...	...	...	x	...	x	x	...	x	...	...	...
27	x	x	x	x	x	x	x	x	...	...	x	...	...

[1] Arbitrary numbers adopted for this survey.

[2] x indicates substance is present.

but the final analyses lead to the same conclusion. In the Pennsylvania study a large number of plants were visited, in most of which one, several, or a small group of sprayers were found. Here no comparisons by plants are attempted but emphasis is placed on medical histories and blood findings, the latter being analyzed in a manner which we feel shows the progress of blood changes due to moderate, more or less continuing exposures to benzol fumes. The National Safety Council study includes a comparison of plant conditions as they affect the sprayer. This was possible as larger groups of sprayers were examined in a comparatively small number of plants. Here the blood findings were also analyzed in the same manner as were those in the National Safety Council benzol study so that the two studies could be compared.

Difference in Conditions

In interpreting the results of the Pennsylvania and the National Safety Council studies and correlating them with each other certain differences must be borne in mind. Practically all the spraying seen in Pennsylvania was done in or in front of booths having a top and three sides and with exhaust ventilation in the rear. The bulk of it was on small articles such as furniture and small metal parts or machines. Most of the spraying seen in Detroit and Toledo was done either in an open room or before skeleton booths usually placed in line, with right and left sprayers staggered so that they were not spraying directly opposite each other though often spraying in opposite directions. Many of these booths had only back and top walls and some were merely top canopies open on all sides. The men often worked in a cloud of spray droplets and their exposure averaged considerably greater than that of the Pennsylvania sprayers.

In the small object spraying in the first series, air pressure on the gun averaged around 70 pounds per square inch, ranging from 15 up to 95 pounds. In the second series, in the automotive industry, gun pressures ranged from 80 to 105, the majority being over 90 pounds. Pressures of such degree produce a heavier cloud of spray, thus increasing the exposure. In Pennsylvania, spraying as observed was intermittent, in almost every instance the sprayer stopping to allow removal of coated objects and their replacement by new material. In the Detroit and Toledo shops, spraying was much more continuous, as the cars and bodies being sprayed usually travel down a line from man to man. Stop watch observations on Pennsylvania sprayers showed a maximum of 50 per cent. of the man's working time during which spray was being delivered from the gun. The same test in the National Safety Council series gave the average well over 75 per cent., only seventeen men spraying less than 50 per cent. of the time and sixteen over 90 per cent., with twenty-two spraying 75 per cent. of the time at the booth. This again increases the exposure. All these factors help to explain the greater evidences of toxic effect seen in the second group of workers.

Classifications of Sprayers

In the Pennsylvania study sprayers

were grouped in the following classes according to material sprayed:

1. Lacquer sprayers; with or without other substances.
2. Substitute shellac and oil stain sprayers; both of these substances often containing benzol. Asphaltum paint sprayers should also have been placed in this class.
3. Paint and enamel sprayers.
4. Varnish sprayers.
5. Shellac sprayers; a small group of only six men.

In Pennsylvania, lacquers were found being sprayed with benzol contents varying from negligible to 50 per cent. Fortunately high benzol contents were rarely met with in the automotive industry where the fume exposure is decidedly greater.

In the National Safety Council series, groupings of sprayers are based on plants and also on length of service as sprayers, but in the Pennsylvania study only the latter grouping is used.

Analysis of Materials

A number of samples of materials being sprayed were collected in the field and brought home for analysis. Two lacquer samples were analyzed carefully for benzol, one yielding 9 per cent. and the other 1.46 per cent. of benzol.

Benzol Sampling

In the Pennsylvania survey, air samples for benzol were taken where lacquers, varnish, shellac, substitute shellac, stain, or primer were being sprayed. Cases where benzol was found in the air occurred for each of these classes of materials but they were few; for shellac and varnish only small amounts were found and these infrequently. When found here, the benzol was probably due to the use of a cheap thinner or of denatured alcohol. We attempted to take every sample at such a place as would give a sample identical with the air breathed by the worker. The ideal arrangement for this would have been a sampling tube held beside the man's nose by a head harness and connected with the aspirator bottle by a flexible hose. No operator, however, could be asked to wear such an arrangement for the length of time necessary to take a sample. In addition to being uncomfortable for the worker it would slow up work, thus reducing the amount of material sprayed and consequently the amount of fume in the air. This would have defeated the purpose of the device. As the next best method the sample was drawn through a glass tube pointed vertically downward and fastened to the booth or other support as near the worker's nares as could be done without interfering with his work. More attention was paid to the level of the opening of the sampling tube than to its position in relation to the sides and back of the booth. The velocity of the air stream entering the sampling tube was of the same order of magnitude as that of the air passing through the booth. When the desired volume of air had been sampled, the absorption tube was stoppered with a glass bead placed in the rubber line. As soon as it was convenient, the acid was taken to the laboratory for analysis or washed into glass ampules and sealed in the flame.

In the second survey, the sampling nozzle was usually suspended in a fixed place so as most nearly to

approximate the average position of the sprayer's nostrils. In both series, effort was made to reduce to a minimum the rubber connections in the sampling line. Owing to the use of a more efficient absorption bottle, a smaller adaptation of the Milliken bottle, smaller samples, averaging 2.5 liters, could be taken than in the Pennsylvania study. A field laboratory was set up in Detroit and analyses were started soon after collection of the samples.

In field studies of this character one must be very cautious in attempting comparisons between plants on account of the many variables which cannot be controlled and which have more or less influence on results. In addition to the quantity of material being sprayed and its toxic content, the air pressure at the gun, the adjustment of the gun for liquid flow, the sprayer's technic, the size and shape of the piece being sprayed, the speed of working, the type of booth and arrangement of baffles therein, and the amount, direction, and variation of room air currents, all have a direct bearing on results. Unless most of the foregoing conditions are determinable and comparable one is justified in making only broad general comparisons between groups of similar tests.

Summarizing the tests for benzol in the two studies we find ninety-one samples analyzed in Pennsylvania averaging 100 parts of benzol per million of air, only five of them being over 500 parts and one over 2,000 parts, with twenty-eight tests negative. In Detroit eighty-five air samples, taken where nine different products from five makers were being used, when analyzed for benzol averaged 918 parts per million, forty-four being over 500, eleven over 2,000 with a maximum of 6,500 parts per million, and only five negative. These differences bear out the previous comparisons of the relative severity of the exposure in the two types of work. The actual exposure in the automobile industry at the time of the survey, however, was not quite so great as our tests would indicate, as the plants were working on an average of only five days a week.

Air Measurements

Velocity of air flow in both studies was measured by the kata-thermometer (14) placed as nearly as possible at the location of the sprayer's breathing intake at work. In the National Safety Council study it was at times necessary to take air measurements when the temperatures were too high to permit the use of a standard kata. For this work a kata-thermometer was adapted by carefully opening the top of the column, withdrawing some of the spirit, resealing under vacuum and then recalibrating for temperature conditions above the mid-point of the normal kata. During part of the latter survey the normal kata was broken and pending replacement ventilation was recorded as "good," "poor," and "bad," according to personal judgment.

When attempts are made to correlate benzol content of air with rate of exhaust ventilation, varying results are found even where one product is being sprayed, since the directions of secondary air currents are constantly varying and the objects being sprayed and the sprayer himself are constantly

moving. With three of the products tested, however, undercoat No. 4 and lacquers Nos. 5 and 9, there is a definite inverse relation of benzol content of air to air velocity if the maximum amounts of benzol in the air at each recorded velocity are taken. (See Table 4.)

TABLE 4.—RELATION BETWEEN AIR VELOCITY AND BENZOL FINDINGS, NATIONAL SAFETY COUNCIL SURVEY

MATERIAL SPRAYED	NO. OF TESTS	AV. AIR VELOCITY	BENZOL FOUND	
			Av.	Max.
		ft./min.	*p.p.m.*	*p.p.m.*
Undercoat No. 4	2	0	160	160
	2	42	480	830
	2	54	240	380
	2	92	320	320
Lacquer No. 5	5	bad	872	3,500
	5	poor	1,284	3,100
	3	82	648	1,030
	2	100	910	920
	4	good	348	510
Lacquer No. 9	4	19	1,665	4,700
	1	67	4,500	4,500
	1	75	2,400	2,400
	1	79	1,300	1,300
	2	87	475	590
	7	102	1,083	1,900

The air measurements made in the Pennsylvania studies are summarized as follows: 131 tests average 94 feet per minute with a maximum of 570 and a minimum of 8 feet. In a number of instances listed in the Pennsylvania report an inverse correlation was observed between air velocity and benzol content; the tests made at the experimental booth, where booth size, object sprayed, gun air pressure, air velocity, lacquer volume, and benzol content of lacquer were all under fair control, show this very clearly. Even here there were some uncontrollable variables influencing individual tests. (See Table 5.)

TABLE 5.—RELATION BETWEEN EXHAUST VENTILATION AND BENZOL CONCENTRATION IN AIR, PENNSYLVANIA SURVEY

EXHAUST VELOCITY	BENZOL CONCENTRATION (P.P.M.)				
	0	Under 50	Under 100	Under 150	Under 200
ft./min.	%[1]	%[1]	%[1]	%[1]	%[1]
0– 49.....	25	38	63	75	75
50– 99.....	49	77	90	92	97
100–149.....	58	77	86	95	98
150–199.....	57	76	88	95	95
200 and over	75	88	88	100	100

[1] Cumulative percentages.

These experimental tests showed that with velocities up to 150 feet per minute, which rate was never reached in field tests in Detroit where benzol was being tested for, 86 per cent. of the tests gave benzol under 100 parts per million, and 95 per cent. under 150 parts. With velocities over 200 feet per minute, 100 per cent. of the tests were under 150 parts per million. The 12 per cent. of tests over 100 parts per million at velocities over 150 feet per minute totaled only four tests. One of these gave 125 parts per million with an 8.9 per cent. benzol lacquer and a flat piece too large for the booth; one gave 110 parts with a 10 per cent. benzol lacquer with the same piece and booth; one gave 110 parts and one 220 parts when spraying into a

deep box, under which condition the sprayer always is exposed to a maximum amount of vapor.

Medical Examinations

Medical and working histories of spray operatives examined were recorded, including length of time spent at present and at previous occupations. Physical examinations consisted of percussion and auscultation of heart and lungs, reading of systolic and diastolic blood pressures, testing reflexes and hand grip, hemoglobin determinations, red and white blood cell counts, differential white counts, and urine analyses where samples were collectable.

In many instances in the Pennsylvania study physical examinations of all sprayers in the plant could be made, but this was not always done and not always advisable. In the beginning of the survey every sprayer was examined, but as practically no evidence of ill effects of spraying was found in men who had been at the work for short periods, throughout the rest of the study only men who had been at this job for one month or over were examined.

Wherever physical examinations were made, air measurements were usually made at the spray booths and air samples taken. Air of booths used for the spraying of lacquer was sampled wherever possible, but air of varnish and shellac booths was not sampled unless sufficient time was being spent in the plant making physical examinations to warrant it.

Physical examinations, blood pressure studies, and urine analyses threw little light on the problem, but blood examinations and medical histories were invaluable. As was to be expected, men were rarely found at work who were consciously suffering markedly from their exposure, as most operatives stop the work before this stage is reached.

Histories

The highest percentage of those complaining of poor appetite was found among the lacquer sprayers, and the next highest among the varnish sprayers. The highest percentages of those with disturbed digestion were found among varnish and paint sprayers. There is not much difference in the percentages complaining of constipation in the different groups and no cases were very marked. A number of sprayers in all groups complained of headache, the highest percentage being in the small group of substitute shellac and stain sprayers. Dizziness and dyspnea are most pronounced in the same group, as are also unrelated symptoms.

To summarize, evidence of benzol absorption to the extent of the production of mild symptoms was found in many lacquer, substitute shellac, and stain sprayers (see Table 6), evidence of absorption to a less degree in some paint sprayers and a few varnish sprayers; but no evidence of absorption in shellac sprayers. This is discussed more fully in the Pennsylvania report.

Table 7 gives a summary of the frequency of complaints by length of service of lacquer sprayers examined in Detroit and Toledo. In this study medical examinations were made of 164 persons—160 in seven lacquer

spraying plants, two in one custom shop, and two members of the survey staff who were most exposed to spray in their work.

TABLE 6.—SYMPTOMS REPORTED BY LACQUER, AND SUBSTITUTE SHELLAC AND STAIN SPRAYERS, PENNSYLVANIA SURVEY

SYMPTOM	LACQUER SPRAYERS		SUBSTITUTE SHELLAC AND STAIN SPRAYERS	
	No.	%	No.	%
Poor appetite	18	14	0	0
Loss of weight	4	3	0	0
Digestive disturbance	26	20	1	6
Constipation	16	13	2	13
Headache	30	24	5	33
Dizziness	29	23	5	33
Coryza	13	10	1	6
Dyspnea	14	11	3	20
Dysmenorrhea	4	36[1]	0	0
Other symptoms	41	32	9	60
Total sprayers	127	100	15	100
Total females	11	9	2	13

[1] Percentage of total females.

The histories of the 164 workers in this group give a picture of 2.2 physical complaints per man, the most common being digestive disturbances, constipation, headache, nasal or postnasal irritation, dyspnea, and eye irritation. It is of significance that the total of reported symptoms increases with length of service, the figures being 1.5 complaints per man for those employed for less than six months, 2.2 for those employed for from six months to two years, and 2.7 for those employed for over two years. It will be observed from the table that the frequency of every one of the complaints noted tends to increase with length of service, although dyspnea and bleeding fall off again in the workers with the maximum length of service. This is attributed to a selective process which tends to eliminate from the industry all but the individuals having a naturally high resistance to benzol.

TABLE 7.—FREQUENCY OF SYMPTOMS BY LENGTH OF SERVICE AS LACQUER SPRAYERS, NATIONAL SAFETY COUNCIL SURVEY

SYMPTOM	TOTAL LACQUER SPRAYERS	LACQUER SPRAYERS EMPLOYED		
		Under 6 Mos.	6 Mos.–2 Yrs.	Over 2 Yrs.
	%	%	%	%
Eye irritation	28	26	25	32
Headache	18	13	16	23
Dizziness	18	10	14	26
Constipation	15	6	14	16
Digestive disturbance	13	10	16	13
Dyspnea	12	16	16	7
Loss of weight	16	6	11	17
Bleeding	8	0	13	6
Numbness	3	0	3	4
Tingling	4	3	3	4
Loss of appetite	10	10	14	6
Lead line on gums	1	0	0	1
Total in group	100	19	38	42

These studies show comparatively little evidence of bladder or renal irritation as evidenced by polyuria, nocturia, or burning. The prevalence of white cells in the urines is attributed to the frequency of venereal infections rather than to chemical irritation.

A number of other symptoms traceable to benzol or other solvents were noted in particular instances, but not any one of them was found in a great number of cases; that is, such symptoms as chilliness, faintness, languor, general nervousness, and fretfulness. A few heart lesions were found and a certain number of cases with irregular heart action, but no more than would be expected in any working group of this size.

A few sprayers of lacquer and of undercoats in both studies reported dermatitis from thinner and other materials used to clean the hands after work, and in both cases it was principally marked in those men who neglected to remove the cleaning material with soap and water immediately after it had served its purpose. In fact, no history of dermatitis was found where men have taken this precaution.

Contrary to the Pennsylvania experience, a large percentage of the sprayers in the second study complained of more or less eye irritation, 28 per cent. of lacquer sprayers and 37 per cent. of undercoat sprayers. This is due to the fact, already referred to, that they spray more in the path of a cloud of droplets than do those in front of complete booths.

Blood Examinations

Special attention was, of course, paid to the blood picture since changes in blood cells, particularly a reduction in white cell count, are the most characteristic index of very early benzol poisoning. Hemoglobin and color index findings yielded no striking results, as was perhaps to be expected since the red cells are affected markedly only in the later stages of benzol poisoning. A red cell count below 4,000,000 was found in twenty lacquer sprayers.

The white cell counts proved highly significant. Of a total group of 142 lacquer, and substitute shellac and stain sprayers in Pennsylvania, 5.6 per cent. gave a total white cell count below 5,625, the figure fixed by the Committee on Benzol (8) as indicative of clearly defined benzol poisoning; of the 160 counts made in the second study where the exposure was greater, 11 per cent. were found below this level.

Normal Blood Pictures.—In both studies efforts were made to obtain at least a few normal blood pictures of working individuals, but the success was not marked in either case. In Pennsylvania, twenty-four employees of the Department of Labor and Industry were examined, four members of the family of one of the investigators, five vitreous enamel sprayers, and seven sprayers of shellac and filler. There was not, however, the same age or sex distribution in this small group of norms as was met with generally in the survey.

The forty normals averaged 5,100,000 red cells, 9,382 white cells, 5,898 polymorphonuclears, and 2,648 lymphocytes. Four gave moderately disturbed blood pictures, none high grade, averaging 4,500,000 red cells, 7,110 white cells, 3,704 polymorphonuclears, and 2,907 lymphocytes. The lowest polymorphonuclear count was 3,484. Of these four, three gave histories of ill health, in two cases quite prolonged and in the third associated with a distinct, tuberculous family history. The fourth was a

56-year-old colored janitor. This moderate relative lymphocytosis with leukopenia and slightly low red cell count is typical of early tuberculosis and the pretuberculous state. Two of the three with histories of poor health were female clerks. The red cells averaged low because of the large proportion of females. It was surprising to find such a high total white cell count, over 9,000 and very much above the textbook norm based on the examinations of young healthy students.

In the course of the National Safety Council study white cell counts were obtained from fifty-seven and red cell counts from thirty-five supposedly normal industrial workers. These counts were selected by one of the survey staff from the records of St. Joseph's Hospital in Detroit, and represent the blood pictures of patients who entered the hospital after less severe types of street accidents without severe hemorrhage. These yielded even higher total white cell counts than did the Pennsylvania normals, but a rather decidedly lower red cell count. Of the Detroit normals, thirty-five gave an average red cell count of 4,576,000, the counts ranging from 3,980,000 to 5,246,000. Fifty-seven gave a total white count average of 9,806, the counts ranging from 7,400 to 12,700.

Therefore we considered as a normal red cell count in the Detroit district 4,500,000 rather than 5,000,000 as in Pennsylvania, and in both studies we have taken 9,000 as normal white count for the industrial group. This agrees with the experience of the Industrial Health Conservancy Laboratories in Cincinnati as stated in a personal communication from Dr. McCord. The usual textbook white cell average is 7,500 and the Committee on Benzol took a 25 per cent. reduction below this point as indicating a significant decrease. We have attempted here to show a definite downward trend correlated with intensity and length of exposures rather than to set any one level as certainly significant of benzol poisoning. There are other factors than benzol that can lower the count significantly in individual cases and this is seen in studying any large group of counts of even apparently normal persons, but we feel that these low counts are unusual and that an increasing frequency of low counts with increasing time is the significant factor in a study of this kind as showing the influence of continued exposures.

It appears that the normal white cell average for industrial workers in the districts where these studies were made should be placed at 9,000 rather than at 7,500, the higher value being attributable to the general prevalence of catarrhal inflammations of the upper respiratory tract, of pyorrheal conditions of the gums, and of venereal disease, all much noticed during the surveys.

Development of Benzol Blood Pictures

As a definite evidence of benzol poisoning in individual cases we would certainly not exceed the limit set by the Benzol Committee in spite of our use of a higher figure in Pennsylvania as a dividing line in studying group trends.

We had hoped that differential counts might be used as an indication of toxic action, but we soon realized that, with the great variations in total

white cell counts, variations in differentials would be rather meaningless unless interpreted in terms of total white cells; therefore the basic tables submitted in both reports record total white cell counts, calculated polymorphonuclear totals, and calculated lymphocyte totals.

Dr. Alice Hamilton (15) has made rather an exhaustive study of the literature relating to benzol poisoning. In referring to the blood picture of the early stages of benzol absorption, she quotes Newton to the effect that benzol causes a leukopenia with relative increase of large mononuclears and increased red cells to 5,760,000, with hemoglobin 80 per cent. (15, p. 473). She further cites Selling as stating that parallel with the aplasia there is an irritant action and that for a while the two actions go on simultaneously (15, p. 476).

A study of the differential white cell count and its interpretation in terms of the total white cell count might indicate possible earlier evidence of benzol absorption before symptoms develop. If the exposure is mild and the subject's resistance high, this early evidence of absorption might not increase or might even decrease, but if exposure is great or resistance low it might be progressive and this early picture might be an indication for a change of occupation. In these two studies there are complete blood pictures of 287 lacquer sprayers, 135 undercoat sprayers many of whom are spraying materials containing benzol (quick-drying undercoats contain benzol but oven dried undercoats do not), fifteen sprayers of substitute shellac or stain containing benzol, eighty-one paint or enamel sprayers, thirty-four varnish sprayers, as well as of forty supposedly normal persons, and ninety-two partial pictures of other normal persons.

As it was felt that the three most instructive counts were total white cells, polymorphonuclears, and lymphocytes, the averages of these counts in the different occupational groups, together with red cell counts, are given in Table 8. In each class of sprayers four groups are averaged and tabulated separately:

1. Those with no disturbed blood picture, or, in other words, those with a polymorphonuclear count of over 4,500, an arbitrary figure chosen as being well below the normal range.
2. The total sprayers in the group.
3. Those with a polymorphonuclear count below 4,500.
4. Those with the extreme disturbance represented by a total white count under 5,625, the figure taken by the Benzol Committee as indicative of frank benzol poisoning.

It is felt that, if there is a distinct blood picture due to benzol poisoning, these four groupings, in the order given, will present a good picture of the progress of the blood changes as a whole and of the way in which changes in one count are correlated with changes in the others. Group 1, possibly beginning to show the effects of exposure, has not yet progressed to the point of abnormality, and should represent the very earliest stages of absorption or early absorption in the most resistant individuals. Group 2 is obtained by adding to Group 1 those who have passed the dividing line into definite blood alterations and, including, as it does, all sprayers of the material in question, should show a further change. Group 3 shows defi-

nite changes of all degrees. Group 4 shows only those markedly affected. main unchanged in Group 2, and then fall to 5,200,000 and 5,000,000 in

TABLE 8.—AVERAGES OF BLOOD FINDINGS BY SEVERITY GROUPS

GROUP	NO. OF SPRAYERS	PERCENTAGE OF GROUP	R.B.C. (MILLIONS)	W.B.C.	POLYMORPHONUCLEARS	LYMPHOCYTES
Controls:						
Pa.	40	...	5.1	9,382	5,898	2,648
N. S. C.	35	...	4.57	.....	.....	.....
	57	...	....	9,806	.....	.....
Pa. Group 3.	4	...	4.5	7,110	3,704	2,907
Pa. Lacquer:						
Group 1.	77	61	5.3	10,131	6,429	2,647
Group 2.	127	100	5.3	8,962	5,231	2,806
Group 3.	50	39	5.2	7,362	3,386	3,051
Group 4.	7	5	5.0	5,014	1,800	2,434
Pa. Substitute Shellac and Stain:						
Group 1.	8	53	5.2	10,085	6,217	2,926
Group 2.	15	100	5.0	8,856	4,593	3,207
Group 3.	7	47	4.8	7,451	2,738	3,529
Group 4.	1	6	4.6	5,520	2,428	1,656
N. S. C. Lacquer:						
Group 1.	80	49	4.4	9,041	5,709	3,037
Group 2.	163	100	4.3	7,651	4,712	2,228
Group 3.	83	51	4.4	6,737	3,729	3,103
Group 4.	18	10	4.5	5,175	3,061	1,945
N. S. C. Undercoats:						
Group 1.	79	59	4.4	9,266	5,720	3,118
Group 2.	135	100	4.4	8,351	5,313	3,201
Group 3.	56	41	4.1	7,040	3,489	2,962
Group 4.	5	3	4.2	4,990	2,679	2,077
Pa. Varnish:						
Group 1.	29	85	5.4	9,611	6,082	2,559
Group 2.	34	100	5.4	9,063	5,710	2,455
Group 3.	5	15	5.3	5,884	3,552	1,852
Group 4.	2	5	5.3	5,220	3,054	1,807
Pa. Paint and Enamel:						
Group 1.	59	73	5.1	9,855	6,534	2,441
Group 2.	81	100	5.1	9,230	5,696	2,657
Group 3.	22	27	5.2	7,555	3,449	3,236
Group 4.	2	2	5.5	5,550	2,936	2,002

With this in mind, let us consider each column under lacquer sprayers separately. In the Pennsylvania group red cells start in Group 1 at 5,300,000, slightly above normal, re- Groups 3 and 4 with a minimum in the last group of 4,300,000. It will be seen that here we encountered no severe anemias. Apparently there is at first a stimulation and then a gradual

fall in red cell production. It must be borne in mind that the use of lacquers is comparatively new, and all lacquers are not equally rich in benzol. Also, the average sprayer in this study was exposed to his maximum hazard for not more than one-quarter of his working time. In the National Safety Council series there is not much evidence of red cell change. Starting with a lower count of 4,400,000 there is a slight drop and a subsequent rise, neither of them enough to be significant. The undercoat group show more drop in red count but here there is the added influence of lead in many cases. Evidently red cell change is not very marked or very significant in early mild benzol absorption.

Studying total white cell counts, there is seen in Pennsylvania the same primary stimulation followed by a steady decline. From a normal of 9,382, the average rises to 10,131 in Group 1, drops to 8,962 in Group 2, 7,362 in Group 3, and 5,014 in Group 4 with a minimum of 4,320, or about 1,300 below the Benzol Committee line. Polymorphonuclear counts start at 5,898, rise to 6,429, then fall to 5,231, 3,386, and 1,800, with a minimum of 1,252.

In the National Safety Council series there are found total white cell counts of 9,806 in the normal group, 9,041 in Group 1, 7,651 in Group 2, 6,737 in Group 3, 5,175 in Group 4, and a minimum of 4,050. Polymorphonuclear counts, for which there is no separate normal figure for the district, show 5,709, 4,712, 3,729, and 3,061 in the four groups with a minimum of 1,536. These counts show the same trend as those in the first study except that with the greater intensity of exposure the primary stimulation is missed. The drop in white cell counts is more rapid and much more marked than the drop in red cells.

In both studies the lymphocyte counts rise at first and eventually drop below the normal but the drop is delayed and is not so extreme in either study as is that of the other white counts, so that there soon develops a relative lymphocytosis. In the Pennsylvania lacquer sprayers the lymphocyte count in Group 4 is greater than the polymorphonuclear count, but in the other classes of sprayers using benzol preparations and subjected to greater exposures this is not so.

The same types of changes are seen in the classes of varnish and paint sprayers but the instances of low counts are much fewer and extremely low counts do not appear in either group. The undercoat class in the second study shows nearly the same picture as does the lacquer group, except for fewer low counts. It must be remembered that many of these men use compounds containing benzol and those that do not are mostly spraying coatings containing a considerable amount of lead.

If these pictures represent early and progressive benzol absorption leading up to poisoning, as it is felt that they do, there is first a stimulation of all blood making organs, but without increased hemoglobin. This is followed by a depression, first noticed in the polymorphonuclears, the lymphocytes continuing to be increased absolutely for some time. Later they also decrease until there is the commonly recognized frank benzol picture of relative lymphocytosis but absolute lymphopenia followed by progressive

decrease
subacute

FIG. 3.-
relation t
C = av
counts; 2
polymorp
counts be

stages w
be very
sorption
concentr
well bec
another,
again a
doubted
absolute
ceased.
group of
mild exp
prove th
In orc

decrease in red cells. In acute and subacute benzol poisoning these early stages would naturally be missed or be very evanescent, and in mild absorption from long exposure to low concentrations the condition might well become stationary at one stage or another, or might even improve and again approach normal, though it is doubted if it ever would return to absolute normal unless the exposure ceased. Repeated examinations on a group of men under conditions of such mild exposure would be necessary to prove these surmises.

In order to make clear the changes in these four groups of sprayers in each class, they have been plotted as curves in Figure 3. In presenting these curves it is realized fully that the method of grouping is an artificial one and gives no indication of the rate of change in the blood picture. This is shown in what is to follow.

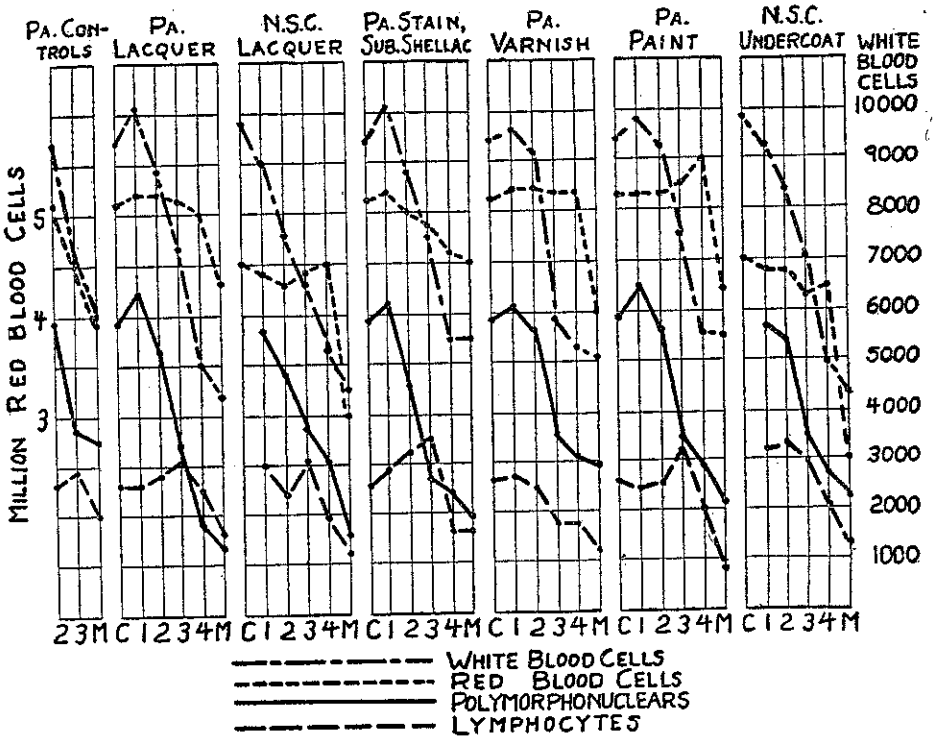

FIG. 3.—Variations in differential blood cell counts in sprayers of different materials in relation to total white cell count.
C = average counts of controls; 1 = Group 1: sprayers in the class without disturbed counts; 2 = Group 2: all sprayers in the class; 3 = Group 3: sprayers in the class with polymorphonuclear counts below 4,500; 4 = Group 4: sprayers in the class with total white counts below 5,625; M = minimum counts in the class.

Effect of Length of Service on Blood Pictures.—The relation of the white cell counts to length of service, as shown in Figure 4 for both studies, brings out some very interesting points. It will be noted that the averages for the National Safety Council series are throughout very much

lower than the Pennsylvania figures, as one would expect from the much

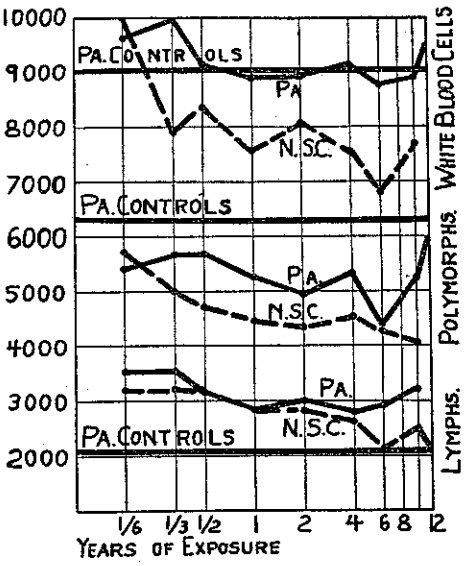

FIG. 4.—Influence on white cell counts of continuing exposure to lacquer fumes.

TABLE 9.—RELATION BETWEEN TOTAL WHITE CELL AND POLYMORPHONUCLEAR CELL COUNTS, NATIONAL SAFETY COUNCIL SURVEY

POLYMORPHONUCLEAR COUNT	TOTAL WHITE CELL COUNT				
	4,000–4,999	5,000–5,999	6,000–6,999	7,000–7,999	8,000 and Over
1,000–1,999.....	1	1	0	0	0
2,000–2,999.....	4	2	3	0	1
3,000–3,999.....	1	15	18	3	7
4,000–4,999.....	0	2	14	19	17
5,000 and over	0	0	0	3	49

greater average exposures. These curves of actual average counts at different time intervals after beginning spraying show the rate of development of the same conditions as indicated by the grouping discussed above and justify the conclusions drawn therefrom. It will be noted that in both studies after six years the averages rise again. This is interpreted as the result of a process of selection which has by this time weeded out all but the more resistant subjects. The presence of a number of cases of benzol absorption in the totals sends both the total white cell and the polymorphonuclear count averages well below the normal while it raises the lymphocyte counts decidedly. The normal lines given in the chart are based on an industrial normal of 9,000, on 70 per cent. of that normal for polymorphonuclears (65 to 75 per cent.), and on 23.5 per cent. of it for lymphocytes (22 to 25 per cent.). If the textbook normal of 7,500 were used, this would still be true of the total white count of the second survey and of both polymorphonuclear counts (based on an average of 5,252) and even more so of the lymphocyte counts (based on an average of 1,763).

Table 9 indicates that the number of polymorphonuclears followed closely the distribution of the total white cells, although falling off somewhat less sharply. Both counts seem to be very delicate indexes of early benzol absorption.

Table 10 shows the white cell counts of the second survey grouped by thousands from 4,000 up to 8,000, omitting the higher counts, and brings out the percentage distribution of counts as influenced by length of service as sprayers.

Blood Pictures and Air Velocities.—The highest air velocity measured

where benzol tests were made was 108 feet per minute, but in tests with undercoats velocities up to 140 feet were observed. In one factory in Toledo where benzol tests could not be made, velocities up to 336 feet per minute as measured by vane anemometer were encountered, and here of ninety-nine such tests fifty-eight were over 100 feet, twelve between 200 and 300 feet, and three over 300. A number of workers with disturbed blood pictures were found here but they were using a lacquer containing a considerable amount of benzol and the ventilation equipment in the plant had been only recently overhauled. The old equipment not yet replaced gave uniformly very low air velocities, a number of them too low to be recorded by anemometer. Findings as to air velocities in this plant, as in some instances in Pennyslvania, show that it is perfectly possible to obtain the velocities above the 150 or 200 feet per minute suggested in the two reports.

TABLE 10.—TOTAL WHITE CELL AND POLYMORPHONUCLEAR COUNTS OF LACQUER SPRAYERS BY LENGTH OF SERVICE AS SPRAYERS, NATIONAL SAFETY COUNCIL SURVEY

LENGTH OF SERVICE	NO. OF SPRAYERS	TOTAL WHITE BLOOD CELLS								POLYMORPHONUCLEARS							
		4,000–4,999		5,000–5,999		6,000–6,999		7,000–7,999		1,000–1,999		2,000–2,999		3,000–3,999		4,000–4,999	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Up to 2 mos.	6	0	0	0	0	1	17	0	0	0	0	0	0	0	0	1	17
2–4 "	10	0	0	0	0	4	40	1	10	0	0	0	0	2	20	4	40
4–6 "	15	0	0	3	20	1	7	2	13	0	0	1	7	3	20	5	33
6–12 "	34	1	3	6	18	7	21	4	12	0	0	4	12	12	35	9	26
1–2 yrs.	29	0	0	4	14	7	24	3	10	0	0	0	0	10	34	7	24
2–4 "	50	3	6	4	8	14	28	10	20	1	2	3	6	13	26	21	42
4–6 "	9	2	22	2	22	0	0	2	22	0	0	2	22	2	22	1	11
Over 6 "	7	0	0	1	14	1	14	3	43	1	14	0	0	2	29	3	43
Totals.....	160	6	4	20	13	35	22	25	16	2	1	10	6	44	28	51	32

In only twenty-five instances was it possible to correlate blood examinations with ventilation tests, and although it must be clearly understood that conditions at booths are constantly varying and that test findings do not necessarily represent the average degree of exposure of the worker, yet it will be seen that in general there is some relation between degree of exposure, represented by concentration times length of exposure, and disturbed blood picture. This is shown in Table 11.

When the findings are grouped according to plants, as is done in the second report but omitted for lack of space here, they show decidedly more cases with low counts in plants where ventilation conditions were poor or where benzol lacquers were used.

White Cell Counts below 5,625.—Grouping the lacquer sprayers who show counts of white cells below the Benzol Committee limit of 5,625 according to length of service, we find

in Pennsylvania one sprayer working two months and one working six months with counts of 5,520 and 5,580; three with counts below 5,000 had been working two, seven, and nine years respectively. In the second series there is no sprayer with a count under 5,625 who has been spraying less than six months and none with a total white count under 5,000 who has been spraying less than eight months. Only one man with a white count under 5,000 had been spraying less than three years, whereas those who had been spraying for three years or more show five out of ten with a count below 5,000, one being as low as 4,050. These figures are given in Table 12.

TABLE 11.—LENGTH OF SERVICE AND BENZOL CONCENTRATIONS FOUND FOR SPRAYERS WITH AND WITHOUT DISTURBED BLOOD PICTURES, NATIONAL SAFETY COUNCIL SURVEY

SPRAYER NO.	TIME WORKED	BENZOL IN AIR *p.p.m.*
With Normal Blood Pictures		
261	2 wks.	350
205	1 mo.	230 av.
271	6 mos.	1,850 av.
198	8 "	1,253 av.
260	8 "	0
259	10 "	320
277	1 yr.	590
3	1 "	420
258	1½ yrs.	240
5	3 "	375 av.
269	4 "	4,500
257	4 "	18
With Disturbed Blood Pictures		
2	4 mos.	210 av.
280	6 "	1,300
206	6 "	318
272	6 "	1,300
278	6 "	1,610 av.
4	11 "	803 av.
11	1½ yrs.	494 av.
1	2 "	803 av.
256	3 "	1,310
270	3 "	0
39	4 "	0
264	4 "	475 av.
28	6 "	646 av.

TABLE 12.—SPRAYERS WITH BENZOL BLOOD PICTURE AS GIVEN BY BENZOL COMMITTEE

SPRAYER NO.	TIME WORKED	WHITE CELL COUNT
Pennsylvania Survey		
149	2 mos.	5,520
120	4 "	5,520
80	6 "	5,580
179	2 yrs.	4,320
230	3 "	5,400
111	3 "	5,220
114	5 "	5,520
81	5 "	5,340
183	7 "	5,400
139	7 "	4,740
129	9 "	4,560
National Safety Council Survey		
72	6 mos.	5,550
291	7 "	5,400
302	8 "	4,800
15	1 yr.	5,150
23	1 "	5,200
284	1 1/12 yrs.	5,200
295	1½ "	5,550
12	1¾ "	5,150
71	3 "	5,350
305	3 "	4,800
40	3 "	4,800
39	4 "	5,600
264	4 "	5,350
25	4 "	4,900
41	4½ "	4,050
7	5 "	4,600
155	6 "	5,550
28	6 "	5,450

This indicates that with lacquer spraying as generally practised the development of benzol poisoning is gradual and that periodic medical examinations and blood counts, therefore, would furnish sufficient warning for the average sprayer. With careless practice and complete absence of exhaust ventilation, however, poisoning may be acute and irreparable harm may be done in a short time.

Discussion

The findings of the two surveys show that benzol cannot be sprayed even in low percentages without accumulating in the air and affecting the health of the sprayer unless he is protected in some way. It was found that most exhaust ventilation installations in use are inadequate to afford this protection, either because they are poorly designed, not kept clean, or not adjusted as intended by the designer, or else because they are not supplied with enough air. It has also been noted that many of these installations can be made efficient, some without change of design and some by changing duct size and design. Some new installations have been found working admirably and giving a considerable margin of safety for lacquer or other spraying.

Whether plotted according to degree of blood change or to length of time spent as sprayers, our National Safety Council survey records show the same type of curves as those obtained in Pennsylvania, except that, owing to the greater intensity of exposure, the preliminary stimulation is not so evident and the development of disturbed blood pictures is more rapid and more intense.

In the automobile industry in general, with its quantity production and continuous line spraying, operatives are using their guns and are enveloped in spray from 80 to 90 per cent. of their time. Therefore the exposure is greater for the same materials than was found in Pennsylvania.

The only discrepancy between the two reports is more apparent than real. The Pennsylvania report recommends a minimum exhaust rate of 150 feet per minute, or 125 as tested with a vane anemometer which almost always registers low at this velocity; while the National Safety Council report recommends 200 feet. The former is the minimum rate which should be permitted by regulation and is based on average findings, making allowances for the unusual conditions found in the few experimental booth tests where fairly high concentrations occurred with high velocities, while the latter is an attempt to recommend conditions under which the worker will be absolutely assured of protection. Personally, we feel, however, that it will not be possible to have any usable setup that will guarantee absolute protection where benzol lacquers are used and therefore we heartily concur in the final recommendation of the Committee that no lacquers be used for spraying which contain over 0.5 per cent. of benzol; this limit allows for the small amounts that may be found in high grade toluols recommended as substitutes for benzol and in the denatured alcohol used in lacquer making.

Where for any reason materials containing benzol must be sprayed, it would be best to furnish the sprayer with an efficient air mask or helmet

that assures him of an adequate supply of pure, benzol free air. Two types of such devices are illustrated in the National Safety Council report.

Conclusions

Even relatively small amounts of benzol in lacquers may give rise to benzol concentrations in the air breathed by the sprayer well above the danger limit of 100 parts per million for continuous exposure, as set by the Benzol Committee of the National Safety Council (8).

While adequate exhaust ventilation equivalent to air movement past the sprayer toward the spray gun of from 150 to 200 feet per minute will usually reduce such benzol concentrations to within the safe limit, yet safety for the sprayer is not assured by this alone.

Air masks or helmets offer the only adequate protection where the exposure is high or continuous.

In all cases sprayers of volatile substances should be offered the protection of periodic medical examinations as outlined in the concluding section of this paper.

Protection against the benzol hazard is best afforded by discontinuing the use of any spraying materials containing more than the minimum amounts of benzol that may be present in the best commercial toluol (2°C. boiling range) and in denatured alcohol used in lacquer manufacture—not over 0.5 per cent. in all.

In the two surveys considered in this paper the benzol hazard resulting from the spraying of lacquers and similar materials containing volatile solvents was studied in well over 150 different industrial plants, 177 air samples for benzol were taken in industrial plants in addition to those at an experimental booth. These tests were nearly always accompanied by air velocity measurements.

Two hundred and ninety-one lacquer sprayers were examined, as well as 266 sprayers of other materials.

Since this paper was written, an article has appeared in the February number of This Journal by Selma Meyer, reporting blood findings in a group of workers exposed to fumes of benzol, toluol, and xylol. At times the benzol predominated and at times it was present as a very small percentage of the whole. In all cases, however, the prevailing blood picture found was that usually attributed to benzol—a relative lymphocytosis, with the appearance of immature and pathologic cells of the non-granular series. If anything, this picture was more prevalent in those inhaling mixed fumes than in those exposed to pure benzol.

The author surmises that the small amounts of benzol in the mixed vapors are not capable of producing these changes alone. Our experiences would lead us to doubt this conclusion and to feel that Meyer had possibly underestimated the amount of benzol that would be vaporized under the circumstances and had underestimated the harm producing possibilities of even small benzol concentrations.

Meyer's experience that the percentile grouping of the differential leukocyte count was a more sensitive index of blood changes following chronic chemical irritation than are the absolute counts of blood cells bears out our contention in this paper. We feel that we have definitely shown this by our discussion of our differential counts interpreted in terms of total white counts. We feel that the true significance of differential counts will often be missed unless this is done.

Paint and Enamel Spraying and the Lead Hazard

Scope of Studies

This section concerns itself with the possibility of lead poisoning from spraying materials, and includes the use of paints and enamels, automobile undercoats, and vitreous enamels as sprayed on metal castings.

In the Pennsylvania survey nine types of industry were included as using materials likely to contain lead. Twenty-two determinations for lead in the air were made in seventeen industries. Only one test was made where contracting painters were at work as that was the only instance where such men were observed actually spraying a lead paint. In fourteen of the plants visited sprayers were examined as were fifty-five other sprayers in an additional group of fifteen industries where there was no opportunity at the time to take air samples for lead.

Eleven contracting painters were interviewed but only those of their employees were examined who were full time sprayers, seven in all. Many of these men spend as much or more time as brush painters than as spray painters and they are more apt to brush lead paints than to spray them. A number of contractors refuse to spray lead paints and those who do spray them use considerably more non-lead than lead coatings. In interior finishing, the flat coat quick-drying zinc paints and the lacquers are replacing lead paints for home and office decoration and cold water paints with no lead are being very extensively sprayed in factories. In the former group the solvents are more harmful than the suspended matter and in the latter no evidence of harm was observed except for possible irritation of the conjunctiva and the nasal mucous membranes, never very marked.

Seventeen workers spraying vitreous enamel on castings in ten different plants were also examined but blood counts were made on only five of them and they showed no evidence of leading, unless for a somewhat low red count in one with a history of "lumbago," and high white counts in two others, one of whom had a slight albuminuria. Histories were obtained of former cases of lead poisoning in three of the vitreous enamel plants, all previous to the installation of the present ventilation system.

In the National Safety Council survey studies were made in six automobile body plants or automobile plants in which undercoats containing lead were being sprayed. Also three groups of structural painters using the spray gun with lead paints on inside or outside work, and six groups of workers spraying vitreous enamels on to castings were examined. There were 172 sprayers included in these groups. Histories were taken and physical examinations were made on all, and blood examinations and tests for lead in the feces on many. A number of other contracting painters were interviewed but their employees were not examined as their time was divided irregularly between brush and spray painting.

Chemical Methods

All the chemical work in the detection of lead in air and material samples and in urines and feces in both surveys

was done by H. F. Smyth, Jr. The methods employed were selected after a conference with members of the staff of the United States Bureau of Mines Laboratory in Pittsburgh and were based on the Fairhall method (16).

Preparation of Samples

Feces specimens were collected in Atlas flint glass, wide-mouthed jars, provided with glass lids and rubber rings. In no case was material which had touched the rubber used in the analyses. Since the samples were to be weighed very soon after collection, no preservative was added. Forty-gram samples were weighed out in Coors porcelain crucibles (in some cases the entire sample collected was less than 40 gm.). The feces were dried in an air bath for about twenty hours and were then ashed in an electric muffle kept at a temperature judged to be 600°C. The ash was allowed to cool, was then warmed with 1:1 hydrochloric acid, and filtered through ashless paper. The residue was washed and the paper ashed. This second ash was extracted with 10 per cent. tartaric acid in 1:1 hydrochloric acid, and filtered. The filtrate from this was added to the first filtrate. The combined filtrates were made alkaline with sodium hydroxide, then made just acid to methyl orange with hydrochloric acid, and allowed to stand one-half hour, after which the reaction was again adjusted.

Dust samples collected on cotton filters were ashed in the muffle and the ash extracted with warm 1:1 hydrochloric acid. The solution obtained was made slightly alkaline, and then just acid to methyl orange with hydrochloric acid, allowed to stand, and the reaction readjusted.

Paint samples were weighed out into Coors crucibles, ashed, the ash extracted with 1:1 hydrochloric acid, and the entire ash suspended in the extract. This was brought to the proper acidity in the way described above.

Enamel samples (vitreous) were warmed with 1:1 hydrochloric acid and the entire sample suspended in the extract, which was brought to the proper acidity.

Determination of Lead

The solutions obtained above were saturated with hydrogen sulphide and allowed to stand at least three hours in an atmosphere of hydrogen sulphide. They were then filtered, washed with water saturated with hydrogen sulphide and containing 0.1 per cent. hydrochloric acid. The sulphide on the filter was dissolved in hot 1:1 nitric acid, the filter paper washed into the filtrate, which was then evaporated to a small bulk to coagulate the sulphur. This was then diluted and sulphur filtered off, the solution cooled, thymol blue added, then enough strong sodium hydroxide solution to turn it a faint blue. Acetic acid was added to make a pale green, then 3 c.c. in excess, then 10 c.c. of 10 per cent. sodium chromate were added, and the solution was brought nearly to boiling. It was allowed to stand overnight, then it was filtered through asbestos, washed with hot water very thoroughly.

The lead chromate on the asbestos was dissolved in 10 per cent. hydrochloric acid, the filter was washed well into a Nessler tube, and 2 c.c. of a 1

per cent. s-diphenyl carbazide solution in glacial acetic acid was added. The volume was made up to the mark, and after it had been standing two minutes the color developed was compared with a series of tubes made up from a known lead chromate solution (in hydrochloric acid). It was usually necessary to compare the color of an aliquot part of the solution, owing to the deep color developed by large amounts of lead.

All reagents used were previously tested for lead. Frequent blanks were run, using the same amounts of reagents. These blanks were consistently zero. New pyrex glassware was used throughout. All porcelain was new Coors. No other work with lead was being done in the same building.

Analysis of Materials

Table 13 gives a synopsis of the analyses of samples of materials being sprayed in Pennsylvania, as collected in the field. Vitreous enamels were analyzed for "soluble lead," as suggested by English workers (17), as well as for total lead. English authorities feel that insoluble or fritted lead silicate is much less toxic than are unfritted lead compounds, and English practice now is to add all lead to glazes before fritting on this account. American manufacturers, as the table indicates, often add considerable lead containing material after the glazes are fritted. Dr. Alice Hamilton (18) called attention to this as long ago as 1912 but the practice still continues. Little lead was found in flat paints but enamels always contained appreciable amounts.

In the National Safety Council survey it was possible to determine the presence of lead in the sprayed materials in almost all instances.

TABLE 13.—LEAD IN MATERIALS SPRAYED, PENNSYLVANIA SURVEY

MATERIAL	LEAD CONTENT			TOTAL SAMPLES	NO. NEGATIVE
	Av.	Max.	Min.		
	%	%	%		
Paint and enamel	2.65	58.8	0	37	7
Silicious material	.....	.....	...	17	...
Soluble lead	8.50	35.0	0	...	9
Total lead	13.30	54.0	0	...	3

Lead was constantly present to the amount of 10 per cent. in three of the five plants spraying undercoats, to 11 per cent. in the fourth, and to 19 per cent. in the fifth. The paint used by two groups of indoor room sprayers contained 0.002 per cent. and 0.5 per cent. of lead, respectively, while that used by one group of exterior painters contained 19 per cent. The percentage of soluble lead in the vitreous enamels tested varied widely. One plant used material containing 0.4 per cent. of soluble lead, one 0.7 per cent., one 3.8 per cent., one 11 per cent., one 14 per cent., and one 20 per cent. One other refused to allow a sample to be taken for analysis, but material sold by the same firm and tested in Pennsylvania gave a higher lead content than any of the foregoing. Table 14 gives the results of material analyses.

Conditions Affecting Lead in Air

Table 15 records the results of tests for lead in the air at spraying booths in the Pennsylvania study, with the

percentage of lead in the material being sprayed, the air velocity, the air pressure on the gun, and the relative humidity at the time of sampling. All these factors were tabulated together in an effort to develop some correlation or explanation of the variations in the amounts of lead found.

TABLE 14.—ANALYSIS OF MATERIAL SAMPLES, NATIONAL SAFETY COUNCIL SURVEY

SAMPLE NO.	SILICA IN DRIED SAMPLE	CLASS OF MATERIAL	DESCRIPTION	MAX. LEAD IN AIR TESTS	LEAD IN MATERIAL AS SPRAYED
	%			*mg./l.*	%
1	....	glaze	.....	0.000	3.0
2	....	primer	first coat	0.000	15.0
3	....	paint	Staywhite	0.000	0.0
4	....	primer	oxide, first coat	0.000	15.0
5	....	surfacer	.....	0.096	24.0
6	....	primer	.....	0.490	11.0
7	....	surfacer	.....	0.001	9.0
8	....	primer	oil solvents	0.000	12.0
9	....	surfacer	lacquer solvent	0.000	0.0
10	....	lacquer	.....	.....	0.19
11	....	lacquer	.....	.....	0.13
12	42.8	vitreous enamel	for sheet metal	.....	0.7 sol. 2.8 total
13	21.2	vitreous enamel	for castings	.....	0.4 sol. 26.0 total
14	44.8	vitreous enamel	for sheet metal	.....	0.0 total
15	25.8	vitreous enamel	for castings	.....	20.0 sol. 23.0 total
16	....	paint	Asepticote	0.000	0.5
17	....	paint	lead in oil	0.001	19.0
18	....	primer	red lacquer solvent	0.007	0.01
19	....	glaze	purple lacquer solvent	0.007	0.8
20	....	guide	yellow lacquer solvent	0.007	6.3
21	....	surfacer	.....	0.600	19.0
22	....	primer	red oxide	0.100	8.0
23	....	primer	second coat	0.045	29.0
24	47.1	vitreous enamel	for sheet metal	.....	0.0
25	24.5	vitreous enamel	for castings	.....	14.0 sol. 15.0 total
26	37.2	vitreous enamel	for castings	.....	3.8 sol. 3.8 total
27	....	paint	French gray	.....	0.07
28	42.1	vitreous enamel	for sheet metal	.....	0.0
29	43.6	vitreous enamel	for sheet metal	.....	0.0
30	24.0	vitreous enamel	for castings	.....	11.0 sol. 13.0 total

In the spraying of materials contain-

ing lead one is dealing with solids in suspension rather than with solvent vapors and consequently there was an even greater variation in the amount of material found than in the benzol tests—depending on air currents, the height at which the worker holds his spray gun, the air pressure on the gun, the distance at which it is held from the object being coated, the shape of the object, and the relative humidity. The specific gravity of the vehicle and the size of the lead particles in suspension influence the rate of settling and, therefore, the amount of lead reaching the breathing area of the worker. There seems to be no definite relation between percentage of lead in materials sprayed and lead recovered in the air sample. Six tests were zero for lead. In two of these instances the paint contained 1.1 per cent. of lead and in a third 0.15 per cent., but in another test with only 0.13 per cent. of lead in the paint 0.0034 mg. per liter of air was found. This was, however, the lowest positive lead finding in any air sample.

In six other tests, where the material being sprayed contained less than 1 per cent. of lead, amounts varying from 0.0134 to 0.245 mg. per liter of air were recovered, the latter being the highest concentration of lead recovered from any air sample. With paints containing from 1.1 per cent. up to 7.9 per cent. of lead, amounts ranging from 0 to 0.072 mg. per liter were found and with one sample containing over 50 per cent. of lead only 0.035 mg. per liter was found. In this instance metal wastebaskets were being sprayed on a low stand in a very large booth and a very small amount of the spray reached the height of the sampling nozzle, or the sprayer's nose. When air pressures at the gun are studied in relation to lead found, in general the larger amounts of lead were correlated with the high gun pressures, although one of the smallest samples was obtained where the highest gun pressure was used. There was no air velocity measurement at this booth.

It was impossible to correlate air velocities with lead recovered, except in a very general way. The higher

TABLE 15.—SUMMARY OF LEAD TESTS IN PAINT AND ENAMEL SPRAYING, PENNSYLVANIA SURVEY

LEAD IN AIR	LEAD IN MATERIAL SPRAYED	AIR VELOCITY	RELATIVE HUMIDITY	AIR PRESSURE AT SPRAY GUN
mg./l.	%	*ft./min.*	%	*lbs.*
0.0	.....	38	..	..
0.0	.....	90	..	90
0.0	.....	15	..	55
0.0	0.15	69	80	70
0.0	1.10	94	79	60
0.0	1.10	104	87	60
0.0034	0.13	68	64	80
0.0070	1.10	94	76	60
0.0090	6.80	...	..	100
0.0100	7.90	56	..	90
0.0134	0.38	92	74	90
0.0156	0.36	35	69	100
0.0250	.....	...	82	40
0.0260	.....	54	..	55
0.0350	58.80	51	39	90
0.0370	0.39	124	38	90
0.0410	5.50	178	..	70
0.0550	0.17	66	40	70
0.0720	2.00	21	47	70
0.1360	.....	60	45	90
0.1930	0.90	103	51	90
0.2450	0.86	48	58	80

percentages, over 0.05 mg. per liter, were found where velocities ranged, with one exception, under 70 feet per minute. Lower amounts, up to 0.0134 mg. per liter, were found with velocities of 68 feet per minute or over, except in one instance where the velocity was 56 feet. In two instances, however, high velocities were found with high lead contents, 0.037 mg. with 124 feet per minute, and 0.041 mg. with 178 feet.

Rather surprisingly, tests do show a more definite negative correlation between lead in the air and relative humidity than between any other two factors, but with so many variables to be considered this may be accidental.

In only two instances where material containing over 1 per cent. of lead was being sprayed were air tests negative for lead. Outside of the six negative results, in only three of which we are sure the material sprayed contained lead, tests showed in every instance amounts of lead in the air considerably above the 0.5 mg. per cubic meter limit given by Legge (17, p. 207) as the smallest amount causing poisoning in the course of years. (The National Safety Council Report (7) considers 0.6 mg. per cubic meter as a safe limit.) In spite of this fact no cases of frank lead poisoning were found in the first survey.

In the National Safety Council survey, twenty-seven analyses for lead in the air as breathed by the sprayer were made, the sample being aspirated through a well-packed 2-inch cotton filter. In the case of exterior and interior wall painters it was necessary to follow the operator about with the sampling tube fixed on the end of a long rod. This was connected by a long rubber tube with the aspirator which was at times stationary and at times carried by a second member of the survey staff.

Of the five plants spraying undercoats studied, two gave values averaged as 0.2 mg. of lead per cubic meter of air—well below the danger limit of about 0.6 mg. set by the Spray Coating Committee. The other three plants gave very high average figures, 32 mg., 99 mg., and 164 mg. The air in the vicinity of the indoor wall painters was negative for lead. Air in the vicinity of the exterior wall painters using a paint testing 19 per cent. lead and spraying in a strong air current averaging 300 feet per minute gave 1 mg. per cubic meter, a possibly significant amount. The smallest air sample was 2.25 liters, four were between 4 and 5 liters, four between 5 and 8 liters, and the remaining were 9 liters or over, up to 12 liters in three instances. In the smaller samples the opportunity for chance errors is, of course, great and whenever possible the larger samples were taken except when the concentration was evidently very high.

In analyzing the air tests made in this second survey it was noted that, as in Pennsylvania, the air pressure at the gun had a decided influence on the amount of lead in suspension in the air sampled. One negative result was obtained with gun pressure over 95 pounds, while only two out of eight tests with pressures under 90 pounds were positive, one of these being the minimum amount detected by the method employed. The results of air tests are given in Table 16. All tests with a trace of lead were reported as 0.001 mg. per liter. They were so reported as it was felt that this was the low limit of sensitivity of the

method as used, and as corresponding blanks were in each instance zero.

TABLE 16.—AIR TESTS FOR LEAD, NATIONAL SAFETY COUNCIL SURVEY

LEAD IN AIR	VOLUME SAMPLE TAKEN	LEAD FOUND	LEAD IN MATERIAL	AIR VELOCITY	RELATIVE HUMIDITY	AIR PRESSURE AT SPRAY GUN
mg./l.	*l.*	*mg.*	%	*ft./min.*	%	*lbs.*
0.0	12.0	0.0	0.5	0	65	50
0.0	9.0	0.0	3.0	61	51	85
0.001[1]	9.0	0.006	.....	140	61	85
0.0	9.0	0.0	15.0	49	51	85
0.0	9.0	0.0	15.0	49	51	85
0.0	2.25	0.0	0.01,0.3[2]	43	54	85
0.007	9.0	0.06	0.6,0.8	41	54	85
0.0	9.0	0.0	19.2	...	33	85
0.0	7.5	0.0	0.002	0	52	90
0.0	9.2	0.0	0.002	0	52	90
0.001[1]	12.0	0.01	19.0	300	67	90
0.001[1]	12.0	0.009	19.0	300	67	90
0.0	9.0	0.0	15.0	49	52	95
0.0	9.0	0.0	15.0	49	52	95
0.6	9.0	5.4	19.2	40	33	95
0.0	9.0	0.0	8.0	8	33	95
0.1	9.0	0.88	8.0	8	33	95
0.04	9.0	0.36	29.0	...	30	95
0.045	9.0	0.403	29.0	...	30	95
0.096	9.0	0.87	24.0	64	65	100
0.49	4.4	2.16	11.0	65	74	105
0.001[1]	5.05	0.003	9.0	46	65	105
0.0	4.7	0.0	0.0	160	44	105
0.0	5.25	0.0	0.0	160	44	105
0.0	5.05	0.0	12.0	good	dry	105
0.001[1]	4.45	0.004	12.0	good	wet	105
0.001[1]	4.7	0.006	9.0	46	65	...

[1] These values represent an arbitrary minimum, based on the probable sensitivity of the method of estimation, and may be interpreted as "a trace."

[2] Tests at same booth.

They may not, however, be significant, and certainly are no proof that lead would always be found in the air of that booth under similar working conditions.

Extent of Exposure to Lead

It must be borne in mind that no sprayer is continuously exposed to the full extent of his hazard. Every man spraying walls, either interior or exterior, spends more time getting ready for spraying and clearing up than he does at the gun. With booth spraying the operative is actually spraying a maximum of 50 per cent. of his time and in some instances not more than 10 per cent. In the automobile industry, however, the percentage of time spent in spraying is much higher owing to continuous line spraying, as was indicated in the section on lacquer

spraying. If we bear these facts in mind, it seems fair to divide the observed exposure by at least 4 in order to estimate the actual hazard.

Sharpe (3) says that in his tests with respirators he found that an efficient respirator will reduce the lead content of air from 232 mg. per 10 cu. m. (or 0.0232 per liter) to between 11 and 12.4 mg. per 10 cu. m.—still two or more times the safe limit. A full discussion of the efficiency of various types of respirators is given in the National Safety Council Report (7, Appendix II).

Medical Examinations

Histories

Very little definite history of leading was found in the Pennsylvania study other than that previously referred to in the vitreous enamel industry. One manufacturer of structural iron which is spray painted in the open reported frequent complaints of gastric pains from his men before he discontinued spraying lead paint. A plant spraying freight cars and locomotives reported a rapid turnover among sprayers but they used little lead. Table 17 gives a summary of the symptom complaints of paint and enamel sprayers in the first survey. Some of these men were spraying material containing some benzol; therefore their troubles cannot all be attributed to the lead. Only 5 per cent. gave a history of loss of appetite; the same percentage reported loss of weight; 23 per cent. gave a history of digestive disturbances; 14 per cent. complained of constipation; and 22 per cent. gave a history of headache. The figures for digestive disturbances and constipation are higher than those obtained from

TABLE 17.—SYMPTOMS REPORTED BY PAINT AND ENAMEL SPRAYERS, PENNSYLVANIA SURVEY

SYMPTOM	SPRAYERS	
	No.	%
Poor appetite	4	5
Loss of weight	4	5
Digestive disturbance	19	23
Constipation	11	14
Headache	18	22
Dizziness	6	7
Coryza	7	9
Dysmenorrhea	2	50[1]
Other symptoms	43	53
Total sprayers	81	100

[1] Percentage of total females.

lacquer sprayers and may indicate the effect of lead.

In the National Safety Council survey the sprayers examined were grouped, not by plants, but by materials sprayed, as follows: undercoats, all containing more or less lead and many also containing some benzol or other volatile solvent; paints mostly for interior use containing no lead, but some of them quick driers which may contain benzol, etc., and certainly do contain benzine; exterior paints containing lead; glaze, ground, rough coat, oxide, and fillers, all trade names for various specific undercoats many of which contain considerable lead but no benzol as they are oven dried; and slush coat, an oily base stain sprayed on frames and a quick drier probably containing considerable benzol. Medical examinations were made on a total of 172 persons in these

groups, including ninety-eight undercoat sprayers, thirty-nine house painters, and thirty-five vitreous enamel sprayers on castings.

The histories of these men show 1.8 complaints reported per man, slightly less than the figure 2.2 reported by the lacquer sprayers. Analyzed by length of service, there was 0.8 complaint per man in the group employed less than six months, 2.1 in the group employed six months to two years, and 2.2 in the group employed over two years.

The incidence of the more specific complaints by length of service is indicated in Table 18 for the entire National Safety Council group. Of the thirteen complaints listed, only six—constipation, digestive disturbances, loss of weight, loss of appetite, gastric pain, and lead line on the gums—are of special significance in relation to lead poisoning but any evidence of poor health may, of course, be directly or indirectly attributable to lead if there is lead exposure. As in the case of lacquer sprayers, with the exception of eye irritation, the incidence of every symptom recorded increases with length of service in the first two periods, while the incidence of many symptoms decreases again in the group employed over two years, as the result of natural selection. Some of these men at times spray lacquer and at other times undercoats. There was comparatively little evidence of pallor except in sprayers in particular plants where conditions were recognizably bad, and in some sprayers of vitreous enamels containing lead. A few of the lead sprayers showed altered patellar reflexes—either increased or decreased. Several of these men showed definite weakness in the wrist extensors.

TABLE 18.—FREQUENCY OF SYMPTOMS BY LENGTH OF SERVICE AS LEAD SPRAYERS, NATIONAL SAFETY COUNCIL SURVEY

SYMPTOM	TOTAL LEAD SPRAYERS[1]	LEAD SPRAYERS EMPLOYED		
		Under 6 Mos.	6 Mos.–2 Yrs.	Over 2 Yrs.
	%	%	%	%
Eye irritation	19	17	13	25
Headache	18	8	16	23
Dizziness	17	3	18	23
Constipation	9	3	12	10
Digestive disturbance	19	6	24	20
Dyspnea	10	6	13	10
Loss of weight	10	3	10	13
Bleeding	4	0	4	6
Numbness	1	0	3	0
Tingling	7	3	7	9
Loss of appetite	8	6	10	8
Gastric pain	3	0	4	4
Lead line	5	3	7	3

[1]Includes all undercoat, paint, and vitreous enamel sprayers as possible lead sprayers.

Comparing the total incidence of symptoms among lead sprayers in this second survey with that among lacquer sprayers in the same study, we find that the lead sprayers show more digestive disturbance, gastric pain, and lead line while the benzol sprayers show more eye irritation and nasal bleeding.

Urine Analyses

In the Pennsylvania survey urine samples were examined from eighty-one paint and enamel sprayers, 37

per cent. of which showed a trace or more of albumin, as did 29 per cent. of those from the varnish sprayers and 36 per cent. of those from the vitreous enamel sprayers. Casts were found in nine samples from vitreous enamel sprayers, and in five from paint sprayers. Cylindroids were reported from six vitreous enamel and six paint sprayers. These examinations do not show much evident damage to the kidneys attributable to lead.

Tests for lead in the urine made in this first survey as an evidence of lead absorption gave the following results: Vitreous enamel sprayers more often than not gave positive tests (nineteen out of thirty-one) as only those spraying lead enamels were so tested. Among paint sprayers, four out of seven gave positive tests, and among enamel sprayers, four out of five. The enamels usually contained lead. From these tests it would appear that lead is being absorbed by nearly all operatives spraying materials containing lead.

Analyses of Feces

Feces examinations as evidence of lead ingestion, but not necessarily of lead absorption, were made in the National Safety Council study for the purpose of comparison with those reported by the committee appointed by the Surgeon General, United States Public Health Service, to study the hazards involved in the use of tetraethyl lead gasoline (19). Fifty-five such tests were made and grouped in the same way as those of the Surgeon General's Committee and they are averaged in Table 19. It will be seen that the sprayers of lead materials fall midway between the normals and the workers in highly intensive lead hazards.

TABLE 19.—LEAD IN FECES OF LEAD SPRAYERS, NATIONAL SAFETY COUNCIL SURVEY

LEAD IN FECES	NORMALS[1]	SPRAY COATERS	LEAD WORKERS[2]
mg./gm.	%	%	%
0–0.003.....	52	65	5
0.003–0.01...	45	4	27
0.01–0.03....	2	15	34
0.03–0.1.....	0	15	32
0.1–0.3.....	0	2	2

[1] United States Public Health Service Groups A and B—77 automobile drivers.
[2] United States Public Health Service Group E—41 workers in highly hazardous lead industry.

Blood Examinations

The average blood cell counts of paint and enamel sprayers examined in the first study have been given in Table 8 in the section on lacquer spraying, as some of these men sprayed material containing benzol, which we think is often present in the cheap thinners incorrectly used and sold at times as "mineral spirits." This fact of course influences the average findings of the group.

Of the eighty-one paint and enamel sprayers examined in Pennsylvania twenty-two, or 27 per cent., gave a calculated polymorphonuclear count below 4,500 and only two gave a total white count under 5,625—one 5,580 and one 5,520. This would indicate that the benzol exposure was only slight and accidental in this group. Red cell counts, however, averaged 5,100,000, with thirty counts under 5,000,000—a larger porportion of low red counts than in any except the small

group of fifteen substitute shellac and stain sprayers. In most instances blood slides were stained by the McCord method (20) for basophilic aggregations and in no instance was there evidence of a higher concentration than 5 plus according to Dr. McCord's scale. Usually when found they were reported as 2 or 3 plus, not indicative of leading.

It will be seen from these results that in Pennsylvania we found comparatively little evidence of harm from lead, though a number of men were working in atmospheres at times containing considerable amounts of lead.

In the case of workers exposed to lead in the plants studied in the National Safety Council survey, determinations were made, as far as circumstances permitted, not only of hemoglobin, color index, total red cells, and differential white cells but also of the specific index of lead poisoning furnished by the observation of stippled cells.

The hemoglobin and color index results were slightly lower than those recorded for lacquer sprayers, averaging 76 per cent. hemoglobin and 0.83 color index as against 82 per cent. and 0.89 for lacquer sprayers. These figures are of some significance as evidence of lead in the group when it is considered that a number of members of the group do not spray lead.

Of the group, twenty-five, or 15 per cent., gave a red blood cell count below 4,000,000 as against 12 per cent. of the lacquer group, with a minimum count of 2,800,000. Only six, or 4 per cent., gave a total white count below 5,625 as against 12 per cent. of the lacquer group. Analysis of red cell counts by length of service showed that of the men employed less than six months 21 per cent. had counts below 4,000,000 while 19 per cent. of those spraying over two years gave counts below that figure.

It would seem strange at first that the men spraying lead paints on walls showed higher red counts than did the others. This is the only group where the red counts can be considered as normal. This is due to the fact that the lead hazard in this group is not nearly so great as would be expected. No lead paints, or very few such, according to our observations at least, are used at present in interior decoration, and all their lead spraying was on exterior walls. This is a seasonal occupation and never engaged in to the exclusion of other types of painting, so that the general painter spraying lead containing materials is spraying lead for only a few months in the year and even then not to the exclusion of other work. Owing to their large percentage of outdoor work these men were found to be more healthy generally and more robust than were the factory sprayers.

The polymorphonuclear counts in this entire group of undercoat and paint sprayers average about the same as those of the lacquer group owing to the benzol exposure of many of the sprayers and to the lead exposure of others. Lead carbonate, however, is not found in lacquers as it is incompatible with nitrocellulose. The lowest counts were in the sprayers of primers and slush coats, both containing benzol, and the highest counts in the oxide and glaze sprayers using no benzol.

With most of the sprayers of these

groups basophilic aggregation tests according to the McCord technic as first described (20) were made. Dr.

TABLE 20.—STIPPLED CELL COUNTS FOR LACQUER AND LEAD SPRAYERS, NATIONAL SAFETY COUNCIL SURVEY

STIPPLED CELLS PER MILLION RED CELLS	NORMALS[1]	LACQUER SPRAYERS	LEAD WORKERS[2]	LEAD SPRAYERS
0–20	112	7	26	5
21–100	1	7	16	4
Over 100	0	1	19	7

[1] United States Public Health Service Groups A and B—113 automobile drivers.
[2] United States Public Health Service Group E—61 workers in highly hazardous lead industry.

McCord considered 4 plus or over as evidence of leading, if symptoms suggestive of lead were present. In ninety-eight undercoat sprayers tested, sixteen, or 16 per cent., gave readings of 4 plus or higher with nine as high as 10 plus. In twenty-one paint sprayers tested, eight, or 38 per cent., were 4 plus or over. In thirty-two sprayers of vitreous enamel on castings tested, seventeen gave a reading of 4 plus or over with eight up to 10 plus, whereas in those spraying on sheet metal and using little or no lead only three out of nine so tested showed 4 plus or over and these all had previously sprayed on castings. There was usually a rather definite correlation between lead in the feces and basophilic aggregations in the blood, and even between lead in materials sprayed and basophilia.

As a check on this method of showing leading, stippled cell counts by the method used by the Tetraethyl Lead Committee (19) were made on a consecutive group of fifty sprayers. In thirty-one of this group we have some information as to the lead in the material sprayed. Fifteen of these were lacquer sprayers working with material containing little or no lead and the remaining sixteen were using undercoats or vitreous enamels mostly rich in lead. The results of these tests appear in Table 20. Only one lacquer sprayer showed over fifty stippled cells per million red cells, whereas a few paint sprayers who had shown basophilia by the McCord method, as well as a number of vitreous enamel sprayers handling material rich in lead, showed high counts up to a maximum of 9,000 per million red cells.

Cases of Lead Poisoning

The National Safety Committee selected from the survey records six cases of probable early lead poisoning among the sprayers in one auto body plant, three among structural painters, and five among vitreous enamel sprayers. The findings on which they based these diagnoses are given in their report (7, p. 27). A number of histories of former lead poisoning were obtained.

Discussion

The combined surveys considered in this section show that it is impossible to spray any materials containing appreciable amounts of lead without at times exceeding the safe limit for lead in inspired air for continuous exposure.

With under 1 per cent. of lead in the

material being sprayed this limit should usually not be exceeded if reasonable care is exercised and reasonable exhaust ventilation provided. With amounts much in excess of 1 per cent. concentrations much above the safe limit will frequently be encountered, though not always. The many uncontrollable variables in commercial spraying make it impossible always to be sure of safety in this respect.

While good exhaust ventilation will usually protect the sprayer, the only safe practice where materials with much over 1 per cent. of lead are likely to be sprayed is to use an efficient respirator or air mask as in the case of benzol spraying.

In the automobile and vitreous enamel industries many operatives are at present being leaded through lack of these precautions.

Conclusions

There are so many variable and uncontrollable conditions met with in the application of coating materials containing lead in any form that exhaust ventilation as at present generally practised cannot always be depended upon properly to protect the sprayer.

Where adequate exhaust ventilation is not assured, sprayers of lead materials should wear protective hose masks or respirators as indicated in the National Safety Council Report.

Adequate ventilation should provide for an air movement past the sprayer of from 150 to 200 feet per minute toward the exhaust duct.

It would be safest to discontinue the spraying of any paints or lacquer coats containing over 1 per cent. of lead.

All workers who spray materials containing lead should be given the protection of periodic medical examinations as outlined in the concluding section of this paper.

The findings discussed in this paper are based on forty-nine air tests for lead in twenty-five industrial plants, etc., and on examinations of 253 workers spraying various paints, enamels, automobile undercoats, and vitreous enamels.

Vitreous Enamel Spraying and Silicosis

One of the newer applications of the spray gun is in the spraying of vitreous enamels on to metal parts for stoves, signs, scales, and other metal objects. The enamel used is a glaze composed of silicates and pigments and often containing more or less lead salts. The lead hazards of the use of this material have already been discussed and this section of the paper will be concerned only with the possible silicosis hazard from the inhalation of the spray containing very finely divided silicious matter. Dr. Alice Hamilton has given a discussion of the composition of this class of material (18) and it will not be gone into in detail here.

The silica in these glazes is present mainly as combined silicates and partly as free silica but our work did not attempt to separate the two. The total silica was reported as SiO_2 in the second survey but no analyses were made for silica in the first. There is considerable difference of opinion as to the harmfulness of the silicates,

English authorities (21) claiming that it is only silica itself in the form of an oxide that does permanent damage to the lungs. A number of foreign and American workers do not accept this view and it was felt that a study such as reported here would throw some additional light on the matter.

The use of the spray gun for this work is very new and many of the operatives seen had been spraying for only a short time. Workers who had been spraying less than one year were generally not included in the studies as it was felt that it would be a waste of effort to have them X-rayed. Of seventy-six sprayers interviewed in Pennsylvania twenty-two had sprayed for three years or more but only three had sprayed for over five years. Of sixty-one sprayers interviewed in the second study sixteen had sprayed for three years or more but only seven for five years or more.

Scope of Studies

In the first study twenty plants were visited and studies made in sixteen of them. In most instances blood examinations were not made but histories were taken and physical examinations made, and in so far as possible X-rays obtained of the lungs of all who had been spraying this material for one year or more. No portable outfit for this work was available and it was necessary to depend on the aid of local hospitals. This was not always available and the negatives received were not always readable but fifty-two readable negatives were obtained.

In the second study sixty-one sprayers of vitreous enamels were examined and thirty-one readable X-rays were obtained.

Air Conditions

Air samples at the booths were taken with a Palmer air sampler in Pennsylvania but this was not found to be very satisfactory. The bulk of the carrying case was an inconvenience as it was apt to interfere with the worker and it also acted as a baffle, disturbing the air currents. In the second survey an impinger apparatus was assembled which was found to be much more satisfactory from the standpoints of both convenience and efficiency. In comparing the counts from plants appearing identically dusty to the eye from the two surveys it was felt that it would be necessary to multiply the Pennsylvania results by 4 to be able to compare conditions with those found in the second study.

Table 21 gives a summary of the dust counts obtained in the first study, listed by material sprayed and by air velocity but not by plant. There is some difference in practice in the spraying of steel stampings and of castings. In the former case the glaze has little or no lead as a rule and almost no so-called soluble lead but it contains a higher percentage of silica and is sprayed at a higher air pressure and in a heavier cloud. The glaze for castings almost always contains lead but analyses show that it contains about half as much silica as does that for steel stampings.

Air velocities did not always show correlation with dust counts even in the same plant owing to the always present uncontrollable variables, such as size and shape of object sprayed,

size and shape of booth, variability of room air currents, and ability to

floating dust and a sample taken 6 feet away from the booth gave a count of

TABLE 21.—PALMER COUNTS IN VITREOUS ENAMEL PLANTS, PENNSYLVANIA SURVEY

OBJECT SPRAYED	AIR VELOCITY	PALMER COUNT	REMARKS
	ft./min.	*¼-unit part./cu.ft.*	
Steel stampings; standing	68	80,000,000	No count in group under 5,000,000.
	110	5,300,000	
	143	192,000,000	
Steel stampings; flat	192	86,000	4 counts in group under 1,000,000.
	73	170,000	
	93	1,530,000	
	124	266,000	
	88	2,160,000	
	199	833,000	
Castings; stove parts	23	53,400,000	
	22	4,711,000	
	22	4,000,000	
	51	960,000	
	71	5,700,000	
	72	42,000,000	
	111	70,000,000	
	115	1,680,000	
	119	80,000	Velocities over 115 ft. per min. gave counts under 1,000,000.
	199	400,000	
	210	800,000	
	241	87,000	Velocities over 210 ft. per min. gave counts under 250,000.
	244	223,000	
Castings; sanitary ironware	0	76,800,000	
	16	577,000	
	49	108,000	
Castings; no exhaust ventilation; test 6 feet from sprayer	...	4,240,000	

place the sampling device in the most favorable position to obtain a representative sample. In one plant where the exhaust system was out of order small portable electric fans were placed inside the booths. Here the air of the entire room was filled with over 4,000,000 quarter-unit particles (with a maximum diameter of 10 microns) per cubic foot. The samples collected showed remarkable uniformity in size distribution of dust particles, practically all of them falling between 0.5 and 10 microns in diameter and

so within the danger zone. These findings agree closely with those of Watkins-Pitchford and Moir (22) and of Smyth and Iszard (23).

One plant making large sanitary ironware was spraying a slush coat on the tubs before enameling and a silicious paint on the bottoms of enameled tubs. Here there was a distinct inverse correlation between air flow and suspended particles at different spray booths. With an almost imperceptible air velocity there was a count of over 76,000,000, with a velocity of 16 feet per minute a count of over 500,000, and with a velocity of 49 feet a count of 108,000. These counts are distinctly lower than any vitreous enamel counts at corresponding speeds.

With the spraying of stove castings there is considerable irregularity as to counts but these tests fall clearly into two groups. No tests with velocity under 100 feet per minute gave less than 960,000 quarter-unit particles per cubic foot and all but one gave 4,000,000 or over. With velocities between 116 and 210 feet counts were between 80,000 and 800,000 and with velocities over 210 feet, neither count reached 250,000.

With the spraying of stampings which afford larger flat surfaces to reflect the spray back toward the operator the counts ran higher for high velocities, but where the pieces being coated were laid flat or nearly so and were sprayed on a turntable no counts ran as high as 2,250,000. When the pieces were upright or only slightly slanting the lowest of three tests gave over 5,000,000 quarter-unit particles per cubic foot. These tests indicate that even with large flat surfaces, if properly placed in the booth, it is perfectly possible to spray so as to expose the sprayer to a minimum cloud of enamel averaging under 1,000,000 quarter-unit particles per cubic foot by Palmer test, and if air velocities are maintained over 100 feet per minute this should always be possible. With velocities over 200 feet this should be even easier to obtain and such velocities are by no means unique. Twelve of the twenty-six tests gave velocities over 100 feet, and three over 200 feet.

The enamels as sprayed are in the form of a very thin paste suspended in water but the atomization is so complete that by the time they reach the object being coated they are almost dry and the booth air is full of dry particles. For purposes of estimating health hazard the material may be considered as a dust.

Table 22 gives the results of the air tests in the second study in somewhat more detail. In this study analyses of samples for total silica as well as for lead were made by the method described in the National Safety Council Report (7), and the figures appear in the table. Air velocities ranged from imperceptible in one plant, which however was about to install a new system, to a maximum of 257 feet per minute, with fourteen out of thirty-three tests over 100 feet and three over 200. Counts of suspended particles collected by the impinger ranged from 310,000 per cubic foot in one plant, and an average of three tests in this plant of 397,000 and at an average air velocity of 212 feet, to 1,800,000,000 in another where there was an average of 445,000,000 for six tests and no measurable air flow. Only one in-

TABLE 22

IMPINGER

¼-unit par
24,0
27,0
13,0
23,0
25,0
9,0
4,9
5,6
20,0
19,0
11,0
6,6
3,7
4,2
1,800,0
350,0
170,0
100,0
140,0
110,0
5
3
3
30,0
34,0
27,0
2,2
2,0
7
1,2
1,1
1,6
1,5

[1] Autom

TABLE 22.—IMPINGER TESTS IN VITREOUS ENAMEL PLANTS, NATIONAL SAFETY COUNCIL SURVEY

IMPINGER COUNT	AIR VELOCITY AT SAMPLING POINT	AIR PRESSURE AT SPRAY GUN	AREA OF WORK	CASTINGS (C) OR SHEET METAL (S)	AMOUNT OF TIME MAN IS SPRAYING	ENAMEL SPRAYED PER DAY	TOTAL LEAD IN MATERIAL SPRAYED	SOLUBLE LEAD IN MATERIAL SPRAYED	TOTAL SILICA (AS SiO_2) IN MATERIAL SPRAYED
¼-unit part./cu. ft.	*ft./min.*	*lbs.*	*sq. in.*		%	*lbs.*	%	%	%
24,000,000	36	85	200	s	95	1,000	2.8	0.7	42.8[1]
27,000,000	36	85	200	s	95	1,000	2.8	0.7	42.8[1]
13,000,000	30	85	12	s	50	500	2.8	0.7	42.8
23,000,000	130	85	50	c	50	500	26.0	0.4	21.2
25,000,000	130	85	50	c	50	500	26.0	0.4	21.2
9,000,000	142	85	200	s	95	1,000	2.8	0.7	42.8[1]
4,900,000	137	100	10	c	30	200	23.0	20.0	25.8
5,600,000	111	100	50	c	45	200	23.0	20.0	25.8
20,000,000	240	100	180	s	80	400	0.0	0.0	44.8
19,000,000	120	100	100	s	50	400	0.0	0.0	44.8
11,000,000	120	100	60	s	50	400	0.0	0.0	44.8
6,600,000	98	100	180	s	60	400	0.0	0.0	44.8
3,700,000	98	100	180	s	60	400	0.0	0.0	44.8
4,200,000	74	100	144	s	50	400	0.0	0.0	44.8
1,800,000,000	negligible	100	300	s	80	500	0.0	0.0	47.1
350,000,000	"	100	300	s	80	500	0.0	0.0	47.1
170,000,000	"	100	300	s	80	500	0.0	0.0	47.1
100,000,000	"	100	300	s	80	500	0.0	0.0	47.1
140,000,000	"	100	300	s	80	500	0.0	0.0	47.1
110,000,000	"	100	300	s	80	500	0.0	0.0	47.1
540,000	257	65	100	c	90	400	3.8	3.8	37.2
310,000	213	65	200	c	90	400	3.8	3.8	37.2
340,000	166	65	100	c	90	400	3.8	3.8	37.2
30,000,000	...	100	300	s	80	300	0.0	0.0	42.6
34,000,000	...	100	300	s	70	300	0.0	0.0	42.6
27,000,000	...	100	300	s	80	300	0.0	0.0	42.6
2,200,000	...	100	400	c	60	200	13.0	11.0	24.0
2,000,000	...	100	400	c	60	200	13.0	11.0	24.0
740,000	97	100	300	c	60	400	....	....	....
1,200,000	109	100	300	c	60	400	....	....	....
1,100,000	128	100	50	c	40	200	....	....	....
1,600,000	128	100	50	c	40	200	....	....	....
1,500,000	...	100	100	c	60	400	....	....	....

[1] Automatic booth.

stance of high count with high air velocity was noted with 20,000,000 quarter-unit particles and an air flow of 240 feet. Large stampings were being sprayed. In this plant six tests with stampings being sprayed averaged 10,750,000 particles and two with castings only 5,250,000.

Medical Examinations

Histories

A study of the medical histories of the seventy-six vitreous enamel sprayers interviewed in Pennsylvania showed 9 per cent. with a history of loss of weight, the highest percentage for this complaint in any of the spray groups. Ten per cent. gave a history of digestive disturbances—not an especially high figure. Fourteen per cent. complained of constipation, 10 per cent. of headaches, also a low figure. Over 15 per cent. complained of more or less dizziness and 17 per cent. of shortness of breath, the highest percentage of any except the small group of substitute shellac and stain sprayers.

There were seventeen women or young girls in the group and seven of these gave a history of dysmenorrhea, as against six out of eighteen women sprayers in the other groups—possibly not a significant increase. Of the urine samples twenty-seven, or 35 per cent., showed some albuminuria and nine, or 11 per cent., showed casts. These figures are the highest for renal findings in any group and are possibly due to the lead exposure.

In a study of symptom complaints of the sixty-one sprayers of vitreous enamels in the second survey there is a high incidence of most complaints in the sheet metal sprayers possibly owing to the preponderance of females in this group. In both sheet metal and casting sprayers dyspnea is found more often than in any other groups of sprayers, 17 per cent. among casting sprayers and 27 per cent. among sheet metal sprayers. Dizziness is also a common complaint in both groups, 31 per cent. in the former and 27 per cent. in the latter. Other symptoms have been discussed in the section on lead hazards.

X-Ray Findings

The most important studies in both groups were considered to be the X-ray studies of the lungs. In Pennsylvania various local hospitals were depended upon to make these examinations and they were often not made until some time after the survey visit. For one reason or another a number of the workers failed to go to the hospitals for this examination, most of the female sprayers being in this class. Some of the roentgenologists taking the films furnished their own diagnoses of the negatives but not all did so. All negatives collected in both studies were submitted to Dr. H. K. Pancoast of the University of Pennsylvania for final diagnosis. The findings of the two studies are summarized and analyzed in Tables 23 and 24.

In the entire group of fifty-two readable negatives from Pennsylvania and thirty-one from the second study there were found ten, or almost 12 per cent., showing definite silicosis although in four of these there may have been other contributing factors. In addition to these cases of positive silicosis there were fourteen, or about 17 per cent., reported by Dr. Pancoast

as suspicious, with evidence of increase in hilum and peribronchial shadows,

TABLE 23.—SUMMARY OF X-RAY DIAGNOSES FOR BOTH SURVEYS

DIAGNOSIS	PA. SURVEY		N.S.C. SURVEY		TOTAL	
	No.	%	No.	%	No.	%
Negative	27	54	24	78	51	62
Suspicious	13	25	1	3	14	17
Tuberculous foci	3	6	3	9	6	7
Pleurisy	1	2	0	0	1	1
Silicosis	7[1]	13	3	9	10	12
Totals	51	..	31	..	82	..

[1] Age was a possible factor in 2 cases; previous occupation, in 2 others.

and a recommendation for subsequent examination at a later date. In addition to these there were a number of cases reported with increased hilum and peribronchial shadows extending into one or more lobes and diagnosed as suspicious or positive by the local roentgenologists taking the negatives. In most of these cases Dr. Pancoast also stated that there was enough suspicion of harm to make a re-examination at a later date advisable and to recommend the exclusion from the job of all those with evidence of tuberculosis. Six of the negatives showed tuberculous foci of recent or fairly recent origin.

Analysis of the findings (Table 24) shows a distinct difference between the sprayers on castings and those on sheet metal, where the silicosis exposure is decidedly greater. Of the ten definite positives, one was spraying on small castings and nine on sheet metal or other material where no lead is used.

We found no positive silicosis with operatives spraying one year or under,

TABLE 24.—X-RAY DIAGNOSES FOR BOTH SURVEYS ACCORDING TO LENGTH OF SERVICE AND OBJECT SPRAYED

LENGTH OF SERVICE	SPRAYING ON		DIAGNOSIS
	Sheet Metal	Castings	
yrs.			
1 or less	2[1]	8	negative
1–2	4	10	negative
	3	1	suspicious
	0	3	tuberculous foci
	1	0	pleurisy
	3	0	silicosis
2–4	10	9	negative
	2	3	suspicious
	1	2	tuberculous foci
	3	1	silicosis
4–5	3	0	negative
	2	0	silicosis
Over 5	1	2	negative
	1	1	suspicious
	1	0	silicosis
Unknown	0	2	negative
	0	3	suspicious
Totals	20	31	negative
	6	8	suspicious
	1	5	tuberculous foci
	1	0	pleurisy
	9	1	silicosis

[1] One worker from whom a readable negative was obtained is omitted as he had been exposed for only two months.

three cases among twenty-five operatives spraying between one and two years, four cases among thirty-one spraying from two to four years, two cases among five spraying four to five years, and one case and two suspicious among those spraying over five years. One girl spraying nine

years showed a well-marked positive second-stage silicosis. South African workers (24) state that it takes about ten and a quarter years to develop silicosis in miners on the Rand where the silica content of the dust is decidedly higher than is that of these enamels, so it is felt that, in spite of the small number of sprayers examined in these two studies and of the short average working time of the group, these results give evidence of a definite silicosis menace in the industry. Of the three positive cases found in the second study one was in the plant with the highest dust counts, averaging 445,000,000 particles per cubic foot, another in the next dustiest plant with counts averaging over 30,000,000 at booths handling stampings, and the third at a plant where present counts averaged over 1,225,000 with some comparatively new equipment. He had been spraying three and one-half years at this plant and had probably worked under decidedly worse conditions than at present.

In the two studies twelve females were X-rayed and three were found positive or suspicious for silicosis and one, tuberculous. Thirty-eight females were interviewed in the two studies and of this group fifteen were under 20 years of age, eleven under 19, and two were 16 years old. This is a very young group for such a dusty industry.

Discussion

It appears from these studies that the spraying of vitreous enamels involves a distinct silicosis hazard in spite of the fact that the silica content in the material sprayed does not average as much as 50 per cent. The silicosis hazard predominates where sheet metal is sprayed and the lead hazard where castings are sprayed. Air velocities well over 100 feet per minute reduce the dust cloud materially and those over 200 feet as recommended by the National Safety Council Committee produce very satisfactory conditions.

The recommendation of the National Safety Council Committee that glazes be carefully balanced so as to contain no free silica will help conditions but may not remove the hazard, as these findings indicate that with a presumable preponderance of silicates these glazes are capable of producing fibrosis.

Conclusions

In addition to the lead hazard connected with the spraying of vitreous enamels on to castings, as pointed out in the previous section, there is a definite silicosis hazard from the spraying of all such materials, especially that used for coating sheet metal.

The silicosis hazard can usually be controlled or minimized by adequate exhaust ventilation of from 150 to 200 feet per minute past the sprayer toward the exhaust ducts.

If silicious materials are sprayed without exhaust ventilation the operators should always be protected by hose masks or respirators as indicated for other types of spraying.

These conclusions are based on the findings of fifty-nine tests for suspended particles in twenty vitreous enameling plants and on X-ray examinations of eighty-four sprayers of silicious materials out of 137 examined.

Periodic Medical Examinations for All Sprayers

Wherever workers are employed within buildings, booths, or other indoor or enclosed spaces, in spray coating with materials containing benzol or lead in the form of paints or lacquers, or silicious material in vitreous enamel or similar coatings, whether with or without exhaust ventilation or the use of respirators or masks, provision should be made for systematic routine medical examination for the detection of early symptoms of absorption of poison or of silicosis.

The following program has been suggested for this purpose by the National Safety Council Spray Coating Committee.

It is recommended that such operatives be given a physical examination previous to or within one month of employment, in order to determine whether they have any physical defects which might be made worse by their employment and in order to obtain a record of their physical condition for comparison with succeeding examinations.

Persons spraying compounds containing lead or benzol should be reexamined at least once every six months,[1] including the making of white and red blood cell counts, differential white counts, hemoglobin determinations, and stippled cell counts.

Persons spraying silicious materials should be examined and their chests X-rayed at least once every two years.

No person should perform the work of an interior spray painting operator with paints containing lead or benzol if the results of an examination of his blood show any evidence of a disturbance that would be aggravated by exposure to lead or benzol, or if there is any evidence of lead or benzol absorption as indicated by the following findings:

1. The presence of over twenty stippled cells per 100,000 red cells.

2. A distinct evidence of anemia as shown by hemoglobin under 70 per cent., or red cells under 4,000,000 per cubic millimeter for men and 3,800,000 for women.

3. A total white cell count under 5,600 per cubic millimeter, or a total polymorphonuclear count under 4,000. When a second or succeeding differential count is more than 5 per cent. lower in polymorphonuclears than the preceding one, the worker may continue his work for a period of no longer than three months, if he seems to be in good physical condition otherwise. If at the end of that period a recount shows the condition to be progressive, he should not be permitted to continue spraying regardless of his physical condition.

4. No person should spray vitreous enamel or other silicious material if an X-ray examination of his or her chest shows the presence of fibrosis or active tuberculosis. Any evidence of developing fibrosis at subsequent examinations should call for a change of occupation, as should also any evidence of progressive lead absorption as indicated by an increase in stippled red blood cells.

[1] These intervals are twice those suggested in the National Safety Council Report, but it is felt that the findings of the surveys do not justify shortening them. Otherwise the recommendations are the same as in that Report.

Bibliography

1. Albaugh, R. P.: A Fatal Case of Slow Poisoning in the Person of a Young Man Employed as a Sprayer in a Varnishing Department. Ohio Pub. Health Jour., 1915, *6*, 512.
2. Wright, W.: An Industrial Clinic. U. S. Month. Labor Rev., 1917, *5*, 1257.
3. Sharpe, N. C.: Report on an Investigation to Determine the Hazard to the Health of Operators Using the Spraying Machine for Painting: The Risk of Lead Poisoning. This Jour., 1921–1922, *3*, 378.
4. Hamilton, A.: The Prevalence and Distribution of Industrial Lead Poisoning. Jour. Am. Med. Assn., 1924, *83*, 583.
5. General Orders on Spray Coating. Indust. Commission Wisconsin, April 10, 1924; revised Oct., 1925.
6. Spray Painting in Pennsylvania. Pa. Dept. Labor and Industry, Special Bull. No. 16, 1926.
7. Final Report of the Committee on Spray Coating. Nat. Safety Council, Sept., 1927.
8. Final Report of the Committee on Benzol. Nat. Safety Council, May, 1926.
9. Elliott, S., and Dalton, J.: The Estimation of Small Quantities of Acetone, Alcohol, and Benzene in Air. Analyst, 1919, *44*, 132.
10. Pfeiffer, O.: Bestimmung von Benzoldampf im Leuchtgas. Chem.-Ztg., 1904, *28*, 884.
11. Yant, W. P., and Frey, F. E.: Apparatus for Preparing Vapor-Air Mixtures of Constant Composition. Jour. Indust. and Engin. Chem., 1925, *17*, 692.
12. Knecht, E., and Hibbert, E.: New Reduction Methods in Volumetric Analysis. London, Longmans, Green & Co., 1918.
13. English, F. L.: The Analysis of Aromatic Nitro Compounds by Means of Titanous Chloride. Jour. Indust. and Engin. Chem., 1920, *12*, 994.
14. McConnell, W. J., and Yagloglou, C. P.: The Kata Thermometer: Its Value and Defects. U. S. Pub. Health Rep., 1924, *39*, 2293.
15. Hamilton, A.: Industrial Poisons in the United States. New York, The Macmillan Co., 1925.
16. Fairhall, L. T.: Lead Studies: I. The Estimation of Minute Amounts of Lead in Biological Material. This Jour., 1922–1923, *4*, 9.
17. Legge, T. M., and Goadby, K. W.: Lead Poisoning and Lead Absorption. London, Edward Arnold; New York, Longmans, Green & Co., 1912.
18. Hamilton, A.: Lead Poisoning in Potteries, Tile Works, and Porcelain Enameled Sanitary Ware Factories. U. S. Bur. Labor, Bull. No. 104, Aug. 7, 1912.
19. The Use of Tetraethyl Lead Gasoline in its Relation to Public Health. U. S. Pub. Health Bull. No. 163, 1926.
20. McCord, C. P., Minster, D. K., and Rehm, M.: The Basophilic Aggregation Test in Lead Poisoning. Preliminary Report. Jour. Am. Med. Assn., 1924, *82*, 1759.
21. Heffernan, P.: Exposure to Silica Dust without the Occurrence of Silicosis. This Jour., 1926, *8*, 481.
22. Watkins-Pitchford, W., and Moir, J.: On the Nature of the Doubly-Refracting Particles Seen in Microscopic Sections of Silicotic Lungs, and an Improved Method for Disclosing Siliceous Particles in Such Sections. So. African Inst. Med. Res., Pub. No. 7. Johannesburg, Sept. 14, 1916.
23. Smyth, H. F., and Iszard, M.: The Practical Hygienic Efficiency of the Palmer Apparatus for Determining Dust in Air. This Jour., 1921–1922, *3*, 159.
24. Watkins-Pitchford, W.: The Silicosis of the South African Gold Mines, and the Changes Produced in It by Legislative and Administrative Efforts. *Ibid.*, 1927, *9*, 109.