Industrial Lead Poisoning

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CHAPTER XXVI

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ROBERT A. KEHOE, M.D.

I. The Occurrence of Lead Poisoning in Industry

There are no reliable statistics on the frequency of occurrence of occupational lead poisoning in the United States of America as a whole, by localities, or by occupations. This situation arises out of a number of conditions, among which must be mentioned the frequency of errors of diagnosis, the lack of adequate medical supervision of many industrial plants in which there is hazardous occupational exposure to lead, and the failure on the part of certain of the states to set up mechanisms for reporting accurately cases of industrial lead poisoning. As occupational medicine achieves a more complete coverage of industrial operations in the lead-using industries, and the application of state compensation laws becomes more effective and more precise in relation to this occupational disease, the statistical data will approach adequacy, but for the present the industrial hygienist will be well advised to rely only upon those recorded in areas in which the mechanisms for collecting and recording the facts are known by him to be reliable. On this account any statements concerning the incidence of industrial lead poisoning must of necessity be based in large part upon the observations and experience of an individual writer, without benefit of the collective records of his professional colleagues.

Such evidence as is recorded would seem to demonstrate that fatal lead poisoning has decreased in frequency more or less regularly and progressively over the period of the past three or four decades. Just how much of this decrease has resulted from changes in medical viewpoints, with reference to the *primary* cause of death of persons with an apparently significant history of occupational exposure to lead, cannot be determined. It is quite certain, however, that the more severe forms of lead poisoning are seen relatively infrequently now, as compared with earlier periods in the United States, and that primary, fatal, industrial lead poisoning, is infrequent in its occurrence. These facts argue that the more hazardous types of occupational exposure to lead have disappeared, or have been brought under some degree of control, and the experience of industrial physicians and hygienists validates this argument.

It is by no means so certain that there has been any very significant decrease in the incidence of the milder forms of industrial lead poisoning. The experience of the writer leads him to believe that occupational lead exposure has been brought *under some measure of control in the large proportion of American industries* within recent years, and that an entirely satisfactory quality of control has been *achieved in many of these. On the other hand, the opportunities for hazardous* exposure have not been controlled to the degree that is required to eliminate lead *poisoning as the cause of partial and temporary disability* among a large number of workmen in a wide variety of industrial occupations. Moreover, in some industries *some men continue uninterruptedly* at work after they have developed mild symptoms and signs of lead intoxication which are not disabling and which, if noticed, are taken to be the deviations from well-being that beset most people from time to time under a variety of circumstances. Regardless of statistics or the lack of them, it is apparent to any informed observer that industrial lead poisoning occurs with a frequency that bears no reasonable relationships to the accuracy of present criteria for differentiating safe from dangerous occupational exposure to lead, or to the adequacy of presently available medical and engineering means for controlling such exposure within entirely safe limits.

The causes for the present unnecessarily high incidence of industrial lead poisoning are numerous, but certain outstanding factors should be understood by those who would attempt to eliminate this disease from an industry or from the industrial community. First in importance among these causes is the prevailing lack of understanding on the part of industrial management, and many of its medical and technical advisers, of the primary factors that determine the frequency and severity of lead poisoning in a given occupation, and of the means now available for recognizing and appraising these factors. Certain confused and confusing ideas have persisted for a long time in connection with the lead trades. Allegedly wide variations in the "susceptibility" of individuals have given rise to the erroneous belief that there are no dependable means by which wholly safe occupational conditions of exposure to lead can be differentiated from those that are dangerous. Conversely, the comparative mildness of lead intoxication as it is seen commonly in American industry, and the frequency and promptness with which the more troublesome symptoms tend to subside after the termination of the occupational exposure to lead, contribute to the persistence of the irresponsible or illiterate view that there is no need to achieve complete control of the hazard. This view, it seems, is especially prevalent in some of the long-established lead trades in which the conditions are "much better than they used to be" while failing to meet adequate hygienic standards.

A second factor that exerts an important influence upon the incidence of intoxication is the continually changing pattern of modern industrial technology whereby new processes and products create new and sometimes unrecognized opportunities for occupational exposure to lead. By this means lead hazards are introduced into industrial plants in which there is no understanding of such hazards and no experience in coping with them. In other plants, new lead hazards may be added to recognized pre-existing hazards that were well under control, thereby, at

times, increasing the exposure to lead above threshold levels and giving rise to cases of saturnism.

A third factor, and one that came into prominence during World War II and may operate during any period of rapid industrial expansion, is to be found in a large and abrupt increase in the number and volume of lead-bearing materials and commodities. Under such circumstances production schedules are likely to outrun precautionary measures, and the exposure of many workmen to lead may well increase by an increment that is disproportionate to the increase in production. Such increased exposure comes about through actual increase in the variety and volume of materials handled, through increased frequency of failures of plant equipment under the stress of production schedules, through the mistakes and faults of inadequately trained personnel, through inadequacies in supervision, through lengthened hours of work (overtime), and through deficiencies in plant housekeeping and in facilities and training in relation to personal hygiene.

Whatever may be the cause or combination of causes that gives rise to lead poisoning in a specific plant or industry, the means of prevention can be found in the careful study of the origin, nature, and magnitude of the exposure to lead by methods now readily available, and in the application of certain procedures that have demonstrated their capacity to reduce the exposure to a level compatible with the safety of plant personnel. This is not to say that there are no difficult problems to be met in certain industries. It is merely to say that the specifications for the maintenance of safety can be prescribed with adequate accuracy, and that the technical skill required to meet such specifications need not be of a higher order than that so generously expended upon problems of production. There are few types of occupational exposure to lead that offer insurmountable or even serious obstacles to modern engineering methods of attack, and there are none that can elude properly applied procedures for determining the extent of the hazard associated with them. What is required is a sound understanding of the problem that is to be solved, and a genuine determination to solve it, not by prophylactic medical therapy, but by the application of orthodox engineering principles and equipment coupled with satisfactory medical supervision. It is the purpose of the following paragraphs to outline the practical means by which the hazards of industrial exposure to lead may be understood, measured, and eliminated.

II. Types of Exposure to Lead in Industry

Generally speaking, there are two means for the entrance of inorganic lead compounds (cf. later discussion of organic compounds) into the human body under industrial conditions: (*a*) by way of the respiratory tract, through inhalation of vapor, fume, dust, or mist, and (*b*) by way of the gastroenteric tract, through swallowing lead compounds trapped in the upper respiratory tract, or introduced into the mouth on food, tobacco, tools, fingers, or other objects. The inorganic compounds of lead, in solid form or in solutions or dispersions in various solvents or dispersion media, do not penetrate the normal or abraded human skin to any practically important extent. Certain of these compounds may injure or irritate the skin under suitable conditions, but even under these conditions their percutaneous absorption is of only theoretical, rather than of practical, significance. These portals of entry are mentioned for the purpose of calling attention to the forms in which inorganic lead compounds must exist if they are to gain entrance into the body. The presence of the vapors, fume, or fine dust of inorganic lead compounds in the air breathed by workmen is the most generally important factor in occupational exposure to lead. However, lead compounds that contaminate the hands, food, tobacco or other objects taken into the mouth may not be ignored as sources of exposure. In this connection the not uncommon practice *among workmen in certain shops and factories* of keeping food or bottles of milk in convenient places in dusty workrooms or in locker rooms inadequately protected against factory dust is a source of significant hazard. Likewise, the rooms in which workmen eat lunches or "snacks," or make coffee or tea, are contaminated all too frequently with dust from plant operations and materials.

The quantities of lead that are given off as vapor from pots containing molten lead at temperatures under 1000°C. are insufficient in themselves to create an important lead hazard, but alloys of high lead content, prepared and handled at higher temperatures—often near and sometimes above the boiling point of lead (1525°C., 2777°F., see Table 1)—give rise to dangerous concentrations of vaporized lead in the air. Even at lower temperatures, however, lesser contributions made by vaporized lead to the total exposure of workmen to lead may have sufficient importance to warrant their elimination. Molten lead is easily oxidized at its surface, and when it is skimmed, stirred, poured, or otherwise agitated in the presence of air, variable quantities of finely divided lead oxide may be thrown into the air. For these reasons the handling of molten lead or molten alloys of high lead content, in all plant processes that are not fully enclosed or adequately ventilated, is always associated with opportunities for some exposure to lead on the part of workmen. The hazard of such exposure is especially prominent in certain foundry operations in which castings of lead-containing alloys are made. The latter include a wide variety of bearings for motor vehicles, ships, and railroad equipment. The alloys are heated in furnaces to appropriate temperatures, which vary with their composition and use, and in a common type of foundry are conveyed in the molten state in pots on overhead rails to the desired site and poured into molds. In transit, vaporized metal and fume escape into the atmosphere over and around the molds, thereby increasing the respiratory exposure of molders and numerous other employees, whose absorption of lead, in connection with their work, otherwise might well be slight or perhaps even negligible. A wide variety of industrial procedures create exposure to lead in this form, including, as a few of the many examples: soldering in the manufacture of automobile radiators, tin cans, and other receptacles; the production and reclamation of Babbitt metal; the manufacture of lead shot and bullets; the preparation of granular metallic surfaces by means of a finely

TABLE 1

Relevant Physical Properties of Metallic Lead and Certain of Its Alloys and Compounds[a]

Material	Melting point, °C.	Pouring temperature, °C.	Boiling point, °C.	Solubility, in 100 ml. Cold water	Hot water	Acid	Alkali
Metallic lead (common)	327.4	382	1525	Insol.	Insol.	HNO3 Acetic	
"Babbitt metal" Pb-Sn-Sb		329–438					
Electrotype metal {94-3-3 Pb-Sn-Sb		327					
Stereotype metal {80.5-6-13.5 Pb-Sn-Sb		327					
Soft solder {38-62 Pb-Sn	183						
Bearing alloy {10-75-12-3 Pb-Sn-Sb-Cu	306	377					
Bearing alloy {80-5-15 Pb-Sn-Sb	260						
Lead acetate (anhydrous)	280			44.3	221.20		
Lead arsenate (insecticide) mono, di, meta, and ortho	Decomp.			Insol.	Sl. sol.	Sol.	Sol.
Lead azide	Explodes at 350			0.023	0.09	Acetic	
Lead bromide	373		916	0.455	4.71	Sol.	Sol.
Lead carbonate (white lead)	Decomp.			Insol.	Insol.	Sol.	Sol.
Lead chloride	501		954	0.673	3.34	Sol.	Sol.
Lead chromate (chrome yellow)	844		Decomp.	0.00005		Sol. (Insol. acetic)	Sol.
Lead fluoride	855		1290	0.064		Sol. HNO_3-H_2SO_4	Insol.
Lead nitrate	Decomp. at 470		Decomp.	38.8	138.8	Sol.	Sol.
Lead sesquioxide	Decomp. at 360		Decomp.	Insol.	Decomp.	Sol.	Sol.
Lead oxide (red lead)	Decomp. at 500		Decomp.	Insol.	Insol.	Sol.	Insol.
Lead *monoxide*	888			0.0017			Sol.
Lead suboxide	Decomp.			Insol.		Sol.	Sol.
Lead dioxide (peroxide)	Decomp. at 290			Insol.	Insol.	Sol.	Sol.
Lead silicate (glazes)	766			Insol.		Decomp.	Sol.
Lead sulfate	1170			0.0028	0.0056	Sol. conc., insol. acetic	
Lead sulfate (basic)	977			0.0044		Sl. sol. H_2SO_4	
Lead sulfide	1114			Essentially insol.		Sol.	Insol.
Lead tetraethyl	−130		±200	Insol.	Insol.	Insol.	Insol.
Lead tetramethyl	−27.5		±110	Insol.	Insol.	Insol.	Insol.

[a] Taken in part from *Lead in Modern Industries*. Lead Industries Assoc., New York, 1952.

divided spray of molten alloy; and the casting of type in the various processes such as linotyping and electrotyping. One common procedure in many types of chemical plants—that of lining tanks and reaction vessels with metallic lead and repairing these linings from time to time—is a source of significant exposure to lead fume, *especially when the work has to be done on the inside of extensively* corroded receptacles. Indeed, lead burning in general, which includes the operations just referred to and many others, may be a highly hazardous occupation under unfavorable conditions involving prolonged or regularly repeated exposure to vapor and fume. Somewhat similar techniques, from the aspect of respiratory exposure to the vapor or fume of lead compounds, are those involving the cutting, welding, or reshaping of metal surfaces heavily coated with lead-bearing paints or with other corrosion-resisting layers of high lead content such as that of terneplate. The application of a cutting flame to lead-containing alloys or to leaded steel likewise results in the release of lead fume, which under suitable conditions may give rise to hazardous exposure to lead.

Among the most frequently occurring types of industrial exposure to lead are those that arise from handling or processing lead compounds in such a way as to introduce respirable particles of such compounds into the surrounding air. Metallic lead and all of its compounds, when present in finely divided form in the atmosphere breathed by workmen, must be regarded as dangerous, unless the quantities present in the air remain within limits known to be safe. The industrial processes responsible for the dispersion of lead-containing dust into the atmosphere are too numerous and *too variable from one time to another to lend themselves to classifi*cation with respect to hazard. The latter may be very great or negligible in a named occupation or industry, dependent upon its methods of operation or upon the quality of the hygienic control achieved in the operations. The most dangerous of operations, in terms of its potentialities, may be entirely safe, while the most innocent, disregarded or unrecognized, may be highly hazardous.

Lead compounds are also thrown into the atmosphere within droplets of mist in a number of operations in which paints, enamels, and glazes are applied as a spray. The inhalation of such mists constitutes a potential hazard that is not different in principle from that involved in the case of fume and dust. It is necessary here, however, to differentiate the effects induced by respiratory exposure to the solvent or dispersion medium from those due to the absorption of the lead compound, and while this, as a rule, is not very difficult, the failure to do so is not infrequent.

Certain organic lead compounds, of which only tetraethyl lead is manufactured and used in any considerable quantity at present, are liquids, which are sufficiently volatile at ordinary temperatures to give rise to dangerous concentrations of vapor. (Petroleum technologists have been interested for many years and have developed a *greatly heightened interest in recent years in the use in motor* gasoline of a more volatile compound of lead than tetraethyl lead, and it may be that tetramethyl lead or some other suitable lead alkyl will be substituted for tetraethyl lead in whole or in part.) Liquid lead compounds when handled in undiluted form or in concentrated solutions, as in their manufacture and transportation, and in plants in which they are mixed with gasoline, also give rise to exposure to lead by contact with the skin, through which they are absorbed. Any open receptacle that contains these liquids in high concentration, and any container, article of clothing, floor, or other surface that has not been decontaminated thoroughly after contact with them, may give rise to serious exposure to lead on the part of persons who are nearby or whose skin *may come in contact with them.* The acute and frequently fatal character of lead intoxication from absorption of organic lead compounds of this type justifies special precautions for the avoidance of exposure to them.

Many problems of industrial hygiene in connection with the manufacture and handling of *tetraethyl lead (and other lead alkyls)*, differ so strikingly, both qualitatively and quantitatively, from those involved in the production and handling of metallic lead and its compounds, as to require separate treatment. Brief references to certain aspects of these problems will appear here and there in the text that follows, so as not to neglect altogether this important subject. The techniques of industrial hygiene in this industry cannot be covered satisfactorily, however, within the scope of this chapter, and for the most part, hereafter, unless tetraethyl lead (or other lead alkyl) is mentioned specifically, it does not enter into the discussion.

Differentiation should be made between the occupations involving opportunities for exposure to tetraethyl lead in concentrated form and those concerned only with the handling of gasoline containing tetraethyl lead in the concentrations in which it is employed in commercial motor fuels. Dilution of tetraethyl lead with gasoline to such an extent that there are *one thousand parts or more of gasoline by* volume to one part of tetraethyl lead, effectively prevents the absorption of appreciable quantities of tetraethyl lead through human skin. At the same time the vaporization of tetraethyl lead out of such dilute solutions in gasoline is so slight as to be practically insignificant under the normally prevailing conditions of handling and use *that are required to avoid the risks* of fire and explosion. For these reasons, the normal commercial distribution and use of leaded gasoline as a motor fuel involves no hazardous exposure to lead. (Attention is called to the fact that under the unique conditions that exist within tanks in which leaded gasoline has been stored, there may be highly dangerous exposure to tetraethyl lead and its *decomposition* products, as well as to obviously toxic gasoline vapors, on the part of men who enter the tanks to clean or repair them. Moreover, under any set of conditions in which considerable quantities of leaded gasoline are spilled or sprayed or otherwise vaporized into an enclosed, unventilated, or inadequately ventilated space, the concentration of lead in the air may exceed safe levels. Leaded gasoline is intended for use as a motor fuel only. It should not be used for other purposes, excepting under conditions that will certainly prevent hazardous exposure to lead.)

Certain other compounds of lead, such as the salts of complex organic acids, and especially fatty acids, have been regarded with distrust and apprehension from the aspect of their absorption through human skin. In particular, the use of lead soaps as lubricants and as technological adjuncts to lubricants, under conditions that bring these into frequent or regular contact with the skin of workmen in machining operations, has been under suspicion in this regard. It cannot be said that all of such compounds of lead have been investigated as to their absorbability through the skin, whether in their concentrated commercial form or in the industrial formulations in which they are used, often in high concentrations. Certain representatives of this group of compounds have been found to be essentially unabsorbable, however, through the skin of animals, and others have been found to be unabsorbed under the conditions of their use in industry. While definitive information is incomplete, the preponderance of the evidence, in our opinion, justifies the belief that these compounds are absorbed into the body in potentially dangerous quantities only through inhalation or ingestion.

Certain relevant physical properties of a number of products and compounds of lead are listed in Table 1. The melting points, pouring temperatures, and boiling points of metallic lead and a few of the more commonly used alloys will be of some use in pointing out conditions under which the ambient atmosphere may be expected to be contaminated with vaporized lead. Of some importance, but of considerably less direct significance, are the data with respect to the solubilities of various compounds of lead. While the facts in this regard are of great technological importance, their relation to toxicology and to the occupational hazard of exposure to lead should not be taken too seriously. For example, the solubility of a specific lead compound in water often has little direct bearing upon its absorbability from either the pulmonary or the intestinal surface. Moreover, in the case of a finely divided compound that is inhaled and retained to some extent within the pulmonary alveoli, relative solubility is of less significance than size of particle, since, if the particles are soluble at all in or on the pulmonary membrane (this is not necessarily a matter of solubility in water), they will be absorbed sooner or later, depending upon the surface relationships. The solubility of lead compounds has some significance in relation to their absorption in the alimentary tract. Even here, however, the highly soluble compounds are poorly absorbed, and the only compounds that are not absorbed at all are those that are incapable of conversion to soluble compounds in the complex medium of the alimentary contents within the time required to traverse the tract. Lead sulfide, for example, appears to be absorbed but little, if at all, from the lung, but some of it may be converted in the stomach to the slightly soluble chloride and so absorbed, to some extent, before reaching the colon, in which it may be converted again to the sulfide.

III. The Detection of Exposure to Lead in Industry

The *existence* of occupational exposure to lead can usually be recognized by careful observance of the activities of an industrial plant. Some experience is

required before one can attempt to estimate the *severity* of the exposure, and even then it is best to reserve judgment until the results of more precise methods of estimation are available. Nevertheless, systematic examination of processes and equipment, while following the flow of materials through manufacturing operations, will give valuable information concerning conditions that require further study; therefore, frequent trips of inspection should be made throughout a potentially hazardous plant as part of a general program of hygienic supervision. Attention should be paid to the cleanliness and orderliness of the workrooms and to the condition of sanitary and clothes-changing facilities, as indices of the quality of the care being given to matters of health and safety.

In lieu of precise measurements of the extent of the potential exposure to lead in an industrial establishment, or of the actual absorption of lead by the workmen, both of which will be referred to extensively later, it may sometimes be desirable to arrive at a prompt conclusion concerning the severity of the exposure to which a group of men is being subjected. Here, resort may be had to an immediate examination into the hygienic status of the workmen. This may be done in several ways, depending upon the information and facilities that are available. An experienced physician may find it possible to establish the facts by examining a limited number of carefully selected and representative workmen. Examination of employment records, if such are available, will reveal the extent of the labor turnover, and if the latter is excessive, the records may suggest the reasons, especially if there are wide differences in this respect among the different occupations. Records of absenteeism and illness may also contribute highly significant information. The recorded incidence of lead poisoning among the workmen carries its own significance, but an unduly high rate of illness of any type, regardless of its classification, calls for interpretation. A survey conducted along these lines can be made quickly, and will usually provide a fairly definitive answer as to the satisfactory or unsatisfactory quality of industrial hygiene in the operations.

IV. The Measurement of Industrial Exposure to Lead

A. DETERMINATION OF LEAD IN AIR AS A MEANS OF ESTIMATING THE RESPIRATORY EXPOSURE OF WORKMEN

Poisoning solely or mainly from the ingestion of lead compounds is of relatively infrequent occurrence in American industry, partly because of the usually good quality of washroom and lunchroom facilities in industrial plants and the resultant promotion of cleanly habits among the workmen, but chiefly because of the virtual inevitability of the contamination of the atmosphere of workrooms in the lead-using industries with lead compounds, and the difficulties that attend the avoidance of some degree of respiratory exposure to, and absorption of, these compounds. In other words, ingestion of lead compounds in the course of the day's work can and should always be prevented through the exercise of regular, attentive care in matters of personal cleanliness and good housekeeping, while prevention of the inhalation of lead is much more difficult. Then, too, almost half of a somewhat *soluble, particulate, inhaled* lead compound (35 per cent or more of particles of 0.75 μ or less in diameter) is retained in the lungs and absorbed promptly or slowly while most of even the soluble lead that is *swallowed* (85 to 92 per cent) passes *through the alimentary tract* unabsorbed. As might be expected, therefore, much the largest proportion of the lead absorbed by the usual victim of industrial lead poisoning is derived from the respired air. For these reasons determinations of the *respirable lead in the atmosphere* of workrooms may yield fairly adequate information as to the magnitude of the occupational lead hazard in such rooms. Satisfactory methods for sampling and estimating the lead content of the atmosphere have been devised and employed extensively in a variety of industries, not only in hygienic surveys but also in the routine periodic investigation of occupational conditions. The student of this subject should consult standard texts and official reports, some of which are listed at the end of this chapter, for detailed information. The development of these methods, their practical application to the study of industrial processes, and the correlation of data obtained by their use with the results of clinical and physiological observations on workmen have provided a practical means for the appraisal of industrial lead hazards. As experience has been gained it has become increasingly apparent that it is feasible to express the general magnitude of the lead hazards of a plant and of its individual operations in terms of the lead content of sufficient numbers of properly selected air samples, and to anticipate with reasonable accuracy the results of exposure thereto.

The satisfactory application of the methods of sampling the air and of analyzing such samples requires a sound understanding of the principles involved in their use, as well as experience in handling the equipment and in selecting the sites for sampling. As to the actual analysis, a number of methods are available. (Cf. references at end of chapter.) The choice of method must be based upon the quantities of lead that are to be dealt with, and upon the presence or absence of other interfering substances in the atmosphere of the plant. Highly specific and sensitive methods must be used if the quantities of lead are small and if other metals are present in significant quantities. These matters should be considered carefully, and the choice and application of methods should be made by competent and experienced chemists.

In the case of a single analytical survey of a plant, a sufficient number of samples of air must be taken to give a comprehensive picture of all parts of the plant. Moreover, samples must be collected at appropriate intervals of time and with sufficient frequency in the various locations to yield representative results. If analyses of the air are employed as part of a regular program for controlling the exposure to lead, they should be applied either continuously at selected representative sites or at such intervals as will reveal the effects of any changes in environmental conditions, whether due to changing weather or to operating conditions within the plant. (It should be recognized that a sample collected over a period of hours may not reveal the existence of episodes of intense exposure of short duration, thereby failing to yield a true picture of the existing hazard.) Especially should the effects of all alterations in plant processes be checked by air analyses.

B. ANALYSIS OF THE BLOOD, URINE, AND FECES OF EXPOSED WORKMEN AS A MEANS OF MEASURING THE LEAD HAZARDS OF THEIR OCCUPATIONS

A second general method that is available for measuring the lead hazards of an individual, an occupational group, or an industrial population is based upon the facts pertaining to the physiological behavior of lead in the human body. Thus, the periodic determination of the lead content of the blood or urine of exposed workmen will demonstrate the general magnitude of their current absorption of lead in the complete absence of any or all other signs of lead absorption, and will disclose the severity of their hazard or the relative margin of their freedom from hazard. Under certain circumstances, but usually not as a regular procedure, the determination of the total lead content of samples of feces, so obtained as to comprise the total alimentary evacuation of each of a representative group of workmen after one or more typical workdays, will give an approximate but very useful measurement of the amount of lead swallowed from the upper respiratory tract, as well as that taken with food, beverages, and other objects introduced into the mouth, on the day or two immediately preceding the date of the collection of the samples. Such data are especially useful in relation to air-borne dust, in the appraisal of the use and adequacy of respirators (which may be required at times, in emergencies or under unusual circumstances, although dependence upon them is not the usual or recommended procedure), or in assessing the faithfulness and care of employees in their avoidance of the ingestion of lead in connection with their work.

The general physiological background on which the interpretation of the results of analyses of the lead in the blood and excreta must be based will be presented later in this chapter. Methods for collecting and analyzing samples are referred to in the bibliography at the end of this chapter. These matters play an all-important part in the medical supervision of workmen in certain lead-using industries, and, therefore, they require careful and expert consideration. They are referred to here only in relation to the measurement of exposure of lead, and the differentiation of safe from dangerous exposure.

V. Safe Occupational Exposure to Lead (Permissible Limits)

Inasmuch as lead is a normal constituent of human tissues, and the regular absorption of lead is a universal human experience, it is evident that there must be some line of demarcation between harmless and dangerous conditions and degrees of exposure to, and absorption of, lead. It is not surprising, therefore, that careful and prolonged medical supervision of workmen in a variety of potentially hazardous occupations should have demonstrated the existence of such a line or, more properly, such a zone, many years ago. The first expression of this differentiation was formulated in 1912 through the work of Legge and Duckering in British industry. More recent investigations have served to provide a sound physiological background for this concept, and at the same time, have yielded well-defined criteria for safety in the lead-using industries. In this connection, both clinical and physiological evidence refute the suspicion, often felt and sometimes expressed, that some slight exposure to, and absorption of, lead, above that which is "normal," should result in some slight or eventual harm, perhaps too insidious to be recognized as such. Experience has shown that when occupational exposure to lead, as measured technically or physiologically, is insufficient to cause occasional signs or episodes of toxemia resembling those characteristic of plumbism, no evidence is found of vague general disorders or obscure types of impairment of good health that differ in frequency or degree from those encountered in any comparable *group of persons whose work environment is free of specific stress or hazard.* On the basis of measurements of environmental exposure to lead, or of those concerned with the absorption of lead by workmen carried out in parallel with clinical observations that involve interpretations of human deviations from health and well-being, certain specifications have been advanced from time to time as hygienic *standards in industrial practice.* *Of those worthy of consideration and application* at present, there are two general types and three specific examples, which, by reason of their sound theoretical and practical backgrounds, are recommended.

A. LEAD IN THE ATMOSPHERE OF THE WORK SITE

Expressed in terms of air analyses, the upper limit of safety for industrial exposure to the more readily soluble, particulate, inorganic compounds of lead is represented in American practice to be the concentration of 0.2 mg. of lead (Pb) per cubic meter of air. This standard, put in plain and simple language, specifies that, *when the air of workrooms contains regularly not more than 0.2 mg. of lead* (in inorganic form) per cubic meter of air, as measured by prescribed methods, cases of disabling lead intoxication will not occur among the men who work for many years on the usual schedule in such workrooms, and cases of questionable or mild intoxication will occur only rarely, if at all In practice, the attempt is made *to maintain the lead content of the air within such limits as will yield an average* of not more than 0.2 mg. of lead per cubic meter throughout the working day, while preventing the occurrence of materially higher concentrations (0.5 mg. or more per cubic meter). Evidence of the validity of this standard has been provided elsewhere and need not be enlarged upon here. It should be said, however, that its *adequacy depends upon the limitation of the occupational exposure to lead dispersed in the air.* It assumes, for its applicability, that the unnecessary and more easily avoided ingestion of lead, because of faulty personal habits and unclean surroundings in connection with the day's work, is kept at a negligible level.

The upper limit of safety in the range of the concentration of certain highly *insoluble compounds of lead appears to be appreciably higher than that indicated* above. Since it is difficult, on both practical and theoretical grounds, to give quantitative expression to differences of this type at this time, no attempt is made here in that direction.

B. LEAD IN THE BLOOD AND URINE OF WORKMEN

1. In Blood

The extreme upper limit of safety for the concentration of lead in the blood of *men under the conditions associated with the absorption of inorganic compounds* of lead in industry (or elsewhere), is just short of 80 μg. per 100 g. of whole blood. Since the analytical error is rarely less than ±10 per cent in this general range (when dealing with samples of blood of 10 to 15 ml., containing somewhat more or less than 1 μg. of lead), one can be sure that the concentration of lead in the blood, *at or near this threshold value, is slightly under,* rather than somewhat over, this concentration only by analyzing a series of samples of blood by a method of high precision. The threshold value is actually so sharp that the utmost in precision is necessary to define it in the individual person, and in practice it is necessary for the analyst either to employ the procedure of analyzing multiple samples, or to *adopt a threshold value sufficiently low to make allowance for the known error* associated with his specific procedure and facilities. In any case, whether the analytical result is interpreted in its application by a physician, or by someone other than a physician, who accepts thereby a considerable share of the responsibility for the safety of workmen, the deviation of the analytical result must be *defined precisely by the analyst, since otherwise a result near the threshold lacks* its true significance.

With the foregoing factors in mind, this standard for industrial safety can best be stated (to be modified in the specific situation, as the precision of the analytical method requires or permits) as follows: When the concentration of lead in the *whole blood of an individual workman is 70 μg.* or less per 100 g., the individual, while he may have little margin of safety for further or more severe occupational exposure to lead, is in no danger from his exposure to, or absorption of, lead, as of the time of sampling.

In an occupational group any individual whose lead level in the blood is *80 μg. or more, while not necessarily ill in any way,* is in danger of developing an episode of lead intoxication without warning, and should not incur further occupational exposure to lead until the concentration of lead in his blood has diminished significantly. Individuals in such a group, whose lead levels are below 70 μg. per 100 g. of whole blood, have margins of safety that are the greater the more nearly *they approach the mean normal level of approximately 30 μg. per 100 g.* The occupational hazard of a group of men whose work is subject to little variability in nature or duration is defined in fully predictable terms by the mean level of the lead concentration reached and maintained in their blood after a period of months (up to 8 or 9) during which they have engaged regularly in the occupation. Unless there is a significant change in the severity of their exposure, there will be no further significant change in the concentration of lead in their blood. Hence, a significant change in the latter is indicative of a change in the former. Such changes parallel each other, being comparable in direction, in rate, and in extent.

This standard, following the development and increasing use of precise analytical procedures, and with the test of time and experience, has become much the best and most reliable single criterion for the clean-cut differentiation of safe from dangerous types and conditions of industrial exposure to the inorganic compounds of lead. *On the one hand, if the sampling of the personnel is adequate, the criterion* can be counted on to ensure that there will be no cases of lead poisoning under conditions which it defines as safe, and, on the other, it can be trusted to point out the conditions that will be productive of lead poisoning, and the precise personnel among whom such cases will occur. In Table 2 characteristic analytical results obtained from a group of persons devoid of occupational exposure to lead are

TABLE 2

Frequencies of Lead Concentrations in Blood of Workmen
Correlated with Severity of Exposure to Lead

(Comparison of various occupational groups from various industries,[a] according to the frequencies of occurrence of various levels of the concentration, and according to the mean concentration, of lead in their blood, *in association with varying degrees of severity of exposure*, below and above the threshold of safety, as judged by the nonoccurrence or occurrence of lead poisoning within the individual groups)

Lead in blood, mg. per 100 g.	Severity of exposure to lead: Normal	Demonstrable: Barely	Demonstrable: Readily	Slight to severe	Moderate to severe	Near threshold: Safe	Near threshold: Unsafe	Very severe, very dangerous
Total examined	86	36	19	272	59	62	54	75
0.00–0.019								
0.02–0.039	85	11	6	85	8	4	1	
0.04–0.059	1	24	8	122	35	30	18	9
0.06–0.079		1	5	50	10	22	21	12
0.08–0.099				7	5	5	6	17
0.10–0.119				6	1	1	6	14
0.12–0.139				2			1	5
0.14–0.159								4
0.16–0.179								1
0.18–0.199								1
0.20–0.219								2
0.22 and over							1	10
Mean	0.027[b]	0.042[b]	0.051[b]	0.050	0.057	0.060	0.075	0.130[b]
P.E.	0.003	0.001	±0.002	±0.001	0.002	±0.001	±0.004	±0.007
S.D.	0.004	0.008	±0.013	±0.019	0.022	±0.016	±0.041	±0.091

[a] The samples of blood repeated in this table were obtained at the same time from the same groups arranged in the same order as the samples of urine in Table 3.

[b] Calculated from a different arrangement of the frequencies.

compared with those obtained from certain groups of persons from a variety of industries whose occupations have subjected them to different degrees of severity *of exposure to inorganic* lead compounds. The gradation from safe to dangerous types of exposure is illustrated. It is important to note that certain individuals, within groups of men whose exposure to lead was *predominantly* nonhazardous, had absorbed dangerous quantities of lead. These individuals would require special investigation to determine wherein their exposure had deviated from the others in the group, unless the special hazard of their specific jobs should be readily apparent. In the instances illustrated here, the latter was true, for there were certain special hazards that had not been brought under complete control at the time of making the observations. It is important to realize, and to have the means of demonstrating that, in a generally safe series of industrial operations, there may be specific opportunities for excessive exposure to lead. The failure to recognize this simple fact in many a lead-using industry is the primary reason for the frequent belief and statement that an "unusually susceptible" workman contracted lead poisoning under conditions that were "well controlled" and safe for other workmen.

This standard cannot be employed successfully in any situation in which a significant exposure to tetraethyl lead occurs. The absorption of tetraethyl lead does not produce an increase in the lead content of the blood that bears any apparent or proportional relationship to the quantity of lead absorbed. Analysis of the blood, under these circumstances, for the purposes of either diagnosis or industrial hygiene, will yield a grossly misleading result.

2. In Urine

The upper limit of safety for the concentration of lead in the urine cannot be expressed in the simple and invariable terms that are applicable to the blood, for the reason that, under the same conditions in the same individual, the variability of the concentration of lead in the urine is many times greater than that in the blood. This greater variability is illustrated in Table 3, as compared with Table 2. The "spot" samples of urine tabulated for each group in Table 3 were obtained at the time the samples of blood (Table 2) were taken and so are generally comparable in relation to the physiological state of each individual in each group. This is not strictly true, however, since there is an appreciable delay in the occurrence of a change, as well as a leveling out of the magnitude of the change, in the concentration of lead in the blood in response to exposure to lead under ordinary occupational conditions. *Not so in the case of the urine*, which undergoes relatively prompt change in response to such exposure. In addition, however, to this response, there are other factors that influence the rate of the urinary excretion of lead, such as the amount of water available for excretion and the amount of physical exertion put forth by the individual during the excretory period. A seasonal factor, which *does not* lend itself to precise interpretation, is also discernible. These are not

TABLE 3

Frequencies of *Lead Concentrations in Urine of Workmen* Correlated with Severity of Exposure to Lead

(Comparison of occupational groups from various industries,[a] according to the frequencies of occurrence of various levels of the concentration, and according to the mean concentration, of lead in their urine, in association with varying degrees of severity of exposure, below and above the threshold of safety, as judged by the nonoccurrence or occurrence of lead poisoning within the individual groups)

Lead in urine, mg. per liter	Severity of exposure to lead: Normal	Demonstrable: Barely	Demonstrable: Readily	Slight to severe	Moderate to severe	Near threshold: Safe	Near threshold: Unsafe	Very severe, very dangerous
Total examined	86	206	19	273	55	63	57	79
0.00–0.039	66	41	4	35	1		3	2
0.04–0.079	18	156	13	98	14	11	7	2
0.08–0.119	2	9	2	56	24	22	10	13
0.12–0.159				35	11	16	14	14
0.16–0.199				27	2	7	11	9
0.20–0.239				8	1	2	3	9
0.24–0.279				7	1	2	4	6
0.28–0.319				4		3	3	5
0.32 and over				3	1		2	19
Mean	0.033[b]	0.051[b]	0.067[b]	0.102[b]	0.108[b]	0.130[b]	0.152[b]	0.238
P.E.	±0.001	±0.007	±0.006	±0.003	±0.005	±0.005	±0.002	±0.011
S.D.	±0.015	±0.014	±0.037	±0.069	±0.057	±0.059	±0.024	±0.151

[a] The samples of urine represented in this table were obtained at the same time from the same groups arranged in the same order, as the samples of blood in Table 2.
[b] Calculated from a different arrangement of the frequencies.

necessarily minor variations, and the only way by which one can determine the current general rate of urinary excretion of lead of an individual or group, in its relation to the current rate of lead absorption, is that of obtaining an appropriate representation of the many variables, in a sample of urine of large volume (from an individual) or in a series of samples of small volume (from an individual or a representative group) in sufficient numbers for statistical treatment. The attempt has been made to reduce the variability of individual samples of urine to satisfactory limits for practical purposes by relating the lead content of a sample of urine to the time over which it was excreted, rather than to its volume, on the hypothesis that the output of lead from the body within a unit of time is essentially independent of the throughput of water. Other attempts have involved corrections of the concentration of lead in the urine in terms of the concentration of creatinine therein, or in terms of a standard "normal" specific gravity, on the theory that the

true rate of excretion of lead in the urine may be gauged by the rate of excretion of a relatively constant metabolite or of the total solids. All of these procedures fail in practice at the very points at which they are most needed (when unusually low or high concentrations of lead are encountered in the urine and require interpretation), and they fail always, in the physiological sense, because they are based upon false premises. Instead of resorting to rules of thumb which reduce the physiological variability by purely manipulative devices, it is necessary to attack the problem directly by the methods indicated above. This is especially true in dealing with a diagnostic problem in an individual, in which a "short cut" usually provides misinformation and leads often to needless controversy and fruitless litigation. For the purpose of appraising the safety or hazard associated with industrial exposure to lead, the problem is soluble, however, in that one makes use of the results obtained by the periodic sampling of *groups* of employees whose exposure to lead can be visualized in relation to their participation in specific industrial operations. The information obtained in this manner under a wide variety of conditions in a large number of industries has provided a wealth of data for the differentiation of safe from dangerous exposure. The differentiation is made on a statistical basis, in terms of the mean concentration of lead (and the standard deviation) found in samples of urine collected in a carefully selected and uniform manner, at or within a designated time. The upper limit of safety for the concentration of lead in the urine varies significantly with the type of sample obtained for analysis. Thus composite samples of large volume (2 to 3 liters) collected from workmen after the hours of work or over the weekend are lower in their lead concentration than are individual samples of small volume collected (with corresponding care for the avoidance of contamination) during the workday or workshift. There is also a slight but statistically significant difference between the levels of lead concentration found in the urine on the last day of the work week and at the end of the long weekend.

The differences which arise out of variations in the volume of samples, in the time of sampling, and in the manner of sampling, with specific reference to the means of reducing or avoiding contamination of the samples, when added to the variations in the precision of the methods employed by various analysts, and when augmented further by the lack of uniformity in the interpretation (statistical or otherwise) of the results obtained, account, in part, for the variety of the standards that are advocated by observers in a number of American industries in which the results of analyses of the urine of workmen are being employed for purposes of hygienic control. A larger factor in this lack of uniformity is contributed, however, by the variation in the points of view of physicians or others responsible for industrial hygiene, as to the degree of freedom from hazard—that is, the margin of safety—that should be incorporated in a standard of this type. There are valid differences in professional opinion in such matters and when these differences cannot be resolved on physiological or clinical grounds, they can sometimes be brought to a point of understanding or of practical compromise. The margin of safety that can be built into the specification, at a reasonable cost for compliance therewith, may well be a matter of policy, to be decided on economic or other practical grounds, so long as the interpretation of the nature and characteristics of lead intoxication as a medical entity is not obscured thereby. The standards promulgated in these paragraphs in physiological terms provide a margin of safety sufficient to include the variations in the susceptibility of workmen, as they are selected for their work in ordinary industrial medical practice, and so to prevent even the earliest and mildest signs of lead intoxication that are now recognizable.

In view of the fact that samples of urine of small volume, comprising a single voiding, are obtained for analysis more frequently than are other types of samples, the standard set herein is based on the analytical findings in such samples.

With the foregoing considerations in mind, the upper limit of safety, *in terms of the mean concentration of lead in the urine of a group of workmen whose occupational exposure to lead is fairly uniform*, is 0.13 mg. per liter for samples that exceed 0.18 mg. per liter only infrequently, and exceed 0.24 mg. per liter only rarely. This standard can be applied to an individual, or to a small number of individuals, only after the collection of multiple samples from the individual or individuals in sufficient number to provide a statistically stable group of observations. (In the individual case, in industries in which only inorganic compounds of lead are handled, it is both simpler and more dependable to rely upon the results of analyses of the blood, either exclusively or in combination with analyses of the urine.)

As indicated previously, the concentration of lead in the urine provides the only analytical criterion for the estimation of the significance of exposure to, and absorption of, tetraethyl lead, and the standard expressed above *has demonstrated* its efficacy in defining the upper limit of safety in the industries concerned with such exposure. It is *equally applicable, however, to occupational conditions* associated with exposure to the inorganic compounds of lead, where it provides a somewhat, but not excessively, larger margin of safety, as a rule, because of the lesser rates of both the absorption of and the excretion of inorganic, as compared to organic, compounds of lead.

3. *Interpretation of Analytical Findings in Blood and Urine*

Some discussion, along with comments on certain of the data in Table 3, may be useful in providing the most satisfactory interpretation of the analytical information from certain of the industrial groups. Some comparisons of these data with those of Table 2 may also be made with profit. It will be *noted that there are a few* excessively high levels of urinary lead concentration (i.e., in excess of 0.24 mg. per liter) in each group *to the right of the third column of numbers* in Table 3, despite the fact that the mean concentration of lead in the urine reaches the threshold *level* (as here defined) only at the sixth column. Reference to Table 2 will show that some individuals in each of the groups represented in the fourth, fifth, and sixth columns had excessive concentrations (0.08 mg. or more per 100 g.) of lead in their blood. The data in Table 3 do not *prove* that there was any real danger in the occupational conditions represented in the fourth, fifth, and sixth columns, although individual results in excess of 0.24 mg. per liter justify some concern on that score. Values in excess of 0.08 mg. per 100 g. of whole blood of themselves, however, denote the actual occurrence of dangerous absorption of lead. Thus it is clear that, while most of the individuals in the groups represented in the fourth, fifth, and sixth columns of *both Table 2 and Table 3* had been working under safe conditions, a few in each group had not. Such findings are in full accordance with the observed facts concerning the several industries and occupations represented in Tables 2 and 3. While the observations recorded in the fourth column were being made the industry concerned was undergoing changes in their operations, which resulted a little later in the elimination of hazardous conditions. After these changes had been accomplished, the *mean* levels of lead concentration in the urine and blood of the workmen diminished but little, but the excessively high values disappeared completely from the blood (and thereafter none of the men were transferred to other operations), and those in the urine diminished nearly to the vanishing point.

Somewhat similar situations accounted for the excessively high results recorded in the fifth and sixth columns in Tables 2 and 3. There is nothing unusual in such a pattern of results. Only *rarely are the composite operations of a lead-using* industry so completely controlled and so nearly uniform in type that all of them *are equally free of hazard; and only rarely can complete freedom from hazardous* exposure be maintained indefinitely in the operations of these industries without *frequent precise monitoring* of both the operations and personnel. There were no cases of lead poisoning within any of these groups (i.e., up to the seventh column in Tables 2 and 3) during the period of several years of our surveillance, presumably for the reason that any man who gave evidence of excessive absorption, as defined herein, was transferred promptly to work involving great reduction in his exposure to lead or a termination of his exposure for a considerable period of time. This presumption, borne out amply by other experience, is supported by the positive clinical evidence associated with the findings tabulated in the seventh and eighth columns of Tables 2 and 3. In the plant represented by the data in the seventh column there were infrequent, *irregularly spaced cases of mild lead intoxication*. The findings recorded in the eighth column of both tables, on the other hand, *are illustrative of highly dangerous conditions*. Only a few of the persons in this industry (office staff) worked under even approximately safe conditions. Lead *poisoning was frequent* in its occurrence and all persons whose employment had persisted for as long as three weeks were found to have absorbed potentially dangerous quantities of lead. Nevertheless (and this is a fact that has contributed to the complacency of some employers, and has frustrated some industrial physicians who otherwise might have had more interest in good industrial hygiene), there were persons in this group who had worked steadily for several years without illness, and who, at the time of this survey, were wholly free of any sign of lead intoxication.

In the practice of industrial hygiene in the industries concerned with the inorganic compounds of lead, in which, despite generally *effectual methods of control*, there are opportunities for hazardous exposure, it is advantageous to obtain ana-

lytical information periodically and in parallel on both the blood and the urine of representative employees (and of all employees occasionally). The results of analyses of the blood reveal the range and the general level of the *total quantity of lead absorbed* by workmen individually and in occupational groups, in consequence of their more or less prolonged occupational exposure. The *range of concentration*, and the mean concentration, of lead in the urine of the group, in comparison with prior results on the same or on similar occupational groups portray the relative magnitude of the *current occupational exposure*. Significant variations in the mean concentration of lead in the urine of the group, from time to time, will serve, better and more quickly than any other means, to demonstrate improvement or deterioration in the efficacy of measures of hygienic control. (As indicated previously, the concentration of lead in the blood of an individual indicates clearly his status with reference to safety or danger, and provides a basis for action, if need be, on his individual behalf.)

C. CLINICAL CRITERIA FOR THE DIFFERENTIATION OF SAFE FROM HAZARDOUS ABSORPTION OF LEAD

Brief mention may be made here of the determination of basophilic granulation of the erythrocytes in the blood of workmen, and of the analysis of their urine *for porphyrins, as medical techniques* for the estimation of the extent of the hazard of occupational exposure to lead. The first of these procedures is an unsatisfactory and outmoded clinical method for this purpose. Since the phenomenon of "stippling" of the erythrocytes is not a specific sign of the absorption of lead, and since it does not vary quantitatively in the individual with *either the rate of absorption or the quantity of* lead absorbed, it is but a poor and makeshift substitute for the specific procedures recommended above. It serves no useful purpose in the absence of actual danger, and when danger exists it is not adequate to cope with it. It cannot be recommended as a means of differentiating, in any other than a very crude manner, harmless from *hazardous absorption of lead, and no semiquantitative expression of* the results of the application of this method or its modification can be recommended as a hygienic standard in industry. The characteristics of the phenomenon, and the extent of its usefulness for diagnostic purposes will be dealt with later in this text.

The significance of porphyrinuria, *in relation to the diagnosis of lead intoxication, is considerable*. Suffice it to say, in the present relationship, however, that abnormal quantities of porphyrins, chiefly coproporphyrin III, appear in the urine as an expression of a derangement of the synthesis of hemoglobin in a number of diseases, including lead poisoning, of which, at present, it seems to be among the first, if not the first of all, evidences of intoxication. Since the *goal of industrial hygiene in the* lead-using industries is the *prevention* of lead intoxication, reliance upon this incipient sign of intoxication, as a means of recognizing and terminating hazardous exposure to lead prior to the appearance of more serious manifestations, while advantageous to that extent, would seem to be considerably less than satisfactory from the medical viewpoint, since there are methods by which even the slightest manifestations of lead intoxication can be anticipated and avoided. There may be unusual situations or emergencies in which its use can be justified, as, for example, during brief periods when facilities for the performance of the more precise and *specific analytical* procedures are not available. In general, however, the use of this technical procedure lies in diagnostic, rather than in preventive, medicine, and it will not be dealt with further in this chapter, although references to it are listed at the end. It should be pointed out that this hematological derangement is not observed in poisoning with tetraethyl lead, *in which the central nervous system is the primary*, and usually the sole, point of attack.

VI. The Control of Industrial Exposure to Lead

A. ENGINEERING METHODS OF CONTROL

The elimination of hazardous exposure to lead from the many industrial operations that involve the use of lead compounds is primarily a technical problem. Its satisfactory *solution in any instance* depends upon adequate knowledge *of how* the specific industrial product can be made satisfactorily, economically, and safely. The choice of the materials (with respect to lead content or physical state, i.e., whether in the form of solid, powder, or paste), the processes, and the equipment will determine the general character of the plant that is to be built or adapted for the *purpose. The potential health* hazards should influence all of these choices, and in addition will introduce their own requirements into the project. For these reasons a new plant should be designed and built, or an old one should be remodeled, only after taking into account all the factors that have to do with the safety and health of the employees.

Certain *general principles* of procedure have been found to be worthy of attention in the construction and arrangement of industrial plants, and in the remodeling of old ones.

1. Hazardous types of exposure should not be distributed throughout a plant, if it is possible to localize them in *specific areas* where they can be subjected to *concentrated procedures* of control. The application of this principle has a bearing upon the movement of materials through a plant, the arrangement of equipment within it, and the manner of employing ventilating equipment (whether local or general, or both). These, along with other considerations, determine the layout of the plant, its structural *characteristics and, thereby*, to a considerable extent, its cost.

2. The equipment should be arranged with reference to the hazards and the means of their control, as well as to convenience and speed in production. For example, ventilation can rarely be introduced with completely *satisfactory results* as an afterthought. There must be *space for fans* and ducts and for the heating or *cooling equipment* that may be required to temper the air.

3. The matter of ventilation in general is dealt with in Volume I, and therefore, little need be said here. Three points, however, merit specific mention in connection with particulate lead compounds: (*1*) the necessity for the use of carefully designed local exhaust systems to remove vapor, fume, or dust at their points of origin; (*2*) the need to exercise great care to prevent the reintroduction of exhausted, contaminated, air into workrooms; and (*3*) the desirability of collecting exhausted dust and fume so as not to contribute to the pollution of the atmosphere in the neighborhood. The importance of these points will be appreciated only by those who have had broad experience, or by those who, lacking experience, have undertaken to solve these practical problems by methods of trial and error. It is of considerable importance also to so design the ventilation system and the ventilated areas as to ensure satisfactory results in independence of weather conditions and the personal predilections of workmen.

4. The construction and arrangement of the plant must be such as to promote cleanliness and good housekeeping. Floors, window ledges, walls, and working space in general must be designed with specific reference to the materials to be used and the methods of housekeeping that will be employed. For example, floors that are to be hosed down must have unobstructed surfaces and adequate drainage, and must not be slippery when wet. Similar purposes may be served by metal grills overlaying a secondary floor equipped with adequate drains. Areas and equipment that are to be cleaned by vacuum must be smooth, regular, and free of all unnecessary obstructions and sharp angles.

5. Facilities for medical services must be designed on the basis of the medical program that is contemplated, and not on what remains of space and location after other requirements have been satisfied.

6. Toilets, washrooms, locker rooms, lunchrooms, and sanitary equipment in general, including a satisfactory supply of drinking water, should be so planned as to encourage their use. Convenience, comfort, and adequacy in relation to the number of employees are first considerations. Almost without exception in lead-using industries, certain groups of workmen must change clothing completely when going to work, and change and bathe at the end of the day's work. Therefore, there must be double lockers for the two sets of clothing, and good bathing facilities. Workmen must not eat in certain workrooms; consequently, a clean and comfortable lunchroom must be provided, in which hot or cold beverages and perhaps hot food should be available. Good washroom facilities are required to enable the men to cleanse themselves properly before entering the lunchroom. All of these rooms and spaces must be located or otherwise designed so as to prevent their contamination with dust-laden or fume-laden air, and to facilitate frequent and thorough cleaning.

The problem of coping with exposure to lead in a plant already built and in operation resolves itself into two distinct parts. First, it is necessary to determine the origin and the extent of the exposure to lead associated with the various occupations and operations of the plant. Second, come the choice and application of the

methods for control. The simplest means by which the first step can be achieved has been mentioned previously, but certain practical points are worthy of some elaboration. Adequate systematic sampling of the air of workrooms while work is in progress, and the use of accurate methods for the analysis of such samples, will serve to portray the general distribution and the order of severity of the lead hazards. In a plant in which the quality of sanitary facilities and of the general hygienic performance is good, the results of air analysis will demonstrate the hazard or the lack of it with considerable accuracy and will indicate clearly what is to be done and where to begin. It may happen, however, that hygienic conditions in general are unsatisfactory, that the instruction and supervision of the workmen in precautionary measures are defective, and that as a consequence the men are inadequately informed and indifferent in matters of safety. Under these conditions the extent of their occupational absorption of lead can be expected to be considerably greater than that which would naturally follow from the magnitude of the contamination of the air. In addition there is an educational problem to be met, both among the workmen and the management, as a first step toward the accomplishment of the task that lies ahead. Both must be brought to recognize the actuality of the hazards, while at the same time they are informed of their respective responsibilities in a comprehensive plan for the control of such hazards.

The methods for controlling the exposure to lead will depend upon the circumstances and the nature of the plant processes. In a generally well-designed and well-managed plant the problem is straightforward and comparatively simple. Mechanical measures of control can be applied where and as they are needed, the results being checked by air-sampling and analysis until the desired conditions have been achieved. Under the unsatisfactory conditions referred to above, however, and even under the best of conditions, considerable time may be required to obtain and install the necessary equipment. It may be highly important, therefore, to do all that can be done to reduce existing lead hazards, pending their elimination by more adequate or permanent means. In such instances the use of respirators is fully justified as a temporary expedient for the control of otherwise unavoidable respiratory exposure to lead. Moreover, every effort should be made to prevent the wholly unnecessary ingestion of lead that may result from inadequacies in the instruction of personnel and in plant practices with respect to personal cleanliness and the handling of food, beverages, and tobacco during working hours. Improvement of sanitary facilities, instruction of workmen through talks, formal regulations, and placards, as well as provision for adequate hygienic supervision in the performance of the day's work, may be highly necessary and helpful in alleviating the situation.

It has been implied above that respirators should be regarded as temporary means for preventing the inhalation of lead compounds. This implication was intentional. Occasional situations arise that necessitate the use of respiratory equipment of some type, and certain intermittent operations of brief duration may best be dealt with in this manner; but in the main, exposure to lead should be prevented by other means, not only for the sake of the comfort and efficiency of the workmen but also on account of the continual care and supervision that are required to see that this type of equipment is used properly and effectively. As to the selection of respirators or masks in relation to specific lead hazards, as well as the necessities for proper use and maintenance, the reader is referred to Volume I, Chapter XI. It should be emphasized, however, that no aspect of this matter should be left to the workmen. The care of such equipment, including inspection, cleansing, maintenance, and replacement, as well as all decisions as to when and how it is to be used, must be set up under the control of trained and responsible personnel.

In a potentially hazardous lead-using industry, all of the operations of production, repair and replacement of equipment, the investigative work on processes, the laboratory control of materials and products, and even general housekeeping, involve opportunities for exposure to lead, and, therefore, come within the province of industrial hygiene. What is often forgotten in dealing with pounds and tons of material is that one is concerned, in matters of human health, with mere milligrams of lead compounds. The technical background and experience required to grasp and retain this quantitative concept, as an effective principle of daily work, are not common among production personnel; therefore, the industrial hygienist must supply and implement this viewpoint. The continuous search for the small departures from satisfactory practice, for the minor sources of exposure to lead that otherwise pass unnoticed is his responsibility. In setting these upon a firm and understandable quantitative basis, in terms of accepted standards of air contamination, he eliminates mystery and conjecture and thereby may gain the effective assistance of technical and production personnel. A single demonstration of the efficacy of a procedure recommended for the elimination of air-borne contamination, by means of "before and after" analytical results, will have a more salutary effect than volumes of verbal propaganda.

The orderly and effective application of safe methods for the performance of many items of plant procedure, especially those involving repair and maintenance of equipment, often calls for written instructions and regulations. The preparation of such instructions requires a sound understanding of operating processes, as well as of hygienic and physiological principles. Here, and at many other points of contact, there must be effective collaboration between the industrial hygiene engineer, the physician, and production personnel. It is highly important, therefore, that the organization of the activities of a plant, in relation to industrial health in general, should be such as to facilitate teamwork of this type.

B. MEDICAL METHODS OF CONTROL

As has been indicated previously, the control of occupational exposure to lead through the maintenance of a safe environment is essentially a mechanical problem, which therefore lies within the province of the engineer. If the maintenance of a safe level of atmospheric contamination with lead were accepted as a necessary condition of plant hygiene in the lead trades generally, there would seem to be no medical problem. The situation is not quite so simple, however. There is a great deal of misunderstanding on this score on the part of industrial management, engineers, and even physicians. Actually safe conditions with respect to occupational exposure to lead are not generally achieved in industry, and there is an unfortunate belief that it is the function of the industrial physician, by some special clinical skill or legerdemain, to convert hazardous work into safe, or at least to avert the more serious consequences of hazardous exposure to lead. Let us clear the air by admitting that this cannot be done except to a limited degree, and only then through the use of highly specialized physiological tools. The physician may find it possible to recognize the early clinical manifestations of saturnism and thereby prevent the development of the more serious and disabling forms of lead poisoning among industrial workers. Under actually hazardous conditions of exposure to lead, however, he will not always succeed in this attempt, as experience has amply demonstrated. He may also alleviate suffering and shorten the period of disability through proper care and treatment of poisoned workmen, but by no stretch of the imagination can this be regarded as preventive medicine. Indeed to the extent that such medical practice tends to obscure the hazardous character of an occupation, it is an obstacle rather than an aid to the achievement of industrial health. There are, however, certain functions in the control of industrial lead hazards that can best be served by the industrial physician. There is great need at present for a greater understanding and a wider application of these medical functions.

The first and foremost function of the physician in the lead trades is to recognize and record the earliest manifestations of lead intoxication. The proper performance of this function serves a threefold purpose. It enables him to recognize and document the existence of hazardous exposure, thereby demonstrating that measures being taken for its control are inadequate. The recognized occurrence of lead poisoning, when related to the work location and the duration of the exposure of affected individuals, often serves to reveal the source and nature of the lead hazard, thereby pointing the way for its elimination. The existence of plumbism in one or more members of an occupational group will demonstrate the need for prompt protection of the others in the group, whether by special means or by temporary discontinuance of the work until the hazard has been eliminated.

It should be apparent to all students of the subject that criteria for the safety of any type of occupational exposure to lead are based, ultimately, upon the sensitivity of clinical methods for the recognition of the signs of lead intoxication. Such present criteria are wholly pragmatic and practical, since they have been derived from the correlation of analytical data and clinical observations. If new and better clinical methods based upon more complete understanding of the toxicology of lead compounds should be developed, these criteria may well be modified in the future as they have been in the past. The importance of continued clinical investigation in the lead industries, therefore, is quite obvious.

There is also, of course, the matter of nonoccupational illnesses among industrial workmen. The differentiation of these, especially the chronic diseases of obscure origin, from saturnism is a problem the complexity of which varies considerably with conditions that have little relation to clinical diagnosis as such. The inevitable tendencies of some workmen, members of their families, their legal advisors, and their sympathetic and sometimes ill-informed family physicians to attribute any illness to the effects of lead absorption are heightened tremendously by unsatisfactory labor-management relations, by stringent general, local, and individual economic conditions, and by local professional friction. Nevertheless the clinical problem itself is sometimes difficult to solve, requiring a high degree of technical expertness and general professional judgment, as well as complete freedom from prejudice. It is not enough for the physician to determine to his own satisfaction that an illness is or is not due to lead absorption. Proper professional standards as well as medicolegal considerations demand that he put forth every effort consonant with current medical knowledge, not only to convict or exclude lead as an etiological or contributory factor in an illness, but also to demonstrate the actual nature of the disease in question.

A second function of the physician in the lead trades lies in the utilization of physiological methods for the measurement of lead exposure, and the interpretation of the data obtained for this purpose under his supervision, when such information is required. Reference has been made previously to criteria for the differentiation of safe from dangerous lead exposure in terms of the concentration of lead in the blood or urine of exposed persons. The analysis of these materials calls for the services of a competent analytical chemist. The collection of suitable samples of such biological materials, on the other hand, should be done by or under the guidance of a physician whose familiarity with the workmen and their working conditions is complete, and whose understanding of the physiological and technical background of the sampling procedures is comprehensive. There appears to be considerable uncertainty as to the proper role of analytical data of this type in the control of industrial lead exposure. The specific meaning of various types of analytical data is dealt with elsewhere in this chapter, but questions concerning the desirability and the need for such data in the given instance can be answered briefly and simply. In general, when the exposure to lead in an occupation, a plant, or an industry is of such type and character as to be substantially uniform and readily controlled by mechanical means, so that essentially safe occupational conditions are maintained regularly, there may be no real need for systematic determination of the lead content of the blood or urine of workmen. In comparison with the sampling and analysis of the air of workrooms, the sampling and analysis of the blood and urine of workmen are difficult, time-consuming, and expensive, while, under the conditions indicated, the former procedures may well be entirely adequate to maintain safe working conditions. In such circumstances the analysis of biological materials is required only occasionally, if at all, in connection with medical or medicolegal differential diagnoses.

On the other hand, when the exposure to lead in an industry is highly variable for technical or other reasons, or when the control of such exposure is difficult to achieve and maintain, precise analytical data, especially through analyses of suitable samples of the blood or urine of the exposed personnel, become a necessity. Only by such means can one protect those who are actually involved in hazardous exposure. The medical problem in such a situation is to determine how long an individual or a group may safely continue to work. When workmen reach a level of absorption at which it is no longer safe for them to accept the ordinary or recurring opportunities for exposure associated with their day's work, they must be removed and transferred to work involving less exposure or perhaps none at all. The quantity of lead that is retained in the tissues of workmen under a given set of occupational conditions is determined largely by the factor of time, that is, by the duration of continuous employment in the specific occupation. The influence of the time factor in relation to a known intensity of exposure to lead can be estimated roughly, but in a number of industries and occupations it can be ascertained with adequate assurance only by the analyses of blood or urine or both blood and urine. For this reason in the medical supervision of occupations in which the exposure to lead is uncertain or near the threshold of danger, the use of such methods is generally advantageous and often indispensable.

A third function of the industrial physician is the maintenance of adequate records of preplacement and periodic examinations, and the use of such records to determine the hygienic status of individuals and occupational groups of plant personnel. The necessity and propriety of comprehensive examinations of this type in hazardous occupations is beyond argument and requires no discussion here. It is not so commonly recognized that the information that can be gained thereby in matters of general industrial health or in relation to specific hazards is of such importance as to justify considerable expenditure of time and effort in the accumulation of complete and precise records and in periodic systematic study of the data contained therein. Obviously, much of the information in such records must be held in proper professional confidence, but the essential data related to the main problems of industrial hygiene rarely have individual or personal implications, and can be employed to demonstrate the facts to the management.

1. Specific Medical Procedures

The preceding paragraphs are intended merely to outline the general professional methods of the physician in the lead industries. Certain specific procedures and practices merit detailed discussion, however, for the reason that their significance is not always fully understood nor are they always applied in a satisfactory manner. These are concerned primarily with the detection of dangerous levels of lead absorption prior to the development of toxic manifestations. The evidences of lead absorption, as distinguished from those of intoxication, consist of: (*a*) certain blood changes of which the most important are apparently the result of some degree of stimulation of the blood-forming tissues with the release of increased numbers of juvenile forms of erythrocytes (reticulocytes and erythrocytes with basophilic granulation); (*b*) the development of punctate deposits of lead sulfide in the gum tissues and in the mucosa of the colon and anus; and (*c*) an elevation of the lead content of the blood and urine (or tissues) above the normal level. The first two of these cannot be regarded as specific evidence of lead absorption, since many stimuli affect the hematopoietic tissues, and since any metal that will form a black sulfide may cause a blue line in the gum tissues or a bluish black deposit in the anal mucosa. The third, on the contrary, is entirely specific and reliable in indicating the extent of the absorption of lead.

(*a*) *The Significance of "Stippling" of the Erythrocytes.* The limits of normal numerical variation of the several formed elements of the blood that are specifically involved in lead absorption, have been observed and reported upon by numerous clinicians and investigators. Discussion herein will be limited to punctate basophilia or "stippling" of the erythrocytes. (References are given at the end of this chapter to articles on these and other blood elements and on methods.) The latter occur normally in human blood in small numbers. The numbers of stippled erythrocytes in the blood show little or no change with small increments of increased lead intake, but at higher levels of exposure and absorption their number in the circulating blood shows a somewhat irregular tendency toward an increase. Considerable variation in the degree of individual response is observed, and fairly wide variations occur from day to day, but with increasingly severe conditions of exposure to lead there is a trend toward increasing numbers of stippled erythrocytes in the blood of exposed workmen, if comparisons are based on groups rather than on individuals. Unfortunately the trend in this direction is neither striking nor dependable, and a sizable proportion of the results of any series of such observations is always within the range of normal values.

The above facts stated briefly and somewhat too simply show clearly why it is impossible to rely upon this and related hematological tests for estimating the extent of the absorption of lead by individuals and occupational groups with sufficient promptness and exactitude for practical purposes. And yet some modification of this procedure is the common, and in many instances the only, method employed for this purpose. The time has passed long since when industrial physicians may justify reliance upon these procedures as more than clinical adjuncts to other more specific and sensitive methods.

Certain additional facts demonstrate the value of blood examinations of this type in relation to clinical diagnosis, when properly employed and interpreted. Under conditions of hazardous exposure to lead, an abrupt and *progressive* increase in stippled erythrocytes above the previous normal level of the individual is strongly suggestive of an increased rate of absorption of lead, and should be so regarded unless there is adequate evidence to the contrary. Such an increase cannot be taken as evidence of the existence or imminence of lead intoxication, for large variations occur without symptoms or signs of illness, but it should be considered a harbinger of danger, somewhat in proportion to its magnitude and speed of development. On the other hand, the absence of stippled erythrocytes in the blood in a suspected or alleged case of lead poisoning, during a period of active intoxication, constitutes very nearly conclusive evidence that the toxemia is due to some factor other than lead. The only exceptions, in our experience, are found in cases of acute overwhelming intoxication from a single or very brief massive exposure, and in cases of poisoning by tetraethyl lead. The absorption of the latter compound has never been found to result in hematological abnormalities.

(*b*) *The Significance of the "Lead Line."* A lead line may appear at the margin of a tooth (or teeth) in gums that are somewhat inflamed by bacterial invasion—that is, when hydrogen sulfide is produced locally—whenever the lead content of the involved tissues is sufficiently elevated. We have observed the appearance of a punctate blue line in the tissue of an infected pocket overlying a single tooth in a person whose blood contained lead only to the extent of 0.05 mg. per 100 g. Easily identified lead lines usually signify somewhat greater absorption of lead than that indicated in this instance. Obvious deposits of lead sulfide are seen in the gums of persons with no demonstrable symptoms or signs of intoxication, but the intensification and extension of a lead line may be accepted as an indication of progressive absorption of lead and thereby as a warning of possible danger. The lead line must be differentiated from similar deposits resulting from the precipitation of other metallic sulfides, notably of bismuth; and it must not be confused with the normal pigment of Negroes and correspondingly dark-skinned peoples. The former differentiation is sometimes provided by the medical history of the person in question, but may require analysis of the blood or urine or both; the latter can usually be made by careful study of the locus and appearance of the pigment. The natural pigment is rarely found in the gum tissue on the lingual side, while despite the scant attention given the fact by clinicians in general, a favored site for the first appearance of a lead line is in the extreme lingual edge of the gum opposite the bicuspids and lower molars. The bluish purple line of gingival congestion may be taken for a lead line by the inexperienced physician, especially if examination is not made after expression of the blood by means of a transparent applicator (such as a glass slide). More commonly, the stained or discolored surface of a tooth just visible beneath a thin layer of gum tissue is called a lead line. The differentiation is not always easy, and resort must sometimes be had to the use of a hand lens, or even to biopsy followed by microchemical or, better, spectrographic analysis.

(*c*) *The Significance of the Results of Analyses of the Blood, the Urine, and (Post-Mortem) Various Tissues for Their Lead Content.* Information concerning the lead content of the blood and urine in relation to standards of industrial safety has been presented in some detail previously. In achieving an understanding of the physiological background on which such standards are based, the normal pattern of the metabolism of lead in the human organism and the quantitative changes in this pattern in response to abnormal quantities and types of lead absorption should be summarized briefly. The student of this subject as it relates to industrial and public health should seek more extensive information in the literature, some of which is indicated in the references at the end of this chapter.

VII. The Metabolism of Lead in Man

A. NORMAL LEAD METABOLISM

The general character of the metabolism of lead in the body of the average normal, healthy, North American adult may be described with considerable quantitative accuracy. He ingests with his food and beverages quantities of lead varying from 0.05 to somewhat more than 2.00 mg. (rarely in excess of 4 mg.) per day, the mean daily quantity over a period of months being approximately 0.30 mg., varying somewhat from individual to individual in accordance with the gross quantity and the variety of food consumed. He inhales air containing a small quantity, which rarely, if ever, exceeds 0.10 mg. per 24 hours, of which only a portion—for example, 35 to 50 per cent of particles 0.75 μ or less in diameter—is retained in the lungs and, if not utterly insoluble, is absorbed, rapidly or slowly, as the case may be. Fifty to sixty-five per cent of particles of such small size are exhaled. A large proportion of appreciably larger particles is trapped in the upper respiratory tract and subsequently swallowed, while still larger particles, 10 μ or more in diameter, fail to remain air-borne for long and thus occur infrequently in the general ambient atmosphere. (The quantity of lead absorbed from the "normal" atmosphere is so small as to be barely apparent in prolonged experiments in which the total output of lead in the feces and urine is balanced against the total intake of lead by ingestion. In Cincinnati it appears to be of the order of ±0.02 mg. per day.) Only a small proportion (8 to 10 per cent or less) of normally ingested lead is actually absorbed into the body. Most of it traverses the alimentary tract unabsorbed and appears in the feces. The portion absorbed is distributed, mainly into the skeleton, but also into other tissues, including the liver, from which a small quantity is secreted back into the alimentary tract with the bile. The effect of the generally poor alimentary absorption of lead, together with the biliary secretion (and perhaps other lead-containing secretions into the alimentary tract), is to make the daily fecal lead output almost equivalent to the total intake by ingestion. The small quantity that escapes elimination in the feces finds its way into the tissues (including the skeleton), the blood, the body fluids, and secretions. The concentration of lead in the blood at any specific time depends upon two main factors: the rate of absorption from the intestine and lung, and the magnitude of the countercurrent of lead entering the circulation from the tissues of the body collectively. Thus the whole blood of normal healthy North American adults usually contains from 0.01 to 0.05 mg. per 100 g., the mean concentration being approximately 0.03 mg. per 100 g. (see Table 2). Concentrations as high as 0.06 mg. per 100 g. are found occasionally in a large series of analyses, probably as an expression of a chance contamination or an unusually large analytical error. Only traces of the lead in the blood are found in the plasma, 95 per cent or more being found in the erythrocytes. Lead is found normally in physiologically representative volumes of urine (large samples of 2 to 3 liters) ranging from 0.01 to 0.08 mg. per liter. The mean concentration in the urine approximates 0.03 mg. per liter (sweat

contains lead in concentrations comparable to those in the urine). The lead in the tissues of the average normal man is distributed in accordance with a definite pattern. This pattern is displayed partially in Table 4, but the other tissues and organs participate in it. The major portion is found in the skeleton, the long bones, such as the femur, containing higher concentrations than the flat. (This relationship is reversed during and for some time after a period of abnormal absorption (Table 4).) Measurable and fairly uniform concentrations are found in the other tissues. The average gross quantity of lead present in the body of the normal human adult in the United States of America is not less than 100 mg. nor much more than three times this quantity, with due regard to variations in the body weight, and to the quantity and variety of food and beverages consumed. Both direct and indirect types of evidence indicate that there is little or no progressive accumulation of lead in the human body under the average conditions of lead intake and absorption described above.

TABLE 4

The Levels of Concentration of Lead in Certain Human Tissues and Organs under Varying Circumstances: Random and Inadequate Sampling (Lead in milligrams per 100 g. of wet—fresh or fixed—tissue)

Tissue	Persons with no occupational exposure			Persons deceased (irrelevant cause) in course of prolonged occupational exposure			Fatal lead poisoning (children)		
	Minimum	Maximum	Mean	Minimum	Maximum	Average	Minimum	Maximum	Average
Brain	0.01	0.09	0.02	Few results		0.24	0.24	0.58	0.40
Bone (long)	0.67	3.59	1.88				Few results		10.07
Bone (flat)	0.21	1.11	0.47	Few results		4.53	10.65	26.80	17.00
Kidney	0.02	0.16	0.027	0.07	0.32	0.16	0.22	2.59	1.71
Liver	0.04	0.28	0.13	0.60	1.75	0.92	2.96	4.40	3.71

Note: From the levels of the concentration of lead in these and other tissues, including striated muscle because of its gross weight, the lead content of the entire body can be calculated with fair accuracy. The total lead content of the body of the average adult in each of the three categories above, assuming an average weight of 75 kg., may be estimated at approximately 200, 460, and 1800 mg., respectively.

B. ABNORMAL LEAD METABOLISM

When there is an increase in the exposure of an individual to more than the usual quantities of lead in the "normal" environment, as defined in the foregoing paragraphs, whether by reason of an increase in the lead content of his food and drink, or of the air he breathes, the evidence of such an increase may be found promptly, although such increase may be of small magnitude, as well as regularly or irregularly intermittent in its occurrence, and of brief or prolonged duration. The means of finding the evidence will differ somewhat according to the nature of the increase. Since the primary concern here is that of occupational exposure to lead, attention should be focused mainly on the types and characteristics of such exposure. However, it must not be forgotten entirely that opportunities for abnormal exposure to lead other than those that occur in a specific industry present themselves to some industrial employees, since some of them have more than one job, and since, occasionally, the environment of the home may provide a significant exposure to lead, because of a faulty supply of water, or for some other strictly local reason. Moreover, persons have been known to take various lead compounds by mouth in order to induce or to prolong an episode of lead poisoning. (The writer has had but three such cases in the past twenty years, but such cases may be expected to occur from time to time, as an expression of the quest for compensation, or in pursuit of other economic or personal ends.) When abnormal quantities of lead are taken by mouth on a single occasion, there is a corresponding increase in the lead content of the feces for one to three days thereafter (until the alimentary tract has been completely evacuated). If the ingestion of an abnormal quantity of lead is repeated one or more times, at intervals, the fecal output of lead will undergo corresponding increases at approximately corresponding intervals, and if the ingestion is continuous (daily), the level of the lead output of the feces will be elevated correspondingly and regularly. The lead content of the feces of workmen in lead-using industries will also be increased when they work regularly (with one or two days of freedom at the weekend) without respiratory protection in an atmosphere containing lead-bearing dust of which some of the particles exceed 1 μ in diameter. The increase under these circumstances will vary with the severity of the atmospheric contamination with lead-containing particles of relatively large size (and mass). If the atmospheric contamination is limited to minute lead-bearing particles (vapor, fume, or extremely fine dust) under 1 μ in diameter, there will be little or no demonstrable increase in the lead content of the feces (only to the extent that there is an increase in the true alimentary excretion of lead).

Under any set of conditions through which greater than "normal" (usual) quantities of somewhat absorbable lead compounds (it is impossible at present to be certain that there is any particulate compound of lead that is completely unabsorbed for practical purposes by the pulmonary or alimentary membranes) are introduced into the body by the respiratory or alimentary routes, or by both routes as is usually the case in industry, there is a prompt increase in the rate of *absorption* of lead, as shown first by a proportional elevation of the concentration and output of lead in the urine. This is followed a little later (if the increase in absorption is sufficient) by a lesser increment of increase in the concentration of lead in the blood. There is also an increase in the distribution of lead into the tissues of the body, and for a time during the period of the elevated intake and absorption of lead there is a proportional increase in the retention and accumulation of lead in the body. If the increase in the intake and absorption of lead is maintained continuously (24 hours/day, 7 days/week) for months or years, there

is a *corresponding and steady increase (proportional to the daily dose)* in the concentration of lead in the urine and blood and in the body as a whole. However, if the elevated absorption is intermittent, according to the usual industrial schedule of 40 hours, more or less, of exposure per week, the levels of lead concentration in the urine and blood reach a plateau after some months (the actual time required varies with the severity of the exposure), after which they remain essentially constant so long as the severity and duration of the exposure remain constant. After this plateau has been reached, and so long as it is maintained, there is little progressive increase in the accumulation of lead in the tissues. It cannot be said that there is none, for the reason that industrial exposure to lead is not only intermittent by reason of the hours and days of work, but it also varies somewhat in magnitude from day to day and from time to time. As it increases and decreases, the metabolic equilibrium is disturbed and the lead content of the body increases and decreases accordingly, with some delay, especially on the decreasing side of the cycle (a longer time is required for the elimination than for the absorption and retention of lead). The evidence indicates that there is also a *shift of the lead within the skeleton from its more active (in terms of metabolism)* to its less active parts during a period of elevated absorption, and this feature of the skeletal metabolism tends to result in a slow accumulation of lead within this great mass of tissue (roughly one-seventh of the body weight in the adult) during such a period. Such factors as these introduce serious difficulties into observations designed to determine the precise relationships between the intake and output of lead by man over prolonged periods of time, even under precise experimental conditions in the laboratory. Such experiments have shown, however, that during any period within which the concentrations of lead in the blood and urine remain essentially constant (i.e., subject only to ordinary and inevitable variations above and below a mean or medium level), progressive accumulation of lead within the body is slight to the point of insignificance.

After the discontinuance of occupational exposure to lead, the lead retained in the body during the period of increased absorption maintains the concentration of lead in the tissues, the blood, and the urine above normal levels for a period of time that depends upon both the quantity of lead retained and the time over which *the retention was occurring. Thus the concentration of lead in the blood and urine* decreases progressively, reaching the normal range in a period that varies from a few weeks to considerably more than one year. The alimentary tract, on the contrary, to the extent that particulate lead compounds from the nasopharynx were being swallowed, is emptied of its abnormal lead content to a very large extent within a few days after the termination of the occupational exposure. From then on the alimentary lead output is so largely composed of lead ingested with food and beverages as to be indistinguishable therefrom, except under carefully controlled conditions in which the total lead content of the ingested food and beverages is ascertained by the analysis of duplicate samples. The lead content of the tissues of the body diminishes in accordance with the elevated rate of the excretion of lead, there being some lag, but by no means immobility in this regard, on the part of the skeleton. Available analytical data indicate that approximately normal concentrations of lead in the tissues are commonly reached within 12 to 18 months after the termination of a prolonged period of occupational exposure, the skeleton being the last to return to the normal range.

VIII. Recommended Procedures of Preventive Medicine

The importance of the facts outlined in the foregoing paragraphs cannot be overemphasized in their relation to the problem of occupational exposure to lead. They demonstrate clearly that lead occurs in the human body without prejudice to normal health, and that a toxic effect on the part of this element is a matter of concentration. Combined with other experimental and clinical evidence, they also indicate that the absorption and excretion of quantities of lead considerably in excess of the usual and normal levels, are wholly compatible with normal and healthy human life and activity, and that lead intoxication is not to be anticipated if certain limits of exposure and absorption are not exceeded. They also point the way to the proper medical handling of workmen who are found to have absorbed quantities of lead that are potentially dangerous, as judged by the criteria recommended herein. The removal of such a man from the occupation in which he is engaged, prior to his development of any symptom or sign of intoxication, becomes an ideal procedure of preventive medicine, in that an occupational illness can certainly be avoided and the man can be returned to the same work, after he has excreted the potentially dangerous lead from his tissues, without prejudice to his health. If, in the meantime, while he works at a nonhazardous job, the hazardous conditions that were responsible for his excessive absorption of lead shall have been eliminated or brought under control, the entire problem will have been solved. On the same physiological basis, the rotation of men into and out of occupations that are unusually resistant to hygienic control becomes a rational procedure of preventive medicine. There are problems here with respect to the handling of personnel, admittedly, but the validity of such procedures in the strict terms of personal health, when properly implemented as medical and personnel policies, removes these problems from the realm of makeshift and compromise.

Considering all of the facts in relation to the problems of sampling and analysis and the interpretation of analytical data, there are several types and combinations of practical preventive procedures that can be employed in the medical supervision of workmen in hazardous occupations in lead-using industries. Certain of these that have proved their efficacy over a period of many years may be worthy of presentation. Any one of them may be the procedure of choice in a given situation.

As a means of demonstrating the severity of the exposure to lead associated with each of a series of different occupations in a plant, periodic analyses have

been carried out after collecting samples of urine of large volume (2 liters or more) from each of a group of workmen chosen to represent the several operations and operating areas. These samples are obtained by the workmen during time spent at their homes, after having bathed and changed clothes at the plant. Verbal and written instructions are provided for their guidance so as to cultivate their informed cooperation and to avoid errors of sampling, so far as possible. Each series of analytical data is subjected to careful study and to statistical analysis. Since the occupational groups are kept unchanged for as long as possible and are modified in composition and augmented or diminished in number only after careful consideration, so as to maintain their representative character, the status of the hazard of the daily work, from the aspect of the absorption of lead associated with specific occupations, is made evident on each occasion. The results will reveal the status of individual workmen from time to time, but a comparison of the successive series of results is especially valuable in demonstrating the satisfactory or unsatisfactory quality of the hygienic control in all parts of the plant. The interval between successive series of analysis can be varied in accordance with the extent of the hazard associated with the operations, after this has been established. Inasmuch as this regimen fails to provide observations on all of the workmen who are subjected to exposure to lead, it is usually advisable to supplement it, periodically, by a complete analytical survey of all such workmen. This may be done in the manner described above, but analysis of the blood (except in connection with exposure to tetraethyl lead) is the method of choice in determining the status of individual workmen.

The foregoing regimen, while being highly useful and satisfactory, has met with difficulties in some instances, and has then been discarded in favor of the use of samples of urine of small volume (spot samples) collected, with sufficient frequency to make up for the greater variability of their lead content, from a similarly representative group of workmen. The results of these analyses are assembled periodically in relation to the occupations represented, and are subjected to statistical analysis, so as to reveal the hygienic status of the occupations. In addition, everyone engaged in operations that give rise to exposure to lead is sampled at least twice per year in the same manner. Any unusual result on the high side is checked by the analysis of such further samples of urine as may be required to determine the status of the individual concerned. Here again, the sampling and analysis of the blood usually prove, with the exception indicated above, to be the method of choice in investigating the absorption of lead by individuals, at infrequent intervals.

Another regimen of sampling and analysis—one that is employed frequently and advantageously—is that of obtaining samples of blood and "spot" samples of urine from all of the individuals who are subjected to occupational exposure to lead, on a schedule that is adjusted to the severity of the exposure to lead associated with the various operations and operating areas. Some of the operations and the personnel concerned with them may require little attention, while others may call for frequent analytical surveillance. The advantages of this regimen have been pointed out previously. An alternative that retains most of these advantages is that of limiting the analyses to the blood alone, and in some situations this limitation is fully justified. It is sometimes necessary, and it is usually wise, to keep the cost of all such services at the lowest level that is compatible with satisfactory performance. Here considerations of economy, tinctured with medical judgment, will dictate the choice of procedures that will best meet the requirements of the given situation.

The basis for the interpretation of the results obtained by the analysis of the blood and urine has been presented previously in some detail. It has been found to be useful, however, to set down certain practical applications of such interpretations as guides for uniform medical and administrative action. The presentation of these in the form of a directive might convey the impression that undue importance is attributed to the analytical regimen and its findings, and that the medical examination of workmen and the exercise of sound clinical judgment in their behalf are to some extent disregarded. Nothing could be further removed from the substance and intent of these statements concerning procedure. Rather, they stem from the basic consideration that the workmen in potentially hazardous industries should be kept under a medical surveillance that is competent and conscientious; that thorough physical examinations, supplemented by appropriate procedures of the clinical laboratory, are employed capably and with sufficient frequency to provide satisfactory information on the general health of the workmen, as well as on specific environmental hazards. Nothing said here or elsewhere in this chapter should be thought of as condoning the practice, often seen some years ago in the lead-using industries, of limiting the medical supervision of workmen to the examination of blood films for "stippled" erythrocytes by a technician. That the presently available analytical techniques are infinitely superior, in their specificity and sensitivity, to those based on hematological findings, cannot justify their substitution for medical knowledge, judgment, and skill. Despite the fact that analyses of the blood and urine for lead call for greater precision and skill, on the part of a good chemist, than are required in most of the procedures of the medical laboratory, they are clinical procedures and they should be regarded as a part of the armamentarium of the physician in industrial hygiene. In this context the following criteria for the interpretation and application of analytical results as a part of the medical handling of personnel are advanced.

A. CRITERIA FOR THE INTERPRETATION OF THE RESULTS OF ANALYSES OF BLOOD OR URINE, IN THE RECONSIDERATION OF THE CLINICAL DIAGNOSIS ARRIVED AT IN INDEPENDENCE OF SUCH RESULTS

1. A cause-and-effect or a contributory relationship between the absorption of lead and any type of illness presented by a workman whose current exposure to lead continued uninterruptedly up to the onset of his illness and in direct temporal relationship to the collection of the samples for analysis, and who has not been subjected meanwhile to therapy of a type that would disturb the lead metabolism of the body, may be excluded, when (*a*) the levels of concentration of lead in duplicate samples of blood and a "spot" sample of urine are well within safe limits—not more than 0.06 mg. per 100 g. of blood and under 0.13 mg./liter of urine; or when (*b*) the levels of concentration of lead in repeated "spot" samples of urine are within safe limits as defined above; or when (*c*) the concentration of lead in a sample of urine of large volume is not in excess of 0.10 mg. per liter.

2. A cause-and-effect relationship between the absorption of lead and the existence of nonspecific or obscure symptoms or signs of illness cannot certainly be excluded and so may be assumed (not proved) to exist, when (*a*) other causes of illness have been excluded beyond reasonable doubt, and the levels of concentration of lead in duplicate samples of blood and a "spot" sample of urine, uninfluenced by eliminative therapy, are indicative of potentially dangerous absorption of lead—more than 0.08 mg. per 100 g. of whole blood, and more than 0.18 mg./liter of urine; or when (*b*) in the same clinical situation, the results of the analysis of multiple "spot" samples of urine (or of a sample of urine of large volume, collected with appropriate care to avoid contamination) are in agreement in demonstrating the occurrence of potentially dangerous absorption of lead—more than 0.18 mg./liter.

3. A cause-and-effect relationship between the absorption of lead and the existence of strongly suggestive or characteristic symptoms and signs of lead intoxication may be assumed to exist, when (*a*) the levels of concentration of lead in the blood and urine are within the dangerous range, as previously defined; or when (*b*) it is known that the levels of concentration were well above safe limits during a period of exposure to lead that has now been discontinued for some weeks.

B. CRITERIA FOR THE REMOVAL OF WORKMEN FROM OCCUPATIONS IN WHICH THEY MAY INCUR SIGNIFICANT EXPOSURE TO LEAD, DESPITE THEIR FAILURE TO DISPLAY ANY SYMPTOMS OR SIGNS SUGGESTIVE OR CHARACTERISTIC OF LEAD INTOXICATION, OR ANY OTHER OBSCURE OR ILL-DEFINED SYMPTOMS OR SIGNS OF ILLNESS

1. The exposure of a workman to lead should be terminated abruptly (*a*) when the concentration of lead in his blood, as demonstrated by multiple analyses, is found, more than fleetingly, to be at or in excess of 0.08 mg. per 100 g., or when (*b*) the level of concentration of lead in multiple "spot" samples of urine, or in a properly collected sample of urine of large volume, is found to be in excess of 0.18 mg./liter; or when (*c*) the concentration of lead in the blood is found to be increasing and approaching the threshold of danger, and the level of lead concentration in the urine remains constantly in the lower third of the normal range and thus gives presumptive evidence of impairment of renal function with respect to the excretion of lead.

C. CRITERIA FOR THE RESTORATION OF WORKMEN TO OCCUPATIONS FROM WHICH THEY WERE REMOVED BECAUSE OF POTENTIALLY DANGEROUS ABSORPTION OF LEAD

1. Workmen who are free of illness may be returned to their former occupations involving exposure to lead, with no more than the medical reservations of judgment that apply to the original selection of workmen for employment in such occupations, when (*a*) the concentration of lead in their blood has diminished to a point at which it is consistently well within the safe range, i.e., less than 0.06 mg. per 100 g.; or when (*b*) the general level of their urinary excretion of lead, as judged by the analysis of multiple samples of small or large volume, is well within the safe range, that is, less than 0.13 mg. per liter; or when (*c*) following the correction of the occupational conditions (whether personal or environmental) that gave rise to their excessive absorption of lead, the levels of lead concentration in the blood or urine (or both preferably) have diminished and are within the range indicated above.

2. The severity and the duration of the exposure that was responsible for the excessive absorption of lead are important factors in the consideration of the wisdom of returning such a workman to his former occupation, since his probable body burden of lead, in relation to the severity of the exposure to which he will be subjected on his return, will be a significant factor in the length of time he will be able to continue in his occupation without a further return to a dangerous level of lead absorption. His return to a safe work environment involves little or no risk, but if the environment is dangerous or only dubiously safe, the risk will have been multiplied by his previous experience. In any case, the duration of the period of his freedom from exposure should be extended *in proportion to the duration of the* period of exposure that resulted in his absorption of excessive quantities of lead. The elimination of lead accumulated in the body, during a period of exposure, requires at least twice as long as the period over which the accumulation occurred.

IX. The Problem of Industrial Lead Poisoning in Relation to *Industrial Hygiene*

The diagnosis and treatment of lead poisoning are in the realm of clinical medicine, and can scarcely be dealt with adequately in a discussion devoted primarily to the control of occupational exposure to lead and the prevention of occupational illness. Accordingly, attention is called to adequate sources of information in the references at the end of this chapter, and only a few points that impinge upon industrial hygiene will be touched upon.

A. PROPHYLAXIS

When incipient or well-defined lead intoxication has appeared in an individual case, certain steps should be taken at once (see criteria for disposition of men in relation to analytical results in preceding section). The first requirement is the elimination of further exposure to lead on the part of the affected person. The means by which this is done will depend upon the circumstances. If the exposure to lead has resulted from accidental and unforeseen causes, and if the resultant illness is slight and fleeting, it may be sufficient to see that the opportunities for subsequent exposure are reduced or dispensed with, after which the workman may resume his work. If the cause was carelessness, ineptitude, or inattention to instructions on the part of the workman, it may be necessary to transfer him indefinitely or permanently to other less exacting work.

When cases of lead intoxication occur within a group of employees, the other employees are likely to be concerned, and the physician will be concerned for them, and will consider what can be done to reduce their present danger. Dietary supplements for the workmen, such as acid beverages, milk, and vitamin preparations are not to be recommended as prophylactic measures. If they are employed as means of improving the quality of the food and correcting dietary deficiencies that often exist, they are not open to criticism on this score. Even then, however, it seems probable that advice and instruction in matters of diet, such as may be given by the industrial physician to individuals and groups of workmen, may better serve the purpose. A still more effective method for meeting nutritional needs is that of providing a satisfactory restaurant in which a good midday or mid-shift meal is served.

The regular administration of cathartic medication is to be condemned unreservedly, and this practice, often resorted to by the workmen themselves, should be combated. Constipation is a frequent human ailment, and for the workman in the lead-using trades it is especially disadvantageous, since it delays the evacuation of the alimentary tract and thereby promotes the absorption of lead. To the degree that it is caused by the absorption of lead, it is a sign of lead intoxication, and should be dealt with by the control of the exposure to lead, not by cathartics; but to the degree that it is due to other causes, such as carelessness and faulty diet, it should be dealt with by the recognition and elimination of these causes. The physician in industry has an important advisory and educational function to perform in this and many other hygienic matters.

The use of specific chelating agents, prophylactically, as a means of hastening the excretion of lead by men who are working in potentially dangerous occupations, regardless of the specificity or harmlessness of such agents of this type as may be made available in the future (no such specific or harmless agent is available as yet) is unworthy of favorable consideration by the members of a humane and socially sensitive profession. A physician should make clear to an employer *the necessity of providing a safe and healthful work place for his employees,* rather than give him support and comfort in his complacency and his preoccupation with other concerns. A physician can properly accept some responsibility for unsafe conditions and for employing means of mitigating their effects for a time only when every effort is being made to eliminate hazards as promptly as possible after they have been disclosed.

There are, however, times of stress in many industries, when the hazards of the day's work tend to be augmented or multiplied, and this situation arises from time to time in those concerned with the production or use of lead compounds. The physician should be especially vigilant in periods of accelerated industrial production when hours of work per day and per week tend to increase. At such times, as mentioned previously, it may be advantageous or even necessary to resort to the rotation of men and jobs so as to reduce the time spent by individuals in the more hazardous occupations. No specific rule can be given by which to adapt such rotation to the requirements of the situation, but any regularly occurring interruption of the exposure to lead will result in some reduction in absorption. The desired end can be accomplished satisfactorily under the guidance of an analytical surveillance of the men involved.

B. THE DISPOSITION OF WORKMEN AFTER RECOVERY

For reasons indicated previously, the therapy of lead poisoning is not dealt with herein. However, the recovery of a workman from an episode of lead poisoning creates a new problem of industrial hygiene, in that the question of re-employment then arises. Should the workman return to his former job, and if not, what work should he undertake? In general, it may be said that if he has regained good health and if the conditions that were responsible for his illness have been identified and corrected, he may return to his previous work. Otherwise, provision should be made for his employment in a position that will not subject him to potentially hazardous exposure to lead. This will not be difficult to do in an industry that is engaged in varied types of production, and it is not likely to be an insoluble problem in a well-managed lead-using industry. It should not be undertaken lightly, however, for if the outcome is to be successful, there must be fairly precise information on the status of the workman, with reference to his body burden, and adequate information as to the intensity of the exposure to lead, if any, to which he is to be subjected. It will not suffice to put such a man to work in an occupation or area that is considered, without evidence, to be essentially or largely free of exposure to lead, nor will it be satisfactory merely to provide a job, unsuited as it may be to the workman and his capabilities. All too frequently, the odd job or the "outside work" is potentially hazardous in terms of exposure to lead, often because it did not seem important enough or continuous enough to justify careful appraisal of its hazard. It is also worth pondering that a job that requires little effort or skill, or one manufactured for the occasion, may well be a means of converting a once skillful and energetic workman into a frustrated loafer or perhaps into a chronic invalid. Satisfactory work in favorable environment, on the other hand, often provides one of the necessary stimuli for prompt and complete rehabilitation.

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