BUNTING BRASS AND BRONZE COMPANY

Toledo, Ohio

A Study of the Lead Exposure Associated with the Operation of a Plant Engaged in the Manufacture of Bearings of High Lead Content.

by

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Introductory Comment on the Study of Occupational Lead Exposure

In veiw of the fact that the general methods of plant study employed by the Kettering Laboratory of Applied Physiology differ somewhat from those used generally in industrial surveys, it may be of some interest to refer to the available methods and to point out some of the advantages and disadvantages in their use.

(1) A single critical inspection of operating conditions in a plant, made by an experienced person, will provide a general idea of the opportunities for lead exposure and some knowledge of the location of the greatest hazards. Periodic inspections of this type will prove to be more useful than one, for obvious reasons, and moreover they are a useful adjunct to any other method of study and control.

(2) A single clinical survey of groups of workmen representative of various occupational activities in the plant will define the general levels of lead exposure in terms of clinical evidences of lead absorption and will tend to reveal the most hazardous types of employment.

(3) Maintained medical supervision, with periodic examinations of all employees and with carefully recorded information as to the character and incidence of illness, the amount of lost time and the extent of the labor turnover, will eventually show the hygienic significance of plant conditions as no other method can do, and if the information so obtained is combined with detailed knowledge of plant procedures, including the changes in equipment and plant prac-

tice, a clear composite picture of the hygienic situation can be obtained. All methods of evaluating the hygienic significance of lead exposure depend upon sound clinical data. Indeed the belief is well entrenched in the medical as well as the non-medical mind that individual susceptibility to lead intoxication is extremely variable and that even the smallest quantities of absorbed lead may, in time, result in lead poisoning in certain persons, while certain other persons may receive no injury from massive dosages. The complete acceptance of such a point of view, (which in our judgment is erroneous), implies that there is little or no value in any type of measurement of the quantity of lead absorbed or potentially available for absorption on the part of workmen. So long as such an opinion is applied with even partial effectiveness in medico-legal and trade-union phases of industrial practice, business management cannot afford to operate plants associated with any of the lead trades without competent and adequate medical service. Fortunately, evidence has accumulated to demonstrate the existence of a relationship between quantity of lead absorption and the occurrence of lead intoxication. Various expressions have been given to this relationship, and it cannot be said that there is complete agreement among authorities as to the safe limits of occupational lead absorption. Nevertheless, it is now fairly generally accepted that there is a limit of lead exposure above which the danger of lead poisoning becomes progressively greater among a plant population, and below which cases of poisoning will either not occur at all or will be of an essentially harmless type. Thus it becomes feasible to estimate the significance of lead exposure in quantitative terms.

(4) The lead exposure associated with an occupation may be estimated by the analysis of air samples taken from representative parts of the building or area in which the work is done. Obviously the use of this method involves certain assumptions; - (1) that the inhalation of lead compounds constitutes the only important source of lead absorption on the part of the plant population; (2) that the lead compounds or particles found in air samples may be breathed in and retained within the lung to a more or less uniform extent by the workmen in the area. Various technical procedures have been employed to increase the practical reliability of this method. Frequent sampling over prolonged periods tends to reduce sampliig errors. The manner of preparing samples for analysis also tends to exclude particles of lead compounds which because of their size are incapable of inhalation or of retention in the lung. Moreover the greater practical significance of inhaled lead in comparison with ingested lead has been well demonstrated by experience and experiment, and is now almost universally recognized. On the other hand, lead poisoning can and does occur through ingestion of lead compounds, and unless precautionary measures are effectively taken against carelessness and uncleanly habits on the part of workmen, ingestion can occur to such an extent as to void conclusions arrived at by the analysis of air samples.

With certain reservations required by the preceding considerations, it may be said that if the concentration of respirable lead compounds in the atmosphere of plant work-rooms is generally kept below the level of 1.5 mg. Pb per 10 cu.m. of air, and is permitted to exceed such a level for only fleeting periods of time, cases of plumbism in the plant population will rarely, if ever, occur.

(5) It has been shown that the magnitude of the lead exposure in a plant can be determined by the study of the lead content of the excreta of the employees. Briefly stated, the lead content of a single evacuation of the feces of a workman serves to show the magnitude of his lead exposure for the period of twenty-four to seventy-two hours previous to the collection of the sample. A large proportion of all inhaled lead is collected in the nose and pharynx and eventually reaches the alimentary tract, through which it passes in large measure unabsorbed. It becomes, thereby, an indicator of a man's gross lead intake for the period represented by the feces accumulated in the lower bowel - a period which experience has shown to be approximately twenty-four hours in average normal persons. The concentration of lead in a large sample of urine (collected over a period of forty-eight or seventy-two hours) varies with the rate of daily lead absorption and with the lead content of the body. Therefore, it discloses the general magnitude of the lead absorption over a considerable period of time.

More recently, it has been found that analyses of the blood of exposed persons will also reveal the general magnitude of their lead absorption and exposure. The changes in the lead concentration of blood are not so rapid in their occurrence nor so proportionately great as those in the urine, in response to lead absorption, and, therefore, blood analyses are not so sensitive a means of detecting lead exposure. Such analyses, however, are useful in the study of industrial workmen for a number of practical reasons which need not be discussed here.

The correlation of analytical data of the above types with the observed conditions in industrial plants, and with the clinical findings in plant employees, has established a basis for the differentiation of safe from dangerous occupational lead exposure in practical terms. Attention should be called here to the detailed data of our various studies of the lead excretion of normal persons and of workmen in various lead trades. These data demonstrate clearly that above a certain level of lead exposure, as expressed by the rate of lead excretion of representative groups of workmen, the occurrence of lead intoxication is progressively more frequent as the occupational exposure increases in magnitude. They also show quite conclusively that no cases of lead intoxication occur below a certain level of lead intake and absorption. The precise point - (if it be a point) - of the critical differentiation of non-hazardous and hazardous exposure, in these terms, is not sharply defined at present, but a range of values can be set up on the basis of present information with every assurance that they are substantially correct for all practical purposes. Reference to those ranges will be made subsequently.

The Technique and Scope of the Present Investigation

A preliminary inspection of the plant - a brass foundry - was made, on the basis of which a small group of employees was selected for study from what appeared to be the commonest and most hazardous occupations. Subjects with the longest records of continuous employment, and with the greatest expectation of continued employment, were chosen, the final choice having been made by the physician in charge of the plant, on the basis of his records and his detailed knowledge of the occupational and personal history of the employees.

The large proportions of the workmen were employed in one large room, - i.e. the main part of the plant -, in which a varied group of molding operations were carried out. These operations will not be described in detail. Suffice it to say that they were of the type that are common to such plants and that some of them involved little or no necessary exposure to lead. This fact, however, is quite unimportant, in relation to the actual lead exposure, since the handling of molten metal of high lead content in one part of this room resulted in the contamination of the air in all parts of the room. A considerable degree of control of the fumes was accomplished by means of general andlocally applied ventilation. However, on account of the mechanical difficulties of fume removal from rapidly moving pots or ladles, the chief effect of the ventilation was to dilute the lead fumes extensively but not uniformly in the large room. As a consequence of this condition, it wasnot possible to differentiate degrees of severity of exposure with any assurance of accuracy. Further discussion of this problem will develop later. It is mentioned here only to show that the general lead exposure of the plant had to be studied not so much in relation to specific occupations, but rather in relation to the volume of lead vapors and fumes, and their dissemination through the plant.

A large amount of molten metal, much of it of high lead quiry established the fact that there were seasonal variations in the productivity of the plant. Such variations would result in considerable change in the quantity of lead vapors and fumes. There were also irregular variations in the proportion of high lead bearings in the plant production. These factors could be expected to influence greatly the severity of the lead exposure of the men working in the large room of the foundry. In addition the general ventilation of the plant was subject to change during the warm months of the year when doors and windows could be opened. This factor could hardly be expected to operate with strict uniformity in reducing the lead exposure, in that some persons would be benefitted more than others. The overall effect, however, would be to dilute the lead concentration in the air of the plant. No attempt has been made in this report to assemble the data on production as a whole or with reference to bearings of high lead content. It would be interesting to correlate these data, if available, with the results obtained. Moreover, the information with respect to the number of persons employed in the different parts of the plant has not been obtained for this report. Finally, there are no data on the seasonal changes in ventilation. Direct information as to the influence of these changes upon the mean concentration of lead in the air of the plant, would be of considerable interest in view of the indirect evidence of decreased exposure on the part of the men as revealed by the analytical data given in a later part of the report.

Twenty employees were selected for study over a period of time, and several others were included in the observations before their completion. Samples of feces and urine were obtained in December of 1936, and in May and September of 1937, by methods which experience had shown to be satisfactory. Blood films from these men were studied at regular intervals for the determination of the numbers of stippled erythrocytes. Additional blood films were obtained for counts of the reticulocytes and for certain special observations on the leucocytes. No useful relevant information was obtained from the reticulocyte counts or the examination of the leucocytes, and no further mention will be made of them.

The composition of the group of selected workmen with respect to age is shown in Table 1. It may be seen that a wide range is covered, although the total number of the group did not provide adequate representation of various age groups. For this reason the clinical effects of lead absorption upon the occurrence and development of the degenerative diseases of the middle and later years of life, as well as upon disabilities in the earlier years, could not be studied here. Previous observations have shown that age does not influence lead excretion materially, and, therefore, there is no reason to doubt that the analytical data are valid as an indication of the over-all lead exposure of the group. This small group is not necessarily representative of the age distribution of the workmen in the plant, but Table 1 shows that no age group within theperiod between early adult life and early old age is lacking in the plant population.

Table 2, in which the subjects are grouped according to the duration of their continuous exposure in the plant, merely shows that the group has been well selected in that regard. It should be possible to determine whether or not time is an important factor in the lead exposure and absorption of such a group unless there should be too much variation in exposure among them because of diversity of occupation. The effect of the latter is open to doubt for reasons pointed out above.

Table 3 presents the facts with reference to the type of employment represented in the selected group, giving also the duration of employment of the representatives of each occupation. The molders alone are sufficient in number to be adequately representative of their group.

In April of 1937, following the winter period of maximum lead exposure, twenty two workmen were examined. Each person in the group was subjected to detailed questioning. Every effort was made to gain his confidence and to induce him to talk freely about any ailment, illness, or injury which, in his mind, might have been due to occupational conditions in the past, or might arise from present conditions. Leading questions were avoided at first so as not to color the employee's response, but were employed subsequently with respect to specific symptoms. Information as to past and present conditions in the plant, the attitude of other workmen toward the potential hazards of this work, and the extent of the labor turnover because of illness or dissatisfaction, was sought discreetly from a number of the older employees. These men appeared to respond with complete frankness, and gave useful statements of fact and opinion.

A careful physical examination was carried out, in the course of which a special effort was made to observe and record any symptoms and signs of lead absorption. Thus, special care was given to the examination of the gums, and to nervous and neuromuscular reactions. A complete microscopic examination of the blood of each man was carried out at the time, and a fresh sample of urine was examined for reaction, the presence or absence of albumin and sugar, and for sediments.

The clinical data were studied carefully, both as to individual persons and for the group as a whole, and in so far as it was useful or feasible to do so, they were examined by statistical means.

The Results of the Investigation

The initial inspection of the plant indicated that the opportunities for exposure to lead fumes and vapors were widespread. It was difficult, however, to make an even reasonably intelligent estimate of the severity of this exposure. Lead fumes, manifestly, were given off from the pots while in transit to the molds, and during the pouring, but there was so much smoke in the main foundry room that one could not judge the degree of contamination of the air with metal fumes. The ventilation, large in volume, was designed, so far as possible, to remove the fumes from furnaces and pots, but it was not entirely successful, and for reasons that were quite apparent. Lead-bearing dusts were also distributed into the air at various points, and even the metal-washing process, which could have been free of dust, was not entirely so, by reason of some laxity in the handling of the material. Housekeeping, in foundries, is a difficult problem, at best. One felt that while this source of lead exposure had not been ignored, it was not receiving the continual meticulous attention that is required for its elimination.

There was little or no separation of the functional areas of the plant on the basis of the lead exposures that characterized specific occupations. This, in some respects, at least, was unfortunate, since certain occupations could have been freed of lead exposure through isolation. On the other hand the frank dependence upon ventilation as the primary means of controlling the lead hazard throughout the plant, indicated the acceptance of responsibility by the management, and if the ventilation were adequate, this hygienic problem could be regarded as solved to a large extent. If the ventilation should be inadequate then it would be necessary either to make it more affective or to limit the number of severely exposed persons by isolating the areas and occupations that, in themselves, were free of lead hazards. Something further will be said on this subject later.

The examination of the small group of workmen revealed several facts of importance. There was suggestive evidence, in response to questioning, of the existenceof dangerous lead exposure. The conditions in the plant, as revealed by the men, had been much worse with respect to the removal of fumes, prior to the installation of the present ventilating equipment. During that period "brass chills" had not been uncommon among the workmen. These had been eliminated entirely, apparently, by the improved ventilation. On the other hand, there had been cases of lead intoxication before the ventilation was provided, as well as afterward, as judged by the description of apparently characteristic episodes by certain workmen. Apparently, during the period in which the bearings were generally low in lead content, the lead exposure was not very serious. Later, however, with the increased lead content of the bearings, the lead exposure from this source increased to such a degree as to be hazardous, in the face of greatly increased ventilation. However, there was no noteworthy anxiety among the men concerning their health, and the feeling was general, that the conditions in the plant were not unduly hazardous. A number of the men denied flatly that they had experienced any impairment in health or well-being as a consequence of their work. A fewwere somewhat concerned about the prevalence of strong air currents that gave rise to common colds.

The physical signs of lead absorption, while considerably less prominent than one was led to expect from observation and questioning, were sufficiently numerous to justify the conclusion that the lead exposure was not being held within entirely safe limits.

Table 4 summarizes the purely clinical evidences of significant lead absorption. The significance of some of the items is open to question, considering the smallness of the group. The frequancies of occurrence of constipation, vague abdominal discomfort, and polyuria, as complaints, belong in this category, as well as such physical signs as exaggerated reflexes and tremors. The occurrence of six persons with gingival lead line, however, among twenty-two men is highly significant in that this sign, in general, does not appear except under conditions of fairly severe exposure. The degree of extensor weakness of the forearm is somewhat difficult to estimate, but two cases with a degree of weakness that seemed definite to the examiner, cannot be ignored.

Other information obtained from the examination of the men while of general medical interest, had little or no significance in relation to occupational lead exposure. However, in view of the effects upon the vascular system which have been attributed so generally and for so long to prolonged lead absorption, it seems pertinent to examine the data on the blood pressure of these men in the systolic and diastolic pressures of the men while seated. Ten of the group had distinct elevation of the systolic pressure. Of these ten, five showed a more or less corresponding degree of increase in the diastolic pressure, thereby meriting consideration as victims of definite and significant vascular change. One of these, aged 26, had only a moderate degree of hypertension (136/36), and need not be regarded too seriously. Another, aged 35, gave somewhat similar findings (138/88). The others, all in their 42nd year, and having diastolic pressures of 92, 100, and 110 respectively must be recognized as potentially dangerous cases of hypertension. There was one other instance of high diastolic pressure (88), in a man of 48 years of age, with a systolic pressure of 130. These results are not sufficient in number to prove anything with respect to the effects of lead absorption, but they are suggestive, especially when it is recognized that there is not a definite correlation between blood pressure and age in this group. This, of course, may be due to the small size of the group. Table 7, in which the data are set up in four-fold form, shows, by mere inspection, the complete lack of such correlation when the entire group is studied with respect to age on the one hand, and systolic or diastolic blood pressure on the other. Table 15, to which attention will be directed later, also shows that there is no relationship between the level of lead absorption as shown by lead analyses on the urine, and the height of the blood pressure. One must withhold any conclusions, therefore, on this question. Presumably, the data are too few to warrant a judgment.

The results of the clinical urinalyses require no tabulation. Aside from an increase in urinary acidity, which is not uncommon among men working vigorously, the only noteworthy abnormalities consisted of the presence of a trace of albumin in two instances. These were called to the attention of the plant physician for further investigation.

The results of the leucocyte counts are shown on Table 8. Only two were in the ranges commonly regarded as abnormal, and these were not of any specific significance.

Table 9 shows that most of the men examined had some degree of anemia, and in six instances this could be classified as fairly severe. The significance of this situation, as to general health, although not necessarily in relation to lead absorption, is shown by the data on the hemoglobin of the blood in Table 10. The suggestion that lead absorption may well be a factor is offered by the relatively low incidence of definitely abnormal hemoglobin concentration in the blood. That is to say, these were anemias with a high hemoglobin index, a type characteristic of anemias due to lead absorption, although not confined to that condition.

We come next, in Table 11, to the consideration of data which are more specifically related to lead absorption than those previously dealt with. Moreover, the observations by which they were obtained were carried out repeatedly and at different seasons of the year. It has been established that normal healthy persons with no occupational lead exposure show varying numbers of stippled erythrocytes in their blood. In our hands, the mean value for such persons is about 4 per fifty fields, with occasional results as high as 15, and rarely, even larger numbers. The group here under study yielded a mean value of almost ten times the normal in December, with a gradual falling off to such an extent that in September a number of the workmen showed no stippling and the mean value for the group approached the normal level. It is of considerable practical importance to determine whether this change in the blood picture was associated with an actual and more or less corresponding decrease in the lead exposure in the plant. Previous observations have shown that the mean or average levels of stippling of sufficiently large groups of persons vary with the severity of the lead exposure of the group. However, individual responses to lead absorption are highly variable within such groups and certain unknown factors unrelated to lead absorption and, perhaps, seasonal or nutritional in origin, induce wide fluctuations. If so small a group as this reacts to changes in lead exposure to such a striking degree, despite the extensive variations due to other factors, a very useful and relatively simple method of recognizing increases and decreases in the lead exposure of a plant as a whole would seem to be available. On this account the comparison of these observations with the data on lead excretion is of great interest.

The analytical findings are grouped in Tables 12, 13, and 14. It is apparent that the lead in the feces of these men is abnormal as compared with the mean normal levels of approximately 0.33 mg. Pb per sample, and 0.06 mg. Pb per gram of ash in the feces. On the whole, however, these results are not as high as might be expected in view of the apparent severity of the occupational lead exposure as indicated by the clinical observations. The reasons for this would seem to be that the most hazardous exposure in this plant was to the vapors and fumes of lead, which in their finely divided form would not be entrapped to any large extent in the upper respiratory tract. Only a small proportion of such lead would find its way into the alimentary tract. There is, moreover, little evidence of change in the lead exposure and absorption, over the period of study, as evidenced by change in the fecal lead content. There is some slight diminution in the fecal lead concentration in March, as compared with December, when expressed in milligrams per gram of ash, but in the statistical sense it is not significant, - i.e., the difference between the mean values is less than four times its own probable error.

The mean urinary lead concentration of the group shows a progressive decrease over the period of the study. The difference between December and March is not very striking, and, indeed, from a statistical viewpoint it could be a matter of pure chance. The same is true as between the March and September results. The change from December to September, on the other hand, is a significant one, statistically, and even more so physiologically, since the decrease in lead concentration at such a time is opposed to the normal seasonal increase, (based on decreased water output in the urine during warm weather). We may safely conclude, therefore, that the lead absorption of the men decreased definitely in the period preceding the collection of the samples in September as compared with the period prior to the sampling in December. Granting the correctness of this conclusion, it seems probable that the trend throughout the period of study was in that direction, as suggested by the individual steps, themselves insignificant. The absence of a corresponding trend in the results or the feces is not remarkable in view of the sources of fecal lead, and considering the difficulty of obtaining samples that bear a demonstrable relationship to alimentary function. In contrast, the factors which influence the urinary excretion of lead are few in number and fairly well defined as to their effects. The renal lead excretion, therefore, is a sensitive means of measuring lead absorption, while the lead in a fecal evacuation is a useful but crude indication of the prevalence of lead in the food and the respired air of an individual for the somewhat indefinite period of time represented by the sample. The decrease in the lead absorption of the group as revealed by the urinary lead analyses is of two-fold practical importance in this study, - first, because it is associated with a corresponding or even more striking decrease in the frequency of occurrence of stippling among the men, and second, because the occupational lead exposure as indicated by lead excretion was definitely hazardous in December while approaching safe limits in September.

It is apparent that the frequency of occurrence of stippling in the group is a clear indication of the relative severity of the exposure. This fact should be taken into account in considering the various procedures available for checking the lead exposure of the plant. It should not be forgotten, however, that the data of this study do not make a clear distinction between dangerous and safe conditions of exposure in terms of stippling. They suggest that when the mean value of the stippling of the group of workmen approaches the value recorded for December in Table 11, the conditions of exposure are unsafe and are likely to produce cases of lead intoxication. Other and more extensive observations indicate that when, as in this instance, the lead exposure is largely of one type, the upper limit of safety, as expressed interms of the mean frequency of stippling of a fairly large group of workmen, approximates 10 per fifty fields, with only occasional results in excess of 30 per fifty fields. (These values are based upon a precise and uniform technique in preparing, staining and examining blood films. They would be different if the methods were to be modified or carried out less uniformly.)

The severity of the lead exposure, as shown by the urinary lead concentration, can be compared with that observed in other industrial plants in which corresponding observations have been made. In our experience cases of lead poisoning either do not occur at all, or are of the mildest type, if the mean urinary lead concentration of representative groups of workmen does not exceed 0.10 mg. per liter. Cases are infrequent and comparatively mild, if the mean value is 0.15 mg. per liter or less. Above this level severe and disabling lead intoxication can occur, and does so with increasing frequency as the mean value increases. The significance of the observations on this plant is obvious, therefore, and it is a matter of particular importance that the severe conditions of exposure noted in December did not continue throughout the year. This factor, in all probability, was responsible for the non-occurrence of plumbism among the men during the period of study. Nevertheless, the results demonstrate that the exposure was not so controlled at any time during these observations as to be actually safe. The method of control, therefore, should be strengthened and improved, and the factors which caused the decrease that was noted should be determined and augmented, if that is feasible. In any case, the ventilaor in quantity.

An attempt was made to relate the level of the lead excretion of individual workmen to their occupation. This attempt was entirely fruitless, and since no such relationship could be established, no tabulation of the data in the fashion has been given. As indicated previously, this was to be expected from the nature of the plant operations, from the lack of any segregation of working groups, and from certain inadequacies in the housekeeping.

Table 15 shows the results of the search for a correlation between the severity of the lead exposure, as indicated by the urinary lead excretion of individuals in the group, and (1) the duration of the exposure, (2) blood pressure, (3) hemoglobin content of the blood, and (4) numbers of erythrocytes in the blood, and (5) the numbers of stippled erythrocytes in the blood. It should be noted that there are four entries under each pair of rubrics, and that these are mutually exclusive, constituting thereby, a so-called four-fold table. Correlation in any two items, whether positive or negative, would be shown by asymmetry in the four-fold table, whereas substantially equal numbers in the four corners of the table signify that there is no relationship between the items. The fact that no correlation appears in any instance may be due to the small size of the group. Regardless of this possibility, the significance of the result is quite clear at certain points, especially with respect to stippling. The frequency of stippling of the erythrocytes in the group as a whole was found to vary at different times in accordance with the level of urinary lead excretion. Despite this fact, there is no correlation between the individual findings on urinary lead concentration and the corresponding data on stippling. Since the urinary lead excretion of an individual is known to be an adequate criterion of his lead absorption, the lack of correlation can be due only to the lack of any precise relationship between lead absorption and the extent of stippling in the individual case. In other words, the hemotopoietic response of individuals to lead absorption is uniform in type, but is highly variable in degree. The practical importence of this is obvious in that an absolute standard for a potentially dangerous level of stippling can hardly be set, except on the basis of a figure low enough to cover practically all cases. In considering the individual case it is the change in the numbers of stippled erythrocytes that is important, and not the absolute number found. In general, experience has shown that the person who tends to have large numbers of stippled erythrocytes when there is little or no lead exposure is subject to relatively large increases in stippling in response to lead exposure.

The lack of correlation between the urinary lead concentration and the length of continuous employment in the plant is probably due to the variability of the lead exposure and absorption from season to season, from day to day, and from place to place in the plant. Theother items indicated in Table 15 need not be commented on at this time, since any attempt to explain them would be speculative in character.

Summary and Recommendations

The discussion of the results which has accompanied the presentation of the data need little amplification. However, it may be useful to summarize the salient facts as a basis for recommendations.

The lead exposure associated with the operation of this plant during the period of these observations was of an order of magnitude that must be regarded as hazardous and capable of producing lead intoxication. This conclusion is justified both by clinical findings on the men and by the results of analyses of their excreta.

The lead exposure, while variable, was sufficiently general in the plant that all the employees that were examined, regardless of the nature of their work, were subjected to hazardous exposure with approximately equal frequency, so far as could be judged from the observations.

The general lead exposure in the plant decreased in March as compared with December, and again in September as compared with March. This decrease is attributed to the increase over-all ventilation incident to changing weather conditions. It is important to know whether or not this is the correct explanation, and for this reason the plant records for this entire period on employment, total production, and proportional production of bearings of high lead content should be scrutinized carefully. It would be well also to look into the local weather reports of this period of 1937-38 and to consider them in relation to the probable number and location of open windows and doors. If ventilation alone can produce a change of the magnitude indicated by the results of this survey, one means of improving conditions is obviously available.

In general, the precautions taken against the dissemination of dusts is a number of procedures were somewhat inadequate. The men, themselves, were not sufficiently careful and there was not such supervision in matters of safety as would be desired. It is believed that there was a significant amount of unnecessary exposure on this account.

The mean frequency of stippling of the erythrocytes of the group of workmen as a whole decreased sharply and significantly, during the period of the study, as the lead exposure of the group decreased. This fact demonstrates the usefulness of observations on stippling when all of the results obtained in a given period are grouped and compared with corresponding sets of observations. On the other hand, there was no correlation between the level of lead absorption of the individuals in the group and the number of stippled erythrocytes found in their blood at the same time. Considerable caution is required, therefore, in the interpretation of counts of stippled erythrocytes in individuals. Comparison must be made with previous results on the same person, in order to avoid the important factor of large individual variation.

Certain recommendations naturally follow from the facts stated in the foregoing paragraphs. Others arise out of more general considerations. Some are offered in the full knowledge that the means of carrying them out is not immediately at hand. All of them are believed to be worthy of careful consideration to the end that practicable and servicable steps may be taken to eliminate the lead hazards in this plant. There are two general methods of approach to the problem of elminating these hazards. The one depends upon the application of general ventilation to such an extent that the lead content of the air breathed by the workmen is reduced and maintained below the danger point. The other is concerned with the recognition of the specific points of origin of the hazards and with their elimination at their source. The latter is the better method, if it is practicable. It seems probable that some combination of the two will be required. Obviously, it will be necessary to determine the degree of success of any attempts which are made to eliminate lead exposure. Several means of doing this have been referred to in this report.

It is strongly recommended that some study of the ventilating equipment be made with special reference to the removal of fumes at their point of origin. The amount of movement of air necessary to do this is much less than that required to dilute the fumes after their escape into the general atmosphere of the plant. The problem of providing adequate heat in cold weather will be partly solved by this means, whereas it will be greatly increased by a general increase in ventilation. The difficulty of accomplishing this purpose arises from the mobile nature of the sources of fume. It would seem that the logical way of dealing with this, if feasible, would be to localize the handling of molten metal, applying the ventilation at this point, and to move the molds to the molten metal. If this cannot be done, even in part, under present conditions of urgency, it would be feasible in all probability to improve the local ventilation at the sites of the pouring operations.

Further improvements in the ventilation might well consist in attempts to avoid dead air pockets and points of inadequate ventilation. Adequate balancing of input of air at proper points against exhaust ventilation would be desirable.

Isolation of certain areas of theplant in which non-hazardous operations are carried out is probably desirable and may come to be entirely necessary. This could be accomplished in large measure by localizing the more hazardous areas and applying ventilation to them, while at the same time maintaining good housekeeping and intelligent avoidance of unnecessary exposure among the men in the relatively unexposed areas. There is no need for the molders, for example, to be exposed to lead fumes or to significant quantities of dust. If the over-all lead exposure were insignificant this would be of little importance. Under present conditions it is a highly important matter, for if there is no segregation of relatively unexposed persons, there is no possibility of transferring men out of dangerous areas into safe ones for either short or long periods. Moreover, the medical care and supervision required by the men who need not be exposed could be greatly reduced, thereby freeing time control.

Supervision of all the operations in the plant from the point of view of safety is definitely needed. It is conceivable that this can be done by operating supervisors, if the latter are sufficiently interested or capable of having their interest aroused in the maintenance of safety coincident with or in spite of the requirements of production schedules. Detailed supervision of the men is necessary to prevent acts of carelessness on their part, to maintain cleanliness in housekeeping and to see that cleaning is carried out by methods that do not disseminate dust. Training in the minutiae of procedures is necessary, and education in the sources and significance of lead exposure is an absolute requirement in such supervision. Perhaps a trained safety engineer, properly fitted into the hygienic and medical organization of the plant would be required, but in any case the person or persons responsible for hygienic matters must be completely versed in all the activities ofthe plant and must be in continuous touch with any and all changes in production and with all operations which influence lead exposure in any manner.

The removal of fumes from the plant involves their distribution into the outside atmosphere. The extent to which these fumes return into the building, or settle in the immediate vicinity of the plant is of some consequence. The deposition of lead compounds on surrounding surfaces from which they may be swept into the plant by winds and other air currents may create an additional factor of exposure in the plant. The re-entry of fumes into the plant through open windows or doors, under suitable conditions of wind and weather may also be a factor. Furthermore, the lead exposure of persons who live in the vicinity of the plant merits some consideration, especially in the case of children who may swallow appreciable quantities of lead derived from dust laden surfaces with which their hands are in frequent and intimate contact. (Children sometimes lick or chew window sills and similar surfaces, and a number of cases of lead poisoning in childred have developed in this manner, chiefly, of course, from swallowing dislodged paint.) Considering the finely divided character of the fumes, it is unlikely that there is any danger of this type, but information on this point would serve to establish facts which may turn out to be very useful. If there is actual danger from this source either in the plant or in the neighborhood, adequate means of handling the problem can be provided.

It is recommended that observations be carried out regularly whereby the severityof the lead exposure can be followed. The clinical data needed to maintain an awareness of the condition of the men must be obtained. In any period in which there is reason to believe that the exposure is increasing or has been increased above the usual level, the men should be examined more frequently and more critically. If dependence is to be put on the results of the examination of blbod films for the recognition of changes in lead exposure among groups of persons, such films should be made and examined at intervals which are frequent enough to reveal the trends promptly. If they are employed to detect changes in the status of an individual workman, they should be repeated frequently whenever any significant increase occurs in a man, so as to establish the trend in his case as promptly as possible.

It would be useful to be able to check the lead excretion of persons suspected of having prodromal symptoms of lead intoxication or of persons thought to be unduly exposed in their work. It is not feasible to analyse samples of blood or urine in any laboratory which is situated within or near a plant in which lead compounds are handled, unless the lead compounds can be excluded from the laboratory quantitatively. This requires exceedingly efficient filtration of the air of the laboratory, and the exclusion of dusts carried on the person or clothing of individuals. On the whole the difficulty of accomplishing these results renders impractical the establishment of an analytical laboratory of this type in an industrial plant. Facilities for carrying out such analyses elsewhere might well be provided, and it would be especially advantageous if a group of industries were to sponsor a local laboratory so equipped and manned as to provide unquestionably accurate results. The advantages to the plant physicians in having an available source of such information would be great indeed. It is not to be supposed that such a laboratory will prevent lead poisoning if the conditions of exposure are hazardous. The only remedy for that condition is the elimination of exposure, and if the latter can be done, expenditures for analytical facilities are probably unjustified. It is possible, however, to recognize dangerous lead exposure in advance of its worst effects, and to differentiate prodromal plumbism from a variety of other illnesses. If lead hazards among workmen are unavoidable for a time for any one of several reasons which may be operative, it is highly advisable to have available the most precise means for the early diagnosis of lead poisoning.

Table 1

Distribution of Workmen According to Age

Age in Years	Number of Persons
20 - 24	4
25 - 29	2
30 - 34	
35 - 39	3
40 - 44	10
45 - 49	2
50 - 54	1
Total	22

Table 2

Distribution of Workmen

According to Duration of Continuous Exposure

Period of Exposure in Years	Number of Persons
1 - 2	10
3 - 4	
5 - 6	2
7 - 8	5
9 - 10	1
11 - 12	
13 - 14	3
15 - 16	1
Total	22

TABLE 3

DISTRIBUTION OF WORKMEN

ACCORDING TO PRESENT OCCUPATION IN PLANT

PRESENT OCCUPATION	NUMBER OF PERSONS	YEARS IN PLANT
Molders	7	1, 2, 5, 7, 14, 14, 15
"Shaking Out" laborers	2	2, 7
Handlers of Molten Metal	2	1, 6
Furnace Chargers	3	1, 2, 2
Furnace Repairman	1	8
Coremaker	1	1
Foreman	1	10
Trucker	1	1
Sand Machine Operator	1	13
Millwright (General Reapir)	1	8
Metal Washer	1	1
Outside Laborer	1	8

Table 4

Clinical Data Indicative of Lead Absorption

Among Workmen

Complaint or Physical Sign	Number of Persons with Complaint or Sign	
History of previous episodes of Plumbism	4 definite	2 questionable
History of present constipation	5	
Occasional abdominal discomfort	1	
Polyuria	1 definite	1 questionable
Lead line	6 definite	2 questionable
Tremor	8	
Pallor	6	
Extensor weakness of forearm	2	
Exaggerated reflexes	2	

Table 5

Distribution of Workmen

According to Systolic Blood Pressure

Systolic Blood Pressure in mm. Hg.	Number of Persons
110 - 119	2
120	5
130	10
140	1
150	3
160 - 169	1
Total	22

Table 6

Distribution of Workmen

According to Diastolic Pressure

Diastolic Blood Pressure in mm. Hg.	Number of Persons
60 - 69	1
70	11
80	7
90	1
100	1
110 - 119	1
Total	22

Table 7

Relationship of Blood Pressure to Age

	Systolic Blood Pressure		Diastolic Blood Pressure	
	Above 134	Below 134	Above 74	Below 74
Above 40 years of Age	5	7	7	5
Below 40 years of Age	5	5	6	4

Table 8

Distribution of Workmen

According to Leucocyte Count

Leucocytes per cu. mm.	Number of Persons
3,000 - 3,999	1
4,000	2
5,000	6
6,000	3
7,000	3
8,000	5
9,000	
10,000	
11,000 - 11,999	2
Total	22

Table 9

Distribution of Workmen

According to Erythrocyte Count

Erythrocytes in thousands per cu. mm.	Number of Persons
3,250 - 3,499	2
3,500	2
3,750	4
4,000	7
4,250	2
4,500	1
4,750	1
5,000 - 5,249	3
Total	22

Table 10

Distribution of Workmen

According to Hemoglobin of Blood

Hemoglobin Content in percent	Number of Persons
65 - 69	2
70	5
75	3
80	3
85	5
90	3
95 - 100	1
Total	22

Table 11

Distribution of Workmen

According to Stippling of Erythrocytes

Stippled Erythrocytes per 50 fields	Number of Persons				
	December	February	April	September	All
0 - 9	1	7	11	19	38
10	4	5	3		12
20	5	4	2	1	12
30	4	3	3		10

40	4	1	1		6
50	1	1			2
60	1				1
70		1			1
80 - 90	2				2
Total	22	22	20	20	84
Mean and error	36.36 $\pm$ 3.01	22.27 $\pm$2.61	15.00 $\pm$1.97	6.00 $\pm$0.66	20.36 $\pm$1.42
Standard Deviation	$\pm$20.95	$\pm$18.14	$\pm$13.04	$\pm$4.36	$\pm$19.29

Table 12

Distribution of Workmen

According to Lead in Samples of Feces

Mgs. Pb per Sample	Number of Persons			
	December	March	September	All
0 - 0.29		9	10	19
0.30	6	4	5	15
0.60	7	3	3	13
0.90	1	2		3
1.20		1		1
1.50		1		1
1.80		1		1
2.10			1	1
2.40				
2.70 - 2.99			1	1
Total	14	21	20	55
Mean and error	0.64 ±0.03	0.59 ±0.08	0.60 ±0.11	0.59 ±0.05
Standard Deviation	±0.18	±0.53	±0.71	±0.55

Table 13

Distribution of Workmen

According to Lead per Gram of Ash of Feces

Mgs. Pb per Gram of Ash	Number of Persons December	March	September	All
0 - 0.049		1		1
0.05	1	5	4	10
0.10	2	6	5	13
0.15	6	1	4	11
0.20	1	6	5	12
0.25	1		1	2
0.30		1	1	2
0.35	2	1		3
0.40	1			1
Total	14	21	20	55
Mean and error	0.22 ±0.02	0.16 ±0.01	0.17 ±0.01	0.18 ±0.01
Standard Deviation	±0.10	±0.09	±0.07	±0.09

Table 14

Distribution of Workmen

According to Lead Content of Urine

Mgs. Pb per Liter	Number of Persons			
	December	March	September	All
0 - 0.049			2	2
0.05	2	4	3	9
0.10	4	6	10	20
0.15	3	7	3	13
0.20	4	4	1	9
0.25	1	2	1	4

0.30	1	1		2
0.35	1			1
Total	16	24	20	60
Mean and error	0.191 $\pm$0.014	0.169 $\pm$0.009	0.128 $\pm$0.009	0.161 $\pm$0.007
Standard Deviation	$\pm$0.082	$\pm$0.067	$\pm$0.058	$\pm$0.081

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Table 15

The Relationship of the Urinary Lead Concentration to Blood Pressure, Hemoglobin Content of Blood, Numbers of Erythrocytes and Stippled Erythrocytes, and the Duration of Occupational Lead Exposure

Lead Concentration in Urine	Years of Exposure		Systolic Pressure		Diastolic Pressure		Hemoglobin (Percent)		Erythr (Thous	
	Above 3	Below 3	Above 134	Below 134	Above 74	Below 74	Above 80	Below 80	Above 4,500	B
Above 0.18 mg. per Liter	6	5	6	5	6	5	6	5	3	
Below 0.18 mg. per Liter	6	5	4	7	7	4	6	5	2	