# TABLE OF CONTENTS

## TITLES OF TABLES

(19) Distribution According to Certain Subjective Abnormalities of Groups of Subjects Not Exposed to Ethyl Gasoline, Examined in 1927.

(20) Distribution According to Certain Objective Abnormalities of Groups of Subjects Not Exposed to Ethyl Gasoline, Examined in 1927.

(21) Distribution According to Systolic Blood Pressure of Groups of Subjects Not Exposed to Ethyl Gasoline, Examined in 1927.

(22) Distribution According to Haemoglobin of Blood of Group of Subjects Not Exposed to Ethyl Gasoline, Examined in 1927.

(23) Distribution According to Stippling of Erythrocytes of Groups of Subjects Not Exposed to Ethyl Gasoline, Examined in 1927.

(24) Distribution According to Lead Found in Faeces of Groups of Subjects Not Exposed to Ethyl Gasoline, Examined in 1927.

(25) Distribution According to Milligrams per Gram Ash of Faeces of Groups of Subjects Not Exposed to Ethyl Gasoline, Examined in 1927.

(26) Distribution According to Milligrams of Lead per Liter of Urine of Groups of Subjects Not Exposed to Ethyl Gasoline, Examined in 1927.

(27) Summary of Mean Values of Age, Systolic Blood Pressure, Haemoglobin, and Excretion of Lead in Faeces and Urine, for Various Groups of Subjects.

(28) Mean Values of Lead in Faeces and Urine of Filling Station Attendants and Tank Wagon Handlers, Exposed to Ethyl Gasoline, Excluding All Results Obtained on Persons With Other Industrial Exposure to Lead Compounds.

(29) Showing Lack of Correlation Between Duration of Employment of Garage Mechanics and Lead Excretion, and Duration of Exposure to Ethyl Gasoline and Lead Excretion.

(30) Distribution of Identical Subjects for the years 1927 and 1929 According to Milligrams of Lead Found in Faeces.

(31) Distribution of Identical Subjects for the Years 1927 and 1929 According to Milligrams of Lead per Gram Ash in the Faeces.

(32) Distribution of Identical Subjects for the years 1927 and 1929 According to Milligrams of Lead per Liter of Urine.

(33) Summary of Mean Values of Lead Found in Samples of Faeces, of Lead in Milligrams per Gram of Ash in Faeces, and of Lead in Milligrams per Liter of Urine, for Identical Subjects Examined in 1927 and 1929.

## Preface

The experimental work which is the subject of this report was carried out by the staff of the Kettering Laboratory of Applied Physiology in the University of Cincinnati, Cincinnati, Ohio. The expense of the work was borne by the Ethyl Gasoline Corporation in accordance with an agreement between the Board of Directors of the University and the officials of the Ethyl Gasoline Corporation.

The report details the hypothetical opportunities for occupational and general lead exposure which are associated with the distribution and use of gasoline containing tetraethyl lead, and describes investigations which have been completed since the appearance of other reports from the same sources. The methods employed in the estimation of lead in human excreta are omitted, since they have been described in detail in a report dated April 1928. The statistical study of the data was made by T. J. LeBlanc, Associate Professor of Preventive Medicine in the University of Cincinnati.

Attention is directed to Appendices 1 and 2, in which some special consideration has been given to the hygienic problems which occur in the manufacture of tetraethyl lead and in the preparation of Ethyl Gasoline. Appendix 3 presents further information in relation to the distribution of Ethyl Gasoline in the United States up to the end of 1931.

# <u>An Appraisal of the Lead Hazards Associated with the Distribution and Use of Gasoline Containing Tetraethyl Lead.</u>

by

Robert A. Kehoe, M. D.*

## 1. <u>The Nature of the Lead Hazards</u>

The development of a motor fuel containing tetraethyl lead raised certain questions in industrial and public health which have claimed an unusual amount of attention. In an early stage of the new commercial enterprise it became apparent that the manufacture of tetraethyl lead and the blending of the concentrated fluid employed in the preparation of the commodity known as Ethyl Gasoline, was an hazardous occupation which furnished unique opportunities for the rapid development of lead intoxication. The serious dangers of these manufacturing processes have no relation to the problem with which we are concerned in the present discussion. However, the initial confusion of the actual hazards of manufacture with the problematical dangers arising from the use of the finished fuel, has apparently persisted in many minds. Therefore the distinction between them must be made clear.

### <u>Hazards Associated with Manufacture of Tetraethyl Lead and Ethyl Gasoline.</u>

Pure tetraethyl lead is a heavy, colorless, oily liquid which is peculiarly difficult to retain within jointed receptacles and pipe lines. It is insoluble in hot or cold water, but readily soluble in alcohol and acetone and miscible in all proportions with fats and oils. As might be suspected from the latter property it penetrates the unbroken skin of animals. Indeed skin absorption alone may result in the rapid production of acute illness and death

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in experimental animals.[1] From a purely physical point of view, the volatility of tetraethyl lead is low, but considered in toxicological terms it is dangerously high, since at ordinary temperatures air saturated with its vapor contains approximately five milligrams of lead (as Pb) per liter. This concentration is lethal for experimental animals (rabbits) in a few hours,[1] a fact which demonstrates the ease with which tetraethyl lead penetrates the pulmonary epithelium. Under certain conditions, notably in the presence of sunlight, tetraethyl lead is unstable, breaking down to yield water-soluble, crystalline triethyl lead compounds. Slight agitation serves to suspend these fine crystals in the air, when in a dry state, thereby producing a dust hazard which has the quality - unique among lead hazards - of providing sharp warning of its presence, in that a very low concentration of these substances induces irritation of the mucous membranes with weeping and sneezing.

The dangers associated with the preparation and handling of tetraethyl lead are fairly obvious, when these properties are recognized. Unfortunately, this information was not available when the manufacture of the product was first contemplated. It is not strange therefore that when the production of tetraethyl lead emerged from a laboratory scale into an incipient commercial stage requiring factory facilities, cases of lead poisoning of the most serious type occurred, characterized by the sudden onset of cerebral symptoms and resulting in a high mortality.

Without entering into an irrelevant description of the various steps by which Ethyl Gasoline is prepared for the market, suffice it to say that the hazards of the manufacturing processes are inseparably associated with the characteristics of tetraethyl lead described above. The hygienic problem at every point consists in the prevention of skin contact with tetraethyl lead on the part of the workmen, and in the maintenance of conditions under which the vapor of tetraethyl lead is not present in the air breathed by workmen. Because of the sharp localization of the dangers, they are amenable to exact and adequate control; nevertheless the potential hazards are great, so that safety is maintained only by continual vigilance in the prevention of accidents and in the avoidance of careless practices.*

Possible Hazards Associated with the Distribution and Use of Ethyl Gazoline.

The hazards associated with the handling and use of the finished product, Ethyl Gasoline, differ both in quality and quantity from those which lurk in its preparation. Nothing could demonstrate the difference in the magnitude of the potential lead exposure of the two sets of conditions in a more pragmatic manner, than the failure on the part of Ethyl Gasoline to produce a substantiated case of lead intoxication up to the present (November 1932) after nine and a half years of its continuous use in certain parts of the United States and about eight years for practically the entire United States. This basis of differentiation is the more significant when one considers that the hypothetical opportunities for the absorption of lead, as a result of the distribution of Ethyl Gasoline, are so varied and so widespread as to defy regulation. But there are other points of difference which have not required the test of experience for their recognition. Ethyl Gasoline contains tetraethyl lead in amounts so small that the solution has lost the essential toxicological properties of tetraethyl lead. Thus, whereas tetraethyl lead alone, or in high concentration in gasoline, is absorbed through the skin rapidly, its absorption is retarded greatly by dilution in gasoline. Indeed we have been unable to obtain avidence of appre-

*The results which have been obtained through attention to details in the use of special equipment, and through the inauguration and operation of suitable safety measures are described in Appendices 1 and 2 of this report.

ciable lead absorption through the skin of experimental animals after their prolonged exposure to concentrations of one part of tetraethyl lead per thousand parts of gasoline, by volume.[2] The importance of this fact is twofold. Not only does it indicate the improbability of the absorption of lead out of gasoline on the part of persons who come in contact with Ethyl Gasoline, but it also establishes the certainty that any minute amount of lead which might be absorbed would be unable to distribute itself in the fatty tissues and the nervous system in the manner characteristic of tetraethyl lead when absorbed at a rapid rate.[2] An equally important effect of the dilution of tetraethyl lead with gasoline is the elimination of the danger of inhalation of lead, to a very large extent. The difference between the volatility of tetraethyl lead and the various gasoline bases with which it is mixed, is so great that approximately half the gasoline may be evaporated before lead can be found in the vapor.* It follows, from this fact, that the vapors rising from tanks containing Ethyl Gasoline do not contain appreciable amounts of lead. However, this does not mean that no tetraethyl lead is evaporated under any of the practical conditions of handling and use or spillage of Ethyl Gasoline.

Although years of experience have not shown the existence of danger to the community in the use of Ethyl Gasoline, and although the qualities of the fuel, as described above, explain this result in a large measure, the possible lead exposure associated with the general dissemination of such a product may not be dismissed lightly. A full appreciation of the opportunities for exposure is required for an understanding of the problem which they provide for investigation.

*We have found that no accumulation of lead occurs in rabbits as the result of months of exposure for several hours daily to such vapors, in experiments in which the gasoline vapors were sufficiently concentrated to maintain the animals in a state of mild intoxication with vertigo.

Ethyl Gasoline is handled at refineries, bulk storage plants, filling stations, and in public and private garages. It is transported from one to another of these sites in tank ships, tank cars, tank trucks, barrels, and tins. In the United States and in Canada an overwhelming proportion of this motor fuel is dispensed through filling station pumps. In England a large amount of gasoline is distributed in two-gallon cans which are filled by essentially automatic machines at refineries and at storage points. Large numbers of persons come in contact with Ethyl Gasoline to a greater or lesser degree through spillage, as an unavoidable result of the various methods of distribution. They also inhale vapors from tanks, hose lines and from surfaces on which the gasoline is spilled. At refinery loading racks, at filling stations and at other points where gasoline is handled regularly, the repeated spillage of Ethyl Gasoline may bring about the accumulation of higher boiling petroleum fractions, and of small amounts of tetraethyl lead, by reason of their absorption into wooden platforms, or other surface materials such as concrete, asphalt, gravel, cinders or earth. Under these conditions some portion of the tetraethyl lead is evaporated slowly, and the remainder undergoes decomposition. In either case, opportunity for inhalation of lead on the part of persons in the vicinity may be provided, though, no doubt, most of the accumulations are dissipated by frequent hosing, or by rainfall.

The sale of the gasoline to the consumer takes it into the province of the general public where some degree of exposure to skin contact and to vapors may occur. Of much more importance, however, is the appearance of a new set of conditions based upon the combustion of the fuel. Tetraethyl lead is converted, thereby, into finely divided inorganic lead compounds (chiefly lead bromide), which are deposited, in part, along the exhaust system, but which, otherwise, are discharged into the atmosphere with the exhaust gases of the motor. The extent of the accumulation of exhaust gases from many automobiles in busy city streets, and especially in poorly ventilated areas where cars operate in considerable numbers, becomes a question of considerable importance. This aspect of the matter concerns the entire urban population, but it develops a special significance in the case of garage mechanics. Garages, in general, are poorly ventilated. Few of them, indeed, are equipped to maintain an adequate dilution of exhaust gases, under the most favorable conditions, and, when doors and windows are closed, in cold weather, ventilation is often negligible. For this reason, through the winter months, many mechanics develop late afternoon headaches from the absorption of carbon monoxide. Their exposure to lead in the exhaust gas of automobiles burning Ethyl Gasoline is greater, therefore, than that of any other group of persons in the community. Further, the handling and the spillage of gasoline, the adjustment of carburetors, and the repair of other parts of the car often involve skin contact with Ethyl Gasoline and with lubricating oil which may contain minute amounts of tetraethyl lead. The spillage and evaporation of gasoline may leave behind the less volatile tetraethyl lead to be slowly volatilized at a later time, or to decompose, and by so doing to add to the lead dust in the garage. In the dismantling of motors the combustion products of tetraethyl lead may be encountered by the mechanic, and although these cannot be absorbed through the skin, they may be a further means of contaminating his hands, his clothing and his surroundings. We must regard these factors, as well as the deposited lead of the exhaust gases, as contributors to the accumulations of lead dust within the garage although the amounts of lead involved are probably not so great as those which originate from the repair of electrical storage batteries and the use of paints and solder in the repair of automobiles. Such lead dusts, from all sources, may be picked up by air currents and mixed into the air breathed by workmen.

One further point must be considered in a complete analysis of the possibilities for general lead exposure in the use of gasoline containing lead. The deposition of lead compounds upon the highways, city streets,- in short, upon the surface of the earth - may conceivably influence the amount of lead breathed by animals and men, as well as the quantity incorporated in and deposited upon vegetation employed as food.

The Distribution and Sale of Ethyl Gasoline in the United States.

The qualitative character of the lead hazards derived from the use of Ethyl Gasoline is based upon the methods of its distribution and use. The general magnitude of these hazards is dependent upon the extent of the distribution of Ethyl Gasoline, the volume of consumption in a given area, and the period of time over which distribution and use have extended, these factors being modified to some extent by the variations in the lead concentration in gasoline, which have occurred in various sections of the country. Accordingly a complete representation of the situation requires some attention to these details.

Ethyl Gasoline was distributed first in the early months of 1923 in Dayton, Ohio. A few months later it was on sale in Cincinnati and in the district around Dayton and Cincinnati. Thence its use was extended to middle-western and southern United States, into areas represented most satisfactorily by the cities of Chicago, Detroit, St. Louis, Jacksonville, Atlanta and Savannah. The quantity of Ethyl Gasoline sold up to 1926 cannot be estimated accurately, but it was limited to this general area, and there was a steady increase in the volume of distribution during this time except for a period of almost a year beginning in May, 1925. At this time Ethyl Gasoline was withdrawn from the market pending an investigation of the United States Public Health Service, though for various reasons its use was not interrupted in certain areas in which it first appeared on the market, - viz., in the cities of Dayton, Cincinnati, Savannah, Jacksonville and Atlanta and their vicinities. The resumption of distribution in 1926 resulted in the rapid expansion of the area over which the fuel was used. This expansion continued until Ethyl Gasoline had become available in all parts of the United States. Table I demonstrates the spread in the distribution in terms of the dates at which sale began in various cities of the United States. The duration of continuous distribution for these areas is also recorded up to the time of the observations which are to be described. The approximate quantities of Ethyl Gasoline sold during the years for which figures are available are shown in Table 2. (See Appendix 3 for data on the distribution of Ethyl Gasoline since 1929.) It should be noted that the general areas into which Ethyl Gasoline was first introduced have maintained the largest proportional and gross consumption.

In the Ohio territory, where the greater part of the early investigation was carried out, the concentration of tetraethyl lead in gasoline up to 1926 was maintained at three cubic centimeters per gallon - approximately one part of tetraethyl lead in thirteen hundred parts of gasoline, by volume. In certain other areas, during this same period, as low as two cubic centimeters was used. Since that time, the lead concentration has varied in accordance with the quantity required to bring the available gasoline base up to a definite standard of performance in a test engine, except that the amount introduced has not exceeded three cubic centimeters of tetraethyl lead per gallon of gasoline. The average lead concentration by years for different regions of the country may be seen in Table 3.

A brief study of the contents of these tables is sufficient to give a clear indication of the areas in which the greatest opportunities for lead exposure have been provided. They also yield a graphic conception of the proportions of the problem which confronts us.

TABLE 1

Period of Distribution of Ethyl Gasoline in Various American Cities

Up to October 1929

| Locality | Date of First Distribution | Interval of Discontinuance | Years of Continuous Distribution |
|---|---|---|---|
| Dayton, Ohio | February 1923 | none | 6.7 |
| Cincinnati, Ohio | April 1923 | none | 6.5 |
| Wheeling, W. Va. | Summer 1923 | May 1925 to summer 1926 | 3.2 |
| Chicago, Ill. | Autumn 1923 | May 1925 to Summer 1926 | 3.2 |
| Detroit, Mich. | Autumn 1923 | May 1925 to Summer 1926 | 3.2 |
| St. Louis, Mo. | Spring 1924 | May 1925 to Summer 1926 | 3.2 |
| Kansas City, Mo. | Spring 1924 | May 1925 to Summer 1926 | 3.2 |
| Minneapolis, Minn. | Spring 1924 | May 1925 to Summer 1926 | 3.2 |
| Milwaukee, Wis. | Spring 1924 | May 1925 to Summer 1926 | 3.2 |
| Baltimore, Md. | Spring 1924 | May 1925 to Summer 1926 | 3.2 |
| Washington, D.C. | Spring 1924 | May 1925 to Summer 1926 | 3.2 |
| San Antonio, Texas | Spring 1924 | May 1925 to Summer 1926 | 3.2 |
| Savannah, Ga. | Autumn 1924 | none | 5.0 |
| Atlanta, Ga. | Autumn 1924 | none | 5.0 |
| Jacksonville, Fla. | Autumn 1924 | none | 5.0 |
| New Orleans, La. | Summer 1926 | none | 3.2 |
| Cleveland, Ohio | Summer 1926 | none | 3.2 |
| Philadelphia, Pa. | Summer 1926 | none | 3.2 |
| Boston, Mass. | Summer 1926 | none | 3.2 |
| Denver, Colo. | Summer 1926 | none | 2.2 |
| San Francisco, Cal. | Summer 1927 | none | 2.2 |
| Los Angeles, Cal. | Summer 1927 | none | 2.2 |
| Spokane, Wash. | Summer 1927 | none | 2.2 |
| Tulsa, Okla. | Summer 1927 | none | 2.2 |
| New York City | Autumn 1928 | none | 1.0 |

276.5

0.58

TABLE 2

*Approximate Gross and Comparative Consumption of Ethyl Gasoline in Various Areas of the United*
From 1926 to October of 1929

| Distribution Areas of the United States | 1926 Millions of Gallons of Ethyl Gasoline. | 1926 Percentage of Ethyl Gasoline to Total Gasoline. | 1927 Millions of Gallons of Ethyl Gasoline. | 1927 Percentage of Ethyl Gasoline to Total Gasoline. | 1928 Millions of Gallons of Ethyl Gasoline. | 1928 Percentage of Ethyl Gasoline to Total Gasoline. |
|---|---|---|---|---|---|---|
| New England States and New York | 8.0 | 0.5 | 52.0 | 3.2 | 91.0 | 4.9 |
| Pennsylvania | 5.0 | 0.9 | 30.0 | 4.4 | 75.0 | 9.9 |
| Atlantic Coast States | 7.0 | 0.7 | 6.0 | 0.6 | 18.0 | 1.4 |
| Ohio | 1.0 | 0.15 | 16.0 | 2.1 | 93.0 | 10.8 |
| Kentucky, Georgia Florida Mississippi Alabama | 3.0 | 0.36 | 18.0 | 1.9 | 39.0 | 3.7 |
| Louisiana Arkansas Tennessee | 0.5 | 0.2 | 0.5 | 0.2 | 8.0 | 2.9 |
| Central States | 25.0 | 0.8 | 110.0 | 3.3 | 172.0 | 4.9 |
| Texas, Oklahoma | 0.8 | 0.1 | 4.0 | 0.5 | 8.0 | 0.8 |
| Rocky Mt. States | 2.5 | 0.8 | 10.0 | 3.1 | 16.0 | 4.3 |
| West Coast States | 0.0 | 0.0 | 30.0 | 2.1 | 27.0 | 1.8 |
| TOTAL | 52.8 | 0.58 | 276.5 | 2.8 | 547.0 | 5.0 |

TABLE 3

Average Tetraethyl Lead Content of Ethyl Gasoline in Various Areas of the United States from 1926 to 1929

| Distribution Areas of United States | Average Tetraethyl Lead Content in Cubic Centimeters per Gal. | | | |
|---|---|---|---|---|
| | 1926 | 1927 | 1928 | 1929 |
| New England States and New York | 1.4 | 1.1 | 1.2 | 0.9 |
| Pennsylvania | 1.2 | 1.0 | 1.2 | 1.65 |
| Atlantic Coast States | 1.7 | 1.6 | 1.4 | 1.5 |
| Ohio | 0.9 | 1.2 | 1.1 | 1.5 |
| Kentucky, Georgia Florida, Mississippi and Alabama | 1.0 | 1.7 | 1.7 | 1.9 |
| Louisiana, Arkansas and Tennessee | 0.9 | 0.6 | 0.9 | 1.3 |
| Central States | 1.4 | 1.6 | 2.2 | 2.0 |
| Texas Oklahoma | 1.4 | 1.7 | 2.0 | 2.7 |
| Rocky Mountain States | 1.3 | 2.0 | 2.4 | 2.4 |
| West Coast States | - | 0.7 | 1.5 | 1.5 |
| Average for United States | 1.4* | 1.6* | 1.75 | 1.62 |

*These figures are estimates only and may be somewhat in error.

2. Previous Investigations of Ethyl Gasoline in Relation to the Public Health.

It is not to be supposed that the possibilities of danger in the general use of Ethyl Gasoline have gone unnoticed up to the present time. On the contrary, numerous experimental inquiries have been carried out. Thus the United States Bureau of Mines[3] began an investigation of lead absorption from inhalation of exhaust gas of automobiles employing Ethyl Gasoline as a fuel, in the autumn of 1923, before the new fuel had developed more than a localized distribution. The further investigations of the Bureau of Mines were extended to include other phases of the question. The United States Public Health Service[4] studied the matter in 1925, and the Ministry of Health of Great Britain[5] critically reviewed the previous experimental work and made further contributions to it in 1928. Each of the latter two governmental agencies acted under the guidance of its own committee of experts appointed especially for that purpose. Our observations, beginning in 1924, have dealt with several aspects of the problem. First in 1925, and successively in 1926 and 1927, we investigated the lead exposure of persons engaged in the handling of Ethyl Gasoline and in the repair of automobiles using Ethyl Gasoline as a fuel. These have been described in detailed reports[6] to the United States Public Health Service, and to the Ethyl Gasoline Corporation, whose officials sponsored the work.

3. Investigations Carried out in 1929-30.

A fourth field investigation is the subject of the paragraphs which are to follow. I shall not discuss the methods or the results of the earlier experimental work carried out by ourselves or others, except to point out that none of them disclosed evidence of danger either to the health of persons engaged in the handling of Ethyl Gasoline or to that of the general public. In the light of the information which they have furnished, there can be little doubt that some of the hypothetical hazards which have been described, do not exist. However, I shall disregard such considerations for present purposes and shall confine myself to the presentation of observations which were made in the autumn and winter of 1929-30, employing certain items of our earlier data only for purposes of comparison. The object of these observations was to provide an answer to one question. Is the magnitude of lead exposure arising from the combined hazards of the use of Ethyl Gasoline such as to bring about appreciable lead absorption on the part of any group of individuals in the community? Accordingly, groups of subjects have been selected for detailed study of the effects of their occupation upon their health, and upon such physiological processes as are specifically influenced by a significant increase in lead absorption.

The Selection of Experimental Subjects.

Table 4 shows the numbers and types of subjects selected, together with the locality in which they were employed. The three groups of workmen who experience all the means of lead exposure associated with the use of Ethyl Gasoline are adequately represented by fifty-six filling station attendants, fifty tank-truck handlers of such gasoline, and two hundred and one garage mechanics.

The filling station attendants were chosen with attention to several matters: men who had been employed as subjects previously, who had been handling Ethyl Gasoline for the longest period of time, who had handled gasoline containing the highest concentrations of tetraethyl lead, and who handled the largest amounts of Ethyl Gasoline daily, were especially desirable. Until May of 1925 a small metering device containing a liter can of Ethyl Fluid was used on filling station hose lines to treat gasoline with the lead mixture as required. This method of distribution brought about some degree of exposure to concentrated tetraethyl lead on the part of filling station employees. Therefore, those subjects whose employment dates back to this period have had opportunities for the absorption of lead from this source. They were particularly favorable subjects for the determination of the maximal lead exposure associated with their occupation. It has been pointed out previously that in the cities of Dayton, Cincinnati, Savannah, Jacksonville and Atlanta there had been no interruption in the distribution of Ethyl Gasoline since its introduction on the market. Furthermore the employment turnover of filling station attendants had been so slight that it was not difficult to find a satisfactory group of men who had dispensed Ethyl Gasoline since it was first marketed from their stations.

The consumption of Ethyl Gasoline had been greatest in certain central states represented by the cities of Dayton, Cincinnati, Detroit, Chicago and St. Louis. In these cities individual attendants at certain well located filling stations had handled more Ethyl Gasoline than had men similarly employed in any other part of the country.

The tank wagon handlers were selected on the basis of the severity and length of their exposure to Ethyl Gasoline. Twenty-seven of them had served as subjects for study in 1927. Thus a direct comparison of the results obtained on the two occasions was made possible.

The garage mechanic group was made up of one hundred and nine persons who had been working on cars which used only Ethyl Gasoline, and an additional ninety-three who had been repairing cars of which a high percentage used such gasoline. Effort was made to find all the mechanics in the United States who had experienced prolonged exposure in garages in which all the cars had used Ethyl Gasoline exclusively over a period of several years. Ten members of the group had been employed in a public service garage in Dayton, Ohio, in which Ethyl Gasoline had been the exclusive fuel from 1923 to the time of the present investigation. Thirty-nine subjects had had from three to six years of daily repair work on cars in which Ethyl Gasoline was the exclusive fuel. The entire group was composed of subjects who had been employed in continual repair work on fleets of cars.

From every point of view the subjects selected for examination had the maximal opportunity for exposure to lead arising from their respective occupational relationships to Ethyl Gasoline. The garage mechanic group is entitled to special consideration since it is composed of men whose occupation combines all the potential lead exposures derived from Ethyl Gasoline in an intensified form, together with certain other lead exposures which are not related to Ethyl Gasoline. It is for this reason that it was expanded to a large number at the expense of the less exposed groups.

The barrel-fillers referred to in Table 4 were included among the subjects chosen for the present investigation for a specific reason which will appear later. The data are available through a fortunate combination of circumstances. Several years of observation of persons whose occupation involved considerable exposure to gasoline had aroused our interest in the influence of repeated and prolonged gasoline absorption. Accordingly search was made for a group of subjects whose exposure to gasoline was severe and uncomplicated by other factors. In the summer of 1928 such a group was found in a refinery in which large quantities of gasoline were put into fifty gallon barrels for transportation. The barrels were filled in a specially constructed room provided with forced ventilation. Despite the magnitude of ventilation the concentration of gasoline vapor was high enough to be immediately disturbing to one who was not accustomed to such vapors. In addition, the skin, clothing

TABLE 4

Distribution of Subjects According to Occupation and Locality

| Locality | Number of Filling Station Attendants Exposed to Ethyl Gas. #1 - #56 | Number of Tank Wagon Handlers Exposed to Ethyl Gas. #101-#150 | Number of Garage Mechanics Exposed to Ethyl Gas. #301-#501 | Number of Barrel Fillers Not Exposed to Ethyl Gasoline. #201 - #227 | Number of Barrel Fillers Exposed to Ethyl Gasoline #251 - #272 |
|---|---|---|---|---|---|
| Cleveland Ohio | | | 15 | | |
| Cincinnati Ohio | 11 | 1 | 13 | | |
| Dayton Ohio | 11 | 10 | 15 | | |
| Chicago Illinois | 6 | 9 | 13 | | |
| Detroit Michigan | 1 | 11 | 12 | | |
| St. Louis Missouri | 11 | 8 | 48 | | |
| Kansas City Missouri | | 1 | 5 | | |
| Minneapolis Minnesota | | | 5 | | |
| Jacksonville Florida | 6 | 6 | 5 | | |
| Atlanta Georgia | 10 | 4 | 5 | | |
| Milwaukee Wisconsin | | | 5 | | |
| Boston Mass | | | 50 | | |
| Wheeling W. Va. | | | 10 | | |
| New York New York | | | | 27 | 22 |
| TOTAL | 56 | 50 | 201 | 27 | 22 |

and shoes of the workmen were frequently and almost continuously soaked with gasoline. The barrels were lined up in a double row along corresponding rows of pipe lines each of which was provided with an elbow, a flexible hose and a float valve. Each hose line with its valve was inserted into a drum, and the valve was opened. Gasoline flowed in at considerable pressure until the level of liquid in the drum released the valve, thus closing it. Occasionally the valve refused to work properly, at which time a stream of gasoline rose from the drum and thoroughly drenched any workmen in its immediate vicinity.

The number of men engaged in filling and handling the drums of gasoline was small but the severity of exposure was such as to give excellent opportunity for the detection of any effects which might result from gasoline absorption. These men were carefully examined in a manner which will be described later, and several types of laboratory data were obtained, including the lead content of the urine and faeces. (These latter data were obtained because of our interest in the lead excretion of groups of workmen with no occupational exposure to lead compounds.)

Shortly after these examinations had been completed the refinery in question undertook the distribution of Ethyl Gasoline. The latter was handled in the manner described above for ordinary gasoline. Inasmuch as experimental evidence indicated that the hazards of lead absorption from skin contact and inhalation of vapor from gasoline containing tetraethyl lead were practically negligible, no fears were entertained as to the consequences of the additional factor of a low concentration of tetraethyl lead. Nevertheless, this constituted a unique situation from the point of view of severity of exposure. Therefore it was considered imperative to obtain information which would show whether or not an appreciable lead absorption was occurring in the men. Accordingly, at the end of a period of six months, during which Ethyl Gasoline had been handled daily in this manner, the workmen so employed were examined, and samples of their excreta were obtained for analysis. In this second group made up of twenty-two men, there were ten who had been included in the first set of examinations.

Except in the case of the barrel-fillers, comparable groups of subjects unexposed to the potential dangers of Ethyl Gasoline, were not obtained for study. At the time of the present study of filling station employees, tank wagon handlers of Ethyl Gasoline and garage mechanics, there was no area of the United States in which the selection of entirely unexposed subjects could be made with precision. The use of leaded gasoline had increased rapidly, so as to involve all parts of the country. Furthermore the employees of a large proportion of the major gasoline distributing companies were handling Ethyl Gasoline. Therefore it was necessary to rely on information obtained prior to the general distribution of Ethyl Gasoline, for comparative data on similar groups of subjects independent of the factor of leaded gasoline. Fortunately, such data were adequate. Furthermore, repeated observations had been made on the same individuals under conditions of continuous exposure. These successive findings furnish a means for the discovery of progressive effects of any type.

Methods of Study.

Experimental studies on animals and men have established the existence of a relationship between the magnitude of lead exposure and absorption and the rate of lead excretion, in that faecal excretion is a measure of ingestion on the day preceding the collection of the sample, while the urinary excretion indicates the magnitude of lead absorption. Data which substantiate these points are presented later in this report under heading "4. Investigations Continued since 1930." Nevertheless, considering the importance of the matter at issue, we have considered it desirable to leave no stone unturned which might yield additional information. Accordingly we have searched for clinical evidences of lead absorption with the same care that we have applied to the collection of accurate analytical data. The general clinical methods were similar to those employed by J. P. Leake[4] and his associates and by ourselves in other investigations of the same question. A comprehensive neurological examination constituted the only significant addition to the previous technique.

Care was taken to obtain all the information possible from each subject, and to record such information in a uniform manner. For this reason cards for recording data were provided as reproduced below and the work was divided among four physicians each of whom carried out the same type of observations on each subject. So far as possible quantitative information was obtained in the physical examination, but without the subordination of clinical judgment to the necessities of statistical comparability. Thus while it was recognized that a statistical study of all the data was desirable and necessary, sound clinical diagnostic methods as applied to individual cases were regarded as of greater importance, in determining whether or not any evidence of lead intoxication had appeared among the subjects. As an example of this point of view, each subject was tested for evidences of atrophy or muscular weakness by palpation and by opposing the examiner's strength to that of the corresponding muscle group of the subject. But for the purposes of statistical comparison of a single neuro-muscular factor, the grip was tested by a hand dynamometer. (The same instrument was employed throughout the tests.)

Measurements of the blood pressure of each subject while seated, were made with a standard manometric apparatus.

## A. HISTORY SHEET

No. Examiner's Initials Date

Name Age Race Color Birthplace

Marital Ages Children .Miscarriages Stage

Residence

Other places lived in, with dates

Place of Employment

Type of work (exact description of nature and conditions)

Length of present employment and previous employment at same work

Previous Occupations Dates

| Previous Lead Hazards | Dates | Previous Lead Hazards | Dates |
|---|---|---|---|
| Painting | | Brass Founding | |
| Plumbing | | Soldering | |
| Carriage, Auto or Car | | Enameling | |
| Type Casting | | Paint Mfg. | |
| Smelting or Refining | | Pottery | |
| "Treating" Refineries | | Glass | |
| Storage Bat. Mfg. or Rep. | | Polishing Cut Glass | |
| Lead Burning | | White Lead | |
| Printing or Lithog. | | Rubber | |
| Mining | | Garage | |
| Foil, Solder, Babbit, Mfg. | | Telephone or Telegraph Rep. | |

Automobile Owner Gasoline Used Repair Work

Previous Illnesses with dates and exact descriptions (no leading questions)

Tbc. Malaria Rheumatism Lues. Go. Scarlet Diph. Typhoid

Tonsillitis Frequent Colds Convulsions Heart Disease Asthma

Significant Family History:

Remarks:

A. HISTORY SHEET (Cont)

No. Examiner's Initials Date

Sleep Hours in Bed Dreams Restful Disturbed

Bowel Movements Frequency Hour

Tendency to Constipation Cathartics

Tendency to Frequent Stools

Teeth Brushing When Last Trip to Dentist

Usual Weight Best Weight Recent Loss Weight (seasonal?)

General Health

Rate of Tiring Recent Change

Headaches Time

Eye Trouble (character and time of development)

Taste in Mouth Character Time

Pains in Joints Swelling of Joints

Muscular Strength Cramps in Muscles

Pains in Belly Character Frequency

Appetite Different Meals

Digestive Disturbances Nausea or Vomiting

Skin Infection or Eruption General Hands

Polyuria Nocturia Frequency

Nervousness General Weakness

Other Complaints Right or Left Handed

Loss of Strength in Arms or Legs at any time

Shooting pains

Numbness or tingling

Loss of Sensation

## B. PHYSICAL EXAMINATION SHEET

No. Examiner's Init. Date Age Height Weight

General Appearance
Nutrition
Pulse
Temperature

Posture
Musculature
Blood Pressure (seated)

Condition of Skin

Color of Skin (exact)

Condition of Skin of Hands

Cornea Sclera

Nose Throat

Glands Tonsils

Mucous Membranes Ears (structure)

Teeth Gums Pyorrhoea

Lead Line (Appearance and Location)

Heart Apex Rate
After 25 hops
2 minutes after

R.C.D. x
R.S.D.

Lungs: K.I. - R.
L.

D.E. - R.
L.

L.L.B. - R.
L.

Chest Diagnosis

Abdomen

Liver Spleen Kidneys

Rectum Genitalia

Upper Extremities Lower Extremities

Diagnosis and Remarks

## C. NEUROLOGICAL EXAMINATION

Examiner's Init.

Cranial Nerves

I Smell

II Sight R - 15/ Condition
L - 15/ Correction

III, IV, VI Extrinsic Eye Muscles

Pupils Reflexes

Visual Field

V Motor Sensory

VII Facies

VIII Audition R Equilibrium
L

IX, X, XII Speech Swallowing Tongue

XI Neck Shoulders

Upper Extremities Reflexes

| | |
|---|---|
| Tonus | Pharyngeal |
| Atrophy | Biceps |
| Ataxia | Triceps |
| Tremor | Radial |
| Muscular Power | Petellar |
| Dynamometer | Achilles |
| Stereognostic | Epigastric |
| Epicritic | Abdominal |
| Protopathic | Cremasteric |
| Kinaesthetic | Plantar |
| Thermal | |
| Vibratory | |
| Nerve Trunk Tenderness | |

Lower Extremities Gait

## D. LABORATORY SHEET

No. Examiner's Initials Date

URINALYSIS:

Quantity

Sp.G.

Reaction (Methyl Red)

Albumin (Heller's) Heat and Acetic

Sugar (Fehling's)

Acetone (Nitroprusside)

Microscopic

BLOOD: White Count Haemoglobin (Dare)

Red Count

Differential (100 cells): Poly. Neutrophiles
Poly. Eosinophiles
Poly. Basophiles
Lymphocytes
Endothelial
Large Mononuclear
Transitional

Abnormal
Polychromasia

Stippling per 50 fields

ANALYTICAL EXAMINATION:

Accurate statement of hours required for collection of:

Urine Faeces

Constipation Diarrhoea Cathartic (type)

FAECES

Wt. dish dried faeces
Wt. dish ash
Wt. dish
Wt. dried faeces
Wt. ash

lead Mgs.
Mgs./gram of ash
Analysis No.

URINE

Volume c.c.

Lead Mgs.
Mgs./liter
Analysis No.

A fresh specimen of urine was obtained from each subject and examined at once for its reaction, the presence of albumin, and sugar. Microscopic examination of the urine and a test for acetone were carried out only when indicated by chemical abnormalities or by suggestive clinical findings.

Erythrocyte, leucocyte and differential leucocyte counts were made as a routine procedure only on the barrel-filler group of subjects. Otherwise, such procedures were followed only when indicated for diagnostic purposes.

Haemoglobin determinations were made on each subject by means of the Dare haemoglobinometer. A single instrument was employed for all observations, and all readings were made by the same observer.

Blood smears were made on all subjects, and were examined for stippling of the erythrocytes by the method previously described.

Samples of urine and faeces were obtained from the subjects for the determination of their lead content. The collection of these and the analyses were carried out according to methods which we have described in an earlier report.[6] In a few instances no samples were obtainable. A further small number of samples were lost in transit and in process of analysis. With these few exceptions, the analytical results were obtained without difficulty.

## Experimental Findings.

No case of lead intoxication was found among the subjects. In fact, no combination of symptoms and physical findings was suggestive of lead intoxication. Such evidences of lead absorption as are common among lead workers were conspicuously absent. Of special negative clinical importance were the complete absence of lead line, the lack of significant microscopic blood changes (stippling), and the striking infrequency of vague symptoms of ill health. Under these circumstances any evidences of significant lead absorption as a consequence of exposure to Ethyl Gasoline must be sought in the data on the excretion of lead.

The clinical and analytical data for the groups are presented in a series of tables, in which the factors are set down in the exact manner of the statistical study except as otherwise noted.

Table 5 shows the classification of the subjects according to the duration of their exposure to Ethyl Gasoline. One-half of the filling station attendants and a little less than half of the tank wagon handlers had been exposed for five or more years, while sixty-nine percent of the garage mechanics had repaired cars which used Ethyl Gasoline over a period of three years or more.

Whether or not it has any bearing on the problem at issue, the occurrence of previous industrial lead exposure among the subjects may not be ignored. Information on this point obtained from the occupational histories is shown in Table 6. Here it may be seen that a large proportion of the subjects had been employed in trades which involved some opportunity for lead absorption, prior to their exposure to Ethyl Gasoline. None of the garage mechanics may be regarded as free from the possibility of lead exposure in their occupation, apart from the factor of Ethyl Gasoline. However, it may be assumed that few garage mechanics have more than a slight lead exposure in the course of their normal day's work, since small jobs of soldering and painting, and the occasional repair of a storage battery have not produced a noticeable occurrence of lead intoxication among garage mechanics. One tank wagon driver and eight garage mechanics had been employed at some previous time in hazardous lead trades, in which their exposure had not been severe either in quality or duration.

The distribution of the subjects according to age, seen in Table 7,

TABLE 5

Distribution of Subjects According to Period of Exposure to Ethyl Gasoline

| Period of Exposure in Years | Filling Station Attendants | | Tank Wagon Handlers | | Garage Mechanics | | Barrel Fillers Exposed to Ethyl Gasoline | |
|---|---|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % | Number | % |
| 0.1-0.25 | | | | | | | 4 | 18 |
| 0.5 | | | | | | | 18 | 82 |
| 1 | 1 | 2 | 1 | 2 | 26 | 13 | | |
| 2 | | | 4 | 8 | 36 | 18 | | |
| 3 | 6 | 11 | 4 | 8 | 98 | 49 | | |
| 4 | 16 | 28 | 19 | 38 | 22 | 11 | | |
| 5 | 23 | 41 | 16 | 32 | 12 | 6 | | |
| 6 | 10 | 18 | 6 | 12 | 7 | 3 | | |
| TOTALS | 56 | 100 | 50 | 100 | 201 | 100 | 22 | 100 |

TABLE 6

Distribution of Subjects According to History of Previous Exposure to Lead Other Than Ethyl Gasoline

| Description of Lead Exposure | Filling Station Attendants | | Tank Wagon Handlers | | Garage Mechanics | | Barrel Fillers Not Exposed to Ethyl Gasoline | | Barrel Fillers Exposed to Ethyl Gasoline | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % | Number | % | Number | % |
| None | 20 | 36 | 18 | 36 | | | 15 | 55 | 10 | 46 |
| Questionable | 8 | 14 | 10 | 20 | 30 | 15 | 8 | 30 | 6 | 27 |
| Slight | 28 | 50 | 21 | 42 | 163 | 82 | 3 | 11 | 6 | 27 |
| Moderate | | | 1 | 2 | 8 | 4 | 1 | 4 | | |
| TOTAL | 56 | 100 | 50 | 100 | 201 | 100 | 27 | 100 | 22 | 100 |

TABLE 7

Distribution of Subjects According to Age

| Age in Years | Filling Station Attendants | | Tank Wagon Handlers | | Garage Mechanics | | Barrel Fillers Not Exposed to Ethyl Gasoline | | Barrel Fillers Exposed to Ethyl Gasoline | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % | Number | % | Number | % |
| 15-19 | | | | | 9 | 4 | | | | |
| 20-24 | 3 | 5 | | | 32 | 16 | | | 1 | 5 |
| 25-29 | 12 | 21 | 15 | 30 | 33 | 17 | 6 | 23 | 2 | 9 |
| 30-34 | 12 | 21 | 7 | 14 | 34 | 17 | 5 | 19 | 6 | 27 |
| 35-39 | 5 | 9 | 10 | 20 | 42 | 21 | 5 | 19 | 2 | 9 |
| 40-44 | 2 | 4 | 5 | 10 | 26 | 13 | 6 | 23 | 7 | 31 |
| 45-49 | 5 | 9 | 5 | 10 | 11 | 5 | 1 | 4 | 2 | 9 |
| 50-54 | 4 | 7 | 3 | 6 | 8 | 4 | 1 | 4 | | |
| 55-59 | 7 | 13 | 1 | 2 | 4 | 2 | 2 | 8 | 1 | 5 |
| 60-64 | 6 | 11 | 3 | 6 | 2 | 1 | | | 1 | 5 |
| 65-69 | | | 1 | 2 | | | | | | |
| Total | 56 | 100 | 50 | 100 | 201 | 100 | 26 | 100 | 22 | 100 |

| | Filling Station Attendants | Tank Wagon Handlers | Garage Mechanics | Barrel Fillers Not Exposed to Ethyl Gasoline | Barrel Fillers Exposed to Ethyl Gasoline |
|---|---|---|---|---|---|
| Mean | 40.6 | 38.6 | 34.3 | 37.9 | 39.1 |
| Probable Error of Mean | ±1.2 | ±1.1 | ±0.5 | ±1.2 | ±1.3 |
| Standard Deviation | 13.07 | 11.28 | 9.86 | 8.76 | 9.34 |

TABLE 8

Distribution of Subjects According to Certain Subjective Abnormalities

| Type of Abnormality | 56 Filling Station Attendants | | 50 Tank Wagon Handlers | | 201 Garage Mechanics | | 27 Barrel Fillers Not Exposed to Ethyl Gasoline | | 22 Barrel Fillers Exposed to Ethyl Gasoline | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % | Number | % | Number | % |
| Recent Loss of Weight | 3 | 6 | 2 | 4 | 7 | 4 | | | | |
| Increased Tendency to Fatigue | 1 | 2 | 1 | 2 | 8 | 4 | 2 | 7 | | |
| Frequent Headache | 6 | 10 | 2 | 4 | 31 | 15 | 2 | 7 | 1 | 5 |
| Occasional Abdominal Cramp | 2 | 4 | 2 | 4 | 12 | 6 | 1 | 4 | 1 | 5 |
| Occasional Digestive Disturbance | 3 | 5 | 2 | 4 | 4 | 2 | 1 | 4 | 1 | 5 |
| Occasional Neuritic Symptoms | 3 | 5 | | | 7 | 3 | | | 1 | 5 |
| Poor General Health | | | | | 1 | 1 | | | | |

KE 0017356

TABLE 9

Distribution of Subjects According to Certain Objective Abnormalities

| Type of Abnormality | Filling Station Attendants | | Tank Wagon Handlers | | Garage Mechanics | | Barrel Fillers Not Exposed to Ethyl Gasoline | | Barrel Fillers Exposed to Ethyl Gasoline | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % | Number | % | Number | % |
| Under-Nutrition | 4 | 6 | 2 | 4 | 8 | 4 | 4 | 15 | 2 | 10 |
| Pallor | 2 | 4 | 2 | 4 | 23 | 11 | 8 | 30 | 2 | 10 |
| Irritation of Skin of Hands | 11 | 20 | 12 | 24 | 56 | 28 | 16 | 60 | 12 | 54 |
| Lead Line | | | | | | | | | | |
| Nerve Trunk Tenderness | 6 | 11 | 17 | 34 | 17 | 8 | 3 | 11 | 1 | 5 |
| Tremors | 20 | 36 | 21 | 42 | 71 | 35 | 8 | 39 | 9 | 41 |
| Sensory Disturbances | 1 | 2 | 3 | 6 | 4 | 2 | | | 2 | 10 |
| Extensor Paresis | 1 | 2 | 3 | 6 | 1 | 1 | | | | |
| Atrophy of Upper Extremities | 1 | 2 | 4 | 8 | 9 | 4 | | | 1 | 5 |
| Abnormalities of Visual Field | 2 | 4 | 1 | 2 | | | | | 2 | 10 |
| Urinary Acidity | 20 | 39 | 15 | 33 | 92 | 46 | 1 | 4 | 16 | 73 |
| Albuminuria | | | 4 | 9 | 6 | 3 | | | | |

is significant only in that it demonstrates the inclusion of widely varying age groups among the subjects under investigation.

Tables 8 and 9 represent the frequency of occurrence of certain subjective and objective abnormalities which are indicative of the presence of low grade intoxication. Among the symptoms, attention should be called to the high incidence of headache among the garage mechanics. The histories clearly suggested carbon monoxide absorption as the background of this complaint. Irritation of the skin of the hands due to frequent contact with petroleum products showed a high frequency of occurrence in all the groups. Pallor was most prominent in the garage mechanic group and in the barrel fillers not exposed to Ethyl Gasoline. The explanations of this circumstance in the latter group is undoubtedly found in the fact that this group was examined in the summer when the inhalation of gasoline vapor was at its height. These men showed a correlative diminution of haemoglobin and a high average stippling - further indications of blood changes resulting from their exposure to gasoline. Comparison of the remaining items with the results of similar observations on various groups of subjects unexposed to Ethyl Gasoline fails to yield any significant information. (Cf. Tables 19 and 20).

In Tables 10, 11, and 12, the findings as regards blood pressure, haemoglobin of the blood, and stippling of the erythrocytes are recorded. No mean values were computed for the occurrence of stippling by reason of the high proportion of negative results. It may be seen from the tables that no significance may be attached to variation in these matters in relation to Ethyl Gasoline exposure, since practically all the findings are within normal limits. In the case of the systolic blood pressure, which is used here only as a general means of pointing out the probable existence of vascular disease, the high readings are sharply correlated with age, and hence have no significance.

The low results are of no greater frequency than is common among corresponding groups of presumably normal persons. The haemoglobin determinations show only a high frequency of low results among the barrel-fillers unexposed to Ethyl Gasoline, as previously pointed out. Likewise the only point of interest in Table 12 consists in the relatively high results among these same barrel fillers. Apparently, exposure to gasoline vapors may produce blood changes, including the appearance of stippling.

Tables 13 and 14 record the observations on the strength of the grip of the left hand and right hand, respectively, of the subjects. The frequencies and the means do not show any very striking differences between the groups, excepting that the barrel fillers as a whole, gave a somewhat weaker response to the test.

The facts obtained from the analysis of the excreta of the subjects are presented in Tables 15, 16 and 17. A survey of the tabulated results shows that a few high results are scattered irregularly through the data. Where these occur in faecal samples it may be assumed that they have resulted either from contamination of the sample or from the ingestion of unusual amounts of lead with food material, and that they have no necessary or probable relationship to occupational lead exposure. Accordingly the inclusion of such findings in the computation of mean values increases appreciably the probable error of the means. Nevertheless, such results have been recorded, and have been included in the calculations unless otherwise specifically noted in the tables. Where a result has been excluded it has been for the obvious purpose of eliminating a finding which has no possible relation to the problem at issue. In the case of the urine samples, aberrant results are of rare occurrence, as would be expected. On the other hand, contamination of an occasional sample during the process of collection is apparently unavoidable, despite the most

TABLE 10

Distribution of Subjects According to Systolic Blood Pressure

| Blood Pressure Readings | Filling Station Attendants | | Tank Wagon Handlers | | Garage Mechanics | | Barrel Fillers | | Barrel Fillers | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % | Number | % | Number | % |
| 80-89 | | | | | 1 | 1 | | | | |
| 90-99 | 1 | 2 | | | 4 | 2 | | | 1 | 5 |
| 100-109 | 3 | 5 | 2 | 4 | 16 | 8 | | | | |
| 110-119 | 10 | 18 | 16 | 32 | 52 | 26 | 4 | 15 | 5 | 22 |
| 120-129 | 18 | 32 | 10 | 20 | 62 | 30 | 7 | 26 | 7 | 32 |
| 130-139 | 9 | 16 | 7 | 14 | 36 | 18 | 8 | 30 | 4 | 18 |
| 140-149 | 7 | 12 | 4 | 8 | 18 | 9 | 5 | 18 | 4 | 18 |
| 150-159 | 2 | 4 | 2 | 4 | 5 | 2 | 1 | 4 | | |
| 160-169 | | | 3 | 6 | 4 | 2 | 2 | 7 | | |
| 170-179 | 1 | 2 | | | | | | | 1 | 5 |
| 180-189 | 2 | 4 | 2 | 4 | 2 | 1 | | | | |
| No Information | 3 | 5 | 4 | 8 | 1 | 1 | | | | |
| Total | 56 | 100 | 50 | 100 | 201 | 100 | 27 | 100 | 22 | 100 |

| | Filling Station Attendants | Tank Wagon Handlers | Garage Mechanics | Barrel Fillers | Barrel Fillers |
|---|---|---|---|---|---|
| Mean | 130.1 | 130.4 | 125.7 | 134.3 | 129.1 |
| Probable Error of Mean | ±1.7 | ±1.9 | ±0.7 | ±1.8 | ±2.3 |
| Standard Deviation | 17.86 | 19.30 | 15.10 | 13.59 | 15.86 |

KE 0017360

TABLE 11

Distribution of Subjects According to Haemoglobin in Blood

| Haemoglobinometer Reading (Dare) | Filling Station Attendants | | Tank Wagon Handlers | | Garage Mechanics | | Barrel Fillers Not Exposed to Ethyl Gasoline | | Barrel Fillers Exposed to Ethyl Gasoline | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % | Number | % | Number | % |
| 60 - 67 | | | 1 | 2 | | | 9 | 33 | 1 | 5 |
| 68 - 75 | 15 | 27 | 4 | 8 | 13 | 6 | 12 | 44 | 1 | 5 |
| 76 - 83 | 21 | 37 | 12 | 24 | 77 | 39 | 4 | 15 | 8 | 35 |
| 84 - 91 | 15 | 27 | 27 | 54 | 92 | 46 | 1 | 4 | 11 | 50 |
| 92 - 99 | 5 | 9 | 5 | 10 | 15 | 7 | | | 1 | 5 |
| No Information | | | 1 | 2 | 4 | 2 | 1 | 4 | | |
| Total | 56 | 100 | 50 | 100 | 201 | 100 | 27 | 100 | 22 | 100 |

| | Filling Station Attendants | Tank Wagon Handlers | Garage Mechanics | Barrel Fillers Not Exposed to Ethyl Gasoline | Barrel Fillers Exposed to Ethyl Gasoline |
|---|---|---|---|---|---|
| Mean | 80.9* | 85.0* | 84.5* | 71.1* | 83.3* |
| Probable error of mean | ±0.67 | ±0.59 | ±0.24 | ±0.92 | ±0.91 |
| Standard deviation | 7.39 | 6.11 | 5.09 | 6.98 | 6.34 |

*All means calculated on a wider grouping of readings.

TABLE 12

Distribution of Subjects According to Stippling of Erythrocytes

| Number of Stippled Cells Per 50 Fields | Filling Station Attendants | | Tank Wagon Handlers | | Garage Mechanics | | Barrel Fillers Not Exposed to Ethyl Gasoline | | Barrel Fillers Exposed to Ethyl Gasoline | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % | Number | % | Number | % |
| 0 | 36 | 64 | 33 | 66 | 159 | 79 | 7 | 26 | 21 | 95 |
| 1 | 6 | 11 | 8 | 16 | 19 | 9 | 1 | 4 | 1 | 5 |
| 2 - 5 | 6 | 11 | 5 | 10 | 17 | 8 | 6 | 22 | | |
| 6 -10 | 3 | 5 | 2 | 4 | 5 | 3 | 3 | 11 | | |
| 11 -20 | 3 | 5 | 1 | 2 | 1 | 1 | 4 | 15 | | |
| 21 -32 | 2 | 4 | 1 | 2 | | | 6 | 22 | | |
| Total | 56 | 100 | 50 | 100 | 201 | 100 | 27 | 100 | 22 | 100 |

TABLE 13

Distribution of Subjects According to Strength of Grip of Left Hand

| Hand Dynamometer Reading | Filling Station Attendants | | Tank Wagon Handlers | | Garage Mechanics | | Barrel Fillers Not Exposed to Ethyl Gasoline | | Barrel Fillers Exposed to Ethyl Gasoline | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % | Number | % | Number | % |
| 50-59 | | | 2 | 4 | 4 | 2 | | | | |
| 60-69 | 1 | 2 | 2 | 4 | 3 | 1 | 5 | 19 | 2 | 9 |
| 70-79 | 7 | 12 | 2 | 4 | 8 | 4 | 2 | 7 | 3 | 14 |
| 80-89 | 5 | 9 | 3 | 6 | 30 | 15 | 4 | 15 | 2 | 9 |
| 90-99 | 7 | 12 | 13 | 26 | 47 | 23 | 3 | 11 | 7 | 32 |
| 100-109 | 10 | 18 | 6 | 12 | 42 | 21 | 6 | 22 | 3 | 14 |
| 110-119 | 2 | 4 | 2 | 4 | 20 | 10 | 2 | 7 | 4 | 18 |
| 120-129 | 1 | 2 | 7 | 14 | 25 | 12 | | | 1 | 4 |
| 130-139 | | | | | 5 | 3 | 1 | 4 | | |
| 140-149 | 1 | 2 | 2 | 4 | 5 | 3 | | | | |
| 150-159 | | | 1 | 2 | 1 | 1 | | | | |
| 160-169 | | | | | 2 | 1 | | | | |
| No Information | 22 | 39 | 10 | 20 | 9 | 4 | 4 | 15 | | |
| Total | 56 | 100 | 50 | 100 | 201 | 100 | 27 | 100 | 22 | 100 |
| Mean | 95.0 | | 101.5 | | 102.9 | | 91.1 | | 95.0 | |
| Probable Error of Mean | ±1.9 | | ±2.4 | | ±0.9 | | ±2.7 | | ±2.4 | |
| Standard Deviation | 16.63 | | 22.75 | | 19.37 | | 19.05 | | 16.51 | |

KE 0017363

TABLE 14

Distribution of Subjects According to Strength of Grip of Right Hand

| Hand Dynamometer Reading | Filling Station Attendants | | Tank Wagon Handlers | | Garage Mechanics | | Barrel Fillers Not Exposed to Ethyl Gasoline | | Barrel Fillers Exposed to Ethyl Gasoline | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % | Number | % | Number | % |
| 50-59 | | | | | | | 2 | 7 | | |
| 60-69 | | | | | 1 | 1 | | | 1 | 4 |
| 70-79 | | | 2 | 4 | 3 | 2 | 3 | 11 | | |
| 80-89 | 3 | 5 | 4 | 8 | 9 | 4 | 1 | 4 | 7 | 33 |
| 90-99 | 8 | 14 | 6 | 12 | 29 | 14 | 4 | 15 | 2 | 9 |
| 100-109 | 4 | 8 | 7 | 14 | 40 | 20 | 3 | 11 | 2 | 9 |
| 110-119 | 7 | 12 | 5 | 10 | 28 | 14 | 5 | 18 | 4 | 18 |
| 120-129 | 5 | 9 | 6 | 12 | 33 | 16 | 3 | 11 | 3 | 14 |
| 130-139 | 3 | 5 | 5 | 10 | 22 | 11 | 1 | 4 | 2 | 9 |
| 140-149 | 2 | 4 | 2 | 4 | 19 | 10 | 1 | 4 | 1 | 4 |
| 150-159 | 1 | 2 | 2 | 4 | 7 | 3 | | | | |
| 160-169 | | | 1 | 2 | 1 | 1 | | | | |
| No Information | 23 | 41 | 10 | 20 | 9 | 4 | 4 | 15 | | |
| Total | 56 | 100 | 50 | 100 | 201 | 100 | 27 | 100 | 22 | 100 |

| | | | | | |
|---|---|---|---|---|---|
| Mean | 112.6 | 114.0 | 116.3 | 101.9 | 105.0 |
| Probable Error of Mean | ±2.2 | ±2.4 | ±0.9 | ±3.3 | ±3.0 |
| Standard Deviation | 18.43 | 22.34 | 19.58 | 23.30 | 20.89 |

TABLE 15

Distribution of Subjects According to Lead Found in Faeces

| Milligrams of Lead Per Sample of Faeces | Filling Station Attendants | | Tank Wagon Handlers | | Garage Mechanics | | Barrel Fillers not Exposed to Ethyl Gasoline | | Barrel Fillers Exposed to Ethyl Gasoline | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % | Number | % | Number | % |
| 0 -0.079 | 6 | 11 | 1 | 2 | 5 | 3 | 2 | 7 | | |
| 0.08-0.159 | 5 | 9 | 4 | 8 | 26 | 13 | 4 | 15 | 2 | 9 |
| 0.16-0.239 | 12 | 21 | 4 | 8 | 33 | 17 | 2 | 7 | 9 | 40 |
| 0.24-0.319 | 4 | 7 | 6 | 12 | 25 | 12 | 3 | 11 | 5 | 22 |
| 0.32-0.399 | 8 | 14 | 6 | 12 | 28 | 14 | 4 | 15 | 1 | 5 |
| 0.40-0.479 | 2 | 4 | 2 | 4 | 17 | 9 | 3 | 11 | 2 | 9 |
| 0.48-0.559 | 2 | 4 | 5 | 10 | 13 | 6 | 1 | 4 | 1 | 5 |
| 0.56-0.639 | 1 | 2 | 2 | 4 | 8 | 4 | | | | |
| 0.64-0.719 | | | 1 | 2 | 7 | 3 | 3 | 11 | | |
| 0.72-0.799 | | | | | 7 | 3 | | | | |
| 0.80-0.879 | 1 | 2 | | | 3 | 2 | | | 1 | 5 |
| 0.88-0.959 | | | | | 2 | 1 | 1 | 4 | | |
| 0.96-1.039 | | | 1 | 2 | 2 | 1 | 1 | 4 | | |
| 0.04-1.119 | | | | | 6 | 3 | | | | |
| 1.12-1.199 | | | | | | | | | | |
| 1.20- + | 2* | 4 | 1* | 2 | 6* | 3 | 3* | 11 | 1* | 5 |
| No Information | 13 | 22 | 17 | 34 | 13 | 6 | | | | |
| Total | 56 | 100 | 50 | 100 | 201 | 100 | 27 | 100 | 22 | 100 |

| | | | | | |
|---|---|---|---|---|---|
| Mean | 0.258 | 0.360 | 0.379 | 0.380 | 0.288 |
| Probable Error of Mean | +0.018 | +0.023 | +0.012 | +0.037 | +0.024 |
| Standard Deviation | 0.169 | 0.197 | 0.245 | 0.266 | 0.160 |

*Omitted in calculation of means.

TABLE 16

Distribution of Subjects According to Lead in Milligrams per Gram Ash of Faeces

| Milligrams of Lead Per Gram of Ash | Filling Station Attendants | | Tank Wagon Handlers | | Garage Mechanics | | Barrel Fillers Not Exposed to Ethyl Gasoline | | Barrel Fillers Exposed to Ethyl Gasoline | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % | Number | % | Number | % |
| 0.00-0.039 | 10 | 18 | 2 | 4 | 5 | 2 | 1 | 4 | | |
| 0.04-0.079 | 14 | 24 | 16 | 32 | 51 | 25 | 9 | 33 | 7 | 32 |
| 0.08-0.119 | 9 | 16 | 4 | 8 | 54 | 27 | 7 | 26 | 8 | 36 |
| 0.02-0.159 | 4 | 8 | 3 | 6 | 36 | 18 | 3 | 11 | 2 | 9 |
| 0.16-0.199 | 2 | 4 | 3 | 6 | 18 | 9 | 2 | 7 | 3 | 14 |
| 0.20-0.239 | 1 | 2 | 1 | 2 | 8 | 4 | 1 | 4 | 2 | 9 |
| 0.24-0.279 | 1 | 2 | 1 | 2 | 4 | 2 | 1 | 4 | | |
| 0.28-0.319 | 1 | 2 | | | 4 | 2 | | | | |
| 0.32-0.359 | | | | | 1 | 1 | 1 | 4 | | |
| 0.36-0.399 | | | | | | | | | | |
| 0.40-0.439 | | | 1 | 2 | | | 2 | 7 | | |
| 0.44-0.479 | | | | | 5 | 2 | | | | |
| 0.48-0.519 | | | | | | | | | | |
| 0.56-0.599 | | | 1 | 2 | | | | | | |
| 0.64-0.679 | | | | | 3 | 1 | | | | |
| 1.00- + | 1* | 2 | 1* | 2 | 1* | 1 | | | | |
| No Information | 13 | 22 | 17 | 34 | 13 | 6 | | | | |
| Total | 56 | 100 | 50 | 100 | 201 | 100 | 27 | 100 | 22 | 100 |

| | Filling Station Attendants | Tank Wagon Handlers | Garage Mechanics | Barrel Fillers Not Exposed to Ethyl Gasoline | Barrel Fillers Exposed to Ethyl Gasoline |
|---|---|---|---|---|---|
| Mean | 0.087 | 0.120 | 0.123** 0.131 | 0.137 | 0.113 |
| Probable Error of Mean | ±0.007 | ±0.014 | ±0.004** ±0.005 | ±0.014 | ±0.007 |
| Standard Deviation | 0.065 | 0.115 | 0.074** 0.100 | 0.106 | 0.052 |

*Excluded in Calculation of Mean.

**Calculated after exclusion of three results over 0.64 milligrams.

KE 0017366

TABLE 17

Distribution of Subjects According to Milligrams of Lead Per Liter of Urine

| Milligrams of Lead Per Liter of Urine | Filling Station Attendants | | Tank Wagon Handlers | | Garage Mechanics | | Barrel Fillers Not Exposed to Ethyl Gasoline | | Barrel Fillers Exposed to Gasoline | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % | Number | % | Number | % |
| 0-0.039 | 18 | 32 | 11 | 22 | 45 | 22 | 6 | 22 | 8 | 36 |
| 0.04-0.079 | 15 | 27 | 18 | 36 | 76 | 38 | 16 | 60 | 10 | 45 |
| 0.08-0.119 | 13 | 23 | 4 | 8 | 34 | 17 | 5 | 18 | 2 | 9 |
| 0.12-0.159 | 3 | 5 | 1 | 2 | 16 | 8 | | | 1 | 5 |
| 0.16-0.199 | 3 | 5 | 1 | 2 | 5 | 2 | | | | |
| 0.20-0.239 | 1 | 2 | | | 3 | 1 | | | | |
| 0.24-0.279 | | | 1 | 2 | 3 | 1 | | | | |
| 0.28-0.319 | | | 1 | 2 | 3 | 1 | | | | |
| 0.32-0.359 | | | 1 | 2 | 1 | 1 | | | | |
| 0.36-0.399 | | | | | 1 | 1 | | | | |
| 0.40-0.439 | | | | | 1 | 1 | | | | |
| 0.44-0.479 | | | | | 1 | 1 | | | | |
| 0.48-0.519 | | | 1 | 2 | 1 | 1 | | | | |
| 0.52- + | 1** | 2 | 1** | 2 | 3** | 1 | | | | |
| No Information | 2 | 4 | 10 | 20 | 8 | 4 | | | 1 | 5 |
| Total | 56 | 100 | 50 | 100 | 201 | 100 | 27 | 100 | 22 | 100 |
| Mean | 0.071 | | 0.089 | | 0.086 | | 0.058* | | 0.052* | |
| Probable Error of Mean | ±0.005 | | ±0.011 | | ±0.004 | | ±0.009 | | ±0.004 | |
| Standard Deviation | 0.050 | | 0.099 | | 0.079 | | 0.071 | | 0.030 | |

*Mean calculated on a wider grouping of findings.

**Excluded in calculation of means.

careful instruction of the subjects. This is not remarkable when the ubiquity of lead compounds is appreciated, and when the lack of understanding of chemical cleanliness on the part of the subjects is taken into account.

The analytical results serve to classify the various groups of subjects as distinctly outside the hazardous lead trades. At first glance, the mean values for the lead content of the faeces of filling station employees, tank wagon handlers and garage mechanics seem high, as compared to those in normal persons with no occupational lead exposure. On the other hand, the small group of barrel fillers who were not exposed to Ethyl Gasoline, and who had no other occupational lead exposure at the time of the examination, show similarly high findings. Furthermore, when the faecal lead is expressed in quantitatively comparable terms, in milligrams per gram of ash, the apparently high results lose their significance. Finally, for reasons which will appear later, it is impossible to draw exact conclusions as to the magnitude of lead absorption, from the results obtained and samples of faeces. Thus it is necessary to resort to the study of the urinary excretion for such information. As judged by this standard, the groups fall into the category of persons lacking occupational exposure to lead compounds.

A special significance derives from the failure of the barrel fillers to show any increase in their lead excretion as a consequence of their exposure to Ethyl Gasoline. Not only do the two groups fail to differentiate themselves from the point of view of lead excretion, but it is equally true that no single individual in the groups can be differentiated. Of the ten persons who were examined prior to exposure to Ethyl Gasoline, and again after six months exposure to Ethyl Gasoline, no one person shows an increase in his rate of lead excretion. This can be interpreted only as meaning that there was no significant lead absorption as a consequence of this exposure. Thus, it seems

KE 0017368

quite clear, that the inability of animals to absorb measurable amounts of tetraethyl lead out of gasoline in dilute solution,[2] (1 part per thousand by volume or less) is shared by man.

Comparison of the Findings of 1929-30 with Results Obtained Earlier.

In view of the important conclusions of the above paragraphs, indicating the completely negative character of the findings, it is proper to present observations of a strictly comparable character on groups of subjects similar to those employed in the present investigation, in every matter save that of exposure to Ethyl Gasoline. Accordingly, Tables 18 to 26, inclusive show the results obtained in 1927, in the study of groups of persons who had not been exposed to the conditions associated with the use of Ethyl Gasoline. The medical student group is composed of members of a newly matriculated class. For the second group, filling station attendants and bulk handlers of ordinary gasoline are combined in order to make a large group for statistical purposes. Unfortunately, no analytical data are available in the case of the bulk handlers of gasoline, because of their unwillingness to coöperate in the collection of samples. Therefore the analytical findings relate only to filling station attendants, as indicated in the tables. The control garage mechanic group is made up of only a small number of men carefully selected in 1926 as lacking any exposure to Ethyl Gasoline. The rigid requirements in the latter regard introduced considerable difficulty into the problem of obtaining coöperative subjects.

No explanatory comments are required, since the tables present the observed facts adequately. It should be pointed out that the observations recorded in these tables were made by the same persons who collected the data on the exposed subjects previously described. The clinical methods employed in the two instances were substantially the same, while the analytical methods were practically identical.

Summary of Certain Findings in Present and Previous Investigation.

Table 27 summarizes the mean values for all the groups of exposed and unexposed persons, in such matters as would seem to have special significance. (Since the frequencies of occurrence of stippling do not lend themselves to computation of mean values, comparison of this important factor must be made from the tables of distribution.) Comparison of the means reveals a striking lack of statistical differentiation of the groups. The medical students show a significant difference in age, but in no other factor. The barrel fillers not exposed to Ethyl Gasoline show a significantly low haemoglobin content of their blood, as previously pointed out. The mean lead content per sample of faeces also shows certain statistically significant variations within the groups, but no actual importance can be attributed to these differences in view of the variability in the size of the faecal samples. When the latter factor is corrected by expressing the lead in the faeces in relation to the quantity of ash, the variability of the groups becomes statistically insignificant.

The Influence of Previous Occupational Lead Exposure.

It has been intimated previously that some significance may be attached to the fact that a considerable number of the subjects had been exposed to lead compounds in previous occupations. Likewise the handling of lead compounds other than leaded gasoline and its deposits on motor parts and elsewhere, might be expected to have some influence upon the lead absorption of the garage mechanic. As a means of ascertaining the importance of these matters, the analytical results derived from two small groups of persons whose occupational histories failed to give evidence of previous lead exposure, were subjected to a study. Table 6 has shown the distribution of the subjects as to previous occupational lead exposure. Table 28 presents the mean values for the lead excretion of these subjects as separate groups and in combination. The results are seen to be slightly lower, but no significant statistical differences have resulted from the exclusion of the previously exposed subjects. Considering the rate at which large quantities of lead have been shown to be eliminated from the body, the effects of previous slight or moderate exposure to lead, would not be expected to manifest themselves in an increased excretion after the lapse of years. Nevertheless it is of some interest and importance to establish the facts in the matter.

Lead Excretion in Relation to Length of Exposure to Ethyl Gasoline.

It would appear that an examination into the relationship between length of service and lead excretion, might provide a means of ascertaining the significance of the lead exposure associated with the occupation of the garage mechanics. This was done first by studying the correlation between the period of continuous employment as mechanics and lead excretion, and then by a corresponding study of the length of exposure in repairing cars which used Ethyl Gasoline, as against lead excretion. The results of these attempted correlations are shown in Table 29. There is a complete lack of correlation in either matter. From these results one must conclude either that the lead exposure associated with the occupation is insignificant, or that it is of such irregular occurrence as to have no measurable time relationship.

There remains one other means of examining the available data in search of evidences of lead absorption from the handling of Ethyl Gasoline.

TABLE 18

Distribution According to Age of Groups of Subjects Not Exposed To Ethyl Gasoline, Examined in 1927

| Age In Years | Medical Students | | Filling Station Attendants and Tank Wagon Handlers | | Garage Mechanics | |
|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % |
| 15-19 | 11 | 15 | 1 | 1 | 2 | 6 |
| 20-24 | 51 | 72 | 18 | 16 | 2 | 6 |
| 25-29 | 9 | 13 | 23 | 20 | 12 | 34 |
| 30-34 | | | 16 | 14 | 12 | 34 |
| 35-39 | | | 11 | 10 | 2 | 6 |
| 40-44 | | | 13 | 11 | 4 | 11 |
| 45-49 | | | 10 | 9 | 1 | 3 |
| 50-54 | | | 10 | 9 | | |
| 55-59 | | | 5 | 4 | | |
| 60-64 | | | 4 | 4 | | |
| 65-69 | | | 3 | 3 | | |
| 70-74 | | | | | | |
| Total | 71 | 100 | 114 | 100 | 35 | 100 |

| | | | |
|---|---|---|---|
| Mean | 22.3 | 37.5 | 31.2 |
| Probable Error of Mean | ±0.2 | ±0.8 | ±0.8 |
| Standard Deviation | 2.3 | 12.54 | 6.69 |

TABLE 19

Distribution According to Certain Subjective Abnormalities of Groups of Subjects Not Exposed to Ethyl Gasoline - Examined in 1927.

| Type of Abnormality | 71 Medical Students | | 69 Filling Station Attendants | | 42 Tank Wagon Handlers | | 35 Garage Mechanics | |
|---|---|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % | Number | % |
| Recent Loss of Weight | 7 | 10 | 1 | 1 | 2 | 5 | 5 | 14 |
| Increased Tendency to Fatigue | 9 | 13 | 12 | 17 | 5 | 12 | 5 | 14 |
| Occasional Headache | 15 | 21 | 17 | 25 | 7 | 17 | 18 | 51 |
| Occasional Abdominal Cramp | 1 | 1 | 2 | 3 | | | | |
| Occasional Digestive Disturbance | 1 | 1 | 8 | 12 | 10 | 24 | 4 | 12 |
| Occasional Neuritic Symptoms | | | 5 | 7 | 2 | 5 | | |
| Poor General Health | 2 | 3 | 3 | 4 | 0 | 0 | 1 | 3 |

TABLE 20

Distribution According to Certain Objective Abnormalities of Groups of Subjects Not Exposed to Ethyl Gasoline - Examined in 1927

| Type of Abnormality | 71 Medical Students | | 69 Filling Station Attendants | | 42 Tank Wagon Handlers | | 35 Garage Mechanics | |
|---|---|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % | Number | % |
| Under-nutrition | 7 | 10 | 13 | 19 | | | | |
| Pallor | 1 | 1 | 3 | 4 | | | | |
| Irritation of Skin of Hands | | | 2 | 3 | | | 4 | 11 |
| Lead Line | | | | | 4 | 10 | 3 | 9 |
| Tremors | 2 | 3 | 9 | 13 | | | | |
| Sensory Disturbances | 3 | 4 | 9 | 13 | 2 | 5 | 1 | 3 |
| Urinary Acidity | 7 | 10 | 3 | 4 | 16 | 38 | 8 | 23 |
| Albuminuria | 1 | 1 | 3 | 4 | 3 | 7 | 3 | 9 |

TABLE 21

Distribution According to Systolic Blood Pressure of Groups of Subjects Not Exposed to Ethyl Gasoline, Examined in 1927

| Blood Pressure Readings | Medical Students | | Filling Station Attendants and Tank Wagon Handlers | | Garage Mechanics | |
|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % |
| 100-109 | 1 | 1 | 2 | 2 | | |
| 110-119 | 22 | 31 | 15 | 13 | 6 | 17 |
| 120-129 | 23 | 33 | 32 | 28 | 14 | 40 |
| 130-139 | 17 | 24 | 29 | 25 | 7 | 20 |
| 140-149 | 7 | 10 | 15 | 13 | 5 | 14 |
| 150-159 | 1 | 1 | 9 | 7 | 3 | 9 |
| 160-169 | | | 2 | 2 | | |
| 170-179 | | | 1 | 1 | | |
| 180-189 | | | 1 | 1 | | |
| 190-199 | | | 3 | 3 | | |
| 200-209 | | | 3 | 3 | | |
| 210-219 | | | 1 | 1 | | |
| 220-229 | | | | | | |
| 230-239 | | | 1 | 1 | | |
| Total | 71 | 100 | 114 | 100 | 35 | 100 |

| | Medical Students | Filling Station Attendants and Tank Wagon Handlers | Garage Mechanics |
|---|---|---|---|
| Mean | 125.9 | 138.2 | 129.8 |
| Probable Error of Mean | ±0.8 | ±1.5 | ±1.3 |
| Standard Deviation | 10.20 | 23.45 | 10.98 |

TABLE 22

Distribution According to Haemoglobin of Blood of Groups of Subjects
Not Exposed to Ethyl Gasoline, Examined in 1927

| Haemoglobinometer Reading (Dare) | Medical Students | | Filling Station Attendants and Tank Wagon Handlers | | Garage Mechanics | |
|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % |
| 60-64 | 1 | 1 | | | | |
| 65-69 | 1 | 1 | 1 | 1 | | |
| 70-74 | | | 9 | 8 | 1 | 3 |
| 75-79 | 3 | 4 | 12 | 11 | 2 | 6 |
| 80-84 | 10 | 15 | 17 | 16 | 6 | 18 |
| 85-89 | 21 | 30 | 43 | 40 | 12 | 35 |
| 90-94 | 17 | 25 | 15 | 14 | 10 | 29 |
| 95-99 | 11 | 16 | 9 | 8 | 3 | 9 |
| 100-104 | 5 | 7 | 2 | 2 | | |
| 105-109 | 1 | 1 | | | | |
| Total | 70 | 100 | 108 | 100 | 34 | 100 |

| | Medical Students | Filling Station Attendants and Tank Wagon Handlers | Garage Mechanics |
|---|---|---|---|
| Mean | 89.8 | 86.0 | 88.0 |
| Probable Error of Mean | ±0.6 | ±0.5 | ±0.7 |
| Standard Deviation | 7.78 | 7.15 | 5.73 |

TABLE 23

Distribution According to Stippling of Erythrocytes of Groups of Subjects Not Exposed to Ethyl Gasoline, Examined in 1927.

| Number of Stippled Cells Per 50 Fields | Medical Students | | Filling Station Attendants and Tank Wagon Handlers | | Garage Mechanics | |
|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % |
| 0 | 58 | 82 | 72 | 63 | 22 | 63 |
| 1 | 5 | 7 | 20 | 18 | 6 | 17 |
| 2-5 | 7 | 10 | 14 | 12 | 6 | 17 |
| 6-10 | 1 | 1 | 7 | 6 | 1 | 3 |
| 11-20 | | | | | | |
| 21-32 | | | 1 | 1 | | |
| Total | 71 | 100 | 114 | 100 | 35 | 100 |

TABLE 24

Distribution According to Lead Found in Faeces of Groups of Subjects Not Exposed to Ethyl Gasoline, Examined in 1927

| Milligrams of Lead Per Sample of Faeces | Medical Students | | Filling Station Attendants | | Garage Mechanics | |
|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % |
| 0 - 0.079 | 17 | 25 | 14 | 20 | 5 | 19 |
| 0.08 - 0.159 | 15 | 22 | 14 | 20 | 7 | 27 |
| 0.16 - 0.239 | 19 | 27 | 18 | 25 | 2 | 8 |
| 0.24 - 0.319 | 6 | 9 | 7 | 10 | 2 | 8 |
| 0.32 - 0.399 | 3 | 5 | 7 | 10 | 3 | 11 |
| 0.40 - 0.479 | 2 | 3 | 6 | 8 | 2 | 8 |
| 0.48 - 0.559 | 2 | 3 | 1 | 1 | 1 | 4 |
| 0.56 - 0.639 | 1 | 1 | | | | |
| 0.64 - 0.719 | 1 | 1 | 1 | 1 | | |
| 0.72 - 0.799 | | | | | | |
| 0.80 - 0.879 | 1 | 1 | 1 | 1 | | |
| 0.88 - 0.959 | 1 | 1 | | | 1 | 4 |
| 0.96 - 1.039 | | | | | | |
| 1.04 - 1.119 | 1 | 1 | | | | |
| 1.12 - 1.199 | 1 | 1 | | | | |
| 1.20 - | | | 3* | 4 | 3* | 11 |
| Total | 70 | 100 | 72 | 100 | 26 | 100 |

| | Medical Students | Filling Station Attendants | Garage Mechanics |
|---|---|---|---|
| Mean | 0.232 | 0.197 | 0.235 |
| Probable Error of Mean | -0.019 | -0.013 | -0.029 |
| Standard Deviation | -0.0236 | -0.159 | -0.205 |

*Excluded in calculation of means.

TABLE 25

Distribution According to Milligrams of Lead Per Gram Ash of Faeces of Groups of Subjects Not Exposed to Ethyl Gasoline, Examined in 1927

| Milligrams of Lead Per Gram of Ash | Medical Students | | Filling Station Attendants | | Garage Mechanics | |
|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % |
| 0 - 0.049 | 29 | 48 | 29 | 41 | 12 | 46 |
| 0.05 - 0.099 | 16 | 27 | 26 | 31 | 6 | 23 |
| 0.10 - 0.149 | 9 | 15 | 8 | 11 | 1 | 4 - |
| 0.15 - 0.199 | 3 | 5 | 4 | 6 | 2 | 8 |
| 0.20 - 0.249 | 1 | 2 - | | | 1 | 4 - |
| 0.25 - 0.299 | | | 1 | 1 | 1 | 4 - |
| 0.30 - 0.349 | | | 1 | 1 | 1 | 4 - |
| 0.35 - 0.399 | | | | | | |
| 0.40 - 0.449 | 1 | 2 - | 1 | 1 | | |
| 0.55 - 0.599 | 1 | 2 - | | | | |
| 0.65 - 0.699 | | | | | 2 | 8 |
| 1.50 - + | | | 2** | 2 | | |
| Total | 60 | 100 | 71 | 100 | 26 | 100 |

| | Medical Students | Filling Station Attendants | Garage Mechanics |
|---|---|---|---|
| Mean | 0.079* | 0.077** | 0.085⊕<br>0.131 |
| Probable Error of Mean | ±0.008 | ±0.006 | ±0.012⊕<br>±0.023 |
| Standard Deviation | 0.094 | 0.071 | 0.085⊕<br>0.177 |

*Mean Calculated on a wider grouping of Findings.
**Excluded in Calculation of Mean.
⊕Calculated after exclusion of two results over 0.65 milligrams.

TABLE 26

Distribution According to Milligrams of Lead Per Liter of Urine of Groups of Subjects Not Exposed to Ethyl Gasoline, Examined in 1927

| Milligrams of Lead Per Liter of Urine | Medical Students | | Filling Station Attendants | | Garage Mechanics | |
|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % |
| 0 - 0.029 | 11 | 17 | 11 | 15 | 8 | 31 |
| 0.03 - 0.059 | 22 | 34 | 20 | 28 | 4 | 15 |
| 0.06 - 0.089 | 16 | 25 | 17 | 24 | 5 | 19 |
| 0.09 - 0.119 | 10 | 15 | 6 | 8 | 2 | 8 |
| 0.12 - 0.149 | 1 | 1 + | 4 | 6 | 5 | 19 |
| 0.15 - 0.179 | 1 | 1 + | 3 | 4 | | |
| 0.18 - 0.209 | 1 | 1 + | 5 | 7 | | |
| 0.21 - 0.239 | 1 | 1 + | | | | |
| 0.24 - 0.269 | | | | | 1 | 4 |
| 0.27 - 0.299 | 1 | 1 + | | | | |
| 0.45 - 0.479 | | | 1 | 1 + | | |
| 0.54 - 0.569 | | | 1* | 1 + | | |
| 0.66 - 0.689 | 1* | 1+ | 1* | 1+ | | |
| 1.00 - + | | | 3* | 4 | 1* | 4 |
| Total | 65 | 100 | 72 | 100 | 26 | 100 |

| | Medical Students | Filling Station Attendants | Garage Mechanics |
|---|---|---|---|
| Mean | 0.078 | 0.081 | 0.077 |
| Probable Error of Mean | ±0.007 | ±0.006 | ±0.008 |
| Standard Deviation | 0.089 | 0.069 | 0.059 |

*Excluded in calculation of means.

KE 0017880

Among the subjects studied in 1929, there were twenty-six filling station attendants, and twenty-four tank wagon handlers who had been employed as subjects in 1927. Presumably, if their occupation contains a significant lead hazard they should show some evidence of change in lead excretion after two years. The findings for the two years, as regards lead excretion, are shown in Tables 30, 31, and 32. The mean values are summarized in Table 33. It may be seen that no statistically valid difference is demonstrable.

### 4. Investigations Continued Since 1930.

Reference has been made to the fact that the faecal output of lead is determined largely by the rate of lead ingestion. Previous observations[6] have shown that under conditions which permit the inhalation of finely divided lead compounds, in the dusty lead trades, the quantity of lead in faecal samples is indicative of the magnitude of the lead exposure. It must not be supposed that such alimentary lead is due to lead absorption and a resultant lead excretion. On the contrary, it is chiefly the result of swallowing lead with the secretions from the upper respiratory tract. It is clear, therefore, that in the lead trades, the lead content of the faeces fails to yield information as to lead absorption. This is equally true in the case of persons outside the lead trades. Here also, the faecal excretion is a measure of the ingestion of lead with food materials. The greater proportion of such ingested lead passes through the alimentary tract unabsorbed.

It is not within the scope of this report to present the experimental evidence which has established these facts. Nevertheless, one series of observations which illustrate the facts may be described on account of its direct relation to the main problem of this report.

*Summary of Mean Values of Age*, Systolic Blood Pressure, Haemoglobin, and Excretion of Lead In Faeces and Urine, For Various Groups of Subjects.

| Description of Subjects | Age in Years | Systolic Blood Pressure (Sitting) | Haemoglobin Readings | Lead in Mgs. In Single Sample of Faeces | Lead in Mgs. Per Gram Ash In Faeces | Lead in Mgs. Per Liter of Urine | Number of Subjects |
|---|---|---|---|---|---|---|---|
| Medical Students Not Exposed to Ethyl Gasoline Examined in 1927 | 22.3 ±0.2 | 125.9 ±0.8 | 89.8 ±0.6 | 0.232 ±0.019 | 0.079 ±0.008 | 0.078 ±0.007 | 71 |
| Filling Station and Tank Wagon Handlers Not Exposed to Ethyl Gasoline-Examined in 1927 | 37.5 ±0.8 | 133.2 ±1.5 | 86.0 ±0.5 | 0.197 0.013 | 0.077 ±0.006 | 0.081 ±0.006 | 114 |
| Filling Station Attendants Exposed to Ethyl Gasoline Examined in 1929 | 40.8 ±1.2 | 130.1 1.7 | 80.9 0.67 | 0.258 ±0.018 | 0.087 0.007 | 0.071 ±0.005 | 56 |
| Tank Wagon Handlers Exposed to Ethyl Gasoline, Examined in 1929. | 38.6 ±1.1 | 130.4 ±1.9 | 85.0 ±0.59 | 0.360 ±0.023 | 0.120 ±0.014 | 0.089 ±0.011 | 50 |
| Garage Mechanics Not Exposed to Ethyl Gasoline Examined in 1927 | 31.12 ±0.8 | 129.8 ±1.3 | 88.0 ±0.7 | 0.235 ±0.029 | 0.131 ±0.023 | 0.077 ±0.008 | 35 |
| Garage Mechanics Exposed to Ethyl Gasoline, Examined in 1929 | 34.3 ±0.5 | 125.7 ±0.7 | 84.5 ±0.24 | 0.379 ±0.012 | 0.131 ±0.005 | 0.086 ±0.004 | 201 |
| Barrel Fillers Not Exposed to Ethyl Gasoline | 37.9 ±1.2 | 134.3 ±1.8 | 71.1 ±0.92 | 0.380 ±0.037 | 0.137 ±0.014 | 0.058 ±0.009 | 27 |
| Barrel Fillers Exposed to Ethyl Gasoline | 39.1 ±1.3 | 129.1 ±2.3 | 83.3 ±0.91 | 0.288 ±0.024 | 0.113 ±0.007 | 0.052 ±0.004 | 22 |

TABLE 28

Mean Values of Lead in Faeces and Urine of Filling Station Attendants and Tank Wagon Handlers, Exposed to Ethyl Gasoline, Excluding All Results Obtained on Persons With Other Industrial Exposure to Lead Compounds.

| | Filling Station Attendants Exposed to Ethyl Gasoline | Tank Wagon Handlers Exposed to Ethyl Gasoline | Combined Filling Station Attendants and Tank Wagon Handlers |
|---|---|---|---|
| Lead in Milligrams in Single Sample of Faeces | 0.338 ± 0.043 | 0.277 ± 0.035 | 0.336 ± 0.030 |
| Lead in Milligrams Per Gram Ash in Faeces | 0.069 ± 0.009 | 0.116 ± 0.024 | 0.086 ± 0.011 |
| Lead in Milligrams Per Liter of Urine | 0.063 ± 0.009 | 0.063 ± 0.010 | 0.065 ± 0.007 |
| Number of Subjects | 19 | 15 | 34 |

TABLE 29

Showing Lack of Correlation Between Duration of Employment of Garage Mechanics and Lead Excretion, and Duration of Exposure to Ethyl Gasoline and Lead Excretion.

| Factors Correlated | Correlation Coefficients |
|---|---|
| Length of Continuous Service as Garage Mechanic with Lead in Faeces in Milligrams per Gram of Ash. | +0.017 ± 0.056 |
| Length of Continuous Service as Garage Mechanic with Lead in Urine in Milligrams per Liter | +0.023 ± 0.055 |
| Length of Exposure to Ethyl Gasoline as Garage Mechanic With Lead in Faeces in Milligrams per Gram of Ash | +0.223 ± 0.099 |
| Length of Exposure to Ethyl Gasoline as Garage Mechanic With Lead in Urine in Milligrams per Liter | +0.243 ± 0.099 |

TABLE 30

Distribution of Identical Subjects For the Years 1927 and 1929
According to Milligrams of Lead Found in Faeces.

| Milligrams of Lead Per Sample of Faeces | Filling Station Attendants Exposed to Ethyl Gasoline | | | | Tank Wagon Handlers Exposed to Ethyl Gasoline | | | |
|---|---|---|---|---|---|---|---|---|
| | 1927 | | 1929 | | 1927 | | 1929 | |
| | Number | % | Number | % | Number | % | Number | % |
| 0 - 0.079 | 1 | 5 | 3 | 15 | | | 2 | 12 |
| 0.08 - 0.159 | 6 | 30 | 3 | 15 | 3 | 17+ | 2 | 12 |
| 0.16 - 0.239 | 2 | 10 | 8 | 40 | 4 | 23+ | 3 | 17+ |
| 0.24 - 0.319 | 3 | 15 | | | 3 | 17+ | 3 | 17+ |
| 0.32 - 0.399 | 2 | 10 | 3 | 15 | 2 | 12 | 1 | 6 |
| 0.40 - 0.479 | 1 | 5 | 1 | 5 | 3 | 17+ | 3 | 17+ |
| 0.48 - 0.559 | | | 1 | 5 | | | 1 | 6 |
| 0.56 - 0.639 | 2 | 10 | 1 | 5 | 2 | 12 | 1 | 6 |
| 0.64 - 0.719 | 1 | 5 | | | | | | |
| 0.72 - 0.799 | | | | | | | | |
| 0.80 - 0.879 | | | | | | | | |
| 0.88 - 0.959 | | | | | | | | |
| 0.96 - 1.039 | | | | | | | 1** | 6 |
| 1.83 | 1* | 5 | | | | | | |
| 5.10 | 1* | 5 | | | | | | |
| Total | 20 | 100 | 20 | 100 | 17 | 100 | 17 | 100 |

| | Filling Station 1927 | Filling Station 1929 | Tank Wagon 1927 | Tank Wagon 1929 |
|---|---|---|---|---|
| Mean | 0.280 | 0.236 | 0.308 | 0.402** |
| Probable Error of Mean | ±0.030 | ±0.023 | ±0.025 | ±0.036 |
| Standard Deviation | 0.187 | 0.153 | 0.150 | 0.218 |

*Excluded in calculation of mean.

**With exclusion of single high result, the mean becomes 0.365 ± 0.028

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TABLE 31

Distribution of Identical Subjects for the Years 1927 and 1929 According to Milligrams of Lead Per Gram Ash in the Faeces

| Milligrams of Lead Per Gram of Ash | Filling Station Attendants Exposed to Ethyl Gasoline | | | | Tank Wagon Handlers Exposed to Ethyl Gasoline | | | |
|---|---|---|---|---|---|---|---|---|
| | 1927 | | 1929 | | 1927 | | 1929 | |
| | Number | % | Number | % | Number | % | Number | % |
| 0 - 0.039 | 2 | 10 | 1 | 5 | 1 | 6 | 7 | 41 |
| 0.04 - 0.079 | 5 | 25 | 7 | 35 | 4 | 23+ | 2 | 12 |
| 0.08 - 0.119 | 5 | 25 | 6 | 30 | 5 | 30 | 3 | 17 |
| 0.12 - 0.159 | 3 | 15 | 3 | 15 | 4 | 23+ | 2 | 12 |
| 0.16 - 0.199 | 1 | 5 | 1 | 5 | 3 | 17 | 1 | 6 |
| 0.20 - 0.239 | | | 1 | 5 | | | 1 | 6 |
| 0.24 - 0.279 | 1 | 5 | 1 | 5 | | | | |
| 0.28 - 0.319 | | | | | | | | |
| 0.32 - 0.359 | | | | | | | | |
| 0.36 - 0.399 | | | | | | | | |
| 0.40 - 0.439 | 1 | 5 | | | | | | |
| 0.44 - 0.479 | | | | | | | | |
| 0.57 | | | | | | | 1** | 6 |
| 0.64 | 1* | 5 | | | | | | |
| 1.36 | 1* | 5 | | | | | | |
| Total | 20 | 100 | 20 | 100 | 17 | 100 | 17 | 100 |

| | | | | |
|---|---|---|---|---|
| Mean | 0.118 | 0.106 | 0.109 | 0.142** |
| Probable Error of Mean | ±0.015 | ±0.009 | ±0.008 | ±0.019 |
| Standard Deviation | 0.093 | 0.058 | 0.047 | 0.117 |

*Excluded in calculation of mean.

**With exclusion of single high result the mean becomes 0.118 - 0.010

TABLE 32

Distribution of Identical Subjects for the Years 1927 and 1929
According to Milligrams of Lead Per Liter of Urine

| Milligrams of Lead Per Liter of Urine | Filling Station Attendants Exposed to Ethyl Gasoline | | | | Tank Wagon Handlers Exposed to Ethyl Gasoline | | | |
|---|---|---|---|---|---|---|---|---|
| | 1927 | | 1929 | | 1927 | | 1929 | |
| | Number | % | Number | % | Number | % | Number | % |
| 0 - 0.039 | 3 | 11 | 7 | 27- | | | 6 | 25 |
| 0.04 - 0.079 | 9 | 35 | 7 | 27- | 10 | 42 | 11 | 46 |
| 0.08 - 0.119 | 6 | 23 | 9 | 35 | 5 | 21 | 2 | 8+ |
| 0.12 - 0.159 | 3 | 11 | 0 | 0 | 3 | 11+ | 1 | 4+ |
| 0.16 - 0.199 | 1 | 4 | 1 | 4 | 1 | 4+ | 1 | 4+ |
| 0.20 - 0.239 | 2 | 8 | 1 | 4 | | | | |
| 0.24 - 0.279 | | | | | | | 1 | 4+ |
| 0.28 - 0.319 | | | | | | | | |
| 0.32 - 0.359 | | | | | 1 | 4+ | 1 | 4+ |
| 0.36 - 0.399 | | | | | 1 | 4+ | | |
| 0.40 - 0.439 | | | | | 1 | 4+ | | |
| 0.58 | 1 | 4 | | | | | | |
| 0.87 | 1 | 4 | | | | | 1 | 4+ |
| 1.00 | | | 1 | 4 | | | | |
| 4.00 -+ | | | | | 2* | 8+ | | |
| Total | 26 | 100 | 26 | 100 | 24 | 100 | 24 | 100 |

| | Filling Station 1927 | Filling Station 1929 | Tank Wagon 1927 | Tank Wagon 1929 |
|---|---|---|---|---|
| Mean | 0.142 | 0.111 | 0.129 | 0.115** |
| Probable Error of Mean | ±0.024 | ±0.025 | ±0.015 | ±0.024 |
| Standard Deviation | 0.180 | 0.188 | 0.106 | 0.173 |

*Excluded in calculation of mean
**Mean drops to 0.083 - 0.11 when one result of 0.87 milligrams is excluded.

KE 0017887

TABLE 33

Summary of Mean Values of Lead Found in Samples of Faeces, of Lead In Milligrams per Gram of Ash in Faeces, and of Lead in Milligrams Per Liter of Urine for Identical Subjects Examined in 1927 and 1929.

| | Filling Station Attendants Exposed to Ethyl Gasoline | | Tank Wagon Handlers Exposed to Ethyl Gasoline | | Combined Filling Station Attendants and Tank Wagon Handlers | |
|---|---|---|---|---|---|---|
| | 1927 | 1929 | 1927 | 1929 | 1927 | 1929 |
| Lead in Milligrams in Single Sample of Faeces | 0.280 ±0.030 | 0.236 ±0.023 | 0.308 ±0.025 | 0.402 ±0.036 | 0.294 ±0.019 | 0.312 ±0.022 |
| Lead in Milligrams Per Gram Ash in Faeces | 0.118 ±0.015 | 0.106 ±0.009 | 0.109 ±0.008 | 0.142 ±0.019 | 0.114 ±0.008 | 0.124 ±0.011 |
| Lead in Milligrams per Liter of Urine | 0.142 ±0.024 | 0.111 ±0.025 | 0.129 ±0.015 | 0.115 ±0.024 | 0.136 ±0.015 | 0.113 ±0.017 |
| Number of Subjects | 26 | 26 | 24 | 24 | 50 | 50 |

Lead Exposure in the Handling of Ethyl Gasoline.

Early in 1931 we made use of a new method of approach to the problem of lead absorption from exposure to Ethyl Gasoline. Having recognized the factor of lead ingestion with food, it became impossible to ignore it in further experimentation. Accordingly, through suitable arrangement with a gasoline distributing company, we were able to obtain two healthy young men for observation, with the understanding that they would be employed as filling station attendants at the conclusion of certain preliminary studies. The two subjects had had no previous experience in the handling of gasoline, nor had they engaged in the repair of automobiles. They had had no occupational exposure to lead compounds. In fact, they had but recently finished school and were seeking steady employment for the first time. Physical examination showed them to be in good health. They were intelligent and cooperative.

For four months these subjects were kept under observation at the laboratory. During this period a duplicate sample of every article of food and drink consumed was provided by each subject. Such items were combined into twenty-four hour composite samples, and were stored in chemically clean containers until they could be analyzed. Each subject also collected twenty-four hour samples of his faeces and forty-eight hour and seventy-two hour samples of his urine. (The number of samples of each week were divided into two forty-eight hour samples and one seventy-two hour sample.) At the end of the four month period, the men were employed at filling stations, where they engaged in the usual routine of their occupation. The stations at which they were employed were large, and were so situated as to serve a large clientele. Each man was employed at three different stations, at each of which the sale of Ethyl Gasoline constituted not less than thirty-five percent of the total gasoline business. Every effort was made to see that a representative Ethyl Gasoline exposure was provided. No unusual precautions were taken against skin contact with gasoline, greases, or discarded crank-case oil. As a means of avoiding contamination of the samples for analysis, the men were advised to wash their hands before handling the containers. Such samples were collected in the manner previously described. The observations were continued for another four months period.

The results of these observations are shown in Tables 34 to 39 inclusive. The analyses of the faecal samples of one subject, and of the food samples of both, for the period of exposure have not been completed at present but the available results are sufficient for present purposes.

If attention is directed first to the data of the control period it may be seen that the mean daily lead content of the food of the subjects is almost equivalent to the mean daily faecal excretion. When the minute daily output of lead in the urine is appreciated it is clear that the lead in the faeces is almost wholly due to the daily ingestion of food which contains lead. Moreover, there is a wide variation in the daily intake of lead, in correspondence with the variation in the daily excretion of lead in the faeces. The recognition of these facts carries with it the certainty that the faecal lead cannot be regarded as a suitable criterion of the rate of lead excretion from the body tissues.

Comparison of the findings of the control period with those of the period of exposure to Ethyl Gasoline discloses the fact that no evidence of appreciable occupational lead exposure or lead absorption can be found. It is apparent that the exposure to lead associated with the daily dispensing of Ethyl Gasoline, and with the inhalation of the exhaust gases of the automobiles of the numerous patrons of a large filling station, is so slight that it cannot be measured.

TABLE 34

Distribution of the Daily Food Samples of Two Normal Subjects, During a Control Period of Observation, According to Lead Content

| Milligrams of Lead | Subject H | Subject M | Both Subjects |
|---|---|---|---|
| 0 -0.04 | 17 | 13 | 30 |
| 0.05-0.09 | 29 | 23 | 52 |
| 0.10-0.14 | 23 | 21 | 44 |
| 0.15-0.19 | 14 | 17 | 31 |
| 0.20-0.24 | 12 | 17 | 29 |
| 0.25-0.29 | 6 | 7 | 13 |
| 0.30-0.34 | 1 | 5 | 6 |
| 0.35-0.39 | 2 | 2 | 4 |
| 0.40-0.44 | 1 | 2 | 3 |
| 0.45-0.49 | | 2 | 2 |
| 0.50-0.54 | 4 | 2 | 6 |
| 0.55-0.59 | | | |
| 0.60-0.64 | 1 | | 1 |
| 0.65-0.69 | | | |
| 0.70-0.74 | 1 | | 1 |
| Total | 111 | 111 | 222 |
| Mean | 0.155 | 0.168 | 0.161 |
| Probable Error of Mean | ±0.008 | ±0.007 | ±0.006 |
| Standard Deviation | ±0.132 | ±0.113 | ±0.123 |

TABLE 35

Distribution of Daily Faecal Samples of Two Normal Subjects During a Control Period of Observation, According to Lead Content

| Milligrams of Lead | Subject H | Subject M | Both Subjects |
|---|---|---|---|
| 0 -0.07 | 17 | 38 | 55 |
| 0.08-0.15 | 30 | 19 | 49 |
| 0.16-0.23 | 28 | 28 | 56 |
| 0.24-0.31 | 20 | 15 | 35 |
| 0.32-0.39 | 13 | 4 | 17 |
| 0.40-0.47 | 5 | 9 | 14 |
| 0.48-0.55 | 7 | 8 | 15 |
| 0.56-0.63 | 1 | 1 | 2 |
| 0.64-0.71 | 1 | 1 | 2 |
| 0.72-0.79 | | 2 | 2 |
| 0.80-0.87 | | | |
| 0.88-0.95 | | 1 | 1 |
| 0.96- | 1 | 1 | 2 |
| Totals | 123 | 127 | 250 |

| | | | |
|---|---|---|---|
| Mean | 0.239 | 0.220 | 0.224 |
| Probable Error of Mean | ±0.013 | ±0.012 | ±0.008 |
| Standard Deviation | ±0.221 | ±0.194 | ±0.197 |

TABLE 36

Distribution of Forty-eight-hour and Seventy-two-hour Samples of Urine of Two Normal Subjects, During a Control Period of Observation to Ethyl Gasoline, According to Lead Content.

| Milligrams of Lead | Subject H 48 Hours | Subject H 72 Hours | Subject M 48 Hours | Subject M 72 Hours |
|---|---|---|---|---|
| 0 | 11 | 3 | 4 | 1 |
| 0.01 | 3 | 2 | 1 | |
| 0.02 | 2 | 2 | | |
| 0.03 | 3 | | 4 | 3 |
| 0.04 | | 1 | 2 | 1 |
| 0.05 | | 1 | 3 | |
| 0.06 | 2 | 1 | 3 | |
| 0.07 | 2 | | 7 | 1 |
| 0.08 | 2 | | 8 | 3 |
| 0.09 | 3 | 1 | 1 | 1 |
| 0.10 | 5 | 2 | 1 | 1 |
| 0.11 | 2 | 1 | | 1 |
| 0.12 | | 1 | 1 | 1 |
| 0.13 | | | 1 | |
| 0.14 | 1 | 1 | | 1 |
| 0.15 | | | | 1 |
| 0.16 | | 2 | | 2 |
| 0.17 | | | | |
| 0.18 | | | | 1 |
| Totals | 36 | 18 | 36 | 18 |
| | | | | |
| Mean | 0.053 | 0.071 | 0.064 | 0.097 |
| Probable Error of Mean | ±0.005 | ±0.009 | ±0.004 | ±0.008 |
| Standard Deviation | ±0.044 | ±0.055 | ±0.032 | ±0.051 |
| Average for 24 Hours | 0.025 | | 0.032 | |

KE 0017893

TABLE 37

Distribution of the Daily Faecal Samples of One Normal Subject During a Period of Exposure to Ethyl Gasoline, According to Lead Content

| Milligrams of Lead | Subject M |
|---|---|
| 0 -0.07 | 38 |
| 0.08-0.15 | 31 |
| 0.16-0.23 | 21 |
| 0.24-0.31 | 12 |
| 0.32-0.39 | 7 |
| 0.40-0.47 | 4 |
| 0.48-0.55 | 2 |
| 0.56-0.63 | 4 |
| 0.64-0.71 | 1 |
| 0.72-0.79 | |
| 0.80-0.87 | 1 |
| 0.88-0.95 | |
| 0.96-1.03 | |
| 1.04-1.11 | 1 |
| Totals | 122 |
| | |
| Mean | 0.190 |
| Probable Error of Mean | ±0.011 |
| Standard Deviation | ±0.179 |

TABLE 38

Distribution of Forty-eight-hour and Seventy-two-hour Samples of Urine of Two Normal Subjects, During a Period of Exposure to Ethyl Gasoline, According to Lead Content

| Milligrams of Lead | Subject H | | Subject M | |
|---|---|---|---|---|
| | 48 Hours | 72 Hours | 48 Hours | 72 Hours |
| 0 | 4 | 1 | 3 | |
| 0.01 | 3 | | 2 | |
| 0.02 | 3 | 1 | 4 | 3 |
| 0.03 | 1 | 1 | 5 | |
| 0.04 | 4 | | 3 | 1 |
| 0.05 | 3 | 1 | 2 | 2 |
| 0.06 | 1 | 2 | 6 | 3 |
| 0.07 | 1 | 2 | 5 | 3 |
| 0.08 | 1 | 2 | 1 | |
| 0.09 | 8 | 3 | 1 | |
| 0.10 | 2 | 3 | | |
| 0.11 | 1 | 1 | 2 | |
| 0.12 | 1 | | | 2 |
| 0.13 | 1 | | | 3 |
| 0.14 | | 1 | | 1 |
| Totals | 34 | 18 | 34 | 18 |
| Mean | 0.061 | 0.079 | 0.051 | 0.081 |
| Probable Error of Mean | ±0.004 | ±0.006 | ±0.003 | ±0.006 |
| Standard Deviation | ±0.039 | ±0.033 | ±0.029 | ±0.041 |
| Average for 24 Hours | 0.028 | | 0.026 | |

TABLE 39

Summary of Mean Amounts of Lead Found in Daily Samples of Food, Faeces and Urine of Two Subjects During a Control Period and During a Period of Exposure to Ethyl Gasoline.

| Subject | Mean Daily Lead Content of Food | | Mean Daily Lead in Faeces | | Mean Daily Lead in Urine | |
|---|---|---|---|---|---|---|
| | Control Pd. | Exposure Pd. | Control Pd. | Exposure Pd. | Control Pd. | Exposure Pd. |
| H | 0.155 | Incomplete | 0.239 | Incomplete | 0.025 | 0.028 |
| M | 0.168 | Incomplete | 0.220 | 0.19 | 0.032 | 0.026 |
| Both | 0.161 | Incomplete | 0.224 | | 0.028 * | 0.027 |

## 5. Summary

(1) The manufacture of tetraethyl lead and the preparation of Ethyl Gasoline involve definite occupational hazards, but means of control have been such that no cases of lead poisoning have occurred in these plants for a period of years.

(2) The possible hazards involved in the distribution and use of Ethyl Gasoline would be expected to be of a different order of magnitude from those which occur in the manufacturing processes, since the high dilution of tetraethyl lead with gasoline greatly modifies its toxicological characteristics. In accordance with these expectations no cases of lead poisoning are known to have occurred from exposure to Ethyl Gasoline, despite the fact that no means for the application of precautionary measures against exposure could be developed among the large numbers of unsupervised garage mechanics and filling station attendants.

(3) An experimental study in 1929-30, carried out on a group of men representing the severest known exposure to Ethyl Gasoline and its combustion products, shows an agreement with earlier investigations, in that no evidence of lead absorption, as a consequence of the exposure, has been obtained, when comparisons of this group is made with corresponding groups of unexposed persons.

(4) A group of men who have been exposed to Ethyl Gasoline, continuously, over a period of years, show no increase in their lead absorption, as measured by their lead excretion, over that of the same individuals two years previously.

(5) A group of workmen with an intense skin exposure to Ethyl Gasoline failed to show evidences of increased lead absorption after a period of six months of such exposure.

(6) Two individuals who were under observation for four months, during which duplicate samples of their food, as well as their excreta, were analyzed, excreted a total amount of lead which was little greater than that found in their food. During a similar four months period, in which they were exposed to Ethyl Gasoline and its combustion products, no change in their rate of lead excretion was detected.

## 6. Conclusions

Further examination of the possibilities of danger to the public health from the distribution and use of Ethyl Gasoline in the United States has failed to yield evidence of the existence of such dangers. The study of groups of persons whose occupations have magnified their exposure to a point well above that which is possible in the general population, has given no reason to believe that appreciable lead absorption results from the combination of lead exposures which have been hypothecated.

Danger from absorbing lead through the skin through contact with Ethyl Gasoline may now be said to be non-existent. The crucial observations under conditions of human exposure agree with previous facts ascertained by animal experimentation.

Lead absorption from the inhalation of finely divided lead compounds in the exhaust gas of automobiles using Ethyl Gasoline, has not been shown to be appreciable. Garage mechanics, chosen by reason of the intensity and duration of their exposure to such exhaust gases, showed no signs of lead absorption.

The specific criterion employed for the detection of lead absorption, namely, evidence of increased lead excretion, has been found to have a high degree of sensitivity, even for short periods of exposure. Since the subjects employed in this investigation have had exposures ranging from one to six years, continuously, the absence of signs of lead absorption means that no significant lead exposure existed.

With the observation that the lead which is excreted by normal human beings is derived largely from food materials, it becomes apparent that the magnitude of this factor in lead absorption may be sufficient to mask the effects due to the use of Ethyl Gasoline. If this be true, the insignificance of the contribution made to the lead absorption of the community, by the advent of

Ethyl Gasoline, is thereby established. Moreover, an attempt to measure the Ethyl Gasoline factor in lead absorption, while controlling the food factor, has resulted in failure. The conclusion is inescapable that lead absorption in the community, as the result of the distribution of Ethyl Gasoline, is insignificant.

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   (b) Kehoe, Robert A. et al: Report similar to above dated May 1927.

   (c) Kehoe, Robert A. et al: Report similar to above dated April 1928.

## Appendix 1

### The Present Status of the Hazards of the Manufacture of Tetraethyl Lead and Ethyl Fluid

The dangers associated with the manufacture of tetraethyl lead have been controlled through the joint application of engineering and medical knowledge. It has been possible to design essentially closed systems for the production, distillation, purification and storage of tetraethyl lead; to handle sludge, to reclaim the residual lead after the completion of the reaction; to mix the tetraethyl lead with the other ingredients of tetraethyl lead; and to fill suitable containers in preparation for shipment by rail or water. With sound toxicological information available it has proven to be feasible to use ventilating equipment in such a way as to maintain a safe atmosphere in workrooms, despite the occurrence of localized air contamination with lead compounds, incident to daily operation of the plant. Constant supervision of plant activities is maintained for the sake of safety as well as productivity. An exact technique for every operation is prescribed, with due regard to safety. In addition to these measures, every person who is employed in any part of the plant area is under medical supervision. Each workman is seen by a physician every week, and in case of absence from work by reason of any kind of illness, investigation of the character of the illness is made promptly. Blood examinations, including an erythrocyte count, haemoglobin determination and the examination of a film for stippling of erythrocytes, are carried out every third week. Measurement of the lead concentration in the air of various parts of the plant are made in such a way that the entire plant is thus investigated quarterly. As a further check on the plant conditions the lead excretion of representative groups of workmen is determined at quarterly intervals.

During a period of six years in which such a regime has been in effect, there have been no cases of lead poisoning among the workmen. Moreover, no workman has been removed from his employment by reason of symptoms of impending lead intoxication. In a few instances, men without symptoms have shown an increase in basophilic stippling or some other sign which may have been due to absorption of lead, whereupon they have been transferred to positions which involved little or no lead exposure, either temporarily or permanently. The labor turnover has been very small, however, so that most of the workmen have been employed at the same type of work for four to six years. The physical character of the plant is such that men engaged in specific parts of the operation are sharply segregated from each other. Excepting the general supervisors, who spend variable periods of time in all parts of the plant, and also the staff of men who carry out maintenance and repair of equipment, the workmen can be grouped in accordance with their specific occupations.

The above circumstances have provided an opportunity for prolonged study of the lead excretion (and stippling of the erythrocytes) of groups of workmen who are representative of the cross-sectional lead hazards of the plant. The conditions as to lead exposure have not remained constant during the period of such observations. As potential hazards have been recognized they have been eliminated or reduced. To this extent the combination of all the results for the past five years does not give an exact picture of present conditions. On the other hand, the number of subjects used at one time was necessarily small, so that repeated observations over the entire period reveal the situation most satisfactorily. Several representatives of each type of work were selected as characteristic subjects. Observations on the same subjects have been repeated quarterly so that the number of items recorded in the data represent the total number of observations.

It is not necessary for present purposes to describe the operation of the plant in detail. The general nature of the procedure is indicated in the following classification of the workmen:

(1) Handlers of a lead-sodium alloy, made by heating lead and sodium in a melting pot; (The alloy is made, poured, cooled, ground to suitable size, and weighed into hoppers, by these workmen.)

(2) Autoclave operators, who introduce the alloy into the autoclave without coming into contact with it, and who tend the autoclaves during the reaction whereby tetraethyl lead is produced;

(3) Still operators, who regulate the distillation of tetraethyl lead from the reaction mixture and residue;

(4) Furnace operators, who reclaim unused lead from the sludge by a melting process;

(5) Blenders, who take the finished product, tetraethyl lead, and mix it with other ingredients, to prepare a fluid which ultimately is to be introduced into gasoline;

(6) Laboratory workers, whose analyses of alloy, sludge and finished product provide information for control of the manufacturing operations; and

(7) Foremen, who supervise the various operations.

The exposure is of two types, essentially, - that occasioned by lead dusts, and that arising from the escape of tetraethyl lead vapors. The respiratory channel alone is of practical importance, in the absorption of lead, under the present plant conditions. The furnace operators and the alloy workers have little or no exposure to tetraethyl lead vapors. On the other hand the still operators, the blenders and the laboratory workers are not exposed to dusts. The hazards of autoclave operators are chiefly from vapor, but the possibility of dust inhalation cannot be entirely ignored. The foremen move about from place to place but they spend their entire time in the plant. They are subject to all the possibilities of exposure in the entire plant, to a considerable degree. The other groups are limited to the exposure characteristic of their own occupation and area.

In accordance with the above facts a series of tables has been constructed in which the groups of workers with related exposures are handled together, so far as possible. Tables 40 A, 41 A, and 42 A present the analytical findings for the still operators, autoclave operators, blenders and laboratory workers, while Tables 40 B, 41 B and 42 B give the findings for the furnace operators, the alloy workers, the foremen, and for the entire group in cross-section. The results shown in these tables are clearly different from those which have been obtained on workmen in dusty lead trades. Indeed, the lead exposure of the laboratory group falls within normal limits, as judged by lead excretion. The number of observations, in the case of this group is too small to produce any appreciable effect upon the composite group, so that the mean values for the latter may be taken as properly representative of conditions of exposure in the plant.

One other matter of importance is suggested in the relationship between the mean urinary excretion and the mean faecal content, for certain groups. If we employ the concept that faecal lead content is a measure of exposure to lead compounds, it would appear that the exposure of the furnace operators is approximately equivalent to that of the still operators. Yet the urinary excretion of the former group is significantly small as compared to that of the latter. This may be due to the large variability inherent in a limited number of observations, but it seems more probable that it is an expression of the difference in the physiological activity of different lead compounds. Tetraethyl lead vapor is readily absorbed, whereas particulate metallic lead and lead oxide are doubtless absorbed more slowly from the lung surfaces. This may explain why the stillmen, exposed only to tetraethyl lead

TABLE 40 A

Distribution of Workers in the Manufacture of Tetraethyl Lead According to Lead in a Single Sample of Faeces

| Lead in Milligrams per Sample of Faeces | Still Operators | | Autoclave Operators | | Blenders | | Laboratory Workers | |
|---|---|---|---|---|---|---|---|---|
| 0 -0.09 | | | 2 | | 2 | | 3 | |
| 0.10-0.19 | 3 | | 4 | | 2 | | 7 | |
| 0.20-0.29 | 4 | | 4 | | 4 | | 1 | |
| 0.30-0.39 | 5 | | 2 | | 3 | | 1 | |
| 0.40-0.49 | 3 | | 4 | | 3 | | | |
| 0.50-0.59 | 7 | | 3 | | 1 | | | |
| 0.60-0.69 | 3 | | 0 | | | | | |
| 0.70-0.79 | 2 | | 2 | | 1 | | | |
| 0.80-0.89 | 1 | | 1 | | | | | |
| 0.90-0.99 | 2 | | 1 | | 2 | | | |
| 1.00-1.09 | | | 1 | | | | | |
| 1.10-1.19 | 1 | | 1 | | | | | |
| 1.20- | 6* | | 1* | | | | | |
| Totals | 37 | | 26 | | 18 | | 12 | |

| | Still Operators | Autoclave Operators | Blenders | Laboratory Workers |
|---|---|---|---|---|
| Mean | 0.51 | 0.45 | 0.39 | 0.15# |
| Probable Error of Mean | ±0.03 | ±0.04 | ±0.04 | 0.02 |
| Standard Deviation | ±0.25 | ±0.31 | ±0.26 | 0.08 |

*Excluded in Calculation of Means

#Calculated on Wider Distribution

TABLE 41 A

Distribution of Workers in the Manufactoring of Tetraethyl Lead
According to Milligrams of Lead Per Gram Ash of Faeces

| ligrams of lead r Gram of Ash | Still Operators | | Autoclave Operators | | Blenders | | Laboratory Workers | |
|---|---|---|---|---|---|---|---|---|
| | Number | Percentage | Number | Percentage | Number | Percentage | Number | Percentage |
| 0 -0.04 | | | 3 | 11.5 | | | | |
| 0.05-0.09 | 8 | 21.6 | 5 | 19.2 | 5 | 27.8 | 5 | 41.7 |
| 0.10-0.14 | 10 | 27.1 | 8 | 30.7 | 5 | 27.8 | 6 | 50.0 |
| 0.15-0.19 | 7 | 18.9 | 3 | 11.5 | 4 | 22.2 | 1 | 8.3 |
| 0.20-0.24 | 8 | 21.6 | 1 | 3.9 | | | | |
| 0.25-0.29 | 2 | 5.4 | 3 | 11.5 | 1 | 5.5 | | |
| 0.30-0.34 | | | | | 2 | 11.1 | | |
| 0.35-0.39 | 1 | 2.7 | | | | | | |
| 0.40-0.44 | | | | | | | | |
| 0.45-0.49 | | | | | | | | |
| 0.50-0.54 | 1 | 2.7 | 1 | 3.9 | | | | |
| 0.55-0.59 | | | 1 | 3.9 | | | | |
| 0.60-0.64 | | | | | 1 | 5.5 | | |
| 0.65-0.69 | | | | | | | | |
| 0.70-0.74 | | | | | | | | |
| 0.75-0.79 | | | | | | | | |
| 0.80-0.84 | | | 1 * | 3.9 | | | | |
| 0.85-0.89 | | | | | | | | |
| 0.90-0.94 | | | | | | | | |
| Totals | 37 | 100.0 | 26 | 100.0 | 18 | 100.0 | 12 | 100.0 |
| Mean | 0.171 | | 0.165 | | 0.181 | | 0.112⊕ | |
| Probable Error of Mean | ± 0.010 | | ± 0.018 | | ± 0.021 | | ± 0.007 | |
| Standard Deviation | ± 0.090 | | ± 0.134 | | ± 0.133 | | ± 0.037 | |

* Excluded in Calculation of Mean
⊕ Calculated on wider Distribution

vapor from day to day show a higher rate of lead excretion in the urine than do the furnace operators. This explanation gains in plausibility when it is observed that all the groups exposed chiefly to tetraethyl lead vapors (excluding the essentially unexposed laboratory workers) have a higher rate of urinary excretion, in proportion to their faecal output, than do the groups exposed to lead dusts.

In the matter of stippling of the erythrocytes, as shown in Tables 43 A and 43 B, we fail to find a differentiation of the workers in this plant. From this alone, it is perfectly clear that though stippling may be a valuable indication of the occurrence of lead absorption, the number of stippled cells cannot be employed as a criterion in making fine distinctions as to the magnitude of lead exposure and lead absorption.

TABLE 42 A

Distribution of Workers in the Manufacture of Tetraethyl Lead
According to Milligrams of Lead Per Liter of Urine

| lligrams of Lead r Liter of Urine | Still Operators | Autoclave Operators | Blenders | Laboratory Workers |
|---|---|---|---|---|
| 0-0.03 | 1 | 2 | | 5 |
| 04-0.07 | 5 | 6 | 2 | 6 |
| 08-0.11 | 2 | 4 | 4 | |
| 12-0.15 | 8 | 4 | 5 | 1 |
| 16-0.19 | 4 | 4 | 1 | |
| 20-0.23 | 5 | 2 | 3 | |
| 24-0.27 | 4 | | 2 | |
| 28-0.31 | | | | |
| 32-0.35 | 3 | 1 | | |
| 36-0.39 | 1 | 1 | | |
| 40-0.43 | 1 | | | |
| 44-0.47 | 2 | 1 | | |
| 48-0.51 | | | | |
| 52-0.55 | | | | |
| 56-0.59 | | | | |
| 60-0.63 | | | | |
| 64-0.67 | | | | |
| tals | 36 | 25 | 17 | 12 |
| an | 0.198 | 0.146 | 0.151 | 0.05 |
| bable Error Mean | ±0.014 | ±0.105 | ±0.010 | ±0.006 |
| ndard viation | ±0.120 | ±0.108 | ±0.060 | ±0.031 |

TABLE 40 B

Distribution of Workers in the Manufacture of Tetraethyl Lead According to Lead in a Single Sample of Faeces

| Lead in Milligrams per Sample of Faeces | Furnace Operators | | Alloy Workers | | Foremen | | Combined Groups | |
|---|---|---|---|---|---|---|---|---|
| 0 -0.09 | | | 3 | | 2 | | 12 | |
| 0.10-0.19 | 3 | | 2 | | 7 | | 28 | |
| 0.20-0.29 | 1 | | 4 | | 7 | | 25 | |
| 0.30-0.39 | 3 | | 3 | | 8 | | 25 | |
| 0.40-0.49 | 1 | | 1 | | 3 | | 15 | |
| 0.50-0.59 | | | 2 | | 2 | | 15 | |
| 0.60-0.69 | | | 1 | | 3 | | 7 | |
| 0.70-0.79 | 1 | | | | 2 | | 8 | |
| 0.80-0.89 | 2 | | 3 | | | | 7 | |
| 0.90-0.99 | | | | | | | 5 | |
| 1.00-1.09 | 2 | | | | | | 3 | |
| 1.10-1.19 | 1 | | | | | | 3 | |
| 1.20- | 4* | | 4* | | 2* | | 17* | |
| Totals | 18 | | 23 | | 36 | | 170 | |

| | Furnace Operators | Alloy Workers | Foremen | Combined Groups |
|---|---|---|---|---|
| Mean | 0.56 | 0.38 | 0.34 | 0.418 |
| Probable Error of Mean | ±0.06 | ±0.04 | ±0.02 | ±0.014 |
| Standard Deviation | ±0.36 | ±0.26 | ±0.19 | ±0.261 |

*Excluded in Calculation of Mean
These consist of 13 widely scattered results from 1.20 to 2.50, and 4 results from 3.00 to 5.00. Including all results except the last four, the mean for the combined groups is 0.504 mg. ±0.023, with a Standard Deviation of 0.446.

TABLE 41 B

Distribution of Workers in the Manufacture of Tetraethyl Lead
According to Milligrams of Lead Per Gram Ash of Faeces

| Milligrams of Lead per Gram of Ash | Furnace Operators | | Alloy Workers | | Foremen | | Combined Groups | |
|---|---|---|---|---|---|---|---|---|
| | No. | % | No. | % | No. | % | No. | % |
| 0-0.04 | | | 4 | 17.4 | 1 | 2.8 | 8 | 4.7 |
| 0.05-0.09 | 3 | 16.7 | 3 | 13.0 | 9 | 25.0 | 38 | 22.3 |
| 0.10-0.14 | 4 | 22.2 | 7 | 30.4 | 11 | 30.6 | 51 | 30.0 |
| 0.15-0.19 | 3 | 16.7 | 1 | 4.4 | 9 | 25.0 | 28 | 16.5 |
| 0.20-0.24 | 1 | 5.5 | 3 | 13.0 | 2 | 5.5 | 15 | 8.8 |
| 0.25-0.29 | 2 | 11.1 | | | 2 | 5.5 | 10 | 5.9 |
| 0.30-0.34 | | | 2 | 8.7 | 1 | 2.8 | 5 | 2.9 |
| 0.35-0.39 | 1 | 5.5 | | | | | 2 | 1.2 |
| 0.40-0.44 | | | 1 | 4.4 | | | 1 | 0.6 |
| 0.45-0.49 | | | | | | | | |
| 0.50-0.54 | | | 2 | 8.7 | | | 4 | 2.3 |
| 0.55-0.59 | | | | | | | 1 | 0.6 |
| 0.60-0.64 | 2 * | 11.1 | | | | | 3 | 1.8 |
| 0.65-0.69 | | | | | | | | |
| 0.70-0.74 | | | | | | | | |
| 0.75-0.79 | | | | | | | | |
| 0.80-0.84 | | | | | | | 1 | 0.6 |
| 0.85-0.89 | | | | | 1 * | 2.8 | 1 | 0.6 |
| 0.90-0.94 | 2 * | 11.1 | | | | | 2 | 1.2 |
| Totals | 18 | 100.0 | 23 | 100.0 | 36 | 100.0 | 170 | 100.0 |

| | Furnace Operators and Alloy Workers | Foremen | Combined Groups |
|---|---|---|---|
| Mean | 0.201 | 0.142 | 0.186 ⊕ |
| Probable Error of Mean | ±0.017 | 0.007 | ±0.009 |
| Standard Deviation | ±0.158 | ±0.065 | ±0.166 |

* Excluded in calculation of Mean

⊕ Excluding the last twelve aberrant results the mean is 0.147± 0.004, with a Standard Deviation of 0.078.

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TABLE 42 B

Distribution of Workers in the Manufacture of Tetraethyl Lead
According to Milligrams of Lead per Liter of Urine

| Milligrams of Lead per Liter of Urine | Furnace Operators | | Alloy Workers | | Foremen | | Combined Groups | |
|---|---|---|---|---|---|---|---|---|
| 0-0.03 | | | 4 | | 9 | | 21 | |
| 0.04-0.07 | 4 | | 10 | | 9 | | 42 | |
| 0.08-0.11 | 4 | | 7 | | 7 | | 28 | |
| 0.12-0.15 | 3 | | 1 | | 3 | | 25 | |
| 0.16-0.19 | 1 | | 1 | | 4 | | 15 | |
| 0.20-0/23 | 2 | | | | | | 12 | |
| 0.24-0.27 | 1 | | | | 1 | | 8 | |
| 0.28-0.31 | 1 | | | | 1 | | 2 | |
| 0.32-0.35 | | | | | | | 4 | |
| 0.36-0.39 | | | | | | | 2 | |
| 0.40-0.43 | | | | | | | 1 | |
| 0.44-0.47 | | | | | | | 3 | |
| 0.48-0.51 | | | | | | | | |
| 0.52-0.55 | 1 * | | | | | | 1 * | |
| 0.56-0.59 | | | 1 * | | | | 1 * | |
| 0.60-0.63 | | | | | | | | |
| 0.64-0.67 | | | | | | | | |
| Totals | 17 | | 24 | | 34 | | 165 | |

| | | | | |
|---|---|---|---|---|
| Mean | 0.140 | 0.074 | 0.092 | 0.129 |
| Probable Error of Mean | ±0.012 | ±0.005 | ±0.008 | ±0.005 |
| Standard Deviation | ±0.073 | ±0.038 | ±0.070 | ±0.098 |

* Excluded in calculation of means.

# TABLE 43 A

Distribution of Workers in the Manufacture of Tetraethyl Lead According to Stippling of Erythrocytes

| Number of Stippled Cells per 50 Field | Still Operators | | Autoclave Operators | | Blenders | | Laboratory Workers | |
|---|---|---|---|---|---|---|---|---|
| 0 | 6 | | 7 | | 3 | | 3 | |
| 1-4 | 10 | | 7 | | 3 | | 3 | |
| 5-8 | 3 | | 3 | | 4 | | | |
| 9-12 | 3 | | 2 | | 1 | | | |
| 13-16 | 2 | | 1 | | 1 | | 2 | |
| 17-20 | 6 | | 1 | | 1 | | 1 | |
| 21-30 | 3 | | 1 | | 2 | | 1 | |
| 31-40 | 3 | | 1 | | 1 | | 1 | |
| 41-60 | 1 | | 1 | | 1 | | | |
| 61-80 | | | 1 | | | | 1 | |
| 85 | | | | | | | | |
| 94 | | | | | | | | |
| 97 | | | | | | | | |
| 146 | | | | | | | | |
| Totals | 37 | | 25 | | 17 | | 12 | |

| | Still Operators | Autoclave Operators | Blenders | Laboratory Workers |
|---|---|---|---|---|
| Mean | 12.64 ⊕ | 10.21 ⊕ | 13.38 ⊕ | 11.59 ⊕ |
| Probable Error of Means | ±1.32 | ±1.87 | ±2.27 | ±2.37 |
| Standard Deviation | ±11.88 | ±13.62 | ±13.85 | ±11.64 |

⊕ Means calculated on even distribution.

**TABLE 43 B**

Distribution of Workers in the Manufacture of Tetraethyl Lead According to Stippling of Erythrocytes

| Number of Stippled Cells per 50 Fields | Furnace Operators | | Alloy Workers | | Foremen | | Combined Groups | |
|---|---|---|---|---|---|---|---|---|
| 0 | 2 | | 5 | | 10 | | 36 | |
| 1-4 | 8 | | 12 | | 10 | | 53 | |
| 5-8 | 1 | | | | 5 | | 16 | |
| 9-12 | 2 | | 3 | | | | 11 | |
| 13-16 | 3 | | 1 | | | | 10 | |
| 17-20 | | | | | | | 9 | |
| 21-30 | | | 2 | | 3 | | 12 | |
| 31-40 | 1 | | | | 3 | | 10 | |
| 41-60 | 1 | | 1 | | | | 5 | |
| 61-80 | | | | | 1 * | | 3 | |
| 85 | | | | | 1 * | | 1 * | |
| 94 | | | | | 1 * | | 1 * | |
| 97 | | | | | 1 * | | 1 * | |
| 146 | | | | | 1 * | | 1 * | |
| Totals | 18 | | 24 | | 36 | | 169 | |

| | Furnace Operators | Alloy Workers | Foremen | Combined Groups |
|---|---|---|---|---|
| Mean | 10.83 ⊕ | 8.54 ⊕ | 8.95 ⊕ | 10.77 ⊕ |
| Probable Error of Mean | ±2.34 | ±1.81 | ±1.39 | ±0.68 |
| Standard Deviation | ±14.72 | ±13.15 | ±11.51 | ±12.93 |

* Excluded in Calculation of Means

⊕ Means Calculated on even distribution.

TABLE 44

Distribution of Workmen Employed in Mixing Tetraethyl Lead with Gasoline According to Lead in a Single Sample of Faeces

| Lead in Milligrams per Sample of Faeces | 1927 | | 1929 | | 1931 | | Composite | |
|---|---|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % | Number | % |
| 0 -0.09 | 16 | 44.4 | 3 | 7.5 | 7 | 15.2 | 26 | 21.3 |
| 0.10-0.19 | 7 | 19.4 | 11 | 27.5 | 10 | 21.7 | 28 | 23.0 |
| 0.20-0.29 | 5 | 13.9 | 9 | 22.5 | 9 | 19.6 | 23 | 18.8 |
| 0.30-0.39 | 3 | 8.3 | 6 | 15.0 | 5 | 10.9 | 14 | 11.5 |
| 0.40-0.49 | 2 | 5.6 | 4 | 10.0 | 4 | 8.7 | 10 | 8.2 |
| 0.50-0.59 | 1 | 2.8 | 4 | 10.0 | 4 | 8.7 | 9 | 7.4 |
| 0.60-0.69 | | | 2 | 5.0 | 3 | 6.5 | 5 | 4.1 |
| 0.70-0.79 | | | | | 1 | 2.2 | 1 | 0.8 |
| 0.80-0.89 | | | | | | | | |
| 0.90- | 2* | 5.6 | 1* | 2.5 | 3* | 6.5 | 6* | 4.9 |
| Totals | 36 | 100.0 | 40 | 100.0 | 46 | 100.0 | 122 | 100.0 |

| | 1927 | 1929 | 1931 | Composite |
|---|---|---|---|---|
| Mean | 0.20 | 0.29 | 0.29 | 0.264 |
| Probable Error of Mean | ±0.02 | ±0.02 | ±0.02 | ±0.011 |
| Standard Deviation | ±0.19 | ±0.16 | ±0.19 | ±0.176 |

*Excluded in Calculation of Means

TABLE 45

Distribution of Workmen Employed in Mixing Tetraethyl Lead with Gasoline According to Milligrams of Lead per Gram Ash of Faeces

| illigram of ead per Gram f Ash | 1927 | | 1929 | | 1931 | | Composite | |
|---|---|---|---|---|---|---|---|---|
| | No. | % | No. | % | No. | % | No. | % |
| 0-0.02 | 14 | 38.9 | 3 | 7.5 | 5 | 10.8 | 22 | 18.1 |
| .03-0.05 | 10 | 27.8 | 12 | 30.0 | 13 | 28.3 | 35 | 28.7 |
| .06-0.08 | 4 | 11.1 | 10 | 25.0 | 14 | 30.4 | 28 | 23.0 |
| .09-0.11 | 4 | 11.1 | 8 | 20.0 | 9 | 19.6 | 21 | 17.2 |
| .12-0.14 | 1 | 2.8 | | | 4 | 8.7 | 5 | 4.1 |
| .15-0.17 | | | 1 | 2.5 | | | 1 | 0.8 |
| .18-0.20 | | | 2 | 5.0 | | | 2 | 1.6 |
| .21-0.23 | 1 | 2.8 | 1 | 2.5 | | | 2 | 1.6 |
| .24-0.26 | | | 1 | 2.5 | | | 1 | 0.8 |
| .27-0.29 | | | | | | | | |
| .30- | 2 * | 5.5 | 2 * | 5.0 | 1 * | 2.2 | 5 * | 4.1 |
| otals | 36 | 100.0 | 40 | 100.0 | 46 | 100.0 | 122 | 100.0 |

| | 1927 | 1929 | 1931 | Composite |
|---|---|---|---|---|
| ean | 0.051 | 0.084 | 0.070 | 0.070 |
| robable Error f Mean | ±0.004 | ±0.006 | ±0.004 | ±0.003 |
| tandard eviation | ±0.035 | ±0.056 | ±0.038 | ±0.047 |

* Excluded in Calculation of Means

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TABLE 46

Distribution of Workmen Employed in Mixing Tetraethyl Lead with Gasoline According to Milligrams of Lead per Liter of Urine

| Milligrams of Lead per Liter of Urine | 1927 | | 1929 | | 1931 | | Composite | |
|---|---|---|---|---|---|---|---|---|
| | Number | Percentage | Number | Percentage | Number | Percentage | Number | Percentage |
| 0-0.01 | 2 | 5.6 | 2 | 5.0 | 19 | 41.3 | 23 | 18.9 |
| 0.02-0.03 | 4 | 11.1 | 10 | 25.0 | 14 | 30.4 | 28 | 23.0 |
| 0.04-0.05 | 11 | 30.5 | 8 | 20.0 | 6 | 13.0 | 25 | 20.5 |
| 0.06-0.07 | 9 | 25.0 | 8 | 20.0 | 2 | 4.3 | 19 | 15.6 |
| 0.08-0.09 | 4 | 11.1 | 6 | 15.0 | 1 | 2.2 | 11 | 9.0 |
| 0.10-0.11 | 3 | 8.3 | 2 | 5.0 | | | 5 | 4.1 |
| 0.12-0.13 | 2 | 5.6 | 2 | 5.0 | | | 4 | 3.3 |
| 0.14-0.15 | | | 1 | 2.5 | 1 | 2.2 | 2 | 1.6 |
| 0.16-0.17 | | | 1 | 2.5 | 1 | 2.2 | 2 | 1.6 |
| 0.18-0.19 | 1 | 2.8 | | | | | 1 | 0.8 |
| 0.20 | | | | | 2 * | 4.3 | 2 * | 1.6 |
| Totals | 36 | 100.0 | 40 | 100.0 | 46 | 100.0 | 122 | 100.0 |

| | 1927 | 1929 | 1931 | Composite |
|---|---|---|---|---|
| Mean | 0.068 | 0.066 | 0.033 | 0.055 |
| Probable Error of Mean | ±0.004 | ±0.004 | ±0.003 | ±0.002 |
| Standard Deviation | ±0.036 | ±0.037 | ±0.034 | ±0.039 |

* Two results 0.32 and 0.64 excluded in Calculation of Means

TABLE 47

Distribution of Workmen Employed in Mixing Tetraethyl Lead with Gasoline According to Stippling of Erythrocytes

| Number of Stippled Cells per 50 Fields | 1927 | | 1929 | | 1931 | | Composite | |
|---|---|---|---|---|---|---|---|---|
| 0 | 25 | 67.6 | 17 | 43.5 | 16 | 34.8 | 58 | 47.5 |
| 1-4 | 10 | 27.0 | 8 | 20.5 | 13 | 28.2 | 31 | 25.4 |
| 5-8 | 2 | 5.4 | 1 | 2.6 | 7 | 15.2 | 10 | 8.2 |
| 9-12 | | | 4 | 10.2 | 5 | 10.9 | 9 | 7.4 |
| 13-16 | | | 3 | 7.7 | | | 3 | 2.5 |
| 17-20 | | | 1 | 2.6 | 1 | 2.2 | 2 | 1.6 |
| 21-24 | | | 1 | 2.6 | 1 | 2.2 | 2 | 1.6 |
| 25-49 | | | 1 | 2.6 | 3 | 6.5 | 4 | 3.3 |
| 50-74 | | | 3 | 7.7 | | | 3 | 2.5 |
| Totals | 37 | 100.0 | 39 | 100.0 | 46 | 100.0 | 122 | 100.0 |
| Approximate Mean | 1.66 ⊕ | | 5.06 | | 4.40 | | 3.79 | |
| Probable Error of Mean | ±0.22 | | ±0.67 | | ±0.54 | | ±0.31 | |
| Standard Deviation | ±2.02 | | ±5.88 | | ±5.22 | | ±4.85 | |

⊕ Calculated on a wider distribution

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TABLE 48

Summary of Mean Values of Lead Found in Single Samples of Faeces, of Lead in Milligrams per Gram of Ash in Gaeces, of Lead in Milligrams per Liter of Urine, and of Stippling of Erythrocytes, for Various Groups within and outside the Lead Trades

| | | Workers in White Lead Plant | Workers in Electrical Storage Battery Manufacturing Plant | Workers in a Tetraethyl Lead Manufacturing Plant | Workers Employed in Mixing Tetraethyl Lead in Gasoline | Normal Persons Outside the Lead Trades |
|---|---|---|---|---|---|---|
| 1 | Lead in Milligrams in a Single Sample of Faeces | 3.76 ± 0.26 | 2.53 ± 0.18 | 0.42 ± 0.01+ | 0.26 ± 0.01 | 0.20 ± 0.01- |
| 2 | Lead in Milligrams per Gram of Ash in Faeces | 0.57 ± 0.32 | 0.45 ± 0.03 | 0.19 ± 0.01- | 0.07 ± 0.01- | 0.07 ± 0.01- |
| 3 | Lead in Milligrams per Liter of Urine | 0.24 ± 0.01 | 0.18 ± 0.01 | 0.13 ± 0.01- | 0.06 ± 0.01- | 0.07 ± 0.01- |
| 4 | Stippled Erythrocytes per 50 Fields | 18.73 ± 1.66 | 9.79 ± 1.48 | 10.77 ± 0.68 | 3.79 ± 0.31 | 1+ |
| 5 | Number of Subjects or Observations | 86 | 71 | 170 | 122 | 169 |
| 6 | Significance of Lead Exposure | Associated with Occurrence of Plumbism | Associated with Occurrence of Plumbism | No occurrence of Plumbism in 5 Years | No occurrence of Plumbism | No occurrence of Plumbism |

The results of the foregoing observations coincide with the chemical evidences that the manufacture of tetraethyl lead has been carried out in such a manner as to prevent extensive lead absorption among the plant operators. On the other hand, certain groups of the workmen can be differentiated from persons who are not exposed to lead, despite the fact that the magnitude of their lead exposure has not been sufficient to produce symptoms of lead intoxication. This fact demonstrates the sensitivity of measurements of lead excretion as a means of estimating lead exposure. The extent of this sensitivity in the general method is displayed graphically in Table 48 in Appendix 2, where a classification of groups of subjects of variable lead exposure is made in terms of the magnitude of their mean lead excretions.

## Appendix 2

### The Present Status of the Hazards in the Manufacture of Ethyl Gasoline by Mixing Ethyl Fluid with Gasoline

Since 1925 Ethyl Gasoline has been prepared at gasoline refineries and large bulk distributing centers by means of special equipment, designed and prescribed by the Ethyl Gasoline Corporation. Regulations for the operation of the equipment, and for the safeguarding of the mixing personnel have been promulgated, and medical supervision of the operating personnel has been maintained by the medical staff of the same corporation. There are approximately two hundred points at which the mixing is carried out, and from one to six men are employed at each point to carry out all the operations concerned with the handling of the materials and their containers. The opportunities for lead exposure in the course of normal operation are meagre and since mixing is not required more frequently than once a week, such exposure is irregular in occurrence. Nevertheless, the potential hazards of the work are sufficient to justify the maintenance of precise technique and adherence to the prescribed precautionary measures.

No cases of lead poisoning have occurred among these workmen, and no person has been removed from his employment as a result of occupational lead absorption. In coincidence with this indication of the safety of the work, observations of the lead excretion, and of stippling of the erythrocytes of representative groups of workmen fail to give evidence of a significant lead absorption.

Tables 44-47 show the findings obtained from time to time in the study of such workmen. It is not possible to differentiate them from persons in the normal unexposed population.

The last table (Table 48) gives the mean results obtained in our study of several groups of persons within the lead trades and outside the lead trades. This table has been referred to previously, as evidence of the sensitivity of the method of estimating lead exposure and lead absorption, through the accurate determination of the lead output in the faeces and in the urine of representative groups of exposed persons.

# APPENDIX III

## APPROXIMATE GROSS AND COMPARATIVE SALES OF ETHYL GASOLINE IN 1930 AND 1931

| 1930 | | 1931 | |
|---|---|---|---|
| Millions of Gals. of Ethyl Gasoline (U.S.) | Percentage of Ethyl Gasoline to Total Gasoline | Millions of Gals. of Ethyl Gasoline (U.S.) | Percentage of Ethyl Gasoline to Total Gasoline |
| 1,854 | 11.7 | 1,970 | 12.0 |

## AVERAGE CONCENTRATION OF TETRAETHYL LEAD IN ETHYL GASOLINE IN 1930 AND 1931

| 1930 | 1931 |
|---|---|
| 1.84 cc/gallon | 1.91 cc/gallon |