GASOLINE LEAD IN URBAN AND RURAL PLAY AREAS

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ABSTRACT

Leaded gasoline used as fuel for automobiles and trucks has been implicated as a source of lead that eventually reaches small children. Lead has deleterious effects on cognitive development of pre-school age children. Although allowable levels of lead in gasoline were reduced 90% on January 1, 1986 in the U.S., lead previously accumulated in soil will remain. Measurements of surface soil lead in Illinois play areas revealed higher accumulations in center city and suburban areas than in much less densely settled urban and rural areas outside the Chicago area (downstate Illinois).

The results of the soil analysis in this study do not address the larger question of pathways for child-lead ingestion and consequent health effects. However, based on results of the study in the Chicago area, other high traffic suburban areas may wish to consider review of their soils. Risk assessment has not been undertaken, but may be the next step in determining the extent of hazard posed to small children from surface accumulations of lead.

1 INTRODUCTION

1.1 THE LEAD PROBLEM

The human body has no need for lead, at any concentration. Lead is removed from the body when it is encountered in the environment, but only at very low levels of lead. Children are particularly unable to screen out lead that is ingested or inhaled. However, there are many sources of lead in the environment because lead is used in many industrial applications. It has long been part of pigments in paint, an octane enhancer for gasoline, part of solder for tin cans, and parts of automotive batteries.

Fatalities from lead exposure have accompanied industrial use of lead. At lower exposure levels, health effects include anemia and kidney

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damage. There is extensive evidence of nervous system damage in children with apparently low levels of lead in their blood; evidence is in the form of diminished cognitive abilities. Each new study documents measurable health effects lower levels of lead in the blood. Many major efforts have been undertaken to eliminate environmental sources of lead. Work place safety rules have drastically reduced exposure for workers, and for the families of workers. Other additives now enhance the octane of gasoline. Solders used in tin cans use no lead. Since the mid-1970s, paint for interior surfaces may have no more than 0.06% lead in it. In spite of all these improvements, unexpectedly high levels of lead are still found in young children's blood. The importance of soil as part of the pathway of lead to young children has risen, as health officials seek to explain the high lead levels.[1]

1.2 STUDY OF ILLINOIS SOILS IN PLAY AREAS

A joint study of lead in park soils throughout Illinois was undertaken by researchers at Argonne National Lab, (under sponsorship by the U.S. Department of Energy) and staff of the Illinois Department of Public Health and the Chicago Department of Health, as well as several suburban health departments. Participants wanted to learn the levels of lead in surface soils, in locations accessible to small children, under 7 years of age. The goal of the study was to learn the concentrations of lead in surface soil as related to the volume of traffic on nearby roads, as a stepping stone in the larger picture of estimating exposure levels of small children. The study was timed to coincide with the onset of the U.S. reduction of lead in gasoline,[2] which should nearly halt the increase in surface lead concentrations due to accumulation of airborne emissions. Although lead emissions will be substantially reduced as a result of both the phasedown and the switch to unleaded fuels, lead presently in surface soils will stay there, due to lead's relative immobility in soils.[3]

Soil lead concentrations were determined using acid digestion of ground and sieved soil, analyzed via flame atomic absorption spectrophotometry. Samples were collected following a protocol developed at Argonne Lab.

No state has yet set standards indicating a safe or allowable level of lead in surface soil, although Minnesota is working toward such a goal: the legislature has requested the state pollution control agency develop a standard by January 1, 1988.[4] The Illinois study is not designed for setting a standard, but to provide observations of soil lead, collected consistently across the state, with associated data on automobile traffic.

No other study has included detailed analysis of suburban soils. The focus in the past has been on central cities[5,6,7,8,9] or, conversely, on crop land near major Interstate freeways.[10,11,12,13] In those studies, higher central city soil lead levels were related to the total lead emissions in central cities; rural soil lead levels were related to distance from one road. Prior research has not related observed surface soil lead levels to distance from, or traffic on, several nearby roads, nor distinguished the effect of traffic volume from that of traffic density. It was believed by public health specialists that the highest levels of exposure to lead would be exclusively in central cities because of higher traffic volumes there.[14] The Chicago area's suburbs are noted for high traffic streets; this is true for the suburbs of most of the very large metropolitan areas in the U.S. The traffic levels in many of Chicago's suburbs are higher than those found in the downtowns of many large cities.[15]

We expected the study to reveal patterns of lead concentration in surface soils, as related to traffic volumes, distance from the road, age of the park, and other physical features of the park; the patterns may prove useful in guiding more widespread soil testing for lead. It is not expected that we would be able to determine a safe level of lead in soil as a result of this study. Further research and policy analysis are required before such a decision could be made.

2 TRANSPORTATION, LEAD, AND CHILDREN

The pathway from lead in gasoline to lead in children's blood is complex, both because of topographic variations and climate variations, as well as relationship with traffic. The pathway for exposure has been determined by medical researchers, and public health specialists.[16,17,18] The likelihood of exposure and the number of children likely to be exposed to lead in soil in public parks, as well as the amount of exposure are yet to be quantitatively specified. The major effects are discussed here.

2.1 ONE EFFECT OF CHILD'S PLAY

Children are the population of special concern from exposure to lead. Lead is toxic to adults as well as to children, but the pathways to adults are fewer than to children. The primary reason is the behavior by children referred to as "mouthing behavior". As you can recall from your observations of any small child, the child's fingers, toys, many other objects are put into the mouth frequently. Children at some ages eat dirt directly. These are not behaviors of adults. This constitutes an extra and significant pathway for lead-contaminated soils to reach small children.

Children are of further concern because of their lower level of protection against a given amount of lead exposure. Given exposure to one gram of soil containing 100 ug/g, an adult will absorb approximately 8%, or 8 ug/g of lead, while a child will absorb approximate 6 times that much, 50 ug/g of lead.[19] As the child also has a lower volume of blood, the concentration in the blood is sharply higher in the child than in the adult. The development of the nervous system is influenced by the presence of lead in the blood. It appears that lead replaces calcium or iron in the blood, especially affecting the central nervous system development in deleterious fashion.[20,21] Children with poor nutrition are therefore at even greater risk of damage from exposure to lead. Calcium deficiency is common in lower income children, while iron deficiency is common in almost all children. Lower income children under the age of 7 living in areas with high traffic are at higher risk than other classes of children. It has further been suggested that black children may be more susceptible to damage of lead than are white children.[22]

The U.S. Environmental Protection Agency (EPA) has estimated that in 1986, 176,000 children over 6 months old would have blood lead levels exceeding the standard set by the Centers for Disease Control (CDC) (25 ug of Pb/dl of blood).[2] These children are susceptible to the health effects described above, including diminished cognitive abilities. In the city of Chicago alone, over 1600 children were found, in 1985, to have elevated blood lead levels, above the previous CDC standard of 30 ug of Pb/dl of blood.

The serious nature of the effects of lead on children, at such critical stages of their intellectual development, makes an almost overwhelming case to remove lead from the environment. Removal of lead from many products has been beneficial, as evidenced by falling concentrations of lead in air. Lead will continue to be controlled throughout industry, from paint manufacturers to gasoline refiners; however, the residuals of past practice are still with us, leaving us with a measurement and, perhaps, a clean-up problem in the future.

2.2 "ETHYL" GASOLINE

Once the internal combustion engine automobile took off as the most popular form of motorized travel, the demand for high performance fuel soon followed. Early engines required high octane fuel to burn smoothly and eliminate knocking in the engine. Knocking affects driveability of vehicles in the short-term. To answer that need, General Motors researchers discovered that tetraethyl lead added to gasoline greatly enhanced the octane level of the fuel and opened the door to development of higher compression engines. (Octane refers to the ability of the fuel to ignite in a predictable fashion). To keep the lead from building up in the engine, bromine and chlorine compounds were added to scavenge lead out of the engine and assure its passage into the environment. A certain amount of lead build-up was tolerated in the engine, and even needed for lubrication, but is no longer needed since the advent of hardened valve seats.[24]

The discovery of lead's octane-enhancing properties in the early 1920s was a boon to the fuel industry, but the toxicity of lead was being re-discovered at the same time, in lead mines and battery plants. An alarm was raised even at that time about the use of lead in gasoline, as documented in a detailed review of the introduction of leaded gasoline in the U.S.[25] There was extensive debate that lead would be too hazardous for widespread use, according to that review. The final judgment on lead, at least by the auto industry in 1923, was that the toxic effects of carbon monoxide, also a by-product of combustion engines, were greater than those of lead; therefore, lead toxicity was not a serious problem. The federal government agreed with the auto industry. Thus the search for alternatives to lead was laid aside for many years, as this judgment valuing lead's benefits over its costs was institutionalized. Because the public was learning about the very serious effects of lead on miners, the industry coined the term ethyl gasoline, rather than leaded gasoline. The marketing of the fuel promoted the advantages of smoother burning for engines requiring extremely high octane (as high as 95 compared to the 87 - 91 now required).

This inauspicious beginning was all but forgotten until the late 1970's, when mounting evidence of pervasive lead in the environment was pointing back to the automobile as a significant source of lead. In the 1970's, devices to control pollutants from internal combustion engines, including the noxious carbon monoxide, had the characteristic that lead particles in the exhaust would disable the devices. This requirement spurred refiners to develop fuels using other octane enhancers than lead. The decision to develop unleaded fuels was at first strictly based on the inability of a catalytic convertor to tolerate any kind of particles in the exhaust. This was somewhat of a serendipitous event, given the growing body of knowledge implicating leaded gasoline as a source of environmental lead exposure.

2.3 URBAN, SUBURBAN AND RURAL TRAVEL

The other piece in the puzzle of children's exposure to lead from combustion of leaded gasoline is the amount of traffic near the children's homes and schools. Historically, public health specialists have zeroed in on the central cities of urban areas as the best place to study children and their environments, and to break the pathway of lead from the environment to the child. Efforts focused on the central cities were quite sensible, since lead-intoxicated children were frequently found in central cities. Several major cities began screening programs after a simple blood test was developed. Many cases of lead intoxication were discovered in this fashion, further confirming the importance of central cities. Other less populated areas also had screening programs, but on a much smaller scale.[26] The biggest problems were clearly likely to happen in urban areas, because industrial sources and paint sources are added to possible traffic-related exposures.

Traffic in suburban areas, particularly very large metropolitan areas, can be as high as that in urban areas, however. In fact, the only substantial difference between the suburban and central city traffic situations in Chicago is the density of traffic, or vehicle-miles of travel per unit area. The Chicago area is deemed an excellent subject for study, as its suburban counties experience very high traffic, including many arterials with over 30,000 vehicles per day, and freeways with 40,000 vehicles per day and up. As in the central city of Chicago, parks are distributed throughout the region, near low-traffic as well as high-traffic roads.

Rural locations are distinctly different from urban areas in the level of traffic. Both volume of traffic (average daily traffic) and the density (vehicle-miles of travel per square mile) show a sharply lower profile than in more densely settled areas. Small cities throughout the downstate portion of Illinois (all of Illinois beyond the six-county Chicago area), are characterized by low density development. Some downstate towns have been active much longer than some Chicago area suburbs have been developed, perhaps influencing lead accumulations.

The relative accumulation of lead along various roadway types, assumed proportional to lead emissions on the roadway,[27,28] is displayed in Figures 1 and 2. In the first figure, the effect of traffic volumes and speed of traffic on lead production by a road carrying all lead-gasoline-fueled vehicles are shown. A reference situation of 2 g/gal of lead in the gasoline is assumed as part of the calculation to show the relative total lead production along different roads. The calculation assumes an average speed approprpiate to each arterial or freeway traffic volume, ranging from 12.5 to 45 mph (20-72 km/h), and fuel use equations based on the assumed speed and traffic flow conditions. It is quite clear from this figure that volume has the dominant effect, rather than speed. At volumes that could occur both on very busy arterials and moderately busy freeways (30,000 to 50,000 cars per day), average speed does have a noticeable effect on total lead emissions. However, even the improvement from steady-speed operation does not compensate for the effect of volume. That is, a 40,000 vehicles/day road produces more lead than a 20,000 vehicles/day road regardless of average speed.

The second figure (Figure 2) provides an index of the effect of traffic volumes growing over time. The bars reflect the changing amount of lead per gallon of gasoline over time, the share of fuel that was leaded, and vehicle-miles of travel. Half of the lead deposited since 1924 was deposited after 1964.[29]

3 A PATTERN OF LEAD IN SURFACE SOILS IN ILLINOIS PLAY AREAS

The study undertaken in Illinois will help to determine patterns of lead in typical play areas, a difficult objective. There are very many factors influencing surface lead concentrations. The essence of our observations are presented in this section. As indicated in the introduction, the present study does not delve into all of the possible issues and does not begin to address the issue of an exposure model to small children. As such, the results presented here are somewhat limited relative to larger issue of the child-lead problem.

3.1 TYPICAL PLAY AREAS

Over 150 parks were sampled statewide for this study. Most sampled parks throughout the state are located near roads with less than 5,000 vehicles/day on them. This is the dominant pattern for downstate parks, very prevalent for parks in the City of Chicago, and least prevalent for the parks we sampled in the suburbs. It should be kept in mind that ours were not randomly selected parks; parks were selected because of the proximity to roads, use of soil in the play area, and inclusion of a play area for small children.

The layout of parks varied across the state. In some cases, the children's play area was located in the center of the park, far from any border street. In others, by contrast, the small children's play area was adjacent to a major arterial street bordering the park. Some of our locations were day care centers, school yards, or state parks; we also included a couple of roadside parks in rural areas. The day care centers were systematically different from the parks, in that there was a building 20-50 ft (6-15 m) from the play area in all cases. It was rare for the play area in a park to be located near (less than 2 m away from) a field house or any other type of structure. School yards were similar to day care centers, in that there was usually a building between the play area and the road.

These differences in the layout of the park clearly will yield differences in the surface soil concentrations. Distance from roads is anticipated to have a major effect on accumulations of lead in surface soils. It has also been observed that lead concentrations are higher in soil very near a building; this is caused by the washdown during rainfall of particles that have accumulated on the building prior to the rain.

Other features were also anticipated to influence lead concentration, such as sampling within the dripline of a tree, or near any other source of lead. We tried to stay away from other sources of lead, since our goal was to find gasoline lead. This goal was largely met, in that only one site was closer than one mile to an industrial source of lead, and that particular site showed very little evidence of accumulation. We also have a limited number of samples within two meters of any building, and a small number that were under the dripline of the tree. Surface accumulations under the tree could be expected to be higher than beyond the tree, as the leaves collect particles, including lead-bearing particles, from the air that are then deposited on the soil at the time of leaf fall in autumn.

Vegetation on the soil surface may also play a role in determining the surface soil concentration of lead. This effect is not as clear-cut. Vegetation covers the soil surface, inhibiting direct contact of airborne lead on the soil, but vegetation has a greater surface itself to catch lead, which then can be washed into the soil by rain.

The level of traffic on perimeter streets for each sampling location is shown in Figure 3.

3.2 CENTER CITY, SUBURBAN AND DOWNSTATE TRENDS

We were interested in observing whether parks in suburban areas were more similar to those in the center city or in downstate communities. In our study, suburban lead concentrations were between that of center city and downstate, but generally closer to the results of the center city than those of the downstate locations. The reasons for this pattern are not entirely clear. Density of traffic activity appears to be important; however, the underlying distribution of lead in the soil (measured at 10 to 12 in or 25-30 cm below soil surface), appears to play an important role in determining surface level. The mechanisms relating surface to depth measurements are not clear at this time.

The differing distributions of the surface samples concentration of lead is highlighted in Figure 4. The figure shows that each area shared the same right-skewed distribution of concentrations, and that the peak lead concentration values in the city and the suburbs were both quite high (over 1000 ppm). The center city parks had the highest values on average, closely followed by the suburban parks. The first research question is answered: the accumulation of lead in high traffic suburban parks is higher than in rural locations, but not quite as high as in the central city. All areas had average surface values higher than the approximate U.S. natural background level of 16 ppm lead.[3] There is a significant level of accumulation of lead in suburban soils, about equal to the accumulation in center city soils, although absolute concentrations in center city soils were generally higher than those in suburban soils for reasons not yet fully understood. Whether the accumulation at <u>any</u> level has substantial effects on small children remains to be determined.

3.3 RELATIONSHIPS BETWEEN TRAFFIC AND SOIL LEAD ACCUMULATION

Our expectation before the start of the study was that distance from roads would have a major positive effect on lead concentrations, and that the volume of traffic on nearby roads also would have a positive effect, but probably smaller than the first cause. As shown in Figures 5 and 6 these expectations were born out. However, the standard deviation on each of the means is extremely large. Further examination of the difference between the means have indicated that only a few of these differences are statistically significant. Most surprising is that the highest-traffic roads, at over 50,000 vehicles/day, are not associated with the highest surface lead levels, apparently due to different dispersion patterns near those roads.

4 STANDARDS FOR LEAD IN SOIL

Although there have been many standards set for the usage of lead in various industries, there have not yet been any national standards for lead in soil, nor any state standards. The standard for lead in gasoline has recently been lowered, which should end soil accumulation of lead. The lead already in the soil will not disappear without some action, however, so states are now grappling with the issue of a safe level of lead in soil.

4.1 U.S. EPA'S REGULATION OF LEAD IN GASOLINE

The Environmental Protection Agency in the U.S. became aware of the connection between gasoline lead and lead in the blood of small children in the middle to late 1970s. They were already aware of the need to remove lead from gasoline, because the pollution control devices needed for reducing emissions of carbon monoxide, hydrocarbons, and oxides of nitrogen could not tolerate lead in the exhaust. In 1974, unleaded gasoline was introduced in gasoline service stations throughout the United States.

Further awareness by the EPA of the seriousness of the health effects of lead, and the growing evidence connecting gasoline lead to lead in the blood of small children, led EPA to promulgate a regulation limiting the amount of lead allowed in leaded gasoline.[2] The U.S. began a phasedown of allowable lead in leaded gasoline, from 1.1 g/gal to 0.5 g/gal on July 1, 1985. This was further reduced to 0.1 g/leaded gal on January 1, 1986, constituting a 90% reduction in allowable lead in gasoline. The level of 1.1

was set in 1982, a reduction from the days when two to three grams of lead per gallon had been common. The combination of the increased usage of unleaded gasoline, and the 90% reduction in the allowable lead in leaded gasoline, has essentially removed gasoline as a source airborne lead within the U.S. (although EPA is still considering a complete ban on the use of added lead in gasoline). The problem then facing the U.S. is how to deal with the lead that has already been dispersed in the environment.

4.2 STATE STANDARDS FOR SOIL

States are actively considering the need for standards for lead in soil. In Illinois, when a child has been found to be intoxicated with lead (at a level above the Centers for Disease Control standard now at 25 $\mu g/dl$), and the soil in the child's yard is found to be above 200 ppm, that soil must be removed, and replaced with less toxic soil or another material. This regulation is very recent and has been invoked only a few times.[30]

As mentioned in the introduction, the state of Minnesota is actively developing such a standard, expecting to collect thousands of soil samples statewide within the next year. Wisconsin is also actively considering this issue, and analyzing soil samples within the state.

The states will need to establish the exposure model to determine their standards. But considerable activity will be taking place in the near term, to determine whether there is a problem, and if so what are the best actions to take to deal with the problem.

5 WHAT IS NEXT?

Although this study has produced invaluable information on soil lead levels throughout Illinois, many questions are left unanswered. This study however, provides the basis for raising those questions, moving on to the important questions of exposure.

5.1 DETERMINING THE HEALTH RISKS OF GASOLINE LEAD

Once it is established that there is sufficient lead in soil to reach small children, the larger and more important question must be answered. What is the risk due to this source for small children? It must be determined how often a child will be in the play area, how long and to how many other exposure sources will the child be exposed that day. It must also be decided what is a reasonable estimate of ingested soil for a child on a typical day, in a typical park. Some studies have suggested that a child exposed to 60-100 µg/g lead via ingestion could expect blood lead in the range from 17-57 µg/dl; ingestion of 50 mg of soil during play due to mouthing behavior is not unexpected.[8] This type of relationship must be melded with data on frequency and duration of use of parks, as part of the research supporting the standard-setting process.

5.2 IMPLICATIONS FOR OTHER AREAS

The pattern of higher accumulations in suburban locations in Illinois may suggest that other high-traffic suburban areas warrant a survey of soils in play areas. Of course, this suggestion is made without placing a value on the importance of the levels observed in Illinois, because risk assessment has not yet been done. Other states may find it of value to survey their states in this fashion, or in the more detailed method being used by Minnesota. The relationships seen in the Illinois study are not unexpected. Relatively high traffic roads, above 20,000 vehicle/day, definitely have generated greater lead burdens in nearby soils, than did local roads of much lower traffic levels. There appears to be a strong areawide component, however, to the surface lead concentrations. Understanding of these relationships will be enhanced by better knowledge of the interconnection among surface and sub-surface soils relative to lead concentration.

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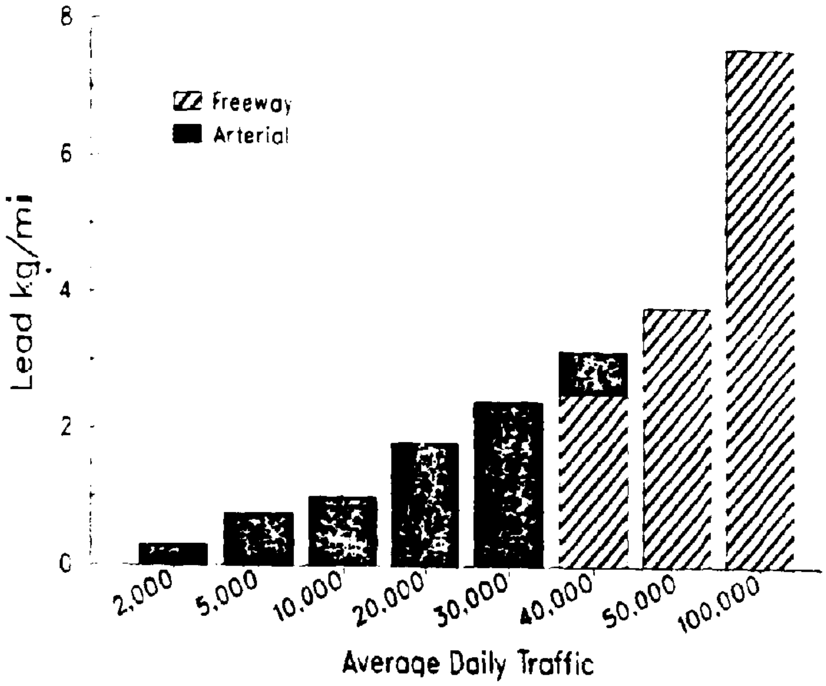

FIGURE 1 Relative Lead Emissions on Urban Roads

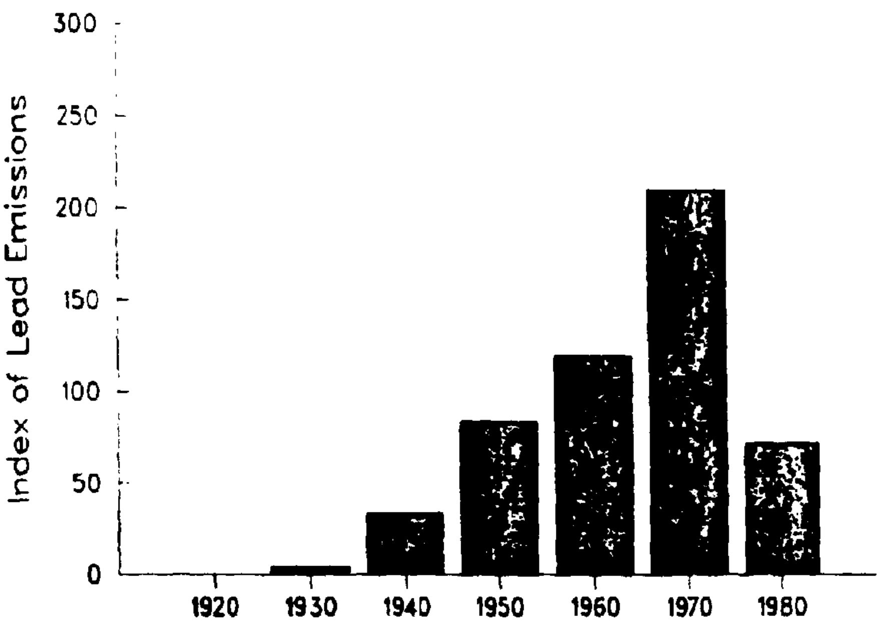

FIGURE 2 Relative Emissions of Lead from Gasoline-Fueled Vehicles in the USA 1920-1980

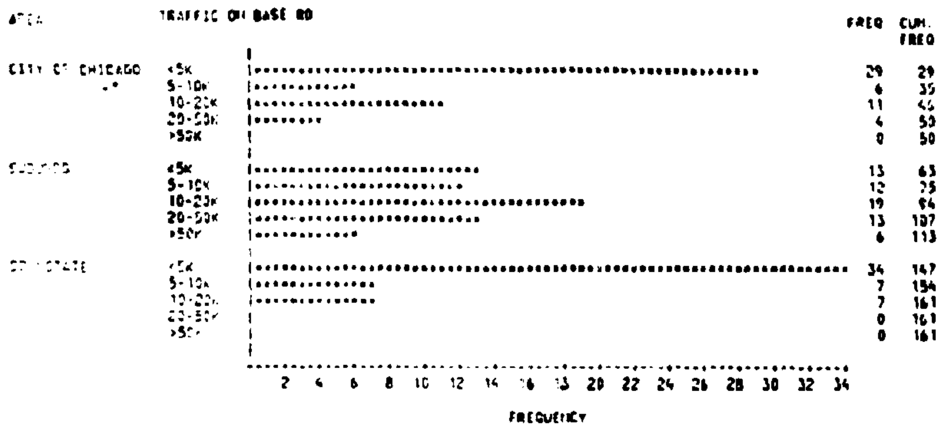

FIGURE 3 Number of Parks in Illinois Study by Traffic on Adjacent Road in Illinois

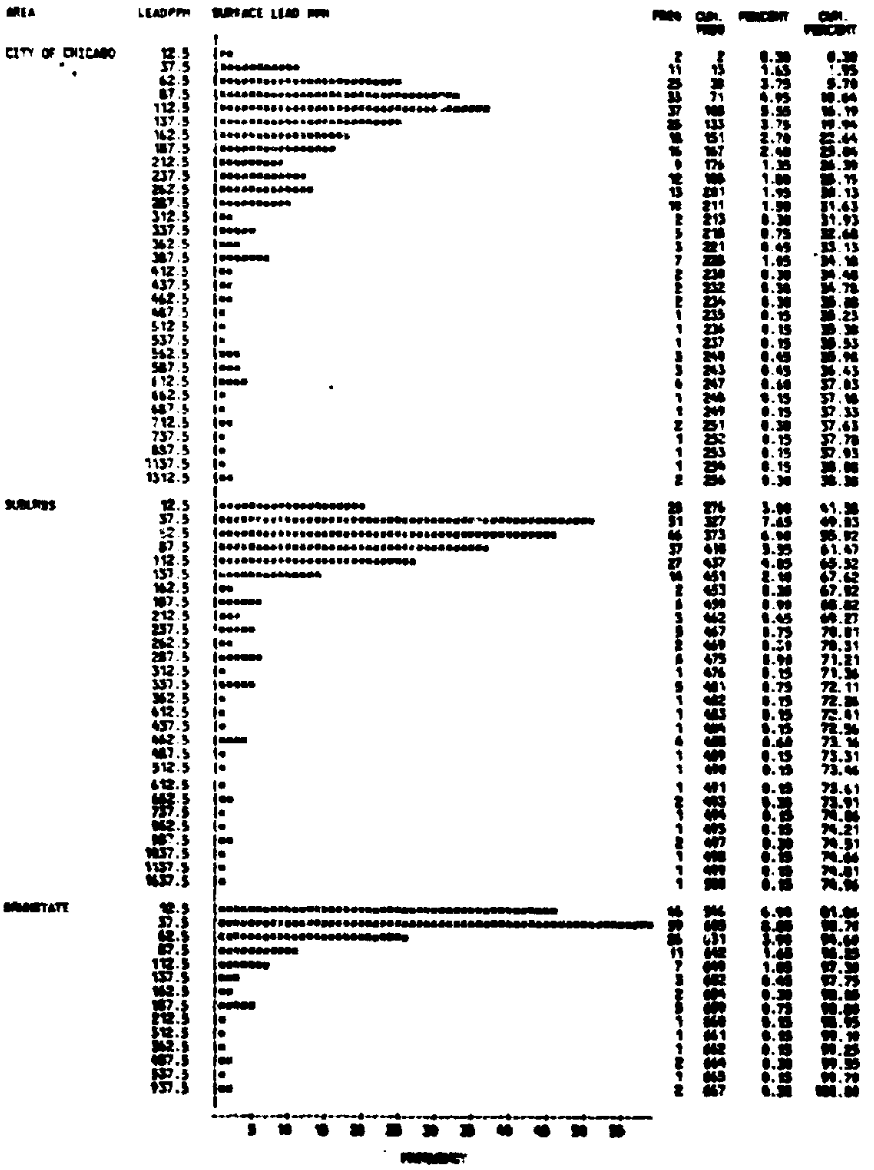

FIGURE 4 Distribution of Lead in Surface Soils in Illinois Play Areas

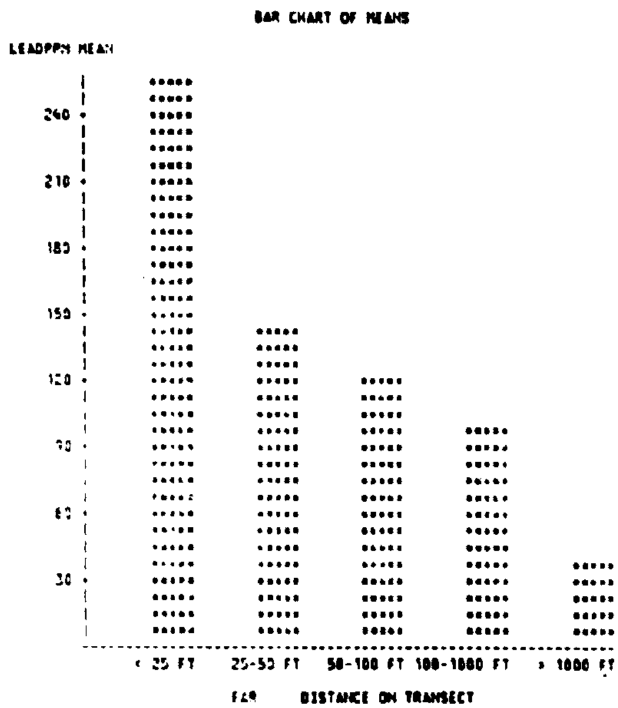

FIGURE 5 Mean Lead in Surface Soil by Distance from One Perimeter Road

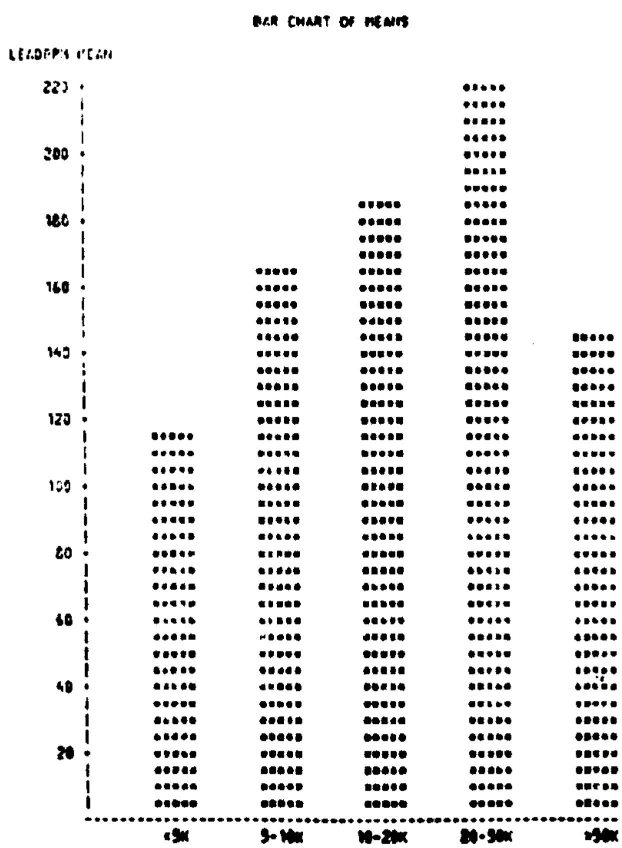

FIGURE 6 Mean Lead in Surface Soil by Traffic Volume on One Perimeter Road