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January 11, 1995

Ms. Susan Pastor
Community Relations Coordinator
Office of Public Affairs (P-19-J)
U.S. EPA Region 5
77 W. Jackson Blvd.
Chicago, IL 60604

RE: Public Comments - NL Industries/Taracorp Superfund Site

Dear Ms. Pastor:

On behalf of the City of Granite City, enclosed please find the comments of the City of Granite City, as well as the separate comments of Alderman Craig Tarpoff. Also for filing are the following studies/reports and articles:

1. Response to Comments of U.S. EPA Reviewers Regarding the Granite City Lead Study Draft Report, by Dr. Maurice LeVois, dated July 21, 1994;

2. Review and Comment of the Preliminary Assessment of Data from the Madison County Lead Study and Implication for Remediation of Lead Contaminated Soil, by Dr. Renate D. Kimbrough;

3. Management of Children with Slightly Elevated Blood Levels, by Dr. Renate D. Kimbrough, et al;

4. Survey of Lead Exposure Around a Closed Lead Smelter, by Dr. Renate D. Kimbrough, et al;

5. Report on Traffic Related Issues, prepared by Crawford, Bunte, Brammeier;

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6. Summary Report - Evaluation of USACOE Remedial Action Program, Granite City, Illinois, by Jonathan Spencer, P.E., DEE Vice President-Engineering Services, Earth Sciences Consultants, Inc.;

7. Economic Impact Assessment of the Proposed Clean-up in Granite City, by Dr. Geoffrey Hewings, PhD., Professor in the Departments of Geography and Urban and Regional Planning at the University of Illinois; Director of the Regional Economics Applications Laboratory.

Sincerely,

Edward C. Fitzhugh Jr.

ECF/jlg
Enclosure

15142

NL INDUSTRIES/TARACORP SITE

COMMENTS TO PROPOSED PLAN

Introduction

In March, 1990, the United States Environmental Protection Agency (U.S. EPA) issued a Record of Decision (ROD) for the NL Industries/Taracorp Superfund Site located in Granite City, Illinois. The U.S. EPA requires a soil clean-up level for lead of 500 parts per million (ppm) of approximately 1,300 properties in a 55 block area. The site includes a secondary smelter facility, which has not been in operation since 1983, and which is claimed to be the source of lead contamination in the soils in the area. The majority of the properties proposed to be cleaned are residential, and the remaining properties are commercial and industrial. Near the smelter facility on the site is a pile composed primarily of blast furnace slag and battery case material. The volume of the pile is approximately 85,000 cubic yards.

In October, 1994, the U.S. EPA issued a proposed plan whereby the agency indicated a consideration of the soil clean-up level for lead of 500 ppm, and indicated further that it had yet to make a decision concerning the pile. Public comments were invited.

The City of Granite City has remained steadfast in its resolve to assure that any remediation strategy employed by the U.S. EPA take into account the health and safety of its citizens, and the overall well being of the City. This was true in 1990 and is equally true in 1995. Through two mayoral administrations and

numerous changes in the City Council, the City's resolve has remained unchanged. The City has been active in the pending litigation, including requesting injunctive relief in August, 1994 to prevent the unanticipated and inappropriate residential soil clean-up. The City has retained qualified experts in numerous fields of study to guide it in its decisionmaking, and most recently sponsored an environmental sampling study of the seventeen residences that were subject to soil remediation during the fall of 1994.

Notwithstanding the plight and circumstances of the very citizens it purports to protect, the U.S. EPA is prepared to go forward with a clean-up of soils that will not result in any material benefit to the health of the citizens, cause hazardous conditions to prevail within the City, dramatically affect the social and economic well being of the City, and create an unnecessary stigma that will thwart the social and economic growth of the City.

Health Study

Based upon a review of the documents and information provided in the ROD, in particular the Madison County Lead Exposure Study, (Health Study), the U.S. EPA cannot justify the 500 ppm clean-up level being proposed. The Health Study substantiates there is no valid nexus between a clean-up at that level and a reduction in blood lead levels in children, which are considered to be the population sub-group that is most at risk with regard to soil lead

contamination. (Indeed, as demonstrated elsewhere, a clean-up at the 500 ppm level as proposed by the U.S. EPA will prove to be injurious to the health and safety of those very citizens intended to be protected.)

In fact, and as proven by the Health Study, the level of blood lead in children in Granite City is no different than any similar group in urban areas. The mean blood lead level of the 490 children younger than six years in the Health Study was below the Center for Disease Control's (CDC) level of concern. Even for the children who had elevated blood lead levels (78), the majority of their blood lead levels was less than 25 mg/dL, which was the CDC level of concern until 1991.

Most of the houses in the community that were subject to the Health Study were built before 1920 and had high lead paint levels, both in the interior and exterior of these homes. High levels of lead were also found in many house dust and soil samples. These factors should have been evaluated by the U.S. EPA to determine the proportional contribution of lead from all sources. Had they been considered, the only conclusion that could be reached was that lead paint was a major contributing factor whereas soil lead was relatively insignificant. In this regard, the Health Study validates the impropriety of remediating soils at the 500 ppm level.

The U.S. EPA has attempted to rebuke the Health Study in its "Comments on Madison County Lead Exposure Study, Granite City,

Illinois" by A. H. Marcus, et al and its "Preliminary Assessment of Data from the Madison County Lead Study and Implications for Remediation of Lead-Contaminated Soil" by A. H. Marcus. However, neither analysis has any merit as proven by the memorandum from Dr. Maurice LeVois to Dr. Tom Long dated July 21, 1994, "Response to Comments of U.S. EPA Reviewers Regarding the Granite City Lead Study Draft Report" and the comments from Dr. Renate D. Kimbrough, reviewing and commenting on Dr. Marcus' preliminary assessment study. It is apparent that the U.S. EPA reviewers do not understand the application of the hierarchical regression model and, accordingly, any of the U.S. EPA's comments regarding same should be ignored. Additionally, the U.S. EPA reviewers failed to comprehend the nature and significance of the data and its relation to the study conclusions. For example, while children living closer to the smelter had higher blood lead levels, these children lived in houses that were poorly maintained and which contained higher concentrations of lead in paint, as compared to children living further away from the smelter. It was not the distance to the smelter that presented a strong correlative factor with regard to blood lead levels, but rather the quality of the housing stock and the high lead levels in interior and exterior paint that influenced the blood lead levels. The Health Study which is already part of the record, is also described and its results explained in two separate articles in "Pediatrics", Management of Children with Slightly Elevated Blood Lead Levels, and "Survey of

Lead Exposure Around a Closed Lead Smelter", both authored by Drs. Kimbrough and LeVois and David Webb, M.S.

The U.S. EPA's reliance on the IEUBK model to justify the 500 ppm level of clean-up is inappropriate and gross in its application in this instance. The U.S. EPA has chosen to rely upon a faulty model, as described in the comments by Dr. Gary L. Ginsberg, et al "The Granite City Lead Exposure Dataset: IEUBK Modeling and Evaluation of Soil Lead as a Risk Factor", filed as part of this record. First, the U.S. EPA has chosen to ignore site specific data, which is provided in the Health Study, in deference to the model. Second, the model does not take into account or consider lead in paint, which is a major contributor of lead in house dust. Logic dictates a conclusion that a model which does not take into account a major contributing lead source, is intuitively deficient.

Rather than duplicate comments to be part of the ROD, the City of Granite City joins in the comments made by the PRPs relating to the impropriety of the selection of the 500 ppm level and use of the IEUBK model.

Waste Pile

The remediation strategy now being considered by the U.S. EPA is additionally deficient as there is no proposal with regard to the pile. Information obtained from U.S. EPA representatives indicates that a decision on the pile was not made a part of the amended ROD because of the lack of valid information from contractors as to the cost of either capping or removing the pile.

Setting aside that reason as a valid justification for not making a decision with regard to the pile, it would be improper and illegal to consider any remediation strategy until such time as a decision is made with regard to the pile, by the U.S. EPA.

The pile is vast in terms of its dimensions, as well as the concentration of lead where in many parts it is as much as 300,000 ppm lead. The record already demonstrates the amount and density of lead in the pile that is to be capped or removed. Whether the final remediation strategy is to cap or remove the pile, either effort will result in the use of heavy equipment, including trucks and excavation machinery, over an extended period of time, which will cause significant health risks to the population and be injurious to the City's social and economic well being. The heavy machinery, trucks and excavation equipment will cause airborne dust emissions containing lead to infiltrate the air in the surrounding community. Further, as the heavy machinery, trucks and excavation equipment transport materials and soil and move about the streets and avenues of the City, additional contaminated soils will transverse throughout the City. The U.S. EPA has yet to substantiate <u>how</u> it will be able to proceed with either capping or removal of the pile in a way that will not result in a contamination of surrounding properties and/or a recontamination of properties already cleaned.

<u>Impact to City</u>

The U.S. EPA's failure to make a decision concerning the pile will prove to be damaging to the City's social and economic well

being, as will the decision to rely upon the 500 ppm standard. Essentially, the U.S. EPA proposes to remediate hundreds of properties, which will literally take years, and then at some point in time decide what to do with the pile. Thereafter, whatever action is contemplated for the pile, there is a likelihood those actions will result in a contamination or recontamination of properties that surround the smelter facility. This action may result in a remediation of these properties once more. This kind of bureaucratic redundancy will affect the City's ability to survive economically. A municipality faces a difficult task of dealing with the social and economic stigma that results from any U.S. EPA clean-up, let alone having to face the same consequences twice. Yet, this is the course the U.S. EPA has chosen for Granite City.

Dr. Geoffrey Hewings asserts the U.S. EPA's remedy may reduce property values in the City of Granite City. Of course, this decrease will effect the residents directly, as many now are unable to move from the area without suffering a great financial loss on the sale of their homes. These decreased property values will likely continue during the time the U.S. EPA expects to complete the remedy which, based on the time used thus far, will take at least ten years.

The magnitude of the proposed remedy will also effect business and other commercial interests in the downtown area, as increased traffic, congestion, and delays will result. Rather than deal with

these inconveniences, customers and other visitors will likely do business elsewhere, resulting in an adverse effect on the businesses and commercial interests in the downtown area.

The impact on decreased property values and less business will have a proprietary impact on the City of Granite City in the form of decreasing tax revenues. As property values and the number of valuable businesses decrease, tax revenues will also decrease. This chain reaction will result in less revenues to provide for municipal services to the citizens of the City.

Jonathan Spencer, Vice President of Engineering Services for Earth Sciences Consultants, Inc., in his summary report, concludes that their are a "number of serious concerns regarding the ability of the program to control lead exposure in the community and to do so in a cost effective manner". Based on his review of the activities to date, it is reasonable to expect a contamination of clean areas outside the active work zone and a recontamination of areas previously clean. Mr. Spencer, consistent with the observations of Drs. Kimbrough and LeVois, notes that the problem of lead base paint on the interior and exterior of the homes is not being addressed by the U.S. EPA. Thus, removing soils will have no consequential impact on the blood lead levels of the children, in particular, and the residents in the homes because the major lead source continues to remain.

Finally, Mr. David Brammeier prepared a study on traffic related issues, and he identified specific problems within certain

areas of the 55 block clean-up area. In particular, Mr. Brammeier expressed concern over the clean-up in and around St. Elizabeth's Hospital in Granite City, which is the City's second largest employer. The clean-up in this area is exacerbated by the numerous one way streets and narrow streets that surround the hospital. Furthermore, he anticipates that the activities in question will require the displacement of much on street parking. This results in not only in inconvenience to the citizens, but creates a potential for vehicular and pedestrian accidents.

To date, based on the limited activity engaged by the U.S. EPA, there is already strong evidence that traffic congestion will create havoc. A number of streets and alleys have been blocked, or partially blocked, for weeks and months at a time. Furthermore, the use of such trucks, and machinery and excavation equipment, hinders the visibility of drivers and pedestrians, which may amplify the opportunity for serious or even fatal accidents.

Again, to date, the City is very much aware of the not just the potential for damage to its infrastructure, but knows it to be an actuality. Already the limited remediation activities by the U.S. EPA have resulted in damage to a number of sidewalks on City property, as well as damage to sidewalks, concrete fixtures, fencing, and shrubbery of those residences being cleaned. Magnifying this activity over 1,300 properties results in significant damage to the infrastructure, which cannot be condoned under the premise of the remediation strategy now being considered

by the U.S. EPA.

In summary, the City of Granite City opposes the remediation plan being considered by the U.S. EPA, in particular the use of the 500 ppm standard for soil lead removal and the failure to address the pile.

Respectfully submitted,

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Attorney for the City of
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15096

MEMO TO: Tom Long

FROM: Maurice LeVois

DATE: July, 21, 1994

SUBJECT: RESPONSE TO COMMENTS OF U.S. EPA REVIEWERS REGARDING THE GRANITE CITY LEAD STUDY DRAFT REPORT

The subject review document is presented in two parts. The first part is a lengthy and detailed discussion, termed a "general issues" section. The second part of the review document contains specific comments. However, the 'general' comments section actually recapitulates all of the specific comments contained in the second half of the document. In order to facilitate understanding the relationship of the comments and responses, the responses presented below are numbered so as to correspond to the numbered comments in the general issues section.

1.1 Participation by zone has already been presented.

We made an extra effort to recruit in the high soil lead area - phone calls to residents started with this area, continued throughout the study.

1.2 The term "control group" implies that there is a clear definition of what, how, and why we are controlling by design or analysis strategy. In this case Pontoon Beach was different with respect to SES and living conditions (e.g. newer homes; a trailer park). They were not comparable to residents in our main study area (composed of old houses situated near the proposed cleanup area). Residents from neighboring areas of Granite City were far more comparable to our target group, and therefore, provided the best frame of reference for evaluating the effects of soil lead.

Use of a "control group" is actually an error in the design of studies of the effects of residential lead, unless it can be shown that the control group is like the study group in every respect except soil lead level. Our sample of subjects drawn from a more homogenous population spread over a distinct gradient of soil lead levels is the only sensible study design under these conditions.

1.3 Re-sampling of blood lead, combined with counselling intervention, resulted in a greater drop in blood lead than expected.

2.1 It was the EPA that developed the protocol for sampling house dust. The EPA developed criteria for evaluating the qualifications of prospective contractors, and selected the contractor who did the work. The EPA has all of the environmental data.

2.2 Again, the EPA developed the protocol for sample collection and QA/QC. The EPA selected and supervised the contractor that collected the samples. The EPA has the data.

2.3 Again, the EPA developed the protocol for sample collection and QA/QC. The EPA selected and supervised the contractor that collected the samples. The EPA has the data.

Unfortunately, some copies of our report were inadvertently distributed without an 'Appendix A' (the EPA soil collection protocol). That appendix is attached to this document as 'Attachment 1' to aid those reviewers who did not receive a copy of Appendix A earlier.

Ten soil samples were collected from the primary play areas in the yard around each house. No soil samples were taken from within the drip line of the house. A composite soil sample was made from the ten samples. This procedure should have yielded a representative soil sample from the yards and play areas. Since the great majority of the yards were very small, it is highly unlikely that the soil sampling protocol could have yielded unrepresentative soil lead results.

2.4 In both the inside (CI=1,2,3,4) and the outside (CO=1,2,3) rating of the condition of the house, the higher score was for the worst condition. This is a routine rating used by certified contractors specializing in lead paint inspection programs.

3.1 Although it is potentially useful to know that blood lead peaked in our study sample at around two years of age, the simple descriptive statistics that we present convey this information most directly. The simple graphic we present shows exactly at what age, and at what level, blood lead levels peak. It also shows the slope of the decline with age. Compared with this graphic presentation, the quadratic regression term recommended by the reviewer would have no meaning to most readers of the report.

Employing an nonlinear age covariate in blood lead regression models could increase slightly the amount of blood lead variance accounted for by age. That would have the effect of reducing slightly the amount of variance in blood lead remaining for other variables, such as soil and dust, to explain. However, including a quadratic expression for age would not appreciably change the overall blood lead R^2, nor would such a term improve our understanding of the influence of age or soil on blood lead.

3.2 The fact that our subjects lived in irregularly shaped residential areas, at varying distances form the closed smelter, is a strength, not a problem, in this study. None of our analyses, besides those involving distance from the smelter, depend in any way upon spatial location.

Soil lead is not uniformly distributed around the closed smelter either. Although soil lead levels decrease with distance from the closed smelter, there are hot spots and irregularities in the soil lead distribution throughout the study area. The sampling areas (zones 1--4) were used only to obtain a representative sample of homes and children across the entire range of soil lead levels, regardless of location. Neither distance, nor any other location variable, enters into the main multiple regression/correlation analysis - the point of which is to use the joint distribution of blood, soil, paint, dust, and water lead measures in the homes and yards of study participants, regardless of location, to understand how the variables are associated with one another.

The spatial distribution of blood lead is of interest because it can sometimes help to locate and explain clusters of high blood lead cases. That is why we depicted the physical location of the subjects in the study area. However, it was shown that distance is associated not only with soil lead and blood lead, but with SES, building condition, behavior, and other factors that influence blood lead. Simultaneous spatial depiction of all of these factors cannot be interpreted. That is the role of multiple regression/correlation analysis. The problem with the unadjusted bivariate tabulation presented by the reviewer in TABLE 1 of the EPA comments is that it totally ignores confounding by these other factors, which we have shown to be present.

3.3 This section presents a false and ridiculous argument. The reviewer took a meaningful linear multiple regression equation, mistakenly attempted to exponentiate the entire equation, and transformed it into a meaningless expression. The reviewer obviously misunderstood both the use of logs of the environmental and blood lead variables, and the meaning of the original regression equation.

First, it should be understood that the use of log-linear transformations made only a small difference in any of the analyses. However, since the environmental and blood lead measures were not normally distributed (they were skewed, with a few extreme high values), log transformation of the raw values resulted in more nearly normal distributions, and some improvement in the blood lead variance accounted for by the environmental measures. The methods used to analyze these continuous variables assume normal distributions of the variables, although the methods are robust enough to permit fairly radical departures from this assumption.

3.4 The statements in this section are also false, and indicate a lack of understanding of hierarchical regression. The reviewer incorrectly states that R^2 is not a "measure of effect", when the opposite is true.

> "..., one of the most attractive features of MRC is its automatic provision of proportion of variance and correlation measures of various kinds. These are measures of 'effect size,' of the magnitude of the phenomena being studied."
>
> Cohen and Cohen, in *Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences*, John Wiley & Sons, New York, 1975. p. 5-7.).

In our regression analysis of soil lead and blood lead we avoided including variables that could possibly confound the soil/blood lead relationship if including the other variables could over adjust (reduce) the size of the soil lead effect. The argument presented by the reviewer makes the incorrect assumption that including other variables might have increased the soil lead contribution. That is impossible. Every "adjustment" variable included in the regression model ahead of soil lead would necessarily account for some additional portion of the blood lead variance, thereby further reducing the variance left for soil to account for.

The reviewers do not appear to understand that the parameter estimates in our report (e.g in Table 10). Parameter estimates found at the final step in any stepwise multiple regression procedure capitalize on chance, and are not reliable. They should not be interpreted out of context. Stepwise procedures are only an aid in early exploration of the data, to be used along with careful consideration of the simple correlation matrix, and to be interpreted in the context of the earlier steps of the procedure, in which other variables enter and leave the equation.

The individual parameter estimates in any single step of a multiple regression model do not adequately express the adjusted contributions of the main study factors. In multiple regression, there is no substitute for set-wise hierarchical regression when attempting to adjust for possible confounding.

3.5 Pathway analysis as proposed is a subjective exercise that depends upon the assumptions of the analyst. We presented all of the descriptive statistics, bivariate statistics, and multivariate statistics used in our interpretation of the data. In particular, we described the importance of paint as a major contributor to dust lead in our study.

The point of Table 12 is missed entirely by the reviewer of this section, who misinterpreted the parameter estimates for paint,

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dust, and soil presented in the second model. The correct interpretation of this analysis rests on the increment in R^2 when soil is added to Model 1.

In Model 1, water makes no difference, but it was one of our main environmental measures, and it cannot be viewed as possibly over adjusting the paint and soil effects, so we included it. Paint and building condition are obviously linked, as paint lead is much more likely to find its way into house dust, and to be available for ingestion, if the building is in poor condition. Paint and building condition account for 26% of dust lead variance. The addition of soil lead measures account for another 6% of dust lead variance, less than 1/4 the value of paint. Interpreting only the parameter estimates for the variables in Model 2 ignores the central meaning of the hierarchical analysis.

3.6 As stated above, adding behavioral or other variables to a hierarchical regression model can only reduce the variance accounted for by soil. The reviewer seems to want to find some set of variables that lead to a higher simultaneous parameter estimate for soil, regardless of how little variance is explained by the individual variables, or how all of the other environmental variables are affected by the factors the reviewer wants included in a single analysis. Such an analysis is meaningless. Behavioral variables can over adjust the effects of the main environmental variables, including soil, because behaviors are the pathways for environmental lead to reach the blood. It is incorrect to think that a better understanding of those variables can result from such an approach.

We have presented and discussed numerous bivariate relationships involving environmental, behavioral, and other factors, in order to show the considerable intercorrelation of these variables. Part of the point of that discussion was that we did not feel that it was possible to interpret multivariate analyses if we included all of these variables at once.

3.7 The comments in this section are correct, but this is exactly the opposite of the point of the preceding reviewer's comment (3.6):

Our analysis avoided problems of multicollinearity by not including variables that could be proxies for one another. None of the variables included in the hierarchical regression models we presented are linked in this way.

3.8 While it is true that measurement error tends to reduce the magnitude of associations, this is equally true for all of the variables in this, and any other study. This does not change the relationship of the variables as long as the errors in measurement are not systematic.

We do not believe that there were systematic errors of measurement in this study. As stated above, we used a small set of key predictor variables, and did not have any problem with multicolinearity, or over adjustment of the soil lead effect.

4.1 We used 500 ug/g soil lead, and 10 ug/dl blood lead to conduct some two-group analyses, in addition to conducting other categorical and continuous data analyses. There were two reasons for conducting categorical analyses on these continuous data: 1. The ATSDR requested that we present part of our analysis in this way; 2. These cut points relate to a priori cleanup and blood lead levels set by EPA and CDC, respectively.

4.2 We agree that figures and graphs are helpful. Many more figures and graphs could be presented. However, the document is already quite long, and there is a limit to the amount of information that can be presented in this form. We presented figures and graphs when ever we thought that doing so would clarify a point of discussion.

4.3 The enlarged maps created by the reviewers indicates that our map was not as useless as stated, although we agree that reproduction of the original left a lot to be desired.

4.4 Confidence intervals can be estimated from the data provided, if it is thought by the reader to be important. We find little reason to believe that this is the case, since both the overall, and specific estimates of blood lead variance accounted for by the study factors is quite small in any event, and that is what really matters.

5.1 The facts speak for themselves. Our language choices differ. The majority of our higher blood lead values were not highly elevated (10.1-15). These slightly elevated levels were largely in children from relatively poor, unemployed families, living in run-down houses. Our interpretation is consistent with recommendations made by CDC in their [illegible] (1991).

5.2 The reviewer does not understand that age was intentionally <u>not</u> used in the regression analysis (age was not "entered as a monotone predictor", as the reviewer states). This is because age is a proxy for exposure - through mouthing behavior that enables the ingestion of dust, paint, and soil. Adjusting the contribution of the environmental lead sources for dependence on age would clearly result in over adjustment, thus reducing the blood lead variance accounted for by the environmental measures. Note that only children under six were used in the analyses. While there is a wide range in the behavior of children in this age group, the play and mouthing behaviors that produce lead exposure are present over the entire range. That is why the 6 mos. - 6 years age group was the focus of this analysis.

5.3 The correlation of distance and blood lead was reported. There were other important correlations with distance that were also reported (e.g. parent's education, income, age and condition of the houses). Note that actual soil lead measures are used in the main regression analysis, not a proxy such as distance or location. A much better indication of the association of blood lead and soil lead is obtained by direct analysis of these two factors than can be gained by gerrymandering neighborhood subunits of the sample and speculation about clusters.

The comments here, as elsewhere in the review document, mistakenly focus on univariate and bivariate interpretation of soil lead associations, when the report makes clear that the soil lead data are confounded.

As noted above, the sampling zones were not used in the analysis. They were used only to draw a sample of households that spanned the full range of soil lead levels in an otherwise fairly homogeneous community. We directed extra effort at recruiting households from the central sampling zone in order to be sure we had adequate representation of the most highly (soil) exposed part of the population.

5.4 The EPA has such maps already, and can use the soil data they collected for this study to do additional mapping of the distribution of soil lead in the study area if that is their interest.

EPA soil lead maps were used as a basis for study subject selection. Those maps helped us to obtain a representative range of residential soil lead levels. However, as noted above, we used the joint distribution of soil lead levels measured in the subject's yards, along with other study variables, in our analysis of the predictors of blood lead. Actual soil lead level, not "radial distance", is the basis for our analysis and interpretation of the association of soil lead and blood lead.

5.5 This review comment is clearly false. We were very specific in our analysis of the contribution of dust lead to blood lead in our report, as well as in our analysis of the contribution of paint and soil to dust lead. It would have been a mistake to include dust lead in the analysis of soil and paint lead (as recommended by the reviewer). Since dust lead is almost entirely dependent on the lead in paint and soil, multicolinearity in the regression of all three environmental variables against blood lead could only produce a meaningless regression model.

5.6 The fact that ratings of overall building condition, as well as ratings of the immediate condition of paint at the point of XRF measurement increased the predictive value of paint measures supports our statement about the importance of this factor.

5.7 Inter-individual differences in behavior were important on an individual level. Such factors as hobbies and work related exposures were generally experienced by only a single family, and had no statistical value in the analysis. Important behavior-mediated exposures of this type must be considered on an individual basis, unlike paint and soil levels, which can be evaluated on a statistical level.

5.8 The speculation by the reviewer may, or may not be correct. The argument presented by the reviewer supports our decision not to include education, income, or other similar SES and behavioral factors in the main hierarchical regression model. It is not clear whether including these factors would correct for confound or over adjust the effects of the environmental measures.

5.9 This statement by the reviewer that our analysis cannot establish the contribution to blood lead of the environmental measures in our study is nonsense. That is exactly what our hierarchical analysis demonstrates.

6.0 We appreciate the list of names of individuals the EPA feels are qualified in this area. Dr. Kimbrough has had numerous discussions with Dr. Weitzman, one of the experts mentioned, and was involved in the initial stages of the design of the Urban Soil Lead Demonstration Project in Boston. Dr. Aschengrau was also involved in that study.

IEHR

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January 11, 1994

Memorandum

To: Mr. Edward C. Fitzhenry

From: Renate D. Kimbrough, M.D. Renate Kimbrough, MD

Review and comment of the document entitled:

Preliminary assessment of data from the Madison County lead study and implication for remediation of lead contaminated soil.
By Allan H. Marcus, Environmental Criteria and Assessment Office, U.S. EPA, RTP, NC 27711.

In this document the data obtained in a cross-sectional exposure study of 490 children under six years of age in Granite City, a community located in Madison County are reassessed. The original study was conducted in the summer of 1991 by the Illinois Department of Public Health (Mr. David Webb) and the Institute for Evaluating Health Risks (Renate Kimbrough, M.D. and Maurice LeVois, PhD). A copy of a report of the study to the U.S. Agency for Toxic Substances and Disease Registry and a copy of an article in press in Pediatrics of this study have been provided in the record. Overall the blood lead levels of the participating children were quite similar to blood lead levels found in other older urban areas in the United States with housing stock dating back to the first half of this century and with similar incomes (Pirkle et al. The decline in blood lead levels in the United States. JAMA 1994; 272: 284 - 291).

The interior and exterior of many of the houses in Granite City in the area where the study was done were built before 1920 and were painted with paint containing high levels of lead. Up until 1940 lead based paint contained as much as 40% lead. Paint produced after 1940 contained less lead, but it was not until 1978 that the Consumer Product Safety Commission banned the production of paint containing more than 0.06% of lead. Thus, older houses have lead containing paint on their walls. We substantiated this fact by actually measuring the lead in the paint on the inside and outside walls of the houses. Since the paint on the outside of the houses flakes off, the soil around such houses becomes contaminated with

lead. The lead soil concentrations closer to the houses are therefore higher than in the rest of the yard. In such older urban areas including Granite City soil lead levels may range from a few hundred to several thousand ppm of lead. Not all children living in such environments have elevated (above 10 μg/dl) blood lead levels. Whether a child will/ will not have an elevated blood lead level depends on many behavioral factors including the child's nutrition, how well the child is taken care off, how frequently and thoroughly the house is cleaned and whether the house has/has not been well maintained. Unless children eat paint chips, ingestion of lead occurs in children under 6 years of age because of hand to mouth activities primarily through lead containing house dust. House dust is composed of dust from paint and other building materials (caulking material, grout) hair, lint, insect particles, food particles and dirt brought in from the outside, particularly if feet are not wiped. All of these factors must be evaluated together to determine the proportional contribution from all sources.

Dr. Marcus does not understand the complexity of the situation and is applying a wrong statistical methodology to our data. Statistics are simply an aid in presenting data to make it more easily understood. However, using such a methodology also requires that the right methods and all of the pertinent data are used.

We found in our study that more children living closer to the smelter had higher blood lead levels. However, these children lived in houses that were not as well maintained and had higher concentrations of lead in paint as children living further away from the smelter. In other words, as the distance from the smelter increased the houses were privately owned, were better maintained, and there was less flaking paint in the houses. Poorly maintained houses are also harder to keep clean. Thus, distance from the smelter is indicative of improved housing which negates the idea that the smelter was necessarily responsible for the larger number of children with elevated blood lead levels closer to the smelter. This has been discussed at great length in our report. However, Dr. Marcus chooses to ignore this observation.

The statement number 3, that loadings of deteriorating lead paint inside and outside the house show little or no relationship to distance from the smelter, is wrong. Since lead has been removed from gasoline, deteriorating house paint in houses built before 1978 is now the primary cause of lead poisoning in children under six years of age (see A Statement by the Centers for Disease Control: Preventing Lead Poisoning in Young Children. U.S. Dept. of Health and Human Services/Public Health Service/Centers for Disease Control, October 1991) This is also the position of the EPA. To have made such a statement suggests the author is unfamiliar with lead exposure in small children and the large body of literature available on this subject.

The statement number 4 is also erroneous. Lead in drinking water was not a source of lead poisoning in this population. In fact,

most of the water lead levels were either non-detectable or below the IDPH lead standard for drinking water. The occupants of the few houses with elevated lead water levels were aware of the problem and used bottled water. Some of these families also did not have small children.

The statement 5 is unclear. We found that there was more lead in house dust in houses in poorer condition. These houses were generally also closer to the smelter.

The number of children per household presented in figures 12, 13, 14, 15 are an overinterpretation of the data. There were a few large families who lived closer to the smelter, however, overall the family sizes did not vary much.

Statement 9 on page 3 concerns the representativeness of the study sample. Dr. Marcus notes that our study participants were all volunteers. He does not state why this concerns him. All such studies use volunteers, so this is largely a rhetorical observation. His comments do not state any reason to believe that the volunteer status of the Granite City study subjects biased the data we collected.

As our analysis demonstrates, socioeconomic factors, building condition, residential soil, house paint, and house dust lead were all risk factors for high blood lead that were also associated with distance from the Taracorp site.

We achieved the highest participation rate in the group closest to the smelter which is a strength of this study. Dr. Marcus notes that the participation rate was not as high in the most distant recruitment area. It is unclear why this is alleged to be a drawback. No reason is mentioned by. Dr. Marcus to suggest that this made any difference.

Furthermore, we had enough participants from all the areas, including the area farthest from Taracorp, to provide representative, reliable data for this group. The distributions of education, income, home ownership, as well as all of the environmental variables, indicate that we have drawn a representative sample from each of the study areas.

Most importantly, we were able to recruit participants over the entire range of environmental lead exposures in Granite City. Sampling from the full range of exposures is the real strength of this study, as it permits the most effective use of regression analysis to observe possible associations among the study factors.

Statement 10 on page 3 and 4 is partly correct, and partly misleading. It is true that we were able to account for approximately 40% of blood lead variance in the Granite City lead study, and that this is similar to the proportion of variance accounted for in other studies of blood lead in children. It is also true that the percent of blood lead variance accounted for

(R^2) is influenced in part by the units of measurement of the different variables.

It is incorrect and misleading to state that analysis based upon R^2 (i.e. multiple regression analysis of the blood lead variance accounted for by the different variables) is not a useful way to interpret our data. Multiple regression analysis is the best way to approach the complex set of inter-relationships in our data. This method of analyzing the data is usually used by investigators interpreting such data. The proportion of blood lead variance accounted for by the different variables can be partitioned, through hierarchical modeling, so that confounding effects of some of the variables can be controlled. Equally important, the proportion of blood lead variance accounted for by the different variables is an important indication of the relative contribution of each variable.

On the other hand, the "p value" (statistical significance) of the regression weights of different variables (which Dr. Marcus appears to prefer) tells little about the actual importance of the variable as a contributor to blood lead variance.

Page 4, summary and conclusions: It is stated that many of the yards had large bare areas without grass cover. I visited the houses where children lived with elevated blood lead levels. I was not impressed by the fact that the yards of these houses had large bare spots. These visitations are described in a follow - up study of children with elevated blood lead levels. Basically the blood lead levels in the children dropped below 10 µg/dl, the Center for Disease Controls level of concern and remained below this level of concern during a one year follow up. The remarkable response of the blood lead levels was accomplished through counselling of the parents and instructions on how to clean houses and generally reduce exposure of their children. We observed a very dramatic effect. No such drop in blood lead levels was accomplished in studies were EPA removed lead contaminated soil from the premises of the children in Boston, Baltimore and Cincinnati. The EPA studies also show that there was very little change in the blood lead levels of the children participating in these studies over an observation period of about a year in contrast to our study were we observed a remarkable drop after 4 months which was sustained for a year.

In addition to individual statements, a number of figures (plots) were submitted with the comments. The interpretation of these plots is invalid. The plots show simple bivariate relationships with distance. We have demonstrated in our analysis, and stated repeatedly, that these distance relationships are each seriously confounded with other factors. Dr. Marcus ignores this fact, and presents plots that create the false impression that only distance accounts for the slopes presented. This is incorrect and misleading.

Management of Children With Slightly Elevated Blood Lead Levels

Renate D. Kimbrough, MD*; Maurice LeVois, PhD*; and David R. Webb, MSt

ABSTRACT. *Objective.* To determine whether counseling of parents reduced blood lead levels in their young children.

Participants and methods. A lead exposure study was conducted in the vicinity of a defunct lead smelter. A total of 827 volunteers including 490 children younger than 6 years participated in the study. The mean venous blood lead level in the 490 children was 0.33 µmol/L (6.9 µg/dL), with a range of 0.03 to 1.94 µmol/L (0.7 to 40.2 µg/dL).

A total of 78 (16%) children had blood lead levels ≥0.48 µmol/L (10 µg/dL). However, only 5 (1%) of the children had blood lead levels of ≥1.21 µmol/L (25 µg/dL). The blood lead levels in this community were much lower than levels reported in earlier studies in many areas of the United States, when lead levels in air and in food were higher. Most houses in the study community were built before 1920 and had high lead paint levels. High levels of lead were also found in many house dust and soil samples. Intervention consisted of home visits and counseling of parents of children with blood lead levels of ≥0.48 µmol/L (10 µg/dL).

Results. In children with initial blood lead levels of ≥0.48 µmol/L (10 µg/dL) the blood lead test was repeated 4 months later. The arithmetic mean blood lead level 4 months later showed a decrease from 0.72 µmol/L (15 µg/dL) to 0.38 µmol/L (7.8 µg/dL). An additional blood sample was taken 1 year after the first sample in a subset of 30 children. These children showed a mean blood lead level of 0.43 µmol/L (9 µg/dL) at the 1-year follow-up, whereas their mean blood lead level at the 4-month follow-up had been 0.38 µmol/L (8 µg/dL).

Conclusion. Educating parents proved a very effective tool. Further studies are needed in larger populations to evaluate the effectiveness of this approach. *Pediatrics* 1994;93:188–191; *lead, young children, management, counseling.*

ABBREVIATION: CDC, Centers for Disease Control and Prevention; EPA, Environmental Protection Agency.

In the past lead in ambient air and in food contributed much more to overall exposure of the general population in the United States than it does now. Because lead from these sources has been drastically reduced,[1] blood lead levels in children and in the general population of the United States are now lower than they were one or two decades ago. At the same time there is now also increased concern about lower blood lead levels. In 1991 the Centers for Disease Control and Prevention (CDC)[1] published a new statement on the prevention of lead poisoning in young children. In the CDC statement the 1985 intervention blood lead level of 1.21 µmol/L (25 µg/dL) has been revised downward to 0.48 µmol/L (10 µg/dL) and more extensive screening of children is proposed. This lower level has created much concern among parents and some debate among physicians. Questions have been raised about the necessity of screening all children for blood lead levels. Although many researchers believe that low blood lead levels between 0.48 µmol/L (10 µg/dL) and 0.97 µmol/L (20 µg/dL) are harmful, not all do. Furthermore, it is not entirely clear how to best treat children who have blood lead levels between 0.48 µmol/L (10 µg/dL) and 1.21 µmol/L (25 µg/dL).

Intervention was undertaken in conjunction with a lead exposure study conducted in the vicinity of a Superfund site listed on the Environmental Protection Agency (EPA) National Priority List. The Superfund site was a secondary lead smelter in the center of a medium-sized town. The smelter was closed in 1983 because it exceeded ambient lead air standards. No cleanup had been conducted when the study was initiated. The intervention consisted primarily of education and counseling. It is the purpose of this paper to report the results of this effort.

METHODS

At the end of August and during September 1991, based on census information obtained by the Illinois Department of Public Health, families with children between the ages of 6 and 71 months were contacted and invited to enroll in the study.[2] The children were eligible for the study if they had lived at their present address for at least 3 months. The parents or guardians were asked to sign a human studies review board-approved consent form. A questionnaire was administered in which questions were asked about the household, occupation, income, and education of the parents, behavior of the children, and all potential exposures to lead.

A venous blood specimen was collected and analyzed for lead at the CDC[3] with a limit of detection of 0.03 µmol/L (0.6 µg/dL). Additional venous blood specimens were collected 4 months and 1 year later from children with an initial blood lead level of ≥0.48 µmol/L (10 µg/dL) and were analyzed for lead at the CDC. Samples of soil, house dust, and drinking water were also collected after the collection of the initial blood specimen. In situ paint analyses by x-ray fluorescence were performed on outdoor and indoor paint. The study participants which also included older children and adults lived in 388 households. Valid environmental samples were collected from most of these households. The soil samples and the dust samples were analyzed by EPA method 6010[4] using inductively coupled argon plasma emission spectroscopy. The concentration of lead in drinking water was determined in a first draw sample by graphite furnace atomic absorption. The limit of detection for lead in house dust was 20 ppm (mg/kg), for soil ≤20 mg/kg, and for drinking water ≤2 ppb (µg/L).

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Presented at the Annual meeting of the American Academy of Toxicology and the American and Canadian Poison Control Centers, September 22, 1992, Tampa, FL.

Received for publication Mar 3, 1993; accepted Jul 26, 1993.

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Follow-up

All households with at least one child with a blood lead level of ≥0.48 µmol/L (10 µg/dL) were visited, and the sources of lead in and around the home were discussed with the parents or guardians and their children. The parents or guardians were given literature on the prevention of lead poisoning and on behavioral factors that increase the potential for lead exposure. They were told to wash their children's hands before eating and before putting them to bed, to keep their children's fingernails clipped short, and to offer a well-balanced diet. Where indicated, suggestions were made to carefully remove peeling paint or to make sources of lead inaccessible in the home by installing barriers. Specific instructions on the safe removal of paint were provided, and the parents were also given advice on good housekeeping. The children with the elevated blood lead levels and their siblings were instructed not to put their hands and nonfood items into their mouths and to wash their hands before eating. The counseling sessions were usually conducted when the entire family was at home. Each session lasted approximately 30 to 45 minutes. Tests for blood lead levels were repeated on most of these children about 4 months later and again on a subset of children 1 year after the determination of the initial blood lead level. The specimens were again analyzed by CDC. One family whose children had the highest initial blood lead levels of about 1.94 µmol/L (40 µg/dL) lived in condemned housing. This family was moved out of their lead-contaminated environment.

RESULTS

Many parents had a 12th grade or lower level of education and a low income. The unemployment rate in the town where the study was conducted is presently around 18%. Results of blood lead analyses are given in Tables 1 and 2. Of the 490 children aged 6 to 71 months old, 261 were boys and 229 were girls. Their arithmetic mean blood lead level was 0.33 µmol/L (6.9 µg/dL) with a range of 0.03 to 1.94 µmol/L (0.7 to 40 µg/dL). A total of 78 (16%) of 490 children had blood lead levels ≥0.48 µmol/L (10 µg/dL); however, 46 (9%) of them had blood lead levels between 0.48 and 0.72 µmol/L (10 and 15 µg/dL) and only 5 (1%) of all children exceeded the previous level of concern of 1.21 µmol/L (25 µg/dL) of the CDC. A total of 51 children with blood lead levels of ≥0.48 µmol/L (10 µg/dL) were retested approximately 4 months later, and 30 children donated a third blood specimen 1 year later.

Results of the repeated blood lead level determinations and comparisons with the results of the initial blood lead level are given in Table 2. The mean blood lead levels decreased to about half of the original value with one child showing a difference of 1.2 µmol/L (24 µg/dL). The third blood lead analysis of 30 children 1 year after the initial testing showed little change from the second testing. This subgroup of children had a mean blood lead level of 0.39 µmol/L (8 µg/dL) at the second testing and a mean blood lead level of 0.43 µmol/L (9 µg/dL) at the third testing. No difference of complete blood counts was seen when children with blood lead levels greater or less than 0.48 µmol/L (10 µg/dL) were compared, and no other abnormal clinical findings related to lead exposure were noted in this group of children.

TABLE 1. Number and Percent of Children 6 to 71 Months Old With Blood Lead Levels of ≥48 µmol/L (≥10 µg/dL)

78/490	16.0%	≥0.48 µmol/L (10 µg/dL)
46/490	9.0%	<0.72 µmol/L (15 µg/dL)
32/490	6.5%	≥0.72 µmol/L (15 µg/dL)
05/490	1.0%	≥1.21 µmol/L (25 µg/dL)

Lead levels measured in paint and in soil of the houses are given in Tables 3 and 4. Many of the children lived in houses built before 1920 with high paint lead concentrations in at least one of the areas measured. In many yards the lead concentrations in soil were much higher than background levels which can range from nondetectable levels to 200 ppm (mg/kg).

Lead in drinking water of 374 households was below the limit of detection of 2 µg/L (ppb) in 62% of the samples, and 97% were below 15 µg/L (ppb), the present US EPA/IEPA action level. Drinking water did not seem to contribute to the exposure of the children. The contribution of the other sources of lead to overall exposure of these children is described in another report.[2]

DISCUSSION

The mean blood lead level of the 490 children younger than 6 years in our study was below the CDC level of concern. This is remarkable because most children lived in houses with high interior and exterior lead paint levels and high lead soil levels. Even among the 78 children with elevated blood lead levels most had blood lead levels <1.2 µmol/L (25 µg/dL), the CDC level of concern until 1991. In the National Health and Nutrition Examination Survey conducted between 1976 and 1980 the arithmetic mean blood lead levels for young children were approximately 0.7 to 0.97 µmol/L (15 to 20 µg/dL).[5] Most of the elevated blood lead levels in our study are lower than these levels, and the arithmetic mean of the entire group of children was 0.33 µmol/L (6.9 µg/dL). Although removal of lead from the child's environment is advocated, this is not always possible due to financial constraints and an infrastructure insufficient to abate lead in all housing in a safe and cost-effective manner. In well-maintained homes with high concentrations of lead in paint and in soil in the yards in our study[2] children did not have elevated blood lead levels, and poorly performed abatement has actually resulted in an increase in blood lead levels. Thus, a more individualized approach to the lead exposure problem in young children seems appropriate. Finally, for "Superfund" studies no money is available for the treatment and follow-up of children with elevated blood lead levels. Many of the children in our study with elevated blood lead levels did not have easy access to health care or to lead abatement procedures and the parents were at a loss as to what to do. To be of some assistance we decided to counsel the parents and children and to follow up the children's blood lead levels. Our findings suggest that education and counseling of the parents and the children is effective in reducing blood lead levels in combination with careful removal of hot spots such as peeling paint on window sills and porch banisters. Counseling in the home of the affected child is appropriate as soon as the results of the environmental data are available. A rapid turnaround of the analysis of blood and environmental samples for lead is mandatory. To prevent further exposure, appropriate nutrition of the child and cleanliness are extremely important. Inspection of the house may re-

TABLE 2. Comparison of Repeat Blood Lead (BPb) Levels (µmol/L µg/dL) With Original Lead Levels in 51 Participants

Age, mo	1st BPb Range	Mean	2nd BPb Range	Mean	Difference	
					Range	Mean
6–71	0.48–1.69 (10–35)	0.72 (15)	0.17–0.61 (3.5–12.7)	0.38 (7.8)	0.14–1.16 (2.9–24.1)	0.35 (7.2)

TABLE 3. Lead in Paint: Percent of Households With X-ray Fluorescence Readings >6 mg/cm²

Location	Houses (n)	>6 mg/cm²/,%
Indoor paint	372	40
Outdoor paint	380	51
Indoor and outdoor paint	371	30

veal that it has not been properly cleaned. The parents should be instructed to clean their house and to maintain its cleanliness in the future. Parents were warned not to undertake renovations in their homes without first reading the written instructions they were given during our visit. They were advised to contact the Illinois Department of Public Health before any renovation and to use only contractors and painters certified or knowledgeable in the removal of lead-based paint.

In the past seasonal fluctuations in children's blood lead levels have been reported with principal emphasis on the summer peak.[6,7] However, Marrero et al[8] reported two peaks, one in late winter and one in midsummer. Marrero et al[8] found that the low levels were at most about one third less than the peak value. Our initial blood lead level determinations were made in late August and in September when the midsummer peak had already passed. Furthermore, in our follow-up study in January, the blood lead levels decreased to at least half of their original value and remained there for a year.

The seasonal fluctuations observed many years ago were closely associated with the sale of leaded gasoline, fluctuations in lead air levels, weather patterns, and traffic density.[9] Because lead in gasoline has been phased out, seasonal variation is now less of an issue. Furthermore, the blood lead levels in our study were determined a year later and had increased at most by 0.048 µmol/L (1.0 µg/dL). However, children's blood lead levels also decrease as the children get older. The magnitude of this decrease is much less than what we observed in our follow-up. For instance, in a recent study to determine the effect of soil and interior loose paint removal on blood lead levels the mean decline in blood lead levels between preabatement and 11 months after abatement was 0.12 µmol/L (2.44 µg/dL) in children younger than 6 years with blood lead levels quite similar to the blood lead levels in our follow-up study of children of similar age. In that study loose paint removal per se only resulted in a decline of 0.02 µmol/L (0.52 µg/dL).[10] These differences are very small in comparison with our findings. Fluctuations in blood lead levels are also affected by the analytical method which must be very accurate, precise, and free of drift over time.

Our follow-up does not address the question of whether simply repeating the blood lead measurements without any intervention would have resulted in a decreased blood lead level. This question can only be addressed by observing one group of children without counseling and one group with counseling and comparing their blood lead levels over time. It seems unlikely that all the blood lead levels would have consistently decreased to at least half of their original value and then remained at the same low value for 8 months. When we conducted the follow-up we did not expect that counseling would be effective in our cohort. Because of the high environmental lead levels in the community and the conventional wisdom that thorough abatement is necessary to reduce children's blood lead levels, we assumed that our efforts would be futile. Under the circumstances we were very surprised by our results. They merit consideration and further exploration.

Since we made this finding, the Illinois Department of Public Health (Thomas Long, PhD, personal communication 1993) has used counseling for the past year with similar success. Counseling may be useful if prevention of exposure of the child through more extensive abatement activities is not immediately available or can not be guaranteed.

Rosen et al[11] in 1989 compared bone lead levels in persons aged 5 to 18 years and older within 1 mile of a secondary smelter with a group of unexposed individuals. The smelter had been active until 1981. The population living close to the smelter had

TABLE 4. Lead (Pb) in Environmental Samples: Soil, Dust, Water, and Paint

Environmental Sample	n	Mean Pb	Minimum	Maximum	SD
Soil: dry composite, mg/kg	375	450	37	3 010	411
Dust by weight, mg/kg	371	1283	5.2	71 000	5236
Dust by surface, µg/m²	367	886	1.6	58 800	4489
Drinking H_2O, µg/L (ppb)	373	3.4	<2	96	8
Indoor paint, mg/cm²†	372	1.2	0	10.4	1.6
Outdoor paint mg/cm²†	380	5.3	0	31.2	6.4

Lead in dust by surface area was calculated by dividing the dust sample weight by the surface area vacuumed and multiplying this ratio by the dust lead concentration.

† The paint values represent means of 18 indoor and 12 outside readings. Readings of 0 were included in the calculations.

higher bone lead concentrations and their blood lead levels were also slightly higher. However, according to the authors the blood lead levels were uninformative, and only means and standard deviations were provided in their paper. It would be interesting to know how the blood lead level of the individual correlates with his/her bone lead level. The accuracy and precision of the two measurements would affect this correlation. It is unclear how relevant this study is for the younger age group of 6 to 71 months, the focus of the present report. In younger children the soft tissue pool seems to be more important. In blood 90% of the lead is stored in red blood cells. The turnover rate of red blood cells is about 120 days. By measuring blood lead levels 4 months and then 12 months after the initial sampling, differences in exposure should have been captured because blood lead levels are a good indicator of recent exposure. The half-life of lead in bone is >20 years.[12] Blood lead levels decline during adolescence. This decline may be related to bone growth and deposition of lead in bone with calcium.[12] Thus, unless the toxicokinetics of lead during different age periods are considered, the comparison of lead in bone with lead in blood is not very informative.

ACKNOWLEDGMENTS

Funding and support for the initial study in which children with elevated blood lead levels were identified was provided by the Agency for Toxic Substances and Disease Registry and the Centers for Disease Control and Prevention through the Illinois Department of Public Health and the US EPA Region V, Chicago.

The assistance of Thomas Long, Catherine Copley, and C. Michael Moomey of the Illinois Department of Public Health, Dr Frederick Stallings and Sarah Sarasua of Agency for Toxic Substances and Disease Registry, Dr Daniel C. Paschal of the National Center for Environmental Health of the Centers for Disease Control and Prevention, Don Stander of St. Elizabeth Medical Center in Granite City, and Bradford Bradley of US EPA Region V is gratefully acknowledged. Thanks also goes to the participants of the study.

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Survey of lead exposure around a closed lead smelter[1]

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[1]Funding and support for this study was provided by the Agency for Toxic Substances and Disease Registry (ATSDR), the U.S. Environmental Protection Agency (U.S. EPA) and the Illinois Department of Public Health (IDPH). A detailed report of this investigation was also submitted to ATSDR and is available upon request from IDPH.

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DISCLAIMER

Mention of the name of any company or product does not constitute endorsement by the Illinois Department of Public Health or the Agency for Toxic Substances and Disease Registry, Public Health Service, U.S. Department of Health and Human Services.

Abstract

Objective - To test the hypothesis that elevated lead in soil is positively correlated with blood lead levels in children in an urban population surrounding a closed lead smelter, a U.S. EPA Superfund clean-up site was surveyed.

Method:

A total of 827 volunteers including 490 children under 6 years participated. A questionnaire was administered. Lead was determined in various blood specimens, house dust, soil, paint, and water of the participants' homes.

Results - The arithmetic mean venous blood lead level in 490 children under 6 was 6.9 μg/dL (0.33 μmol/L) range 0.7-40.2 μg/dL (0.03-1.94 μmol/L). The blood lead levels of 78 (16%) children in this group were ≥10 μg/dL (0.48 μmol/L). Based on multiple regression modeling, children's blood lead levels could only be accounted for to a small extent by lead in soil (R^2=0.03), house dust (R^2=0.06), or paint (R^2=0.03). Lead in soil accounted for only 3% of the variance in children's blood lead levels. Lead in paint, in conjunction with a rating of the 'condition of the house', accounted for 11% of the blood lead variance. Factors unrelated to environmental lead such as education of parents, household income, and behavior were associated with blood lead levels.

Conclusions - The mean blood lead level in children was below the present level of concern of the Centers for Disease Control and Prevention (CDC). Children with blood lead levels of ≥10 μg/L (0.48 μmol/L) tended to live in poorly maintained older houses.

Based on these findings lead in soil and paint in well-maintained homes contributed little to the lead exposure of children.

Introduction

The industrial site, a closed lead smelter, is located in a mixed industrial and residential area in Granite City, Illinois. It is one of 41 National Priority List (NPL) or Superfund hazardous waste sites in Illinois. Approximately 34,000 people live within a 4.6 km radius of the site. Industrial lead operations at the smelter site began in 1895. Battery recycling began in the 1950s. The smelter was closed in 1983 and in a preliminary site assessment in May 1983, it was estimated that 200,000 tons of lead waste were present at the site.

Prior to the present study, the site had been evaluated by federal and state environmental and health agencies. Soil samples collected on the industrial site in 1988 contained lead in concentrations ranging from 1,500 to 48,000 ppm (mg/kg). Slag piles and other surface waste was estimated to contain up to 300,000 ppm (mg/kg) of lead. Samples collected from residential yards and gardens at varying distances from the site revealed lead concentrations ranging from 106 to 9,493 ppm (mg/kg). Ambient air lead levels taken from monitors closest to the site (when the smelter was active) regularly exceeded the 1.5 $\mu g/m^3$ National Ambient Air Quality Standard (NAAQS) for lead. Air levels have not exceeded NAAQS since the smelter was shut down.

In 1991, based on high soil lead levels, the U.S. EPA proposed a clean-up area extending 0.8-1.0 km from the smelter. The present study was conducted to determine the blood lead levels in the population residing in this area and from outside this area

extending for another 3.2 km around the designated clean-up area. This report describes the blood lead levels in children under 6 years of age.

Methods

Study Population

A population census of the proposed NPL clean-up site and the surrounding area was conducted in July 1991 to identify all households with children under 6 years of age. The census included all residential units within the proposed Superfund clean-up site and an additional area extending 3.0 km in all directions from the border of the proposed Superfund clean-up site. A suitable comparison group that was not a continuum of the EPA proposed clean up area could not be identified in the immediate urban area.

Trained census takers recorded age, gender, and length of residence of all household members for every residential unit in the defined area. Families with children under 6 years of age and pregnant females who had lived at their present address for at least 90 days were invited to participate in the study.

All adult members of the participating households signed Southern Illinois School of Medicine approved consent forms giving permission for themselves and/or their minor children to provide venous blood specimens, to measure lead in soil, house dust, water and paint from the residence and for a detailed interview of the head of the household. Blood was collected at the local hospital by trained pediatric phlebotomists. The interviews were

administered by a trained interviewer at a centrally located office using a pre-coded questionnaire. Questions were asked about the demographics of each household member; occupation, income and education of the parents (or head of household); history of smoking for all household members; the behavior of the children, time at home and outdoors, where the child played, and number of weekly baths. Factors related to the house itself were also determined such as age of the home, presence or absence of air conditioning, and the occurrence of repairs or renovations on the house. Alternative exposures to lead were also queried. Interview information, blood specimens, and environmental samples were collected from August 22 to September 12, 1991. The teams collecting the environmental samples did not know the results of the blood lead analyses.

Blood Sampling

The blood lead analyses were performed by CDC using a published method[1] with a limit of detection of 0.6 μg/dL (0.03 μmol/L). Duplicate samples and quality control samples were also collected and analyzed. Within one week following the blood specimen collections, soil, house dust, and drinking water samples were collected from each residence and in-situ paint analyses were performed. All environmental sampling and analyses were performed by EPA-paid trained contractors.

Soil Sampling and Analysis.

The yards around the houses measured 100x100 yards (33x33m) or less. Play areas were identified on each property. At least 10

locations were sampled with a corer of no less than 2 aliquots per location at a depth of one inch (2.54 cm) and composited. Debris and leafy vegetation was removed from the top of the core. Unless children played close to the house, soil samples were taken at least 30 cm from the house per story to avoid the drip line. Soil samples were analyzed by EPA method 6010 using inductively coupled argon plasma emission spectroscopy (ICAP)[2]. The limit of detection for lead in soil was ≥20 ppm (mg/kg). For the calculations one half the limit of detection was used for nondetectable values.

Wet and dry soil lead levels and total solids were determined. Only the dry weight lead levels are reported in this paper. Obvious chips of paint were removed from the soil prior to analysis. Thirty nine duplicate soil samples were also analyzed.

Dust Sampling and Analysis

Interior surface dust was collected by using a Hoover brush vacuum cleaner, 1/3 HP, 2 Amp. motor. Dust samples consisted of a composite of at least three subsamples from an area adjacent to the main entrance, a floor area from the room most utilized by the study child, a floor area of the child's bedroom. For each surface area at least one m^2 was vacuumed three times. Window sills accessible to children were vacuumed. Dust samples were analyzed by EPA method 6010 using inductively coupled argon plasma emission spectroscopy (ICAP)[2]. The limit of detection for lead in house dust was ≤20 ppm (mg/kg). For the calculations, one half the limit of detection was used for nondetectable values. To more accurately relate lead in dust to exposure a variable named "dust load" was

calculated by dividing the dust sample weight by the surface area vacuumed and multiplying this ratio by the dust lead concentration.

Water Sampling and Analysis

The concentration of lead in tap water was determined in a first draw sample by graphite furnace atomic absorption[3]. The limit of detection for lead in drinking water was ≤2 ppb (μg/L) for the calculations one half the limit of detection was used for nondetectable values.

Analysis of Paint

Lead in paint was determined in situ by a licensed contractor using an X-Ray fluorescence analyzer. The XK - 3 instrument manufactured by Princeton Gamma - Tech, Inc., was used. This instrument has a range of 0-10 mg of lead per cm^2. At each site three readings were made and an average calculated. In each room a reading was made on the woodwork and the painted wall for a total of 18 readings. If lead was not present a zero reading was given. Missing values were treated as such in the calculations. Up to eighteen readings of walls and wood work were taken from the main living area, the child's bedroom and another frequently occupied area. Three readings/surface area for a total of 9-12 exterior readings were made on the front, back, and one side of the house. The XK-3 instruments measure lead paint concentrations up to 10 mg/cm^2. Lead concentrations above 10 mg/cm^2 are displayed as 10 mg/cm^2. The amount of lead in paint above 10 mg/cm^2 was estimated by using the average weakly calibration time and dividing the test

reading (10) by the ratio of the time to obtain the reading over the average calibration time.

The condition of paint where each reading was made was rated for the inside of the house using the designations of intact = 1, slight peeling = 2, moderate peeling = 3, and extreme deterioration paint = 4. These conditions depended on the judgment of the certified contractor. For the outside of the house three conditions were used: good = 1, fair = 2 and poor = 3. These weights were used in the calculations to combine the condition of the paint surfaces with the concentration of lead in paint.

For the XRF readings, the value 0.01 mg/cm^2 (one half the limit of detection) was used for zero readings. Since intact paint is less likely to result in exposure, the XRF readings were transformed by multiplying each interior paint XRF reading by its surface condition code to calculate an average condition x XRF. The condition score C multiplied by the XRF reading (C x XRF) was divided by the number of surfaces measured to obtain a mean C x XRF for the house.

Ratings for the exterior condition of the house were missing for 59 houses or 15%. The mean building condition score was assigned to these houses. Missing values for the building condition were not associated with any other variable.

Data Analysis Methods

Data from the census forms and the questionnaire were entered into electronic data files. Quality control was maintained by double entry of important data points.

Statistical analyses were done using the statistical analysis system (SAS) for the microcomputer[4]. Univariate statistics were performed using Chi-square analyses for all categorical variables and two-tailed t-tests for all continuous variables, both of which required a significance level of $p < 0.05$. A correlation matrix was calculated to determine what factors were associated with blood lead as well as the degree to which there was intercorrelation of the independent variables. Blood lead values ≥10 μg/dL (0.48 μmol/L) were used to define the high blood lead group for group comparisons. Positively skewed data were transformed to logarithms, which resulted in a more normal distribution.

Multiple regression and correlation modeling[5] was performed to help identify variable(s) that had some utility for predicting blood lead levels, and to determine the independent influence of environmental measures of lead on blood lead levels.

Results

Study Population

Based on the census questionnaires, 906 (17.6%) households had one or more children under 6 years of age who had lived at the residence for at least three months. Of these households, 116 were disqualified because the family had moved or could not be contacted by phone, repeated visits to the home, and inquiries at neighbors during the 3.5 weeks of the field study. All children were >6 months or <6 years at the time of the study; or the family had lived at their present address for less than three months. The

final target population from the census data consisted of 790 households. Of the 790 target households, 355 households with at least one child under 6 years of age participated in the study. Another 33 households participated who did not have children between the ages of 6 and 71 months. The results of these participants and those of older children and other adults who in the aggregate numbered 337 participants will not be given in this report. A total of 266 (34%) households refused to participate primarily because they did not want to subject their child to a venipuncture or their children recently had had a blood lead determination. Another 169 (21%) missed repeated appointments or could not be contacted to reschedule appointments. This resulted in an overall participation rate of 45%.

The houses occupied by the participants and by families who refused to participate were scattered throughout the same neighborhood. To better relate distance from the closed smelter to the location of the participants' houses and the proposed EPA clean up area, we created four regions roughly representing concentric circles around the closed smelter. Region I, a commercial area, was located closest to the smelter and contained few residences with 39 eligible families. Of these families, 20 participated in the study (51%). In the second concentric circle, Region II, 60% of the eligible households participated. In the next outer circle, Region III, 53% of the households participated and 39% participated in the outer circle, Region IV, farthest removed from the smelter.

Region I extended roughly 0.8-1 km from the boundaries of the closed smelter in all directions. Regions II and III were also about 0.8-1 km in width. Region IV was 1.2 km wide. The clean-up area proposed by EPA in 1991 included all of Region I and about half of Region II and the distance from the periphery of the superfund site to the boundary of the entire study area was about 3.4-4.2 km (2-2.6 miles) in all direction.

Occasionally more than one family shared a household. A total of 230 families with one child, 106 families with two children and 14 families with three or more children over 6 months and under 6 years of age participated. There were 101 non-white children under 6 years of age and, of these, 87% were African-American.

Blood Lead Levels

Results of blood lead analyses are given in Tables 1 and 2, with an arithmetic mean blood lead level of 6.9 μg/dL (0.33 μmol/L) and below, the present CDC level of concern[6]. In the entire group of 490 children, 78 children (16%) had blood lead levels of ≥10 μg/dL (0.48 μmol/L); however, only 5 (1%) had blood lead levels above the pre-1991 level of concern of 25 μg/dL (1.21 μmol/L) of the CDC (Table 2). The arithmetic mean age of all children under 6 years was 3.3 years and the mean ages of the two groups of children with low and high blood lead levels were 3.2 and 3.3 years, respectively.

Among the 101 non-white children under 6 years of age, 19% had elevated blood lead levels. The arithmetic mean blood lead levels of all white children under 6 years of age was 6.8 μg/dL (0.32

μmol/L) and for the non-white children 7.4 μg/dL (0.35 μmol/L). There was no statistically significant difference in the mean blood lead levels of white and non-white children under 6 years of age ($t = -1.1$, $p > .05$). The two groups were therefore combined in the analyses.

Environmental Lead Measures

Mean lead levels measured in soil, house dust, drinking water and paint of the houses are given in Table 3. The majority of houses in this study were built around the turn of the century through the 1950s. The levels of lead in indoor and outdoor paint in many houses reflect the lead in paint during that period.

Soil

The mean soil lead level for the 376 analyzed composite soil samples from participant yards was 450 ppm (mg/kg) with a range of 37 ppm (mg/kg) to 3010 ppm (mg/kg) (Table 3). The concentration of lead in 39 split soil samples ranged from 106 to 1610 ppm (mg/kg). The average difference between the primary and the duplicate sample was 89 ppm (mg/kg), and was not statistically significantly different.

Dust

Levels of lead for 371 house dust samples are given in Table 3. Blood lead levels of children under 6 years of age were highly correlated with the dust load (the concentration of lead in dust/m^2 of area vacuumed) ($r = 0.42$, $p < 0.0001$).

Drinking Water

Lead in drinking water from 374 households was below the limit of detection of 2 ppb (μg/L) in 62% of the samples and 97% of the samples had levels below 15 ppb (μg/L), the present EPA action level. In 13 instances, levels of lead in drinking water were higher with a range of 15.4 - 95.5 ppb (μg/L). The study participants using this water did not have elevated blood lead levels. The correlation between the log water measure and log blood lead was very low ($r = 0.07$, N.S.).

Home Repairs

Among families with children under 6 years of age whose blood lead levels were <10 μg/dL (0.48 μmol/L), 192 (48%) had done some repair work on their house in the last year. In contrast, 44 (63%) of the families whose children had blood lead levels ≥10 μg/dL (0.48 μmol/L) had done some repair work on their house in the year prior to the study ($p < 0.02$). The information was missing for 17 households.

Dust and Soil

The geometric mean dust load in houses with soil lead levels of ≥500 ppm (mg/kg) was 0.4 $\mu g/m^2$ compared to 0.1 $\mu g/m^2$ in houses with soil lead levels <500 ppm (mg/kg) ($p<0.01$). The geometric mean lead concentration in dust on a weight basis rather than surface area was 780 ppm (mg/kg) for houses with soil levels ≥500 ppm (mg/kg) compared to 309 ppm (mg/kg) for houses with soil lead levels <500 ppm (mg/kg) ($p<0.01$).

Paint and Soil

The geometric mean indoor paint lead level in houses with soil lead levels ≥500 ppm (mg/kg) was 1.4 mg/cm^2 compared to 0.5 mg/cm^2 for houses with soil lead levels <500 ppm (mg/kg) ($p<0.01$). The geometric mean outdoor paint lead level in houses with soil lead levels of ≥500 ppm (mg/kg) was 8.6 mg/cm^2 compared to 3.0 mg/cm^2 in houses with soil lead levels <500 ppm (mg/kg) ($p<0.01$).

Factors Associated with Blood Lead Levels

At the univariate level the following factors were positively correlated ($p<0.01$) with an increase in the blood lead level of children under 6 years of age: dust load; composite soil lead; dust lead concentration; number of cigarettes smoked in the house per day; hours child played outdoors; number of baths per week; indoor paint lead; and number of smokers in household. Blood lead levels were negatively correlated ($p<0.01$) with parents education, distance from the closed smelter, and parents income. Blood lead levels in children under 6 years of age were more likely to be higher when the building they lived in was in poor condition, did not have air conditioning, the living space was rented rather than owned, repair of the home had taken place in the last year and the home was older ($p<0.01$).

In addition to univariate associations to blood lead levels many of these factors were significantly ($p<0.01$) correlated and associated with each other. For example, soil lead levels were positively correlated with dust load; indoor lead paint; cigarettes smoked in the house per day; and the age of the home. As parents'

education and income improved children were more likely to have significantly ($p<0.01$) lower blood lead levels. Lead in soil was significantly and positively associated with renting versus owning; absence of air conditioning and a poor rating of the 'condition of the house.'

Condition of the house was significantly and positively associated with the number of cigarettes smoked in the house per day, indoor paint lead, outdoor paint lead, soil lead, water lead, and dust lead ($p<0.01$).

Distance to the closed smelter was correlated with several factors in addition to blood lead levels. The older houses were located closer to the smelter and, as the distance from the smelter increased, home ownership increased and dust lead concentration and the dust load decreased. Additionally, the number of houses with air conditioning increased and the condition of the houses improved. Number of cigarettes smoked in the house per day, as well as the number of smokers, was negatively correlated with distance from the smelter. Income and education of the parents improved as distance from the smelter increased. These correlations suggested that distance from the smelter was strongly associated with socio-economic factors which may contribute to the variation seen in blood lead levels.

Multivariate Analysis

Multivariate analyses were conducted to determine the independent influence of environmental measures, and demographic and socio-economic factors, had on blood lead levels in the

children under 6 years of age. However, blood lead, while not well accounted for by any set of variables in this study, was significantly associated with more than a dozen study factors. The interpretation of these associations is complicated since most of the variables associated with blood lead are also associated with one another.

Lead in tap water, house paint lead, recent repair work on houses, and the building condition accounted for 11% of the blood lead variance (adjusted $R^2 = 0.11$). When composite soil lead measures were added, the adjusted R^2 increased slightly to an adjusted $R^2 = 0.14$. Thus, only 3% of the variance in blood lead observed in this population was accounted for by soil lead.

The contribution of dust lead was assessed by multiple regression of blood lead with log dust load, together with the demographic and behavioral variables of age, race, parents education, cigarettes smoked in the home per day, renting or owning a home, recent remodeling, distance from the site, hours of outdoor play, and log lead concentration in tap water. R^2 was equal to 0.37 for all factors together; Log dust load parameter estimate equalled 0.13; $p<0.01$.

Indoor and outdoor paint lead, and the condition of the building, accounted for 26% of the variance in dust lead. When the composite soil data were added, R^2 increased to 0.32, an increase of 6% in dust lead variance. Thus, paint lead and building condition accounted for about four times as much variance in dust lead as soil lead.

Discussion

It has been suggested in many studies that children under 6 years of age ingest lead primarily through dust, but they may also ingest lead-containing paint chips and soil. In addition, children will be exposed to lead through food, water, and air. How much environmental lead a child will receive from these various sources depends on many behavioral variables and on the child's nutrition[7].

Most of our study participants had comparatively low blood lead levels in spite of many significant sources of lead in their immediate environment. The decrease in blood lead levels observed in this study population, and in the United States population overall in recent years[7,8], has resulted mainly from the reduction of lead in air primarily from the decreased use of leaded gasoline[8]. Lead in food, particularly in infant food, has also been reduced[9]. In spite of high lead levels in soil and in indoor and outdoor paint, many children in this study had very low blood lead levels. Even the group with elevated blood lead levels had mean blood lead levels that 20 years ago were representative of small children of the general population and were mostly below the CDC level of concern for elevated blood lead levels of 25 μg/dL (1.21 μmol/L) in effect until October 1991. In the NHANES II survey (National Health and Nutrition Evaluation Survey) conducted between 1976-1980, the arithmetic mean blood lead levels for different groups

of screened children not exceeding 30 µg/dL (1.44 µmol/L) mean blood lead concentrations ranged from 15-20 µg/dL[7] (0.7 - 0.97 µmol/L)[7].

Condition of the house; lead in paint; lead in dust; lead in soil; smoking of the parents; proximity to the closed smelter; education and income of the parents; and behavioral factors of the children predicted blood lead levels in young children. Only about 37% of the variance could be accounted by the variables investigated in this study. Of the 37%, lead from soil made a very minor contribution, (an upper-bound of 3% of the variance) while the 'condition of the house' and the amount of lead in paint were responsible for as much as 11% of the variance. Weitzman et al.[10] recently demonstrated that removal of lead-contaminated soil around homes and interior loose paint removal resulted in a modest mean blood lead level decline of 2.44 µg/dL (0.12 µmol/L) within an 11 month period in children under 6 years of age. Since the decline was so small the authors stated that removing lead contaminated soil is not a useful clinical intervention for the majority of urban children. Our results support these findings. Our data show that elevated blood lead levels are encountered in poorly maintained houses with high lead paint, lead dust, and lead soil values. Simply correlating blood lead levels to individual environmental sources (e.g., soil) is a misrepresentation of the data. Overall, the environmental lead measures per se did not account for most of the variation in blood lead levels of the

children. Other factors such as the 'condition of the house,' and housekeeping practices and other variables played a major role.

Improving the condition of homes and educating the parents and caretakers about personal hygiene such as washing hands and cutting fingernails short, house cleaning, and pathways of lead exposure appear to be effective in reducing slightly elevated blood lead levels and should be studied further[11].

Most of the important variables such as education and income of the parents; behavior variables; smoking; air conditioning; lead in paint; soil lead; and house dust lead were all highly correlated. Thus, correlations, t-tests and Chi-square tests if taken out of context would be misleading. Very small, but statistically significant, differences of a few percent of the variance contributing to blood lead levels are not of any apparent clinical importance. We attempted to determine by step-wise regression of 22 variables what the overall contribution of these variables to lead exposure was. However, as some variables were added to the analyses, other variables dropped out and variables that had previously dropped out were in the regression again. This suggested that some of the variables were also proxies for other variables and that they did not represent a meaningful contribution to the overall exposure of small children.

Multiple regression modeling of the relationship between soil lead and blood lead permits statistical control of potential confounders. However, statistical adjustment for possible confounding may result in "over-control", incorrectly eliminating

true effects of the adjusted variable. For instance, house dust lead is a composite of paint lead and soil lead. Statistical control of the relationship of soil lead and blood lead for the effect of confounding by house dust lead could result in overadjustment. Furthermore, the mechanism relating blood lead and soil lead to such potential confounders as education, income, cigarette smoking, air conditioning, and home ownership is not well understood. We have, therefore, taken a cautious approach to statistical adjustment for possible confounding.

Parental cigarette smoking was positively correlated with blood lead levels in young children. Other authors have reported that environmental tobacco smoke may contribute to blood lead levels[12]. However, cigarette smoking also correlated with other predictors of blood lead. Furthermore, the number of cigarettes smoked per day and the number of smokers per household did not correlate with lead in house dust. The lack of an association between cigarettes and lead in house dust has also been reported by Willers et al.[13,14]. Cigarette smoking was most likely a proxy for other risk factors for lead exposure such as education and socioeconomic status of the parents.

In conclusion, indiscriminate removal of leaded paint and soil in residential areas may have little or no practical benefit. A more targeted approach in which the condition of the houses, socioeconomic, and behavioral variables are also considered should prove more useful and realistic. Education of parents about pathways of exposure, consistent and adequate removal of house dust

(cleaning), personal hygiene and good nutrition are important additional measures that are helpful in reducing lead exposure in children[11].

Acknowledgements

The assistance of John Lumpkin, M.D. and the staff of the Illinois Department of Public Health, Springfield and Edwardsville, IL., Fred Stallings, M.D. Sara Sarasua, Agency for Toxic Substances and Disease Registry, Atlanta, GA.; Martha Doenland, Institute for Evaluating Health Risks, Washington, D.C.; Lori Stanzell, St. Elisabeth Medical Center, Granite City, IL; Craig Tarpoff, Catherine Andrea, Mayor Von Dee Kruse, Mayor John Bellcoff; Mayor Tyrone Echols; Donna Fanning, Brad Bradley and the staff of the U.S. EPA, Region V, Chicago,IL. McDonalds, Capri Sun, Inc. and Prairie Farms, all of Granite City, IL. are gratefully acknowledged.

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Table 1 - Total Blood Lead Levels (BPb) in 6-71 Month Old Children[1]

Total N	490
Males (%)	261 (53%)
Mean BPb	6.9 μg/dL (0.33 μmol/L)
Range	0.7-40.2 μg/dL (0.33-1.94 μmol/L)
Number	≥10.0 μg/dL (0.48 μmol/L) = 78 (16%)
Std. Dev.	5.02

[1]Nine children included in this table lived at their present residence slightly less than 3 months at the time of the study. The limit of detection for the blood lead analyses is <0.6 μg/DL (<0.03 μmol/L). The range of the means at 6-month age intervals for children with blood lead levels of ≥10 μg/dL (0.48 μmol/L) was 13.6 μg/dL (0.66 μmol/L) at 6-12 months to 18.2 μg/dL (0.88 μmol/L) at 36-42 months. The range of the means at 6-month age intervals for children with blood lead levels <10 μg/dL (0.48 μmol/L) was 4.3 μg/dL (0.21 μmol/L) at 6-12 months to 5.9 μg/dL (0.29 μmol/L) at 30-36 months.

Table 2 - Blood Lead Levels ≥10 μg/dL (0.48 μmol/L)

Number	Percent of 490 Children	Blood Lead Level
78	16%	≥10 μg/DL (≥0.48 μmol/L)
46	9%	≤15 μg/DL (≤0.72 μmol/L)
27	6%	≤25 μg/DL (≤1.21 μmol/L)
5	1%	≥1.21 μmol/L (>25 μg/DL)

Table 3 - Lead in Environmental Samples: Dry Soil Composite, Dust, Water and Paint

Environmental sample	N	Mean Lead	Minimum	Maximum	Standard[1] Deviation
Soil mg/kg (ppm)	375	450	37	3010	411
Dust by weight mg/kg (ppm)	371	1283	5.2	71,000	5236
[1]Dust by surface $\mu g/m^2$	367	885	1.6	58,800	4489
Tap water $\mu g/L$ (ppb)	373	3.3	<2	96	8
[2]Indoor paint mg/cm^2	372	1.2	0	10.4	1.6
[2]Outdoor paint mg/cm^2	380	5.3	0	31.2	6.4

[1]The "dust load" was calculated by dividing the dust sample weight by the surface area vacuumed and multiplying this ratio by the dust lead concentration. Surface area was not recorded for 4 samples.

[2]The paint values represent means for 18 indoor and 9-12 outside readings. Readings of zero were included in the calculations.

** TOTAL PAGE.011 **

Report No. FHWA-TS-81-210
April 1981

U.S. Department of Transportation
Federal Highway Administration

A Method for Estimating Fuel Consumption and Vehicle Emissions on Urban Arterials and Networks

Prepared by
Juri Raus
Office of Research and Development

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

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ABSTRACT

A search was conducted for a method to estimate motor vehicle fuel consumption and vehicle emissions in an urban driving environment which would require a minimum of field data collection and processing effort. It was found that average transient speed as measured by travel time is a good composite parameter reflecting stops and slowdowns and is closely correlated with fuel consumption and vehicle emission rates.

Data was obtained for fuel-speed and emission-speed profiles for a 1980 typical mix of passenger cars, single unit trucks, tractor-trailers and busses. Tables and figures of this data are provided for easy reference. Fuel consumption projections for 1981 through 1983 are also presented for these vehicle categories.

The supplied data and computational procedure provides a relatively easy and straightforward approach for estimating fuel consumption and emissions and can be used to gain insight into existing traffic operations and the merits of proposed or actual flow improvements.

A sample problem is also provided which shows step by step computations for calculating the annual fuel consumption and emissions for peak and off-peak periods for a typical urban arterial, two miles long and with 11 signalized intersections. The annual fuel consumption is calculated to be about 2,400,000 gallons and vehicle emissions about 4,300,000 lbs. A comparison with a similar arterial street operating at 5 mph higher average speed showed reduced fuel consumption by about 360,000 gallons (15%) and reduced emissions by about 900,000 lbs. (22%).

ACKNOWLEDGMENTS

The author wishes to extend his gratitude to the many individuals in Government and private industry who provided information and advice in the development of the background and sources for this report.

Special thanks go to Ms. Ruth Hunter and Mr. Richard Beck of the U.S. DOT Transportation Systems Center for data on truck and bus fuel consumption, Mr. J.D. Murrel from the U.S. Environmental Protection Agency for passenger car fuel economy trends and to Mr. Henry Seiff of the U.S. National Highway Traffic Safety Administration for information on truck fuel economy trends.

In FHWA, appreciation is expressed to Dr. Stephen Cohen for the state-of-the-art information, Mr. Jesse Chaves for information on vehicle emissions, Mr. David Wood for the MOBILE I program runs, Mr. Lawrence McCarthy for statistical data analysis, Mr. Robert Ellington for the development of the programmable calculator example and numerous individuals in the Office of Highway Planning for information on energy regulations and policies, highway user statistics and traffic trends.

A. INTRODUCTION

The problems associated with the cost and availability of energy in general and motor vehicle fuel in particular have become self evident and need no extensive elaboration. It is also evident that all possible methods to conserve fuel must be examined and implemented where feasible.

Along these lines, the Federal Government has taken a number of steps. One such provision is the requirement in the Emergency Energy Conservation Act of 1979 for the States and metropolitan areas to formulate energy conservation plans including a transportation element.

The Federal Highway Administration is required by Executive Order 12185 (December 17, 1978) to support those Federal-aid projects which offer substantive energy conservation potential and has formulated a policy which identifies among other aspects the improvement of traffic flow through traffic signals and systems as one measure which offers such energy conservation potential.

Another aspect related to the efficiency of traffic flow and operations are vehicle emissions of pollutants. The Federal Clean Air Act (as revised August 1977) requires the States to develop an implementation plan, including a transportation control element, to attain and maintain National Ambient Air Quality standards.

The above requirements, as well as the increasing recognition for the need to evaluate the performance of our street and highway system in terms of fuel consumption and emissions (the two being compatible) demonstrate the need for methods to compute these measures. It is useful and indeed necessary for the States and local communities to develop such estimates in order to define existing operating conditions, identify trouble spots and evaluate proposed or actual improvements.

The Federal Highway Administration has made available two computer programs which simulate traffic flow at signalized intersections and compute stops and delays. The first program, Network Simulation (NETSIM) (1) gives values for fuel consumption and emissions and the second, Signal Operations Analysis Package (SOAP) (2) estimates fuel consumption only.

A manual method which deals with individual intersections has also been developed and published (3).

The computer programs require an extensive data collection, coding and running effort. The manual technique needs field studies of stops and delays at intersections.

About 45 percent of total vehicle miles of travel (VMT) in the nation occurs on urban streets, which have an estimated 204,000 signalized intersections. These are flow restrictive by nature due to the requirement to assign right-of-way to alternate conflicting movements. Considering the magnitude of the problem, it may not be feasible for many jurisdictions to collect detailed field data for all roadways and intersections in their system and therefore, the need exists for a method to estimate fuel consumption and emissions based on data normally available or requiring only minimum expenditures and effort.

It is the purpose of this report to provide the States and local communities with such a method which should greatly facilitate the development of a base of information needed for the evaluation of existing operations and required improvements.

B. FUEL CONSUMPTION

1. The Study Method

The search for the method to estimate fuel consumption was based on the premise that the data requirement should be restricted to information already available to the user or obtainable with a minimum of collection effort.

For most communities, information in this category includes average daily traffic volumes, peak and off-peak volumes (either percent of ADT or actual counts) and measurements or estimates of average travel time or speed over a distance. Even if the latter data is not already available, it is relatively easy to obtain by floating car runs without any special instrumentation.

Several field and simulation studies have found a good correlation between fuel consumption and travel time or average speed over a distance (4)(5). In an urban environment, as is the case here, this speed is really a composite parameter reflecting stops and delays (acceleration noise). At lower speeds, such disturbances are more frequent than at higher speeds with a corresponding increase in the rate of fuel consumption. It is important that the measurements be taken over a sufficient time or distance so as to represent the actual driving cycle and not a spot speed.

2. The Speed-Fuel Profile

Having established average speed as the key parameter, the search centered around finding a good but simple formula to express the relationship. From information available, it appeared that the best relationship was developed by the General Motors Research Laboratories (GM) (4) as shown below:

$$\phi = \frac{1}{E} = k_1 + \frac{k_2}{\bar{v}} \qquad \bar{v} < 35 \text{ mph}$$

where:

- ϕ is fuel consumption (gallons per mile)
- E is fuel economy (miles per gallon)
- k_1 is a vehicle dependent parameter (gallons per mile) associated with fuel consumed to overcome the rolling resistance and is approximately proportional to the weight of the vehicle.
- k_2 is also a vehicle dependent parameter (gallons per hour) approximately proportional to idle fuel flow rate.
- $\bar{v}$ is the average speed in miles per hour as measured over a distance.

The above relationship was derived from field data collected by driving instrumented vehicles in Detroit metropolitan area urban traffic. GM has compared their equation with the results obtained from fixed urban driving schedules as developed by the Society of Automotive Engineers (SAE) and the U.S. Environmental Protection Agency (EPA) and found the relationship to be valid, although with slightly different values for k_1 and k_2.

The values for k_1 and k_2 are determined by testing a homogeneous vehicle population such as passengers cars in this case.

A review of the available information indicated that for the purpose of developing numerical values (k_1 and k_2) for the speed-fuel profile, again the data obtained by General Motors seemed the most suitable. Field test data under actual urban driving conditions was available for a mix of 1973 through 1976 cars of various sizes. Considering the fact that the average age of the cars on the road is about six years, this mix seemed to represent a good typical value. This was further corroborated by the comparison of EPA model year 1973 through 1976 fleet average fuel economy of 13.24 miles per gallon (6) at their standard transient city driving speed of 19.6 mph to the GM equation derived value of 13.44 miles per gallon for the same speed, showing only a minor difference in fuel economy.

349-097 0 - 81 - 2

In view of the above, the following values were selected from the above mentioned GM study:

$k_1 = 0.0362$ $k_2 = 0.746$

resulting in the equation:

$$\text{Fuel consumption (gallons per vehicle-mile)} = 0.0362 + \frac{0.746}{\bar{v}}$$

The above relationship is good only for speeds up to about 35 mph. For higher speeds, the air resistance (drag) assumes an increasingly dominant role. For the situation under consideration here, i.e., urban driving, the upper limit of 35 mph is quite adequate.

Table I and figures 1 and 2 show the computed values for fuel consumption and economy.

It is important to note that the values given represent only the best available estimates on a broad scale. For a given situation, there could well be variance depending on environment, roadway alignment, gradient and condition, vehicle characteristics and driver behavior. These variables probably can not be quantified for the purpose of general application. In view of this, some may question as to why the values given in Table I are shown to three or four decimal places. This was done only to reflect the k_1 and k_2 values given. If any further rounding off is desired, it is left to the judgment of the user.

It is also very important to keep in mind that the speed derived from the above relationship is not a steady state or uniform speed but a transient speed reflecting stops and speed changes. Most previously published references on fuel consumption give values based on uniform speed. This is not the case here and the two data sets are not compatible.

TABLE I

Speed - Fuel Relationship

Passenger Cars

Travel Time minutes/mile	Average Speed miles/hour	Fuel Consumption gallons/mile	Fuel Economy miles/gallon
60.0	1	0.7822	1.278
30.0	2	0.4092	2.444
20.0	3	0.2849	3.510
15.0	4	0.2227	4.490
12.0	5	0.1854	5.394
10.0	6	0.1605	6.229
8.6	7	0.1428	7.004
7.5	8	0.1295	7.725
6.7	9	0.1191	8.397
6.0	10	0.1108	9.025
5.5	11	0.1040	9.614
5.0	12	0.0984	10.166
4.6	13	0.0936	10.686
4.3	14	0.0895	11.175
4.0	15	0.0859	11.637
3.8	16	0.0828	12.074
3.5	17	0.0801	12.487
3.3	18	0.0776	12.879
3.2	19	0.0755	13.251
3.0	20	0.0735	13.605
2.9	21	0.0717	13.942
2.7	22	0.0701	14.263
2.6	23	0.0686	14.570
2.5	24	0.0673	14.863
2.4	25	0.0660	15.142
2.3	26	0.0649	15.410
2.2	27	0.0638	15.667
2.1	28	0.0628	15.913
2.1	29	0.0619	16.149
2.0	30	0.0611	16.376
1.9	31	0.0603	16.594
1.9	32	0.0595	16.803
1.8	33	0.0588	17.005
1.8	34	0.0581	17.200
1.7	35	0.0575	17.387

Figure 1

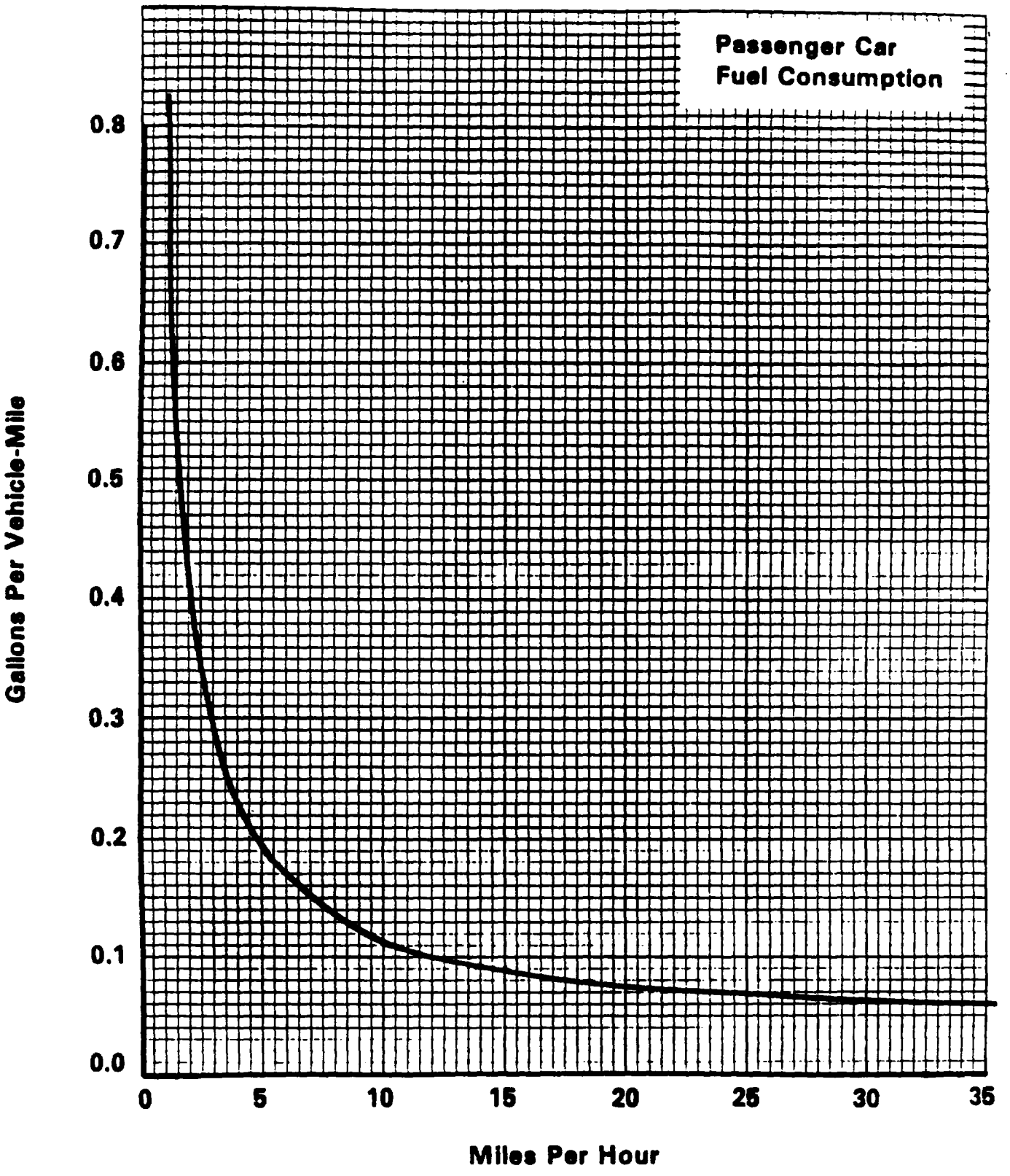
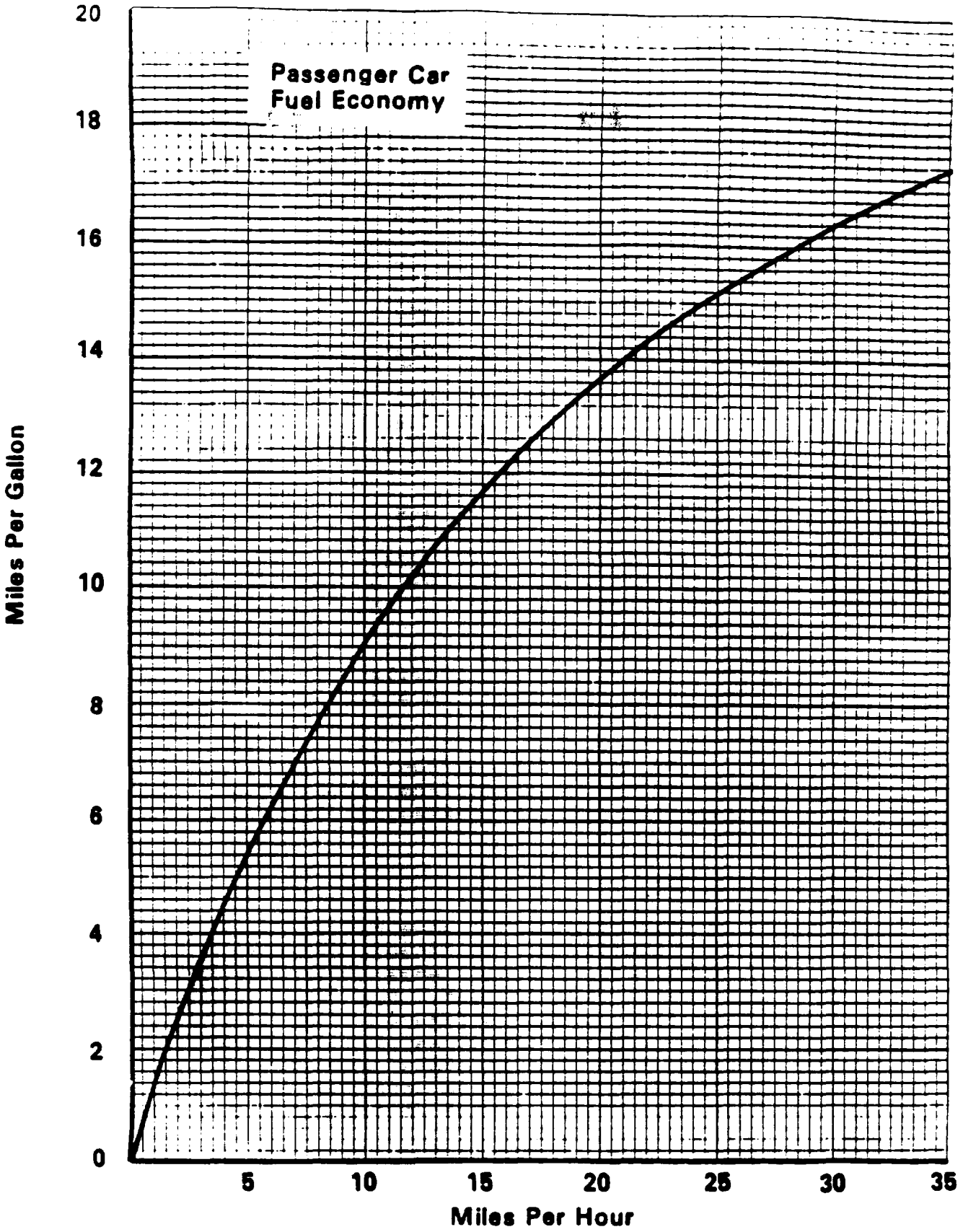

Passenger Car
Fuel Consumption
Gallons Per Vehicle-Mile
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
Miles Per Hour

Figure 2


Passenger Car
Fuel Economy
Miles Per Gallon
0
2
4
6
8
10
12
14
16
18
20
5
10
15
20
25
30
35
Miles Per Hour

3. Other Vehicles

The previous discussion dealt with passenger cars only. The following guidelines should be helpful in developing fuel consumption estimates for other vehicle types.

a. Light Duty Trucks

This category includes an assortment of small trucks, vans, etc. with a Gross Vehicle Weight (GVW) up to 8500 lbs. It was concluded from available information that these types can be treated as passenger car without any significant degradation in the overall fuel consumption estimate.

b. Single Unit Trucks (Class 6)

These are gasoline engine trucks with GVW of 19,500 to 26,000 lb. Fuel consumption and economy figures for urban driving for this class are shown on figures 3 and 4.

c. Tractor-trailers (Class 8)

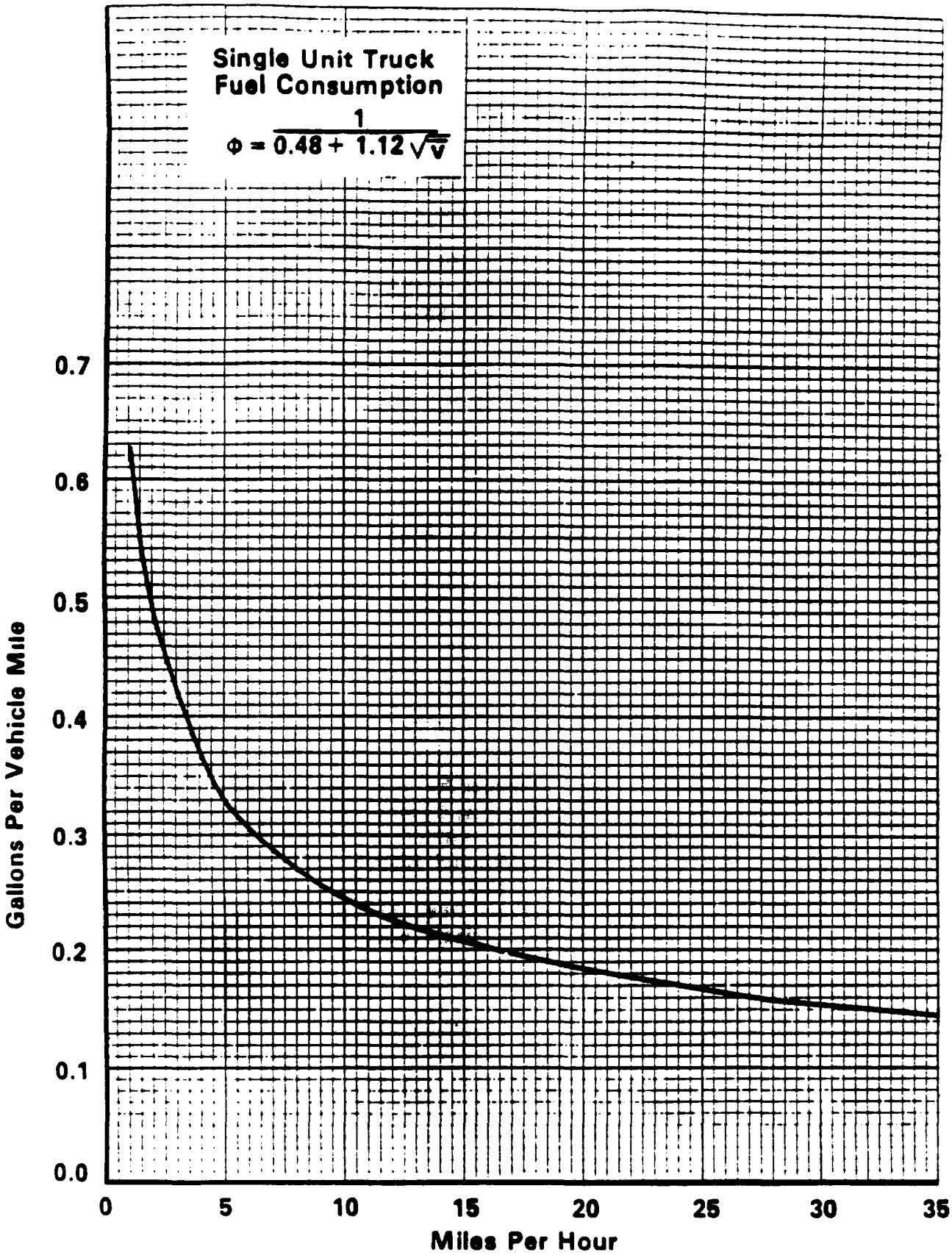
This category is for diesel engine tractor-trailers with GVW of 33,000 lbs. and above. Fuel consumption and economy values for this class are shown on figures 5 and 6.

NOTE: The speed-fuel profiles for class 6 and 8 trucks were obtained from a recent U.S. Department of Transportation and industry joint study which was conducted with instrumented test vehicles in 10 cities. The fuel consumption and economy values can be obtained from curves given, which represent a best statistical fit to the empirical data.

d. Busses

Busses represent a somewhat different category in the traffic stream because of their unique stopping schedule. In that sense their presence in the normal flow is intermittent. For this reason the fuel profiles shown in figures 7 and 8 were not calibrated with average speed, as were other vehicles, but with average number of stops per mile. The estimate for stops should include both the scheduled bus stops as well as stops due to traffic flow characteristics.

Figure 3


Single Unit Truck
Fuel Consumption
$\Phi = \frac{1}{0.48 + 1.12\sqrt{v}}$
Gallons Per Vehicle Mile
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
5
10
15
20
25
30
35
Miles Per Hour

REPORT ON TRAFFIC RELATED ISSUES

U.S. VS. N.L. INDUSTRIES
GRANITE CITY, ILLINOIS
CBB JOB NO. 91-94

JANUARY 13, 1995

Prepared by
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TRAFFIC RELATED ISSUES
U.S. VS. N.L. INDUSTRIES
GRANITE CITY, ILLINOIS

Introduction

The following report has been prepared for the traffic issues relating to the suit U.S. vs. N.L. Industries, Granite City, Illinois

The purpose of this work was to study traffic conditions and realities should the U.S. EPA proposed cleanup go forward. In order to accomplish this work, data from various sources was obtained and field observations were made. The data base assembled is as follows:

1. Coburn and Croft (Attorneys)
   - Video of Cleanup
   - Various Documents
   - EPA ROD
   - Photographs of the Cleanup

2. Juneau & Associates (Engineers)
   - Maps of the City showing street widths, infrastructure, etc.

3. Field Observations
   - Past experience and work in Granite City
   - Observations of cleanup activities within the city

4. Miscellaneous Publications - In-House
   - Manual on Uniform Traffic Control Devices for Streets and Highways
   - Signing Manuals
   - Fuel and Emission References

The site designated for clean up encompasses a variety of different land uses. These land uses vary in intensity from "low" to "extremely busy". The cleanup area includes the following areas:

1) Industrial sites within the Granite City Central Business District (CBD)

2) The Central Business District of Granite City

3) A diversified mix of residential uses including apartments, duplexes and single-family homes within the Granite City Central Business District and throughout the cleanup area.

4) Industrial land uses which support the residential uses and the employment base of the city which includes:

- Credit Unions and Banks
- Utility Offices (Illinois Power)
- Churches, Day Care and Schools
- Needed Community Services:

  - Doctor Offices
  - Hospital
  - Services; Gasoline, Convenience, Food, etc.

The streets in the area designated for cleanup are very narrow. The area designated for clean up consists of a 55-block area from 15th Street near Madison, Illinois to 23rd in Granite City and between Adams Street and Madison, Lee and Iowa Streets. During the August 1994 phase of the clean up, in which ±12 sites were addressed, field observations were made of these sites as they were being cleaned up.

Furthermore, detailed field observations were made within the 55-block clean up area by driving every street and making various notations regarding on-street parking, pedestrian activity, neighborhood institutions, schools, etc. The following were observed:

- Large numbers of trucks parked along the street
- Significantly increased truck traffic
- Trucks sitting idol awaiting loads
- Backhoes used to cleanup property

Executive Summary

Based on my review and observations, the following issues are of concern:

- The increased truck traffic will cause significant increases in pedestrian and bystander injuries.

- The increased truck traffic will cause crowding of streets and traffic problems for Granite City.

- Emergency vehicles will have great difficulty in reaching the hospital and residential areas designated for cleanup.

- The trucks and other equipment from the cleanup will cause unacceptable increases in air emissions.

Discussion

A concise effort to clean up this 55-block area proposed by EPA will cause the following problems and/or creates the following concerns:

1. Within the Area of the Hospital

This area has an acute shortage of on and off-street parking due to the high intensity land uses within this area. The cleanup will cause a number of problems due to the narrow one-way streets and the need to keep the roads open for emergency purposes. The cleanup activities require a number of trucks, construction equipment, tractor trailers to prepare the sites, to remove away from the site the soils and to haul in new replacement soils. These activities will require the displacement of much of the on-street parking that is always at peak demand in and around the hospital area. In addition, there are numerous pedestrians that use the streets and sidewalks to access the medical services. These users are both young children and elderly persons. This intensive cleanup activity within this area is likely to create a number of safety issues as construction equipment and pedestrians/school children cross paths.

2. The Area East and North of Niedringhaus

This area comprises one of the significant Granite City communities. Its west end is the CBD and various support institutions. As one travels easterly, the residential portions of the community are blended with the churches, schools, and neighborhood stores, etc. Many of the streets are narrow and thereby provide only one way flow. Parking demand exists in sufficient quantities to require on-street parking on both sides at all times during the day. As noted above, the cleanup activities require a number of vehicles and these will materially interfere with the residential activities that occur within these areas. There will be conflict between the residents seeking to use their existing on-street parking and the construction workers trying to locate construction equipment on one side or both sides of these roads. As previously noted, many of these residential streets are already one-way as a result of their narrowness. Such narrow streets, when combined with the vehicles involved in the cleanup, will severely limit the ability of emergency vehicles serving those areas.

There are numerous pedestrians and school children present in this residential area. Additional trucks and increased traffic in the area caused by the cleanup make it highly likely that pedestrians and school children will suffer injury.

Along some of the rather long block lengths, there are numerous residential housing units that use the street in front of their house for both access and vehicular storage. There is insufficient areas along these blocks for both on-street residential parking and for the vehicles required for the cleanup activities. With the presence of the required cleanup vehicles, there will be a severe shortage of on-street parking which will be unacceptable to the area residents.

In addition to the above, it should be noted that these residential areas are not today inundated with any volumes of truck traffic. The city has been successful in keeping these areas restricted to residential traffic. The city has designated truck routes and based on field observations, they appear to be used as intended.

Madison Avenue, a major city arterial, cannot be closed since it serves as a major east to west arterial and any restrictions of this route would severely impact the adjacent residential areas.

3. Other Issues of Concern

A number of other issues that are concerns of the proposed clean up are as follows:

1. There appears to be no approved plan for traffic control, no approved plan to handle pedestrians/school children, or any plan to accommodate emergency calls for fire, police or ambulance. Absence of this type of planning often creates situations where there is an increased likelihood of serious accidents. The appendix contains various articles that support this comment.

2. Granite City is already a non-attainment area as defined by the Clean Air Act. The carbon monoxide levels are higher than what the USEPA and CAAA would expect or like to see. A conservative estimate has been made of additional air contaminants that will be emitted in the Granite City area as the result of the intensive cleanup. The following uses will emit additional air pollutants within this area already designated as being a "non-attainment" area as defined by the EPA:

   - Construction equipment operated ±8-12 hours daily.
   - Additional truck traffic removing the wastes

   On a daily basis, the clean up activities will add the following vehicle emissions to Granite City air per site: 1/

- 80 gallons/fuel will be burned by the trucks and construction equipment involved in the cleanup which will produce the following pollutants:

  - 164 lbs./day of Carbon Monoxide (CO)
  - 16 lbs./day of Hydrocarbons (HC)
  - 5 lbs./day of Nitrogen Oxides (NO_x)

It should be noted that carbon monoxide (CO) is associated with its ability to combine with hemoglobin in blood which results in the impairment of the normal transfer of oxygen from the lungs to be rest of the body.1/ Hydrocarbons (HC) relate to the photochemical smog. Nitrogen oxides (NO^x) are nitric oxide (NO) and nitrogen dioxide (NO_2). NO_x plays a significant role in the formation of photochemical smog.

1/ "A Method of Estimating Fuel Consumption and Vehicle Emissions on Urban Arterials and Networks", Report #FHWA-TS-81-210.

This increase of pollutants in these residential, church, hospital, and other areas used by residents is undesirable.

Conclusion

The EPA proposed cleanup will have a significant impact on traffic patterns in Granite City. Increases in traffic necessarily mean increases in accidents and injuries. Such increases also mean unacceptable increases in air emissions.

APPENDIX

- Selected Articles on Accident Rates/Construction Zones.
- FHWA Manual "A Method of Estimating Fuel Consumption and Vehicle Emission on Urban Arterials and Networks", Report #FHWA-TS-S1-210.

EXHIBIT 2102

NATIONAL ACCIDENT RATES FOR
SELECTED GROUPS OF WORKERS

WORKER GROUP	ACCIDENT FREQUENCY RATE (1)	ACCIDENT SEVERITY RATE (2)
All industry average	11.2	670
Construction industry	14.5	1558
State highway departments	15.6	1715
Municipal employees	36.8	1176
Municipal street maintenance	57.5	1815
Municipal refuse collection	95.1	2825

(1) The accident frequency rate is the number of lost-time accidents per million man-hours

(2) The accident severity rate is the number of days lost per million man-hours

Source: National Safety Council three-year average rates (1973-1975) R-110

EXHIBIT _.03

CALIFORNIA CONSTRUCTION ZONE ACCIDENT STUDY STATISTICS

	BEFORE CONSTRUCTION									DURING CONSTRUCTION								
	NO MONTHS	MVM	NUMBER OF ACCIDENTS				ACCIDENT RATES			NO MONTHS	MVM	NUMBER OF ACCIDENTS				ACCIDENT RATES		
			TOT	FAT *	INJ	PDO	TOT	FAT	FATALITY			TOT	FAT *	INJ	PDO	TOT	FAT	FATALITY
10 Construction Zones Studied in 1965	118	278.3	559	11(14)	251	297	2.01	0.94	5.03	103	305.1	745	28(35)	334	383	2.44	1.19	11.47
31 Construction Zones Studied in 1970	415	2393	4242	75(101)	1645	2522	1.77	0.72	4.22	415	2606	4927	83(106)	1954	2890	1.89	0.78	4.07

*Figures in parenthesis show the number of persons killed.

DURING CONSTRUCTION 1965: PRIOR TO APPLYING NEW PRINCIPLES

PDO	accident rate increased	17.8% (1.07 to 1.26 acc/mvm)
Injury	accident rate increased	21.1% (0.90 to 1.09 acc/mvm)
Fatal	accident rate increased	132.4% (3.95 to 9.18 acc/100 mvm)
TOTAL	accident rate increased	21.4% (2.01 to 2.44 acc/mvm)

DURING CONSTRUCTION 1970 SINCE APPLYING NEW PRINCIPLES

PDO	accident rate increased	5.7% (1.05 to 1.11 acc/mvm)
Injury	accident rate increased	8.7% (0.69 to 0.75 acc/mvm)
Fatal	accident rate increased	1.6% (3.13 to 3.18 acc/100 mvm)
TOTAL	accident rate increased	6.8% (1.77 to 1.89 acc/mvm)

Source: R-15

SESSION GUIDE

TOPIC: 20 BACKGROUND

SESSION TITLE: 22. Traffic Control Problem Areas

DURATION: 0 to 40 minutes

OBJECTIVE:

Participants will identify traffic control practices which contribute to motorist confusion and create hazardous conditions.

REFERENCES:

CONTENT:

Typical Traffic Control Deficiencies 22-1

Reasons for Deficiencies 22-3

RESOURCE MATERIAL:

Examples of Poor Practices

TYPICAL TRAFFIC CONTROL DEFICIENCIES

Many examples can be found of deficient traffic control procedures in use at highway construction and maintenance worksites. The first step in establishing improved traffic control procedures is to identify and classify the types of problems that are frequently found in actual installations.

Typical problems encountered which contribute to motorist confusion and create hazardous conditions are as follows.

- Insufficient advance warning
  - inadequate signs
  - insufficient distance in which to respond
  - unclear instructions
- Inadequate guidance and delineation
  - lack of information
  - poorly placed devices
  - conflicting pavement markings
- Unprotected hazards
  - shoulder drop-offs
- Conflicts created by the work activity
  - material improperly stored
  - equipment operating or stored outside of protected area
  - workers in or adjacent to travel lanes
- Poor housekeeping
  - debris on roadway
  - water or mud on pavement
  - dirty devices
  - non-functioning devices
- Distractions to motorist
  - gawking
  - unusual devices or traffic control techniques
- Confusion
  - non-standard devices
  - improper placement of devices
  - insufficient number of devices
  - too many choices for motorist

VI. SPECIAL TRAFFIC CONDITIONS

Methods for Measuring Traffic Flow: A pre-construction study should include traffic volume information on the street in which work is to be done. The preferred manner in which to obtain such information is through the setting of machine traffic counters which record directional traffic volumes at least every hour, for the full 24-hour day. Lacking such equipment, manual directional traffic counts should be taken for at least two hours of the morning peak traffic period, and two hours of the afternoon peak traffic period.

Determine When Volume Reaches Roadway Capacity: Peak weekday traffic flows occur in many areas for approximately two hours in the morning and two hours in the afternoon. During these hours, work which encroaches into a moving lane of traffic should not be allowed on arterial streets where it has been determined that the full roadway width is needed for the volume of traffic.

A. Restrictions

The following volume criteria may be used as guidelines in determining lane and peak hour time restrictions.[9]

For two lane roads (both directions):

- If Average Daily Traffic (ADT) is less than 1,500, or if Peak Hour Traffic (PHT) is less than 150, maintain one lane (alternate directional flow over the same lane).
- If ADT is equal to/or greater than 1,500, or if PHT is equal to/or greater than 150, maintain two lanes.

For four-lane undivided roads (both directions):

- If ADT is less than 10,000 or if PHT is less than 1,000, maintain one lane each direction.
- If ADT is equal to/or greater than 10,000, maintain three lanes (two in heavy direction).

Acceptable Levels of Service: There are occasions when the amount of traffic past a construction site is not predictable, even with existing traffic volume information. This may occur due to traffic "self-detouring" (choosing an alternate route), or because of a series of road closures on several streets in an areas. When this occurs, a rule-of-thumb to determine how much street can be closed is that no vehicle in either direction should suffer more than a 90-second delay. Any consistent delay to traffic in excess of 90 seconds means that the level of service has deteriorated to the point where more traffic lanes should be opened if possible.

Lanes To Remain Open: There are certain conditions under which traffic lanes should not be closed under any circumstances. Generally these exist when there is no alternative access to private property, major traffic generators, freeway ramps, etc. Under such conditions, work may have to be performed at night, or under a special "closing and detour permit".

Times When Work Must Be Stopped: A good general rule on any arterial street is that work should be stopped altogether between 7:00 and 9:00 AM, and between 4:00 and 6:00 PM for work in the direction of major traffic flow. These hours may vary of course in accordance with local peak hour conditions. Such work stoppage is not just to accommodate the volume of traffic, but for safety reasons too; -- driver's attention may be diverted, workers are over-exposed, and there is a "natural" reduction in traffic speed (commonly known as "Gaper's Block") due to drivers wanting to see what is taking place. Although it is a serious cost consideration, it is not unusual to require that all work on major arterials be performed during off peak hours, or even, in the case of critical traffic locations, during late night and early morning hours.

Freeway Maintenance: Special consideration must be given to closing lanes for freeway maintenace. In most urban areas, freeway lanes cannot be closed during the peak hours, and closing lanes even during non-:k hours often creates extensive congestion. Under these conditions, ..ght work is often done to meet maintenance needs. Prior to day-time freeway lane closures, traffic pattern studies should be made of closing a lane or lanes of a freeway to determine the consequences of such closures. Whenever possible, freeway traffic should be allowed to proceed past the worksite at normal speeds, or to adjust voluntarily to lower speeds as required.

B. Work Areas

Work Area Available For Work Crews Based On Traffic Conditions: It must be recognized by both the constructor and the traffic engineer that the constructor's work area requirements and the moving traffic requirements constitute a constant arena of compromise. Rarely can both be maximized. There are certain construction operations that cannot be performed in a small amount of space. Yet there is a level of traffic delay and inconvenience that cannot be tolerated by the public. The obvious key to such situations is pre-construction planning. When traffic starts backing up a mile in both directions, it is too late to discover that there is no other way for the constructor to get his job done.

Traffic Control Plan: For any project on an arterial or collector street in which lane closures will be required, a pre-construction traffic control plan is essential. Such a plan should, wherever possible, be a part of the project specifications. If it is not, then it should be prepared by the structor, then reviewed and agreed to by the project and/or traffic engineer. promises should be made regarding the space allocated to the work area, traffic control devices, vehicles and pedestrians. This space allocation should be utilized so that the various space allocations can be distributed to provide the maximum allowable area for each need. If necessary, there

should be compromises made so that the constructor's work area, traffic lane closures, barricading, signing, etc., are optimized.

Time restrictions could be imposed based on economic calculations of the costs to motorists associated with time delays. This may be particularly helpful for large, long-term projects where the costs could be quite high.

Permit Procedures: Where there is no time to prepare a Traffic Control Plan, or if there is no apprsrent need, there should nevertheless be a permit procedure which allows the traffic engineer to review the application of any private or public agency planning to do work which may interfere with traffic. The traffic engineer should have the authority to place conditions upon the permit which will assure the best possible level of traffic efficiency and safety. Several methods for establishing such procedures are suggested in "Utility Accommodation" research reports of the American Public Works Association.[10]

Agencies should have a map on file showing roadways where time restrictions by direction will be imposed for maintenance and construction operations, and where it will be necessary to obtain a permit at least 24 hours in advance of doing the work, except for emergencies.

Special Conditions: Multiple operations conducted at the same time, such as two construction groups working on opposite sides of the roadway, can cause serious traffic congestion. Where the street must remain open for traffic, only one operation at a time should be conducted.

In a railroad crossing area, a constructor must use extra precaution in the manner in which space is utilized and warning devices placed. No working space should be taken if it will obstruct the drivers view of railroad warning devices or oncoming trains.

Work space taken in school zones must be recognized as an "attractive nuisance", with extra precautions taken to protect the area from inquisitive children. Sometimes fencing may be in order to keep children completely away from the work area. Nevertheless, it is an area of mandatory access and thus may require extra security, the hiring of a uniformed guard, or other precautionary means.

If at all possible, work space should not be taken at a bus stop, since it is an important point of vehicular/pedestrian access. If work space is required at a bus stop, an alternate nearby bus stop should be designated and provided after approval of appropriate authorities (e.g., bus company, police and traffic engineer). A bus stop cannot simply be eliminated since many persons, particularly the elderly and disabled, may become seriously inconvenienced.

Any street or area closure must nevertheless contain provision for access by emergency vehicles. One must beware of reaching the conclusion that emergency access is not required because there are no people in the area. Fires, crimes, floods, etc. are always a possibility.

SUMMARY

DO

Plan for time restrictions, volumes, pedestrians, transit routes, traffic mix, turning movements, parking, railroad crossings, school zones, emergency access and bicycle paths.

DON'TS

1) Forget to differentiate between freeways, arterials, collectors and local roadways.

2) Deny access to private property.

VII. PROTECTION OF PEDESTRIANS AND WORKERS

The pedestrian and the workers as pedestrians are very susceptible to danger in the worksite area. Thus, when the work area encroaches upon a sidewalk, crosswalk, or other area near moving traffic, special consideration shall be given to pedestrian safety. The constructor has an interest to perform a job quickly and efficiently, and the traffic engineer has an interest to keep traffic moving. Therefore, they are inclined to overlook or don't place the necessary emphasis on pedestrian safety.

A. Application Of New Safety Materials

In providing for the safety of pedestrians and workmen, the single most important requirement is the visibility and recognition of hazards. To call attention to potential hazards, new safety materials are constantly appearing on the market. Recent useful developments include high-intensity reflective material, audio warning of work area encroachment, "back-up" flashers and horns on vehicles, adjustable ramps to replace inconspicuous steps, and automatic warning flashers at pedestrian/vehicle conflict points. New (or old but effective) materials such as these should be used whenever the conditions warrant.

B. Proper Dress For Workers/Flaggers

Much as the visibility and recognition of hazards is important to pedestrians and workers, the visibility of workers and other construction personnel to drivers is equally important. Workers and flaggers exposed to vehicular or construction hazards should "stand out" by wearing orange vests or jackets, headgear, and have their position protected by cones, flashers, barricades, or high-level warning devices. For nighttime conditions, similar outside garments must be reflectorized, see MUTCD, Page 313.

C. Special Non-Motorist Considerations

Protective barricades, fencing, handrails and bridges together with warning and guidance devices should be used so that passageways for pedestrians and bicycles, bridal paths and other non-motorists are safe and well defined.

Where walks are closed by construction or maintenance, an alternate walkway should be provided when feasible. Where it is necessary to divert pedestrians into the parking lane of a street, barricades and delineation should be provided to separate the pedestrian walkway from the adjacent traffic lane. Pedestrians should not be diverted into a portion of the street used by vehicular traffic. At locations where adjacent alternate walkways cannot be provided, appropriate signs should be posted at the limits of construction and in advance of the closure at the nearest crosswalk or intersection to divert pedestrians across the street.

When hazardous work conditions exist overhead, it may be necessary to install a fixed pedestrian walkway of the fence or canopy type to protect and control pedestrians. In such cases wood and chain link fencing can be used with warning lights and illumination to warn and guide both pedestrians and motorists.

Fences around a construction area are often necessary and may be a requirement of the local jurisdiction building code. They are often constructed in conjunction with a special pedestrian walkway or when there are deep excavations or when pedestrian access to the job site is not desirable. Installation of such fencing must take into account relocation of existing control devices and facilities such as traffic signals, pedestrian signals, traffic signs and parking meters. The use of chain link fencing which can be seen through may be needed at intersections to provide adequate sight distance.

D. Temporary Guardrail Installation

In some instances, a guardrail may be used to give added protection between vehicles and pedestrian-worker areas. Such guardrail should not be used alone, but in conjunction with more positive pedestrian fencing, since pedestrians can easily step over a guardrail. The guardrail is effective in creating a buffer zone to keep moving traffic a safe distance away from pedestrian barriers.

Worker Protection

Worker protection is divided into two categories: mobile and fixed. Mobile protection is that form of device which moves along the roadway to provide protection to mobile operations. Fixed protection is that used at a stationary location.

Mobile Protection: Mobile protection provides advance warning to the public that slow moving vehicles or equipment are ahead so that lane changes, slow downs, and stops can be safely made.

Use of a shadow vehicle (usually a truck) can be justified in those locations where there is restricted sight distance and the workers and equipment are exceptionally vulnerable. Lighted directional (arrow) signs can be used on shadow vehicles along with slow-moving vehicle emblems. The shadow vehicle may also be equipped with an energy absorption device which would lessen the severity of an accident caused by a vehicle impacting the rear of the shadow vehicle.

The shadow vehicle should follow at a distance far enough from the activity (work) vehicle to allow for safe stopping especially in case of emergency stopping.

Fixed Protection: Setting up fixed protection and working within that area is considered to be one of the most hazardous exposures of employees. Training in how to set up and take down the protection as safely and rapidly

Work Zone Accidents

To increase public awareness of the inherent dangers in work zone construction areas, the 'Give 'em a Brake' program was established in 1989. This program has two major parts: public education and state police hireback. Pamphlets, posters, stickers, buttons and signs are visual elements being used to remind drivers to use caution when driving through work zone areas. In addition, a videotape has been developed for use in driver education classes. The state police hireback program provides for extra patrol hours in construction zones throughout the state.

Work zone accidents are determined by location only, regardless of contributing factors. All reported accidents that occur in the vicinity of roadway construction workers or designated work zone areas are included. Of the 39 people killed in work zones in 1990, 2 were pedestrian workers. Of the 2,766 people injured, only 28 were pedestrian workers. It is interesting to note that in any given year the number of work zone accidents is directly correlated to the money spent on construction and repairs to roads.

WORK ZONE STATISTICS

	1986	1987	1988	1989	1990
Total Accidents	7,617	6,524	6,279	6,782	7,205
Fatal Accidents	22	20	13	16	37
Injury Accidents	1,939	1,586	1,523	1,628	1,733
Persons Killed	26	24	17	22	39
Persons Injured	2,846	2,336	2,247	2,442	2,766
Location of Accidents:					
Urban					
Controlled access Roads	1,608	1,632	1,232	1,979	1,421
State Routes	2,366	1,109	1,076	598	2,484
City Streets & Roads	2,135	1,675	1,791	1,677	1,349
Unmarked State Routes	834	759	1,284	1,545	687
Toll Roads	107	336	236	277	122
Total	7,050	5,511	5,619	6,076	6,063
Rural					
Controlled access Roads	118	163	236	248	324
State Routes	328	234	215	335	398
County & Local Roads	89	99	88	74	119
Unmarked State Routes	22	8	8	13	16
Toll Roads	10	509	113	36	285
Total	567	1,013	660	706	1,142

Pedestrian Accidents

	1986	1987	1988	1989	1990
Total Accidents	10,149	10,300	10,303	10,298	9,588
Pedestrians Killed	276	308	281	279	273
Pedestrians Injured	10,274	10,367	10,340	10,436	10,151

LIGHT CONDITIONS	NUMBER OF FATAL ACCIDENTS				
Daylight	94	101	106	102	103
Dawn	4	5	4	4	2
Dusk	5	10	13	6	6
Darkness	74	75	53	62	55
Dark-Road Lighted	100	115	102	98	102
NS [1]	-	-	4	1	-

PEDESTRIANS KILLED IN 1990 [2]

	BAC LEVELS					
AGE GROUPS	.00	.01-.09	.10-.20	>.20	NO TEST/ UNKNOWN	TOTAL
0-4	2	-	-	-	6	8
5-9	8	-	-	-	9	17
10-14	7	-	-	-	3	10
15-19	7	-	2	1	3	13
20-24	7	-	2	8	3	20
25-34	8	3	10	14	3	38
35-44	14	5	4	2	6	31
45-54	10	3	3	8	3	27
55-64	17	4	5	2	5	33
65-74	20	1	2	2	8	33
75+	28	-	-	-	14	42
NS [1]	-	-	-	-	1	-
Total	128	16	28	37	64	273

[1] Not Stated

[2] This chart was compiled using the Fatal Accident Reporting System (FARS).

Pedestrian accidents are down by 6.9 percent when comparing 1989 with 1990. In 1990, 38 percent of all *fatal* pedestrian accidents occurred in daylight. 13.6 percent of all pedestrians killed this year were less than 14 years of age; 27.1 percent were over 65 years of age. 39 percent of all pedestrians killed, who were tested for Blood Alcohol Concentration, had been drinking.

Report No. FHWA-TS-81-210
April 1981

US Department
of Transportation
Federal Highway
Administration

A Method for Estimating Fuel Consumption and Vehicle Emissions on Urban Arterials and Networks

Office of Research and Development

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X. SEPARATION OF WORKSITE FROM TRAFFIC LANES

The goal of controlling traffic at construction and maintenance worksites is to provide for safe movement of traffic through and/or around the worksite while encouraging the most expedicious level of traffic flow attainable under the prevailing conditions. This goal requires that the following objectives be met:

1. Prevention of accidents and injuries to motorists, passengers, pedestrians and worksite personnel.
2. Minimal delay to the motorist.
3. Prevention of damage to the motorists' vehicles, worksite equipment, street furniture and private property.
4. Prevention of secondary effects upon the environment, such as air and noise pollution, negative economical impacts (i.e., motorist increased costs due to delay, and commercial revenue loss, etc.)

At the worksite, there exist two basic activities, the construction or maintenance activity and the flow of traffic. Since these two activities are occuring simultaneously, there is always the potential for conflict.

Traffic must be guided through and/or around the worksite providing a minimum width of travelled lane of ten (10) feet when passenger cars make up the total mix. Otherwise a larger width should be provided dependent upon existing conditions; for example, providing for the "tracking effect" when there is truck traffic and horizontal curves in the roadway, and also vehicles of a larger width (i.e., public transit and oversize house trailers). The worksite activity must be confined so that it will not encroach upon the travelled way provided for traffic during the construction or maintenance activity, but allow sufficient area in the right-of-way in order that the work can be completed as efficiently as possible in the shortest length of time.

A variety of devices and methods are available to separate the worksite and traffic. These devices range from direct physical separation such as portable reinforced concrete barriers to only visual delineation such as directional signing and pavement lane markings used for moving operations like lane line striping, street cleaning, and snow plowing.

Devices and methods used for moving worksites include warning devices on the rear of the working vehicle or equipment and a shadow vehicle with warning and protection devices attached.

A listing of available traffic control devices is shown in Table 6, Devices and Methods for the Separation of Worksite and Traffic. The elements, in Table 7, Relevant Elements at Worksites, must be considered in the process of selecting the most effective and appropriate traffic control devices to serve as separators. This decision-making process is one composed of engineering judgment and is dependent upon the conditions present at each worksite.

TABLE 6. TYPICAL DEVICES AND METHODS FOR THE SEPARATION OF WORKSITE AND TRAFFIC

Longitudinal Pavement Markings
Delineators
Pylons
Cones
Barrels and Drums
Barricades -- Type I (L or R)
Barricades -- Type II (L or R)
Barricades -- Type III (L or R)
Fence -- Chain Link for Sight Distance
Energy Absorption Devices
Guardrail
    Fixed
    Portable
Reinforced Concrete Barrier
Shadow Vehicle
Sandbags
Spoil-Dirt Windrows

Note: These items should not be used by themselves. Other warning devices must be used to effect a total worksite setup for traffic control.

One of the objectives of separators is to keep vehicles in a traffic lane, far enough away from workers, equipment and obstructions to prevent the possibility of personal injury and property damage. Likewise, separators confine the worksite personnel and equipment to specific areas.

Generally, the more substantial heavy duty separators, such as the reinforced concrete barriers, are used at worksites that have one or more of the following characteristics: high speed, high traffic volume, and when worksite personnel are highly vulnerable and unprotected by equipment.

A separator should not be used if it will cause more damage upon being struck than the object which it is protecting unless it is protecting people.

Refer to the national MUTCD for the design and application of the more common devices that are not elaborated upon in this manual. There are methods or devices that are gaining prominence in use. They are reinforced concrete barriers, and impact attenuators. The following is a discussion on each of these separators. They all must be used in conjunction with advance warning signs, tapering and channelizing devices that are needed to conform with the national MUTCD.