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Inorganic Arsenic Risk Assessment For Primary and Secondary Lead Smelters, Primary Zinc Smelters, Zinc Oxide Plants, Cotton Gins, and Arsenic Chemical Plants

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Inorganic Arsenic Risk Assessment for Primary and Secondary Lead Smelters, Primary Zinc Smelters, Zinc Oxide Plants, Cotton Gins, and Arsenic Chemical Plants

Strategies and Air Standards Division

**U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711**

April 1985

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INORGANIC ARSENIC RISK ASSESSMENT FOR PRIMARY AND SECONDARY LEAD SMELTERS, PRIMARY ZINC SMELTERS AND ZINC OXIDE PLANTS, COTTON GINS AND ARSENIC CHEMICAL PLANTS

1 INTRODUCTION

1.1 Overview

The quantitative expressions of public cancer risks presented in this document are based on (1) a dose-response model that numerically relates the degree of exposure to airborne inorganic arsenic to the risk of getting lung cancer, and (2) numerical expressions of public exposure to ambient air concentrations of inorganic arsenic estimated to be caused by emissions from stationary sources. Each of these factors is discussed briefly below and details are provided in the following sections of this document.

1.2 The Relationship of Exposure to Cancer Risk

The relationship of exposure to the risk of contracting lung cancer is derived from epidemiological studies in occupational settings rather than from studies of excess cancer incidence among the public. The epidemiological methods that have successfully revealed associations between occupational exposure and cancer for substances such as asbestos, benzene, vinyl chloride, and ionizing radiation, as well as for inorganic arsenic, are not readily applied to the public sector, with its increased number of confounding variables, much more diverse and mobile exposed population, lack of consolidated medical records, and almost total absence of historical exposure data. Given such uncertainties, EPA considers it improbable that any association, short of very large increases in cancer, can be verified in the general population with any reasonable certainty by an epidemiological study. Furthermore, as noted by the National Academy of Sciences (NAS)¹, "...when there is exposure to a material, we are not starting at an origin

of zero cancers. Nor are we starting at an origin of zero carcinogenic agents in our environment. Thus, it is likely that any carcinogenic agent added to the environment will act by a particular mechanism on a particular cell population that is already being acted on by the same mechanism to induce cancers." In discussing experimental dose-response curves, the NAS observed that most information on carcinogenesis is derived from studies of ionizing radiation with experimental animals and with humans which indicate a linear no-threshold dose-response relationship at low doses. They added that although some evidence exists for thresholds in some animal tissues, by and large, thresholds have not been established for most tissues. NAS concluded that establishing such low-dose thresholds "...would require massive, expensive, and impractical experiments ..." and recognized that the U.S. population "...is a large, diverse, and genetically heterogeneous group exposed to a large variety of toxic agents." This fact, coupled with the known genetic variability to carcinogenesis and the predisposition of some individuals to some form of cancer, makes it extremely difficult, if not impossible, to identify a threshold.

For these reasons, EPA has taken the position, shared by other Federal regulatory agencies, that in the absence of sound scientific evidence to the contrary, carcinogens should be considered to pose some cancer risk at any exposure level. This no-threshold presumption is based on the view that as little as one molecule of a carcinogenic substance may be sufficient to transform a normal cell into a cancer cell. Evidence is available from both the human and animal health literature that cancers may arise from a single transformed cell. Mutation research with ionizing radiation in cell cultures indicates that such a transformation can occur as the result of interaction with as little as a single cluster of ion pairs. In reviewing the available data regarding carcinogenicity, EPA found no compelling scientific reason to abandon the no-threshold presumption for inorganic arsenic.

In developing the exposure-risk relationship for inorganic arsenic, EPA has assumed that a linear no-threshold relationship exists at and below the levels of exposure reported in the epidemiological studies of occupational exposure. This means that any exposure to inorganic arsenic is assumed to pose some risk of lung cancer and that the linear relationship between cancer risks and levels of public exposure is the same as that between cancer risks and levels of occupational exposure. EPA believes that this assumption is reasonable for public health protection in light of presently available information. However, it should be recognized that the case for the linear no-threshold dose-response relationship model for inorganic arsenic is not quite as strong as that for carcinogens which interact directly or in metabolic form with DNA. Nevertheless, there is no adequate basis for dismissing the linear no-threshold model for inorganic arsenic. Assuming that exposure has been accurately quantified, it is the Agency's belief that the exposure-risk relationship used by EPA at low concentrations represents only a plausible upper-limit risk estimate in the sense that the risk is probably not higher than the calculated level and could be much lower.

The numerical constant that defines the exposure-risk relationship used by EPA in its analysis of carcinogens is called the unit risk estimate. The unit risk estimate for an air pollutant is defined as the lifetime cancer risk occurring in a hypothetical population in which all individuals are exposed throughout their lifetimes (about 70 years) to an average concentration of $1 \mu\text{g}/\text{m}^3$ of the agent in the air which they breathe. Unit risk estimates are used for two purposes: (1) to compare the carcinogenic potency of several agents with each other, and (2) to give a crude indication of the public health risk which might be associated with estimated air exposure to these agents.

The unit risk estimate for inorganic arsenic that is used in this appendix was prepared by combining the five different exposure-risk numerical constants developed from four occupational studies.² The methodology used to develop the unit risk estimate from the four studies is described in Section 2 below.

1.3 Public Exposure

The unit risk estimate is only one of the factors needed to produce quantitative expressions of public health risks. Another factor needed is a numerical expression of public exposure, i.e., the numbers of people exposed to the various concentrations of inorganic arsenic. The difficulty of defining public exposure was noted by the National Task Force on Environmental Cancer and Health and Lung Disease in their 5th Annual Report to Congress, in 1982.³ They reported that "...a large proportion of the American population works some distance away from their homes and experience different types of pollution in their homes, on the way to and from work, and in the workplace. Also, the American population is quite mobile, and many people move every few years." They also noted the necessity and difficulty of dealing with long-term exposures because of "...the long latent period required for the development and expression of neoplasia [cancer]..." The reader should note that the unit risk estimate has been changed from that value used in the inorganic NESHAP proposal as a result of EPA's analysis of several occupational epidemiological studies that have recently been completed.

EPA's numerical expression of public exposure is based on two estimates. The first is an estimate of the magnitude and location of long-term average ambient air concentrations of inorganic arsenic in the vicinity of emitting sources based on dispersion modeling using long-term estimates of source emissions and meteorological conditions. The second is an estimate of the number and distribution of people living in the vicinity of emitting sources based on 1980 Bureau of Census data which "locates" people by population

centroids in census tract areas. The people and concentrations are combined to produce numerical expressions of public exposure by an approximating technique contained in a computerized model. The methodology is described in Section 3 below.

1.4 Public Cancer Risks

By combining numerical expressions of public exposure with the unit risk estimate, two types of numerical expressions of public cancer risks are produced. The first, called individual risk, relates to the person or persons estimated to live in the area of highest concentration as estimated by the computer model. Individual risk is expressed as "maximum lifetime risk." As used here, the word "maximum" does not mean the greatest possible risk of cancer to the public. It is based only on the maximum annual average exposure estimated by the procedure used. The second, called aggregate risk, is a summation of all the risks to people estimated to be living within the vicinity (usually within 50 kilometers) of a source and is customarily summed for all the sources in a particular category. The aggregate risk is expressed as incidences of cancer among all of the exposed population after 70 years of exposure; for convenience, it is often divided by 70 and expressed as cancer incidences per year. These calculations are described in more detail in Section 4 below.

There are also risks of nonfatal cancer and other potential health effects, depending on which organs receive the exposure. No numerical expressions of such risks have been developed.

2. THE UNIT RISK ESTIMATE FOR INORGANIC ARSENIC²

The following discussion is summarized from a more detailed description of the Agency's derivation of the inorganic arsenic unit risk estimate as found in EPA's "Health Assessment Document for Inorganic Arsenic" (EPA-600/8-83-021F).

2.1 The Linear No-Threshold Model for Estimation of Unit Risk Based on Human Data (General)

The methodologies used to arrive at quantitative estimates of risk must be capable of being implemented using the data available in existing epidemiologic studies of exposure to airborne arsenic. This requires extrapolation from the exposure levels and temporal exposure patterns in these studies to those for which risk estimates are required. It is assumed that the age-specific mortality rate of respiratory cancer per year per 100,000 persons for a particular 5-year age interval, i , can be represented using the following linear absolute or additive risk model:

$$a_i(D) = a_i + 100,000a'D \quad (1)$$

With this model, a_i is the age-specific mortality rate per year of respiratory cancer in a control population not exposed to arsenic, a' is a parameter representing the potential of airborne arsenic to cause respiratory cancer, and D is some measure of the exposure to arsenic up to the i th age interval. For example, D might be the cumulative dose in years- $\mu\text{g}/\text{m}^3$, the cumulative dose neglecting exposure during the last 10 years prior to the i th age interval, or the average dose in $\mu\text{g}/\text{m}^3$ over some time period prior to the i th age interval. The forms to be used for D are constrained by the manner in which dose was treated in each individual epidemiologic study. At low exposures the extra lifetime probability of respiratory cancer mortality will vary correspondingly (e.g., linearly).

The dose-response data available in the epidemiologic studies for estimating the parameters in these models consists primarily of a dose measure D_j for the j th exposure group, the person-years of observation Y_j , the observed number of respiratory cancer deaths O_j , and the number E_j of these deaths expected in a control population with the same sex and age distribution as the exposure group. The expected number E_j is calculated as

$$E_j = \sum_i Y_{ji} a_i / 100,000 \quad (2)$$

here Y_{ji} is the number of person-years of observation in the i th age category and the j th exposure group ($Y_j = \sum_i Y_{ji}$). This is actually a simplified

representation, because the calculation also takes account of the change in the age-specific incidence rates with absolute time. The expected number of respiratory cancer deaths for the i th exposure group is

$$\begin{aligned} E(O_j) &= \sum_i Y_{ji} (a_i + 100,000 a' D_j) / 100,000 \\ &= E_j + a' Y_j D_j \end{aligned} \quad (3)$$

under the linear absolute risk model. Consequently, $E(O_j)$ can be expressed in terms of quantities typically available from the published epidemiologic studies.

Making the reasonable assumption that O_j has a Poisson distribution, the parameter a' can be estimated from the above equation using the method of maximum likelihood. Once this parameter is estimated, the age-specific mortality rates for respiratory cancer can be estimated for any desired exposure pattern.

To estimate the corresponding additional lifetime probability of respiratory cancer mortality, let b_1, \dots, b_{18} be the mortality rates, in the absence of exposure, for all cases per year per 100,000 persons for the age intervals 0-4, 5-9, ..., 80-84, and 85+, respectively; let a_1, \dots, a_{18} represent the corresponding rates for malignant neoplasms of the respiratory system. The probability of survival to the beginning of the i th 5-year age interval is estimated as

$$\prod_{j=1}^{i-1} [1 - 5b_j/100,000] \quad (4)$$

Given survival to the beginning of age interval i , the probability of dying of respiratory cancer during this 5-year interval is estimated as

$$5a_i/100,000 \quad (5)$$

The probability of dying of respiratory cancer given survival to age 85 is estimated as a_{18}/b_{18} . Therefore, the probability of dying of respiratory cancer in the absence of exposure to arsenic can be estimated as:

$$P_0 = \sum_{i=1}^{17} [5a_i/100,000) \prod_{j=1}^{i-1} (1-5b_j/100,000)] \\ + (a_{18}/b_{18}) \prod_{j=1}^{17} (1 - 5b_j/100,000)$$

Here the mortality rates a_i apply to the target population for which risk estimates are desired, and consequently will be different from those in

(1)-(5), which applied to the epidemiologic study cohort. If the 1976 U.S. mortality rates (male, female, white, and non-white combined) are used in this expression, then $P_0 = 0.0451$.

To estimate the probability P_{EP} of respiratory cancer mortality when exposed to a particular exposure pattern EP, the formula (6) is again used, but a_i and b_i are replaced by $a_i(D_i)$ and $b_i(D_i)$, where D_i is the exposure measure calculated for the i th age interval from the exposure pattern EP. For example, if the dose measure used in (1) is cumulative dose to the beginning of the i th age interval in $\mu\text{g}/\text{m}^3\text{-years}$, and the exposure pattern EP is a lifetime exposure to a constant level of $10 \mu\text{g}/\text{m}^3$, then $D_i = (i-1)(5)(10)$, where the 5 accounts for the fact that each age interval has a width of 5 years. The additional risk of respiratory cancer mortality is estimated as

$$P_{EP} - P_0 \quad (7)$$

If the exposure pattern EP is constant exposure to $1 \mu\text{g}/\text{m}^3$, then $P_{EP} - P_0$ is called the "unit risk."

This approach can easily be modified to estimate the extra probability of respiratory cancer mortality by a particular age due to any specified exposure pattern.

2.2 Unit Risk Estimates Derived from Epidemiologic Studies

Prospective studies of the relationship between mortality and exposure to airborne arsenic have been conducted for the Anaconda, Montana smelter and the Tacoma, Washington smelter. Table 1 summarizes the fit of the absolute linear model to dose-response data from 4 different studies at the two smelters. (See the "Health Assessment Document for Inorganic Arsenic",

Table 1
Summary of Quantitative Risk Analyses

Exposed Population	Study and Data Source	Model	Results of Goodness-of-Fit Test		
			χ^2 (d.f.)	p-value	"unit" risk ^a
Anaconda smelter workers	Lee-Feldstein (heavy exposure omitted)	absolute risk	12.7(5)	0.025	2.80(-3) ^b
	Higgins et al.	absolute risk	1.2(3)	0.75	4.90(-3)
	Brown & Chu	absolute risk	7.01(7)	0.41	1.25(-3)
ASARCO smelter workers	Enterline & Marsh (zero lag)	absolute risk	5.5(4)	0.24	6.81(-3)
	Enterline & Marsh (10-year lag)	absolute risk	7.0(4)	0.14	7.60(-3)

^aAdditional lifetime risk of respiratory cancer mortality from lifetime environmental exposure to 1 μgm^3 arsenic.

^b2.80 (-3) means 2.80×10^{-3}

Chapter 7, EPA-600/8-83-021F for detailed description of occupational studies.) Table 1 also displays the carcinogenic potencies a'. It should be noted that the potencies estimated from different models are in different units, and are therefore not comparable.

The estimated unit risk is presented for each fit for which the chi-square goodness-of-fit p-value is greater than 0.01. The unit risks derived from linear models--8 in all--range from 0.0013 to 0.0136. The largest of these is from the Ott et al. study, which probably is the least reliable for developing quantitative estimates, and which also involved exposures to pentavalent arsenic, whereas the other studies involved trivalent arsenic. The unit risks derived from the linear absolute-risk models are considered to be the most reliable; although derived from 5 sets of data involving 4 sets of investigators and 2 distinct exposed populations, these estimates are quite consistent, ranging from 0.0013 to 0.0076.

To establish a single point estimate, the geometric mean for data sets is obtained within distinct exposed populations, and the final estimate is taken to be the geometric mean of those values. This process is illustrated in Table 2.

Table 2
Combined Unit Risk Estimates for Absolute-Risk Linear Models

Exposure Source	Study	Unit Risk	Geometric Mean Unit Risk	Final Estimated Unit Risk
Anaconda smelter	Brown & Chu	1.25×10^{-3}	2.56×10^{-3}	4.29×10^{-3}
	Lee-Feldstein	2.80×10^{-3}		
	Higgins et al.	4.90×10^{-3}		
ASARCO smelter	Enterline & Marsh	6.81×10^{-3}	7.19×10^{-3}	
		7.60×10^{-3}		

3. QUANTITATIVE EXPRESSIONS OF PUBLIC EXPOSURE TO INORGANIC ARSENIC EMISSIONS

3.1 EPA's Human Exposure Model (HEM) (General)

EPA's Human Exposure Model is a general model capable of producing quantitative expressions of public exposure to ambient air concentrations of pollutants emitted from stationary sources. HEM contains (1) an atmospheric dispersion model, with included meteorological data, and (2) a population distribution estimate based on Bureau of Census data. The input data needed to operate this model are source data, e.g., plant location, height of the emission release point, and volumetric rate of release temperature of the off-gases. Based on the source data, the model estimates the magnitude and distribution of ambient air concentrations of the pollutant in the vicinity of the source. The model is programmed to estimate these concentrations for a specific set of points within a radial distance of 50 kilometers from the source. If the user wishes to use a dispersion model other than the one contained in HEM to estimate ambient air concentrations in the vicinity of a source, HEM can accept the concentrations if they are put into an appropriate format.

Based on the radial distance specified, HEM numerically combines the distributions of pollutant concentrations and people to produce quantitative expressions of public exposure to the pollutant.

3.1.1 Pollutant Concentrations Near a Source

The HEM dispersion model is a climatological model which is a sector-averaged gaussian dispersion algorithm that has been simplified to improve computational efficiency.⁵

Stability array (STAR) summaries are the principal meteorological input to the HEM dispersion model. STAR data are standard climatological frequency-of-occurrence summaries formulated for use in EPA models and available for major U.S. meteorological monitoring sites from the National Climatic Center, Asheville, N.C. A STAR summary is a joint frequency-of-occurrence of wind speed, atmospheric stability, and wind direction, classified according to Pasquill's categories. The STAR summaries in HEM usually reflect five years of meteorological data for each of 314 sites nationwide. The model produces polar coordinate receptor grid points consisting of 10 downwind distances located along each of 16 radials which represent wind directions. Concentrations are estimated by the dispersion model for each of the 160 receptors located on this grid. The radials are separated by 22.5-degree intervals beginning with 0.0 degrees and proceeding clockwise to 337.5 degrees. The 10 downwind distances for each radial are 0.2, 0.5, 1.0, 2.0, 5.0, 10.0, 20.0, 30.0, 40.0, and 50.0 kilometers. The center of the receptor grid for each plant is assumed to be the plant center. Concentrations at other points were calculated by using a log-linear scheme as illustrated in Figure 1.

3.1.2 Expansion of Analysis Area

At proposal, exposure and risk were estimated for people residing within 20 kilometers of the smelter. Some commenters pointed out that since people beyond 20 kilometers are exposed to some level of arsenic due to a source's emissions, EPA's proposal analysis underestimates the total exposure and risk. EPA agreed with the commenters and expanded its analysis out to 50 kilometers. When applying air dispersion models, the EPA's modeling guidelines recommend that, because of the increasing uncertainty of estimates with distance from the modeled source and because of the paucity of validation studies at larger distances, the impact may extend

out to 50 kilometers but the analysis should generally be limited to this distance from the source.⁴ Such site-specific factors as terrain features (complex or flat), the objectives of the modeling exercise, and distance to which the model has been validated will determine the appropriate distance (whether greater than or less than the guideline distance) for which the Agency should apply the model.

3.2 Methodology for Reviewing Pollutant Concentrations

Before making HEM computer runs, EPA reviewed small-scale U.S. Geological Survey topographical maps (scale 1:24000) to verify locational data for each arsenic source. Plants were given accurate latitude and longitude values which were then incorporated into the HEM program.

After completing the HEM runs, nearby monitoring sites with ambient air quality data were identified by a computer search of EPA's National Aerometric Data Bank (NADB) (Table 3). At some sites, data collected over several years along with annual averages (based on different numbers of sample sizes for the years monitored) for each year were available. In these instances, weighted multi-year averages were calculated to provide an overall mean for each monitoring site. For purposes of annual mean calculations, values measured below minimum detection limits were considered by EPA to be equal to one-half the detection limit. These ambient arsenic data were then compared to HEM predicted values in order to gauge the accuracy of the air dispersion model's estimates. As noted above, HEM predicted values were based on concentrations at 160 polar coordinate receptor grid points consisting of 10 downwind distances located along each of 16 radials which represented wind directions. Because the actual monitoring site locations identified in the NADB retrieval usually did not correspond to exact grid point locations, a log-linear interpolation scheme (Figure 1) was used to calculate an estimated concentration at the site.

Table 3

Arsenic Concentrations Near ASARCO-East Helena
Primary Lead Smelter

Plant	# Obs.	Distance ¹ (km)	Bearing	Predicted ² ($\mu\text{g}/\text{m}^3$)	Measured ³ ($\mu\text{g}/\text{m}^3$)	MDL ⁴ ($\mu\text{g}/\text{m}^3$)	Percentile ⁵
ASARCO-East Helena	27	.5	119.6	0.230	0.108	0.02	30< % <50
	41	.7	11.5	0.078	0.151	0.02	<10
	137	.8	20.4	0.056	0.242	0.02	<10
	25	.9	343.9	0.050	0.161	0.02	<10
	31	1.4	45.3	0.076	0.078	0.02	30< % <50
	36	1.5	156.9	0.047	0.109	0.02	<10
	81	3.9	176.5	0.0159	0.031	0.02	70< % <90*
	23	4.7	270.4	0.005	0.025	0.02	50< % <70*
	20	7.2	273.4	0.003	0.030	0.0055	30< % <50*
<hr/>							
Company Data	1460	1.1	275	0.024	0.059	--	--
	1460	1.3	5	0.050	0.24	--	--
	1460	1.3	145	0.077	0.078	--	--
	638	2.1	92	0.071	0.074	--	--
	1460	6.1	275	0.0037	0.024	--	--
	274	7.2	162	0.0084	0.028	--	--

* Indicates data point was disregarded; see Section 3.2.1

¹ Distance from source to monitor (km)

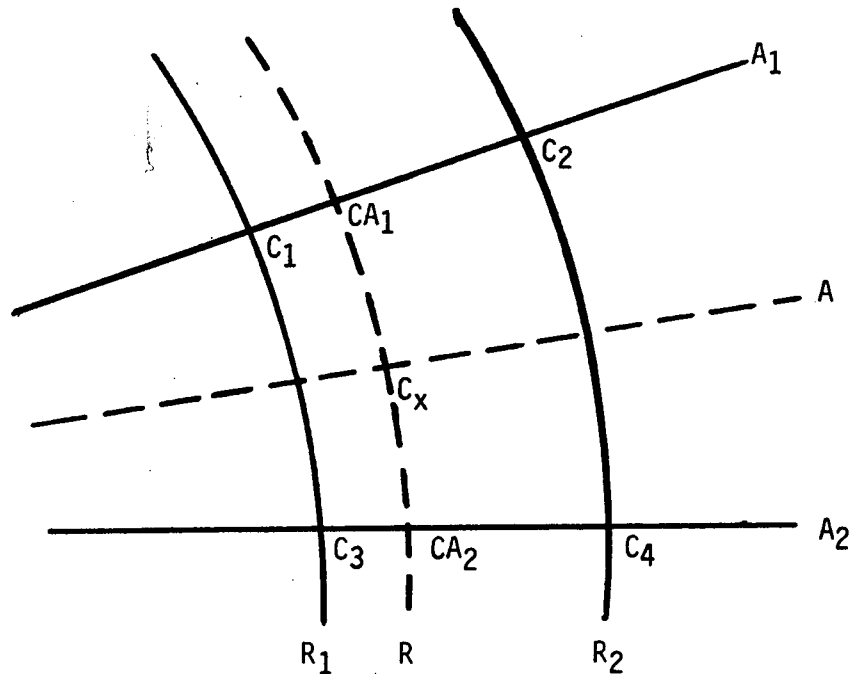
² Concentration predicted by Human Exposure Model (HEM). See Section 3.1.

³ The measured values are weighted averages. When the sampled arsenic concentrations were below the MDL, a value of 1/2 MDL was assumed for purposes of calculating the annual averages

⁴ Minimum detection limit

⁵ Percentile indicates percentage of data falling below minimum detectable levels.

Figure 1 Group 2 BG/ED Interpolation



Given:

- A - The angle in radians subtended clockwise about the source from due south to the BG/ED centroid;
- A_1 - The angle from due south to the radial line immediately counter-clockwise of A, or passing through A if there is an exact match;
- A_2 - The angle from due south to the radial line immediately clockwise of A_1 (A_2 is 0 if it is due south);
- R - The distance in km from the source to the BG/ED centroid;
- R_1 - The distance from the source to the largest circular arc of radius less than R;
- R_2 - The distance from the source to the smallest circular arc of radius greater than or equal to R;
- C_1 - The natural logarithm of the concentration value at (A_1 , R_1);
- C_2 - The natural logarithm of the concentration value at (A_1 , R_2);

C3 - The natural logarithm of the concentration value at (A2, R1);

C4 - The natural logarithm of the concentration value at (A2, R2);

then:

$RTEMP = \ln(R/R1)/\ln(R2/R1);$

$ATEMP = (A-A1)/(A2-A1);$

$CA1 = \exp(C1 + (C2-C1) \times RTEMP);$

$CA2 = \exp(C3 + (C4-C3) \times RTEMP);$ and

$CX = CA1 + (CA2-CA1) \times ATEMP,$

where CX is the interpolated concentration at the BG/ED centroid.

3.2.1 Use of Ambient Data

Certain criteria were considered in review of ambient levels. Mean concentration values derived from sample sizes of less than 25 data points were disregarded. When reviewing the available monitoring data, it appeared that monitors situated at distances greater than 15 km from the arsenic source were considered too far from the source to gauge air dispersion results without interference from other arsenic sources. Furthermore, at distances greater than 15 km from the source, plant impacts were often predicted to be significantly lower than minimum detection limits. These data were not incorporated in the analyses. A third consideration in reviewing ambient data concerned the percentage of monitored data which fell below minimum detection limits. Although some monitoring sites registered data with over 90 percent of the values above minimum detection levels, many had about half the data points or more below such levels. Instances where more than 50 percent of the data were below MDL were disregarded. It should be noted that the various tables in subsequent sections display, in addition to company-collected data, all ambient monitoring data that were collected at sites within 15 kilometers of the source as identified by EPA's computer search although not all the data were used in the final analysis.

3.2.2 The People Living Near A Source

To estimate the number and distribution of people residing within 50 kilometers of the source, the HEM model uses the 1980 Master Area Reference File (MARF) from the U.S. Bureau of Census. This data base consists of enumeration district/block group (ED/BG) values. MARF contains the population centroid coordinates (latitude and longitude) and the 1980 population of each ED/BG (approximately 300,000) in the United States (50 states plus the District of Columbia). HEM identifies the population around each plant, by using the

geographical coordinates of the plant, and identifies, selects, and stores for later use those ED/BGs with coordinates falling within 50 kilometers of plant center.

3.2.3 Exposure⁵

The Human Exposure Model (HEM) uses the estimated ground level concentrations of a pollutant together with population data to calculate public exposure. For each of 160 receptors located around a plant, the concentration of the pollutant and the number of people estimated by the HEM to be exposed to that particular concentration are identified. The HEM multiplies these two numbers to produce exposure estimates and sums these products for each plant.

A two-level scheme has been adopted in order to pair concentrations and populations prior to the computation of exposure. The two level approach is used because the concentrations are defined on a radius-azimuth (polar) grid pattern with non-uniform spacing. At small radii, the grid cells are usually smaller than ED/BG's; at large radii, the grid cells are usually larger than ED/BG's. The area surrounding the source is divided into two regions, and each ED/BG is classified by the region in which its centroid lies. Population exposure is calculated differently for the ED/BG's located within each region. For ED/BG centroids located between 0.2 and 3.5 km from the emission source, populations are divided between neighboring concentration grid points. There are 64 (4 x 16) polar grid points within this range. Each ED/BG can be paired with one or many concentration points. The population associated with the ED/BG centroid is then divided among all concentration grid points assigned to it. The land area within each polar sector is considered in the apportionment.

For population centroids between 3.5 and 50 km from the source, a concentration grid cell, the area approximating a rectangular shape bounded by four receptors, is much larger than the area of a typical ED/BG. Since there is an approximate linear relationship between the logarithm of concentration and the logarithm of distance for receptors more than 2 km from the source, the entire population of the ED/BG is assumed to be exposed to the concentration that is logarithmically interpolated radially and arithmetically interpolated azimuthally from the four receptors bounding the grid cell. Concentration estimates for 96 (6 x 16) grid cell receptors at 5.0, 10.0, 20.0, 30.0, 40.0, and 50.0 km from the source along each of 16 wind directions are used as reference points for this interpolation.

In summary, two approaches are used to arrive at coincident concentration/population data points. For the 64 concentration points within 3.5 km of the source, the pairing occurs at the polar grid points using an apportionment of ED/BG population by land area. For the remaining portions of the grid, pairing occurs at the ED/BG centroids themselves through the use of log-log and linear interpolation. (For a more detailed discussion of the model used to estimate exposure, see Reference 5.)

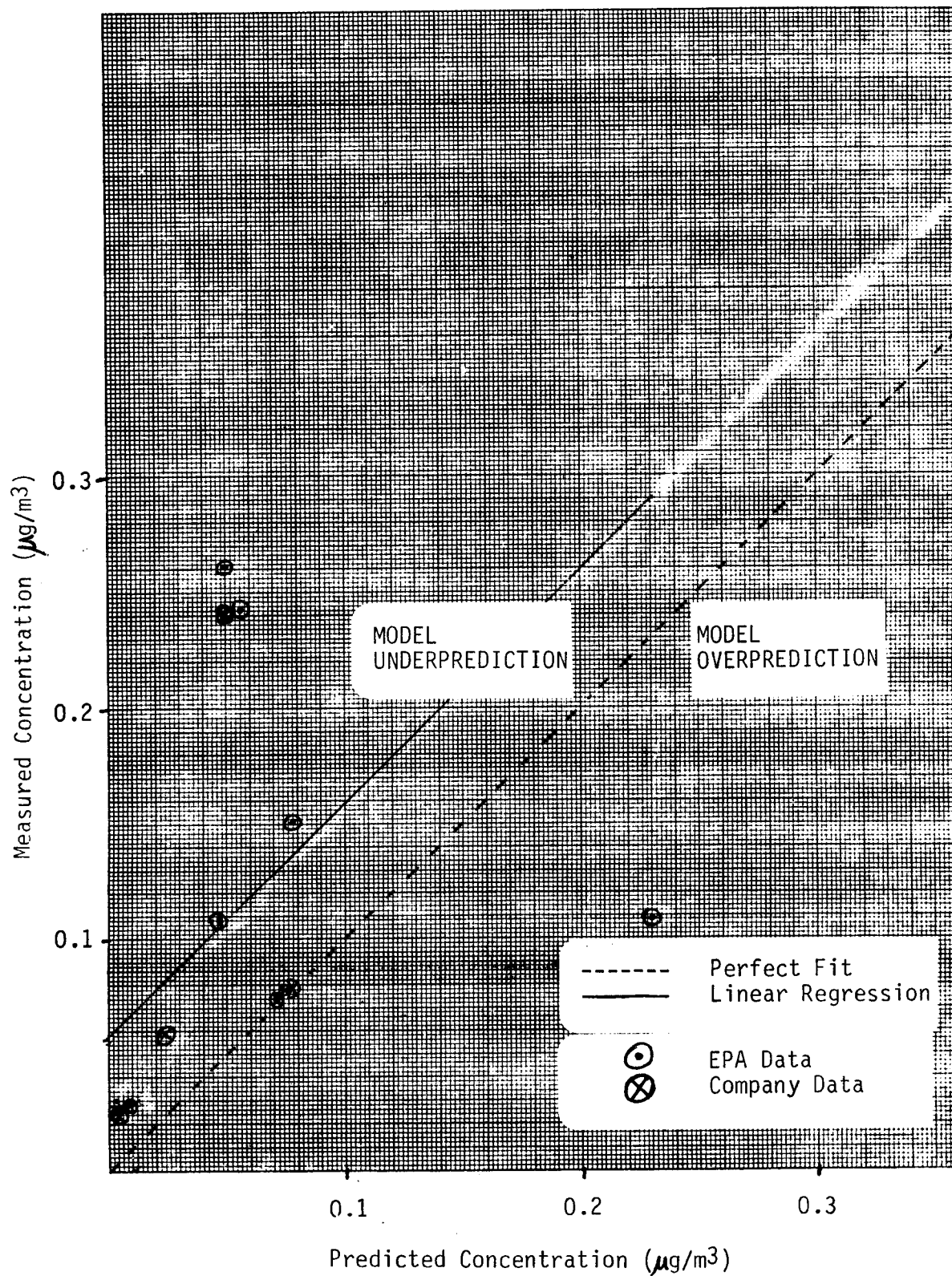
3.3 ASARCO-East Helena

Predicted (HEM) versus measured data were plotted (Figure 2) and a least squares weighted linear regression analysis was run based on thirteen data points (see Table 3). The least squares regression line (solid line) was determined on the basis of a comparison of National Aerometric Data Bank monitoring data (circumscribed dots) and ASARCO monitoring data (circumscribed Xs) with ambient concentrations predicted by the Human Exposure Model.

The reader should note that a perfect fit for the least squares regression analysis results in a line running through the origin at a 45° angle (dotted line on Figure 2). This means that if the HEM model predicts the measured data perfectly, then the data points would fall on the dotted line. In cases where the HEM model underpredicts concentrations, data points will be located above the 45° perfect fit line. Likewise, when the HEM model overpredicts concentrations, data points will be located below the perfect fit line. The regression line resulting from our comparison of predicted and monitored data runs nearly parallel to the perfect fit line but intersects the ordinate axis at a value of approximately 0.05 $\mu\text{g}/\text{m}^3$. This result is consistent with the expectation that air dispersion modeling would underpredict ambient concentrations. The air dispersion modeling did not consider other local sources of arsenic such as naturally-occurring arsenic in the windblown dust and reentrained arsenic particulate matter that had settled to the earth from past smelter emissions.

A study to determine source apportionment for particulate lead and total suspended particulates (TSP) in East Helena was completed in 1982. High volume TSP, low volume TSP, and dichotomous samplers were co-collected (same time period and same site) to permit differences in sample collection mass and chemistry to be understood. Analysis of hi-vol samples was carried out by the State of Montana and lo-vol and dichotomous samples were analyzed

FIGURE 2 Predicted Versus Measured
Inorganic Arsenic Ambient Concentrations
(ASARCO - East Helena, MT)



by NEA, Inc. In addition to particulate lead and TSP, samples were also measured in some cases for arsenic.⁶

At six locations where arsenic concentrations were measured using both lo-vol and hi-vol samplers, the ratio of lo-vol to hi-vol in percent ranged from 104 to 133 with a mean of 118%. This loss of arsenic compounds could have occurred in two areas: (1) the volatilization of the arsenic compounds from the hi-vol filter itself during sampling, and (2) the loss of volatile arsenic compounds during digestion and storage of samples prior to analysis. However, based on the data from the study, EPA concluded that the loss of arsenic on hi-vol filters was relatively minor in nature and within the overall accuracy goal of ± 15 -20% considered adequate for most ambient air quality measurements.

3.3.1 Public Exposure to Inorganic Arsenic Emissions from Primary Lead Smelters

3.3.1.1 Source Data

Five primary lead smelters are included in the analysis. Table 4 lists the names and addresses of the plants considered, and Table 5 lists the plant data used as input to the Human Exposure Model (HEM).

3.3.1.2 Exposure Data

Table 6 lists, on a plant-by-plant basis, the total number of people encompassed by the exposure analysis and the total exposure. Total exposure is the sum of the products of number of people times the ambient air concentration to which they are exposed, as calculated by HEM. Table 7 sums, for the entire source category (5 plants), the numbers of people exposed to various ambient concentrations, as calculated by HEM. (Source-by-source exposure results are provided in the EPA docket numbered A-83-23.)

TABLE 4

IDENTIFICATION OF PRIMARY LEAD SMELTERS

Plant Number Code	Plant Name and Address
1	ASARCO East Helena, MT
2	ASARCO El Paso, TX
3	St. Joe Herculaneum, MO
4	ASARCO Glover, MO
5	Amax Boss, MO

Table 5 Input Data to Exposure Model Primary Lead Smelting Industry
(Assuming Baseline Controls)

Plant (Furnace)	Latitude (Degrees Minutes Seconds)	Longitude (Degrees Minutes Seconds)	Emission Rate (Kg/yr)	Emission Point Elevation (Meters)	Emission Point Diameter (Meters)	Emission* Point Cross Sectional Area (m ²)	Emission Point Gas Exit Velocity m/sec	Emission Point Gas Temp. (°K)	Emission Point Type
ASARCO-East Helena, MT	46-34-52	111-55-12	14700	128	2.7	100	16.5	352	Stack
			1680	130	3.0	100	19.4	330	Stack
			1680	122	3.4	100	11.7	375	Stack
			5040	0	--	10000	--	293	Fugitive
ASARCO- El Paso, TX	31-47-06	106-37-23	1680	186	4.3	100	17.0	345	Stack
			1680	91	4.9	100	3.0	330	Stack
			5040	0	--	10000	--	293	Fugitive
St. Joe- Herculaneum, MO	38-15-47	90-22-59	2772	107	6.1	100	13.5	353	Stack
			84	0	--	10000	--	293	Fugitive
ASARCO- Glover, MO	36-29-46	90-41-28	1680	24	1.5	100	18.3	294	Stack
			42	0	--	10000	--	293	Fugitive
Amax- Boss, MO	37-38-31	91-11-35	1680	61	4.6	100	10.0	355	Stack
			50.4	0	--	10000	--	293	Fugitive

TABLE 6 TOTAL EXPOSURE AND NUMBER OF PEOPLE EXPOSED
PRIMARY LEAD SMELTING INDUSTRY*

Plant	Total Number of People Exposed	Total Exposure (People - $\mu\text{g}/\text{m}^3$)
1	48,600	215
2	497,000	715
3	1,510,000	186
4	97,300	27
5	42,700	7

* A 50-kilometer radius was used for the analysis of primary lead smelting industry.

TABLE 7

PUBLIC EXPOSURE FOR PRIMARY LEAD SMELTING INDUSTRY
AS PRODUCED BY THE HUMAN EXPOSURE MODEL
(ASSUMING BASELINE CONTROLS)

Concentration Level ($\mu\text{g}/\text{m}^3$)	Population Exposed (Persons)*	Exposure (Persons - $\mu\text{g}/\text{m}^3$)**
0.437	<1	0
0.25	1	0
0.1	40	6
0.05	441	33
0.025	1240	62
0.01	7700	144
0.005	15900	199
0.0025	71700	398
0.001	340000	801
0.0005	545000	945
0.00025	657000	983
0.0001	1470000	1100
0.00005	2080000	1150
0.0000269	2190000	1150

*Column 2 displays the computed value, rounded to the nearest whole number, of the cumulative number of people exposed to the matching and higher concentration levels found in column 1. For example, 0.5 people would be rounded to 0 and 0.51 people would be rounded to 1.

**Column 3 displays the computed value of the cumulative exposure to the matching and higher concentration levels found in column 1.

3.4 Murph Metals-Dallas and Quemetco-Seattle

Predicted (HEM) versus measured data for Murph Metals-Dallas and Quemetco-Seattle were plotted (Figures 3 and 4) and a least squares weighted linear regression analysis was run based on a number of data points. The least squares regression line (solid line) was determined on the basis of a comparison of National Aerometric Data Bank monitoring data (circumscribed dots) and State agency monitoring data (circumscribed Xs) with ambient concentrations predicted by the Human Exposure Model.

The reader should note that a perfect fit for the least squares regression analysis results in a line running through the origin at a 45° angle (dotted lines in Figures 3 and 4). This means that if the HEM model predicts perfectly, then the data points would fall on the 45° line. In cases where the HEM model underpredicts concentrations, data points will be located above the 45° perfect fit line. Likewise, when the HEM model overpredicts concentrations, data points will be located below the perfect fit line. The regression line resulting from our comparison of predicted and monitored data lies above the perfect fit line, intersecting the ordinate axis at values of approximately 0.011 $\mu\text{g}/\text{m}^3$ and 0.026 $\mu\text{g}/\text{m}^3$ for Murph Metals and Quemetco respectively. This result is consistent with the expectation that air dispersion modeling would underpredict ambient concentrations. The air dispersion modeling did not consider other local sources of arsenic such as naturally-occurring arsenic in the windblown dust and re-entrained arsenic particulate matter that had settled to the earth from past smelter emissions.

FIGURE 3 Predicted Versus Measured
Inorganic Arsenic Ambient Concentrations
(Murph Metals - Dallas, TX)

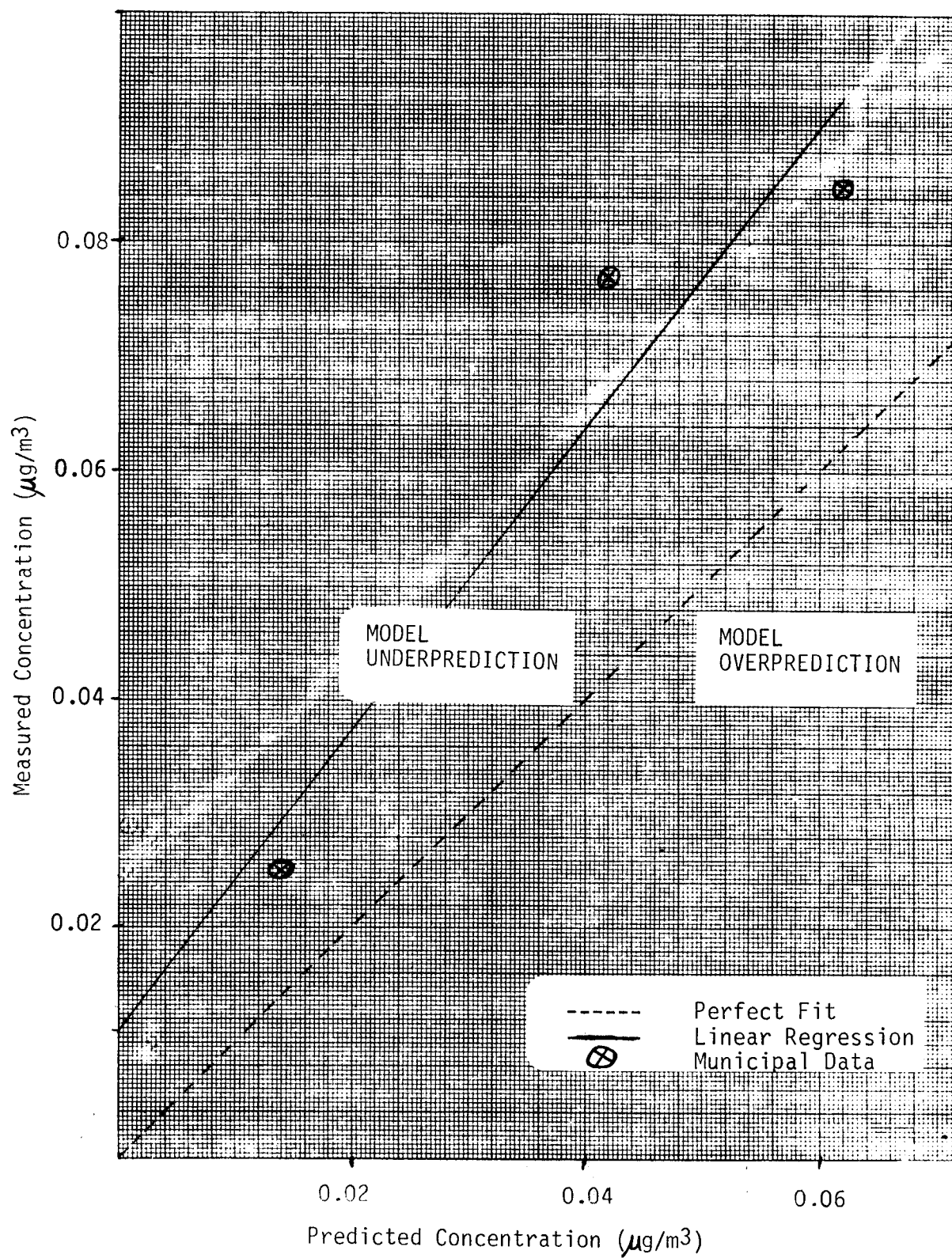
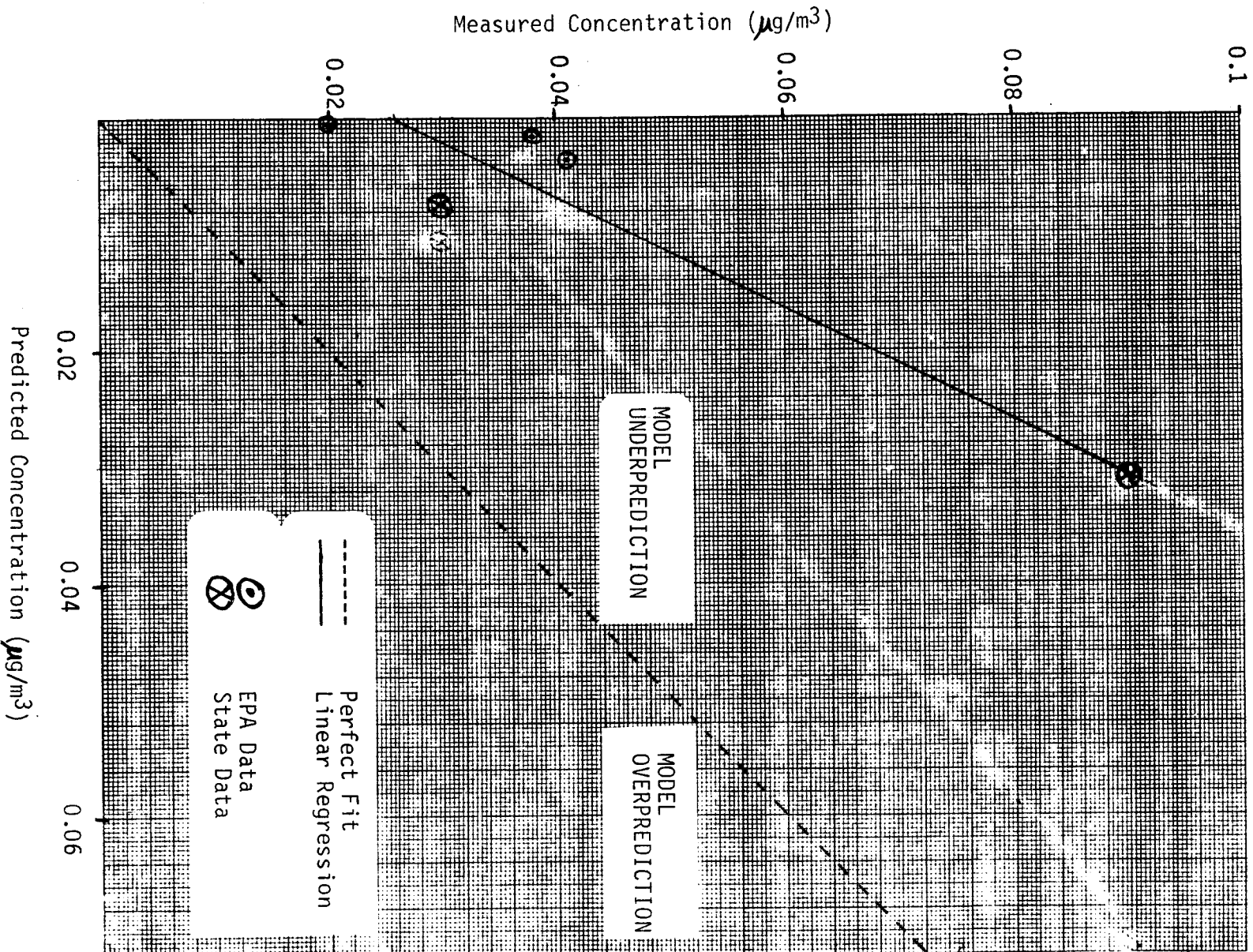


FIGURE 4 Predicted Versus Measured
Inorganic Arsenic Ambient Concentrations
(QUEMETCO - Seattle, WA)



3.4.1 Public Exposure to Inorganic Arsenic Emissions from Secondary Lead Smelters

3.4.1.1 Source Data

Thirty-five secondary lead smelters are included in the analysis. Table 8 lists arsenic concentrations near select secondary lead smelters. Table 9 lists the names and addresses of the plants considered, and Table 10 lists the plant data used as input to the Human Exposure Model (HEM).

3.4.1.2 Exposure Data

Table 11 lists, on a plant-by-plant basis, the total number of people encompassed by the exposure analysis and the total exposure. Total exposure is the sum of the products of number of people times the ambient air concentration to which they are exposed, as calculated by HEM. Table 12 sums, for the entire source category (35 plants), the number of people exposed to various ambient concentrations, as calculated by HEM. (Source-by-source exposure results are provided in the EPA docket numbered A-83-9.)

Table 8

Arsenic Concentrations Near Select
Secondary Lead Smelters

Plant	# Obs.	Distance ¹ (km)	Bearing	Predicted ² ($\mu\text{g}/\text{m}^3$)	Measured ³ ($\mu\text{g}/\text{m}^3$)	MDL ⁴ ($\mu\text{g}/\text{m}^3$)	Percentile ⁵
General Battery, Reading, PA	29	5.1	189.5	0.00104	0.009	0.0055	30< % <50
Murph Metals- Dallas, TX	86	3.6	181.6	0.0024	0.028	0.05	90< % <95*
	21	3.7	181.5	0.0024	0.010	0.0055	30< % <50*
	93	7.6	311.6	0.00095	0.029	0.05	90, % <95*
	57	9.0	256.2	0.0004	0.025	0.05	>99*
Murph Metals-Dallas Texas Air Control Board Data	28	0.2	0	0.062	0.085	--	--
	31	0.2	337.5	0.042	0.077	--	--
	31	0.5	157.5	0.014	0.025	--	--
Quemetco-City of Industry, CA	29	17.8	314.0	0.00037	0.005	0.0055	70< % <90*
	25	22.8	281.9	0.000133	0.003	0.0055	>99*
	81	23.6	164.2	0.00018	0.003	0.0055	90< % <95*
	85	24.0	275.2	0.00023	0.006	0.0055	70< % <90*
	27	31.2	218.2	0.000083	0.003	0.0055	>99*
	47	32.2	161.0	0.000112	0.003	0.0055	70< % <90*
	30	35.1	300.0	0.000106	0.003	0.0055	>99*
	121	36.1	84.8	0.000113	0.005	0.0055	70< % <90*
	29	38.1	235.8	0.000066	0.004	0.0055	70< % <90*
Quemetco- Indianapolis, IN	64	12.5	78.2	0.00040	0.005	0.0055	50< % <70*
Quemetco-Seattle, WA	80	1.9	150.8	0.0036	0.041	0.0055	<10
	60	3.2	30.3	0.00183	0.038	0.0055	30< % <50
	72	13.5	2.6	0.00047	0.020	0.0055	30< % <50
Quemetco-Seattle Washington State Dept. of Ecology Data	60	0.2	157.5	0.031	0.09	--	--
	60	1.4	180	0.0075	0.03	--	--

*Indicates data point was disregarded - see Section 3.3.1.1.

¹Distance from source to monitor (km).

²Concentration predicted by Human Exposure Model (HEM). See Section 3.1.

³The measured values are weighted averages. When the sampled arsenic concentrations were below the MDL, a value of 1/2 MDL was assumed for purposes of calculating the annual averages.

⁴Minimum Detection Limit.

⁵Percentile indicates percentage of data falling below minimum detectable levels.

Table 9

Identification of Secondary Lead Smelters

Plant Number Code	Plant Name and Address
1	Alco Pacific Gardena, CA
2	Bergsoe St Helens, OR
3	Chloride Metals Columbus, GA
4	Chloride Metals Tampa, FL
5	Dixie Metals Dallas, TX
6	East Penn Lyons Station
7	Federated Metals San Fran, CA
8	General Battery Reading, PA
9	General Smelting College Grov, TN
10	Gopher Eugene, Minn
11	Gould Frisco, TX
12	Gould Vernon, CA
13	Gulf Coast Tampa, FL
14	Hyman Viener Richmond, VA
15	Interstate Lead Leeds, AL
16	Lancaster Lancaster, PA
17	Master Metals Cleveland, OH
18	Murph Metals Dallas, TX
19	National Smelting Atlanta, GA
20	National Smelting Pedricktown, NJ
21	Quemetco City of Industry, CA
22	Quemetco Indianapolis, IN
23	Quemetco Seattle, WA
24	Refined Metals Beach Grove, IN
25	Refined Metals Memphis, TN
26	Revere Wall, NY
27	Ross Metals Rossville, TN
28	Sanders Lead Troy, AL
29	Schuykill Batou Rouge, LA
30	Schuykill Forest City, MO
31	Standard San Antonio, TX
32	Taracorp Atlanta, GA
33	Taracorp Granite City, IL
34	Tonolli Nesquehoning, PA
35	USS Lead E. Chicago, IN

Table 10

Secondary Lead Industry Inputs to HEM Model (Assuming Baseline Controls)

[illegible]

Table 10 (Continued)

Secondary Lead Industry Inputs to HEM Model
(Assuming Baseline Controls)

Plant	Lat/Long	Process					Process Fugitive					Area	
		As	Stack Ht. m	Stack Diam. m	Stack Vel. m/sec	Exit Temp. °K	Emission Rt. kg/yr	Stack Ht. m	Stack Diam. m	Stack Vel. m/sec	Exit Temp. °K	As	Area m
		Emission Rate kg/yr										Emission Rt. kg/yr	
Quemetco/CA	34-01-30/117-58-58	61.0	26	1.2	16.6	331	1.99	15.4	1.2	10.6	311	692.1	8,788
Quemetco/IN	39-45-14/86-17-59	139.5	26	1.2	16.6	400	1.99	15.4	1.2	10.6	311	692.1	8,788
Quemetco/WA	47-34-44/122-21-04	69.7	31	0.92	25.9	400	0.99	15.4	1.2	13.3	311	461.4	5,862
Refined Metals/IN	39-42-36/86-03-5 4"	52.3	31	0.92	25.9	400	0.75	15.4	1.2	13.3	311	76.9	5,862
Refined Metals/TN	35-05-13/90-04-10	87.2	31	0.92	25.9	400	1.24	15.4	1.2	13.3	311	76.9	5,862
Revere.NY	41-27-37/74-21-35	139.5	26	1.2	16.6	400	1.99	15.4	1.2	10.6	311	692.1	8,788
Ross Metals	35-02-42/89-34-30	27.9	31	0.62	29	400	0.39	15.4	1.2	10.4	311	0	2,945
Sanders Lead	31-47-28/85-58-16	116.2	31	0.92	25.9	400	1.66	15.4	1.2	13.3	311	29.3	5,862
Schuylkill/LA	30-58-08/91-14-40	232.4	26	1.2	16.6	400	3.31	15.4	1.2	10.6	311	20.9	8,788
Schuylkill/MO	40-01-59/95-13-59	104.6	31	0.92	25.9	400	1.49	15.4	1.2	13.3	311	13.8	5,862
Standard	29-20-00/98-29-38	23.5	31	0.62	29	400	0.34	15.4	1.2	10.4	311	7.6	2,945
Taracorp/GA	33-47/84-22	87.2	31	0.92	25.9	400	1.24	15.4	1.2	13.3	311	13.8	5,862
Taracorp/IL	38-42-05/90-08-37	244.1	26	1.2	16.6	400	3.48	15.4	1.2	10.6	311	23.1	8,788
Tonolli	40-51-03/75-52-46	57.2	26	1.2	16.6	331	1.86	15.4	1.2	10.6	311	69.3	8,788
USS Lead	41-36-58/87-27-47	58.1	31	0.92	25.9	400	0.83	15.4	1.2	13.3	311	61.3	5,862

Table 11

Total Exposure and Number of People Exposed
Secondary Lead Smelting Industry*

Plant	Total Number of People Exposed	Total Exposure (People - $\mu\text{g}/\text{m}^3$)
1	8,450,000	32
2	1,120,000	15
3	314,000	17
4	1,670,000	19
5	2,350,000	228
6	1,310,000	16
7	3,370,000	22
8	1,260,000	250
9	679,000	3
10	58,200	1
11	1,800,000	17
12	8,900,000	189
13	1,690,000	32
14	766,000	15
15	844,000	41
16	1,160,000	6
17	2,530,000	59
18	2,560,000	668
19	1,920,000	51
20	4,210,000	197
21	8,860,000	2300
22	1,150,000	460
23	2,060,000	576
24	1,180,000	67
25	927,000	115
26	948,000	249
27	902,000	4
28	92,000	11
29	143,000	4
30	149,000	2
31	1,050,000	24
32	1,920,000	83
33	2,190,000	159
34	934,000	21
35	5,280,000	103

* A 50-kilometer radius was used for the analysis of secondary lead smelters.

Table 12

Public Exposure for Secondary Lead Smelters
as Produced by the Human Exposure Model
(Assuming Baseline Controls)

Concentration Level ($\mu\text{g}/\text{m}^3$)	Population Exposed (Persons)*	Exposure (Persons - $\mu\text{g}/\text{m}^3$)**
0.101	<1	0
0.1	<1	0
0.05	256	16
0.025	2880	104
0.01	16000	300
0.005	53100	543
0.0025	152000	878
0.001	743000	1770
0.0005	1940000	2590
0.00025	4510000	3480
0.0001	12800000	4750
0.00005	21700000	5390
0.000025	31100000	5720
0.00001	44000000	5930
0.000005	55700000	6010
0.0000025	64100000	6050
0.000001	70800000	6060
0.0000005	73800000	6060
0.00000025	74700000	6060

* Column 2 displays the computed value, rounded to the nearest whole number, of the cumulative number of people exposed to the matching and higher concentration levels found in column 1. For example, 0.5 people would be rounded to 0 and 0.51 people would be rounded to 1.

** Column 3 displays the computed value of the cumulative exposure to the matching and higher concentration levels found in column 1.

3.5 Public Exposure to Inorganic Arsenic Emissions from Primary Zinc Smelters

3.5.1 Source Data

Five primary zinc smelters are included in the analysis. Table 13 lists ambient arsenic concentrations near select primary zinc smelters. Table 14 lists the names and addresses of the plants considered, and Table 15 lists the plant data used as input to the Human Exposure Model (HEM).

3.5.2 Exposure Data

Table 16 lists, on a plant-by-plant basis, the total number of people encompassed by the exposure analysis and the total exposure. Total exposure is the sum of the products of number of people times the ambient air concentration to which they are exposed, as calculated by HEM. Table 17 sums, for the entire source category (5 plants), the numbers of people exposed to various ambient concentrations, as calculated by HEM. (Source-by-source exposure results are provided in the EPA docket numbered A-83-23.)

Table 13

Arsenic Concentrations Near
Select Primary Zinc Smelters

Plant	# Obs	Distance ¹ (km)	Bearing	Predicted ² ($\mu\text{g}/\text{m}^3$)	Measured ³ ($\mu\text{g}/\text{m}^3$)	MDL ⁴ ($\mu\text{g}/\text{m}^3$)	Percentile ⁵
St. Joe- Monaca, PA	No data within 15 km						
ASARCO- Corpus Christi, TX	36	3.0	262.8	0.000024	0.025	0.05	100*
	299	3.8	252.1	0.0000149	0.026	0.05	95 < % < 99*
	33	5.5	299.4	0.0000156	0.025	0.05	100*
	83	6.2	289.7	0.0000125	0.029	0.05	95 < % < 99*
	319	6.9	173.0	0.0000067	0.026	0.05	95 < % < 99*
	26	14.9	187.7	0.0000029	0.008	0.0055	30 < % < 50*
	190	14.9	187.7	0.0000029	0.028	0.05	90 < % < 95*
Amax- Sauget, IL	27	4.1	314.4	0.000042	0.007	0.0055	50 < % < 70*
Jersey Miniere Zinc Co- Clarksville, TN	No data within 15 km						
National Zinc- Bartlesville, OK	No data within 15 km						

* Indicates data point was disregarded; see Section 3.1.

¹ Distance from source to monitor (km).

² Concentration predicted by Human Exposure Model (HEM).

³ The measured values are weighted averages. When the sampled arsenic concentrations were below the MDL, a value of 1/2 MDL was assumed for purposes of calculating the annual averages.

⁴ Minimum detection limit.

⁵ Percentile indicates percentage of data falling below minimum detectable levels.

Table 14
Identification of Primary Zinc Smelters

Plant Number Code	Plant Name and Address
1	St. Joe - Monaca, PA
2	ASARCO - Corpus Christi, TX
3	Amax - Sauget, IL
4	Jersey Miniere Zinc Co - Clarksville, TN
5	National Zinc - Bartlesville, OK

Table 15

Input Data to Exposure Model
Primary Zinc Smelting Industry
(Assuming Baseline Controls)

Plant	Latitude (Degrees Minutes Seconds)	Longitude (Degrees Minutes Seconds)	Emission Rate (Kg/yr)	Emission Point Elevation (Meters)	Emission Point Diameter (Meters)	Emission Point Cross Sectional Area (m ²)	Emission Point Gas Exit Velocity m/sec	Emission Point Gas Temp. (°K)	Emission Point Type
St. Joe - Monaca, PA	40-40-12	80-20-10	109	61	3.4	100	7.0	325	Stack
			8.4	31	1.8	100	1.8	325	Stack
			67.7	37	2.1	100	10.7	336	Stack
			8.4	32	2.0	100	1.1	325	Stack
ASARCO - Corpus Christi, TX	27-48-00	97-23-46	8.4	92	2.0	100	2.7	389	Stack
Amax - Sauget, IL	38-36-07	90-10-16	23.5	46	1.5	100	9.7	373	Stack
Jersey Miniere Zinc Comp. Clarksville, TN	36-30-54	87-24-14	25.2	61	1.8	100	6.3	334	Stack
National Zinc Bartelsville, OK	36-44-24	95-58-59	11.3	31	1.3	100	5.7	325	Stack

Table 16
Total Exposure and Number of People Exposed
Primary Zinc Smelter*

Plant	Total Number of People Exposed	Total Exposure (People - $\mu\text{g}/\text{m}^3$)
1	2,000,000	47
2	336,000	2
3	2,200,000	16
4	235,000	3
5	120,000	2

* A 50-kilometer radius was used for the analysis of primary zinc smelters.

Table 17

Public Exposure for Primary Zinc Smelters
as Produced by the Human Exposure Model
(Assuming Baseline Controls)

Concentration Level ($\mu\text{g}/\text{m}^3$)	Population Exposed (Persons)*	Exposure (Persons - $\mu\text{g}/\text{m}^3$ **
0.00182	7	0
0.001	109	0
0.0005	2350	2
0.00025	19400	8
0.0001	91700	18
0.00005	212000	27
0.000025	450000	35
0.00001	1870000	55
0.000005	3170000	65
0.0000025	3960000	68
0.000001	4650000	69
0.0000005	4800000	69
0.00000025	4850000	69
0.0000001	4870000	69
0.00000005	4890000	69

* Column 2 displays the computed value, rounded to the nearest whole number, of the cumulative number of people exposed to the matching and higher concentration levels found in column 1. For example, 0.5 people would be rounded to 0 and 0.51 people would be rounded to 1.

** Column 3 displays the computed value of the cumulative exposure to the matching and higher concentration levels found in column 1.

3.6 Public Exposure to Inorganic Arsenic Emissions from Zinc Oxide Plants

3.6.1 Source Data

Two zinc oxide plants are included in the analysis. Table 18 lists ambient arsenic concentrations near select zinc oxide plants. Table 19 lists the names and addresses of the plants considered, and Table 20 lists the plant data used as input to the Human Exposure Model (HEM).

3.6.2 Exposure Data

Table 21 lists on a plant-by-plant basis, the total number of people encompassed by the exposure analysis and the total exposure. Total exposure is the sum of the products of number of people times the ambient air concentration to which they are exposed, as calculated by HEM. Table 22 sums, for the entire source category (2 plants), the numbers of people exposed to various ambient concentrations, as calculated by HEM. (Source-by-source exposure results are provided in the EPA docket numbered A-83-11.)

Table 18

Arsenic Concentrations Near
Select Zinc Oxide Plants

Plant	# Obs	Distance ¹ (km)	Bearing	Predicted ² ($\mu\text{g}/\text{m}^3$)	Measured ³ ($\mu\text{g}/\text{m}^3$)	MDL ⁴ ($\mu\text{g}/\text{m}^3$)	Percentile ⁵
ASARCO- Columbus, OH	127	3.8	206.0	0.0000124	0.006	0.0055	70 < % < 90*
New Jersey Zinc- Palmerton, PA	No data within 15 km						

* Indicates data point was disregarded; see Section 3.5.1.1.

¹ Distance from source to monitor (km).

² Concentration predicted by Human Exposure Model (HEM).

³ The measured values are weighted averages. When the sampled arsenic concentrations were below the MDL, a value of 1/2 MDL was assumed for purposes of calculating the annual averages.

⁴ Minimum detection limit.

⁵ Percentile indicates percentage of data falling below minimum detectable levels.

TABLE 19

Identification of Zinc Oxide Plants

Plant Number Code	Plant Name and Address
1	ASARCO-Columbus, OH
2	New Jersey Zinc Palmerton, PA.

Table 20

Input Data to Exposure Model Zinc Oxide Plants
(Assuming Baseline Controls)

Plant	Latitude (Degrees Minutes Seconds)	Longitude (Degrees Minutes Seconds)	Emission Rate (Kg/yr)	Emission Point Elevation (Meters)	Emission Point Diameter (Meters)	Emission* Point Cross Sectional Area (m ²)	Emission Point Gas Exit Velocity m/sec	Emission Point Gas Temp. (°K)	Emission Point Type
ASARCO- Columbus, OH	39-59-53	82-58-48	11.3	61	1.2	100	7.5	333	Stack
New Jersey Zinc- Palmerton, PA	40-49-41	75-35-22	3155 2656 2754	24 18 9	5 1.8 1.2	100 100 100	7.3 7.9 17.4	411 364 466	Stack Stack Stack

Table 21
Total Exposure and Number of People Exposed
(Zinc Oxide Plants)*

Plant	Total Number of People Exposed	Total Exposure (People - ug/m ³)
1	1,210,000	8
2	907,000	1260

* A 50 kilometer radius was used for the analysis of zinc oxide plants.

Table 22

Public Exposure for Zinc Oxide Plants
as Produced by the Human Exposure Model
(Assuming Baseline Controls)

Concentration Level ($\mu\text{g}/\text{m}^3$)	Population Exposed (Persons)*	Exposure (Persons - $\mu\text{g}/\text{m}^3$)**
0.269	2	0
0.25	2	0
0.1	138	17
0.05	1160	79
0.025	3990	180
0.01	11700	300
0.005	21300	366
0.0025	54000	474
0.001	392000	921
0.0005	732000	1200
0.00025	883000	1250
0.0001	908000	1260
0.00005	913000	1260
0.000025	976000	1260
0.00001	1160000	1260
0.000005	1360000	1260
0.0000025	1610000	1270
0.000001	1840000	1270
0.0000005	1960000	1270
0.00000025	2110000	1270

* Column 2 displays the computed value, rounded to the nearest whole number, of the cumulative number of people exposed to the matching and higher concentration levels found in column 1. For example, 0.5 people would be rounded to 0 and 0.51 people would be rounded to 1.

** Column 3 displays the computed value of the cumulative exposure to the matching and higher concentration levels found in column 1.

3.7 Methodology for Reviewing Pollutant Concentrations - Cotton Gins

A total of 320 cotton gins were identified as processors of arsenic desiccated cotton. Due to the large number of gins, EPA determined that it was impractical to obtain the location data necessary for arsenic risk assessment. Based on information regarding the range of processing rates possible, four model plants operating at 4, 7, 12 and 20 bales/hour were designed that are representative of the operations and emissions of the gin population.⁷ These were located at each of three sites typical of the areas in which the gins are located. Of the 320 gins, it was assumed that 32 processed 4 bales per hour, 96 processed 7 bales per hour, 160 processed 12 bales per hour, and 32 processed 20 bales per hour. The Human Exposure Model was run for each scenario to establish a range of exposure and risk estimates for individual sources. To provide data for validating the model plant exposure estimates, two operating gins in south central Texas were chosen for test sites over a one year period. Monitors were arranged in a fan-like array of sites positioned at distances of 100, 200 and 400 meters downwind of the gin. Upwind sites were placed at 400m (one gin only) and 100m. This configuration provided a total of 13 sampling sites. The study was conducted over a period of one year with intense sampling (4 hour intervals) for 15 days during the short ginning season followed by 6 day interval sampling for the remainder of the year.

Data from these two gins were compared to Human Exposure Model calculated values (Table 23). The comparison was hampered somewhat by the large number of monitored values which fell below minimum detection limits -- only 298 measurements out of 708 were above the MDL of 0.05 $\mu\text{g}/\text{m}^3$. To circumvent this problem, a range of mean measured values was developed. At one end, all values below MDL were considered as zero values, and at the other end, all such values were considered equal to the MDL of 0.05 $\mu\text{g}/\text{m}^3$.

Table 23
 Arsenic Concentrations Near Two Texas Cotton Gins

Plant	Distance (km) ¹	Predicted (HEM) ($\mu\text{g}/\text{m}^3$)	Measured ² ($\mu\text{g}/\text{m}^3$)
A (\approx 9 bales/hr)	0.1	--	0.083-0.088
	0.2	0.011	--
	0.2	0.011	0.051-0.060
	0.1	--	0.12 -0.12
B (\approx 12 bales/hr)	0.1	--	0.015-0.024
	0.2	0.011	0.013-0.022
	0.1	--	0.013-0.022

¹ Distance from source to monitor.

² Weighted mean concentrations for one calendar year. Lesser value represents weighted mean concentration calculated with values less than minimum detection limit set equal to zero. Greater value represents weighted mean concentration calculated with values less than minimum detection limit set equal to MDL ($0.0065 \mu\text{g}/\text{m}^3$).

When comparing the measured arsenic values to the predicted concentrations from the appropriate model gin exposure analysis, EPA found that the predicted values were reasonably close to concentrations measured very near the gins. The monitoring study data also showed that the arsenic concentrations fell off very rapidly with distance from the gins. This result suggests that people living at some distance from the gins are not being significantly exposed to the gins' emissions. Such a result, coupled with the observation that many gins are in rural areas supports the Agency's conclusion that the aggregate risks for this source category are low.

3.7.1 Public Exposure to Inorganic Arsenic Emissions from Cotton Gins

3.7.1.1 Source Data

Four model cotton gins at each of three geographic locations are included in the analysis. Table 24 lists the names and addresses of the plants considered, and Table 25 lists the plant data used as input to the Human Exposure Model (HEM).

3.7.1.2 Exposure Data

Tables 26 - 37 sum, for the entire source category (12 plants), the numbers of people exposed to various ambient concentrations, as calculated by HEM. (Model plant-by-model plant exposure results are provided in the EPA docket numbered A-83-10.)

Table 24

Identification of Model Cotton Gins

Model Plant Location	Model Plant Production
Hutto, TX	4 Bales/Hour
	7 Bales/Hour
	12 Bales/Hour
	20 Bales/Hour
Buckholtz, TX	4 Bales/Hour
	7 Bales/Hour
	12 Bales/Hour
	20 Bales/Hour
Itasca, TX	4 Bales/Hour
	7 Bales/Hour
	12 Bales/Hour
	20 Bales/Hour

Table 25

Input Data to Exposure Model Cotton Gins
(Assuming Baseline Controls)

Plant	Latitude (Degrees Minutes Seconds)	Longitude (Degrees Minutes Seconds)	Emission Rate (Kg/yr)	Emission Point Elevation (Meters)	Emission Point Diameter (Meters)	Emission Point Cross Sectional Area (m ²)	Emission Point Gas Exit Velocity m/sec	Emission Point Gas Temp. (°K)	Emission Point Type
Hutto, TX	30-33-00	97-33-00							
4 Bales/Hour			1.0	9	0.3	25	20.4	298	Stack
			1.0	5	--	12	--	298	Fugitive
7 Bales/Hour			2.7	9	0.4	25	20.4	298	Stack
			2.7	5	--	12	--	298	Fugitive
12 Bales/Hour			4.6	9	0.4	25	20.4	298	Stack
			4.6	5	--	27	--	298	Fugitive
20 Bales/Hour			10.2	10	0.4	25	20.4	298	Stack
			10.2	5	--	27	--	298	Fugitive
Buckholts, TX	30-52-00	97-08-00							
4 Bales/Hour			1.0	9	0.3	25	20.4	298	Stack
			1.0	5	--	12	--	298	Fugitive
7 Bales/Hour			2.7	9	0.4	25	20.4	298	Stack
			2.7	5	--	12	--	298	Fugitive
12 Bales/Hour			4.6	9	0.4	25	20.4	298	Stack
			4.6	5	--	27	--	298	Fugitive
20 Bales/Hour			10.2	10	0.4	25	20.4	298	Stack
			10.2	5	--	27	--	298	Fugitive
Itasca, TX	32-10-00	97-09-00							
4 Bales/Hour			1.0	9	0.3	25	20.4	298	Stack
			1.0	5	--	12	--	298	Fugitive
7 Bales/Hour			2.7	9	0.4	25	20.4	298	Stack
			2.7	5	--	12	--	298	Fugitive
12 Bales/Hour			4.6	9	0.4	25	20.4	298	Stack
			4.6	5	--	27	--	298	Fugitive
20 Bales/Hour			10.2	10	0.4	25	20.4	298	Stack
			10.2	5	--	27	--	298	Fugitive

Table 26

Public Exposure for 4 Bales/Hour Model Cotton Gin
(Hutto, TX) as Produced by the Human Exposure Model
(Assuming Baseline Controls)

Concentration Level ($\mu\text{g}/\text{m}^3$)	Population Exposed (Persons)*	Exposure (Persons- $\mu\text{g}/\text{m}^3$)**
0.00263	1	0
0.0025	1	0
0.001	1	0
0.0005	6	0
0.00025	23	0
0.0001	112	0
0.00005	177	0
0.000025	433	0
0.00001	1810	0
0.000005	1810	0
0.0000025	3390	0
0.000001	46800	0
0.0000005	285000	0
0.00000025	506000	0

* Column 2 displays the computed value, rounded to the nearest whole number, of the cumulative number of people exposed to the matching and higher concentration levels found in column 1. For example, 0.5 people would be rounded to 0 and 0.51 people would be rounded to 1.

** Column 3 displays the computed value of the cumulative exposure to the matching and higher concentration levels found in column 1.

Table 27

Public Exposure for 7 Bales/Hour Model Cotton Gin
(Hutto, TX) as Produced by the Human Exposure Model
(Assuming Baseline Controls)

Concentration Level ($\mu\text{g}/\text{m}^3$)	Population Exposed (Persons)*	Exposure (Persons- $\mu\text{g}/\text{m}^3$)**
0.00682	1	0
0.005	1	0
0.0025	1	0
0.001	8	0
0.0005	28	0
0.00025	112	0
0.0001	282	0
0.00005	799	0
0.000025	1810	0
0.00001	2420	0
0.000005	7220	0
0.0000025	55400	0
0.000001	448000	1
0.000000528	506000	1

* Column 2 displays the computed value, rounded to the nearest whole number, of the cumulative number of people exposed to the matching and higher concentration levels found in column 1. For example, 0.5 people would be rounded to 0 and 0.51 people would be rounded to 1.

** Column 3 displays the computed value of the cumulative exposure to the matching and higher concentration levels found in column 1.

Table 28

Public Exposure for 12 Bales/Hour Model Cotton Gin
(Hutto, TX) as Produced by the Human Exposure Model
(Assuming Baseline Controls)

Concentration Level ($\mu\text{g}/\text{m}^3$)	Population Exposed (Persons)*	Exposure (Persons- $\mu\text{g}/\text{m}^3$)**
0.011	1	0
0.01	1	0
0.005	1	0
0.0025	5	0
0.001	25	0
0.0005	102	0
0.00025	161	0
0.0001	523	0
0.00005	1810	0
0.000025	1810	0
0.00001	3820	0
0.000005	39500	1
0.0000025	232000	1
0.000001	506000	2

* Column 2 displays the computed value, rounded to the nearest whole number, of the cumulative number of people exposed to the matching and higher concentration levels found in column 1. For example, 0.5 people would be rounded to 0 and 0.51 people would be rounded to 1.

** Column 3 displays the computed value of the cumulative exposure to the matching and higher concentration levels found in column 1.

Table 29

Public Exposure for 20 Bales/Hour Model Cotton Gin
(Hutto, TX) as Produced by the Human Exposure Model
(Assuming Baseline Controls)

Concentration Level ($\mu\text{g}/\text{m}^3$)	Population Exposed (Persons)*	Exposure (Persons- $\mu\text{g}/\text{m}^3$)**
0.0234	1	0
0.01	1	0
0.005	5	0
0.0025	23	0
0.001	102	0
0.0005	169	0
0.00025	433	0
0.0001	1810	1
0.00005	1810	1
0.000025	3390	1
0.00001	46800	1
0.000005	300000	3
0.0000025	506000	4

* Column 2 displays the computed value, rounded to the nearest whole number, of the cumulative number of people exposed to the matching and higher concentration levels found in column 1. For example, 0.5 people would be rounded to 0 and 0.51 people would be rounded to 1.

** Column 3 displays the computed value of the cumulative exposure to the matching and higher concentration levels found in column 1.

Table 30

Public Exposure for 4 Bales/Hour Model Cotton Gin
(Buckholts, TX) as Produced by the Human Exposure Model
(Assuming Baseline Controls)

Concentration Level ($\mu\text{g}/\text{m}^3$)	Population Exposed (Persons)*	Exposure (Persons- $\mu\text{g}/\text{m}^3$)**
0.00263	<1	0
0.0025	<1	0
0.001	<1	0
0.0005	2	0
0.00025	10	0
0.0001	49	0
0.00005	77	0
0.000025	190	0
0.00001	1050	0
0.000005	1050	0
0.0000025	4020	0
0.000001	10600	0
0.0000005	86700	0
0.00000025	129000	0
0.000000196	131000	0

* Column 2 displays the computed value, rounded to the nearest whole number, of the cumulative number of people exposed to the matching and higher concentration levels found in column 1. For example, 0.5 people would be rounded to 0 and 0.51 people would be rounded to 1.

** Column 3 displays the computed value of the cumulative exposure to the matching and higher concentration levels found in column 1.

Table 31

Public Exposure for 7 Bales/Hour Model Cotton Gin
(Buckholts, TX) as Produced by the Human Exposure Model
(Assuming Baseline Controls)

Concentration Level ($\mu\text{g}/\text{m}^3$)	Population Exposed (Persons)*	Exposure (Persons- $\mu\text{g}/\text{m}^3$)**
0.00682	<1	0
0.005	<1	0
0.0025	<1	0
0.001	3	0
0.0005	12	0
0.00025	49	0
0.0001	124	0
0.00005	269	0
0.000025	1050	0
0.00001	1050	0
0.000005	6020	0
0.0000025	15500	0
0.000001	121000	0
0.000000528	131000	0

* Column 2 displays the computed value, rounded to the nearest whole number, of the cumulative number of people exposed to the matching and higher concentration levels found in column 1. For example, 0.5 people would be rounded to 0 and 0.51 people would be rounded to 1.

** Column 3 displays the computed value of the cumulative exposure to the matching and higher concentration levels found in column 1.

Table 32

Public Exposure for 12 Bales/Hour Model Cotton Gin
(Buckholts, TX) as Produced by the Human Exposure Model
(Assuming Baseline Controls)

Concentration Level ($\mu\text{g}/\text{m}^3$)	Population Exposed (Persons)*	Exposure (Persons- $\mu\text{g}/\text{m}^3$)**
0.011	<1	0
0.01	<1	0
0.005	<1	0
0.0025	2	0
0.001	11	0
0.0005	45	0
0.00025	71	0
0.0001	230	0
0.00005	1050	0
0.000025	1050	0
0.00001	6020	0
0.000005	10100	0
0.0000025	81500	0
0.000001	131000	1

* Column 2 displays the computed value, rounded to the nearest whole number, of the cumulative number of people exposed to the matching and higher concentration levels found in column 1. For example, 0.5 people would be rounded to 0 and 0.51 people would be rounded to 1.

** Column 3 displays the computed value of the cumulative exposure to the matching and higher concentration levels found in column 1.

Table 33

Public Exposure for 20 Bales/Hour Model Cotton Gin
(Buckholts, TX) as Produced by the Human Exposure Model
(Assuming Baseline Controls)

Concentration Level ($\mu\text{g}/\text{m}^3$)	Population Exposed (Persons)*	Exposure (Persons- $\mu\text{g}/\text{m}^3$)**
0.0234	<1	0
0.01	<1	0
0.005	2	0
0.0025	10	0
0.001	45	0
0.0005	74	0
0.00025	190	0
0.0001	1050	0
0.00005	1050	0
0.000025	4020	0
0.00001	11300	1
0.000005	89500	1
0.0000025	129000	1
0.000002	131000	1

* Column 2 displays the computed value, rounded to the nearest whole number, of the cumulative number of people exposed to the matching and higher concentration levels found in column 1. For example, 0.5 people would be rounded to 0 and 0.51 people would be rounded to 1.

** Column 3 displays the computed value of the cumulative exposure to the matching and higher concentration levels found in column 1.

Table 34

Public Exposure for 4 Bales/Hour Model Cotton Gin
(Itasca, TX) as Produced by the Human Exposure Model
(Assuming Baseline Controls)

Concentration Level ($\mu\text{g}/\text{m}^3$)	Population Exposed (Persons)*	Exposure (Persons- $\mu\text{g}/\text{m}^3$)**
0.0011	1	0
0.001	1	0
0.0005	5	0
0.00025	19	0
0.0001	57	0
0.00005	153	0
0.000025	489	0
0.00001	1280	0
0.000005	2140	0
0.0000025	2660	0
0.000001	6520	0
0.0000005	38900	0
0.00000025	107000	0
0.0000001	156000	0
0.0000000634	162000	0

* Column 2 displays the computed value, rounded to the nearest whole number, of the cumulative number of people exposed to the matching and higher concentration levels found in column 1. For example, 0.5 people would be rounded to 0 and 0.51 people would be rounded to 1.

** Column 3 displays the computed value of the cumulative exposure to the matching and higher concentration levels found in column 1.

Table 35

Public Exposure for 7 Bales/Hour Model Cotton Gin
(Itasca, TX) as Produced by the Human Exposure Model
(Assuming Baseline Controls)

Concentration Level ($\mu\text{g}/\text{m}^3$)	Population Exposed (Persons)*	Exposure (Persons- $\mu\text{g}/\text{m}^3$)**
0.00285	1	0
0.0025	1	0
0.001	7	0
0.0005	23	0
0.00025	70	0
0.0001	167	0
0.00005	587	0
0.000025	1280	0
0.00001	2140	0
0.000005	3870	0
0.0000025	6520	0
0.000001	65200	0
0.0000005	120000	0
0.00000025	159000	0
0.000000171	162000	0

* Column 2 displays the computed value, rounded to the nearest whole number, of the cumulative number of people exposed to the matching and higher concentration levels found in column 1. For example, 0.5 people would be rounded to 0 and 0.51 people would be rounded to 1.

** Column 3 displays the computed value of the cumulative exposure to the matching and higher concentration levels found in column 1.

Table 36

Public Exposure for 12 Bales/Hour Model Cotton Gin
(Itasca, TX) as Produced by the Human Exposure Model
(Assuming Baseline Controls)

Concentration Level ($\mu\text{g}/\text{m}^3$)	Population Exposed (Persons)*	Exposure (Persons- $\mu\text{g}/\text{m}^3$)**
0.00461	1	0
0.0025	4	0
0.001	22	0
0.0005	42	0
0.00025	118	0
0.0001	489	0
0.00005	948	0
0.000025	1980	0
0.00001	2660	0
0.000005	4970	0
0.0000025	20300	0
0.000001	114000	0
0.0000005	153000	0
0.000000293	162000	0

* Column 2 displays the computed value, rounded to the nearest whole number, of the cumulative number of people exposed to the matching and higher concentration levels found in column 1. For example, 0.5 people would be rounded to 0 and 0.51 people would be rounded to 1.

** Column 3 displays the computed value of the cumulative exposure to the matching and higher concentration levels found in column 1.

Table 37

Public Exposure for 20 Bales/Hour Model Cotton Gin
(Itasca, TX) as Produced by the Human Exposure Model
(Assuming Baseline Controls)

Concentration Level ($\mu\text{g}/\text{m}^3$)	Population Exposed (Persons)*	Exposure (Persons- $\mu\text{g}/\text{m}^3$)**
0.0097	1	0
0.005	4	0
0.0025	14	0
0.001	46	0
0.0005	146	0
0.00025	489	0
0.0001	1280	0
0.00005	2140	0
0.000025	2660	0
0.00001	6520	1
0.000005	40100	1
0.0000025	109000	1
0.000001	156000	1
0.000000649	162000	1

* Column 2 displays the computed value, rounded to the nearest whole number, of the cumulative number of people exposed to the matching and higher concentration levels found in column 1. For example, 0.5 people would be rounded to 0 and 0.51 people would be rounded to 1.

** Column 3 displays the computed value of the cumulative exposure to the matching and higher concentration levels found in column 1.

3.8 Public Exposure to Inorganic Arsenic Emissions from Arsenic Plants

3.8.1 Source Data

Eight arsenic chemical plants are included in the analysis. Table 38 lists ambient arsenic concentrations near select arsenic chemical plants. Table 39 lists the names and addresses of the plants considered, and Table 40 lists the plant data used as input to the Human Exposure Model (HEM).

3.8.2 Exposure Data

Table 41 lists, on a plant-by-plant basis, the total number of people encompassed by the exposure analysis and the total exposure. Total exposure is the sum of the products of numbers of people times the ambient air concentration to which they are exposed, as calculated by HEM. Table 42 sums, for the entire source category (8 plants), the numbers of people exposed to various ambient concentrations, as calculated by HEM. (Source-by-source exposure results are provided in the EPA docket numbered A-83-23.)

Table 38

Arsenic Concentrations Near Select
Arsenic Chemical Plants

Plant	# Obs	Distance ¹ (km)	Bearing	Predicted ² ($\mu\text{g}/\text{m}^3$)	Measured ³ ($\mu\text{g}/\text{m}^3$)	MDL ⁴ ($\mu\text{g}/\text{m}^3$)	Percentile ⁵
Diamond Shamrock- Greens Bayou, TX	302	1.6	291.1	0.00000042	0.027	0.05	90 < % < 95*
	20	5.5	229.7	0.00000042	0.026	0.05	> 99*
	37	5.9	186.3	0.00000051	0.008	0.0055	50 < % < 70*
	143	6.2	197.3	0.00000029	0.027	0.05	95 < % < 99*
	261	8.3	70.3	0.000000118	0.025	0.05	> 99*
	45	8.7	62.2	0.000000105	0.026	0.05	95 < % *
	26	11.5	195.9	0.000000121	0.025	0.05	100 *
	30	12.0	143.0	0.000000090	0.025	0.05	100 *
Koppers Co.- Conley, GA	76	13.0	336.1	0.000000079	0.008	0.0055	70 < % < 90*
Koppers Co.- Valparaiso, IN	No data within 15 km						
Mineral R&D- Concord, NC	No data within 15 km						
Osmose Wood Preserving Co.- Memphis, TN	32	5.9	27.7	0.000099	0.005	0.0055	70 < % < 90*
	72	9.3	20.8	0.000054	0.004	0.0055	50 < % < 70*
Pennwalt Inc.- Bryan, TX	107	0.1	296.4		0.026	0.05	95 < % < 99*
Vineland Chemical- Vineland, NJ	No data within 15 km						
Voluntary Purchasing Group-Bonham, TX	No data within 15 km						

* Indicates data point was disregarded; see Section 3.7.1.1.

¹ Distance from source to monitor (km).

² Concentration predicted by Human Exposure Model (HEM).

³ The measured values are weighted averages. When the sampled arsenic concentrations were below the MDL, a value of 1/2 MDL was assumed for purposes of calculating the annual averages.

⁴ Minimum detection limit.

⁵ Percentile indicates percentage of data falling below minimum detectable levels.

Table 39

Identification of Arsenic Chemical Plants

Plant Number Code	Plant Name and Address
1	Diamond Shamrock - Greens Bayou, TX
2	Koppers Co. - Conley, GA
3	Koppers Co., - Valparaiso, IN
4	Mineral Research & Development Co. - Concord, NC
5	Osmose Wood Preserving Co., - Memphis, TN
6	Pennwalt Inc. - Bryan, TX
7	Vineland Chemical - Vineland, NJ
8	Voluntary Purchasing Group - Bonham, TX

Table 40

Input Data to Exposure Model Arsenic Chemical Plants
(Assuming Baseline Controls)

Plant	Latitude (Degrees Minutes Seconds)	Longitude (Degrees Minutes Seconds)	Emission Rate (Kg/yr)	Emission Point Elevation (Meters)	Emission Point Diameter (Meters)	Emission Point Cross Sectional Area (m ²)	Emission Point Gas Exit Velocity m/sec	Emission Point Gas Temp. (°K)	Emission Point Type
Diamond Shamrock- Greens Bayou, TX	29-45-58	95-12-22	0.030	13	0.38	3000	11.9	298	Stack
Koppers Co.- Conley, GA	33-38-42	84-19-34	0.027	31	0.61	3000	0.1	298	Stack
Koppers Co.- Valparaiso, IN	41-28-34	87-04-40	0.054	9	0.76	3000	1.6	298	Stack
Mineral R&D Co.- Concord, NC	35-24-29	80-34-44	0.022	11	0.50	3000	8.8	298	Stack
Osmose Wood Preserving Co.- Memphis, TN	35-05-13	90-04-19	51.3	5	0.36	3000	14.3	298	Stack
Pennwalt Inc.- Bryan, TX	30-40-30	96-22-12	0.019	10	0.53	3000	8.9	298	Stack
Vineland Chemical- Vineland, NJ	39-55-59	74-44-53	0.001	13	0.38	3000	0.1	298	Stack
Voluntary Purchasing Group- Bonham, TX	33-34-41	96-10-41	0.019	10	0.53	3000	8.9	298	Stack

Table 41

Total Exposure and Number of People Exposed
(Arsenic Chemical Plants)*

Plant	Total Number of People Exposed	Total Exposure (People - $\mu\text{g}/\text{m}^3$)
1	2,680,000	0
2	1,900,000	0
3	1,190,000	0
4	813,000	0
5	927,000	68
6	138,000	0
7	4,230,000	0
8	152,000	0

* A 50-kilometer radius was used for the analysis of arsenic chemical plants.

Table 42

Public Exposure for Arsenic Chemical Plants
as Produced by the Human Exposure Model
(Assuming Baseline Controls)

Concentration Level ($\mu\text{g}/\text{m}^3$)	Population Exposed (Persons)*	Exposure (Persons- $\mu\text{g}/\text{m}^3$)**
0.0541	31	2
0.05	31	2
0.025	62	3
0.01	472	10
0.005	1440	15
0.0025	2720	19
0.001	8130	28
0.0005	16700	34
0.00025	30900	38
0.0001	105000	49
0.00005	210000	56
0.000025	374000	61
0.00001	653000	66
0.000005	852000	68
0.0000025	908000	68
0.000001	935000	68
0.0000005	952000	68
0.00000025	984000	68
0.0000001	1040000	68
0.00000005	1100000	68
0.000000025	1320000	68
0.00000001	2230000	68
0.000000005	3670000	68
0.0000000025	5880000	68
0.000000001	7750000	68
0.0000000005	7890000	68
0.00000000025	8320000	68
0.0000000001	9910000	68
0.00000000005	11900000	68
0.0000000000395	12000000	68

*Column 2 displays the computed value, rounded to the nearest whole number, of the cumulative number of people exposed to the matching and higher concentration levels found in column 1. For example, 0.5 people would be rounded to 0 and 0.51 people would be rounded to 1.

**Column 3 displays the computed value of the cumulative exposure to the matching and higher concentration levels found in column 1.

4 QUANTITATIVE EXPRESSIONS OF PUBLIC CANCER RISKS FROM INORGANIC ARSENIC EMISSIONS

4.1 Methodology (General)

4.1.1 The Two Basic Types of Risk

Two basic types of risk are dealt with in the analysis. "Aggregate risk" applies to all of the people encompassed by the particular analysis. Aggregate risk can be related to a single source, to all of the sources in a source category, or to all of the source categories analyzed. Aggregate risk is expressed as incidences of cancer among all of the people included in the analysis, after 70 years of exposure. For statistical convenience, it is often divided by 70 and expressed as cancer incidences per year. "Individual risk" applies to the person or persons estimated to live in the area of the highest ambient air concentrations and it applies to the single source associated with this estimate as estimated by the dispersion model. Individual risk is expressed as "maximum lifetime risk" and reflects the probability of getting cancer if one were continuously exposed to the estimated maximum ambient air concentration for 70 years.

4.1.2 The Calculation of Aggregate Risk

Aggregate risk is calculated by multiplying the total exposure produced by HEM (for a single source, a category of sources, or all categories of sources) by the unit risk estimate. The product is cancer incidences among the included population after 70 years of exposure. The total exposure, as calculated by HEM, is illustrated by the following equation:

$$\text{Total Exposure} = \sum_{i=1}^N (P_i C_i)$$

where

- Σ = summation over all grid points where exposure is calculated
 P_i = population associated with grid point i ,
 C_i = long-term average inorganic arsenic concentration at grid point i ,
 N = number of grid points to 2.8 kilometers and number of ED/BG centroids between 2.8 and 50 kilometers of each source.

To more clearly represent the concept of calculating aggregate risk, a simplified example illustrating the concept follows:

EXAMPLE

This example uses assumptions rather than actual data and uses only three levels of exposure rather than the large number produced by HEM. The assumed unit risk estimate is 4.29×10^{-3} at $1 \mu\text{g}/\text{m}^3$ and the assumed exposures are:

<u>ambient air concentrations</u>	<u>number of people exposed to given concentration</u>
2 $\mu\text{g}/\text{m}^3$	1,000
1 $\mu\text{g}/\text{m}^3$	10,000
0.5 $\mu\text{g}/\text{m}^3$	100,000

The probability of getting cancer if continuously exposed to the assumed concentrations for 70 years is given by:

<u>concentration</u>	<u>unit risk</u>	<u>probability of cancer</u>
2 $\mu\text{g}/\text{m}^3$	$x \quad 4.29 \times 10^{-3} (\mu\text{g}/\text{m}^3)^{-1}$	$= \quad 9 \times 10^{-3}$
1 $\mu\text{g}/\text{m}^3$	$x \quad 4.29 \times 10^{-3} \quad "$	$= \quad 4 \times 10^{-3}$
0.5 $\mu\text{g}/\text{m}^3$	$x \quad 4.29 \times 10^{-3} \quad "$	$= \quad 2 \times 10^{-3}$

The 70 year cancer incidence among the people exposed to these concentrations is given by:

<u>probability of cancer at each exposure level</u>		<u>number of people at each exposure level</u>		<u>after 70 years of exposure</u>
9×10^{-3}	x	1,000	=	9
4×10^{-3}	x	10,000	=	40
2×10^{-3}	x	100,000	=	<u>200</u>
				TOTAL = 249

The aggregate risk, or total cancer incidence, is 249 and, expressed as cancer incidence per year, is $249 \div 70$, or 3.6 cancers per year. The total cancer incidence and cancers per year apply to the total of 111,000 people assumed to be exposed to the given concentrations.

4.1.3 The Calculation of Individual Risk

Individual risk, expressed as "maximum lifetime risk," is calculated by multiplying the highest concentration to which the public is exposed, as reported by HEM, by the unit risk estimate. The product, a probability of getting cancer, applies to the number of people which HEM reports as being exposed to the highest listed concentration. The concept involved is a simple proportioning from the $1 \mu\text{g}/\text{m}^3$ on which the unit risk estimate is based to the highest listed concentration. In other words:

$$\frac{\text{maximum lifetime risk}}{\text{highest concentration to which people are exposed}} = \frac{\text{the unit risk estimate}}{1 \mu\text{g}/\text{m}^3}$$

4.2 Risks Calculated for Emissions of Inorganic Arsenic

The explained methodologies for calculating maximum lifetime risk and cancer incidences were applied to each plant, assuming a baseline level of emissions. A baseline level of emissions means the level of emissions after

the application of controls either currently in place or required to be in place to comply with current state or Federal regulations but before application of controls that would be required by a NESHAP.

Tables 43-49 summarize the calculated risks for each source category. To understand the relevance of these numbers, one should refer to the analytical uncertainties discussed in section 5 below. Note that the annual incidence is not calculated for cotton gins. As mentioned earlier in this document, it was impractical to identify and locate all the gins handling arsenic-acid-desiccated cotton (\approx 300 gins). The Agency does not have enough available data to provide an estimate of annual cancer incidence that would be comparable in accuracy to the other source category estimates. As outlined in Section 3.7, three model gins operating at each of four production rates were used to establish a range of exposure and risk estimates for individual sources. Likewise, two operating gins in south central Texas were chosen for ambient air monitoring in order to validate the model plant exposure estimates. Maximum lifetime risk estimates were calculated for each of the three model plants (Table 47) and for the two operating gins (Table 48).

Table 43
Maximum Lifetime Risk and Cancer Incidence for Primary Lead Smelters
(Assuming Baseline Controls)

Plant	Maximum Lifetime Risk	Cancer Incidences Per Year
1	2×10^{-3}	0.013
2	4×10^{-5}	0.044
3	2×10^{-5}	0.011
4	1.3×10^{-5}	0.0016
5	4×10^{-5}	0.0004

Table 44
Maximum Lifetime Risk and Cancer Incidence for Secondary Lead Smelters
(Assuming Baseline Controls)

Plant	Maximum Lifetime Risk	Cancer Incidences Per Year
1	5×10^{-6}	0.0019
2	4×10^{-6}	0.0009
3	8×10^{-6}	0.0010
4	8×10^{-6}	0.0011
5	8×10^{-5}	0.014
6	1.1×10^{-5}	0.0010
7	5×10^{-6}	0.0013
8	1.1×10^{-4}	0.015
9	2×10^{-7}	0.0002
10	1.6×10^{-5}	<0.0001
11	9×10^{-6}	0.0010
12	4×10^{-6}	0.011
13	1.1×10^{-5}	0.0019
14	4×10^{-6}	0.0009
15	6×10^{-5}	0.0024
16	9×10^{-6}	0.0004
17	4×10^{-6}	0.0035
18	3×10^{-4}	0.040
19	8×10^{-6}	0.0031
20	4×10^{-5}	0.012
21	4×10^{-4}	0.14
22	2×10^{-4}	0.028
23	4×10^{-4}	0.035
24	2×10^{-5}	0.0040
25	7×10^{-5}	0.0069
26	3×10^{-4}	0.015
27	2×10^{-6}	0.0002
28	1.2×10^{-5}	0.0007
29	1.7×10^{-6}	0.0002
30	1.1×10^{-6}	0.0001
31	1.5×10^{-5}	0.0015
32	6×10^{-6}	0.0050
33	1.5×10^{-5}	0.0095
34	3×10^{-5}	0.0013
35	2×10^{-5}	0.0062

Table 45
Maximum Lifetime Risk and Cancer Incidence for Primary Zinc Smelters
(Assuming Baseline Controls)

Plant	Maximum Lifetime Risk	Cancer Incidences Per Year
1	8×10^{-6}	0.0029
2	1.9×10^{-7}	0.0001
3	1.1×10^{-6}	0.0010
4	9×10^{-7}	0.0002
5	3×10^{-6}	0.0001

Table 46
Maximum Lifetime Risk and Cancer Incidence for Zinc Oxide Plants
(Assuming Baseline Controls)

Plant	Maximum Lifetime Risk	Cancer Incidences Per Year
1	4×10^{-7}	0.005
2	1.2×10^{-3}	0.077

Table 47
Maximum Lifetime Risk and Cancer Incidence for Model Cotton Gins
(Assuming Baseline Controls)

Model Plant	Maximum Lifetime Risk	Cancer Incidences Per Year
<hr/>		
Hutto, TX		
4 Bales/Hr	1.1×10^{-5}	<0.0001
7 Bales/Hr	3×10^{-5}	0.0001
12 Bales/Hr	5×10^{-5}	0.0001
20 Bales/Hr	1.0×10^{-4}	0.0002
<hr/>		
Buckholts, TX		
4 Bales/Hr	1.1×10^{-5}	<0.0001
7 Bales/Hr	3×10^{-5}	<0.0001
12 Bales/Hr	5×10^{-5}	<0.0001
20 Bales/Hr	1.0×10^{-4}	0.0001
<hr/>		
Itasca, TX		
4 Bales/Hr	5×10^{-6}	<0.0001
7 Bales/Hr	1.2×10^{-5}	<0.0001
12 Bales/Hr	2×10^{-5}	<0.0001
20 Bales/Hr	4×10^{-5}	0.0001

Table 48

Lifetime Risk for Two Texas Cotton Gins
(Assuming Baseline Controls)

<u>Plant</u>	<u>Maximum Lifetime Risk</u>
A	$5 \times 10^{-4*}$
B	1.0×10^{-4}

* Represents final risk estimate as incorporated
by EPA.

Table 49
Maximum Lifetime Risk and Cancer Incidence for Arsenic Chemical Plants
(Assuming Baseline Controls)

Plant	Maximum Lifetime Risk	Cancer Incidences Per Year
1	4×10^{-8}	<0.0001
2	7×10^{-9}	<0.0001
3	3×10^{-8}	<0.0001
4	3×10^{-8}	<0.0001
5	2×10^{-4}	0.0042
6	3×10^{-8}	<0.0001
7	9×10^{-10}	<0.0001
8	3×10^{-8}	<0.0001

5 ANALYTICAL UNCERTAINTIES APPLICABLE TO THE CALCULATIONS OF PUBLIC HEALTH RISKS CONTAINED IN THIS DOCUMENT

5.1 The Unit Risk Estimate

The procedure used to develop the unit risk estimate is described in reference 2. The model used and its application to epidemiological data have been the subjects of substantial comment by health scientists. The uncertainties are too complex to be summarized sensibly in this appendix. Readers who wish to go beyond the information presented in the reference should see the following Federal Register notices: (1) OSHA's "Supplemental Statement of Reasons for the Final Rule", 48 FR 1864 (January 14, 1983); and (2) EPA's "Water Quality Documents Availability" 45 FR 79318 (November 28, 1980).

The unit risk estimate used in this analysis applies only to lung cancer. Other health effects are possible; these include skin cancer, hyperkeratosis, peripheral neuropathy, growth retardation and brain dysfunction among children, and increase in adverse birth outcomes. No numerical expressions of risks relevant to these health effects is included in this analysis.

Although the estimates derived from the various studies are quite consistent, there are a number of uncertainties associated with them. The estimates were made from occupational studies that involved exposures only after employment age was reached. In estimating risks from environmental exposures throughout life, it was assumed through the absolute-risk model that the increase in the age-specific mortality rates of lung cancer was a function only of cumulative exposures, irrespective of how the exposure was accumulated. Although this assumption provides an adequate description of

all of the data, it may be in error when applied to exposures that begin very early in life. Similarly, the linear models possibly are inaccurate at low exposures, even though they provide reasonable descriptions of the experimental data.

The risk assessment methods employed were severely constrained by the fact that they were based only upon the analyses performed and reported by the original authors--analyses that had been performed for purposes other than quantitative risk assessment. For example, although other measures of exposure might be more appropriate, the analyses were necessarily based upon cumulative dose, since that was the only usable measure reported. Given greater access to the data from these studies, other dose measures, as well as models other than the simple absolute-risk model, could be studied. It is possible that such wide analyses would indicate that other approaches are more appropriate than the ones applied here.

5.2 Public Exposure

5.2.1 General

The basic assumptions implicit in the methodology are that all exposure occurs at people's residences, that people stay at the same location for 70 years, that the ambient air concentrations and the emissions which cause these concentrations persist for 70 years, and that the concentrations are the same inside and outside the residences. From this it can be seen that public exposure is based on a hypothetical premise. It is not known whether this results in an over-estimation or an underestimation of public exposure.

5.2.2 The Public

The following are relevant to the public as dealt with in this analysis:

1. Studies show that all people are not equally susceptible to cancer. There is no numerical recognition of the "most susceptible" subset of the population exposed.

2. Studies indicate that whether or not exposure to a particular carcinogen results in cancer may be affected by the person's exposure to other substances. The public's exposure to other substances is not numerically considered.

3. Some members of the public included in this analysis are likely to be exposed to inorganic arsenic in the air in the workplace, and workplace air concentrations of a pollutant are customarily much higher than the concentrations found in the ambient, or public air. Workplace exposures are not numerically approximated.

4. Studies show that there is normally a long latent period between exposure and the onset of lung cancer. This has not been numerically recognized.

5. The people dealt with in the analysis are not located by actual residences. As explained previously, people are grouped by census districts and these groups are located at single points called the population centroids. The effect is that the actual locations of residences with respect to the estimated ambient air concentrations are not known and that the relative locations used in the exposure model may have changed since the 1980 census. However, for the population sectors estimated to be at highest risk, U.S.

Geological Survey topographical maps were checked to verify that people did live or could live in locations near the sources as modeled predictions estimated. Maps in certain instances were old and the possibility could not be excluded that additional areas near sources have been developed since publication of the maps.

6. Many people dealt with in this analysis are subject to exposure to ambient air concentrations of inorganic arsenic where they travel and shop (as in downtown areas and suburban shopping centers), where they congregate (as in public parks, sports stadiums, and schoolyards), and where they work outside (as mailmen, milkmen, and construction workers). These types of exposures are not numerically dealt with.

5.2.3. The Ambient Air Concentrations

The following are relevant to the estimated ambient air concentrations of inorganic arsenic used in this analysis:

1. Flat terrain was assumed in the dispersion model. Concentrations much higher than those estimated would result if emissions impact on elevated terrain or tall buildings near a plant.
2. The estimated concentrations do not account for the additive impact of emissions from plants located close to one another.
3. The increase in concentrations that could result from re-entrainment of arsenic-bearing dust from, e.g., city streets, dirt roads, and vacant lots, is not considered.

4. Meteorological data specific to plant sites are not used in the dispersion model. As explained, HEM uses the meteorological data from the STAR station nearest the plant site. Site-specific meteorological data could result in significantly different estimates, e.g., the estimated location of the highest concentrations.

5. In some cases, the arsenic emission rates are estimates that are based on assumptions rather than on measured data.

6 REFERENCES

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