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ABSTRACT

This study is a reconstruction of historical arsenic exposures at a cadmium smelter. Although an association between cadmium and lung cancer has been observed in previous investigations, it is uncertain as to whether this association may be confounded by arsenic exposure. After the facility became a cadmium smelter, exposure to arsenic occurred from its presence in feedstock material (bag house dust from other plants). The purpose of this study was to estimate the arsenic exposures by compiling air sampling, feedstock composition, and biological monitoring data. The resulting data set contained exposure estimates for 26 departments over the years from 1940 to 1985. Through mathematical manipulations of these sampling data, a departmental exposure matrix was developed including changes in the airborne arsenic levels in the plant over time. The missing values were estimated using regression analysis.

The workers' arsenic exposures decreased over time for all departments. Exposures were highest for the departments that handled and processed the incoming feedstock. These departments and their mean exposure estimates over all years included calcine (0.12 mg/m3), mixer/screener (0.12 mg/m3), loading gang (0.13 mg/m3), concentrated and dry dust (0.13 mg/m3), general labor/unloading (0.13 mg/m3), sampling (0.11 mg/m3), crushing (0.11 mg/m3), roasting (0.11 mg/m3), and auto truck (0.13 mg/m3). Exposures were lowest for the non-production departments, those not directly related to the process, i.e. administration, where the mean estimate was 0.04 mg/m3. Approximately 55

percent of all exposure estimates and 76 percent of the exposure estimates for high exposure departments exceeded the current OSHA PEL and ACGIH TLV of 0.01 mg/m3 for arsenic, indicating that employees were potentially overexposed.

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CHAPTER 1 INTRODUCTION

1.1 Definition of Research Question

Occupational exposure to arsenic can occur in many industries including those that manufacture pesticides, pigments, glass, and alloys as well as smelters and ore refineries. In the environment, arsenic is ubiquitous and is found in soil, water, and food. Most of this arsenic is natural; however, a small amount of arsenic is added to the environment through coal, industrial contaminants, and fertilizers (1).

Occupational exposures at the Globe, Colorado smelter, operated by the American Smelting and Refining Company (ASARCO), have been the subject of previous studies (2-7). These studies have mainly investigated the risk of lung cancer from cadmium exposures at the plant, with some investigators concluding that cadmium is a demonstrated human carcinogen and others concluding that it is not. Also, there has been a great deal of discussion about other causes for the lung cancer in this cohort (2-4). Part of this is due to the fact that the facility was a lead smelter from 1886 to 1919, and an arsenic smelter from 1920 to 1926. Because of this, Thun (2) and Stayner (5) each identified workers who had been employed after 1926. Workers that were employed after 1926 when the facility became a cadmium smelter were exposed to arsenic from its presence in the feedstock material- bag house dust from other plants- and its presence as a by-product of the cadmium production process in the departments that processed the incoming feedstock material. These departments included calcine,

mixer/screener, loading gang, concentrated and dry dust, general labor/unloading, sampling, crushing, roasting, and auto truck. A third potential causal agent for lung cancer found in this working population is cigarette smoking (2,4,5). However, smoking is somewhat unlikely to have played a confounding role in the internal analyses where high exposed workers were compared with workers with lower exposures (5).

Employees of such facilities as the one under study work in multifaceted environments with exposures to a variety of chemical agents, and there is a need for a careful assessment of exposures before attributing increased health risks to a specific exposure. With regard to the potentially confounding exposures, cadmium has formerly been thoroughly investigated and an exposure matrix developed (6) and the effect of smoking can be controlled for in the analyses, as shown previously (4,5). However, interpretation of study findings would be enhanced by the development of a quantitative job exposure matrix for the exposure to arsenic.

1.2 Toxicology and Epidemiology

Disease from occupational exposure to arsenic (8-19, 25-41) and cadmium (2-7, 11, 20-24, 42-44) has been documented very well. These substances are health hazards, causing many different adverse health effects. For the purposes of this study, the following review of epidemiologic literature will focus on these exposures and their association with lung cancer only.

1.2.1 Arsenic Toxicology

The Occupational Safety and Health Administration (OSHA) regulates occupational exposure to inorganic arsenic at 10 micrograms per cubic meter ($\mu g/m^3$) of air averaged over an eight-hour period (8). The American Conference of Governmental Industrial Hygienists (ACGIH) has set a Threshold Limit Value (TLV) of 0.01 mg/m^3 (10 $\mu g/m^3$)for arsenic and has set a Biological Exposure Index (BEI) for arsenic at 35 micrograms of arsenic per liter of urine (9). Arsenic is absorbed by ingestion, inhalation, or percutaneously, with inhalation being the primary route for occupational exposures (10). About 80 to 90 percent of a single dose of arsenic, either arsenite (As (III)) or arsenate (As(V)), can be absorbed from the gastrointestinal tract. Airborne arsenic is usually trivalent arsenic oxide and deposition in airways and absorption from the lungs is dependent on particle size and chemical form (11). Skin can also be a route of exposure. Although typically dermal or mucous membrane contact causes only irritation, systemic toxicity has been reported after severe acute dermal contact (11). In humans, most of the inorganic arsenic is detoxified by methylation and metabolized to monomethylarsonic acid (MMA) and dimethylarsenic acid (DMA). Both trivalent and pentavalent inorganic arsenic may also be present. Of the two, the trivalent form is thought to be more toxic and the body will attempt to convert this to the pentavalent form. The pentavalent arsenic is removed through the urinary system. However, arsenic will be found throughout body tissues (12). Arsenic is bound primarily to the globulin of hemoglobin and enters the organs including

liver, lungs, intestinal tract and spleen and can accumulate in the hair and nails. Arsenic is excreted in the urine mainly within one to two days with a biological half-life of about 24 to 36 hours (1,9,10,11).

The International Agency for Research on Cancer (IARC) (13) and the Environmental Protection Agency (EPA) (14) classify arsenic as a carcinogen, for which there is sufficient evidence from epidemiologic studies to support a causal association between exposure and skin cancer and lung cancer via inhalation. However, arsenic is different from most other human carcinogens in that has been difficult to confirm the carcinogenicity of arsenic in experimental animals (15). Intra-tracheal instillation of arsenic trioxide has produced lung tumors in rats (16,17). But some studies testing oral or skin administration have not shown potential for either promotion or initiation of carcinogenicity (18). Other research suggests low-grade carcinogenic activity by arsenic or the possibility that co-carcinogenic factors must be present for arsenic to have an effect (19).

1.2.2 Cadmium Toxicology

The permissible exposure limit for airborne cadmium is set by OSHA at five mg/m^3 averaged over an eight-hour day (20). The ACGIH TLV for cadmium is 0.01 mg/m^3 and the BEI is five micrograms of cadmium per gram of creatinine in the urine (21). Primary routes of cadmium exposure are through the respiratory and gastrointestinal tracts. In industry, inhalation is the primary route of exposure to aerosols, i.e. dusts and fumes, due to the efficient absorption and

retention of cadmium through the respiratory tract (21,22). Cadmium is transported in blood by binding to red blood cells and high molecular weight proteins in plasma. Primarily, it is distributed to and retained in the liver and kidneys (11, 23). Excretion is slow. Absorbed cadmium is excreted in the urine. The estimated biologic half-life is between 10 and 30 years (21,22). The most important measure of cadmium uptake is increased cadmium excretion in urine. However, with excessive exposure to cadmium, as might occur in workers, an increase in urinary cadmium may not occur until all of the available cadmium binding sites (metallothionein) are saturated (11).

Cadmium has been listed by IARC as a category 1 (human) carcinogen, based primarily on its relationship to pulmonary tumors (24). In rats, cadmium will produce a variety of tumors, including malignant tumors at the site of injection and in the lungs after inhalation. A dose-related increase in carcinoma of the lung has been induced in rats following long-term inhalation exposure to cadmium chloride, oxide, sulfide, and sulfate dust and fume. (11). ACGIH has assigned cadmium an A2 Suspected Human Carcinogen notation based on rat inhalation studies of cadmium that produced lung carcinomas and the reports of the occurrence of lung cancer in cadmium workers (21).

1.2.3 Epidemiology

The National Institute for Occupational Safety and Health (NIOSH) estimates that about 1.5 million people in industry are potentially exposed to arsenic at least

part of the time during the course of their working life (25). This exposure has been shown to be associated with cancer in several occupational epidemiology studies. A considerable body of literature indicates that inorganic arsenic is a human carcinogen, certainly of the skin and lung and probably of the liver and provides evidence of a dose response relationship, i.e. higher exposures for longer periods of time are associated with higher incidence of disease (1,9,26). The time period between initiation of exposure and occurrence of arsenic associated lung cancer has been found to be on the order of 35 to 45 years. Although, some studies (27) report a latency period of 20 years for copper smelter workers (11).

The strongest evidence that arsenic is responsible for lung cancer comes from quantitative dose-response data relating specific arsenic exposure levels to lung cancer risk. These data are available for arsenic-exposed workers at the ASARCO copper smelter in Tacoma, WA, the Anaconda copper smelter in Montana, eight other US copper smelters, and the Ronnskar copper smelter in Sweden (28). Pinto and Enterline (18) also analyzed deaths among retirees from a smelter. An excess of respiratory cancer deaths was found and there appeared to be a linear relation between the increase in deaths from respiratory cancer and magnitude of exposure to arsenic or a material with the same relative exposure scenario.

A criticism of the studies of lung cancer in smelter workers exposed to arsenic is that they do not resolve the question of whether arsenic alone is a lung carcinogen or whether concomitant exposure to other chemicals is necessary for the development of lung cancer. There is no evidence that arsenic trioxide per se can induce respiratory cancer in either humans or animals. Other exposures including smoking, irritant acid gases, and/or associated metals, copper, iron, and lead, have been identified with excesses of respiratory cancer as well(29). Because other contaminants were present in the atmosphere, it is not certain that arsenic was entirely responsible for the respiratory cancer observed in the smelter under study (17, 29). Some investigators believe that although each of these factors may interact with arsenic in the production of respiratory cancer, the data from these studies provide sufficient evidence that arsenic is itself a human lung carcinogen (30). However, some have reported that when the other exposures are absent, mortality from respiratory cancer shows no excesses over statewide rates (17).

Evidence from studies in other industries helps confirm a possible role for arsenic. The role of arsenic as a pulmonary carcinogen has been implicated by a) reports of excess mortality from lung cancer among South Rhodesian miners of gold-bearing ores containing large amounts of arsenic (31); b) the concurrence of lung cancer and clinical arsenicism among German vineyard workers of the Moselle exposed to lead arsenate dust (32, 33); and c) the seemingly high proportion of deaths due to cancers of the lung and skin found in a small

mortality study of workers who were heavily exposed to inorganic arsenic in a British sheep dip factory (34, 35). This overwhelming epidemiological evidence demonstrates that persons exposed in different environments, where the common factor has been arsenic exposure, have a substantial excess risk of respiratory cancer. Acknowledging the existence of other possible co-contaminants in these studies, the US Court of appeals adhered to the position that arsenic should be regulated as a carcinogen (26).

On the other hand, some reports suggest that arsenic is not similar to other carcinogens. If this was a simple cause and effect relation, one would expect that the long-standing exposure to the oxides and salts of arsenic in smelters and mines would result in more cases of cancer than actually occur (36). The anticipated relation between respiratory cancer and exposure duration and between respiratory cancer and time since first exposure do not hold (37). Snegireff (38) failed to find an increase in the incidence of lung cancer among workers engaged in arsenic smelting, and none is noted by Lundgren et al. (39) in their recent studies of the copper and arsenic smelters at Boliden, Sweden (40). Furthermore, Pinto and Bennett (41) reported no adverse effect of chronic arsenic exposure on the relative frequency of respiratory cancer deaths among the current and retired employees of a copper smelter (35).

OSHA estimates that about one half million workers are exposed to cadmium every day (20). This exposure has been studied to assess the association

between cadmium and cancer. However, the literature describing carcinogenicity of cadmium varies. Epidemiologic studies have shown a relationship between occupational (respiratory) exposure to cadmium and lung cancer and possibly prostate cancer (11). Thun reported an increase in respiratory cancers in a study of the cohort at the ASARCO Globe plant. He states (2) that his findings of increased lung cancer mortality related to cumulative exposure to cadmium are consistent with a previous study of the cohort (7), with a rat inhalation study showing carcinogenesis caused by cadmium (42) and with the epidemiologic findings of other investigators (43). In 1993, a Working Group of IARC published a monograph on the evaluation of carcinogenic risks to humans after exposure to cadmium and cadmium compounds. The Working Group concluded that there is sufficient evidence in humans for the carcinogenicity of cadmium and cadmium compounds and the overall evaluation was that cadmium and cadmium compounds are carcinogenic to humans (Group 1) (44). Despite this information reported by IARC, some investigators believe that cadmium exposure alone is not capable of causing the excess in lung cancer seen in these studies. Still others believe that cadmium is not a determinant of lung cancer at all (3,4). Lamm states that his case-control study suggests that the excess lung cancer risk of the workers is not associated with cadmium exposure, but with cigarette smoking and arsenic exposure (4). Stayner stated that although his and previously reported analyses provide evidence against the hypothesis that the relationship between cadmium exposure and lung cancer mortality can be fully attributed to arsenic, it is impossible to fully discount the potential influence of

arsenic exposure on his findings (5). Sorahan also addresses this problem and adds that interpretation of the study findings is difficult because exposure was to multiple compounds: cadmium oxide, fume, dust, sulfate, and sulfide, and arsenic compounds including arsenic trioxide. Because of this, several hypotheses are possible: cadmium oxide, sulfate, and sulfide are human carcinogens; cadmium oxide in the presence of arsenic trioxide is a human lung carcinogen; and cadmium sulfate and sulfide are not human lung carcinogens; arsenic trioxide is a human lung carcinogen; and cadmium oxide, sulfate, and sulfide are not human lung carcinogens (3).

Not withstanding these varying reports, arsenic and cadmium are still regulated and recognized by many authoritative bodies (e.g. IARC and EPA) as carcinogens. Resolution of the issues requires further research.

1.3 Scope of Study

The purpose of this study was to estimate arsenic exposure so future research may investigate any quantitative relation between exposure and lung cancer mortality among the cohort of workers. Previous studies have attempted various methods to estimate arsenic exposure. The use of feedstock concentrations of arsenic as a surrogate for the measure of air arsenic levels has been explored (4). The period of hire of an employee in the cohort has been used as a surrogate for arsenic exposure as related to the feedstock (2,5). Also in the absence of quantitative exposure estimates, the amount of arsenic has been

estimated using qualitative classification of exposures based on department. These classifications included high or minimal arsenic exposure and were determined by a department's contact with the feed material during operation (3). In the present study, in order to obtain quantitative arsenic estimations, the arsenic exposures the workers experienced at the plant were estimated by compiling air sampling, feedstock, and biological monitoring data. Through mathematical manipulations of these data, this study has resulted in a departmental exposure matrix that reflects changes in airborne levels of arsenic in the plant over time.

These data will be available for a re-analysis of the Globe smelter cohort for lung cancer mortality that takes into account exposure to both cadmium and arsenic, which will be an important addition to the body of research that exists for this cohort and for cadmium and arsenic exposures in general. By evaluating exposure-response in this work population and the disease risk from exposure may be calculated. These results may contribute to development of occupational and environmental standards to reduce exposure and disease and other adverse health outcomes.

CHAPTER 2 BACKGROUND

2.1 Plant Process and Facility Descriptions

2.1.1 Introduction

The following descriptions were compiled from many different sources of information pertaining to plant, operational, and procedures history (3,6,7,45-52). The illustrations in this section were developed from information gathered from a plant visit and interviews with employees to reflect the facility during the years of this study. These sketches were adapted from field notes and developed for informational purposes and were not designed to scale.

In Figure 2.1, the general facility layout, the Tankhouse and Casting buildings are labeled as they were in from 1949-1998, as described in the process description. However, individual sketches of these areas are not included in this section because they did not exist at the time of the plant visit.

In nearly every process sketch that follows in Figures 2.2-2.7, dust collectors and ventilation equipment are labeled. There is a distinct difference between these two types of controls. Dust collectors were the controls installed to improve the air quality for the workers' environment. The ventilation equipment was the control installed to collect the by-product for further processing. It was reported that these engineering controls were kept in good working order. Inspections of all ventilation, dust collectors and baghouses were made monthly (48).

Dates on the figures refer to when the department or building was in use and would have been included in the major production processes.

2.1.2 Plant Process

The plant facilities were involved mainly with cadmium smelting, although other operations produced small amounts of indium, lead, thallium and arsenic. The production process itself did not change significantly over the 45 years of this study, except for the introduction of improved engineering controls to reduce in-plant and ambient exposures. A sketch of the facility layout from 1949 to 1998 is shown in Figure 2.1. The feed for the cadmium operations was a highly concentrated cadmium-bearing metal oxide dust (agglomerated fume), a by-product of air pollution controls from nonferrous smelters primarily belonging to the company. This dust came to the plant in covered gondola cars. It was then moved into the Godfrey Roaster building to be unloaded. In 1980, incoming dust from other plants came in enclosed, very large tote bags. This dust was stored in the mixing department. When received, each shipment of raw material was sampled and analyzed for metal content- cadmium, lead, arsenic, thallium, gold, silver, copper, zinc, and selenium.

Prior to the1960s, this cadmium-bearing dust (usually from lead and zinc smelters) was mixed with limestone and coal and roasted in Godfrey roasters (See Figure 2.2) at 850°C to claim the cadmium as cadmium oxide (CdO). The residue containing metals such as lead, zinc, silver, and copper collected in the

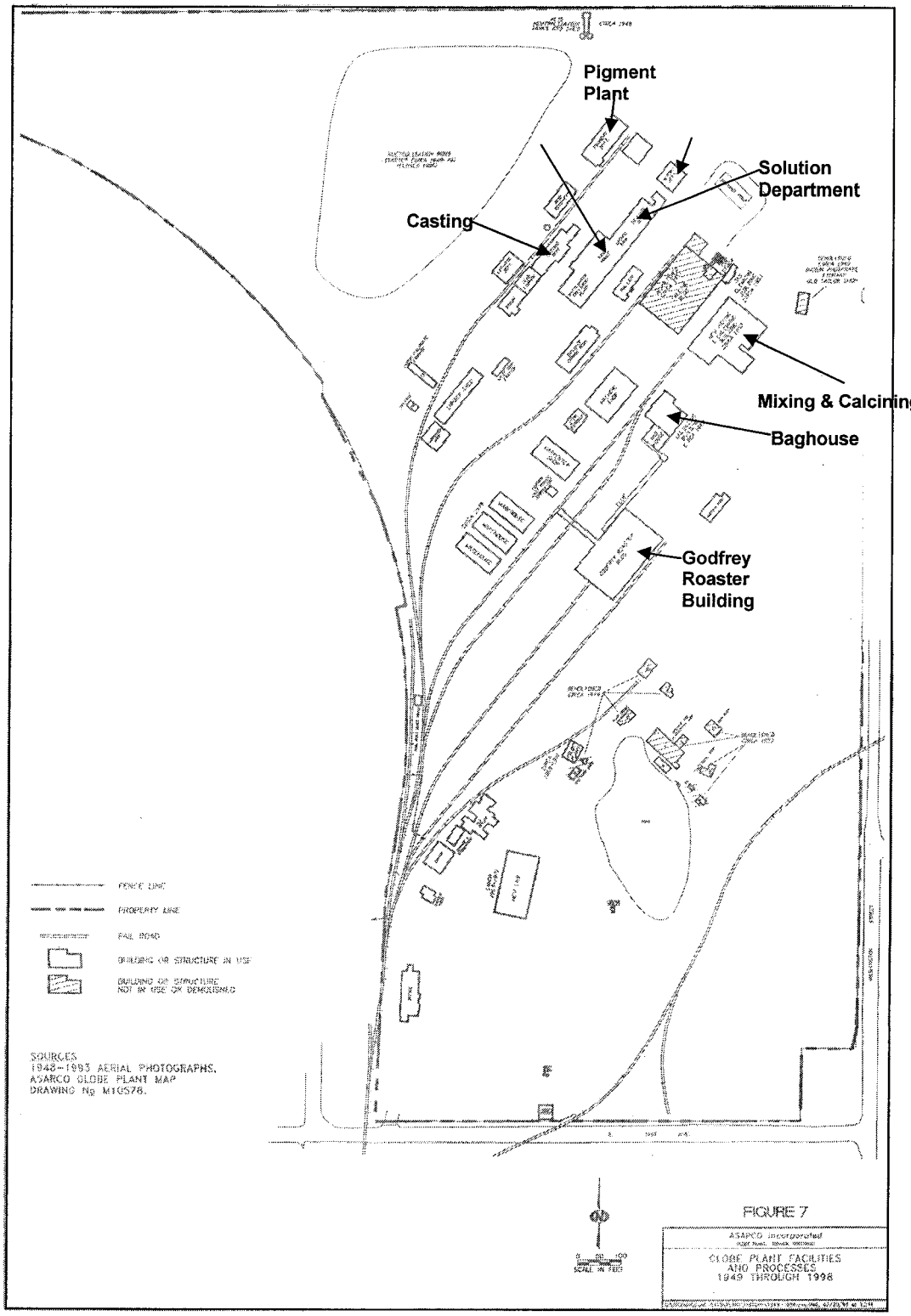

Figure 2.1 Globe Plant Facilities Layout 1949-1998 (49)

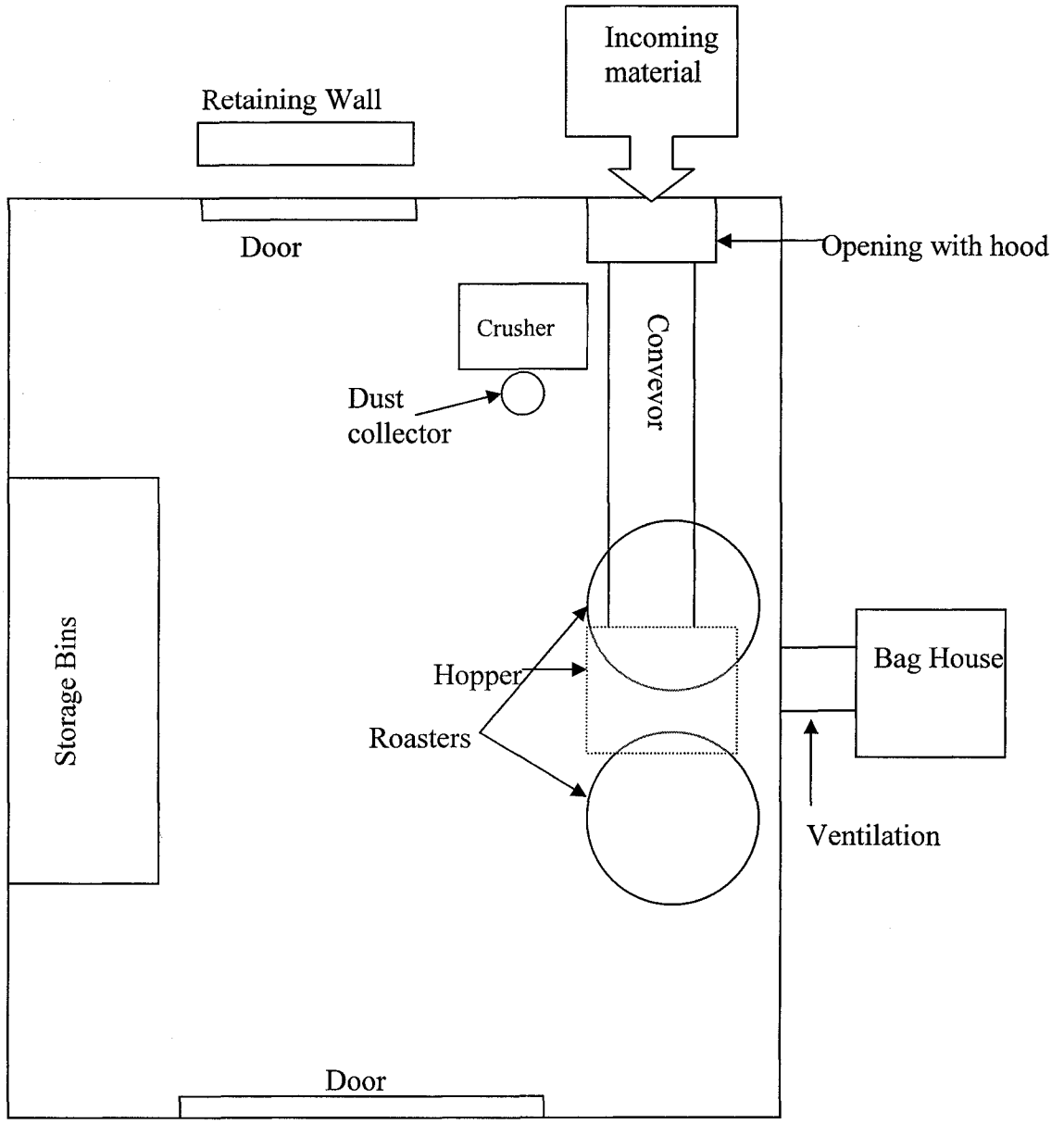

FIGURE 2.2 GODFREY ROASTER BUILDING 1926-1977 (48)

baghouse, was loaded into cars and shipped to the smelter at Leadville. The cadmium recovered in the roaster was quickly oxidized to cadmium oxide in the flue and collected by means of bag filters and dropped into collecting pits under the bags. In some instances, the oxide was re-roasted again after mixing with limerock and coal. In other instances, it was transported by boxcar directly to the mixing department.

After the 1960s, the Godfrey roasters were only used for by-products. By-product waste materials from various operations typically contained cadmium sulfate and cadmium permanganate and were retained and reprocessed in the roaster to recover cadmium. The by-products were stored, and processed during a 1-3 month period every 2-3 years. The material was mixed with coal to increase the heat factor and was then crushed, screened, and re-crushed. It was then stored, until needed, under plastic sheets that kept the material dry and prevented dispersion. This material was then roasted, and the cadmium oxide was captured in the baghouse (See Figure 2.3) and recycled through the plant in the same manner as any other entering feedstock. This material was now comparable to an outside dust source in composition and purity. The residue was shipped to another company smelter for by-product recovery. The Godfrey roaster last ran in 1977. Following this, all by-products were shipped to another plant for processing.

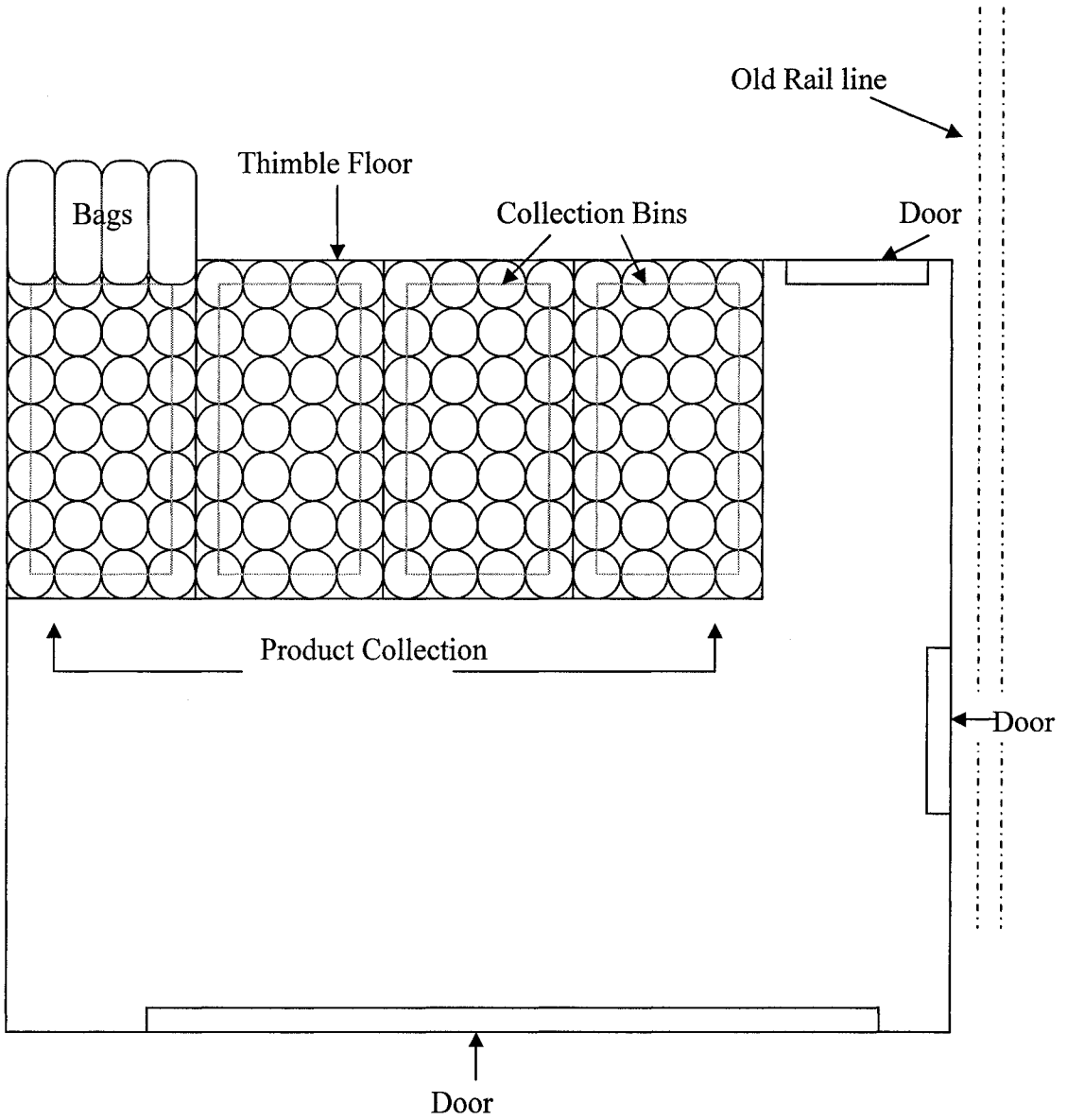

FIGURE 2.3 BAG HOUSE BUILDING 1926-1977 (48)

Following roasting, the feed materials were acid leached, mixed with sulfuric acid, to remove impurities, such as lead, thallium, and copper, and to convert the sulfate. This removal was accomplished through a series of filtrations and chemical precipitations necessary to form a suitable cadmium electrolyte (See Figure 2.4a).

Next the material was sent to be calcined (See Figure 2.4a), which involved heating the sulfuric acid/ cadmium dust mixture (cake) in a calcining furnace. The calciner was a multi-hearth furnace used to convert the cadmium sulfide to cadmium sulfate (See Figure 2.4b). The cake was fed to secondary roasters from the top and roasted at 650°C for approximately four hours. A mechanical arm would then sweep around and the material would be fed into the center hole to drop down to the next hearth (See Figure 2.4c). This process was repeated in each hearth. Every hearth was operated at a different temperature to remove certain impurities. The cadmium reacted with the sulfur in the acid to form soluble cadmium sulfate, while lead and other metals formed insoluble sulfates and sulfides. In this process, any arsenic and sulfuric acid fumes are driven off up the stack; and the other impurities such as copper, iron, zinc, and silver were converted into insoluble sulfates, leaving only cadmium sulfate as a soluble material. As a result, the soluble cadmium could be leached or washed from the mixture, leaving the other metals behind. Arsenic was volatilized and emitted from the calcine roaster stack, or precipitated with the lead sulfate.

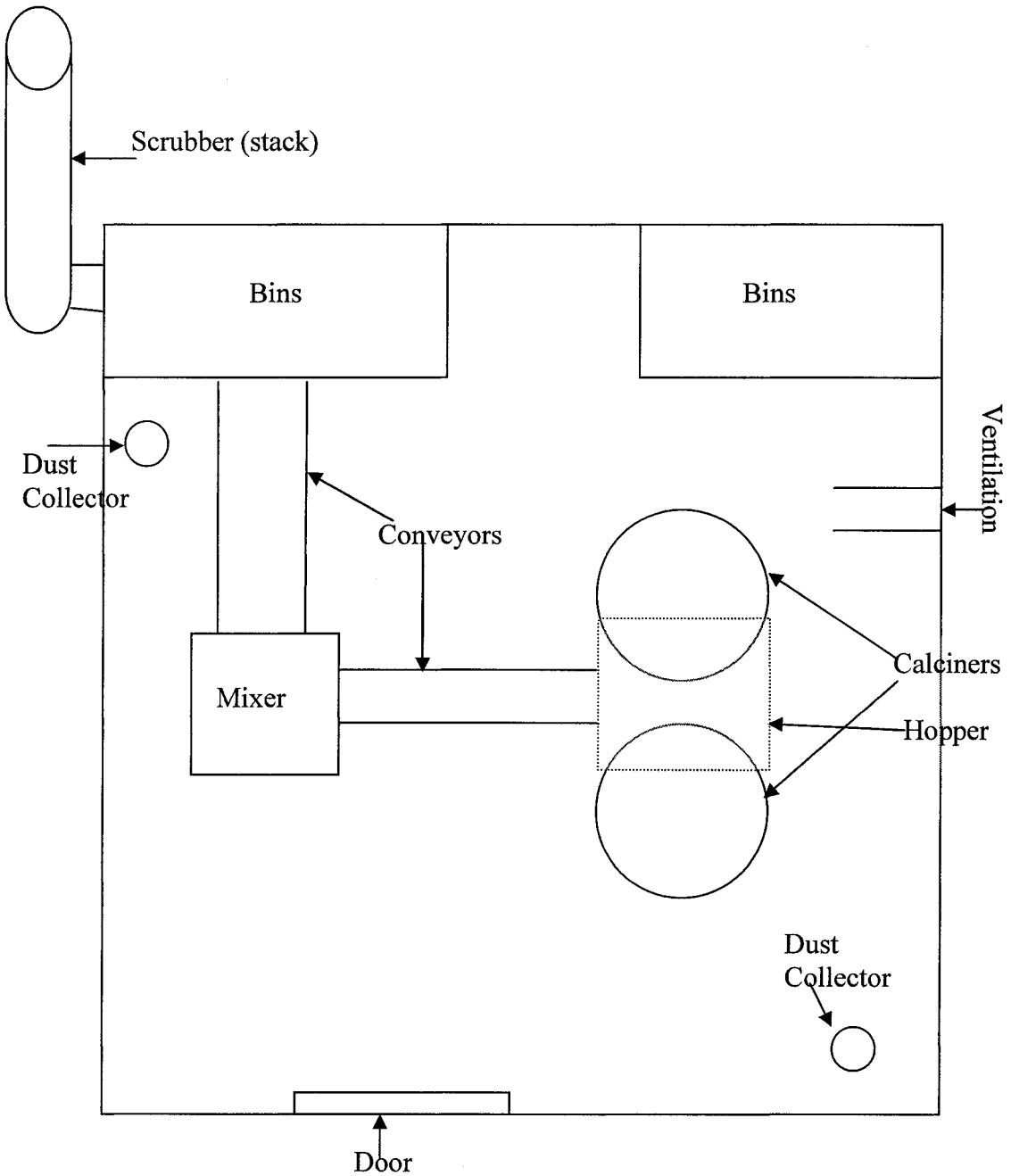

Figure 2.4a Mixing & Calcing Building 1926-1983 (48)

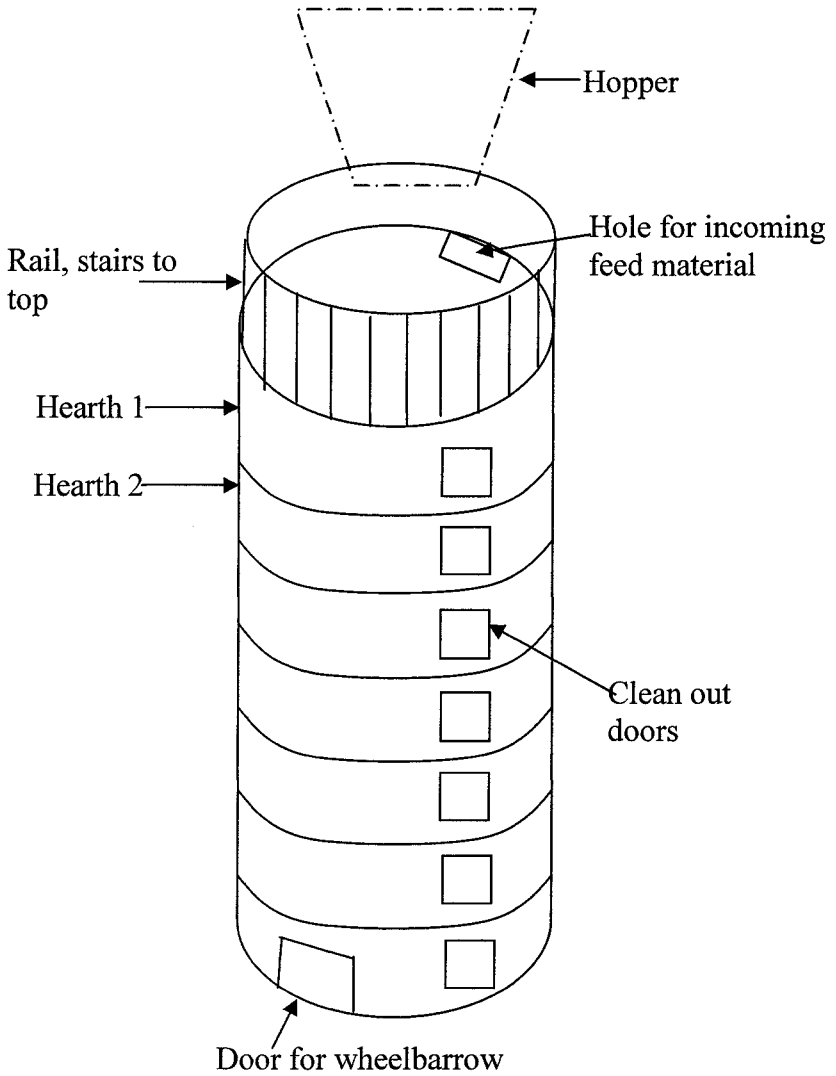

FIGURE 2.4B SIDE VIEW OF CALCINER (48)

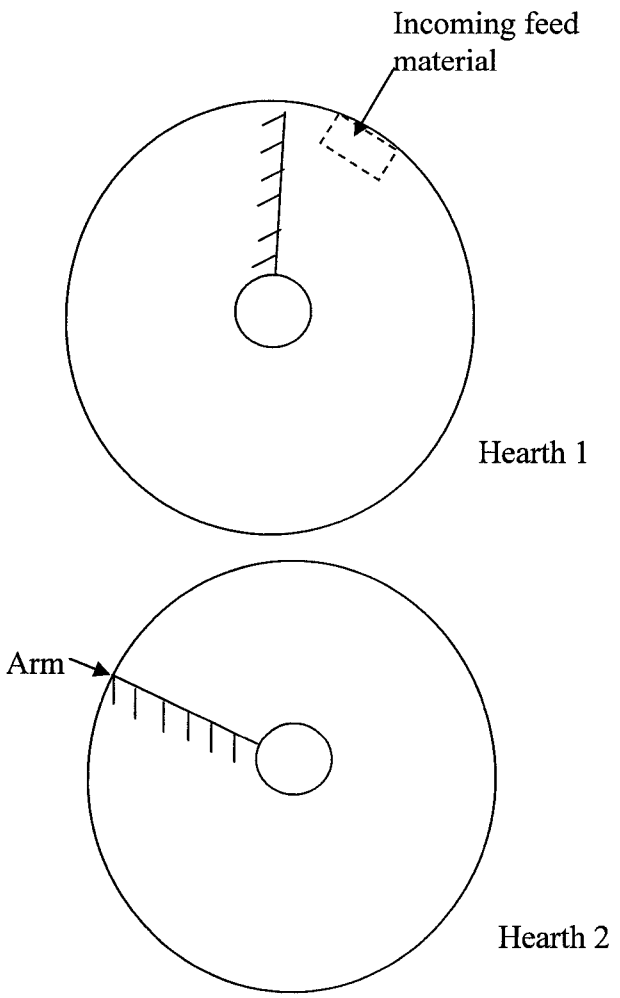

FIGURE 2.4C INSIDE VIEW OF CALCINER (48)

The material was removed from the furnace by hand, wheelbarrows and stored in the open at one end of the calcining area. Workers jack hammered this cake out of the bins where the calcined product was stored. The calcined material from the storage area was used as needed to continue the cadmium recovery process.

In the mid-1980s, after tote bags were in use, the process no longer included mixing and calcining the incoming feed. The bags went directly to solution purification to be processed. The by-products followed the same process stream.

Next the material went to solution purification (See Figure 2.5). The material was re-dissolved in water. After the cadmium sulfate solution was extracted from the calcines, the solution would undergo additional hydrometallurgical purification steps including precipitation and filtration. Three by-products resulted from this process. One containing most of the arsenic impurities was shipped to another plant. The other two by-products were stored in the Godfrey Roaster building for intermittent processing.

The solution was then feed for the cadmium metal process in the tankhouse. Highly purified cadmium metal was plated out of the solution in an electrolytic refinery. A conventional electrolytic operation processed the electrolyte,

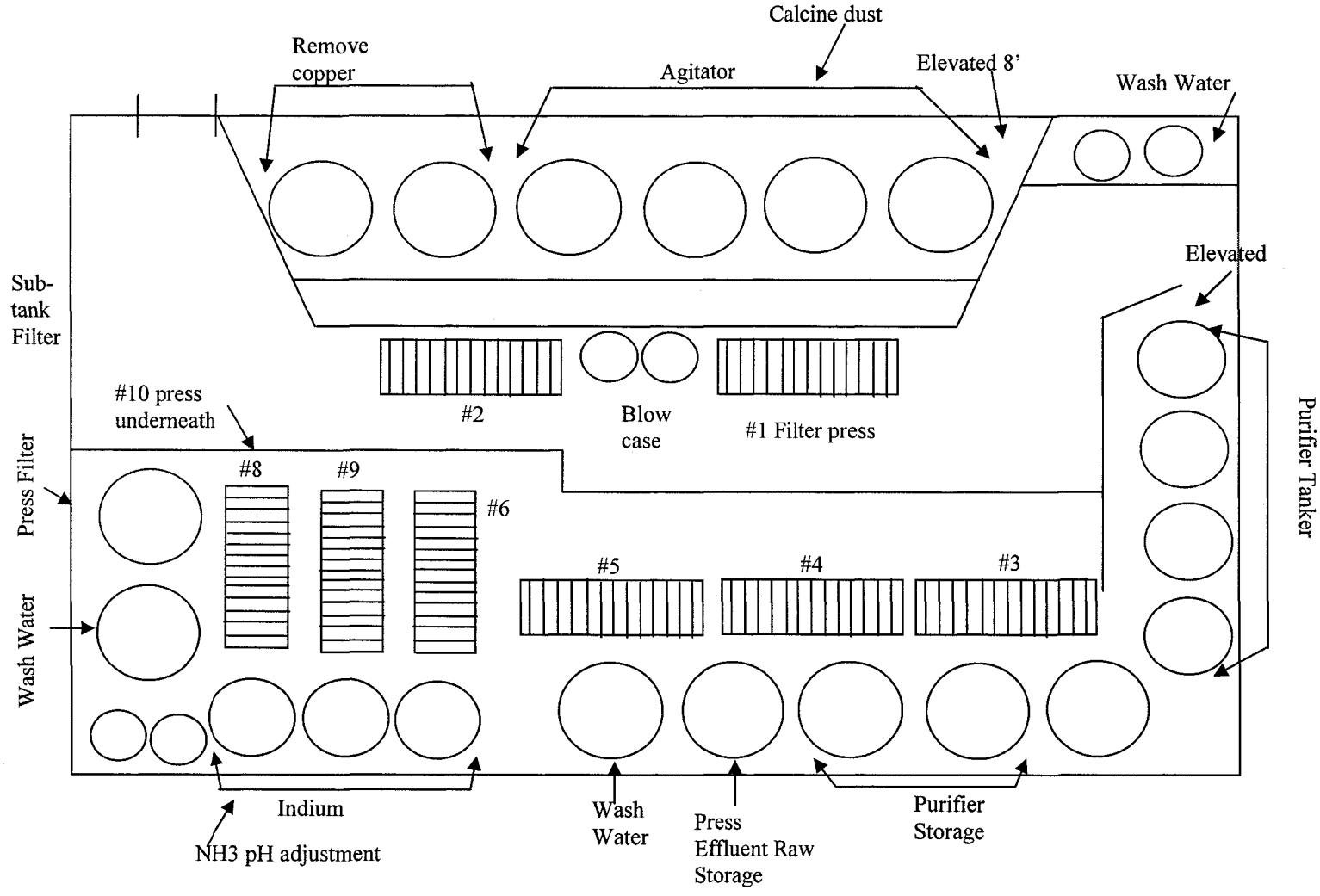

FIGURE 2.5 SOLUTION DEPARTMENT 1926-1993 (48)

depositing cadmium metal of a purity greater than 99.9% on the cathodes. The metal was stripped from the cathodes as cadmium sheets and melted.

In the early 1980s, the plant use of the tankhouse operations ceased. The process then began extracting cadmium out of solution as metal. Neutralization and tailings storage were also curtailed and they began using a wastewater treatment plant.

The sheets of cadmium metal that were stripped off the cathode were then dissolved with caustic, and cast into 50-pound brick molds in the pre-melt/casting/foundry area. These bricks were subsequently recast into finished balls, rods, and mossy metal.

Cadmium oxide and cadmium powder were produced in the retort department (See Figure 2.6a). The cadmium metal was melted and vaporized in retort furnaces. For this operation, the furnace was sealed with fire bricks (See Figure 2.6b). Each shift had to reseal the retort after adding a powder charge to the crucible. The crucible was externally fired to melt the cadmium. Cadmium metal powder was produced by melting the cadmium bricks in the retort, in the absence of oxygen, and capturing the resultant cadmium fume. Cadmium oxide was produced by melting the bricks in the retort, in the presence of oxygen, and capturing the fume. Cadmium sulfide was also produced on an intermittent basis by mixing the cadmium residue in the retort with sulfuric acid and producing

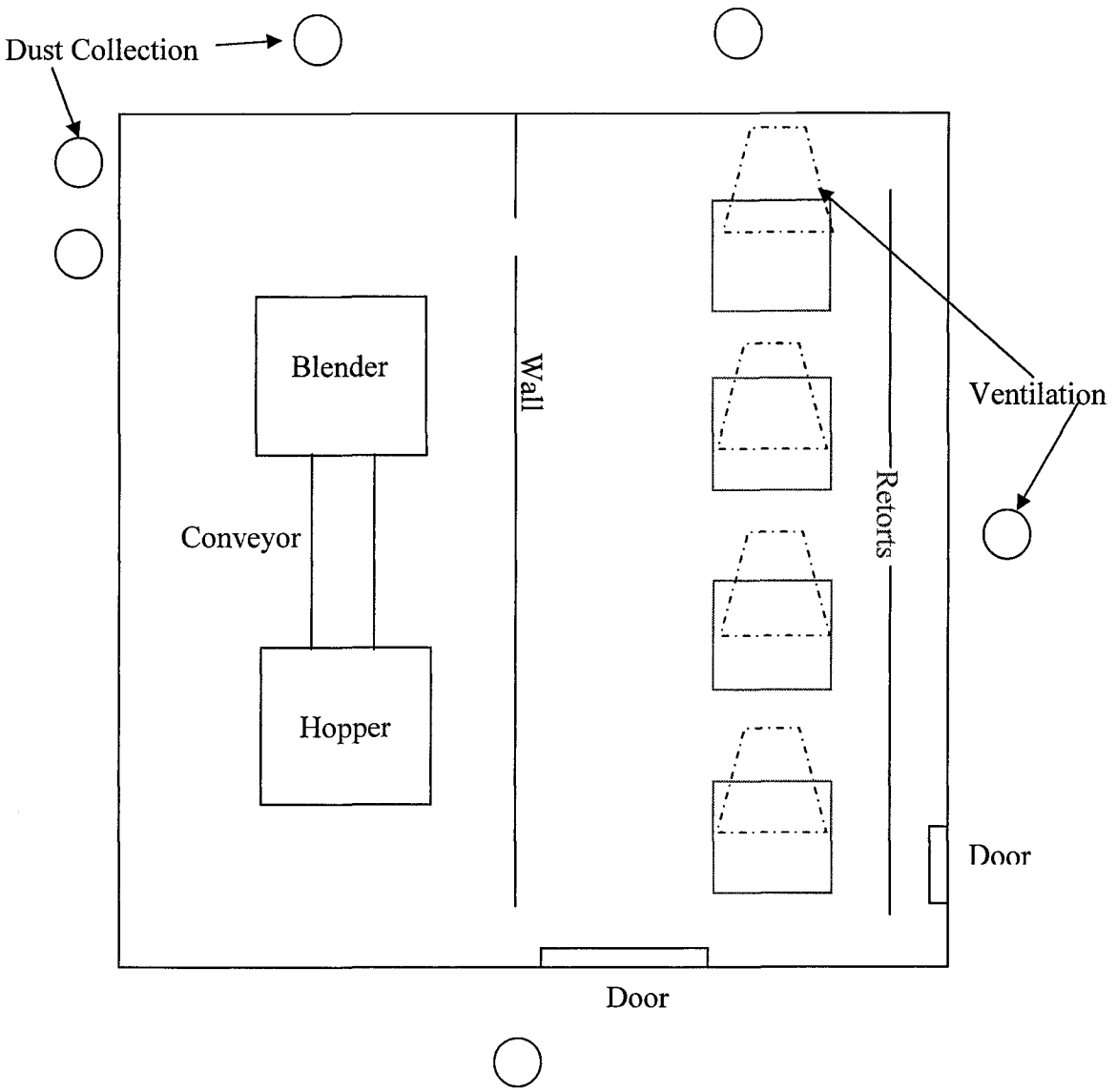

FIGURE 2.6A RETORT BUILDING 1926-1993 (48)

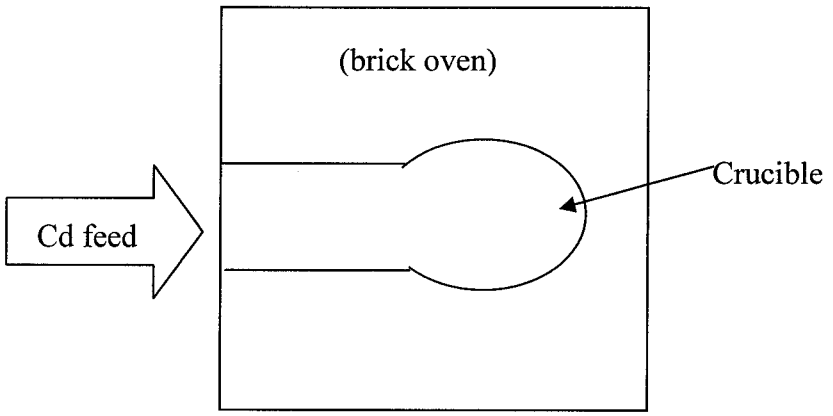

FIGURE 2.6B INSIDE VIEW OF RETORT (48)

cadmium sulfate, which was removed by filtration. Hydrogen sulfide was then bubbled through the cadmium sulfate filtrates to produce the sulfide, which was then removed by presses for use as yellow (cadmium sulfide) pigment (See Figure 2.7).

The plant has also housed several other specialized processes to produce small amounts of indium, lead, thallium, and arsenic. These operations were performed sporadically by a few individuals in three stand-alone buildings. High purity arsenic, thallium, and indium were produced on a laboratory scale.

Also housed on site were the plant offices, laboratories, maintenance facilities, and a general supplies warehouse. These miscellaneous plant facilities are located in separate buildings outside of the production area. Dust may have been carried in on the footwear and clothes of personnel entering and exiting the facility and from general air contamination from the plant's activities.

ASARCO also provided personal hygiene facilities and implemented work practices and procedures to protect the employees. The company provided facilities for the workers to shower and wash their clothes to prevent them from carrying contamination off-site. Also in the 1940s, the company instituted a respirator program that required use by personnel in high exposure departments. Respirator required departments included Roaster, Baghouse, Mixing, Calcining, Premelt, Retort, Oxide, and Pigment.

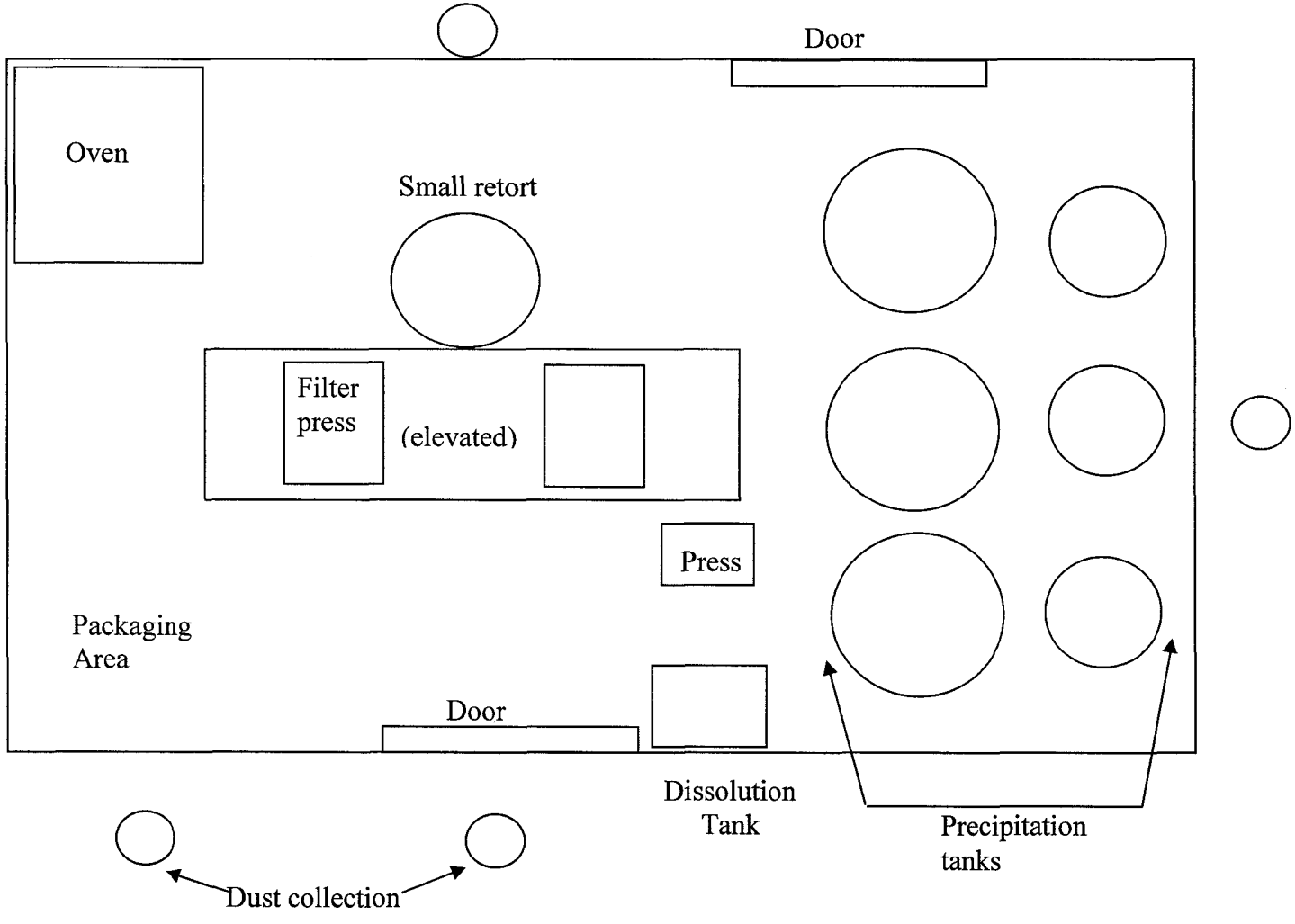

FIGURE 2.7 PIGMENT PLANT 1926-1993 (48)

2.1.3 Types of Exposures

The smelting operations by-product shipped to this plant was mainly cadmium oxide, but the feedstock was also contaminated with other metals including lead, arsenic, thallium, gold, silver, copper, zinc, and selenium. Therefore, when the material was processed at the Globe plant, the workers were exposed to a variety of chemical agents. Also, the process employed at this plant resulted in localized areas of specific exposures and not the more generalized exposures that are often seen in other smelters. Because of this, workers in each department had different exposure experiences. Those in the initial phases of the process were exposed to dust and fumes contaminated with many different metals, those in the later phases would more likely exposed to one or only a few compounds. Those in departments related to non-production operations and services would have negligible exposures most likely resulting from contaminated dust being carried into these areas on the personnel's clothing or shoes or originating from the general air contamination of the entire plant site. Table 2.1 lists each department and its assigned department identification number. This list was taken from a previous study which compiled a job dictionary for the facility (3). This job dictionary is included in its entirety in the Appendix.

TABLE 2.1 DEPARTMENT IDENTIFICATION NUMBERS AND DESCRIPTIONS

ID	Department Label
1a	FOREMAN
1b	CALCINE DEPARTMENT
1c	MIXERS & SCREENER
1e	SOLUTION OPERATORS & PRESSMAN
1f	SOLUTION CHARGER
1h	PIGMENT PLANT
1i	GASMAN - SULFIDE
1l	TANKHOUSE & ELECTROLYTIC
1m	RETORT OPERATOR
1n	CASTER
1o	WEIGHER AND PACKER
2	INDIUM PLANT
3	ACID RECOVERY PLANT
4a	LOADING GANG WORKMAN
4b	CONC. & DRY DUST
4c	GENERAL LABORER, UNLOADING
5	SAMPLING
6	CRUSHING
7	ROASTING
8	LEAD
9	THALLIUM
10a	MACHINE SHOP
10b	MAINTENANCE
11	ELECTRICAL SHOP
12	WELDERS & BURNERS
13	CARPENTER
14	AUTO TRUCK
15	JANITOR - LAUNDRY - GUARD
16	ARSENIC
17	GENERAL, NON-PRODUCTION*

*- This department code includes those departments not directly related to the process or production including administration, laboratory, metallurgists, etc.

2.1.4 Feedstock Source Descriptions

Table 2.2 provides the source of the feed, the type of operation, a range of the percentage of arsenic found in the feed, and years that the feed was used at the Globe facility. This information was gathered from literature (53) and the feedstock receipt records (54).

Table 2.2 Feedstock Source Information

Source	Operation	% Arsenic	Years of Feed
ASARCO Arkansas Valley Plant Leadville, CO	Underground mine-lead, zinc, silver, and gold ores	1-20%	1940-56
ASARCO Chihuahua Plant Chihuahua, Mexico	Lead smelter	0.17-10.40%	1940-75
ASARCO East Helena, MO	Lead smelter	1.10-8.10%	1943-58
ASARCO El Paso Plant El Paso, TX	Lead smelter Copper smelter Zinc smelter	0.5-8.7%	1940-85
ASARCO Federal, IL	N/A	0.02-8.80%	1940-55
ASARCO Murray Plant Murray, UT	Lead smelter	0.8-7.2%	1940-50
ASARCO San Louis (Potosi) Plant Mexico	Lead and copper smelter	0.5-6.4%	1940-60
Selby Plant Selby, CA	Lead and zinc smelter	0.5-13.4%	1944-54
ASARCO Amarillo Plant, TX	Zinc smelter Copper refinery	0.6-4.8%	1940-49
ASARCO Perth Amboy Plant NJ	Copper refinery	1.40%	1940-57
ASARCO Corpus Christi, TX	Zinc refinery	0.10%	1979
Bunker Hill Smelter Brandley, ID	Mine, smelter- lead, zinc, cadmium, silver, gold	3.9-6.9%	1944
Blackwell Zinc (Amer Metal Co) Blackwell, OK	N/A	0.16-13.38%	1946-54
Immel Unit Mascot, Knox County, TN	Underground mine (Zinc concentrates)	5.3-6.5%	1976
Globe (roasters)	Cadmium smelter	0.1-4.1%	1958-77
N/A = No source could be identified for this information			

The following figures are provided to give a graphical representation of the feedstock source information. Figure 2.8 is a barchart of the years a source supplied feed to the ASARCO Globe plant. Figure 2.9 represents the levels of arsenic that existed in feed from each shipment for all sources.

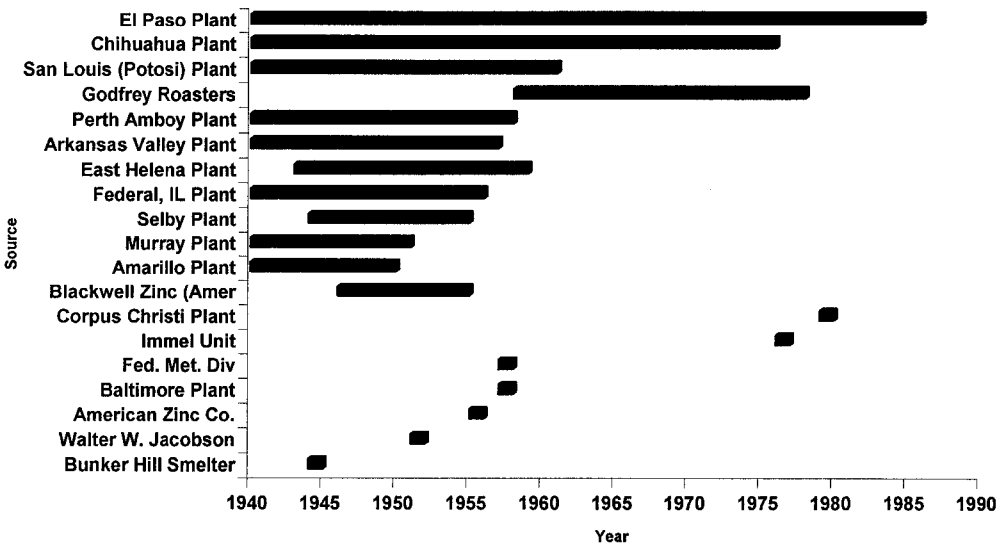

FIGURE 2.8 FEEDSTOCK SOURCE, BY YEAR

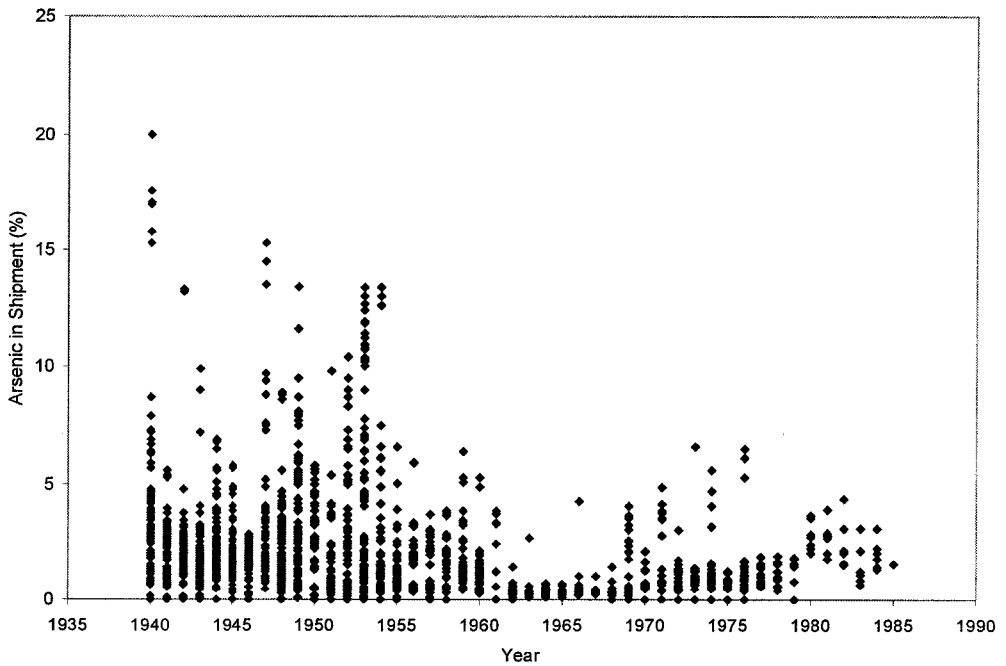

FIGURE 2.9 FEEDSTOCK SHIPMENT DATA, BY YEAR

2.2 Plant History and Chapter Summary

Historical information with respect to plant history and significant changes in the process and exposure control measures was compiled and outlined below (3,6,7, 45-53)

2.2.1 Plant History

1886 to 1901- Gold/silver, lead smelting operations (known at the time as the Holden Smelter).

1901- The plant was acquired by the American Smelting and Refining Company (ASARCO). It became the Globe Smelter and carried out lead smelting operations.

1920 to 1926- The plant functioned as an arsenic trioxide refinery/smelter.

1926- Godfrey Roasters installed used to concentrate cadmium in dust from various lead smelters until mid-1950s.

1928- Erection of the first electrolytic cells took place in February.

1928-1939- Gradual improvements were made in the process, metallurgically and mechanically, and the production steadily increased.

1939-1945- Steps were taken to increase production and a ninth, and later tenth, electrolytic system was added. (During the war years, every effort was made to produce the maximum amount of cadmium.)

1940s- Company instituted respirator program and biological monitoring program to control and monitor employees' exposures.

1944- A plant for the recovery of indium was constructed.

1948- The intake of raw material increased and efforts were made to improve the plant and increase the production of cadmium. A serious hygiene rehabilitation program was begun. A new and carefully engineered cadmium sulfide plant was constructed. A new department area for producing cadmium oxide was constructed in March. A new and modern baghouse was erected in July and a complete hopper and conveyor system was constructed to automatically feed the roasters.

1951- In July, a modern machine shop and carpenter shop were erected.

1948-1953- Besides the construction of the new buildings, older departments were overhauled and equipped with modern machinery, bulldozers leveled and cleaned up old buildings, a complete painting of the facility was initiated, and the entire plant was fenced. Also experimental work was begun to provide better methods of mixing and roasting the raw product.

1953- The mist precipitator and Cotrell gas cleaner were added to control emissions in the calcine operation.

1960s- Most of the concentrating was done at the Godfrey Roaster in El Paso, and the Globe Plant Godfrey Roaster was primarily used for recovery of

cadmium from calcine and purification muds and residues. This by-products roasting became intermittent.

??- Installed showers, clothes washer

1977- The Godfrey Roaster was discontinued entirely, shipped by-products to other plant.

1980s- The use of the tankhouse (electrolytic refinery) ceased. Neutralization and tailings storage were curtailed, This building became the wastewater treatment plant. The incoming feed was received in large "tote bags".

1983- Mixing and calcining operations ceased. Hydrometallurgical leaching processes replaced pyrometallurgical calcining process. Process went straight to solution purification.

1993- Cadmium refining circuit discontinued completely.

1994 to present- Specialty chemicals and high purity metals and compounds are produced. Litharge (lead) and bismuth recovery and refining operations are the focus of the plant.

2.2.2 Chapter Summary

Figure 2.10 serves as a summary for Chapter 2 and illustrates the information provided in this chapter. It diagrams the process flow described and includes information on exposures and process changes. As outlined in the legend, each box represents a department with the department or process label in bold text and the related department identification numbers in parentheses. The typical exposures for each department are included in italicized text. Text in brackets with a dashed arrow indicates a process change. This information was assembled from process descriptions (3,6,7,45-52) and interviews with people associated with ASARCO (48).

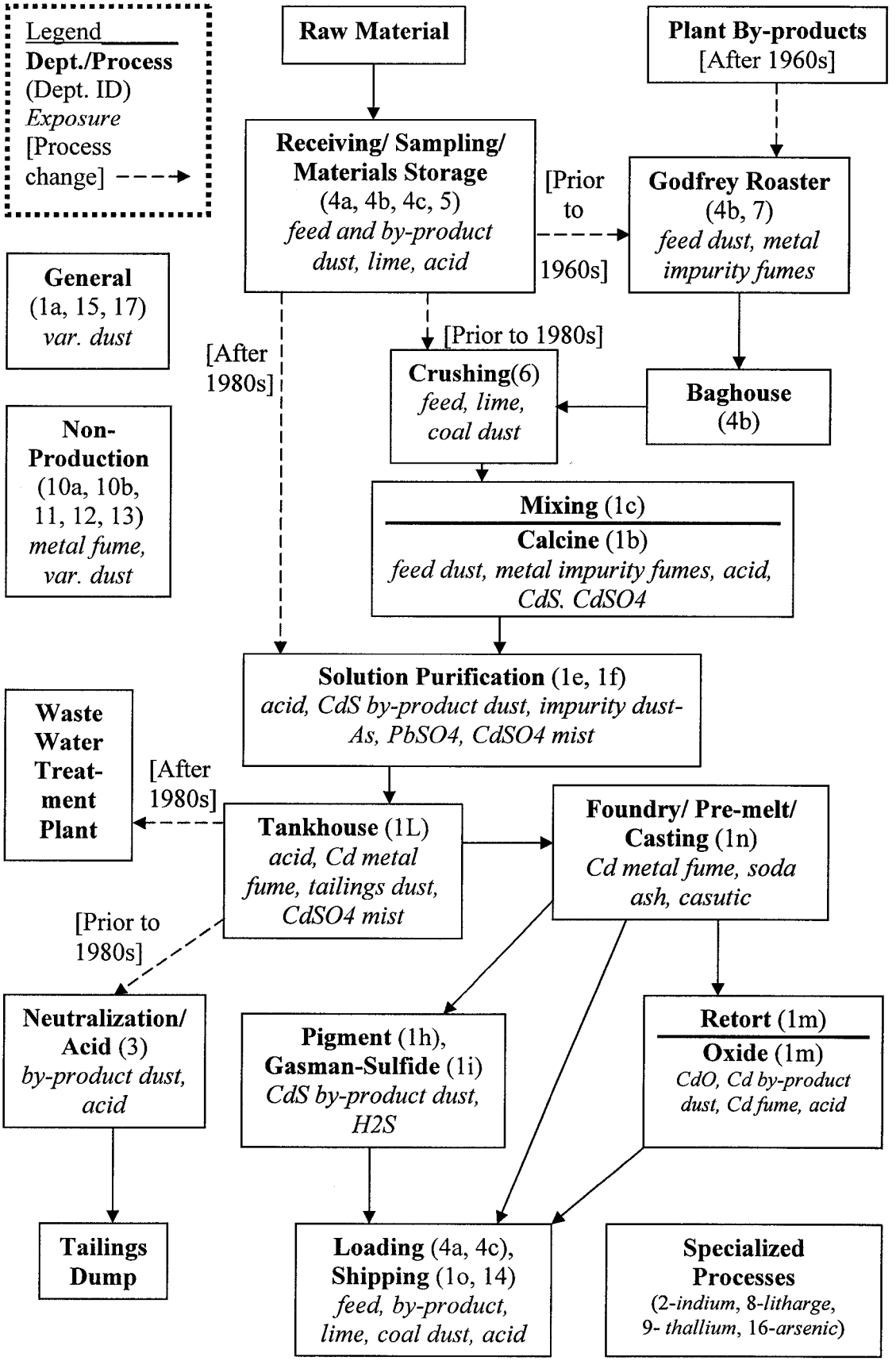

FIGURE 2.10 CHAPTER 2 SUMMARY

CHAPTER 3 METHODOLOGY

3.1 Introduction

The first step in developing this historical job exposure matrix involved researching and collecting all data available of sampling surveys conducted at the plant. The following is a description of the information gathered for this study. To ensure continuity throughout the study, the data gathered was first coded with the department code dictionary developed by Sorahan (3). This dictionary is included in the Appendix.

Lemen Industrial Hygiene Study 1976 (7)- describes results reported in Annals New York Academy of Sciences of an industrial hygiene study conducted at the plant. Reports department and arsenic sampling result.

1944 ASARCO Engineering Report, Globe Plant (51)- report summarizing the air sampling results of the engineering students made by the Division of Industrial Hygiene, University of Colorado School of Medicine and Hospitals in November 1944. Tables include: location/ operation, lead, cadmium, arsenic, zinc levels, and remarks and recommendations.

1945 ASARCO Report of Survey of Dust and Fume Hazards at the Globe Plant (52)- report summarizes the results of the hazards found in a dust and fume survey made in February and March of 1945. Tables include: sample number, volume, location, operation, lead, cadmium, zinc, and arsenic trioxide analysis.

Records of Metal Content of Feedstock Delivered to ASARCO Globe Plant 1924-1985 (54)- original data of the shipment receipts for the plant. Tables include date, shipper, lot number, weight, and analysis of gold, silver, lead, copper, cadmium, arsenic, zinc, tellurium, chlorine, and selenium.

Summary Air Sampling Report, Globe Plant (55)- report summarizing arsenic air sampling data for the plant in June 1973, August 1950, July 1949. Table includes date, number of samples, description, arsenic concentration, number of samples by department, number of samples by job or operation, and exposure to arsenic.

ASARCO Summary of Personal Monitor Samples by Job Classification, Globe Plant (56)- report summarizes results of personal monitoring samples taken at the plant for arsenic from June 1978 to December 1983. Tables include: department/ job class, air sample results, average, maximum, minimum, number, geometric mean, shift, and sample date.

US DOL OSHA Citation and Notification of Penalty, ASARCO Globe Plant 1979 (57)- citation outlining violations of the plant as recorded by OSHA in 1979. Shift sampling conducted by OSHA at the plant included. Table includes sample ID, sample type, department, location, arsenic sampling result, and standard.

ASARCO Globe Personal Monitor Sampling Results 1979 (58)- results of personal monitoring sampling conducted February 1979 as a result of the OSHA citation. Table includes department, job classification, shift, sample date, and arsenic exposure level.

Smith Epidemiological Study (6,47,59)- describes results of a cadmium and kidney function study conducted at the plant. Data includes time period, department and cadmium concentration.

Biological Monitoring Data- Members of Cd-3 (60)- Data compiled by Dr. Michael Thun of Globe employees in the NIOSH cohort in July 1982. File includes date, urine cadmium level, specific gravity, urine thallium level, blood cadmium level, urine lead level, piscator results, protein dipstick results, glucose dipstick results, blood lead level, hemoglobin, quantitative protein results, urine arsenic, and blood thallium.

The methods for exposure estimation were applied to data for all departments except 2-Indium plant, 8- Lead (Litharge), 9-Thallium, and 16-Arsenic (See Table 2.1). These departments may have had exposures to cadmium and arsenic, but they were completely separate from the rest of the process and could not be related to other departments. Because of the lack of data, it was impossible to generate exposure estimates for these departments.

3.2 Relating Data by Sampling Instrument Type

The sampling instruments and techniques employed in each survey varied greatly. Because of this, it was necessary to adjust these data to compensate for differences in instrument type, collection efficiencies, and sampling technique.

To approximate the original air levels, a method adapted from Rice (61) was used. The instruments used for the air sampling included the electrostatic precipitator (ESP), impinger, and 37-mm cassette. The air levels were adjusted by using the collection efficiencies of each instrument for the estimated particle size to estimate the actual air levels from the sample levels.

First the particle sizes of the aerosols were determined. This was accomplished by compiling data and information on the particles collected. Impinger The 1945 industrial hygiene report states that "a small aluminum baffle plate, 25 mm in diameter, was used 3-4 mm above the impinger intake to exclude the very largest dust particles and prevent possible contamination" (52). Typically, the impinger can sample aerosols greater than 1 micrometer (μm) (62). ESP The size of the particles collected by the electrostatic precipitator was estimated by the properties of the instrument. According to Drinker and Hatch (40), the ESP can sample aerosols greater than 0.001 μm. Filter The size of the particles collected by the 37-mm cassette filter sampler were estimated by the properties of the instrument. The cassette has been shown to collect aerosols greater than 0.03 μm (40).

No particle sizing was performed during the sampling events at the plant. Therefore, information on the characteristics of the aerosol present in the sampling areas was used to estimate the particle sizes of the dust and fumes that would have been sampled. These sizes represent the actual diameter of the particle and not mass median aerodynamic diameters (MMAD), as might typically be estimated. The typical size range for fumes is 0.002-1 μm and for dusts is 0.02-3000 μm (63). Because of the processes from which the feed came, the dust entering the facility was technically an agglomerated fume. Because of this, it was assumed that the size of the fumes seen at the plant would have been on the larger end of this range. Also because of the process, it was assumed that the size of dusts seen at the facility would have been on the smaller end of this range. It was estimated that the average size of the aerosol sampled would have ranged from 0.1 to 1 μm.

Next the collection efficiencies of the instruments were determined from the literature (64-69). For this particle size range, it was determined that the efficiency of the impinger was 96%, the electrostatic precipitator was 98%, and the 37-mm cassette filter sampler was 99%.

Then, the sampling results were compiled and sorted for each type of instrument used. The efficiencies of the instruments were applied to each set of data to determine the corrected air level.

3.3 Relating General Area Data and Personal Monitoring Data

Another adjustment that was needed for these sampling data was relating the area samples to the samples taken as personal or breathing zone samples. Because area samples usually tend to inaccurately estimate the workers' exposure, it was necessary to adjust these data to estimate what the personal exposure might have been (6, 70-72).

In this study, the area samples were adjusted to reflect the workers' exposure by a method adapted from Smith (6). For each department where both area samples were obtained, a ratio was developed between the area and personal samples taking into account location of the samples and the duration of typical tasks in that area. This ratio was then applied to other area samples for subsequent years for each of these departments to estimate the personal exposure.

The data gathered was first labeled as either a personal sample or an area sample. This determination was made from information available in each report. The 1944 industrial hygiene report states that, "all samples were taken at the breathing level and work position of the operators (51)." These samples were considered area samples. In the 1945 industrial hygiene report (52) it is stated that,

> "the samples were taken to represent as nearly as possible the air breathed by the workmen under representative working conditions.

> Metallurgists at the Globe Plant were present at the time when most of the samples were taken to give assurance the operating conditions were normal. Unless stated otherwise, all samples were taken at the nose level and while following a worker or workers performing an operation or a cycle of operations. The samples should adequately represent the "exposures" or conditions prevailing at the time of this survey for most of the men working inside buildings and enclosures."

For the purposes of this study, the samples from this report were considered personal because they were at the breathing zone of the worker(s) and considered representative of workers' exposure and accounted for task variability similar to a personal sampler affixed to a worker. Data listed in the report for a location were considered area data. The 1949 and 1950 data were area samples and the 1973 data were personal (55). All ASARCO sampling data collected from 1978-1983 were personal monitoring (56, 58). The 1979 OSHA citation contained both personal and area monitoring and each was clearly noted in the report (57). Data taken from Lemen et al (7) were considered to be area samples from the description of the study.

Next, the personal exposures were calculated from the area concentrations by developing a ratio between the samples. Because of differences in sampling technique, the data was separated into two groups- those from years 1944-1950 and those from 1973-1983. The data were then sorted by department for area and personal samples. The geometric mean was calculated for each department and type of sample. The geometric mean was calculated for each department type of sample and time period. These geometric means were then compared between area and personal for the departments. The personal was then divided

by the area to calculate the ratio. This ratio was then used as a multiplier for the area measurements to estimate the corresponding personal exposures.

3.4 Relating Feedstock Arsenic Data and Airborne Arsenic Exposure Data

As a potential source of information to enhance the data set for years when air sampling results did not exist, the feedstock sampling data were analyzed to determine if it was suitable to be used to interpolate between the sampling data. The data were analyzed to determine if the percent arsenic or total amount of arsenic in the feedstock was related to the air levels of arsenic. The resulting dataset from Method 3.2 was the air arsenic data used here.

First the geometric means of each data set were calculated. For all data sets, i.e. air data, percent arsenic data, and total amount of arsenic data, linear trends were evaluated using the Regression procedure of the Statistical Analysis System (SAS) (73). Only the departments where the feedstock would have been present, handled, or processed were included: calcine, mixer and screener, loading gang workman, concentrated and dry dust, general labor/unloading, sampling, crushing, roasting, and auto truck. The values for the total amount of arsenic processed were calculated by multiplying the percent arsenic by the total weight of the shipment to find the total amount of arsenic, in pounds. Next, the data sets were evaluated for correlation using the Pearson correlation procedure of SAS (73). Air levels (mg/m^3) were related to the percent arsenic and total

amount of arsenic to determine if a correlation existed between the sets of data. A high correlation would allow for the generation of exposure estimates by converting the feedstock data into air data.

3.5 Relating Biological Monitoring Data and Air Exposure Data

As another potential source of additional exposure estimates, biological monitoring data from the plant were gathered. The urinary arsenic level measured of each employee was used for estimating inhaled arsenic levels.

The company began measuring blood and urine concentrations of various metals in employees in the early 1940s. Urine samples that were collected and analyzed for arsenic were sporadic from 1964 to 1975. The departments, which included these workers, were foremen, calcine, mixer, solution, sampling, roaster, welder, auto truck, janitor-guard, and general.

Several methods for converting urinary arsenic to airborne arsenic have been previously developed (74-81). Because of characteristics of the sampling and the data, addressed in Chapter 6, the model developed by Pinto (74,75) was used in this study. The model is shown in Equation 3.1

$$\text{Air Arsenic } (\mu g/m^3) = 0.304 * (\text{Urinary Arsenic } (\mu g/L)) \quad (3.1)$$

The values generated by this method reflect the workers' internal exposure and did not require adjustment for respirator use prior to being included in the final exposure matrix.

3.6 Developing Exposure Adjustment Factors

Excluding the values estimated in 3.5 Relating Biological Monitoring Data and Air Exposure Data, the estimates generated thus far represent airborne levels of arsenic and not necessarily levels of arsenic to which the workers would have been exposed internally. Because of this, information was gathered to develop factors to adjust these exposure estimates (5,40,41,45,47,58,83,84). In an ideal situation, the adjusted exposure estimates would describe the concentration of contaminant that the worker potentially inhaled. This factor would take into account the variable deposition of arsenic from interpersonal differences in physiology, such as breathing rate and lung size; interpersonal differences in work practices, hygiene and habits; and the variation in protection each worker would have received from his respirator.

Because it is extremely difficult to adequately collect data on all of these variables, a different approach was taken to quantify the protection factor. Trends in existing data for airborne and urinary cadmium levels were used to assess the overall effectiveness of the respirator and personal hygiene programs. Cadmium data were used in this procedure because it was more complete. It was assumed that the protection offered by the respirator would be

the same for both metals. Therefore, protection factors developed from cadmium data would be appropriate for arsenic data.

Data and information on urinary and airborne cadmium levels were compiled to determine the respirator protection factors for the years from 1940-1975. Smith's estimation of 3.9 for the protection factor will be used for years after 1975 (45). Applying a single factor to every year was deemed inappropriate. Protection factors were developed for different time periods because of changes in procedures and practices relating to the respirators. This information is discussed later.

Biological monitoring data of each employee and air sampling data were collected from studies conducted at the plant. A model developed previously by Smith (6) was used to convert the airborne cadmium levels to expected urine cadmium levels. This model was derived from data collected on workers at this plant included in the cohort and included data for high and low exposures and respirator and non-respirator use. This model is shown in Equation 3.2.

Average Urinary Cadmium (μg/L) =

5.00 (TWA Inhalation Exposure (μg/m^3))^0.502 (3.2)

The values generated from this calculation would represent a worker's exposure without the use of a respirator. The matrix developed previously (47,58) for

inhaled levels of cadmium was re-adjusted to reflect the concentrations of cadmium in the air and not the workers' inhalation exposure. To do this, the values in the exposure matrix were multiplied by 3.9- Smith's protection factor (45). Next, the biomonitoring data was compiled for employees from 1940-1975. The cadmium urine levels were corrected by the specific gravity, reported with the biological monitoring, with the formula shown in Equation 3.3.

Standardized Urine Cadmium (µg/L) =

Urine Cadmium (µg/L) * (1.018/Urine Specific Gravity) (3.3)

These standardized urine data were then sorted into five-year blocks for comparison because the expected urine values were calculated from air data that was averaged into five-year blocks. These comparisons determined factors that describe the difference between the air concentrations and the concentration to which the worker was actually exposed. Equation 3.4 shows this calculation.

$$\text{Protection Factor (PF)} = \frac{\text{(Expected personal exposure)}}{\text{(Exposure with respirator)}} \quad (3.4)$$

3.7 Estimating Exposure Values

3.7.1 Arsenic Estimates

Finally, values for the air levels generated were compiled and the airborne levels that the workers would have been exposed to were calculated by applying the

adjustment factor to these air levels. Next the results from 3.4 Relating Biological Monitoring Data and Air Exposure Data were included.

3.7.2 Cadmium Estimates

The inclusion of the cadmium exposure matrix is beneficial to this study by supplementing air exposure estimates for departments with no/minimal arsenic exposure. After the new protection factors were developed, the exposure matrix for cadmium was recalculated. This exposure matrix developed previously (6,47,59) was first adjusted with the protection factor of 3.9 that was developed by Smith (45) in 1975. Next, the factors developed in 3.5 Developing Exposure Adjustment Factors were applied to the cadmium exposure estimates in each time period.

CHAPTER 4 RESULTS

The results of the arsenic exposure estimate calculations from the preceding methods are shown in the tables and figures of the following sections.

4.1 Results of Relating Data by Sampling Instrument Type

The results of standardizing the data by instrument type are presented in Table 4.1. This table includes year the sample was collected, department in which it was collected, reported level of arsenic, type of instrument used, instrument efficiency, and final calculated/adjusted level of arsenic. The adjusted levels represent an approximation of the air levels of arsenic in the environment. The sample levels are lower than the air levels because of the inherent inefficiencies of sampling instrumentation. The results included 46 samples with the electrostatic precipitator, seven samples with the impinger, and 104 with the cassette.

TABLE 4.1 ADJUSTING DATA BY INSTRUMENT TYPE

Year	Department Name (ID)	Reported Level (mg/m3)	Sampling Instrument	Efficiency (%)	Adjusted Level (mg/m3)
1944	Calcine (1b)	0.110	Electrostatic Precipitator	0.98	0.112
1944	Calcine (1b)	0.060	Electrostatic Precipitator	0.98	0.061
1944	Calcine (1b)	0.050	Electrostatic Precipitator	0.98	0.051
1944	Mixer (1c)	2.820	Electrostatic Precipitator	0.98	2.878
1944	Acid Plant (3)	0.220	Electrostatic Precipitator	0.98	0.224
1944	Conc. & Dry dust (4b)	0.060	Electrostatic Precipitator	0.98	0.061
1944	Conc. & Dry dust (4b)	0.670	Electrostatic Precipitator	0.98	0.684
1944	Conc. & Dry dust (4b)	0.600	Electrostatic Precipitator	0.98	0.612
1944	Conc. & Dry dust (4b)	0.130	Electrostatic Precipitator	0.98	0.133
1944	Conc. & Dry dust (4b)	3.020	Electrostatic Precipitator	0.98	3.082
1944	Conc. & Dry dust (4b)	1.070	Electrostatic Precipitator	0.98	1.092
1944	Conc. & Dry dust (4b)	0.050	Electrostatic Precipitator	0.98	0.051
1944	Crusher (6)	0.018	Electrostatic Precipitator	0.98	0.018
1944	Crusher (6)	0.040	Electrostatic Precipitator	0.98	0.041
1944	Roasting (7)	0.040	Electrostatic Precipitator	0.98	0.041

1944	Roasting (7)	0.480	Electrostatic Precipitator	0.98	0.490
1944	Transportation (14)	1.560	Electrostatic Precipitator	0.98	1.592
1944	Transportation (14)	0.380	Electrostatic Precipitator	0.98	0.388
1945	Calcine (1b)	0.070	Electrostatic Precipitator	0.98	0.071
1945	Calcine (1b)	0.030	Electrostatic Precipitator	0.98	0.031
1945	Acid Plant (3)	0.030	Electrostatic Precipitator	0.98	0.031
1945	Acid Plant (3)	0.090	Electrostatic Precipitator	0.98	0.092
1945	Conc. & Dry dust (4b)	34.900	Electrostatic Precipitator	0.98	35.612
1945	Conc. & Dry dust (4b)	0.020	Electrostatic Precipitator	0.98	0.020
1945	Conc. & Dry dust (4b)	0.430	Electrostatic Precipitator	0.98	0.439
1945	Crusher (6)	1.550	Electrostatic Precipitator	0.98	1.582
1945	Crusher (6)	0.430	Electrostatic Precipitator	0.98	0.439
1945	Roasting (7)	1.030	Electrostatic Precipitator	0.98	1.051
1945	Calcine (1b)	0.040	Electrostatic Precipitator	0.98	0.041
1945	Calcine (1b)	0.020	Electrostatic Precipitator	0.98	0.020
1945	Solution Charger (1f)	0.020	Electrostatic Precipitator	0.98	0.020
1945	Acid Plant (3)	0.290	Electrostatic Precipitator	0.98	0.296
1945	Acid Plant (3)	0.140	Electrostatic Precipitator	0.98	0.143
1945	Acid Plant (3)	0.210	Electrostatic Precipitator	0.98	0.214
1945	Conc. & Dry dust (4b)	0.130	Electrostatic Precipitator	0.98	0.133
1945	Conc. & Dry dust (4b)	0.360	Electrostatic Precipitator	0.98	0.367
1945	Conc. & Dry dust (4b)	2.300	Electrostatic Precipitator	0.98	2.347
1945	Conc. & Dry dust (4b)	0.260	Electrostatic Precipitator	0.98	0.265
1945	Conc. & Dry dust (4b)	0.230	Electrostatic Precipitator	0.98	0.235
1945	Conc. & Dry dust (4b)	3.900	Electrostatic Precipitator	0.98	3.980
1945	Conc. & Dry dust (4b)	4.120	Electrostatic Precipitator	0.98	4.204
1945	Conc. & Dry dust (4b)	4.400	Electrostatic Precipitator	0.98	4.490
1945	Conc. & Dry dust (4b)	0.680	Electrostatic Precipitator	0.98	0.694
1945	Roasting (7)	1.140	Electrostatic Precipitator	0.98	1.163
1945	Transportation (14)	0.060	Electrostatic Precipitator	0.98	0.061
1945	Transportation (14)	8.500	Electrostatic Precipitator	0.98	8.673
1945	Acid Plant (3)	0.060	Impinger	0.96	0.063
1945	Crusher (6)	0.010	Impinger	0.96	0.010
1945	Crusher (6)	0.500	Impinger	0.96	0.521
1945	Conc. & Dry dust (4b)	0.080	Impinger	0.96	0.083
1945	Transportation (14)	0.040	Impinger	0.96	0.042
1945	Transportation (14)	5.130	Impinger	0.96	5.344
1945	Transportation (14)	1.020	Impinger	0.96	1.063
1949	Conc. & Dry dust (4b)	0.710	Cassette	0.99	0.717
1949	Conc. & Dry dust (4b)	0.355	Cassette	0.99	0.359
1950	Calcine (1b)	0.650	Cassette	0.99	0.657
1950	Mixers (1c)	0.320	Cassette	0.99	0.323
1950	Conc. & Dry dust (4b)	0.730	Cassette	0.99	0.737
1950	Conc. & Dry dust (4b)	0.630	Cassette	0.99	0.636
1973	Retort (1m)	0.001	Cassette	0.99	0.001
1973	Caster (1n)	0.000	Cassette	0.99	0.000
1973	Caster (1n)	0.001	Cassette	0.99	0.001
1979	Calcine (1b)	0.012	Cassette	0.99	0.012
1979	Calcine (1b)	0.018	Cassette	0.99	0.018
1979	Calcine (1b)	0.025	Cassette	0.99	0.025
1979	Calcine (1b)	0.009	Cassette	0.99	0.009
1979	Calcine (1b)	0.026	Cassette	0.99	0.026
1979	Mixers (1c)	0.199	Cassette	0.99	0.201
1979	Mixers (1c)	0.633	Cassette	0.99	0.639
1979	Calcine (1b)	0.020	Cassette	0.99	0.020
1979	Calcine (1b)	0.011	Cassette	0.99	0.011

1979	Calcine (1b)	0.640	Cassette	0.99	0.646
1979	Calcine (1b)	0.057	Cassette	0.99	0.058
1979	Calcine (1b)	0.015	Cassette	0.99	0.015
1979	Calcine (1b)	0.022	Cassette	0.99	0.022
1979	Calcine (1b)	0.031	Cassette	0.99	0.031
1979	Calcine (1b)	0.041	Cassette	0.99	0.041
1979	Calcine (1b)	0.134	Cassette	0.99	0.135
1979	Calcine (1b)	0.147	Cassette	0.99	0.148
1979	Calcine (1b)	0.013	Cassette	0.99	0.013
1979	Calcine (1b)	0.122	Cassette	0.99	0.123
1979	Calcine (1b)	0.101	Cassette	0.99	0.102
1979	Mixers (1c)	0.182	Cassette	0.99	0.184
1979	Mixers (1c)	0.288	Cassette	0.99	0.291
1979	Mixers (1c)	0.104	Cassette	0.99	0.105
1979	Mixers (1c)	0.466	Cassette	0.99	0.471
1979	Mixers (1c)	0.231	Cassette	0.99	0.233
1979	Mixers (1c)	0.086	Cassette	0.99	0.087
1979	General (17)	0.140	Cassette	0.99	0.141
1979	General (17)	0.132	Cassette	0.99	0.133
1979	General (17)	0.143	Cassette	0.99	0.144
1980	Calcine (1b)	0.014	Cassette	0.99	0.014
1980	Calcine (1b)	0.461	Cassette	0.99	0.466
1980	Calcine (1b)	0.400	Cassette	0.99	0.404
1980	Calcine (1b)	0.397	Cassette	0.99	0.401
1980	Calcine (1b)	0.154	Cassette	0.99	0.156
1980	Calcine (1b)	0.039	Cassette	0.99	0.039
1980	Calcine (1b)	0.321	Cassette	0.99	0.324
1980	Calcine (1b)	0.307	Cassette	0.99	0.310
1980	Calcine (1b)	0.319	Cassette	0.99	0.322
1980	Calcine (1b)	0.209	Cassette	0.99	0.211
1980	Mixers (1c)	0.409	Cassette	0.99	0.413
1980	Mixers (1c)	0.599	Cassette	0.99	0.605
1980	Mixers (1c)	0.485	Cassette	0.99	0.490
1980	Retort (1m)	0.001	Cassette	0.99	0.001
1980	Retort (1m)	0.001	Cassette	0.99	0.001
1980	Retort (1m)	0.006	Cassette	0.99	0.006
1981	Calcine (1b)	0.021	Cassette	0.99	0.021
1981	Calcine (1b)	0.264	Cassette	0.99	0.267
1981	Calcine (1b)	0.147	Cassette	0.99	0.148
1981	Calcine (1b)	0.241	Cassette	0.99	0.243
1981	Calcine (1b)	0.432	Cassette	0.99	0.436
1981	Calcine (1b)	0.276	Cassette	0.99	0.279
1981	Tankhouse & Electrolytic (1l)	0.003	Cassette	0.99	0.003
1981	Caster (1n)	0.004	Cassette	0.99	0.004
1983	Foreman, Supervisor (1a)	0.001	Cassette	0.99	0.001
1983	Foreman, Supervisor (1a)	0.004	Cassette	0.99	0.004
1983	Foreman, Supervisor (1a)	0.001	Cassette	0.99	0.001
1983	Foreman, Supervisor (1a)	0.001	Cassette	0.99	0.001
1983	Foreman, Supervisor (1a)	0.004	Cassette	0.99	0.004
1983	Foreman, Supervisor (1a)	0.001	Cassette	0.99	0.001
1983	Foreman,	0.001	Cassette	0.99	0.001

	Supervisor (1a)				
1983	Foreman, Supervisor (1a)	0.004	Cassette	0.99	0.004
1983	Calcine (1b)	0.113	Cassette	0.99	0.114
1983	Calcine (1b)	0.185	Cassette	0.99	0.187
1983	Mixers (1c)	0.206	Cassette	0.99	0.208
1983	Solution Oper (1e)	0.120	Cassette	0.99	0.121
1983	Solution Oper (1e)	0.017	Cassette	0.99	0.017
1983	Solution Charger (1f)	0.021	Cassette	0.99	0.021
1983	Tankhouse & Electrolytic (1l)	0.001	Cassette	0.99	0.001
1983	Tankhouse & Electrolytic (1l)	0.001	Cassette	0.99	0.001
1983	Tankhouse & Electrolytic (1l)	0.001	Cassette	0.99	0.001
1983	Tankhouse & Electrolytic (1l)	0.001	Cassette	0.99	0.001
1983	Tankhouse & Electrolytic (1l)	0.001	Cassette	0.99	0.001
1983	Tankhouse & Electrolytic (1l)	0.001	Cassette	0.99	0.001
1983	Retort (1m)	0.002	Cassette	0.99	0.002
1983	Retort (1m)	0.001	Cassette	0.99	0.001
1983	Caster (1n)	0.002	Cassette	0.99	0.002
1983	Caster (1n)	0.001	Cassette	0.99	0.001
1983	Caster (1n)	0.001	Cassette	0.99	0.001
1983	Weigher & Packer (1o)	0.002	Cassette	0.99	0.002
1983	Acid Plant (3)	0.002	Cassette	0.99	0.002
1983	General Labor (4c)	0.002	Cassette	0.99	0.002
1983	Sampling (5)	0.005	Cassette	0.99	0.005
1983	Machine shop (10a)	0.001	Cassette	0.99	0.001
1983	Maintenance (10b)	0.003	Cassette	0.99	0.003
1983	Maintenance (10b)	0.002	Cassette	0.99	0.002
1983	Electrical (11)	0.003	Cassette	0.99	0.003
1983	Welders & Burners (12)	0.003	Cassette	0.99	0.003
1983	Carpenter (13)	0.002	Cassette	0.99	0.002
1983	Auto Truck (14)	0.016	Cassette	0.99	0.016
1983	Guard (15)	0.002	Cassette	0.99	0.002
1983	Guard (15)	0.002	Cassette	0.99	0.002
1983	General (17)	0.001	Cassette	0.99	0.001
1983	General (17)	0.001	Cassette	0.99	0.001

4.2 Results of Relating General Area Data and Personal Monitoring Data

Table 4.2 shows the ratios developed to relate area and personal sample data. The adjusted values generated in method 3.1 Relating Data by Sampling Instrument Type were separated by 1) type of sample, i.e. area or personal; 2) department; and 3) year, i.e. 1944-1950 or 1973-1983. The value in each cell of the table represents the geometric mean of the samples (mg/m^3) of a given type for that time period. The value in parentheses was the number of values available for the calculation. The ratio represents the result of the value for the area divided into the value for the personal.

Two departments, 1c- Mixing and Screening and 6-Crushing, had area data and no personal data. Since a ratio had been developed for 1b for the time period, this ratio was applied to the 1c 1944-1950 data. This was reasonable because the mixing and screening department and the calcine department were in the same building and sampling and exposures would have been similar between the two areas. Also because the crushing took place in the Roaster building, it was assumed the exposures were similar and the ratio established for the 7-Roasting department was used for the 6-Crushing department as well.

TABLE 4.2 AREA/ PERSONAL RATIOS

		1944-50			1973-83		
Dept. ID	**Name**	**Area**	**Personal**	**Ratio(P/A)**	**Area**	**Personal**	**Ratio(P/A)**
1b	**Calcine**	0.09 (6)	0.03 (2)	0.3	0.017 (5)	0.103 (31)	6.2
1c	**Mixers & Screeners**	0.96 (2)	--	0.3	0.36 (2)	0.26 (10)	0.7
1m	**Retort**				0.0014 (2)	0.0016 (5)	1.1
1n	**Caster**				0.0006 (2)	0.0017 (4)	2.9
3	**Acid Recovery**	0.08(4)	0.31(3)	3.9			
4b	**Conc. & Dry Dust**	0.46 (14)	0.71 (10)	1.5			
6	**Crushing**	0.16 (6)	--	4.2			
7	**Roasting**	0.28 (3)	1.16 (1)	4.2			
14	**Auto Truck**	0.79 (2)	0.66 (5)	0.8			

All values are in mg/m^3
Value = geometric mean, number of values used in calculation of geometric mean in parentheses

Table 4.3 presents the results from applying these ratios to the data. The column labeled "Area Level" contains the values taken from Table 4.1 produced from the method in 3.2 Relating Data by Sampling Instrument Type and "Estimated Personal Exposure Level" contains the result of multiplying the "Area Level" value by the appropriate ratio.

TABLE 4.3 RESULTS OF CONVERTING AREA DATA TO PERSONAL DATA

1944-50			1973-83		
Department Name (ID)	Area Level (mg/m^3)	Estimated Personal Exposure Level (mg/m^3)	Department Name (ID)	Area Level (mg/m^3)	Estimated Personal Exposure Level (mg/m^3)
Calcine (1b)	0.071	0.021	Calcine (1b)	0.012	0.075
Calcine (1b)	0.031	0.009	Calcine (1b)	0.018	0.113
Calcine (1b)	0.112	0.034	Calcine (1b)	0.025	0.157
Calcine (1b)	0.061	0.018	Calcine (1b)	0.009	0.056
Calcine (1b)	0.051	0.015	Calcine (1b)	0.026	0.163
Calcine (1b)	0.657	0.197	Mixers (1c)	0.201	0.141
Mixer (1c)	2.878	0.863	Mixers (1c)	0.639	0.448
Mixers (1c)	0.323	0.097	Retort (1m)	0.001	0.002
Acid Plant (3)	0.031	0.121	Caster (1n)	0.000	0.001
Acid Plant (3)	0.092	0.359	Caster (1n)	0.001	0.003
Acid Plant (3)	0.063	0.246			
Acid Plant (3)	0.224	0.876			
Conc. & Dry dust (4b)	35.612	53.418			
Conc. & Dry dust (4b)	0.020	0.030			
Conc. & Dry dust (4b)	0.439	0.659			
Conc. & Dry dust (4b)	0.061	0.092			
Conc. & Dry dust (4b)	0.684	1.026			
Conc. & Dry dust (4b)	0.612	0.918			
Conc. & Dry dust (4b)	0.133	0.199			
Conc. & Dry dust (4b)	3.082	4.622			
Conc. & Dry dust (4b)	1.092	1.638			
Conc. & Dry dust (4b)	0.051	0.077			
Conc. & Dry dust (4b)	0.717	1.076			
Conc. & Dry dust (4b)	0.359	0.538			
Conc. & Dry dust (4b)	0.737	1.106			
Conc. & Dry dust (4b)	0.636	0.955			
Crusher (6)	1.582	6.644			
Crusher (6)	0.439	1.844			
Crusher (6)	0.000	0.000			
Crusher (6)	0.010	0.042			
Crusher (6)	0.521	2.188			
Crusher (6)	0.018	0.077			
Crusher (6)	0.041	0.171			
Roasting (7)	1.051	4.414			
Roasting (7)	0.041	0.171			
Roasting (7)	0.490	2.057			
Transportation (14)	1.592	1.273			
Transportation (14)	0.388	0.310			

4.3 Results of Relating Feedstock Arsenic Data and Airborne Arsenic Exposure Data

The results of these analyses showed that no strong correlation existed between air data and either feedstock data set (Table 4.4). From qualitative review of the plots, shown in Figures 4.1-4.2, it can be seen that, with the period from 1960-1970 dipping lower than the values before and after it, the feedstock data appears to follow a sigmoid-shaped curve. The plot of the air data shows a marked difference, decreasing between early and later years (Figure 4.3). This difference is most likely explained by the installation of engineering controls and changes in the process that would have decreased the arsenic exposure and is discussed later. Therefore any estimation of airborne arsenic levels from feedstock data was not used. The data used for the airborne arsenic levels included here are shown in a following section (Table 4.8).

TABLE 4.4 RESULTS OF FEEDSTOCK DATA AND AIR DATA ANALYSES

Linear Regression	α=0.05
	p
Airborne arsenic levels/ Arsenic feedstock levels (%)	0.3518
Airborne arsenic levels/ Arsenic feedstock levels (lbs)	0.1707

Pearson Correlation	α=0.05	
	p	**ρ**
Airborne arsenic levels/ Arsenic feedstock levels (%)	0.9322	-0.3527
Airborne arsenic levels/ Arsenic feedstock levels (lbs)	0.9523	-0.4998

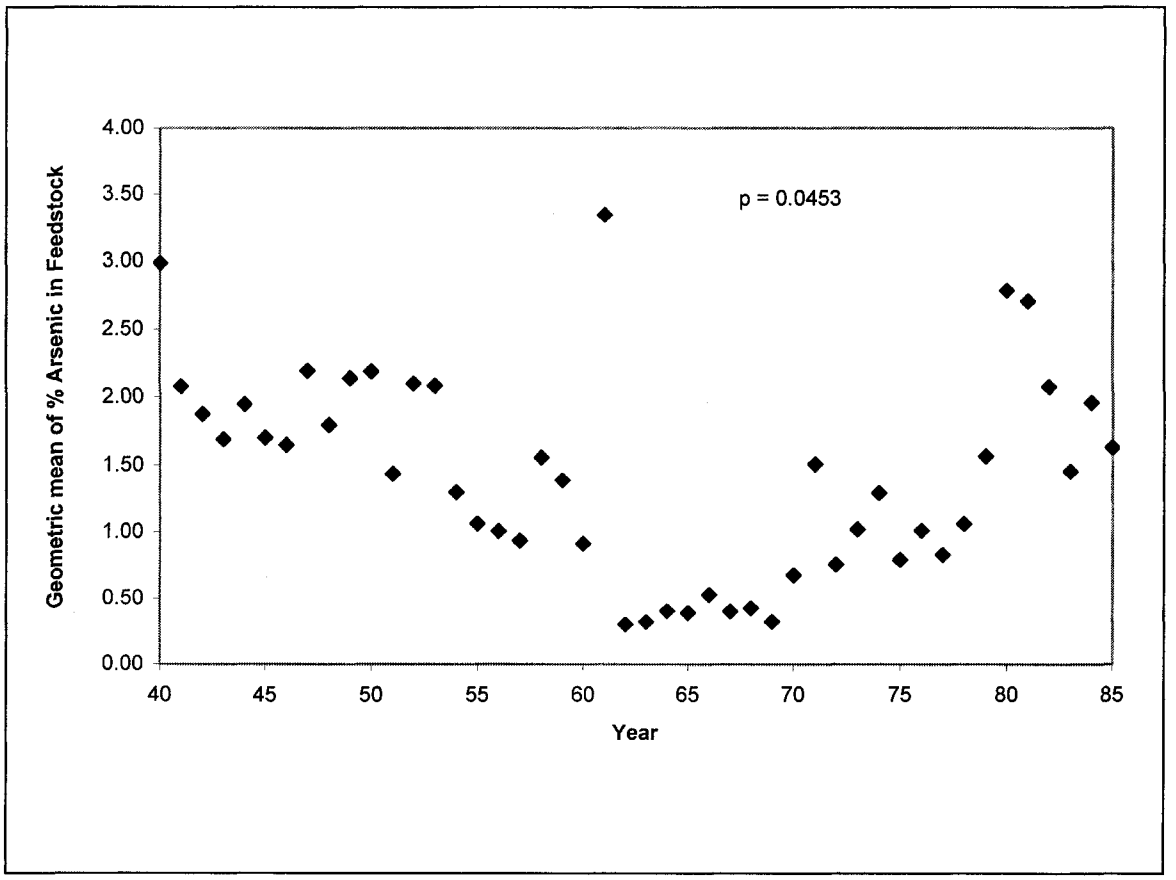

FIGURE 4.1 ARSENIC FEEDSTOCK LEVELS (%) BY YEAR

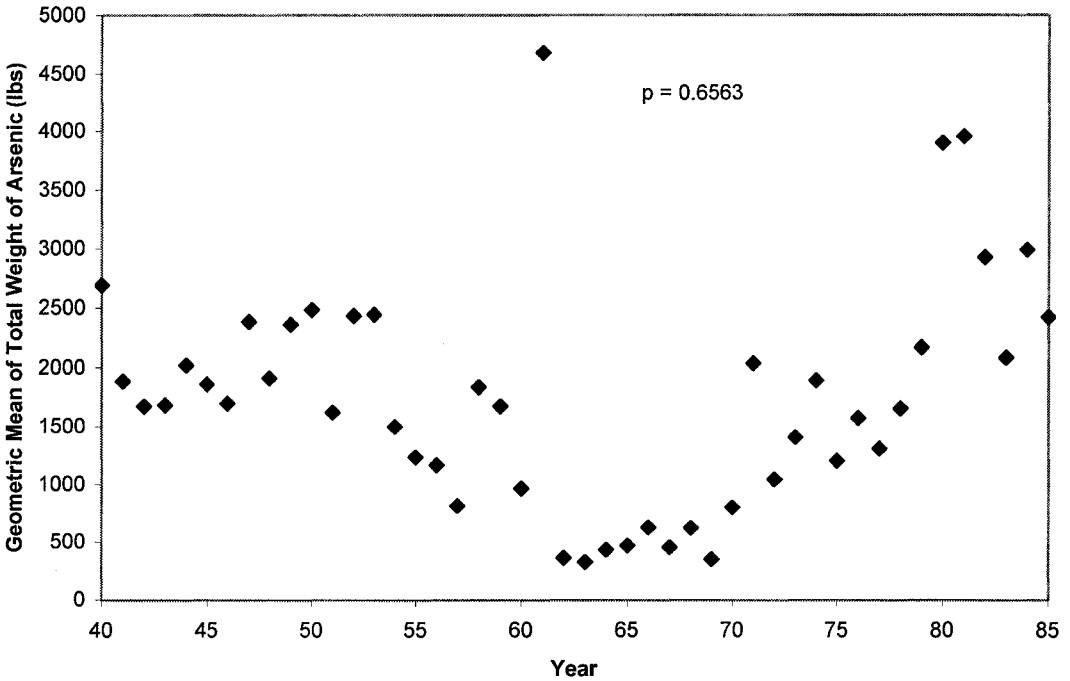

FIGURE 4.2 ARSENIC FEEDSTOCK LEVELS (LBS) BY YEAR

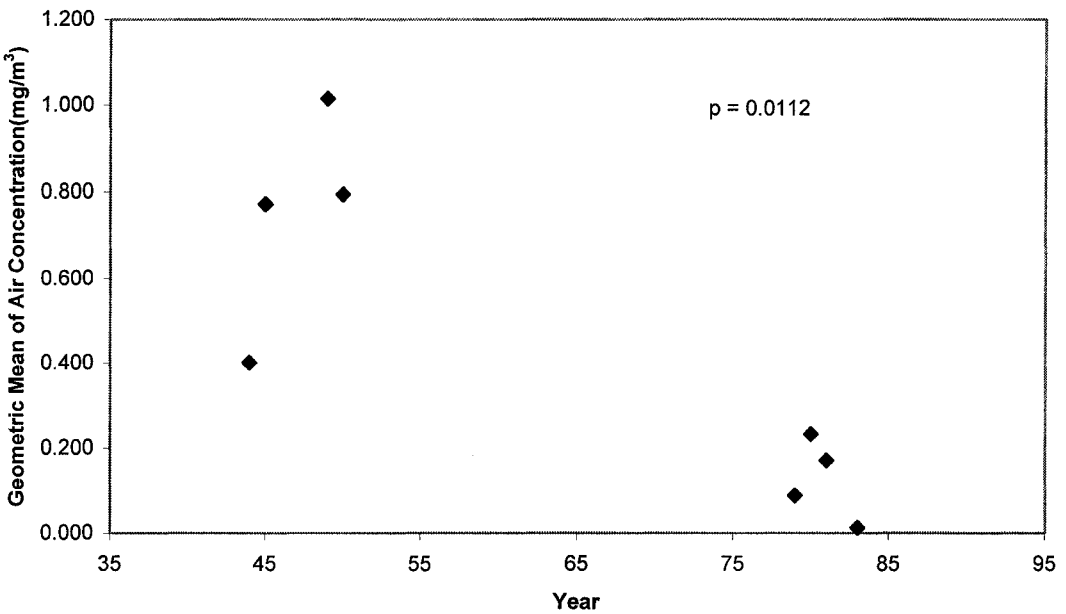

FIGURE 4.3 AIRBORNE ARSENIC CONCENTRATIONS BY YEAR

4.4 Results of Relating Biological Monitoring Data and Air Exposure Data

The results of converting biological monitoring values to inhaled arsenic values are presented in Table 4.5. This table shows the year the biomonitoring sample was taken, department of the employee giving the sample, its reported specific gravity-corrected value, and the final result of the air arsenic calculation using the model (Equation 3.1). These results are included in the exposure matrix (Table 4.8).

TABLE 4.5 RESULTS OF CONVERTING BIOLOGICAL MONITORING DATA TO EXPOSURE DATA

Year	Dept. ID	Department	Urine Arsenic (µg/L)	Estimated Personal Exposure Level (mg/m^3)
70	1a	Foreman	30	0.009
73	1a	Foreman	34	0.010
74	1a	Foreman	39	0.012
74	1a	Foreman	83	0.025
74	1a	Foreman	39	0.012
74	1a	Foreman	51	0.016
74	1a	Foreman	49	0.015
74	1a	Foreman	32	0.010
75	1a	Foreman	39	0.012
75	1a	Foreman	39	0.012
64	1b	Calcine	50	0.015
64	1b	Calcine	100	0.030
74	1b	Calcine	29	0.009
74	1b	Calcine	24	0.007
74	1b	Calcine	49	0.015
74	1b	Calcine	39	0.012
74	1b	Calcine	39	0.012
74	1b	Calcine	54	0.016
74	1b	Calcine	40	0.012
74	1b	Calcine	112	0.034
75	1b	Calcine	104	0.032
75	1b	Calcine	119	0.036
74	1c	Mixers	50	0.015
74	1c	Mixers	62	0.019
75	1c	Mixers	39	0.012
75	1c	Mixers	21	0.006
74	1e	Solution Operator	30	0.009
75	1e	Solution Operator	39	0.012
74	5	Sampling	60	0.018
75	7	Roasting	47	0.014
75	7	Roasting	20	0.006
75	7	Roasting	31	0.009
75	12	Welders & Burners	75	0.023
74	14	Auto Truck	30	0.009
75	14	Auto Truck	53	0.016
75	14	Auto Truck	35	0.011
71	15	Janitor, Laundry, Guard	250	0.076
74	15	Janitor	39	0.012
74	15	Janitor	39	0.012
74	15	Janitor	39	0.012
74	15	Janitor	39	0.012
75	15	Janitor	39	0.012
75	15	Janitor	30	0.009
75	15	Janitor	39	0.012
75	15	Janitor	39	0.012
75	15	Janitor	32	0.010
74	17	Non-Production	39	0.012
74	17	Non-Production	39	0.012
75	17	Non-Production	85	0.026
75	17	Non-Production	43	0.013

4.5 Results of Developing Exposure Adjustment Factors

Table 4.6 shows the results of adjusting the data from the cadmium job exposure matrix, the first step in developing the exposure adjustment factors. A column for department ID was added to the table for consistency and clarification and to relate this data to the present study. The department ID codes were taken from the job dictionary used throughout this study. However, two department categories are labeled differently by the previous researcher than in this study. These include the Non-production and Non-plant departments. The label of Non-production was meant for areas not directly involved in production, i.e. maintenance, repair shops, laundry, janitor, supervisory in plant, litharge, indium, thallium, zinc, selenium. In this study, these would include the Foreman (1a), Machine shop (10a), Maintenance (10b), Electrical shop (11), Welders and burners (12), Carpenters (13), and Janitor-laundry-guard (15). Litharge, indium, thallium, zinc, and selenium are not included in the present study. The label of Non-plant was meant for departments with reduced exposure conditions, i.e. plant guard, tailings dump, and general labor outside plant buildings. These would include Janitor-laundry-guard (15) and General labor-unloading (4b) in this study. In the table, the Reported Value is that reported by the previous cadmium research (6, 47, 58). The Adjusted Values were those multiplied by 3.9 to reflect worker exposure without the use of a respirator, since Smith (6) had applied 3.9 to all values reported.

TABLE 4.6 AIR EXPOSURE DATA FOR CADMIUM, BY CALENDAR PERIOD

Dept. ID	Dept. Name	Pre-1950*		1950-54*		1955-59*		1960-64*		1965-79*		1980-85*	
		Reported Value	Adjusted Value	Reported Value	Adjusted Value	Reported Value	Adjusted Value	Reported Value	Adjusted Value	Reported Value	Adjusted Value	Reported Value	Adjusted Value
5	Sampling	1	3.9	0.6	2.34	0.6	2.34	0.6	2.34	0.6	2.34	0.03	0.117
7	Roaster	1	3.9	0.6	2.34	0.6	2.34	0.6	2.34	0.6	2.34		
1c	Mixing	1.5	5.85	0.4	1.56	0.4	1.56	0.4	1.56	0.4	1.56	0.07	0.273
1b	Calcine	1.5	5.85	1.5	5.85	1.5	5.85	0.4	1.56	0.15	0.585	0.4	1.56
1e,1f	Solution	0.8	3.12	0.8	3.12	0.4	1.56	0.4	1.56	0.04	0.156	0.04	0.156
1l	Tankhouse	0.04	0.156	0.04	0.156	0.04	0.156	0.02	0.078	0.02	0.078	0.04	0.156
1n	Foundry	0.8	3.12	0.1	0.39	0.1	0.39	0.1	0.39	0.04	0.156	0.04	0.156
1m	Retort	1.5	5.85	0.2	0.78	0.2	0.78	0.2	0.78	0.2	0.78	0.2	0.78
1h	Pigment	0.2	0.78	0.2	0.78	0.04	0.156	0.04	0.156	0.04	0.156	0.08	0.312
1a,10a, 10b,11, 12,13, 15	Non-Production	0.09	0.351	0.05	0.195	0.04	0.156	0.024	0.0936	0.02	0.078	0.007	0.0273
17	Office & Lab	0.005	0.0195	0.004	0.0156	0.004	0.0156	0.003	0.0117	0.003	0.0117	0.003	0.0117
4b,15	Non-Plant	0.09	0.351	0.05	0.195	0.04	0.156	0.04	0.156	0.02	0.078	0.02	0.078
4c	General Labor	1.166	4.5474	0.485	1.8915	0.485	1.8915	0.331	1.2909	0.279	1.0881	0.041	0.1599

*All values are in mg/m^3

The results of developing the exposure adjustment factors are presented in Table 4.7. The values in row 1, labeled Air, are the geometric mean of the Adjusted Value results taken from Table 4.6. The values in row 2 of Predicted Cd urine are the values generated from inputting the Air data (from row 1) into the model (Equation 3.2). The values for row 3- Actual Cd urine are the geometric means of the urine data from the biological monitoring file (60). The ratios in row 4 were developed by dividing the Predicted Cd urine by the Actual Cd urine. The value used as the adjustment factor of the arsenic air data was the nearest whole number of this value (row 5). The date ranges for each time period were adapted from the cadmium air data in Table 4.6. Example calculations are shown below.

1. Obtain air cadmium level from Table 4.6 and convert to micrograms.

   1326.6 µg/L

2. Determine predicted urinary cadmium level.

   Average Urinary Cadmium (µg/L) =

   5.00 (TWA Inhalation Exposure (µg/m^3))^0.502 =

   5.00(1326.6)^0.502 =

   184.7

3. Obtain actual cadmium urine level from biomonitoring data.

   79.2 µg/L

4. Calculate ratio.

   Predicted urine/ actual urine = Adjustment Factor

   184.7/ 79.2 = 2.33

TABLE 4.7 RESULTS OF DEVELOPING ADJUSTMENT FACTORS

	pre-1950	1950-54	1955-59	1960-64	1965-79
Air (mg/m^3)	1.326	0.678	0.549	0.429	0.286
Predicted Cd urine	184.7	132.0	118.7	104.9	85.7
Actual Cd urine	79.2	74.2	51.8	46.2	21.0
Ratio	2.33	1.78	2.29	2.27	4.08
Adjustment Factor	2	2	2	2	4

4.6 Results of Estimating Exposure Values

The final arsenic exposure estimates from all the methods were compiled and are presented in Table 4.8. The estimates are sorted by year and department. All values are in mg/m^3.

TABLE 4.8 ARSENIC EXPOSURE ESTIMATES FROM MEASUREMETS (AIR, URINE)

	Year													
Dept.	1944	1945	1949	1950	1964	1970	1971	1973	1974	1975	1979	1980	1981	1983
1a						0.0090		0.0100	0.0120	0.0120				0.0003
1a									0.0250	0.0120				0.0010
1a									0.0120					0.0003
1a									0.0160					0.0003
1a									0.0150					0.0010
1a									0.0100					0.0003
1a														0.0003
1a														0.0010
1b	0.0168	0.0107		0.0985	0.0150				0.0088	0.0316	0.0188	0.0035	0.0053	0.0285
1b	0.0092	0.0047			0.0300				0.0073	0.0362	0.0282	0.1164	0.0667	0.0467
1b	0.0077								0.0149		0.0391	0.1010	0.0371	
1b									0.0119		0.0141	0.1003	0.0609	
1b									0.0119		0.0407	0.0389	0.1091	
1b									0.0164		0.0051	0.0098	0.0697	
1b									0.0122		0.0028	0.0811		
1b									0.0340		0.1616	0.0775		
1b											0.0144	0.0806		
1b											0.0038	0.0528		
1b											0.0056			
1b											0.0078			
1b											0.0104			
1b											0.0338			
1b											0.0371			

1b											0.0033			
1b											0.0308			
1b											0.0255			
1c	0.4316			0.0485					0.0152	0.0119	0.0352	0.1033		0.0520
1c									0.0188	0.0064	0.1119	0.1513		
1c											0.0460	0.1225		
1c											0.0727			
1c											0.0263			
1c											0.1177			
1c											0.0583			
1c											0.0217			
1e									0.0091	0.0119			0.0008	0.0303
1e														0.0043
1f		0.0100												0.0053
1h														
1i														
1l														0.0003
1l														0.0003
1l														0.0002
1l														0.0003
1l														0.0002
1l														0.0003
1m								0.0004				0.0002		0.0003
1m												0.0003		0.0005
1m												0.0015		0.0003
1n								0.0002					0.0010	0.0005
1n								0.0008						0.0003
1n														0.0003
1o														0.0005
3	0.4378	0.0605												0.0005
3		0.1794												
3		0.1229												
3		0.1480												
3		0.0715												
3		0.1070												
3														
4a														

4b	0.0459	26.7090	0.5379	0.5530										
4b	0.5128	0.0150	0.2689	0.4773										
4b	0.4592	0.3293												
4b	0.0995	0.0665												
4b	2.3112	0.1835												
4b	0.8189	1.1735												
4b	0.0383	0.1325												
4b		0.1175												
4b		1.9900												
4b		2.1020												
4b		2.2450												
4b		0.3470												
4b		0.0415												
4c														0.0005
5									0.0182					0.0013
6	0.0386	3.3222												
6	0.0857	0.9219												
6		0.0000												
6		0.0210												
6		1.0941												
7	0.0857	2.2071								0.0143				
7	1.0286	0.5815								0.0061				
7										0.0094				
10a														0.0003
10b														0.0008
10b														0.0005
11														0.0008
12										0.0228				0.0008
13														0.0005
14	0.6367	4.3365							0.0091	0.0161				0.0040
14	0.1551	0.0210								0.0106				
14		2.6720												
14		0.5315												
15							0.0760		0.0119	0.0119				0.0005
15									0.0119	0.0091				0.0005
15									0.0119	0.0119				
15									0.0119	0.0119				

15										0.0097				
17									0.0119	0.0258	0.0354			0.0003
17									0.0119	0.0131	0.0333			0.1172
17											0.0361			0.0003
17														0.0003

The results of readjusting the cadmium exposure estimates by the new adjustment factors are shown in Table 4.9. The values are sorted by department and time period. The date range of the time period was adapted from the original table of data reported by Smith (6). All values are in mg/m^3.

TABLE 4.9 RESULTS OF CADMIUM ESTIMATES

Dept. ID	Department	Pre-1950*	1950-54*	1955-59*	1960-64*	1965-79*	1980-85*
5	Sampling	1.95	1.17	1.17	1.17	0.6	0.03
7	Roaster	1.95	1.17	1.17	1.17	0.6	--
1c	Mixing	2.925	0.78	0.78	0.78	0.4	0.07
1b	Calcine	2.925	2.925	2.925	0.78	0.15	0.4
1e,1f	Solution	1.56	1.56	0.78	0.78	0.04	0.04
1l	Tankhouse	0.078	0.078	0.078	0.039	0.02	0.04
1n	Foundry	1.56	0.195	0.195	0.195	0.04	0.04
1m	Retort	2.925	0.39	0.39	0.39	0.2	0.2
1h	Pigment	0.39	0.39	0.078	0.078	0.04	0.08
1a,10a,10b, 11,12,13,15	Non-Production	0.1755	0.0975	0.078	0.0468	0.02	0.007
17	Office & Lab	0.00975	0.0078	0.0078	0.00585	0.003	0.003
4b,15	Non-Plant	0.1755	0.0975	0.078	0.078	0.02	0.02
4c	General Labor	2.2737	0.94575	0.94575	0.64545	0.279	0.041

* Concentrations are in mg/m^3

CHAPTER 5 IMPUTED EXPOSURE ESTIMATES

It was necessary to generate exposure values for years when measurements did not exist. The exposure data from each department were used to create models to estimate the exposure for these years. Because of the sporadic nature of the data, it was necessary to make assumptions to determine the shape of the model. Based on qualitative information in the literature (49-52), it was assumed that the level of arsenic may not have been a continuous decreasing linear trend across all years. Rather, it was assumed that exposures from 1940 to 1953 would have been relatively constant and that exposures following 1953 would have followed a decreasing trend. It was concluded that 1953 was approximately the beginning of the decreasing trend due to a combination of engineering controls and process changes that would have affected the exposures. Further discussion of this decision is presented later.

Because of these reasons, the estimates of missing years were generated from models with a constant from 1940 to 1953 followed by a decreasing trend thereafter. The constant line was drawn back to 1940 from where the regression line intersected 1953. The portion of the model showing a decreasing trend was created by performing the regression procedure on log-transformed data using SAS (73). Because the data were log-normal, the natural logs of the data were used for analysis. This step was also beneficial because the model would represent an exponential decay for exposure estimates that never reach zero.

The SAS output also included p-values, predicted exposure estimates and 95% confidence intervals of these predictions.

Because many departments had few samples, departments that were most similar were combined for analysis. The departments that were combined were deemed similar based on similar exposure experiences due to the location, process and/or similar tasks. The departments combined were 1b/1c/3, 1e/1f/1h/1i/1l/1m/1n/1o, 5/6/7, 10a/10b/11/12/13, and 15/17 (departments 2, 8, 9, 16 were excluded). This process was determined to be reasonable because the departments would have had different exposure experiences and trends due to process changes and engineering controls.

Figures 5.1 to 5.26 show the models created for each department to generate the exposure estimates. Tables 5.1-5.26 show the results of generating the exposure estimates for each department. These tables present the exposure levels estimated from the methods, their range, the exposure estimates, and 95% confidence interval of the estimates. The 95% confidence interval was included to account for the statistical variability of the calculations in the methods and procedures. A single value would not incorporate the variations in the exposure to a reasonable extent. For this reason, upper (UCL) and lower (LCL) values of exposure are included with the estimates in the tables.

In all tables, results where SAS returned an unreasonable estimate were excluded. These levels were marked as undetermined since it was not possible to accurately quantify an exposure estimate. All values reported are in mg/m^3.

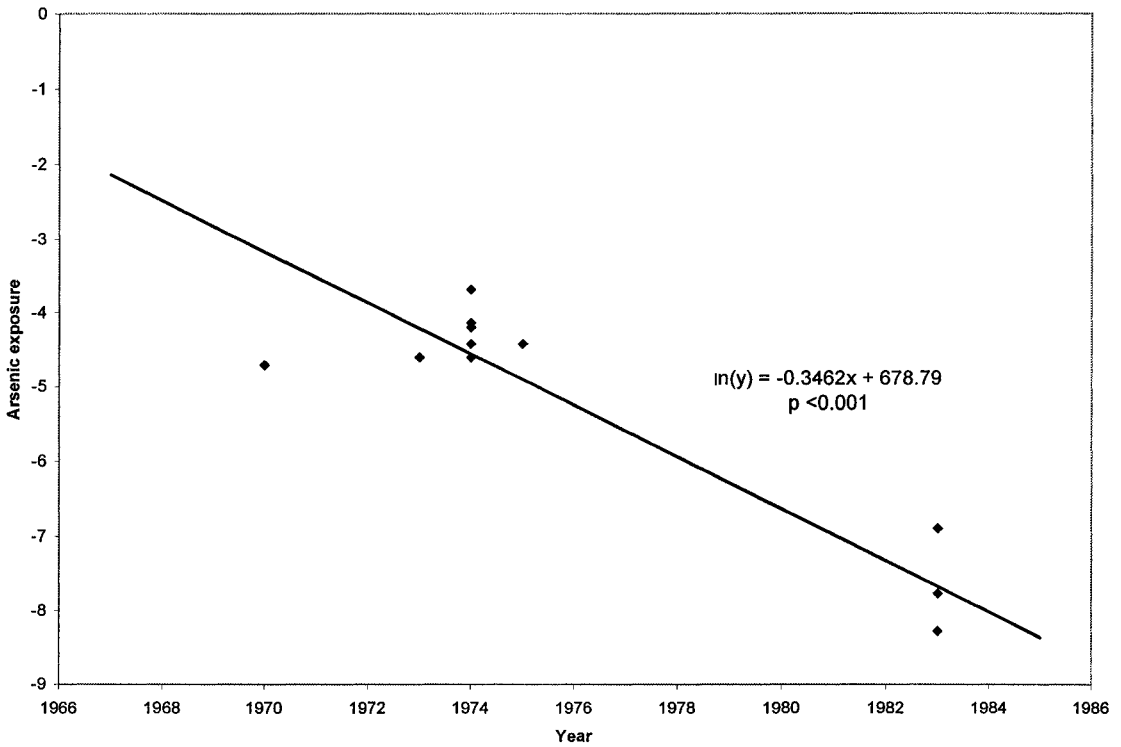

FIGURE 5.1 EXPOSURE MODEL, DEPARTMENT 1A- FOREMAN

TABLE 5.1 EXPOSURE ESTIMATES FOR DEPT. 1A-FOREMAN

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			ND	ND	ND
1941	.			ND	ND	ND
1942	.			ND	ND	ND
1943	.			ND	ND	ND
1944	.			ND	ND	ND
1945	.			ND	ND	ND
1946	.			ND	ND	ND
1947	.			ND	ND	ND
1948	.			ND	ND	ND
1949	.			ND	ND	ND
1950	.			ND	ND	ND
1951	.			ND	ND	ND
1952	.			ND	ND	ND
1953	.			ND	ND	ND
1954	.			ND	ND	ND
1955	.			ND	ND	ND
1956	.			ND	ND	ND
1957	.			ND	ND	ND
1958	.			ND	ND	ND
1959	.			ND	ND	ND
1960	.			ND	ND	ND
1961	.			ND	ND	ND
1962	.			ND	ND	ND
1963	.			ND	ND	ND
1964	.			ND	ND	ND
1965	.			ND	ND	ND
1966	.			ND	ND	ND
1967	.			0.1185	0.0545	0.2579
1968	.			0.0838	0.0409	0.1719
1969	.			0.0593	0.0307	0.1147
1970	0.0090			0.0420	0.0230	0.0766
1971	.			0.0297	0.0172	0.0513
1972	.			0.0210	0.0128	0.0344
1973	0.0100			0.0149	0.0095	0.0232
1974	0.0136	0.0100	0.0250	0.0105	0.0070	0.0157
1975	0.0120			0.0074	0.0052	0.0107
1976	.			0.0053	0.0038	0.0073
1977	.			0.0037	0.0027	0.0051
1978	.			0.0026	0.0019	0.0036
1979	.			0.0019	0.0014	0.0026
1980	.			0.0013	0.0009	0.0018
1981	.			0.0009	0.0006	0.0013
1982	.			0.0007	0.0004	0.0010
1983	0.0004	0.0003	0.0010	0.0005	0.0003	0.0007
1984	.			0.0003	0.0002	0.0005
1985	.			0.0002	0.0001	0.0004

ND = result undetermined

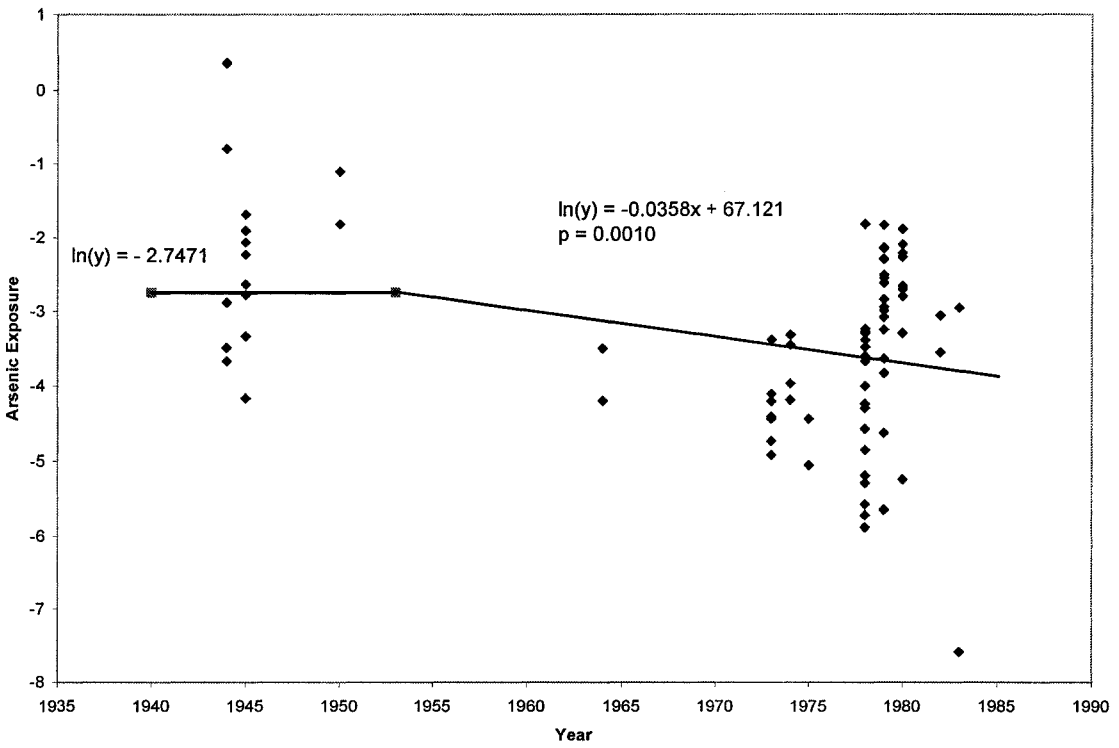

FIGURE 5.2 EXPOSURE MODEL, DEPARTMENT 1B- CALCINE DEPARTMENT

TABLE 5.2 EXPOSURE ESTIMATES FOR DEPT. 1B- CALCINE DEPT.

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			0.064	0.040	0.102
1941	.			0.064	0.040	0.102
1942	.			0.064	0.040	0.102
1943	.			0.064	0.040	0.102
1944	0.1230	0.0255	1.4390	0.064	0.040	0.102
1945	0.0740	0.0155	0.1840	0.064	0.040	0.102
1946	.			0.064	0.040	0.102
1947	.			0.064	0.040	0.102
1948	.			0.064	0.040	0.102
1949	.			0.064	0.040	0.102
1950	0.2303	0.1615	0.3285	0.064	0.040	0.102
1951	.			0.064	0.040	0.102
1952	.			0.064	0.040	0.102
1953	.			0.064	0.040	0.102
1954	.			0.062	0.039	0.097
1955	.			0.060	0.039	0.092
1956	.			0.058	0.038	0.088
1957	.			0.056	0.037	0.083
1958	.			0.054	0.036	0.079
1959	.			0.052	0.036	0.075
1960	.			0.050	0.035	0.072
1961	.			0.048	0.034	0.068
1962	.			0.046	0.033	0.065
1963	.			0.045	0.033	0.062
1964	0.0212	0.0150	0.0300	0.043	0.032	0.059
1965	.			0.042	0.031	0.056
1966	.			0.040	0.030	0.054
1967	.			0.039	0.029	0.052
1968	.			0.037	0.028	0.050
1969	.			0.036	0.027	0.048
1970	.			0.035	0.027	0.046
1971	.			0.034	0.026	0.044
1972	.			0.032	0.025	0.043
1973	0.0132	0.0073	0.0164	0.031	0.024	0.041
1974	0.0239	0.0152	0.0362	0.030	0.023	0.040
1975	0.0087	0.0064	0.0119	0.029	0.022	0.039
1976	.			0.028	0.021	0.037
1977	.			0.027	0.020	0.036
1978	0.0152	0.0028	0.1616	0.026	0.019	0.035
1979	0.0505	0.0035	0.1598	0.025	0.019	0.035
1980	0.0610	0.0053	0.1513	0.024	0.018	0.034
1981	.			0.024	0.017	0.033
1982	0.0365	0.0285	0.0467	0.023	0.016	0.032
1983	0.0051	0.0005	0.0520	0.022	0.015	0.031
1984	.			0.021	0.015	0.031
1985	.			0.020	0.014	0.030

ND = result undetermined

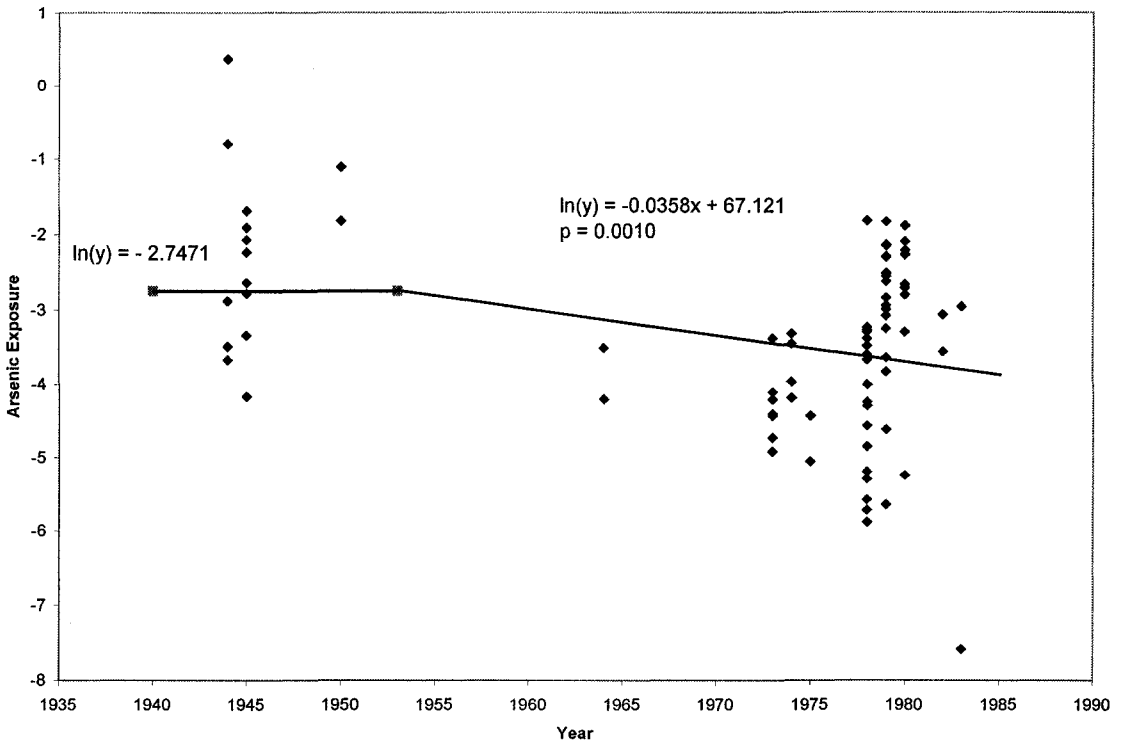

FIGURE 5.3 EXPOSURE MODEL, DEPARTMENT 1C- MIXERS & SCREENERS

TABLE 5.3 EXPOSURE ESTIMATES FOR DEPT. 1C- MIXERS & SCREENERS

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			0.064	0.040	0.102
1941	.			0.064	0.040	0.102
1942	.			0.064	0.040	0.102
1943	.			0.064	0.040	0.102
1944	0.1230	0.0255	1.4390	0.064	0.040	0.102
1945	0.0740	0.0155	0.1840	0.064	0.040	0.102
1946	.			0.064	0.040	0.102
1947	.			0.064	0.040	0.102
1948	.			0.064	0.040	0.102
1949	.			0.064	0.040	0.102
1950	0.2303	0.1615	0.3285	0.064	0.040	0.102
1951	.			0.064	0.040	0.102
1952	.			0.064	0.040	0.102
1953	.			0.064	0.040	0.102
1954	.			0.062	0.039	0.097
1955	.			0.060	0.039	0.092
1956	.			0.058	0.038	0.088
1957	.			0.056	0.037	0.083
1958	.			0.054	0.036	0.079
1959	.			0.052	0.036	0.075
1960	.			0.050	0.035	0.072
1961	.			0.048	0.034	0.068
1962	.			0.046	0.033	0.065
1963	.			0.045	0.033	0.062
1964	0.0212	0.0150	0.0300	0.043	0.032	0.059
1965	.			0.042	0.031	0.056
1966	.			0.040	0.030	0.054
1967	.			0.039	0.029	0.052
1968	.			0.037	0.028	0.050
1969	.			0.036	0.027	0.048
1970	.			0.035	0.027	0.046
1971	.			0.034	0.026	0.044
1972	.			0.032	0.025	0.043
1973	0.0132	0.0073	0.0164	0.031	0.024	0.041
1974	0.0239	0.0152	0.0362	0.030	0.023	0.040
1975	0.0087	0.0064	0.0119	0.029	0.022	0.039
1976	.			0.028	0.021	0.037
1977	.			0.027	0.020	0.036
1978	0.0152	0.0028	0.1616	0.026	0.019	0.035
1979	0.0505	0.0035	0.1598	0.025	0.019	0.035
1980	0.0610	0.0053	0.1513	0.024	0.018	0.034
1981	.			0.024	0.017	0.033
1982	0.0365	0.0285	0.0467	0.023	0.016	0.032
1983	0.0051	0.0005	0.0520	0.022	0.015	0.031
1984	.			0.021	0.015	0.031
1985	.			0.020	0.014	0.030

ND = result undetermined

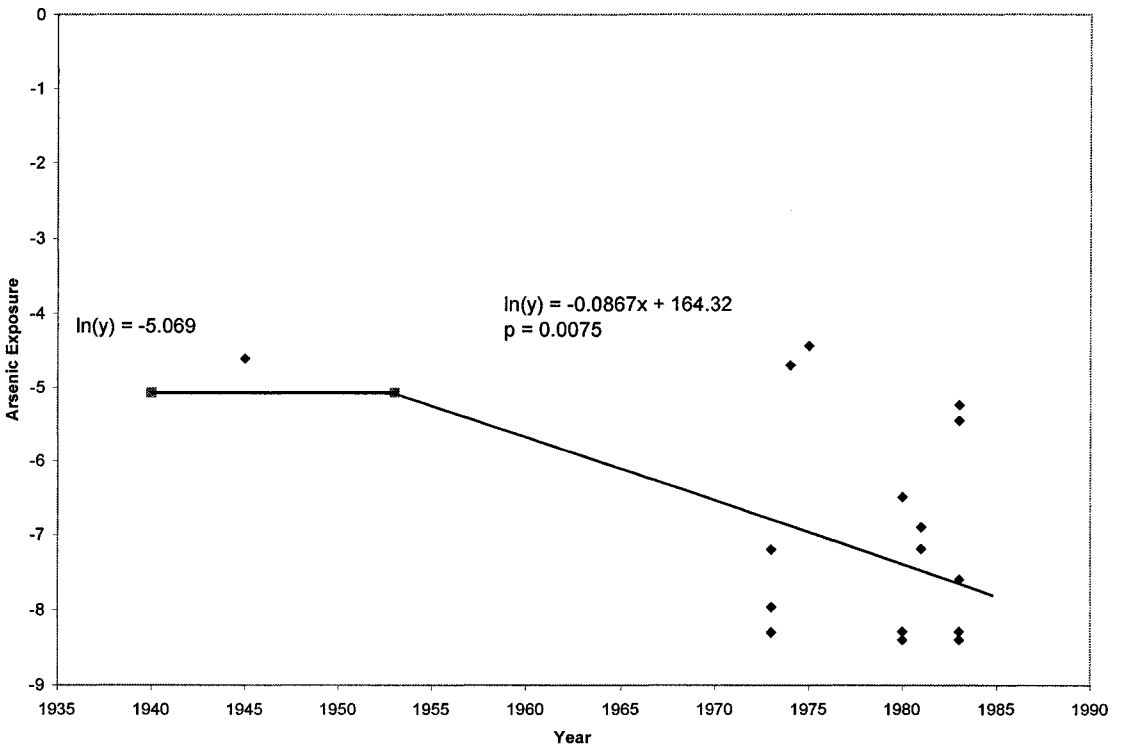

FIGURE 5.4 EXPOSURE MODEL, DEPARTMENT 1E- SOLUTION OPERATORS & PRESSMAN

TABLE 5.4 EXPOSURE ESTIMATES FOR DEPT. 1E- SOLUTION OPERATORS & PRESSMAN

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			0.0063	0.0012	0.0337
1941	.			0.0063	0.0012	0.0337
1942	.			0.0063	0.0012	0.0337
1943	.			0.0063	0.0012	0.0337
1944	.			0.0063	0.0012	0.0337
1945	0.0100			0.0063	0.0012	0.0337
1946	.			0.0063	0.0012	0.0337
1947	.			0.0063	0.0012	0.0337
1948	.			0.0063	0.0012	0.0337
1949	.			0.0063	0.0012	0.0337
1950	.			0.0063	0.0012	0.0337
1951	.			0.0063	0.0012	0.0337
1952	.			0.0063	0.0012	0.0337
1953	.			0.0063	0.0012	0.0337
1954	.			0.0058	0.0011	0.0291
1955	.			0.0053	0.0011	0.0252
1956	.			0.0048	0.0011	0.0218
1957	.			0.0044	0.0010	0.0188
1958	.			0.0041	0.0010	0.0163
1959	.			0.0037	0.0010	0.0141
1960	.			0.0034	0.0010	0.0122
1961	.			0.0031	0.0009	0.0106
1962	.			0.0029	0.0009	0.0092
1963	.			0.0026	0.0009	0.0080
1964	.			0.0024	0.0008	0.0069
1965	.			0.0022	0.0008	0.0060
1966	.			0.0020	0.0008	0.0052
1967	.			0.0019	0.0008	0.0045
1968	.			0.0017	0.0007	0.0040
1969	.			0.0016	0.0007	0.0034
1970	.			0.0014	0.0007	0.0030
1971	.			0.0013	0.0007	0.0026
1972	.			0.0012	0.0006	0.0023
1973	0.0004	0.0003	0.0008	0.0011	0.0006	0.0020
1974	0.0091			0.0010	0.0006	0.0018
1975	0.0119			0.0009	0.0005	0.0016
1976	.			0.0009	0.0005	0.0014
1977	.			0.0008	0.0005	0.0013
1978	.			0.0007	0.0004	0.0012
1979	.			0.0007	0.0004	0.0011
1980	0.0004	0.0015	0.0003	0.0006	0.0004	0.0010
1981	0.0009	0.0008	0.0010	0.0006	0.0003	0.0009
1982	.			0.0005	0.0003	0.0008
1983	0.0004	0.0002	0.0053	0.0005	0.0003	0.0008
1984	.			0.0004	0.0002	0.0007
1985	.			0.0004	0.0002	0.0007

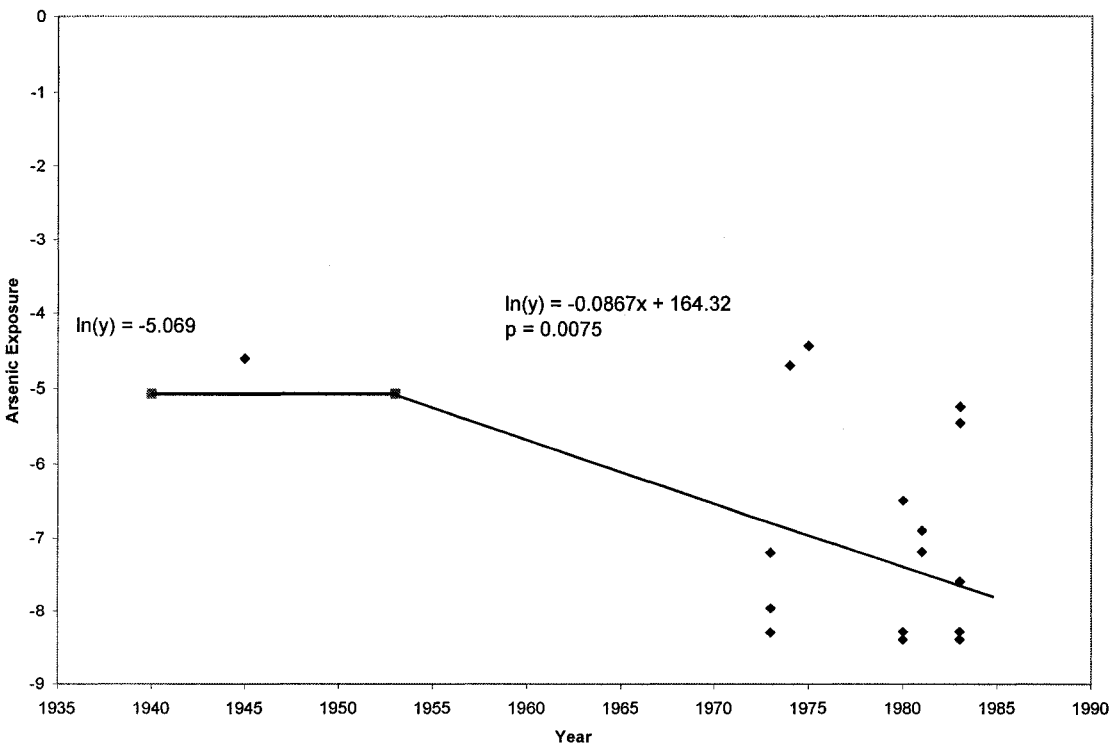

FIGURE 5.5 EXPOSURE MODEL, DEPARTMENT 1F- SOLUTION CHARGER

TABLE 5.5 EXPOSURE ESTIMATES FOR DEPT. 1F- SOLUTION CHARGER

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			0.0063	0.0012	0.0337
1941	.			0.0063	0.0012	0.0337
1942	.			0.0063	0.0012	0.0337
1943	.			0.0063	0.0012	0.0337
1944	.			0.0063	0.0012	0.0337
1945	0.0100			0.0063	0.0012	0.0337
1946	.			0.0063	0.0012	0.0337
1947	.			0.0063	0.0012	0.0337
1948	.			0.0063	0.0012	0.0337
1949	.			0.0063	0.0012	0.0337
1950	.			0.0063	0.0012	0.0337
1951	.			0.0063	0.0012	0.0337
1952	.			0.0063	0.0012	0.0337
1953	.			0.0063	0.0012	0.0337
1954	.			0.0058	0.0011	0.0291
1955	.			0.0053	0.0011	0.0252
1956	.			0.0048	0.0011	0.0218
1957	.			0.0044	0.0010	0.0188
1958	.			0.0041	0.0010	0.0163
1959	.			0.0037	0.0010	0.0141
1960	.			0.0034	0.0010	0.0122
1961	.			0.0031	0.0009	0.0106
1962	.			0.0029	0.0009	0.0092
1963	.			0.0026	0.0009	0.0080
1964	.			0.0024	0.0008	0.0069
1965	.			0.0022	0.0008	0.0060
1966	.			0.0020	0.0008	0.0052
1967	.			0.0019	0.0008	0.0045
1968	.			0.0017	0.0007	0.0040
1969	.			0.0016	0.0007	0.0034
1970	.			0.0014	0.0007	0.0030
1971	.			0.0013	0.0007	0.0026
1972	.			0.0012	0.0006	0.0023
1973	0.0004	0.0003	0.0008	0.0011	0.0006	0.0020
1974	0.0091			0.0010	0.0006	0.0018
1975	0.0119			0.0009	0.0005	0.0016
1976	.			0.0009	0.0005	0.0014
1977	.			0.0008	0.0005	0.0013
1978	.			0.0007	0.0004	0.0012
1979	.			0.0007	0.0004	0.0011
1980	0.0004	0.0015	0.0003	0.0006	0.0004	0.0010
1981	0.0009	0.0008	0.0010	0.0006	0.0003	0.0009
1982	.			0.0005	0.0003	0.0008
1983	0.0004	0.0002	0.0053	0.0005	0.0003	0.0008
1984	.			0.0004	0.0002	0.0007
1985	.			0.0004	0.0002	0.0007

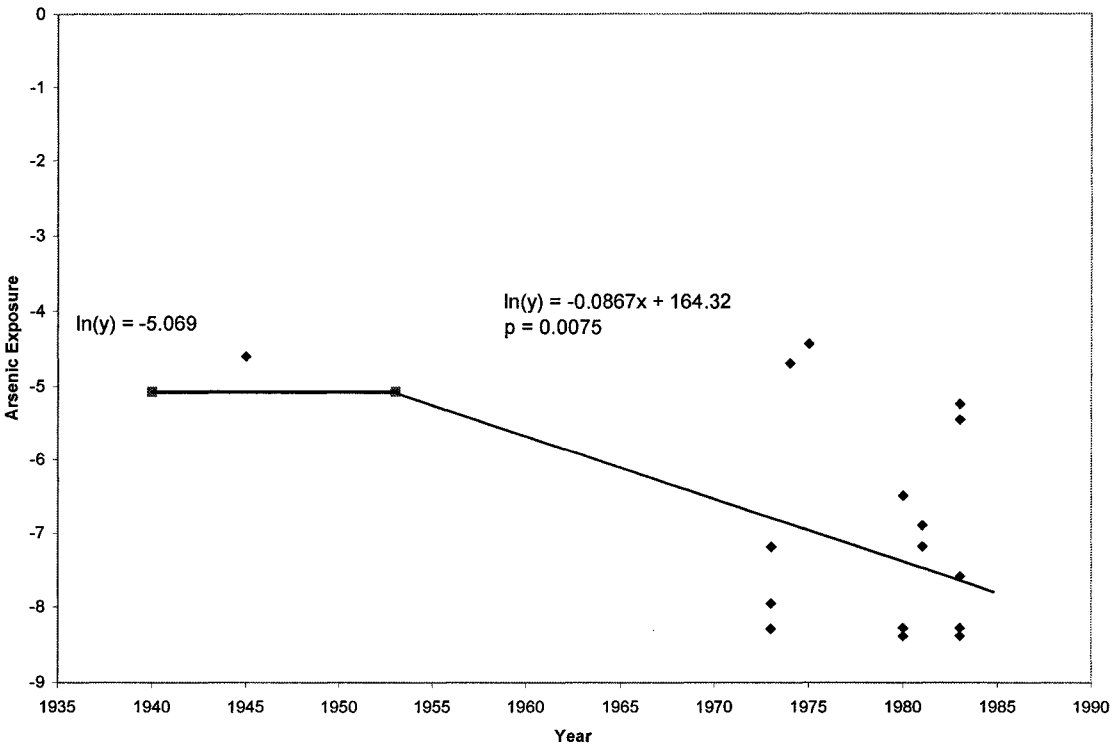

FIGURE 5.6 EXPOSURE MODEL, DEPARTMENT 1H- PIGMENT PLANT

TABLE 5.6 EXPOSURE ESTIMATES FOR DEPT. 1H- PIGMENT PLANT

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			0.0063	0.0012	0.0337
1941	.			0.0063	0.0012	0.0337
1942	.			0.0063	0.0012	0.0337
1943	.			0.0063	0.0012	0.0337
1944	.			0.0063	0.0012	0.0337
1945	0.0100			0.0063	0.0012	0.0337
1946	.			0.0063	0.0012	0.0337
1947	.			0.0063	0.0012	0.0337
1948	.			0.0063	0.0012	0.0337
1949	.			0.0063	0.0012	0.0337
1950	.			0.0063	0.0012	0.0337
1951	.			0.0063	0.0012	0.0337
1952	.			0.0063	0.0012	0.0337
1953	.			0.0063	0.0012	0.0337
1954	.			0.0058	0.0011	0.0291
1955	.			0.0053	0.0011	0.0252
1956	.			0.0048	0.0011	0.0218
1957	.			0.0044	0.0010	0.0188
1958	.			0.0041	0.0010	0.0163
1959	.			0.0037	0.0010	0.0141
1960	.			0.0034	0.0010	0.0122
1961	.			0.0031	0.0009	0.0106
1962	.			0.0029	0.0009	0.0092
1963	.			0.0026	0.0009	0.0080
1964	.			0.0024	0.0008	0.0069
1965	.			0.0022	0.0008	0.0060
1966	.			0.0020	0.0008	0.0052
1967	.			0.0019	0.0008	0.0045
1968	.			0.0017	0.0007	0.0040
1969	.			0.0016	0.0007	0.0034
1970	.			0.0014	0.0007	0.0030
1971	.			0.0013	0.0007	0.0026
1972	.			0.0012	0.0006	0.0023
1973	0.0004	0.0003	0.0008	0.0011	0.0006	0.0020
1974	0.0091			0.0010	0.0006	0.0018
1975	0.0119			0.0009	0.0005	0.0016
1976	.			0.0009	0.0005	0.0014
1977	.			0.0008	0.0005	0.0013
1978	.			0.0007	0.0004	0.0012
1979	.			0.0007	0.0004	0.0011
1980	0.0004	0.0015	0.0003	0.0007	0.0004	0.0011
1981	0.0009	0.0008	0.0010	0.0006	0.0004	0.0010
1982	.			0.0006	0.0003	0.0009
1983	0.0004	0.0002	0.0053	0.0005	0.0003	0.0008
1984	.			0.0005	0.0003	0.0008
1985	.			0.0004	0.0002	0.0007

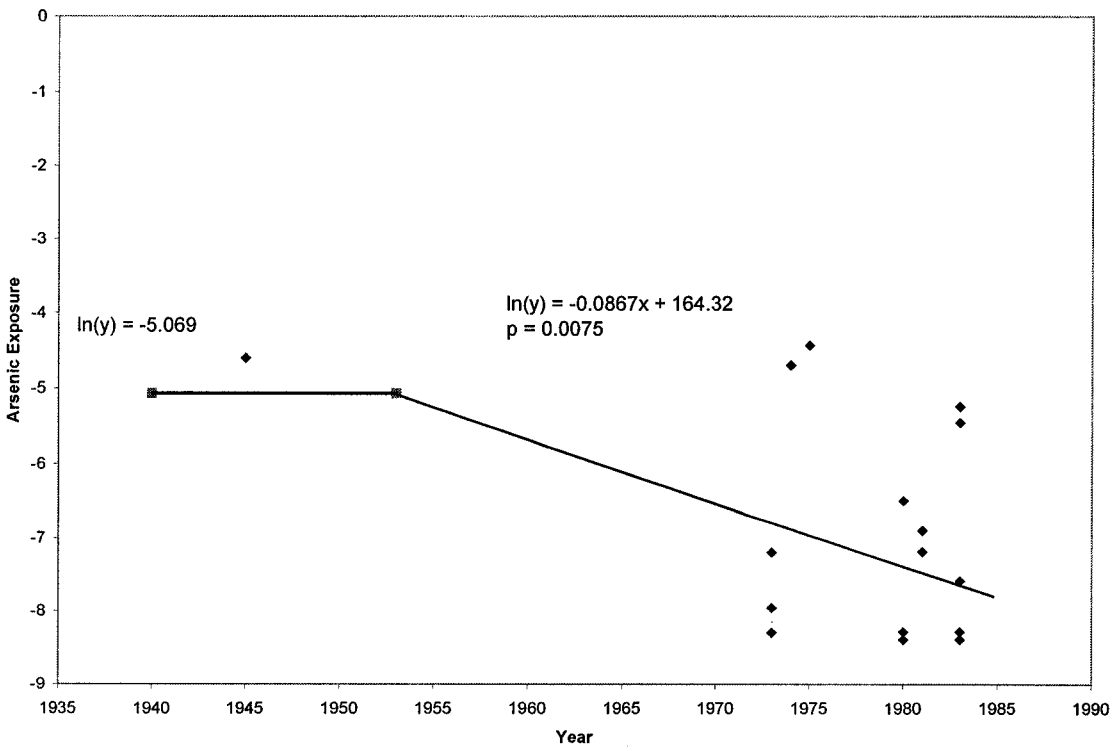

FIGURE 5.7 EXPOSURE MODEL, DEPARTMENT 11- GASMAN-SULFIDE

TABLE 5.7 EXPOSURE ESTIMATES FOR DEPT. 1I- GASMAN-SULFIDE

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			0.0063	0.0012	0.0337
1941	.			0.0063	0.0012	0.0337
1942	.			0.0063	0.0012	0.0337
1943	.			0.0063	0.0012	0.0337
1944	.			0.0063	0.0012	0.0337
1945	0.0100			0.0063	0.0012	0.0337
1946	.			0.0063	0.0012	0.0337
1947	.			0.0063	0.0012	0.0337
1948	.			0.0063	0.0012	0.0337
1949	.			0.0063	0.0012	0.0337
1950	.			0.0063	0.0012	0.0337
1951	.			0.0063	0.0012	0.0337
1952	.			0.0063	0.0012	0.0337
1953	.			0.0063	0.0012	0.0337
1954	.			0.0058	0.0011	0.0291
1955	.			0.0053	0.0011	0.0252
1956	.			0.0048	0.0011	0.0218
1957	.			0.0044	0.0010	0.0188
1958	.			0.0041	0.0010	0.0163
1959	.			0.0037	0.0010	0.0141
1960	.			0.0034	0.0010	0.0122
1961	.			0.0031	0.0009	0.0106
1962	.			0.0029	0.0009	0.0092
1963	.			0.0026	0.0009	0.0080
1964	.			0.0024	0.0008	0.0069
1965	.			0.0022	0.0008	0.0060
1966	.			0.0020	0.0008	0.0052
1967	.			0.0019	0.0008	0.0045
1968	.			0.0017	0.0007	0.0040
1969	.			0.0016	0.0007	0.0034
1970	.			0.0014	0.0007	0.0030
1971	.			0.0013	0.0007	0.0026
1972	.			0.0012	0.0006	0.0023
1973	0.0004	0.0003	0.0008	0.0011	0.0006	0.0020
1974	0.0091			0.0010	0.0006	0.0018
1975	0.0119			0.0009	0.0005	0.0016
1976	.			0.0009	0.0005	0.0014
1977	.			0.0008	0.0005	0.0013
1978	.			0.0007	0.0004	0.0012
1979	.			0.0007	0.0004	0.0011
1980	0.0004	0.0015	0.0003	0.0006	0.0004	0.0010
1981	0.0009	0.0008	0.0010	0.0006	0.0003	0.0009
1982	.			0.0005	0.0003	0.0008
1983	0.0004	0.0002	0.0053	0.0005	0.0003	0.0008
1984	.			0.0004	0.0002	0.0007
1985	.			0.0004	0.0002	0.0007

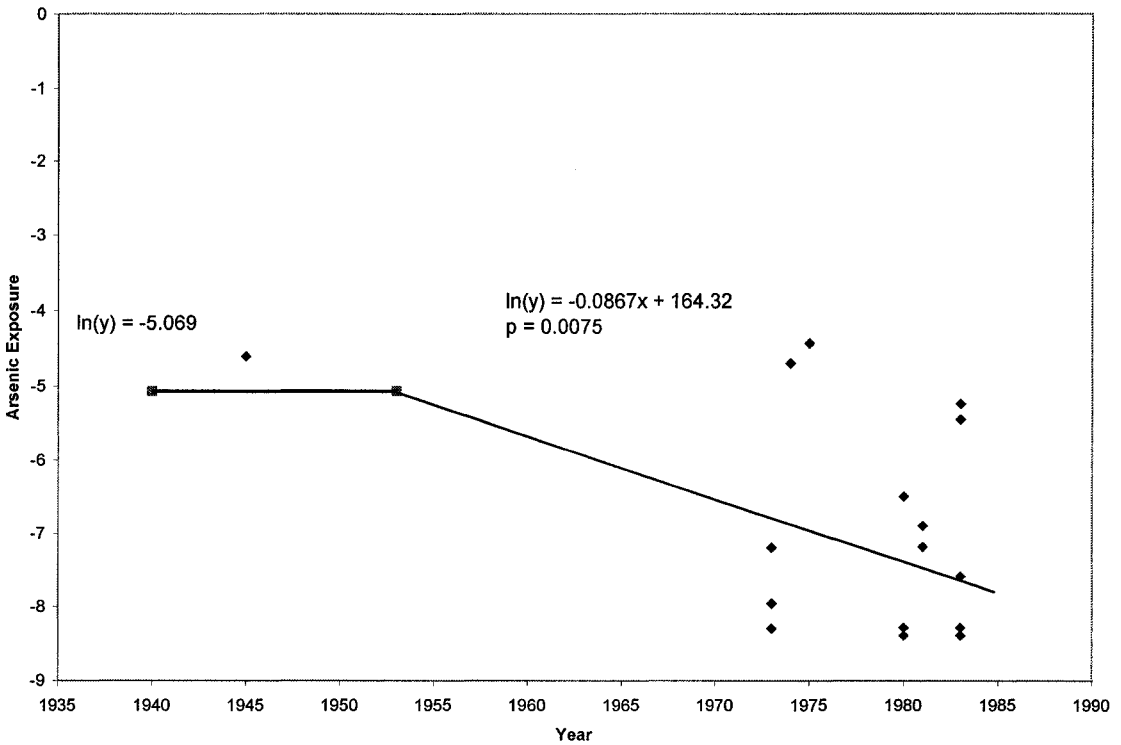

FIGURE 5.8 EXPOSURE MODEL, DEPARTMENT 1L- TANKHOUSE & ELECTROLYTIC

TABLE 5.8 EXPOSURE ESTIMATES FOR DEPT. 1L- TANKHOUSE & ELECTROLYTIC

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			0.0063	0.0012	0.0337
1941	.			0.0063	0.0012	0.0337
1942	.			0.0063	0.0012	0.0337
1943	.			0.0063	0.0012	0.0337
1944	.			0.0063	0.0012	0.0337
1945	0.0100			0.0063	0.0012	0.0337
1946	.			0.0063	0.0012	0.0337
1947	.			0.0063	0.0012	0.0337
1948	.			0.0063	0.0012	0.0337
1949	.			0.0063	0.0012	0.0337
1950	.			0.0063	0.0012	0.0337
1951	.			0.0063	0.0012	0.0337
1952	.			0.0063	0.0012	0.0337
1953	.			0.0063	0.0012	0.0337
1954	.			0.0058	0.0011	0.0291
1955	.			0.0053	0.0011	0.0252
1956	.			0.0048	0.0011	0.0218
1957	.			0.0044	0.0010	0.0188
1958	.			0.0041	0.0010	0.0163
1959	.			0.0037	0.0010	0.0141
1960	.			0.0034	0.0010	0.0122
1961	.			0.0031	0.0009	0.0106
1962	.			0.0029	0.0009	0.0092
1963	.			0.0026	0.0009	0.0080
1964	.			0.0024	0.0008	0.0069
1965	.			0.0022	0.0008	0.0060
1966	.			0.0020	0.0008	0.0052
1967	.			0.0019	0.0008	0.0045
1968	.			0.0017	0.0007	0.0040
1969	.			0.0016	0.0007	0.0034
1970	.			0.0014	0.0007	0.0030
1971	.			0.0013	0.0007	0.0026
1972	.			0.0012	0.0006	0.0023
1973	0.0004	0.0003	0.0008	0.0011	0.0006	0.0020
1974	0.0091			0.0010	0.0006	0.0018
1975	0.0119			0.0009	0.0005	0.0016
1976	.			0.0009	0.0005	0.0014
1977	.			0.0008	0.0005	0.0013
1978	.			0.0007	0.0004	0.0012
1979	.			0.0007	0.0004	0.0011
1980	0.0004	0.0015	0.0003	0.0006	0.0004	0.0010
1981	0.0009	0.0008	0.0010	0.0006	0.0003	0.0009
1982	.			0.0005	0.0003	0.0008
1983	0.0004	0.0002	0.0053	0.0005	0.0003	0.0008
1984	.			0.0004	0.0002	0.0007
1985	.			0.0004	0.0002	0.0007

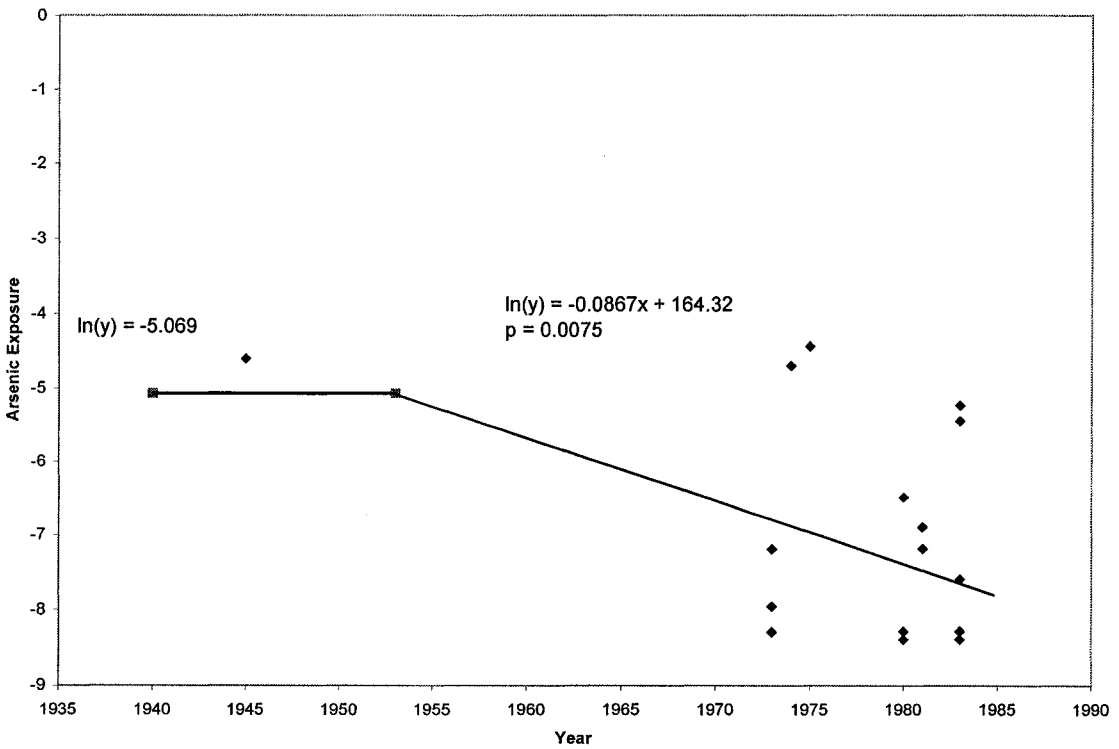

FIGURE 5.9 EXPOSURE MODEL, DEPARTMENT 1M- RETORT OPERATOR

TABLE 5.9 EXPOSURE ESTIMATES FOR DEPT. 1M- RETORT OPERATOR

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			0.0063	0.0012	0.0337
1941	.			0.0063	0.0012	0.0337
1942	.			0.0063	0.0012	0.0337
1943	.			0.0063	0.0012	0.0337
1944	.			0.0063	0.0012	0.0337
1945	0.0100			0.0063	0.0012	0.0337
1946	.			0.0063	0.0012	0.0337
1947	.			0.0063	0.0012	0.0337
1948	.			0.0063	0.0012	0.0337
1949	.			0.0063	0.0012	0.0337
1950	.			0.0063	0.0012	0.0337
1951	.			0.0063	0.0012	0.0337
1952	.			0.0063	0.0012	0.0337
1953	.			0.0063	0.0012	0.0337
1954	.			0.0058	0.0011	0.0291
1955	.			0.0053	0.0011	0.0252
1956	.			0.0048	0.0011	0.0218
1957	.			0.0044	0.0010	0.0188
1958	.			0.0041	0.0010	0.0163
1959	.			0.0037	0.0010	0.0141
1960	.			0.0034	0.0010	0.0122
1961	.			0.0031	0.0009	0.0106
1962	.			0.0029	0.0009	0.0092
1963	.			0.0026	0.0009	0.0080
1964	.			0.0024	0.0008	0.0069
1965	.			0.0022	0.0008	0.0060
1966	.			0.0020	0.0008	0.0052
1967	.			0.0019	0.0008	0.0045
1968	.			0.0017	0.0007	0.0040
1969	.			0.0016	0.0007	0.0034
1970	.			0.0014	0.0007	0.0030
1971	.			0.0013	0.0007	0.0026
1972	.			0.0012	0.0006	0.0023
1973	0.0004	0.0003	0.0008	0.0011	0.0006	0.0020
1974	0.0091			0.0010	0.0006	0.0018
1975	0.0119			0.0009	0.0005	0.0016
1976	.			0.0009	0.0005	0.0014
1977	.			0.0008	0.0005	0.0013
1978	.			0.0007	0.0004	0.0012
1979	.			0.0007	0.0004	0.0011
1980	0.0004	0.0015	0.0003	0.0006	0.0004	0.0010
1981	0.0009	0.0008	0.0010	0.0006	0.0003	0.0009
1982	.			0.0005	0.0003	0.0008
1983	0.0004	0.0002	0.0053	0.0005	0.0003	0.0008
1984	.			0.0004	0.0002	0.0007
1985	.			0.0004	0.0002	0.0007

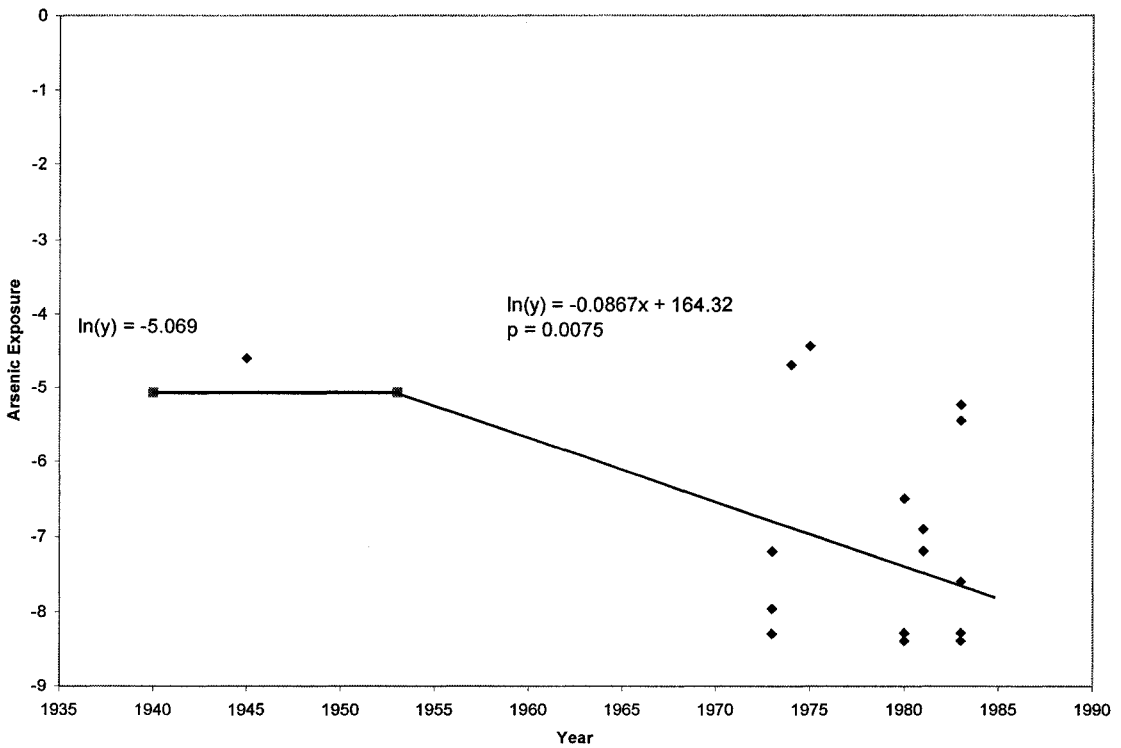

FIGURE 5.10 EXPOSURE MODEL, DEPARTMENT 1N- CASTER

TABLE 5.10 EXPOSURE ESTIMATES FOR DEPT. 1N- CASTER

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			0.0063	0.0012	0.0337
1941	.			0.0063	0.0012	0.0337
1942	.			0.0063	0.0012	0.0337
1943	.			0.0063	0.0012	0.0337
1944	.			0.0063	0.0012	0.0337
1945	0.0100			0.0063	0.0012	0.0337
1946	.			0.0063	0.0012	0.0337
1947	.			0.0063	0.0012	0.0337
1948	.			0.0063	0.0012	0.0337
1949	.			0.0063	0.0012	0.0337
1950	.			0.0063	0.0012	0.0337
1951	.			0.0063	0.0012	0.0337
1952	.			0.0063	0.0012	0.0337
1953	.			0.0063	0.0012	0.0337
1954	.			0.0058	0.0011	0.0291
1955	.			0.0053	0.0011	0.0252
1956	.			0.0048	0.0011	0.0218
1957	.			0.0044	0.0010	0.0188
1958	.			0.0041	0.0010	0.0163
1959	.			0.0037	0.0010	0.0141
1960	.			0.0034	0.0010	0.0122
1961	.			0.0031	0.0009	0.0106
1962	.			0.0029	0.0009	0.0092
1963	.			0.0026	0.0009	0.0080
1964	.			0.0024	0.0008	0.0069
1965	.			0.0022	0.0008	0.0060
1966	.			0.0020	0.0008	0.0052
1967	.			0.0019	0.0008	0.0045
1968	.			0.0017	0.0007	0.0040
1969	.			0.0016	0.0007	0.0034
1970	.			0.0014	0.0007	0.0030
1971	.			0.0013	0.0007	0.0026
1972	.			0.0012	0.0006	0.0023
1973	0.0004	0.0003	0.0008	0.0011	0.0006	0.0020
1974	0.0091			0.0010	0.0006	0.0018
1975	0.0119			0.0009	0.0005	0.0016
1976	.			0.0009	0.0005	0.0014
1977	.			0.0008	0.0005	0.0013
1978	.			0.0007	0.0004	0.0012
1979	.			0.0007	0.0004	0.0011
1980	0.0004	0.0015	0.0003	0.0006	0.0004	0.0010
1981	0.0009	0.0008	0.0010	0.0006	0.0003	0.0009
1982	.			0.0005	0.0003	0.0008
1983	0.0004	0.0002	0.0053	0.0005	0.0003	0.0008
1984	.			0.0004	0.0002	0.0007
1985	.			0.0004	0.0002	0.0007

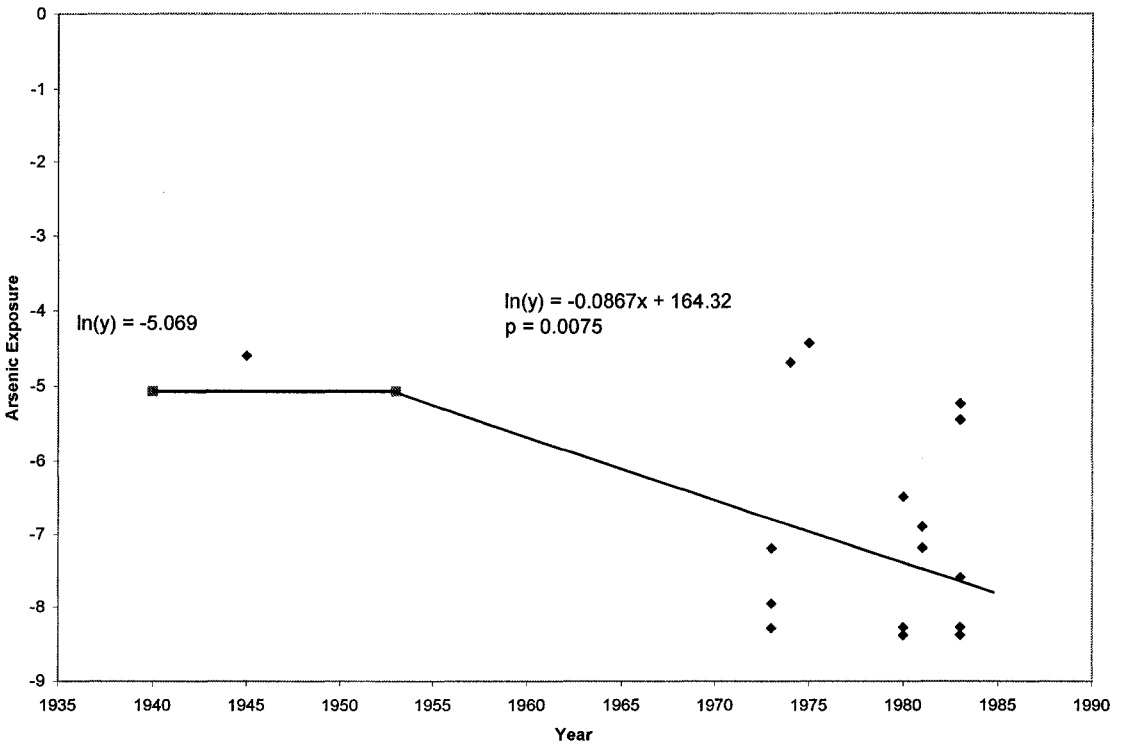

FIGURE 5.11 EXPOSURE MODEL, DEPARTMENT 10- WEIGHER & PACKER

TABLE 5.11 EXPOSURE ESTIMATES FOR DEPT. 10- WEIGHER & PACKER

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			0.0063	0.0012	0.0337
1941	.			0.0063	0.0012	0.0337
1942	.			0.0063	0.0012	0.0337
1943	.			0.0063	0.0012	0.0337
1944	.			0.0063	0.0012	0.0337
1945	0.0100			0.0063	0.0012	0.0337
1946	.			0.0063	0.0012	0.0337
1947	.			0.0063	0.0012	0.0337
1948	.			0.0063	0.0012	0.0337
1949	.			0.0063	0.0012	0.0337
1950	.			0.0063	0.0012	0.0337
1951	.			0.0063	0.0012	0.0337
1952	.			0.0063	0.0012	0.0337
1953	.			0.0063	0.0012	0.0337
1954	.			0.0058	0.0011	0.0291
1955	.			0.0053	0.0011	0.0252
1956	.			0.0048	0.0011	0.0218
1957	.			0.0044	0.0010	0.0188
1958	.			0.0041	0.0010	0.0163
1959	.			0.0037	0.0010	0.0141
1960	.			0.0034	0.0010	0.0122
1961	.			0.0031	0.0009	0.0106
1962	.			0.0029	0.0009	0.0092
1963	.			0.0026	0.0009	0.0080
1964	.			0.0024	0.0008	0.0069
1965	.			0.0022	0.0008	0.0060
1966	.			0.0020	0.0008	0.0052
1967	.			0.0019	0.0008	0.0045
1968	.			0.0017	0.0007	0.0040
1969	.			0.0016	0.0007	0.0034
1970	.			0.0014	0.0007	0.0030
1971	.			0.0013	0.0007	0.0026
1972	.			0.0012	0.0006	0.0023
1973	0.0004	0.0003	0.0008	0.0011	0.0006	0.0020
1974	0.0091			0.0010	0.0006	0.0018
1975	0.0119			0.0009	0.0005	0.0016
1976	.			0.0009	0.0005	0.0014
1977	.			0.0008	0.0005	0.0013
1978	.			0.0007	0.0004	0.0012
1979	.			0.0007	0.0004	0.0011
1980	0.0004	0.0015	0.0003	0.0006	0.0004	0.0010
1981	0.0009	0.0008	0.0010	0.0006	0.0003	0.0009
1982	.			0.0005	0.0003	0.0008
1983	0.0004	0.0002	0.0053	0.0005	0.0003	0.0008
1984	.			0.0004	0.0002	0.0007
1985	.			0.0004	0.0002	0.0007

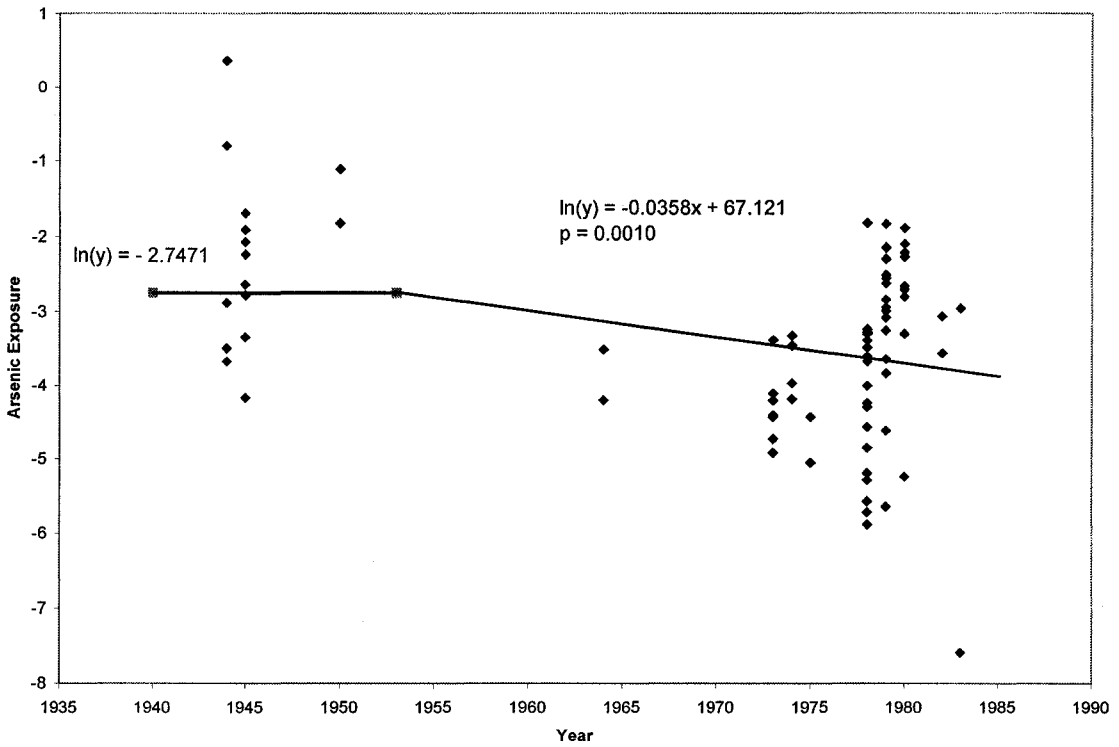

FIGURE 5.12 EXPOSURE MODEL, DEPARTMENT 3- ACID RECOVERY PLANT

TABLE 5.12 EXPOSURE ESTIMATES FOR DEPT. 3- ACID RECOVERY PLANT

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			0.064	0.040	0.102
1941	.			0.064	0.040	0.102
1942	.			0.064	0.040	0.102
1943	.			0.064	0.040	0.102
1944	0.1230	0.0255	1.4390	0.064	0.040	0.102
1945	0.0740	0.0155	0.1840	0.064	0.040	0.102
1946	.			0.064	0.040	0.102
1947	.			0.064	0.040	0.102
1948	.			0.064	0.040	0.102
1949	.			0.064	0.040	0.102
1950	0.2303	0.1615	0.3285	0.064	0.040	0.102
1951	.			0.064	0.040	0.102
1952	.			0.064	0.040	0.102
1953	.			0.064	0.040	0.102
1954	.			0.062	0.039	0.097
1955	.			0.060	0.039	0.092
1956	.			0.058	0.038	0.088
1957	.			0.056	0.037	0.083
1958	.			0.054	0.036	0.079
1959	.			0.052	0.036	0.075
1960	.			0.050	0.035	0.072
1961	.			0.048	0.034	0.068
1962	.			0.046	0.033	0.065
1963	.			0.045	0.033	0.062
1964	0.0212	0.0150	0.0300	0.043	0.032	0.059
1965	.			0.042	0.031	0.056
1966	.			0.040	0.030	0.054
1967	.			0.039	0.029	0.052
1968	.			0.037	0.028	0.050
1969	.			0.036	0.027	0.048
1970	.			0.035	0.027	0.046
1971	.			0.034	0.026	0.044
1972	.			0.032	0.025	0.043
1973	0.0132	0.0073	0.0164	0.031	0.024	0.041
1974	0.0239	0.0152	0.0362	0.030	0.023	0.040
1975	0.0087	0.0064	0.0119	0.029	0.022	0.039
1976	.			0.028	0.021	0.037
1977	.			0.027	0.020	0.036
1978	0.0152	0.0028	0.1616	0.026	0.019	0.035
1979	0.0505	0.0035	0.1598	0.025	0.019	0.035
1980	0.0610	0.0053	0.1513	0.024	0.018	0.034
1981	.			0.024	0.017	0.033
1982	0.0365	0.0285	0.0467	0.023	0.016	0.032
1983	0.0051	0.0005	0.0520	0.022	0.015	0.031
1984	.			0.021	0.015	0.031
1985	.			0.020	0.014	0.030

ND = result undetermined

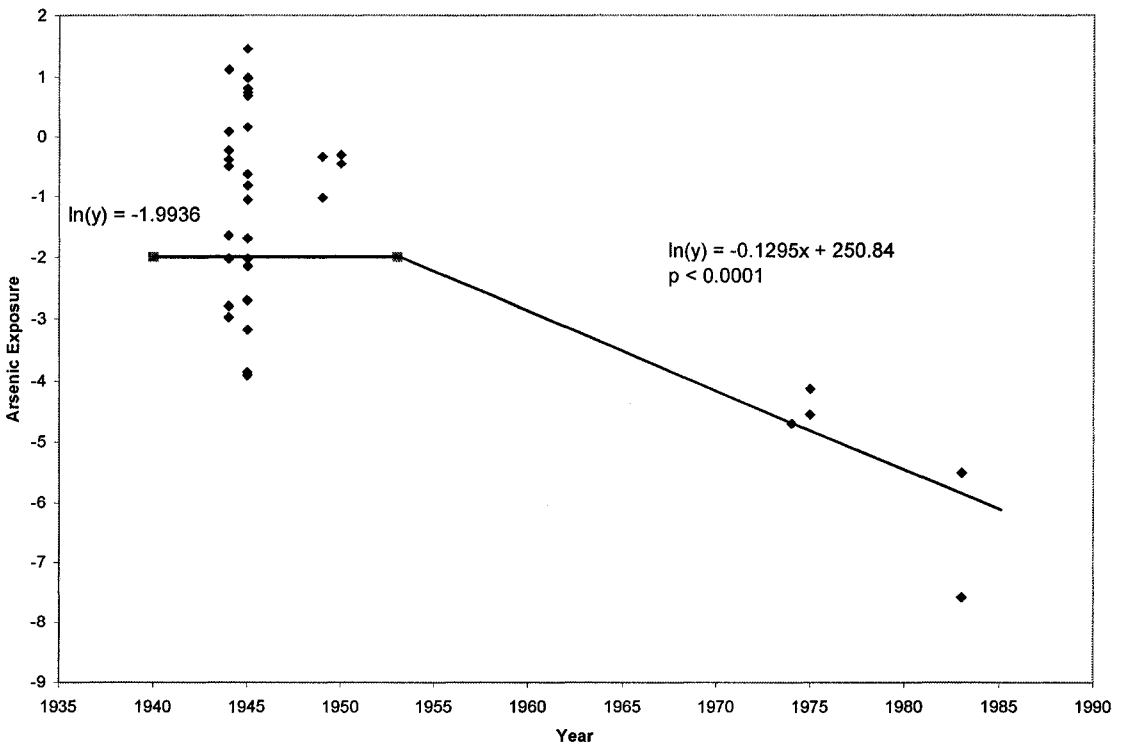

FIGURE 5.13 EXPOSURE MODEL, DEPARTMENT 4A- LOADING GANG WORKMAN

TABLE 5.13 EXPOSURE ESTIMATES FOR DEPT. 4A-LOADING GANG WORKMAN

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			0.1362	0.0794	0.2337
1941	.			0.1362	0.0794	0.2337
1942	.			0.1362	0.0794	0.2337
1943	.			0.1362	0.0794	0.2337
1944	0.3549	0.0510	3.0814	0.1362	0.0794	0.2337
1945	0.3415	0.0200	4.3366	0.1362	0.0794	0.2337
1946	.			0.1362	0.0794	0.2337
1947	.			0.1362	0.0794	0.2337
1948	.			0.1362	0.0794	0.2337
1949	0.5070	0.3585	0.7170	0.1362	0.0794	0.2337
1950	0.6851	0.6365	0.7375	0.1362	0.0794	0.2337
1951	.			0.1362	0.0794	0.2337
1952	.			0.1362	0.0794	0.2337
1953	.			0.1362	0.0794	0.2337
1954	.			0.1197	0.0689	0.2078
1955	.			0.1051	0.0596	0.1855
1956	.			0.0924	0.0514	0.1660
1957	.			0.0812	0.0442	0.1489
1958	.			0.0713	0.0379	0.1340
1959	.			0.0626	0.0325	0.1208
1960	.			0.0550	0.0278	0.1091
1961	.			0.0484	0.0237	0.0987
1962	.			0.0425	0.0202	0.0894
1963	.			0.0373	0.0172	0.0812
1964	.			0.0328	0.0146	0.0737
1965	.			0.0288	0.0124	0.0670
1966	.			0.0253	0.0105	0.0610
1967	.			0.0222	0.0089	0.0556
1968	.			0.0195	0.0075	0.0507
1969	.			0.0172	0.0064	0.0462
1970	.			0.0151	0.0054	0.0422
1971	.			0.0133	0.0046	0.0385
1972	.			0.0116	0.0039	0.0352
1973	.			0.0102	0.0033	0.0321
1974	0.0091			0.0090	0.0028	0.0294
1975	0.0131	0.0161	0.0106	0.0079	0.0023	0.0269
1976	.			0.0069	0.0020	0.0246
1977	.			0.0061	0.0017	0.0225
1978	.			0.0054	0.0014	0.0206
1979	.			0.0047	0.0012	0.0188
1980	.			0.0041	0.0010	0.0173
1981	.			0.0036	0.0008	0.0158
1982	.			0.0032	0.0007	0.0145
1983	0.0014	0.0005	0.0040	0.0028	0.0006	0.0133
1984	.			0.0025	0.0005	0.0121
1985	.			0.0022	0.0004	0.0111

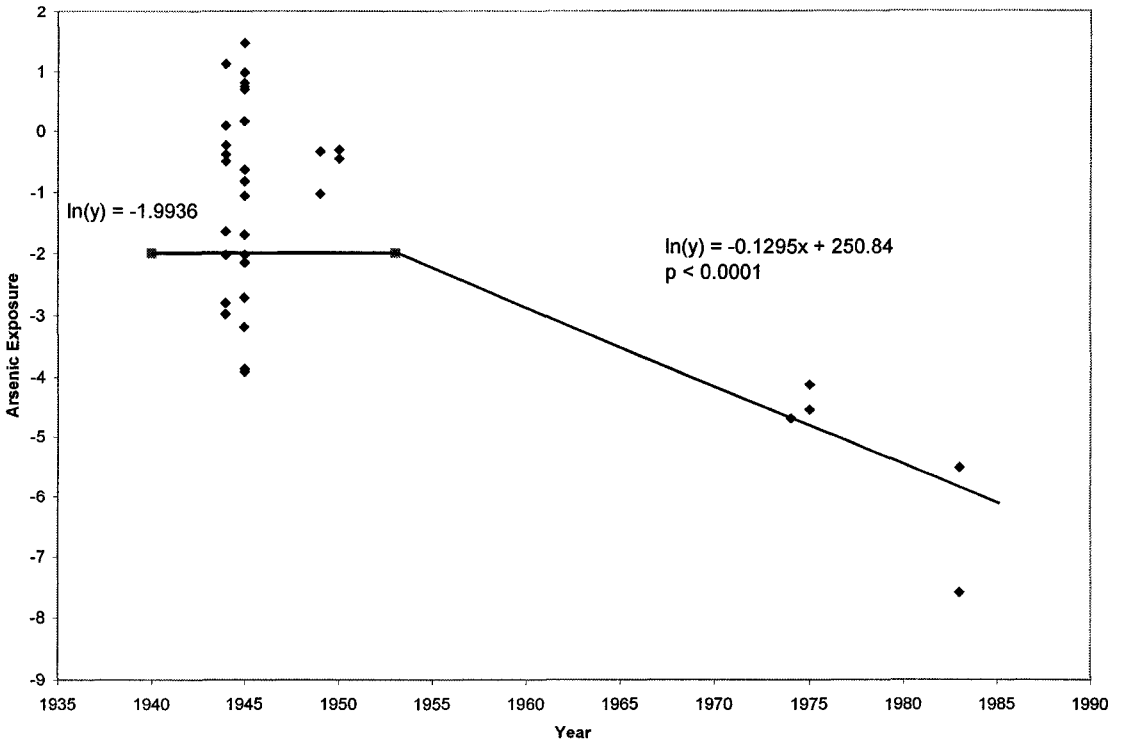

FIGURE 5.14 EXPOSURE MODEL, DEPARTMENT 4B- CONC. & DRY DUST

TABLE 5.14 EXPOSURE ESTIMATES FOR DEPT. 4B- CONC. & DRY DUST

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			0.1362	0.0794	0.2337
1941	.			0.1362	0.0794	0.2337
1942	.			0.1362	0.0794	0.2337
1943	.			0.1362	0.0794	0.2337
1944	0.3549	0.0510	3.0814	0.1362	0.0794	0.2337
1945	0.3415	0.0200	4.3366	0.1362	0.0794	0.2337
1946	.			0.1362	0.0794	0.2337
1947	.			0.1362	0.0794	0.2337
1948	.			0.1362	0.0794	0.2337
1949	0.5070	0.3585	0.7170	0.1362	0.0794	0.2337
1950	0.6851	0.6365	0.7375	0.1362	0.0794	0.2337
1951	.			0.1362	0.0794	0.2337
1952	.			0.1362	0.0794	0.2337
1953	.			0.1362	0.0794	0.2337
1954	.			0.1197	0.0689	0.2078
1955	.			0.1051	0.0596	0.1855
1956	.			0.0924	0.0514	0.1660
1957	.			0.0812	0.0442	0.1489
1958	.			0.0713	0.0379	0.1340
1959	.			0.0626	0.0325	0.1208
1960	.			0.0550	0.0278	0.1091
1961	.			0.0484	0.0237	0.0987
1962	.			0.0425	0.0202	0.0894
1963	.			0.0373	0.0172	0.0812
1964	.			0.0328	0.0146	0.0737
1965	.			0.0288	0.0124	0.0670
1966	.			0.0253	0.0105	0.0610
1967	.			0.0222	0.0089	0.0556
1968	.			0.0195	0.0075	0.0507
1969	.			0.0172	0.0064	0.0462
1970	.			0.0151	0.0054	0.0422
1971	.			0.0133	0.0046	0.0385
1972	.			0.0116	0.0039	0.0352
1973	.			0.0102	0.0033	0.0321
1974	0.0091			0.0090	0.0028	0.0294
1975	0.0131	0.0161	0.0106	0.0079	0.0023	0.0269
1976	.			0.0069	0.0020	0.0246
1977	.			0.0061	0.0017	0.0225
1978	.			0.0054	0.0014	0.0206
1979	.			0.0047	0.0012	0.0188
1980	.			0.0041	0.0010	0.0173
1981	.			0.0036	0.0008	0.0158
1982	.			0.0032	0.0007	0.0145
1983	0.0014	0.0005	0.0040	0.0028	0.0006	0.0133
1984	.			0.0025	0.0005	0.0121
1985	.			0.0022	0.0004	0.0111

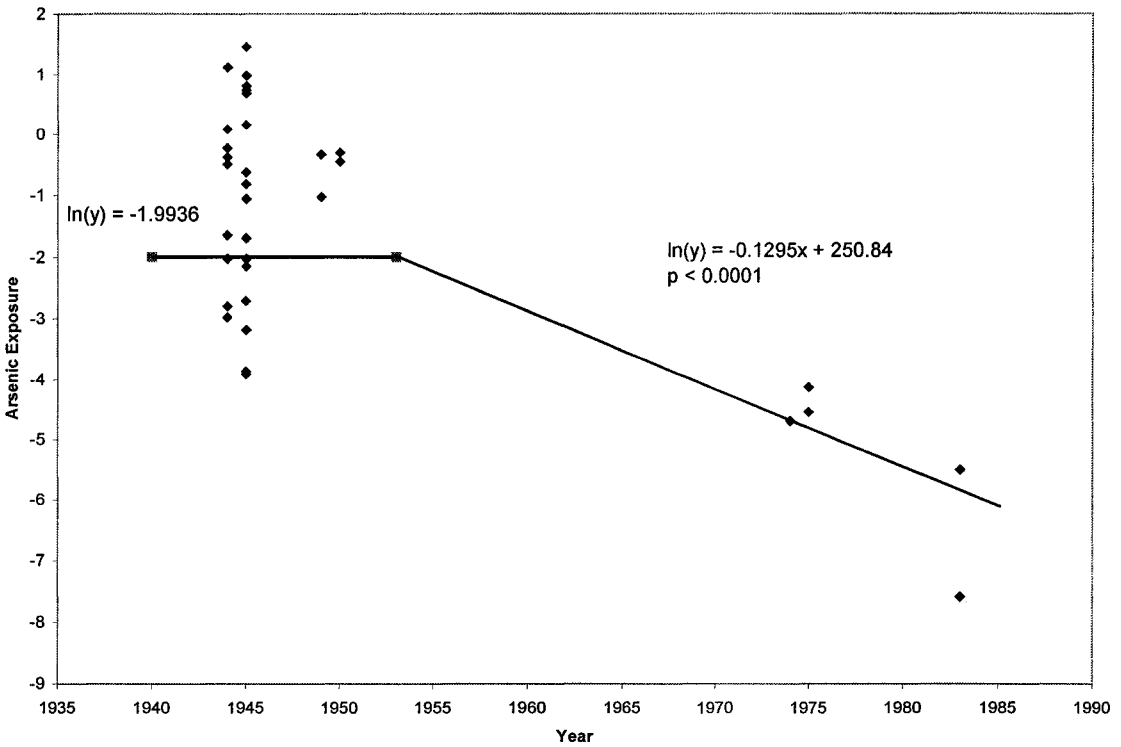

FIGURE 5.15 EXPOSURE MODEL, DEPARTMENT 4C- GENERAL LABORER, UNLOADING

TABLE 5.15 EXPOSURE ESTIMATES FOR DEPT. 4C-GENERAL LABORER, UNLOADING

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			0.1362	0.0794	0.2337
1941	.			0.1362	0.0794	0.2337
1942	.			0.1362	0.0794	0.2337
1943	.			0.1362	0.0794	0.2337
1944	0.3549	0.0510	3.0814	0.1362	0.0794	0.2337
1945	0.3415	0.0200	4.3366	0.1362	0.0794	0.2337
1946	.			0.1362	0.0794	0.2337
1947	.			0.1362	0.0794	0.2337
1948	.			0.1362	0.0794	0.2337
1949	0.5070	0.3585	0.7170	0.1362	0.0794	0.2337
1950	0.6851	0.6365	0.7375	0.1362	0.0794	0.2337
1951	.			0.1362	0.0794	0.2337
1952	.			0.1362	0.0794	0.2337
1953	.			0.1362	0.0794	0.2337
1954	.			0.1197	0.0689	0.2078
1955	.			0.1051	0.0596	0.1855
1956	.			0.0924	0.0514	0.1660
1957	.			0.0812	0.0442	0.1489
1958	.			0.0713	0.0379	0.1340
1959	.			0.0626	0.0325	0.1208
1960	.			0.0550	0.0278	0.1091
1961	.			0.0484	0.0237	0.0987
1962	.			0.0425	0.0202	0.0894
1963	.			0.0373	0.0172	0.0812
1964	.			0.0328	0.0146	0.0737
1965	.			0.0288	0.0124	0.0670
1966	.			0.0253	0.0105	0.0610
1967	.			0.0222	0.0089	0.0556
1968	.			0.0195	0.0075	0.0507
1969	.			0.0172	0.0064	0.0462
1970	.			0.0151	0.0054	0.0422
1971	.			0.0133	0.0046	0.0385
1972	.			0.0116	0.0039	0.0352
1973	.			0.0102	0.0033	0.0321
1974	0.0091			0.0090	0.0028	0.0294
1975	0.0131	0.0161	0.0106	0.0079	0.0023	0.0269
1976	.			0.0069	0.0020	0.0246
1977	.			0.0061	0.0017	0.0225
1978	.			0.0054	0.0014	0.0206
1979	.			0.0047	0.0012	0.0188
1980	.			0.0041	0.0010	0.0173
1981	.			0.0036	0.0008	0.0158
1982	.			0.0032	0.0007	0.0145
1983	0.0014	0.0005	0.0040	0.0028	0.0006	0.0133
1984	.			0.0025	0.0005	0.0121
1985	.			0.0022	0.0004	0.0111

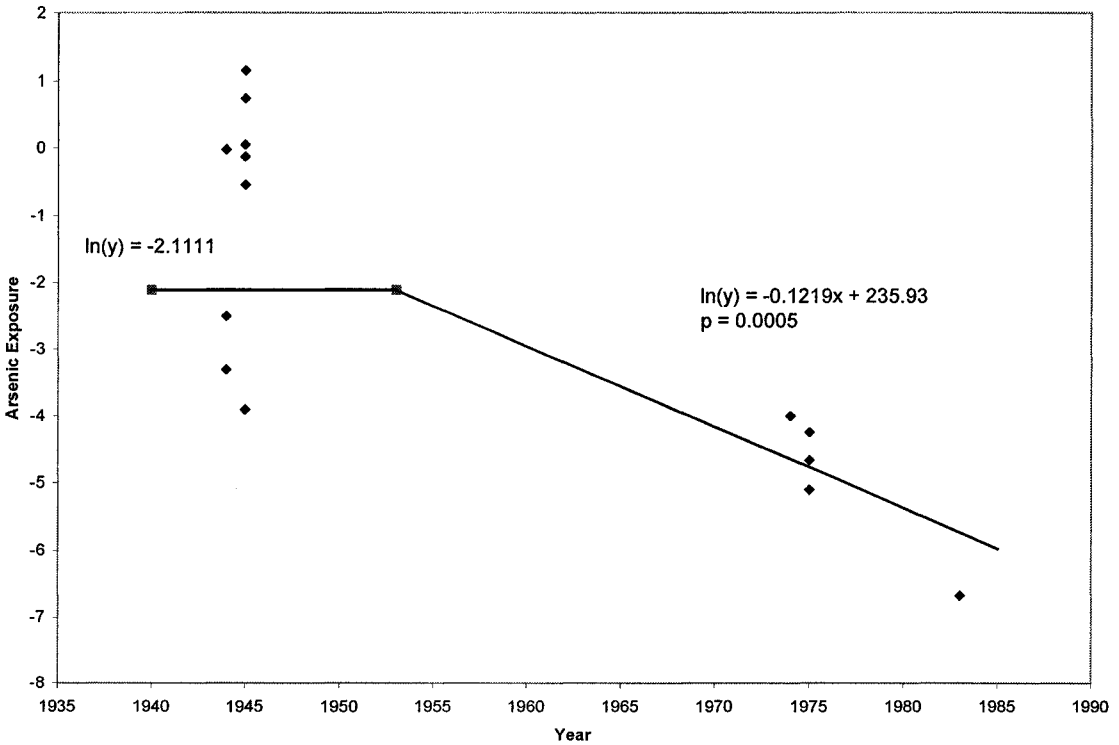

FIGURE 5.16 EXPOSURE MODEL, DEPARTMENT 5- SAMPLING

TABLE 5.16 EXPOSURE ESTIMATES FOR DEPT. 5- SAMPLING

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			0.1211	0.0503	0.2917
1941	.			0.1211	0.0503	0.2917
1942	.			0.1211	0.0503	0.2917
1943	.			0.1211	0.0503	0.2917
1944	0.1241	0.0365	0.9795	0.1211	0.0503	0.2917
1945	0.6431	0.0200	3.1639	0.1211	0.0503	0.2917
1946	.			0.1211	0.0503	0.2917
1947	.			0.1211	0.0503	0.2917
1948	.			0.1211	0.0503	0.2917
1949	.			0.1211	0.0503	0.2917
1950	.			0.1211	0.0503	0.2917
1951	.			0.1211	0.0503	0.2917
1952	.			0.1211	0.0503	0.2917
1953	.			0.1211	0.0503	0.2917
1954	.			0.1072	0.0448	0.2566
1955	.			0.0949	0.0398	0.2265
1956	.			0.0840	0.0352	0.2008
1957	.			0.0744	0.0310	0.1786
1958	.			0.0658	0.0272	0.1595
1959	.			0.0583	0.0238	0.1429
1960	.			0.0516	0.0207	0.1285
1961	.			0.0457	0.0180	0.1160
1962	.			0.0404	0.0156	0.1050
1963	.			0.0358	0.0135	0.0953
1964	.			0.0317	0.0116	0.0867
1965	.			0.0281	0.0099	0.0791
1966	.			0.0248	0.0085	0.0723
1967	.			0.0220	0.0073	0.0663
1968	.			0.0195	0.0062	0.0608
1969	.			0.0172	0.0053	0.0559
1970	.			0.0153	0.0045	0.0515
1971	.			0.0135	0.0038	0.0475
1972	.			0.0120	0.0033	0.0439
1973	.			0.0106	0.0028	0.0406
1974	0.0182			0.0094	0.0023	0.0375
1975	0.0111	0.0061	0.0182	0.0083	0.0020	0.0348
1976	.			0.0073	0.0017	0.0322
1977	.			0.0065	0.0014	0.0299
1978	.			0.0058	0.0012	0.0278
1979	.			0.0051	0.0010	0.0258
1980	.			0.0045	0.0008	0.0240
1981	.			0.0040	0.0007	0.0223
1982	.			0.0035	0.0006	0.0208
1983	0.0013			0.0031	0.0005	0.0193
1984	.			0.0028	0.0004	0.0180
1985	.			0.0025	0.0004	0.0168

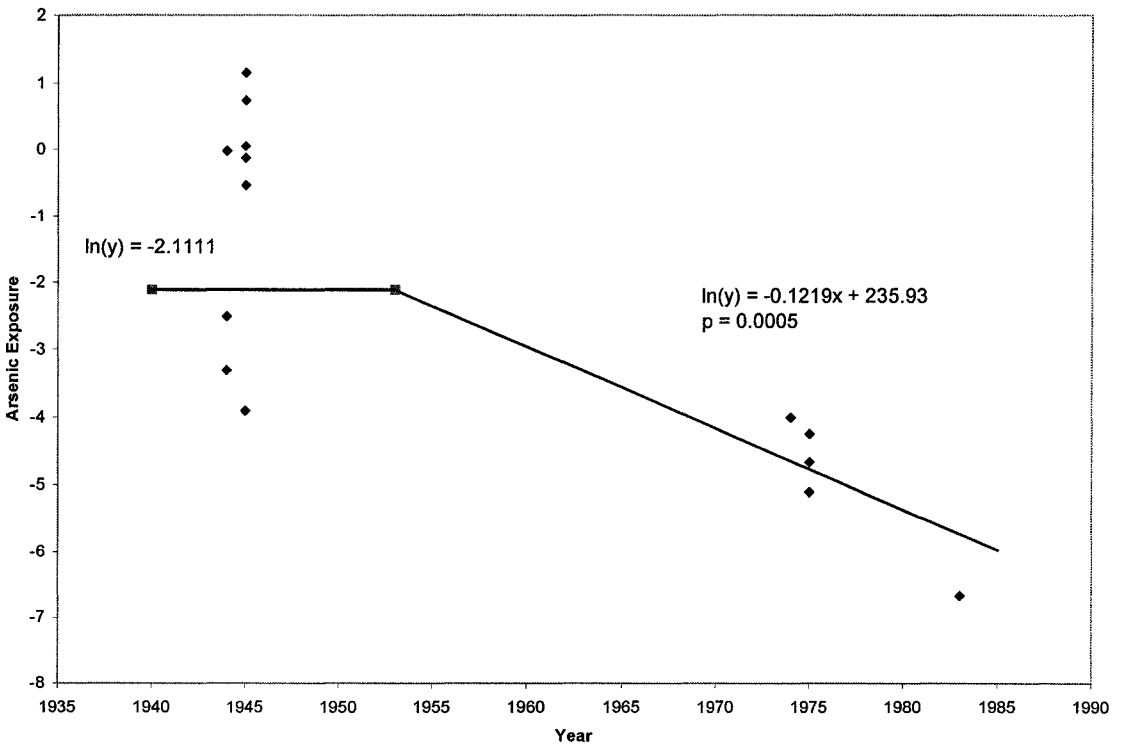

FIGURE 5.17 EXPOSURE MODEL, DEPARTMENT 6- CRUSHING

TABLE 5.17 EXPOSURE ESTIMATES FOR DEPT. 6- CRUSHING

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			0.1211	0.0503	0.2917
1941	.			0.1211	0.0503	0.2917
1942	.			0.1211	0.0503	0.2917
1943	.			0.1211	0.0503	0.2917
1944	0.1241	0.0365	0.9795	0.1211	0.0503	0.2917
1945	0.6431	0.0200	3.1639	0.1211	0.0503	0.2917
1946	.			0.1211	0.0503	0.2917
1947	.			0.1211	0.0503	0.2917
1948	.			0.1211	0.0503	0.2917
1949	.			0.1211	0.0503	0.2917
1950	.			0.1211	0.0503	0.2917
1951	.			0.1211	0.0503	0.2917
1952	.			0.1211	0.0503	0.2917
1953	.			0.1211	0.0503	0.2917
1954	.			0.1072	0.0448	0.2566
1955	.			0.0949	0.0398	0.2265
1956	.			0.0840	0.0352	0.2008
1957	.			0.0744	0.0310	0.1786
1958	.			0.0658	0.0272	0.1595
1959	.			0.0583	0.0238	0.1429
1960	.			0.0516	0.0207	0.1285
1961	.			0.0457	0.0180	0.1160
1962	.			0.0404	0.0156	0.1050
1963	.			0.0358	0.0135	0.0953
1964	.			0.0317	0.0116	0.0867
1965	.			0.0281	0.0099	0.0791
1966	.			0.0248	0.0085	0.0723
1967	.			0.0220	0.0073	0.0663
1968	.			0.0195	0.0062	0.0608
1969	.			0.0172	0.0053	0.0559
1970	.			0.0153	0.0045	0.0515
1971	.			0.0135	0.0038	0.0475
1972	.			0.0120	0.0033	0.0439
1973	.			0.0106	0.0028	0.0406
1974	0.0182			0.0094	0.0023	0.0375
1975	0.0111	0.0061	0.0182	0.0083	0.0020	0.0348
1976	.			0.0073	0.0017	0.0322
1977	.			0.0065	0.0014	0.0299
1978	.			0.0058	0.0012	0.0278
1979	.			0.0051	0.0010	0.0258
1980	.			0.0045	0.0008	0.0240
1981	.			0.0040	0.0007	0.0223
1982	.			0.0035	0.0006	0.0208
1983	0.0013			0.0031	0.0005	0.0193
1984	.			0.0028	0.0004	0.0180
1985	.			0.0025	0.0004	0.0168

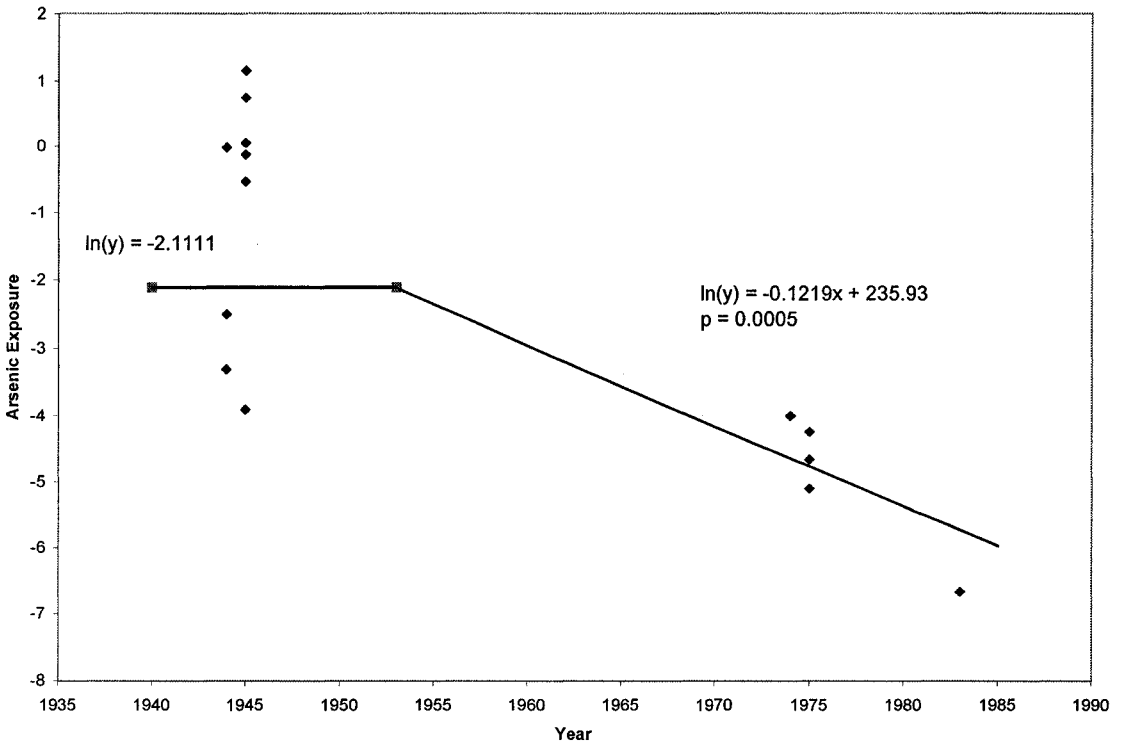

FIGURE 5.18 EXPOSURE MODEL, DEPARTMENT 7- ROASTING

TABLE 5.18 EXPOSURE ESTIMATES FOR DEPT. 7- ROASTING

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			0.1211	0.0503	0.2917
1941	.			0.1211	0.0503	0.2917
1942	.			0.1211	0.0503	0.2917
1943	.			0.1211	0.0503	0.2917
1944	0.1241	0.0365	0.9795	0.1211	0.0503	0.2917
1945	0.6431	0.0200	3.1639	0.1211	0.0503	0.2917
1946	.			0.1211	0.0503	0.2917
1947	.			0.1211	0.0503	0.2917
1948	.			0.1211	0.0503	0.2917
1949	.			0.1211	0.0503	0.2917
1950	.			0.1211	0.0503	0.2917
1951	.			0.1211	0.0503	0.2917
1952	.			0.1211	0.0503	0.2917
1953	.			0.1211	0.0503	0.2917
1954	.			0.1072	0.0448	0.2566
1955	.			0.0949	0.0398	0.2265
1956	.			0.0840	0.0352	0.2008
1957	.			0.0744	0.0310	0.1786
1958	.			0.0658	0.0272	0.1595
1959	.			0.0583	0.0238	0.1429
1960	.			0.0516	0.0207	0.1285
1961	.			0.0457	0.0180	0.1160
1962	.			0.0404	0.0156	0.1050
1963	.			0.0358	0.0135	0.0953
1964	.			0.0317	0.0116	0.0867
1965	.			0.0281	0.0099	0.0791
1966	.			0.0248	0.0085	0.0723
1967	.			0.0220	0.0073	0.0663
1968	.			0.0195	0.0062	0.0608
1969	.			0.0172	0.0053	0.0559
1970	.			0.0153	0.0045	0.0515
1971	.			0.0135	0.0038	0.0475
1972	.			0.0120	0.0033	0.0439
1973	.			0.0106	0.0028	0.0406
1974	0.0182			0.0094	0.0023	0.0375
1975	0.0111	0.0061	0.0182	0.0083	0.0020	0.0348
1976	.			0.0073	0.0017	0.0322
1977	.			0.0065	0.0014	0.0299
1978	.			0.0058	0.0012	0.0278
1979	.			0.0051	0.0010	0.0258
1980	.			0.0045	0.0008	0.0240
1981	.			0.0040	0.0007	0.0223
1982	.			0.0035	0.0006	0.0208
1983	0.0013			0.0031	0.0005	0.0193
1984	.			0.0028	0.0004	0.0180
1985	.			0.0025	0.0004	0.0168

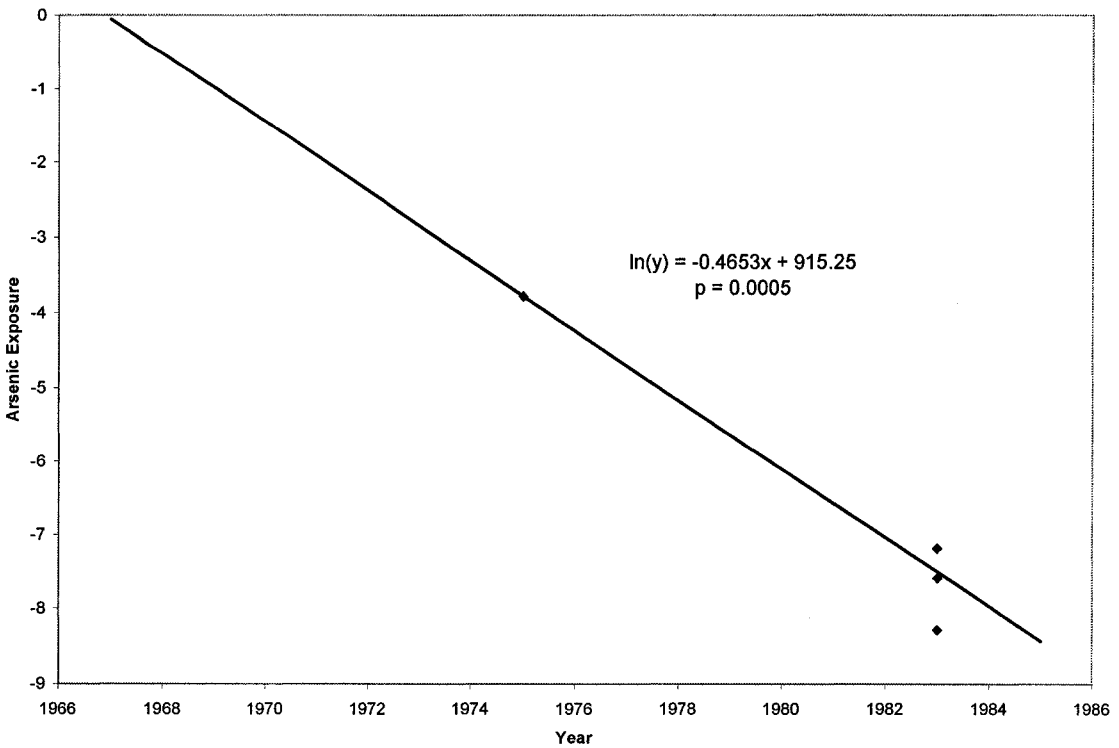

FIGURE 5.19 EXPOSURE MODEL, DEPARTMENT 10A- MACHINE SHOP

TABLE 5.19 EXPOSURE ESTIMATES FOR DEPT. 10A- MACHINE SHOP

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			ND	ND	ND
1941	.			ND	ND	ND
1942	.			ND	ND	ND
1943	.			ND	ND	ND
1944	.			ND	ND	ND
1945	.			ND	ND	ND
1946	.			ND	ND	ND
1947	.			ND	ND	ND
1948	.			ND	ND	ND
1949	.			ND	ND	ND
1950	.			ND	ND	ND
1951	.			ND	ND	ND
1952	.			ND	ND	ND
1953	.			ND	ND	ND
1954	.			ND	ND	ND
1955	.			ND	ND	ND
1956	.			ND	ND	ND
1957	.			ND	ND	ND
1958	.			ND	ND	ND
1959	.			ND	ND	ND
1960	.			ND	ND	ND
1961	.			ND	ND	ND
1962	.			ND	ND	ND
1963	.			ND	ND	ND
1964	.			ND	ND	ND
1965	.			ND	ND	ND
1966	.			ND	ND	ND
1967	.			0.9434	0.0984	9.0449
1968	.			0.5923	0.0715	4.9047
1969	.			0.3719	0.0520	2.6605
1970	.			0.2336	0.0378	1.4438
1971	.			0.1467	0.0274	0.7841
1972	.			0.0921	0.0199	0.4262
1973	.			0.0578	0.0144	0.2319
1974	.			0.0363	0.0104	0.1264
1975	0.0228			0.0228	0.0075	0.0690
1976	.			0.0143	0.0054	0.0378
1977	.			0.0090	0.0039	0.0208
1978	.			0.0056	0.0028	0.0115
1979	.			0.0035	0.0019	0.0064
1980	.			0.0022	0.0013	0.0037
1981	.			0.0014	0.0009	0.0022
1982	.			0.0009	0.0006	0.0013
1983	0.0006	0.0003	0.0008	0.0006	0.0004	0.0009
1984	.			0.0003	0.0002	0.0006
1985	.			0.0002	0.0001	0.0004

ND = result undetermined

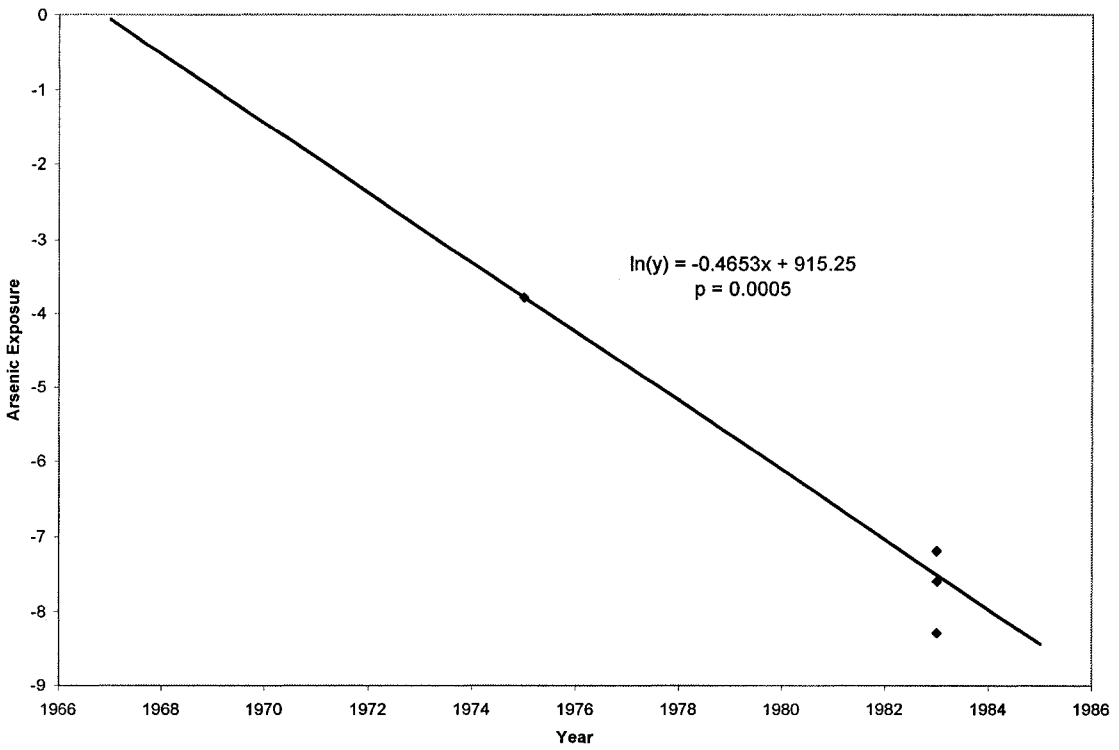

FIGURE 5.20 EXPOSURE MODEL, DEPARTMENT 10B- MAINTENANCE

TABLE 5.20 EXPOSURE ESTIMATES FOR DEPT. 10B- MAINTENANCE

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			ND	ND	ND
1941	.			ND	ND	ND
1942	.			ND	ND	ND
1943	.			ND	ND	ND
1944	.			ND	ND	ND
1945	.			ND	ND	ND
1946	.			ND	ND	ND
1947	.			ND	ND	ND
1948	.			ND	ND	ND
1949	.			ND	ND	ND
1950	.			ND	ND	ND
1951	.			ND	ND	ND
1952	.			ND	ND	ND
1953	.			ND	ND	ND
1954	.			ND	ND	ND
1955	.			ND	ND	ND
1956	.			ND	ND	ND
1957	.			ND	ND	ND
1958	.			ND	ND	ND
1959	.			ND	ND	ND
1960	.			ND	ND	ND
1961	.			ND	ND	ND
1962	.			ND	ND	ND
1963	.			ND	ND	ND
1964	.			ND	ND	ND
1965	.			ND	ND	ND
1966	.			ND	ND	ND
1967	.			0.9434	0.0984	9.0449
1968	.			0.5923	0.0715	4.9047
1969	.			0.3719	0.0520	2.6605
1970	.			0.2336	0.0378	1.4438
1971	.			0.1467	0.0274	0.7841
1972	.			0.0921	0.0199	0.4262
1973	.			0.0578	0.0144	0.2319
1974	.			0.0363	0.0104	0.1264
1975	0.0228			0.0228	0.0075	0.0690
1976	.			0.0143	0.0054	0.0378
1977	.			0.0090	0.0039	0.0208
1978	.			0.0056	0.0028	0.0115
1979	.			0.0035	0.0019	0.0064
1980	.			0.0022	0.0013	0.0037
1981	.			0.0014	0.0009	0.0022
1982	.			0.0009	0.0006	0.0013
1983	0.0006	0.0003	0.0008	0.0006	0.0004	0.0009
1984	.			0.0003	0.0002	0.0006
1985	.			0.0002	0.0001	0.0004

ND = result undetermined

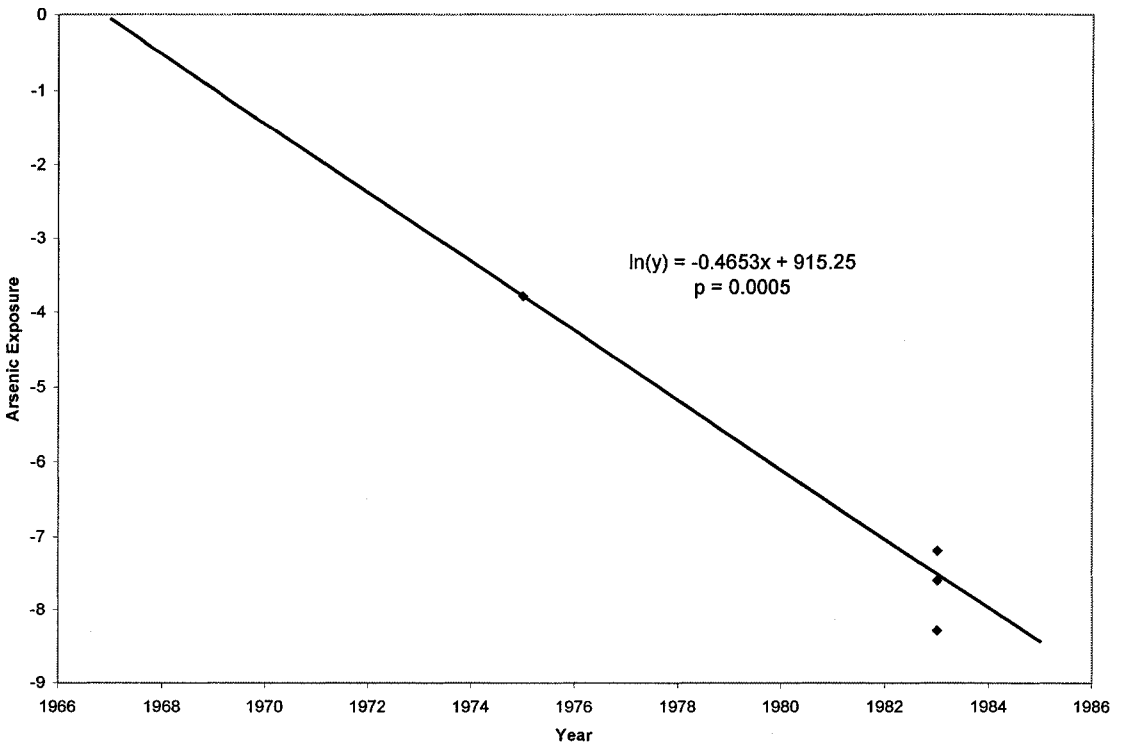

FIGURE 5.21 EXPOSURE MODEL, DEPARTMENT 11- ELECTRICAL SHOP

TABLE 5.21 EXPOSURE ESTIMATES FOR DEPT. 11- ELECTRICAL SHOP

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			ND	ND	ND
1941	.			ND	ND	ND
1942	.			ND	ND	ND
1943	.			ND	ND	ND
1944	.			ND	ND	ND
1945	.			ND	ND	ND
1946	.			ND	ND	ND
1947	.			ND	ND	ND
1948	.			ND	ND	ND
1949	.			ND	ND	ND
1950	.			ND	ND	ND
1951	.			ND	ND	ND
1952	.			ND	ND	ND
1953	.			ND	ND	ND
1954	.			ND	ND	ND
1955	.			ND	ND	ND
1956	.			ND	ND	ND
1957	.			ND	ND	ND
1958	.			ND	ND	ND
1959	.			ND	ND	ND
1960	.			ND	ND	ND
1961	.			ND	ND	ND
1962	.			ND	ND	ND
1963	.			ND	ND	ND
1964	.			ND	ND	ND
1965	.			ND	ND	ND
1966	.			ND	ND	ND
1967	.			0.9434	0.0984	9.0449
1968	.			0.5923	0.0715	4.9047
1969	.			0.3719	0.0520	2.6605
1970	.			0.2336	0.0378	1.4438
1971	.			0.1467	0.0274	0.7841
1972	.			0.0921	0.0199	0.4262
1973	.			0.0578	0.0144	0.2319
1974	.			0.0363	0.0104	0.1264
1975	0.0228			0.0228	0.0075	0.0690
1976	.			0.0143	0.0054	0.0378
1977	.			0.0090	0.0039	0.0208
1978	.			0.0056	0.0028	0.0115
1979	.			0.0035	0.0019	0.0064
1980	.			0.0022	0.0013	0.0037
1981	.			0.0014	0.0009	0.0022
1982	.			0.0009	0.0006	0.0013
1983	0.0006	0.0003	0.0008	0.0006	0.0004	0.0009
1984	.			0.0003	0.0002	0.0006
1985	.			0.0002	0.0001	0.0004

ND = result undetermined

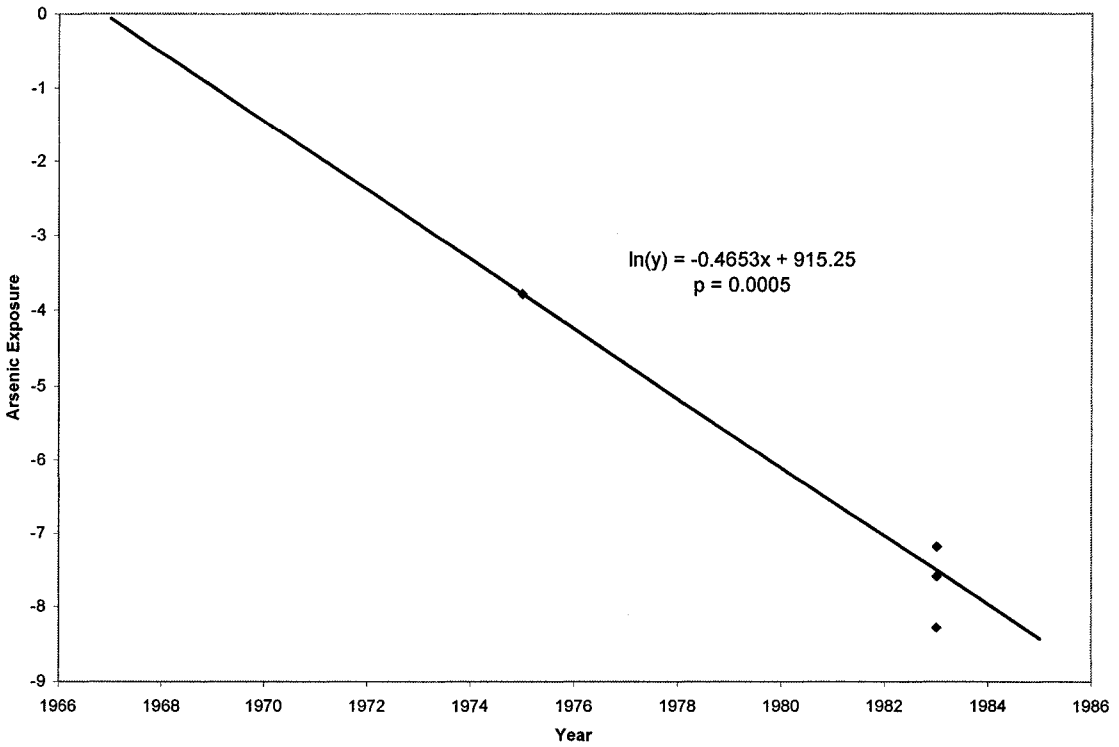

FIGURE 5.22 EXPOSURE MODEL, DEPARTMENT 12- WELDERS & BURNERS

TABLE 5.22 EXPOSURE ESTIMATES FOR DEPT. 12- WELDERS & BURNERS

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			ND	ND	ND
1941	.			ND	ND	ND
1942	.			ND	ND	ND
1943	.			ND	ND	ND
1944	.			ND	ND	ND
1945	.			ND	ND	ND
1946	.			ND	ND	ND
1947	.			ND	ND	ND
1948	.			ND	ND	ND
1949	.			ND	ND	ND
1950	.			ND	ND	ND
1951	.			ND	ND	ND
1952	.			ND	ND	ND
1953	.			ND	ND	ND
1954	.			ND	ND	ND
1955	.			ND	ND	ND
1956	.			ND	ND	ND
1957	.			ND	ND	ND
1958	.			ND	ND	ND
1959	.			ND	ND	ND
1960	.			ND	ND	ND
1961	.			ND	ND	ND
1962	.			ND	ND	ND
1963	.			ND	ND	ND
1964	.			ND	ND	ND
1965	.			ND	ND	ND
1966	.			ND	ND	ND
1967	.			0.9434	0.0984	9.0449
1968	.			0.5923	0.0715	4.9047
1969	.			0.3719	0.0520	2.6605
1970	.			0.2336	0.0378	1.4438
1971	.			0.1467	0.0274	0.7841
1972	.			0.0921	0.0199	0.4262
1973	.			0.0578	0.0144	0.2319
1974	.			0.0363	0.0104	0.1264
1975	0.0228			0.0228	0.0075	0.0690
1976	.			0.0143	0.0054	0.0378
1977	.			0.0090	0.0039	0.0208
1978	.			0.0056	0.0028	0.0115
1979	.			0.0035	0.0019	0.0064
1980	.			0.0022	0.0013	0.0037
1981	.			0.0014	0.0009	0.0022
1982	.			0.0009	0.0006	0.0013
1983	0.0006	0.0003	0.0008	0.0006	0.0004	0.0009
1984	.			0.0003	0.0002	0.0006
1985	.			0.0002	0.0001	0.0004

ND = result undetermined

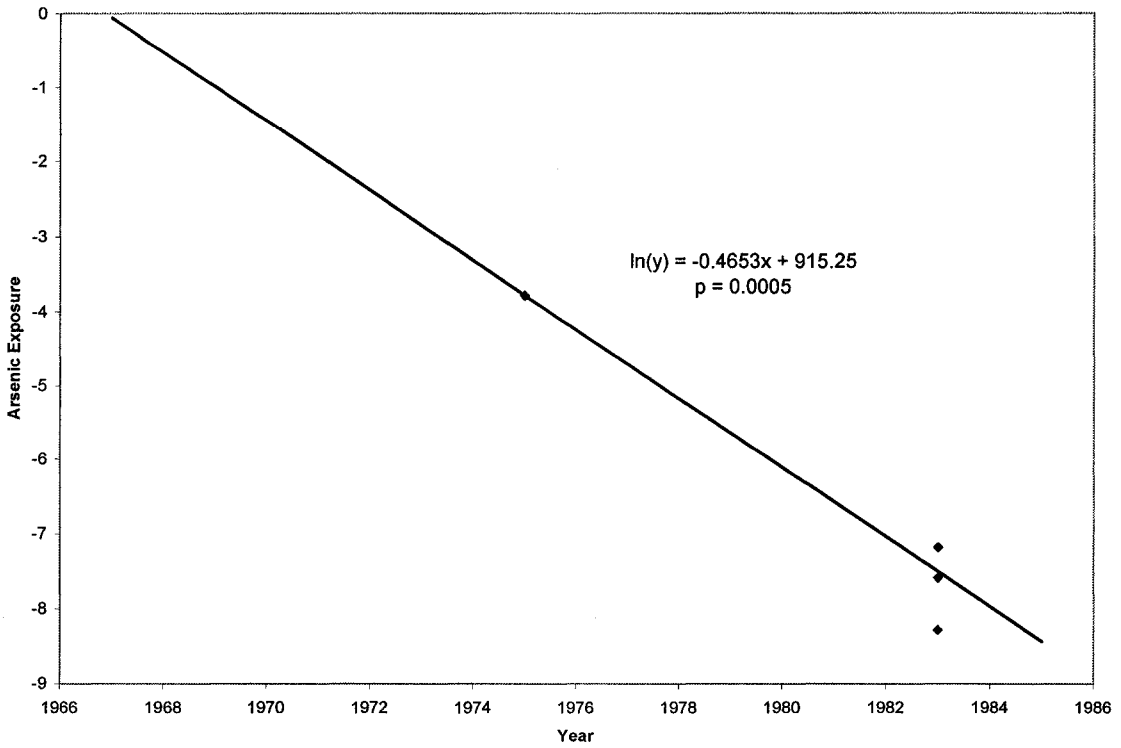

FIGURE 5.23 EXPOSURE MODEL, DEPARTMENT 13- CARPENTER

TABLE 5.23 EXPOSURE ESTIMATES FOR DEPT. 13- CARPENTER

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			ND	ND	ND
1941	.			ND	ND	ND
1942	.			ND	ND	ND
1943	.			ND	ND	ND
1944	.			ND	ND	ND
1945	.			ND	ND	ND
1946	.			ND	ND	ND
1947	.			ND	ND	ND
1948	.			ND	ND	ND
1949	.			ND	ND	ND
1950	.			ND	ND	ND
1951	.			ND	ND	ND
1952	.			ND	ND	ND
1953	.			ND	ND	ND
1954	.			ND	ND	ND
1955	.			ND	ND	ND
1956	.			ND	ND	ND
1957	.			ND	ND	ND
1958	.			ND	ND	ND
1959	.			ND	ND	ND
1960	.			ND	ND	ND
1961	.			ND	ND	ND
1962	.			ND	ND	ND
1963	.			ND	ND	ND
1964	.			ND	ND	ND
1965	.			ND	ND	ND
1966	.			ND	ND	ND
1967	.			0.9434	0.0984	9.0449
1968	.			0.5923	0.0715	4.9047
1969	.			0.3719	0.0520	2.6605
1970	.			0.2336	0.0378	1.4438
1971	.			0.1467	0.0274	0.7841
1972	.			0.0921	0.0199	0.4262
1973	.			0.0578	0.0144	0.2319
1974	.			0.0363	0.0104	0.1264
1975	0.0228			0.0228	0.0075	0.0690
1976	.			0.0143	0.0054	0.0378
1977	.			0.0090	0.0039	0.0208
1978	.			0.0056	0.0028	0.0115
1979	.			0.0035	0.0019	0.0064
1980	.			0.0022	0.0013	0.0037
1981	.			0.0014	0.0009	0.0022
1982	.			0.0009	0.0006	0.0013
1983	0.0006	0.0003	0.0008	0.0006	0.0004	0.0009
1984	.			0.0003	0.0002	0.0006
1985	.			0.0002	0.0001	0.0004

ND = result undetermined

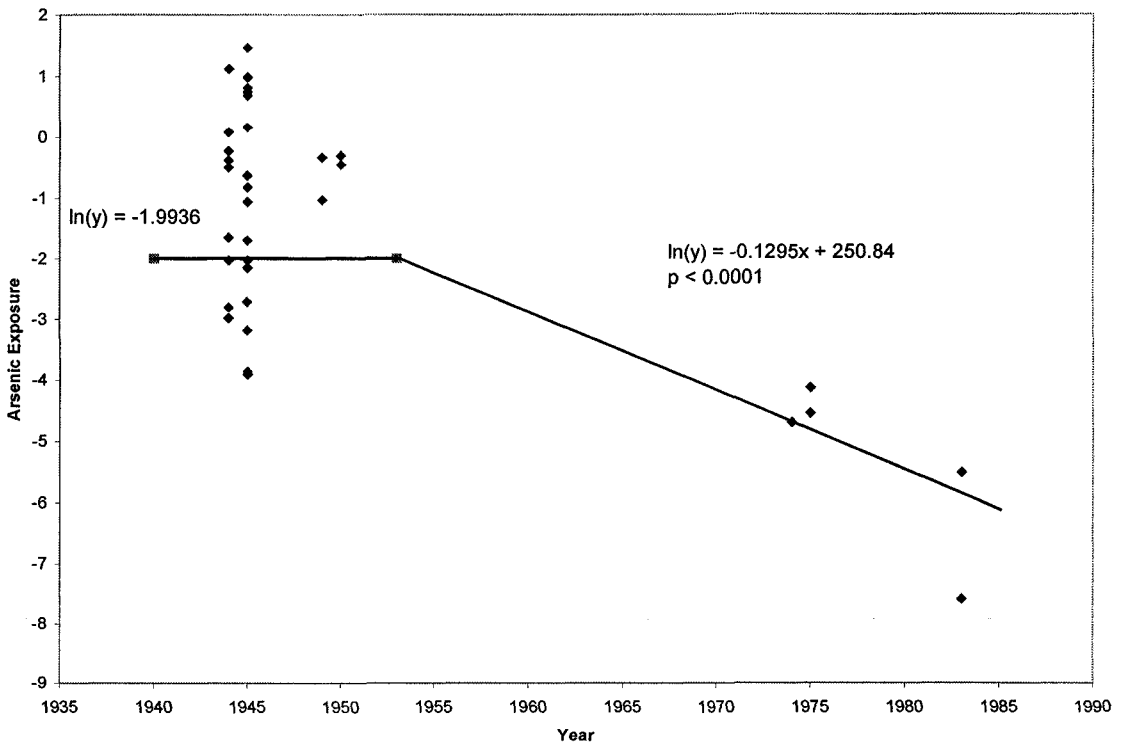

FIGURE 5.24 EXPOSURE MODEL, DEPARTMENT 14- AUTO TRUCK

TABLE 5.24 EXPOSURE ESTIMATES FOR DEPT. 14- AUTO TRUCK

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			0.1362	0.0794	0.2337
1941	.			0.1362	0.0794	0.2337
1942	.			0.1362	0.0794	0.2337
1943	.			0.1362	0.0794	0.2337
1944	0.3549	0.0510	3.0814	0.1362	0.0794	0.2337
1945	0.3415	0.0200	4.3366	0.1362	0.0794	0.2337
1946	.			0.1362	0.0794	0.2337
1947	.			0.1362	0.0794	0.2337
1948	.			0.1362	0.0794	0.2337
1949	0.5070	0.3585	0.7170	0.1362	0.0794	0.2337
1950	0.6851	0.6365	0.7375	0.1362	0.0794	0.2337
1951	.			0.1362	0.0794	0.2337
1952	.			0.1362	0.0794	0.2337
1953	.			0.1362	0.0794	0.2337
1954	.			0.1197	0.0689	0.2078
1955	.			0.1051	0.0596	0.1855
1956	.			0.0924	0.0514	0.1660
1957	.			0.0812	0.0442	0.1489
1958	.			0.0713	0.0379	0.1340
1959	.			0.0626	0.0325	0.1208
1960	.			0.0550	0.0278	0.1091
1961	.			0.0484	0.0237	0.0987
1962	.			0.0425	0.0202	0.0894
1963	.			0.0373	0.0172	0.0812
1964	.			0.0328	0.0146	0.0737
1965	.			0.0288	0.0124	0.0670
1966	.			0.0253	0.0105	0.0610
1967	.			0.0222	0.0089	0.0556
1968	.			0.0195	0.0075	0.0507
1969	.			0.0172	0.0064	0.0462
1970	.			0.0151	0.0054	0.0422
1971	.			0.0133	0.0046	0.0385
1972	.			0.0116	0.0039	0.0352
1973	.			0.0102	0.0033	0.0321
1974	0.0091			0.0090	0.0028	0.0294
1975	0.0131	0.0161	0.0106	0.0079	0.0023	0.0269
1976	.			0.0069	0.0020	0.0246
1977	.			0.0061	0.0017	0.0225
1978	.			0.0054	0.0014	0.0206
1979	.			0.0047	0.0012	0.0188
1980	.			0.0041	0.0010	0.0173
1981	.			0.0036	0.0008	0.0158
1982	.			0.0032	0.0007	0.0145
1983	0.0014	0.0005	0.0040	0.0028	0.0006	0.0133
1984	.			0.0025	0.0005	0.0121
1985	.			0.0022	0.0004	0.0111

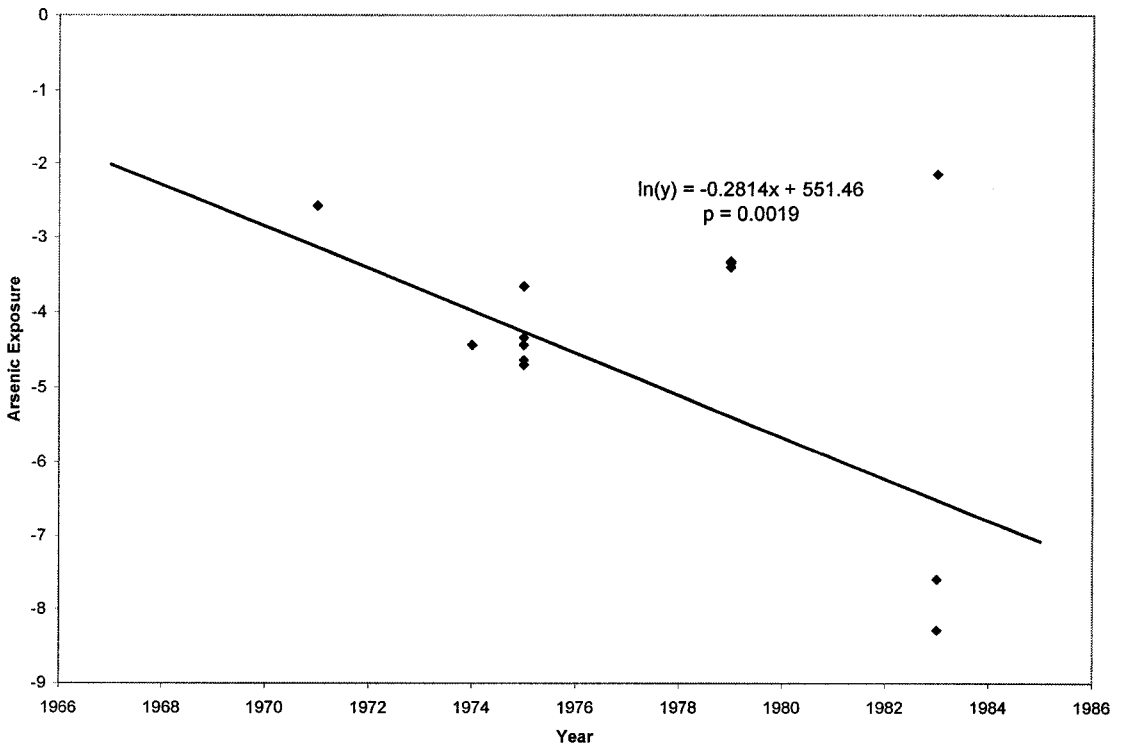

FIGURE 5.25 EXPOSURE MODEL, DEPARTMENT 15- JANITOR, LAUNDRY, GUARD

TABLE 5.25 EXPOSURE ESTIMATES FOR DEPT. 15- JANITOR, LAUNDRY, GUARD

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			ND	ND	ND
1941	.			ND	ND	ND
1942	.			ND	ND	ND
1943	.			ND	ND	ND
1944	.			ND	ND	ND
1945	.			ND	ND	ND
1946	.			ND	ND	ND
1947	.			ND	ND	ND
1948	.			ND	ND	ND
1949	.			ND	ND	ND
1950	.			ND	ND	ND
1951	.			ND	ND	ND
1952	.			ND	ND	ND
1953	.			ND	ND	ND
1954	.			ND	ND	ND
1955	.			ND	ND	ND
1956	.			ND	ND	ND
1957	.			ND	ND	ND
1958	.			ND	ND	ND
1959	.			ND	ND	ND
1960	.			ND	ND	ND
1961	.			ND	ND	ND
1962	.			ND	ND	ND
1963	.			ND	ND	ND
1964	.			ND	ND	ND
1965	.			ND	ND	ND
1966	.			ND	ND	ND
1967	.			0.1341	0.0223	0.8067
1968	.			0.1012	0.0196	0.5225
1969	.			0.0764	0.0172	0.3393
1970	.			0.0576	0.0150	0.2210
1971	0.0760			0.0435	0.0131	0.1447
1972	.			0.0328	0.0113	0.0953
1973	.			0.0248	0.0097	0.0634
1974	0.0119			0.0187	0.0082	0.0427
1975	0.0126	0.0091	0.0258	0.0141	0.0068	0.0294
1976	.			0.0107	0.0055	0.0208
1977	.			0.0080	0.0042	0.0152
1978	.			0.0061	0.0032	0.0117
1979	0.0349	0.0333	0.0361	0.0046	0.0023	0.0093
1980	.			0.0035	0.0016	0.0076
1981	.			0.0026	0.0011	0.0064
1982	.			0.0020	0.0007	0.0055
1983	0.0009	0.0003	0.1172	0.0015	0.0005	0.0047
1984	.			0.0011	0.0003	0.0041
1985	.			0.0008	0.0002	0.0036

ND = result undetermined

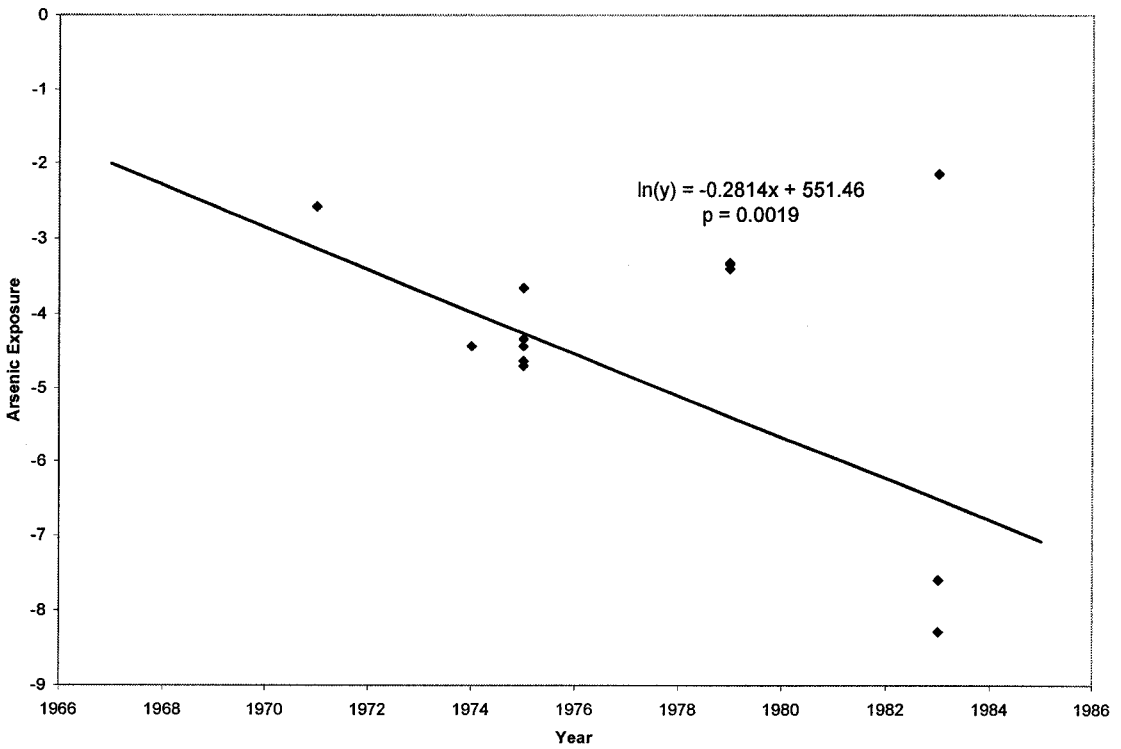

FIGURE 5.26 EXPOSURE MODEL, DEPARTMENT 17- GENERAL, NON-PRODUCTION

TABLE 5.26 EXPOSURE ESTIMATES FOR DEPT. 17- GENERAL, NON-PRODUCTION

Year	Measured (mg/m^3)	Range		Prediction	LCL	UCL
		Min	Max			
1940	.			ND	ND	ND
1941	.			ND	ND	ND
1942	.			ND	ND	ND
1943	.			ND	ND	ND
1944	.			ND	ND	ND
1945	.			ND	ND	ND
1946	.			ND	ND	ND
1947	.			ND	ND	ND
1948	.			ND	ND	ND
1949	.			ND	ND	ND
1950	.			ND	ND	ND
1951	.			ND	ND	ND
1952	.			ND	ND	ND
1953	.			ND	ND	ND
1954	.			ND	ND	ND
1955	.			ND	ND	ND
1956	.			ND	ND	ND
1957	.			ND	ND	ND
1958	.			ND	ND	ND
1959	.			ND	ND	ND
1960	.			ND	ND	ND
1961	.			ND	ND	ND
1962	.			ND	ND	ND
1963	.			ND	ND	ND
1964	.			ND	ND	ND
1965	.			ND	ND	ND
1966	.			ND	ND	ND
1967	.			0.1341	0.0223	0.8067
1968	.			0.1012	0.0196	0.5225
1969	.			0.0764	0.0172	0.3393
1970	.			0.0576	0.0150	0.2210
1971	0.0760			0.0435	0.0131	0.1447
1972	.			0.0328	0.0113	0.0953
1973	.			0.0248	0.0097	0.0634
1974	0.0119			0.0187	0.0082	0.0427
1975	0.0126	0.0091	0.0258	0.0141	0.0068	0.0294
1976	.			0.0107	0.0055	0.0208
1977	.			0.0080	0.0042	0.0152
1978	.			0.0061	0.0032	0.0117
1979	0.0349	0.0333	0.0361	0.0046	0.0023	0.0093
1980	.			0.0035	0.0016	0.0076
1981	.			0.0026	0.0011	0.0064
1982	.			0.0020	0.0007	0.0055
1983	0.0009	0.0003	0.1172	0.0015	0.0005	0.0047
1984	.			0.0011	0.0003	0.0041
1985	.			0.0008	0.0002	0.0036

ND = result undetermined

The final arsenic exposure matrices are presented in Tables 5.27 and 5.28. Values were compiled for all departments and years from 1940-1985. Table 5.27 presents a matrix of the predicted arsenic exposure values generated from the models and Table 5.28 presents one of the geometric mean of the measured arsenic exposure values derived from the methods and procedures in this study.

TABLE 5.27 EXPOSURE MATRIX- PREDICTED ARSENIC EXPOSURE ESTIMATES

ID	Department	1940-1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
1a	FOREMAN	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1b	CALCINE DEPARTMENT	0.0641	0.0619	0.0597	0.0576	0.0556	0.0536	0.0517	0.0499	0.0482	0.0465	0.0448	0.0433	0.0417
1c	MIXERS & SCREENER	0.0641	0.0619	0.0597	0.0576	0.0556	0.0536	0.0517	0.0499	0.0482	0.0465	0.0448	0.0433	0.0417
1e	SOLUTION OPERATORS & PRESSMAN	0.0063	0.0058	0.0053	0.0048	0.0044	0.0041	0.0037	0.0034	0.0031	0.0029	0.0026	0.0024	0.0022
1f	SOLUTION CHARGER	0.0063	0.0058	0.0053	0.0048	0.0044	0.0041	0.0037	0.0034	0.0031	0.0029	0.0026	0.0024	0.0022
1h	PIGMENT PLANT	0.0063	0.0058	0.0053	0.0048	0.0044	0.0041	0.0037	0.0034	0.0031	0.0029	0.0026	0.0024	0.0022
1i	GASMAN - SULFIDE	0.0063	0.0058	0.0053	0.0048	0.0044	0.0041	0.0037	0.0034	0.0031	0.0029	0.0026	0.0024	0.0022
1l	TANKHOUSE & ELECTROLYTIC	0.0063	0.0058	0.0053	0.0048	0.0044	0.0041	0.0037	0.0034	0.0031	0.0029	0.0026	0.0024	0.0022
1m	RETORT OPERATOR	0.0063	0.0058	0.0053	0.0048	0.0044	0.0041	0.0037	0.0034	0.0031	0.0029	0.0026	0.0024	0.0022
1n	CASTER	0.0063	0.0058	0.0053	0.0048	0.0044	0.0041	0.0037	0.0034	0.0031	0.0029	0.0026	0.0024	0.0022
1o	WEIGHER AND PACKER	0.0063	0.0058	0.0053	0.0048	0.0044	0.0041	0.0037	0.0034	0.0031	0.0029	0.0026	0.0024	0.0022
3	ACID RECOVERY PLANT	0.0641	0.0619	0.0597	0.0576	0.0556	0.0536	0.0517	0.0499	0.0482	0.0465	0.0448	0.0433	0.0417
4a	LOADING GANG WORKMAN	0.1362	0.1197	0.1051	0.0924	0.0812	0.0713	0.0626	0.0550	0.0484	0.0425	0.0373	0.0328	0.0288
4b	CONC. & DRY DUST	0.1362	0.1197	0.1051	0.0924	0.0812	0.0713	0.0626	0.0550	0.0484	0.0425	0.0373	0.0328	0.0288
4c	GENERAL LABORER, UNLOADING	0.1362	0.1197	0.1051	0.0924	0.0812	0.0713	0.0626	0.0550	0.0484	0.0425	0.0373	0.0328	0.0288
5	SAMPLING	0.1211	0.1072	0.0949	0.0840	0.0744	0.0658	0.0583	0.0516	0.0457	0.0404	0.0358	0.0317	0.0281
6	CRUSHING	0.1211	0.1072	0.0949	0.0840	0.0744	0.0658	0.0583	0.0516	0.0457	0.0404	0.0358	0.0317	0.0281
7	ROASTING	0.1211	0.1072	0.0949	0.0840	0.0744	0.0658	0.0583	0.0516	0.0457	0.0404	0.0358	0.0317	0.0281
10a	MACHINE SHOP	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10b	MAINTENANCE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11	ELECTRICAL SHOP	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
12	WELDERS & BURNERS	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
13	CARPENTER	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14	AUTO TRUCK	0.1362	0.1197	0.1051	0.0924	0.0812	0.0713	0.0626	0.0550	0.0484	0.0425	0.0373	0.0328	0.0288
15	JANITOR - LAUNDRY - GUARD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
17	GENERAL, NON-PRODUCTION	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = result undetermined

ID	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1a	ND	0.1185	0.0838	0.0593	0.0420	0.0297	0.0210	0.0149	0.0105	0.0074	0.0053	0.0037	0.0026	0.0019
1b	0.0403	0.0389	0.0375	0.0362	0.0349	0.0337	0.0325	0.0313	0.0302	0.0292	0.0282	0.0272	0.0262	0.0253
1c	0.0403	0.0389	0.0375	0.0362	0.0349	0.0337	0.0325	0.0313	0.0302	0.0292	0.0282	0.0272	0.0262	0.0253
1e	0.0020	0.0019	0.0017	0.0016	0.0014	0.0013	0.0012	0.0011	0.0010	0.0009	0.0009	0.0008	0.0007	0.0007
1f	0.0020	0.0019	0.0017	0.0016	0.0014	0.0013	0.0012	0.0011	0.0010	0.0009	0.0009	0.0008	0.0007	0.0007
1h	0.0020	0.0019	0.0017	0.0016	0.0014	0.0013	0.0012	0.0011	0.0010	0.0009	0.0009	0.0008	0.0007	0.0007
1i	0.0020	0.0019	0.0017	0.0016	0.0014	0.0013	0.0012	0.0011	0.0010	0.0009	0.0009	0.0008	0.0007	0.0007
1l	0.0020	0.0019	0.0017	0.0016	0.0014	0.0013	0.0012	0.0011	0.0010	0.0009	0.0009	0.0008	0.0007	0.0007
1m	0.0020	0.0019	0.0017	0.0016	0.0014	0.0013	0.0012	0.0011	0.0010	0.0009	0.0009	0.0008	0.0007	0.0007
1n	0.0020	0.0019	0.0017	0.0016	0.0014	0.0013	0.0012	0.0011	0.0010	0.0009	0.0009	0.0008	0.0007	0.0007
1o	0.0020	0.0019	0.0017	0.0016	0.0014	0.0013	0.0012	0.0011	0.0010	0.0009	0.0009	0.0008	0.0007	0.0007
3	0.0403	0.0389	0.0375	0.0362	0.0349	0.0337	0.0325	0.0313	0.0302	0.0292	0.0282	0.0272	0.0262	0.0253
4a	0.0253	0.0222	0.0195	0.0172	0.0151	0.0133	0.0116	0.0102	0.0090	0.0079	0.0069	0.0061	0.0054	0.0047
4b	0.0253	0.0222	0.0195	0.0172	0.0151	0.0133	0.0116	0.0102	0.0090	0.0079	0.0069	0.0061	0.0054	0.0047
4c	0.0253	0.0222	0.0195	0.0172	0.0151	0.0133	0.0116	0.0102	0.0090	0.0079	0.0069	0.0061	0.0054	0.0047
5	0.0248	0.0220	0.0195	0.0172	0.0153	0.0135	0.0120	0.0106	0.0094	0.0083	0.0073	0.0065	0.0058	0.0051
6	0.0248	0.0220	0.0195	0.0172	0.0153	0.0135	0.0120	0.0106	0.0094	0.0083	0.0073	0.0065	0.0058	0.0051
7	0.0248	0.0220	0.0195	0.0172	0.0153	0.0135	0.0120	0.0106	0.0094	0.0083	0.0073	0.0065	0.0058	0.0051
10a	ND	0.9434	0.5923	0.3719	0.2336	0.1467	0.0921	0.0578	0.0363	0.0228	0.0143	0.0090	0.0056	0.0035
10b	ND	0.9434	0.5923	0.3719	0.2336	0.1467	0.0921	0.0578	0.0363	0.0228	0.0143	0.0090	0.0056	0.0035
11	ND	0.9434	0.5923	0.3719	0.2336	0.1467	0.0921	0.0578	0.0363	0.0228	0.0143	0.0090	0.0056	0.0035
12	ND	0.9434	0.5923	0.3719	0.2336	0.1467	0.0921	0.0578	0.0363	0.0228	0.0143	0.0090	0.0056	0.0035
13	ND	0.9434	0.5923	0.3719	0.2336	0.1467	0.0921	0.0578	0.0363	0.0228	0.0143	0.0090	0.0056	0.0035
14	0.0253	0.0222	0.0195	0.0172	0.0151	0.0133	0.0116	0.0102	0.0090	0.0079	0.0069	0.0061	0.0054	0.0047
15	ND	0.1341	0.1012	0.0764	0.0576	0.0435	0.0328	0.0248	0.0187	0.0141	0.0107	0.0080	0.0061	0.0046
17	ND	0.1341	0.1012	0.0764	0.0576	0.0435	0.0328	0.0248	0.0187	0.0141	0.0107	0.0080	0.0061	0.0046

ND = result undetermined

ID	1980	1981	1982	1983	1984	1985
1a	0.0013	0.0009	0.0007	0.0005	0.0003	0.0002
1b	0.0244	0.0235	0.0227	0.0219	0.0212	0.0204
1c	0.0244	0.0235	0.0227	0.0219	0.0212	0.0204
1e	0.0006	0.0006	0.0005	0.0005	0.0004	0.0004
1f	0.0006	0.0006	0.0005	0.0005	0.0004	0.0004
1h	0.0006	0.0006	0.0005	0.0005	0.0004	0.0004
1i	0.0006	0.0006	0.0005	0.0005	0.0004	0.0004
1l	0.0006	0.0006	0.0005	0.0005	0.0004	0.0004
1m	0.0006	0.0006	0.0005	0.0005	0.0004	0.0004
1n	0.0006	0.0006	0.0005	0.0005	0.0004	0.0004
1o	0.0006	0.0006	0.0005	0.0005	0.0004	0.0004
3	0.0244	0.0235	0.0227	0.0219	0.0212	0.0204
4a	0.0041	0.0036	0.0032	0.0028	0.0025	0.0022
4b	0.0041	0.0036	0.0032	0.0028	0.0025	0.0022
4c	0.0041	0.0036	0.0032	0.0028	0.0025	0.0022
5	0.0045	0.0040	0.0035	0.0031	0.0028	0.0025
6	0.0045	0.0040	0.0035	0.0031	0.0028	0.0025
7	0.0045	0.0040	0.0035	0.0031	0.0028	0.0025
10a	0.0022	0.0014	0.0009	0.0006	0.0003	0.0002
10b	0.0022	0.0014	0.0009	0.0006	0.0003	0.0002
11	0.0022	0.0014	0.0009	0.0006	0.0003	0.0002
12	0.0022	0.0014	0.0009	0.0006	0.0003	0.0002
13	0.0022	0.0014	0.0009	0.0006	0.0003	0.0002
14	0.0041	0.0036	0.0032	0.0028	0.0025	0.0022
15	0.0035	0.0026	0.0020	0.0015	0.0011	0.0008
17	0.0035	0.0026	0.0020	0.0015	0.0011	0.0008

ND = result undetermined

TABLE 5.28 EXPOSURE MATRIX- ACTUAL ARSENIC EXPOSURE ESTIMATES

ID	Department	1944	1945	1949	1950	1964	1970	1971	1973
1a	FOREMAN	.	.	.	.	.	0.0090	.	0.0100
1b	CALCINE DEPARTMENT	0.0106	0.0071	.	0.0985	0.0212	.	.	.
1c	MIXERS & SCREENER	0.4316	.	.	0.0485	.	.	.	.
1e	SOLUTION OPERATORS & PRESSMAN	.	.	.	.	.	.	.	.
1f	SOLUTION CHARGER	.	0.0100	.	.	.	.	.	.
1h	PIGMENT PLANT	.	.	.	.	.	.	.	.
1i	GASMAN - SULFIDE	.	.	.	.	.	.	.	.
1l	TANKHOUSE & ELECTROLYTIC	.	.	.	.	.	.	.	.
1m	RETORT OPERATOR	.	.	.	.	.	.	.	0.0004
1n	CASTER	.	.	.	.	.	.	.	0.0004
1o	WEIGHER AND PACKER	.	.	.	.	.	.	.	.
3	ACID RECOVERY PLANT	0.4378	0.1071	.	.	.	.	.	.
4a	LOADING GANG WORKMAN	.	.	.	.	.	.	.	.
4b	CONC. & DRY DUST	0.2589	0.3842	0.3803	0.5138	.	.	.	.
4c	GENERAL LABORER, UNLOADING	.	.	.	.	.	.	.	.
5	SAMPLING	.	.	.	.	.	.	.	.
6	CRUSHING	0.0575	.	.	.	.	.	.	.
7	ROASTING	0.2969	1.1329	.	.	.	.	.	.
10a	MACHINE SHOP	.	.	.	.	.	.	.	.
10b	MAINTENANCE	.	.	.	.	.	.	.	.
11	ELECTRICAL SHOP	.	.	.	.	.	.	.	.
12	WELDERS & BURNERS	.	.	.	.	.	.	.	.
13	CARPENTER	.	.	.	.	.	.	.	.
14	AUTO TRUCK	0.3142	0.5997	.	.	.	.	.	.
15	JANITOR - LAUNDRY - GUARD	.	.	.	.	.	.	0.0760	.
17	GENERAL, NON-PRODUCTION	.	.	.	.	.	.	.	.

ID	1974	1975	1979	1980	1981	1983
1a	0.0143	0.0120	.	.	.	0.0005
1b	0.0132	0.0338	0.0153	0.0460	0.0427	0.0365
1c	0.0169	0.0087	0.0518	0.1242	.	0.0520
1e	0.0091	0.0119	.	.	0.0008	0.0114
1f	.	.	.	.	.	0.0053
1h	.	.	.	.	.	.
1i	.	.	.	.	.	.
1l	.	.	.	.	.	0.0003
1m	.	.	.	0.0004	.	0.0004
1n	.	.	.	.	0.0010	0.0004
1o	.	.	.	.	.	0.0005
3	.	.	.	.	.	0.0005
4a	.	.	.	.	.	.
4b	.	.	.	.	.	.
4c	.	.	.	.	.	0.0005
5	0.0182	.	.	.	.	0.0013
6	.	.	.	.	.	.
7	.	0.0094	.	.	.	.
10a	.	.	.	.	.	0.0003
10b	.	.	.	.	.	0.0006
11	.	.	.	.	.	0.0008
12	.	0.0228	.	.	.	0.0008
13	.	.	.	.	.	0.0005
14	0.0091	0.0131	.	.	.	0.0040
15	0.0119	0.0108	.	.	.	0.0005
17	0.0119	0.0184	0.0349	.	.	0.0013

CHAPTER 6 DISCUSSION

Retrospective long-term exposure estimates for jobs can be difficult to determine and require many assumptions. Although several sources of uncertainty should be considered when interpreting the results from this analysis, the strength of the estimates developed lies in the foundation of the information on which they are based. Although the existing exposure data was sparse, the historical qualitative and descriptive information available regarding the facility, operation, and procedures was extensive and provided assistance with portraying an accurate picture of this working environment and ensuring the calculation of reasonable estimates. The use of the available industrial hygiene data strengthened the validity of the estimated values. However, the lack of data for all departments necessitated that much of the individual exposure data be based on assumptions and perceived predicted values. The uncertainties associated with these historical projections and the variability in exposures are described in the following sections.

6.1 Relating Data by Sampling Instrument Type

The data used in this method came from several sources and spanned many years. Over the course of the years that this study encompassed, the sampling instruments and techniques employed in each survey varied greatly. Previous studies have excluded the early sampling data taken at the plant from their analyses due to the use of different instruments and sampling methods during the earlier years (6). In this work, all measurements are included to enhance the

data set. However, in order to use these data in the study, the adjustment was necessary to compensate for sampling differences.

The inherent inefficiencies of sampling instrumentation vary in relation to particle size (62). Because no particle sizing was performed during the sampling events at the plant, information on the characteristics of the aerosol present in the sampling areas was used to estimate the particle sizes of the dust and fumes collected. One source of uncertainty was determining the values used to represent the collection efficiencies of the instruments. An incorrect assumption of the particle size would have in turn caused an incorrect determination of the efficiency. The results from determining the instrument efficiency may have been more accurate if more information was known about the particle size of the material collected. A study containing particle size distribution information for the environment would have increased the certainty of the instrument efficiencies estimated.

It was also assumed that the sampling was obtained in a standard manner, i.e. the instruments were properly calibrated and the flow, sampling media, and method were appropriate to adequately sample for the material of interest. In absence of information to the contrary, this assumption is not unreasonable.

Because the collection efficiencies used were all close to 100 percent, the adjustment factor used in this step may seem negligible compared to other

adjustments or errors associated with the estimation process. Although small, it was believed that it was a necessary step in accurately portraying these exposures.

6.2 Relating General Area Data and Personal Monitoring Data

Previous studies debate if area and personal data can be correlated (6,70-72). Studies have shown the differences in sampling results between these types of samples and the importance of relating these exposures (70-71). Breslin was unable to demonstrate a good relationship between the personal measurement and the calculated time-weighted exposure using area and hand-held sampler data (68). Also Sherwood found that area sampling would underestimate workers' exposures where the contamination resulted from the task (71). However, it has been shown that area and personal sample results are correlated, despite day-to-day variations, if certain variables are controlled including time of workers' activities and respirator use (6). Even if area data may not be useful for estimating a given day's exposure, these area data can be used for a general relationship to personal data if certain factors remain constant. The adjustment performed on the data was based on the assumption that the ratio between the area measurements and personal exposure in this plant was relatively constant. This limitation of the study is reasonable due to the fact that the ratios were calculated from geometric means of several measurements since individual samples can vary widely, and as described elsewhere (6), the same sampling locations were used for area samples for the last 20 years, and the jobs

are routine, well-defined, limited by area, and did not change significantly in the past 40 years. Because of this, the area samples should reflect the environmental conditions and should bear a general relationship to the personal exposures of that department's employees since workers tended to only carry-out a single task for the majority of their workday. A future study could include documentation of the area sample locations and an evaluation of their relevance. Another limitation of this method was the existence of such few data in the early years. Relations were created, but would have been easier to explore with more data to support them. Also the installation of engineering controls may have had an effect of these relationships.

An additional limitation of the data used in this method was that it wasn't broken down by task. The estimates calculated for this study were by department. It was assumed, because of lack of specific information, that all jobs and tasks in a department received identical exposures. Also, this method did not quantify time-weighted exposures by job activity as would typically be necessary in this kind of estimation. Because the area results were adjusted by the personal results, specifically accounting for the time in job activities was deemed not necessary. The personal samples taken would already include these differences. By applying the calculated area/ personal ratio, these factors would inherently be included in the estimates.

6.3 Relating Feedstock Arsenic Data and Airborne Arsenic Exposure Data

Other studies have demonstrated that airborne arsenic concentrations may be related to feedstock arsenic operations (4,37). Also, OSHA states that it "believes that it is questionable as to whether the amount of arsenic processed or the arsenic concentration of the ore is a better indicator of worker exposures. It seems reasonable that the amount of fugitive dust present would be likely to be related to the total amount of ore processed and not to the arsenic content. If so, then the total amount of arsenic processed is likely to be a better predictor of the total amount of arsenic released into the air" (85). Because of these statements, the methods in this study included analysis of the relationship between air levels of arsenic and both arsenic percent in the feedstock and total amount of arsenic processed. However, in this study, the results did not indicate any significant relations. This was believed to have occurred because although a decreasing trend was shown in the air dataset; neither feedstock dataset showed a significant decreasing trend causing the arsenic levels to be uncorrelated. Hence, it can be assumed that the decreasing arsenic air level was not a direct result of levels in the feedstock because the levels of arsenic in the air continued to fall when the levels of arsenic in the feedstock did not. It is the believed that other factors existed to affect the amount arsenic that was airborne in the plant. As the feedstock was processed in the operation, factors such as ventilation, engineering controls installed to control air contamination, and production rate would have had an effect on the amount of material that became airborne.

Because specific information regarding these factors was not available, it was impossible to derive a relation based on feedstock alone.

6.4 Relating Biological Monitoring Data and Air Exposure Data

Several methods for converting urinary arsenic to airborne arsenic have been previously developed (74-81). Because of the sampling data, the model developed by Pinto (74,75) was used in this study. Several reasons support this decision. The facility in the Pinto study was also owned by ASARCO. It was assumed that the company's practices of biological sampling would be similar in both plants. In addition, the data on which the model was based is similar to the data available for this study. Also this model was used by a previous investigator of this facility for airborne arsenic estimations (2). Based on qualitative review of the data, it was determined that the data produced by this method were similar to the other data available for these years and departments. Hence, the data were added to the matrix without further adjustment.

One source of uncertainty for this method is the existence of several confounders related to the presence of arsenic in urine. Gender, age, and alcohol intake have all been found to have significant effect on urinary arsenic levels. Fish and other seafood products are known to contain high concentrations of arsenic which may also affect urinary arsenic results (82). However, no data are available to evaluate these factors in this working population.

6.5 Developing Exposure Adjustment Factors

The development of a factor to adjust the exposure estimates was necessary to describe the concentration of contaminant that the worker potentially absorbed and not solely what the airborne level would have been. The factor developed takes into account the variable deposition of arsenic from interpersonal differences in physiology, such as breathing rate and lung size; interpersonal differences in work practices, hygiene and habits; and the variation in protection each worker would have received from his respirator.

In Smith's study, the respirator tested was an air purifying respirator with a cartridge useful for "acid gas and fume". This study was conducted in a controlled setting (45). The protection factor developed from that data was then applied to all exposures across all years in that study. It was questioned whether this technique was adequate or appropriate for the situation in the present study. Hence, applying a single factor to every year was deemed inappropriate. In this study, protection factors were developed for different time periods because of changes in procedures and practices relating to the respirators. Initially, discussion of this issue produced three preliminary adjustment factors. These included: zero for years prior to 1940, one to two for the period from 1940-1975, and 3.9 for the years after 1975. These numbers were developed from adjusting the protection factor developed by Smith in a study conducted at this facility (45) and from conversations with Dr. Smith regarding this issue. These factors vary because they may be affected by the department, type of respirator, use and

personal hygiene programs. In each department the respirator requirements, the presence of feedstock, and the arsenic content of the feedstock varied. The year may be used as a surrogate for protection because of products and practices. Earlier years would have seen less protection from the respirators than later years. Substantial variations in personal protection would be expected between workers, and from day-to-day. These variations are expected because respirators were used intermittently (as needed) throughout the day, under a variety of exposure conditions. Often respirator use was not enforced and workers and management may have been unaware of the existence of small particles present in the air that were unable to be seen but may have represented substantial exposure. The respirator could vary by type and efficiency of the cartridge used, fit, physical factors that would have affected dead space, respiratory stress and rate, and leakage. The majority of variation in exposures is due to worker factors such as habits and personal hygiene. This would affect the frequency of use, correct usage, and maintenance of the respirator. Anecdotal evidence reveals that the respirator requirement of some departments was not always strictly enforced and workers were known to only wear the respirators when they felt a respirator was necessary (48). As noted in previous studies (40,41) and the industrial hygiene reports (51,52), the workers in several areas such as retort and grinding and bucking were not wearing respirators at all or only wearing a handkerchief over the nose and mouth. Also when not in use, the respirators were seen hanging around the workers' neck. In addition, personal factors may affect the fit of the respirator. These factors include facial

hair, glasses, dentures, scars, changes in body weight, and facial bone structure. Data from fit testing would account for these variables. Additional exposures through ingestion from contaminated hands, mouth, food, cigarettes, and clothes may also have occurred.

The method chosen to assess these variables included a model relating airborne and urinary cadmium developed by Smith from his research at the facility (6). The method was chosen because of its simple ability to account for the myriad of variables described above without necessarily quantifying every variable's effect on exposures. The model was chosen because of many similarities to the present study. It was developed at the same facility, on the same set of employees, and under the same exposure conditions as seen in this study.

Naturally, the protection factor was not constant over the 45-year study period. As expected, earlier years were associated with less protection than later years. It was encouraging to discover that the factors were consistent with previous studies of this population (45).

6.6 Estimating Exposure Values

6.6.1 Arsenic Exposure Estimates

The main finding of this study indicates that airborne concentrations of arsenic were present in the environment of the plant beyond the time that the plant ceased operations as an arsenic smelter. Approximately 55 percent of all of the

estimates and 76 percent of the estimates for high exposure departments exceeded the current OSHA PEL and ACGIH TLV (9) of 0.01 mg/m3 for arsenic.

Although the estimates of average air exposure to arsenic rest on several assumptions, they are actually more likely to be underestimates than overestimates. The possibility that the results are over estimates of the exposures seems unlikely because of several factors. The 1945 IH report (51) states in several places that ventilation controls are greatly needed. Even in 1979 and as late as 1989, OSHA citations included violations for over exposure to arsenic, failure to institute engineering and work practice controls to lower exposure, and failure to provide facilities for employees to clean or change clothes (87,88). Also, a NIOSH Health Hazard Evaluation in 1989 showed biological monitoring data for cadmium and arsenic which exceeded recommended limits (89). This evidence would indicate that the actual exposures were higher than what was able to be quantified by the existing data.

Some sources of error of estimating exposure based on air levels include ingestion of arsenic-contaminated food, poor personal hygiene causing contaminated hands and face, smoking, and absorption of arsenic through skin by contact with contaminated dust. The enforcement of regulatory standards would also affect worker exposure. These include requiring workers to wear respirators, access to clean rooms and showers, and the cleaning of respirators.

Although it is impossible to determine the historical exposures in the departments excluded (2- Indium, 8- Lead, 9- Thallium, 16- Arsenic), general exposures can be projected based on the material processed in the department. Because the nature of the smelting process results in localized areas of certain exposures, in all probability, the departments excluded from the matrix had negligible arsenic or cadmium exposures. These departments were not researched during this study, so the process (and source of exposures) in these departments was largely unknown. The recovery of indium took place in a separate building with processing equipment using various smelter by-products (50). The lead/litharge was produced from lead origination and relatively free of impurities. It was processed at the Globe plant with equipment relocated from another ASARCO smelter (50). Thallium was recovered in small quantities, most likely on a laboratory scale, from a smelting by-product solution from which the cadmium had been removed (50). In the arsenic department, arsenic trioxide was purchased as a feed material and refined by a laboratory-scale process to produce a high-purity arsenic material (48, 49). All laboratory procedures were carried-out under hoods and ventilation (48).

6.6.2 Discussion of Models

Several models for estimation were developed and considered. Finally, the shape of this model was accepted as the most appropriate for this data at this time. These were created by taking into account qualitative information (for flat part) and quantitative information (for linear part). The models developed were

based on the consideration of information from many sources of literature (48-52, 87-89). The point of 1953 was chosen as the best indication of environmental changes from a historical characterization of the facility during the study period. Based on the literature (49-52), from 1940 to 1953, no significant process changes occurred. In 1953, however, several noteworthy changes took place in the plant to initiate the beginning of a decreasing trend in exposures. During this time, a major process change occurred- the Godfrey Roasters ceased processing the incoming feed and most of the concentrating was done at the roaster in El Paso from then on. The Globe Godfrey Roaster was then primarily used for recovery of cadmium from the process by-product materials. Also around this time, major engineering controls and ventilation improvements took place. A hygiene rehabilitation program throughout the plant had begun to "control hazardous operations" (50). Ventilation was installed in every building for most every process. Also the mist precipitator and Cotrell gas cleaner were installed to control emissions, including arsenic fume, from the calcining operation. As other researchers agree, the effect of an alteration in the process and operating characteristics of the production, as well as the installation of exposure control devices, on the exposure is very likely to be more drastic than the effect of any other parameter possible to affect exposures (85). Following this time, other changes took place that worked to continually decrease arsenic levels. These include process changes, i.e. use of tote bags that would have decreased dust exposure. In later years, the Godfrey Roaster was only operated intermittently- one to three months a year- until its use was discontinued entirely

in 1977. Also because of compliance requirements, the establishment of OSHA in 1970 may have had an impact on exposures and practices at the plant.

In the future, the study could be enhanced by further analysis of several factors. Other sources of data could be investigated. The feedstock data could be reanalyzed for usefulness and data from plants with similar processes could be explored. More complex models could be developed including more variables or more steps. It seems reasonable that exposures could be dependant on variables other than department or year and would decrease in a step-wise fashion. Also the adjustment factor could be stratified by either production or non-production departments and the data from the sampling surveys could be adjusted for differences in analytical techniques across the 46 year span.

6.6.3 Cadmium Exposure Estimates

The inclusion of the cadmium job exposure matrix was beneficial to this study by supplementing air exposure estimates for departments with no/ minimal arsenic exposure.

CHAPTER 7 CONCLUSIONS

As a result of the limitations described, the estimates of inhalation exposure are realistically at best semi-quantitative, and the precision was probably not as good for the earlier exposures as for the later ones. However, all the exposure estimates can be assumed to be reasonable based on information available regarding the plant, process, and work practices (23,48-59,87-89). This information provides further support for the quality of the exposure estimates. All departments with expected high exposures have similar results, i.e. exposures were highest for the departments that handled and processed the incoming feedstock. The same is true for departments expected to have low exposures, i.e. exposures were lowest for the non-production departments, those not directly related to the process.

Overall, it was concluded that this dataset, although limited, provides useful information on the levels of inhalation exposures associated with airborne arsenic. Although forced to make a number of assumptions, the findings were consistent with previous investigations (2,3,6).

The exposure information outlined here provides researchers with a tool helpful in characterizing workers' potential arsenic exposure during their tenure at the facility. Future studies can use the information provided here to characterize a worker's individual exposure and evaluate the risk of adverse health outcomes as related to that exposure. This data will be used in a re-analysis of the Globe

smelter cohort for lung cancer mortality that takes into account both exposure to cadmium and arsenic will be an important addition to the body of research that exists for this cohort and for cadmium and arsenic exposures in general.

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APPENDIX

Job Dictionary for ASARCO Globe Plant

Dept. ID	Department Name
1a	FOREMAN
1b	CALCINE DEPARTMENT
1c	MIXERS & SCREENER
1e	SOLUTION OPERATORS & PRESSMAN
1f	SOLUTION CHARGER
1h	PIGMENT PLANT
1i	GASMAN - SULFIDE
1l	TANKHOUSE & ELECTROLYTIC
1m	RETORT OPERATOR
1n	CASTER
1o	WEIGHER AND PACKER
2	INDIUM PLANT
3	ACID RECOVERY PLANT
4a	LOADING GANG WORKMAN
4b	CONC. & DRY DUST
4c	GENERAL LABORER, UNLOADING
5	SAMPLING
6	CRUSHING
7	ROASTING
8	LEAD
9	THALLIUM
10a	MACHINE SHOP
10b	MAINTENANCE
11	ELECTRICAL SHOP
12	WELDERS & BURNERS
13	CARPENTER
14	AUTO TRUCK
15	JANITOR - LAUNDRY - GUARD
16	ARSENIC
17	GENERAL-(NON-PRODUCTION) ADMINISTRATION, LAB, METALLURGIST

	FOREMAN
1A	assistant plant foreman
1A	foreman
	CALCINE DEPARTMENT
1B	barring heff. fce. 1
1B	barring no. 1 fce.
1B	barring old drying furnace
1B	calcine furnaceman
1B	calcine workman
1B	clean and replace cover on selenium press
1B	clean big stack flue
1B	clean calcine
1B	clean calcine building
1B	clean calcine dryer
1B	clean carbon blocks
1B	clean conveyors
1B	clean cottrel supply tanks
1B	clean cottrell bricks
1B	clean dryers calcine bl
1B	clean drying fce.
1B	clean dust calcine building
1B	clean globe dust calcine building
1B	clean lights in calcine
1B	clean out cottrel
1B	clean packing rings for scrubber
1B	clean scrubbers saddles
1B	clean stock base and replace soda ash
1B	cottrell area cleanup
1B	cottrell work for shop
1B	drying calcine sand
1B	drying room clean-up
1B	dump bucket at scrubber
1B	empty pit calcine
1B	fill cooling tower
1B	hereshoff fce. area clean up
1B	muck out cottrell tanks
1B	muckout pit calcine
1B	new calcine stack

1B	pull shorted wire cottrell
1B	remove knight saddles from cooler
1B	remove old flue at calcine
1B	remove packing from scrubber
1B	remove rings from scrubber
1B	remove saddle from cooling tower
1B	remove saddles from scrubber
1B	re-pack cooling tower
1B	re-pack scrubber
1B	sand blast cooling tower
1B	scrape carbon blocks
1B	scrape cottrell tubes
1B	sort saddles
1B	steam calcine cleaner
1B	steam clean herreshoff plates
1B	wash cottrell packing rings
1B	wash cottrell saddle_
1B	wash saddles from knight cooler
1B	wash scrubber partion rings
1B	wash spray tower
	MIXERS & SCREENER
1C	barred oxide toaster
1C	barring simpson conveyor
1C	clean mixer
1C	clean mixer scale
1C	mixer and screener
1C	mixer dustbin clean-up
1C	pile conc. dust at mixer
1C	screen cd. dust
1C	screen grind dust
1C	simpson mixer
1C	toast and screen oxide
	SOLUTION OPERATORS & PRESSMAN
1E	agitator
1E	carbonate
1E	clean agitator
1E	clean sol. blowcase sump
1E	clean solution building

1E	clean solution room
1E	filter press
1E	move perm. mud
1E	nitrate
1E	solution foreman
1E	solution operator
1E	solution pressman
1E	solution purification
1E	steam clean sol. sump tank
1E	transfer perm. mud to g.r. bin
1E	wash agitator sand
	SOLUTION CHARGER
1F	charger with loader (solution)
1F	dry carbonate mud
1F	dry ferrocyanide mud
1F	dry lead sulphate mud
1F	dry perm. mud
1F	dry selenium
1F	perm. mud process
1F	permanganate mud processor
1F	solution charger
1F	solution charger and pressman
1F	solution charger mech. equipment
1F	solution charger with hyster
	PIGMENT PLANT
1H	clean old pigment dryer room
1H	dissolve oxide for pigment
1H	foreman pigment
1H	grind and pack pigment
1H	lead sulphide
1H	pigment and filter press
1H	pigment filter
1H	pigment workman
1H	sulphide pressman
1H	sulphide process
1H	sulphide process
1H	sulphiding process
	GASMAN - SULFIDE

1I	pigment gasman
1I	pigment plant gasman
1I	sulphate gassman
1I	sulphide gassman
	TANKHOUSE & ELECTROLYTIC
1L	apply strontium carbonate
1L	cathode hanger
1L	cell house workman
1L	clean strontium press
1L	clean tank cell house
1L	dissolve sweep
1L	elec. sulphide process
1L	elec. tl metal
1L	electro checker
1L	electro crane man
1L	muck-out anode buiding tank
1L	prepare oxide sulphide
1L	press bomb scrap sponge
1L	press sprouts and sweeper
1L	sheet skinner
1L	steam clean tankhouse cell
1L	tankhouse workman
1L	wash caustic drums and sol. sump area
1L	wash sweeps and sprouts
1L	washing caustic slag
1L	washing windows tank house
	RETORT OPERATOR
1M	barrel oxide toaster
1M	barring retort old building
1M	blew cd. metal
1M	blew gran. cadmium
1M	clean and sort oxide bags
1M	clean old retort building
1M	clean oxide building
1M	clean retort building
1M	furnaceman-oxide
1M	grinding oxide residue
1M	oxide bag house

1M	powdered cadmium
1M	put crucible in retort
1M	replace bags in oxide
1M	retort
1M	retort dross
1M	retort operator metal
1M	retort operator oxide
1M	retort swep
1M	roll oxide bags
1M	vacuum retort building
1M	washing windows new retort building
	CASTER
1N	barr out premelt floor
1N	cast c.p. bars.
1N	caster
1N	caster oxide pot
1N	caster premelt pot
1N	caster rod machine operator
1N	casting metal
1N	cathode premelt op
1N	clean casting room
1N	clean premelt room
1N	clean premelting pot
1N	clean residue from melting pot
1N	disc caster
1N	granulated cadmium
1N	grinding premelt molds
1N	melting prills
1N	melting sprouts
1N	premelt pot
1N	premelting
1N	rod machine workman
	WEIGHER AND PACKER
1O	caster rod machine packer
1O	label oxide
1O	oxide shipment
1O	pack cd. powder
1O	packer caster
1O	packing

10	pigment shipment
10	stencil cd oxide
10	stencil cd sulphide
10	stencil cd powder
10	sulphide shipment
10	weigh and strap boxes
10	weigher and packer
10	weigher and packer lead bars
	INDIUM PLANT
2	dump ind. consen. in g.r. bin
2	hydroxide
2	indium
2	indium metal operator
2	indium plant hydroxide
2	indium shipment
2	leaching operator indium
	ACID RECOVERY PLANT
3	acid cake
3	acid mixes
3	acid neut operator
3	acid plant foreman
3	acid plant operator
3	acid plant workman
3	clean acid boxes
3	clean acid boxes acid pit
3	clean acid boxes acid plant
3	clean and storage tank grid plant
3	clean crystal
3	clean crystal tank
3	clean ditch at neut.
3	clean out crystal tank
3	clean storage tank acid plant
3	dissolve metal sweeps for acid cake
3	empty acid boxes acid plant
3	grind sweeps acid cake
3	neut operator
3	wet-down line at neut.
3	wheelout acid cake

	LOADING GANG WORKMAN
4A	calk car for residue
4A	clean tailing ponds
4A	close residue care
4A	dig up fire hydrant at leaching
4A	experimental furnace
4A	flashing plant drains
4A	leach bomb scrap
4A	leaching lead sulphate
4A	leaching sulphate workman
4A	leaching workman
4A	lead sulphate slab cleaning
4A	level lead sulphate car
4A	load amarillo to leadville
4A	load crude ore in drums
4A	load drums with releached hyflo
4A	load lead sulphate
4A	load lead sulphate for a.v. plant
4A	load lead sulphate retort metal
4A	load pb mud
4A	load pb mud for a.v. plant
4A	loading dried selenium
4A	loading gang workman
4A	loading indium phosphate
4A	loading scrap iron for a.v. plant
4A	plug g.r. residue car
4A	re-pack selenium drum
4A	scrape lead sulphate slab
4A	take lumber off el paso car
4A	take top off from san luis car
4A	uncovering lumber
4A	uncovering lumber
4A	unload selenium residue
4A	unload sodium sulphide
	CONC. & DRY DUST
4B	b.h. conc. dust
4B	bag shakers, crushing and roasting
4B	bin repair
4B	clean chi. car
4B	clean conc. dust g.r. b.h.

4B	clean conc. dust g.r. flue
4B	clean conc. g.r. flue
4B	clean dried bag house
4B	clean east helena dust car
4B	clean el paso car
4B	clean el paso dump as loader fills hopper
4B	clean g.r.
4B	clean g.r. and crusher
4B	clean g.r. bin
4B	clean g.r. conc. dust flue
4B	clean g.r. conveyor
4B	clean g.r. dump
4B	clean g.r. fan
4B	clean g.r. flue
4B	clean g.r. flue conc. dust
4B	clean g.r. hoppers
4B	clean sol. at sump tank
4B	clean up concentrates by hand
4B	cover g.r. dump
4B	cover residue car
4B	crusher a.v. dust d.p. 146
4B	crusher g.r. d.p. 162
4B	crushing a.v. dust
4B	crushing a.v. dust b.p. 146
4B	crushing d.p. 162
4B	crushing el paso residue
4B	dry a.v. dust
4B	drying sump tank clean
4B	drying sump tank mud
4B	drying sump tank mud and clean
4B	g.r. bag house
4B	job no 143
4B	load b.h. dust
4B	load concentrate
4B	load godfrey flue dust
4B	load sumptank pans for drier
4B	pile chi. car lumber
4B	pile elp. lumber on scale
4B	remove top chi. dust car
4B	remove top from el paso dust car
4B	re-tie g.r. bags

4B	shake bags in oxide baghouse
4B	shake g.r. bags by hand
4B	shaking bags by hand
4B	stack elp. bags at g.r.
4B	uncover el paso lan
4B	unload a.v. dust
4B	unload amarillo dust
4B	unload blackwell dust
4B	unload chi. car conc. dust
4B	unload concentrate ore truck
4B	unload dust at crusher
4B	unload east helena dust
4B	unload el paso conc. dust
4B	unload g.r. residue
4B	unload murray conc. dust
4B	unload san luis conc. dust
4B	unload selby car
4B	washing murray car
	GENERAL LABORER, UNLOADING
4C	asphalt membrane
4C	bomb scrap workman
4C	break paving by casting room
4C	break up caustic soda
4C	checking fire hose
4C	clean
4C	clean coal dump
4C	clean coal ramp
4C	clean dump
4C	clean for new limerock dump
4C	clean old bath house general
4C	clean old clock house
4C	clean out catch basin
4C	clean plant
4C	clean presser plate frames
4C	clean rail road track
4C	clean rail road track
4C	clean respirators
4C	clean under building
4C	cleaning up drums
4C	clean-up salvage lumber

4C	cutting new canvas for solution presser
4C	dig acid line ditch
4C	federated metal
4C	general labour
4C	lime spray bedded g.r.dump
4C	lime sprayer
4C	load box car with pallets
4C	loading federated metal
4C	miscellaneous
4C	pile lumber at carpenter shop
4C	plant ditch clean up
4C	plant road repair
4C	plant snow clean
4C	press strontium carbonate for tank house
4C	pull nails from salvage lumber
4C	remove lids from steel drums
4C	remove lumber from dust car
4C	remove oxide from pallets
4C	salvage brick from old drying furnace
4C	salvage lumber car
4C	salvage old calcine brick
4C	salvage scrap lumber
4C	sand blast jilag store
4C	sand blast press plates helper
4C	sand blast sol. press plates
4C	scale check
4C	shovel operator
4C	shovelling snow
4C	snow shovelling
4C	stack lumber
4C	steam clean dump truck
4C	steam cleaning equip.
4C	stock oxide
4C	stock pre-melt metal
4C	take lumber car
4C	unload acid boxes
4C	unload anode casting
4C	unload cans
4C	unload car bricks
4C	unload car coal
4C	unload car retort

4C	unload coal
4C	unload crucible car
4C	unload dump truck
4C	unload fed. metal
4C	unload fiber drums
4C	unload fire clay
4C	unload gum arabic
4C	unload gum arabic
4C	unload h.s. cylinders
4C	unload hyflo
4C	unload hyflo + dry reclaimed hyflo
4C	unload iron sulphide
4C	unload lead bars for litharge
4C	unload lead cans
4C	unload limerock
4C	unload litharge pails
4C	unload lumber
4C	unload oxide cans
4C	unload paper drums(mossy)
4C	unload pb. car
4C	unload pigment cans
4C	unload potassium
4C	unload selatone car
4C	unload soda ash
4C	unload sweeps mint
4C	unload test lead bar
4C	unload.potassium
4C	unloading
4C	unloading fed. metal
4C	unloading gang workman
4C	unloading gang workman
4C	unloading roofing
4C	unpack anodes
4C	wash down lab walls
4C	wash respirators
4C	washing in equip. in leadville
	SAMPLING
5	breaking anodes at sample room
5	sample a.v. car
5	sample a.v. dust

5	sample chi. car
5	sample chlorate mud
5	sample east helena car
5	sample el paso car
5	sample lead sulphate
5	sample lead sulphate car
5	sample man
5	sample murray car
5	sample murray car and el paso car
5	sample residue car
5	sample san luis car
5	sample selby car
5	sorting samples
	CRUSHING
6	clean crusher
6	clean crusher product
6	clean crushing g.r. bin
6	crusher
6	crusher workman
6	crushing
6	crushing by products
6	crushing coal for g.r.
6	crushing lead and limerock
6	crushing limerock and coal for el paso
6	crushing rock and coal
6	crushing workman
6	crushing, screening and grinding
6	drying chlorate mud
6	grinding
6	grinding murray dust
	ROASTING
7	barring g.r.
7	barring g.r. furnace
7	burn bags at g.r. fce.
7	charge wheeler
7	charge wheeler conc dust
7	charge wheeler, crushing and roasting
7	charger cd dept
7	checking roster o.p.r.

7	dig hole on g.r. furnace
7	fireman, charge wheeler, crushing and roasting
7	fireman, crushing and roasting
7	g.r.
7	g.r. fireman
7	g.r. workman
7	g.r. furnaceman
7	general labourer, crushing and roasting
7	godfrey workman
7	replace rabble blade
7	residue wheeler
7	scrape down fce. over casts
7	tapping g.r.
7	wetting g.r. area
	LEAD
8	barr out litharge couple
8	caster lead bars
8	clean general litharge plant
8	clean litharge flue
8	clean litharge plant
8	cupelling, lead
8	cut-up scrap lead
8	litharge and test lead shipment
8	litharge cupel repair
8	litharge furnaceman
8	litharge shipment
8	litharge shipment
8	litharge workman
8	manufactured lead
8	melting scrap lead
8	re-pack litharge
8	re-screen 20 mesh test lead
8	scrap test lead pot
8	sew sacks
8	test lead operator
8	test lead shipment
8	test lead workman
	THALLIUM

9	fill in ditch for thallium plant
9	melting dross - thallium metal and lead
9	remove brick from th. repair
9	thallium
9	thallium cell
9	thallium compound
9	thallium metal
9	thallium shipment
9	thallium solution
9	thallium sulphate
	MACHINE SHOP
10A	master mechanical
10A	auto mechanic
10A	automotive mech.
10A	layout man
10A	machinist
10A	mech equipment op (shop)
10A	mechanic
10A	mechanic - lead man
10A	metal work
10A	millwright
	MAINTENANCE
10B	adding alcohol to gas line
10B	handy man
10B	handy man, pump packer
10B	labour mech. dept.
10B	maintenance
10B	mechanic - pipe fitter
10B	oiler
10B	paint t.h. building above crane
10B	painter
10B	painting solution room
10B	patch crucible
10B	pipe fitter
10B	scaffolding, mech. dept.
	ELECTRICAL SHOP
11	electrician
	WELDERS & BURNERS

12	acid cake floor repair
12	acid pit repair
12	b.h. repair
12	calcine floor repair
12	dig up floor
12	g.r repair
12	g.r. flue repair
12	head lead burner
12	lead burner
12	litharge department floor repair
12	mixer floor repair
12	patch old retort
12	repair caustic plant room
12	repair dock for lead sulphide
12	repair floor pits
12	retort repair
12	sheet metal worker
12	steam cleaning
12	vacuum cleaner
12	welder
	CARPENTER
13	box nailer
13	brick up oxide retort
13	bricklayer
13	carpenter
13	carpenter helper
13	cement finisher
13	foundation for sulphide tank
13	hod carrier
13	litharge dept. floor repair
13	mason
13	recooper barrels
13	saw operator mech. dept.
13	tank house building repair
	AUTO TRUCK
14	dump truck
14	haugh operator
14	haul ashes for g.r.
14	haul coal

14	haul litharge cans
14	haul oxide cans
14	haul oxide cons.
14	haul pigment cans
14	hydro crane
14	hyster
14	load g.r. residue
14	load metal on pallets
14	loader
14	loading g.r. residue
14	loading litharge and test lead box car
14	mech
14	move coal from under ramp
14	move dust from g.r. pit
14	move globe dust
14	move lime rock under ramp
14	mover or transfer
14	moving federal sponge to new dump
14	pile lead sulphate
14	pile metal on pallets
14	pile pre-melt metal
14	power sweeper
14	spread slag in plant area
14	spread slags
14	sweeper power
14	to leadville to haul used equip.
14	transfer b.h. conc. dust to cadmium plant
14	transfer b.h. dust to g.r. bins
14	transfer by products to crusher
14	transfer chlorate mud to crusher
14	transfer con. dust to mixer
14	transfer fireclay to crusher
14	transfer murray dust
14	transfer post anodes to crusher
14	truck driver
	JANITOR - LAUNDRY - GUARD
15	bath house
15	clean around plant fence
15	cut weighs main office area
15	first aid

15	grounds and lawn
15	guard
15	janitor
15	laundry
15	main office clean-up
15	restock metal in warehouse
15	warehouse workman
15	wash plant office walls
15	wash walls foreman's locker room
	ARSENIC
16	arsenic
16	grind san louis dust in arsenic mill
16	grinding a.v. dust in arsenic mill
	GENERAL- NON-PRODUCTION
17	administration
17	lab
17	metallurgist