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Silica Exposure to Excavation Workers During the Excavation of a Low Level Radiological Waste Pit and Tritium Disposal Shafts

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Abstract

This study evaluated the task-length average (TLA) respirable dust and respirable silica airborne concentrations to which construction workers excavating volcanic tuff at Los Alamos National Laboratory (LANL) were exposed. These workers were excavating a low level radiological waste disposal pit of final dimensions 720 feet long, 132 feet wide and 60 feet deep. The objectives of this study were as follows: 1) evaluate exposures; 2) determine if the type of machinery used affects the respirable dust concentration in the breathing zone of the worker; 3) evaluate the efficacy of wetting the pit to reduce the respirable dust exposure; and 4) determine if exposure increases with increasing depth of pit due to the walls of the pit blocking the cross wind ventilation.

Samples were collected using a 10 mm metal cyclone followed by a pre-weighed, 37 mm diameter, 5 um pore size PVC filter in a two piece cassette connected in line with a personal sampling pump. A flow rate of 1.9 liters per minute was used, as suggested by the manufacturer of the cyclone. Results indicated that the bulldozer operator, whose geometric mean TLA respirable dust concentration was 0.54 mg/m^3, experienced the highest exposure. The water truck and the Cat scraper, whose geometric mean TLA respirable dust concentrations were 0.08 and 0.06 mg/m^3 respectively, experienced the lowest exposure. Air conditioned, enclosed cabs were the main factor contributing to the different exposures of the bulldozer and the water truck and Cat scraper.

A randomized complete block analysis of variance test was used to evaluate the efficacy of wetting the pit for dust control. The TLA respirable dust concentration data during and in the absence of wetting were compared. Results indicated this engineering control was ineffective as used at Los Alamos. Although the statistical power of this test was low, the existence of potential exceedances of the American Conference of Governmental Industrial Hygienists Threshold Limit Values supports this finding.

The theory that the TLA respirable dust concentrations would increase as the depth of the pit increased was tested using liner regression. For all equipment, except the bulldozer, very little of the variability in the data was explained by depth of pit. However, 23 percent of the variability in the bulldozer data was explained by increasing pit depth. Based on the bulldozer data, the only equipment working predominantly in the pit, it was concluded that exposure will increase with increasing depth of pit for those pieces of equipment working predominantly in the pit.

I Introduction and Background

Los Alamos National Laboratory (LANL) is located on the Parajito Plateau in north-central New Mexico. Over one million years ago a volcano, located just outside of Los Alamos, erupted and deposited volcanic tuff as far away as Kansas. This eruption shaped the terrain of the plateau (1). Geologic surveys indicate the plateau is composed of a series of Pleistocene ash flows and ash fall of Bandelier tuff (2). The volcanic tuffs on Parajito Mesa, located within Parajito Plateau, consist of alkali feldspar (~60% by weight) and combinations of three crystalline silica polymorphs; tridymite, quartz and cristobalite (3).

Volcanic tuff is associated with an elevated concentration of crystalline silica. Elevated or prolonged crystalline silica exposure has been associated with silicosis and lung cancer (4-10). The International Agency for Research on Cancer (IARC) concluded that there was sufficient evidence for carcinogenicity of crystalline silica in experimental animals and limited evidence for carcinogenicity in humans (11). This resulted in the classification of crystalline silica materials as Group 2A--probably carcinogenic to humans (12).

While there is an abundance of scientific literature regarding silica exposure to miners and other workers (4-7,13,14), the literature is lacking in information about crystalline silica exposure to excavation workers. The purpose of this investigation was to determine task-length average (TLA) respirable dust concentrations and respirable crystalline silica exposures of excavation workers, while excavating volcanic tuff. In addition, the data were analyzed to determine the following: 1) if the type of machinery affects the respirable dust concentration in the breathing zone of the worker; 2) the efficacy of wetting the pit to reduce the respirable dust exposure; and 3) if exposure increases with increasing depth of pit due to the walls of the pit blocking the cross wind or natural ventilation. Full-shift respirable dust time weighted averages (TWAs) and full-shift polymorph specific TWA concentrations were also calculated. Due to the great variability in crystalline silica content of the tuff, the silica exposures are considered estimates.

This investigation was performed at the LANL radiological disposal site where a low level radiological waste disposal pit and several tritium disposal shafts were being excavated. In addition to the personal samples, area samples were obtained to determine the ambient dust concentration at various locations around the radiological waste disposal site. Bulk soil samples were collected from the work area and analyzed by x-ray diffraction to determine the percent quartz, cristobalite and tridymite present in the soil. The results of this study will be useful to health and safety professionals involved in protection of excavation workers potentially exposed to high levels of silica.

To protect the employees from exposure to high concentrations of crystalline silica and any resulting potential adverse health effects, the excavation areas were sprayed with water to minimize the amount of airborne dust generated. The water truck used for this operation had an 8000 gallon capacity. Thirty minutes were required to fill the truck, and it took only 15 minutes to empty. The water was sprayed in a fan shape pattern from the rear of the truck to maximize the area covered. In addition to wetting the pit, the operator was responsible for wetting the dirt roads at the site and supplying the water cart used in the tritium disposal shaft area. For additional protection, the employees were trained to use and wear half-face respirators.

Although the excavation area was located within a radiological waste disposal site, radiation was not the agent of concern. The pit and the shafts were being excavated for future disposal; therefore, the excavation workers did not come into contact with radiological waste. The only expected exposure to radiation was to naturally occurring sources. Tests on the sampling media confirmed that the radiation was below the detectable levels.

The low level radiological waste pit and tritium disposal shafts were excavated from June to September, 1994. The final size of the pit was 720 feet long by 132 feet wide and 60 feet deep. The shafts were 7 feet in diameter and 35 feet deep. Approximately 42 people worked at the radiological waste disposal site, but only nine were involved in the excavation. Other jobs on the site included laborers, surveyors, health and safety professionals, administrators and geologists.

The excavation workers were responsible for operating the heavy machinery used during the excavation process. Each worker operated more than one type of machinery . They worked 12-1/2 hour days unless there was a thunderstorm or the emergency paging system was inoperable. If the employee worked 12-1/2 hours, he was allowed one 15 minute break in the morning, 30 minutes for lunch and two 15 minute breaks in the afternoon. If the workday was shortened, the afternoon break was not taken. The employees were allowed five minute travel time to and from the break room, which was located about 1/2 mile from the pit via a paved road. The travel time was not deducted from their break time.

Table 1 displays the various types of machinery and excavation jobs. The jobs were grouped by type of machinery with the exception of the scrapers. Scrapers with air conditioned cabs were treated separately for purposes of this study to facilitate analysis of the effect of air conditioned cabs on dust concentrations. Employees with air conditioned cabs left their windows closed during the workday whereas employees without air conditioning would open their windows for ventilation. Information is provided on the equipment, make, type of cab, if the cab is air conditioned and a brief description of the operator's task. This information is useful to understand why certain jobs have higher respirable dust exposures than do others.

TABLE 1. TYPES OF MACHINERY AND DESCRIPTION OF TASKS FOR EXCAVATION WORK AT LOS ALAMOS NATIONAL LABORATORY

Machinery	Make	Type of cab/ Air conditioned	Description of task
Equipment used for the low level radiological waste pit:			
Scraper	Terex Fiat Caterpillar	enclosed/no enclosed/no enclosed/yes	Move dirt from the pit to the spoils pile.
Bulldozer	International Seabee Series C	open/no open/no open/no	Loosen dirt using the rippers and the blade. Push other machinery out of the dirt when they got stuck.
Water Truck	Caterpillar	enclosed/yes	Wet the pit and dirt roads. Supply the water wagon used at the shafts.
Backhoe	Deere	enclosed/no	Remove dirt from the walls of the pit.
Blade	Galion Deere Caterpillar	enclosed/no enclosed/no enclosed/no	Maintain the roads on the site and form the sides of the pit wall.
Front End Loader	UNK*	enclosed/no	Remove bulk material during the preliminary phase of pit excavation.
Equipment used for the tritium disposal shafts:			
Driller	UNK*	no cab/no	Operate the controls of the drilling rig and guide the drill into the shaft.
Asst. Driller	UNK*	no cab/no	Guide the drill into the shaft and release the spoils from the drill. Operate front end loader to move to spoils from drilling area.

*UNK = unknown

II Health Effects

A. Silicosis

Silicosis, a disease characterized by pulmonary fibrosis and the development of nodules in the lung, can be disabling, progressive and even fatal. Early detection of silicosis is possible by radiography of the chest (15). Silicosis predisposes the patient to tuberculosis and the combined diseases are more rapidly progressive than uncomplicated silicosis (15). Because of the huge reserves of the lung, radiographic appearances may be advanced, yet the patient may not experience any symptoms of silicosis (16). Cough may develop as the disease progresses and occurs mainly in the morning (17). Other symptoms of silicosis include dyspnea, wheezing and repeated nonspecific chest illnesses. Eventually, fibrosis reduces the circulation of blood through the lung and the heart becomes restricted resulting in symptoms of heart failure, such as shortness of breath and swelling of the ankles (16).

When inhaled crystalline silica reaches the alveolar sacs of the lung, it interacts with cell membranes which leads to phagocytosis of the silica particle by macrophages. Since silica is cytotoxic, cell death may ensue thus initiating the fibrotic process (16). Multiple alveolar lesions develop and each contain macrophages, neutrophils, granular material, dust particles and cellular debris of dead macrophages. As the lesions enlarge, multiple nodules may merge. The silicotic nodule seen in human disease consists of inflammatory cells surrounding a core of "whorled" collagen, reticulin and dust particles. The nodules tend to be distributed mainly in the posterior portion of the upper half of the lung and are grey-green to dark grey in color. Their size can range from 2-6 mm in diameter and are readily felt on the unopened lung during autopsy (17). Merging of lesions into nodules and continued enlargement results in distortion of airways and vasculature. In turn, the airway epithelium is damaged resulting in proliferation of type II pneumocytes in the alveolar areas. Collagen deposition continues and the disease progresses (5).

Silicosis is initiated by aerosol exposure and inhalation of free crystalline silicon dioxide (16). Elimination of exposure does not preclude progression of silicosis because silica particles remain in the lung long after cessation of exposure (5). In a study of South African gold miners (6), it was found that in 57% of the silicotic workers the radiological signs developed on average 7.4 years after cessation of mining exposure. Variables which determine whether an exposed individual develops pulmonary pathology include dose, exposure duration and the nature of the dust (5). A study by NIOSH and OSHA indicated that employees with the highest dust exposure developed early silicosis in less than four years after exposure, while the second highest exposure group developed early silicosis more than four years after exposure (15). Generally, silicosis is associated with chronic exposure although, disease may occur as rapidly as five years after a large exposure suggesting that short term, high exposures also lead to the development of silicosis (4). Since, cristobalite and tridymite are more cytotoxic than quartz, (17) the nature of the dust is an important determinant of ultimate toxicity.

The potential for developing silicosis varies widely among industries and locations. The variability seen in the outcomes is related to the variability of exposure and the percent concentration of the three polymorphs present. Exposure will vary as the effectiveness of the ventilation, either engineered or natural, varies. Those industries with effective ventilation thus, low airborne concentrations are likely to see lower incidence of silicosis. As the percent concentration of cristobalite and tridymite in airborne dust increases it can be expected that biologic response will occur at lower doses.

B Lung Cancer

The relationship between silica, silicosis and lung cancer is a controversial issue. The working group of the IARC reviewed scientific data on the relationship between crystalline silica dust exposure and the induction of cancer. The published results indicate there is sufficient evidence for carcinogenicity in experimental animals and limited evidence in humans (11). A recent review however, has questioned the strength and consistency of the animal findings (18).

The epidemiologic data are also plagued by inconsistent results. Studies of crystalline silica exposure which have been adjusted for smoking have found the relative risk for lung cancer to range from 2.0 to 6.9. These studies have included metal miners (8), Italian ceramic workers (9) and Swedish ceramic workers (10). An exposure-response relationship between silica exposure and death from lung cancer was found in a study of South African gold miners. In the same study, a three-fold relative risk in the high exposure group was also reported with indications of a synergistic effect of tobacco smoking (19).

Those who argue silica in of itself is not proven to be carcinogenic maintain thorough consideration has not been given to the possible environmental confounding factors such as radon, arsenic, polycyclic aromatic hydrocarbons (PAHs), asbestos, nickel, talc and cadmium. For example, a study of Chinese workers exposed to respirable silica (20) collected information on these confounding factors. Since exposure to asbestos, nickel, talc and cadmium were minimal at their sites, they were not considered. Increasing exposure to arsenic was significantly associated with risk to lung cancer whereas, exposure to radon and PAHs was less consistently linked to increased risk. Agius (21) maintains the human evidence does not consistently support crystalline silica as a carcinogen per se, but suggests there is evidence it may synergize with other environmental carcinogens by a weak promoting effect on their carcinogenicity or by impairing their clearance. Additional and more specific human epidemiologic studies are necessary to definitively answer this question.

There is conflicting evidence for the hypothesis that silicosis is causally related to lung cancer. A cohort study of foundry workers (22) showed that over the study period, silica exposure and non-malignant respiratory disease were decreasing yet lung cancer was rising.

Since the IARC determined there was sufficient evidence for carcinogenesis of crystalline silica in animals and limited evidence in humans, much research has been done to determine the carcinogenesis mechanism. Researchers have noted that there are three distinct animal models for the study of the effects of crystalline silica. Rats develop pulmonary fibrosis, alveolar hyperplasia and lung tumors. Mice develop pulmonary fibrosis but do not experience persistent epithelial hyperplasia or tumors. Hamsters do not develop fibrosis or tumors. The hypothesis that host susceptibility difference in the human population may be represented by the three pathways observed in the rodent species (23) has been suggested. If it is possible to understand the different susceptibilities in the rodent population, it may then be possible to explain the different responses in the human population. Extensive research has been conducted on the mechanisms of carcinogenicity of lung cancer (24) but it is beyond the scope of this paper.

III Standards and Guidelines

Because of the hazards associated with crystalline silica, the American Conference of Governmental Industrial Hygienists (ACGIH) have set exposure limits where they believe exposures to crystalline silica below these levels will protect employees from suffering material impairment of health or functional capacity. While other agencies have developed similar exposure limits, the ACGIH Threshold Limit Values are used in this study because they are widely accepted and concise. Table 2 outlines the exposure limits for crystalline silica from the various agencies.

Table 2. Summary of Exposure Limits for Crystalline Silica

AGENCY	STANDARD	
American Conference of Governmental Industrial Hygiensits[25]	Quartz[a]	0.10 mg/m^3
	Cristobalite[a]	0.05 mg/m^3
	Tridymite[a]	0.05 mg/m^3
Mine Safety Health Administration[26]	Quartz[a]	0.10 mg/m^3
	Cristobalite[a]	0.05 mg/m^3
	Tridymite[a]	0.05 mg/m^3
National Institute of Occupational Safety and Health[27]	Crystalline[a]	0.05 mg/m^3
Occupational Safety and Health Administration[28]	Quartz[a]	$\frac{10\ mg/m^3}{\%SiO_2+2}$
	Quartz (total dust)	$\frac{30\ mg/m^3}{\%SiO_2+2}$
	Cristobalite	Use 1/2 the value calculated for the count or mass formula for quartz.
	Tridymite	Use 1/2 the value calculated for the count or mass formula for quartz.

a Respirable fraction of dust

NOTE: NIOSH considers crystalline silica to be quartz, cristobalite and tridymite.

III Sampling and Analysis

OSHA and NIOSH have set-up standard methods for personal sampling for silica when X-ray diffraction (XRD) analysis is to be used. Both agencies recommend using a 10 mm nylon cyclone followed by a 37 mm diameter, 5 um pore size polyvinyl chloride (PVC) filter and a two piece cassette. OSHA also suggests using a 37 mm cellulose back-up pad. The flow rate of the personal sampling pump should be 1.7 liters per minute. OSHA recommends an air volume in the range of 408 to 816 liters whereas NIOSH considers the range from 400 liters to 1000 liters to be acceptable. The pump should be calibrated using a representative sample in line. Once sampling has begun, it is critical the assembly is not inverted as this will result in oversized particles from the cyclone depositing onto the filter. Samples and blanks should be mailed to the laboratory in a suitable container to prevent damage. For a more complete discussion of the sampling method the OSHA and NIOSH method documents should be consulted (29,30).

Atomic absorption, microscopy, infrared spectroscopy, gravimetry and XRD can all be used to analyze personal samples for quartz. XRD is the preferred method because the quantities of the different polymorphs of free silica can be determined (29). In some instances, a short "turn around time" for analytical results is necessary. In these cases, XRD analysis is used on a representative sample set to estimate the percent of each polymorph present. Subsequent samples are collected and analyzed using gravimetric analysis. The results of the gravimetric analysis are multiplied by the percent of each polymorph found in the representative sample set to estimate the concentration of each polymorph. While this method yields almost immediate results, the assumption that the percent of each polymorph present does not vary from the original sample is made. This assumption may be incorrect and lead to erroneous results.

Although sensitivity and specificity of atomic absorption analysis are high, the method is not without its limitations. Since it is necessary to have 1 lamp for each element analyzed, the number of elements which can be analyzed per filter is limited to 5 or 6. Another limitation of this method is sample preparation for the elements requested must be compatible.

Microscopy is a fast, simple method for viewing and identifying particles and mineral fibers. Transmission electron microscope (TEM) and polarizing light microscope (PLM) are common tools used for particulate identification. The TEM uses a high energy electron beam for viewing and analyzing particles which are not normally resolvable under the light microscope. The PLM identifies particles by measuring their optical properties. By immersing the particles to be identified in an oil of known refractive index and noting the colors of light transmitted through the particle, and dispersed at the edges, it is possible to estimate the particle's refractive index. This technique is called dispersion staining and provides useful information used to identify the particle. The TEM and the PLM are limited because particles larger than 10 um and smaller than 4 um, respectively cannot be seen. While these methods can be used for quantitative estimates, it would seem they are best suited for particle identification due to the size limitations.

Infrared spectroscopy operates in the infrared region of the electromagnetic spectrum. In the infrared region, vibrations and rotations of molecular bonds occur and it is possible to collect information regarding the molecular structure. Since all molecules absorb some infrared radiation, infrared spectrometry can be useful on a wide variety of substances. However, it is this attribute which renders it almost useless on mixtures. For this reason, infrared spectroscopy is most useful for pure compounds because the detection limits and sensitivities are worse when analyzing mixtures, than other spectral techniques.

IV Methods

To estimate TLA respirable dust concentrations of the excavation workers, a 10 mm, metal cyclone, followed by a pre-weighed 37 mm diameter, 5 um pore size PVC filter and two piece cassette were connected in line with a personal sampling pump. A metal cyclone was used because it has been documented to have a higher collection efficiency than the nylon cyclone (31, 32). The pumps were calibrated each morning to a flow rate of approximately 1.9 liters per minute (LPM) with a representative sampling set-up in line and distributed to the employees as close to the start of the shift as possible. The flow rate of 1.9 LPM was used because it was the flow rate suggested by the manufacturer of the cyclone. The employees were instructed to place the cyclone in their breathing zone and put the pump on hold when they were not operating their machinery. After the sampling period, the filters were removed from the cassette and post-weighed. The change in weight was calculated.

A field blank was also weighed before and after the sampling period and the filter weight change was adjusted corresponding to the field blank change. On those days when the field blank was missing, a weight of 4.37 ug was used. This number represents the average field blank weight change calculated over the course of this investigation. The blank-corrected filter weight change was then divided by the volume of air collected by the pump resulting in the TLA respirable dust concentration. The data collected during this investigation, the TLA respirable dust concentration, full-shift respirable dust TWA concentration and full-shift polymorph specific TWA concentrations were computed and are shown in Appendix I.

To evaluate how the respirable dust concentration in the breathing zone of the worker varied with different types of machinery, the TLA respirable dust concentration data were grouped by type of machinery. The various types of machinery were presented in Table 1. For each grouped data set, the geometric mean, geometric standard deviation, maximum and minimum were calculated. The geometric mean and the geometric standard deviation were used because frequency plots of the TLA concentrations appeared to be skewed. It is common to assume that exposure data are log-normally distributed.

The efficacy of wetting the pit to reduce the respirable dust concentrations was tested using a randomized complete block analysis of variance (ANOVA) table. Data collected during the first four days of excavation, the only data available without wetting, were compared to data collected during the subsequent four days of excavation. The null hypothesis was no difference in the treatment effect, or the respirable dust concentrations are equal both with and without wetting. The alternative hypothesis was the treatment means are unequal, or the wetting of the pit changes the respirable dust concentration in the breathing zone of the worker. Assumptions of this model are as follows: 1) each data point from the overall population constitutes a random, independent sample from one of the populations represented; 2) each population normally distributed with equal variance; and 3) the block and treatment effects are additive. Because the drillers worked in an area remote from the pit, the data on the drillers were omitted from this evaluation. In order to meet the second assumption, the natural log of the data were used during analysis.

It was assumed that respirable dust exposure would increase as the excavation project progressed due to the walls of the pit blocking cross wind ventilation. To test this assumption, the data were evaluated using regression analysis. The first regression analysis performed was TLA respirable dust concentration for all machinery used in the pit on depth of the pit. Next, the

TLA respirable dust concentration data were grouped by type of machinery and regression was performed for each group on depth of the pit. The assumptions of the model are as follows: 1) X, the independent variable, is preselected by the investigator so in collection of the data they are not allowed to vary from these preselected values. Therefore, the variable X is measured without error; 2) for each X there is a subpopulation of Y, or dependent variable, which are independent, normally distributed with equal variances; and 3) the Y values are statistically independent. In order to meet the second assumption, the natural logs of the data were taken.

The objective of this study was to characterize respirable dust concentrations in the breathing zone of excavation workers during the performance of an excavation task. To achieve this end, the employees were instructed to put the pump on hold while not operating their machinery. As a result, the personal samples do not reflect exposure during non-operating times. Therefore, it was necessary to take area samples to estimate respirable dust concentrations in the areas where the employee was located while not operating his machinery. Area samples were obtained at the paved road to the break room, the break room and the general area of the excavation site. The ambient respirable dust concentrations in these areas were estimated to be 0.096, 0.158 and 0.211 mg/m3 for the paved road, the break room and the general area, respectively. Knowing the amount of time the employee spent in each location, and the respirable dust concentration for each area, it was then possible to use this information and the personal sampling data to calculate the full-shift respirable dust TWA concentration using the formula shown in Appendix II.

To determine the full-shift polymorph specific TWA concentration, it was necessary to estimate the percent quartz, cristobalite, and tridymite in the soil. To perform this investigation, five bulk soil samples were collected, divided into three parts, and sent to three labs for XRD analysis. The results from the three labs were averaged to estimate the percent quartz, cristobalite and tridymite. One-half of the limit of detection was used to characterize samples for calculation purposes when they contained crystalline silica at concentrations less than the limit of detection. The third lab reported the percent cristobalite and the percent tridymite as a sum instead of individually. Since there was not a trend in the results from the other two laboratories, for example, the percent of tridymite being consistently higher than the percent of cristobalite, half of the sum reported was assumed to be cristobalite and half was assumed to be tridymite for samples from the third laboratory. The full-shift respirable dust TWA concentration was then multiplied by the percent of each polymorph to obtain the full-shift polymorph specific TWA concentration shown in Appendix III. The full-shift polymorph specific TWA concentrations were compared to the ACGIH threshold limit values for quartz, cristobalite and tridymite to determine if exceedances to the ACGIH guidelines were encountered.

V Results

A. Comparison of the Excavation Jobs

To compare the TLA respirable dust concentrations of the workers operating the various types of equipment, the results are summarized using the geometric mean, geometric standard deviation maximum and minimum. The summary results are shown in Table 3.

The nine employees involved in this investigation operated more than one type of machinery. The number of employees column indicates how many different employees are represented in each sample set. As the study progressed, it became clear the bulldozer operators were experiencing the highest respirable dust concentrations. Therefore, additional samples were obtained to closely monitor this equipment. The front end loader was used only during the startup of the project. As a result, it was possible to collect only 11 samples. Fewer samples were obtained on the Cat scraper than the other scrapers because the Cat scraper was experiencing lower dust concentrations and it was felt additional sampling was not warranted.

The jobs in Table 3 are listed in decreasing order for the geometric mean of the TLA respirable dust concentrations. The bulldozer operator, who had the highest geometric mean TLA respirable dust concentration (0.54 mg/m^3), had the highest single exposure (3.18 mg/m^3) . Examination of the results indicated this maximum exposure was about 20 percent higher than the second highest exposure for that job. The driller, who had a considerably lower geometric mean exposure (0.17 mg/m^3), had the second highest maximum exposure (2.05 mg/m^3). This exposure, however, was approximately 340 percent higher than the second highest exposure for that job. This would indicate that the maximum exposure of 2.05 mg/m^3 was an outlier possibly caused by the cyclone being turned upside down after sampling began. The Cat scraper and the water truck operator had both the lowest geometric mean TLA respirable dust concentration and the lowest maximum concentration for the group.

The following reasons may explain why high respirable dust concentrations were observed in the bulldozer. First, all makes of the bulldozers had an open cab without air conditioning. Second, the bulldozer was responsible for loosening the dirt, which is an inherently dusty process. This was done by dragging two rippers, located at the rear of the bulldozer, through the top, compacted layer of dirt. Third, the bulldozer was responsible for moving the dirt by using a blade located in the front of the equipment. Moving the dirt with the blade resulted in the operator driving into the dust, which was generated with the equipment. The final reason the high respirable dust concentrations were observed for the bulldozer is that it was in the pit the greatest amount of time. The scrapers, water truck and the blade had responsibilities which took them out of the pit.

Table 3. Comparison of the Task Length Average-Respirable Dust Concentrations for Excavation Jobs Performed at Los Alamos National Laboratory

			DUST CONCENTRATIONS		
Equipment Type	Number of Samples	Number of Employees Sampled	Geometric Mean (mg/m^3)	Geometric Standard Deviation	Maximum/ Minimum (mg/m3)
Bulldozer	50	5	0.54	2.01	3.18/0.11
Front End Loader	6	3	0.30	1.67	0.60/0.16
Backhoe	10	4	0.28	1.96	0.81/0.09
Other Scraper	37	5	0.28	1.86	1.16/0.08
Blade	31	2	0.18	2.27	1.76/0.04
Driller*	11	1	0.17	3.32	2.05/<0.01
Asst. Driller*	11	1	0.09	3.90	0.67/<0.01
Water Truck	13	1	0.08	1.75	0.24/0.03
Cat Scraper	28	4	0.06	2.04	0.28/0.02

* The geometric mean and geometric standard deviation were calculated using one-half of the limit of detection of the scale, which was assumed to be 0.005 mg, for samples resulting in a zero blank corrected concentration.

Under normal situations (i.e. no windstorm), the pit area had higher visible dust concentrations than other areas of the site because of the excavation activities.

Air conditioning is an important feature of the equipment which is associated with lower respirable dust concentrations in the breathing zone of the worker. The two pieces of equipment with air conditioning, the water truck and the Cat scraper, had the lowest respirable dust concentrations of any of the equipment used in the pit. Further evidence of the benefit of air conditioning is found when a comparison is made between the Cat scraper and the other scrapers. All makes of scrapers perform the same job and are of comparable design. The major difference is the presence of the air conditioning unit for the Cat scraper. A t-test on the log-transformed data was used to test the difference of the population means. The geometric mean and sample size of the Cat scraper and the other scrapers were 0.28 mg/m^3 and 28 and 0.06 mg/m^3 and 37, respectively. The null hypothesis was no difference in the geometric mean respirable dust concentrations between the Cat scraper and the other scrapers. The assumptions of this model were 1) the data are normally distributed; and 2) the variances were unequal. The result of the test indicated there was evidence the means were different ($p<0.005$), supporting the hypothesis that air conditioned cabs result in lower respirable dust concentrations in the breathing zones of the workers.

Based on a comparison of the geometric means, the drilling operation had the lowest geometric mean respirable dust concentration (0.17 mg/m^3) of those operations performed without an air conditioned cab. A possible explanation for this result is that the drillers worked in an area remote from the pit and, as mentioned earlier, given normal conditions, the highest visible dust concentrations were in the area of the pit. A second explanation of the lower respirable dust concentrations is continuous spraying of the spoils pile and the drilling shaft with water. This engineering control effectively lowered the respirable dust concentrations.

When assuming adherence to a log normal distribution, a geometric standard deviation of 2 is often considered low variability. The geometric standard deviations in this study range from 1.67 for the front end loader to 3.32 and 3.90 for the driller and the assistant driller, respectively. As discussed previously, the maximum exposure for the drilling operation was approximately 340 percent higher than the second highest exposure for that operation. Additional investigation of the drilling operations would be necessary to explain the reason for the outlier and the high variability.

B. Efficacy of Wetting the Pit for Dust Control

The data collected during the first four days of excavation were compared with data collected during the subsequent four days. Table 4 summarizes the results using the geometric mean concentrations. The two data sets represent absence of the engineering control "wetting" and presence of the control, respectively. The randomized complete block ANOVA test discussed previously was used. The results suggested there was evidence this engineering control was ineffective in the manner it was used at LANL. Examination of the data shows that the geometric mean exposure for the scrapers is higher with wetting (0.28 mg/m^3) than without (0.20 mg/m^3). The geometric mean for the front end loader is also higher with wetting (3.29 mg/m^3) than without (0.39 mg/m^3), thus providing further evidence that wetting was ineffective in the manner it was used at Los Alamos National Laboratory. These results, however, are not conclusive because of the lack of statistical power. The statistical power of a test increases as the sample size increases. In this test, the sample sizes were small, resulting a lack of statistical power.

Assuming the results of this test are valid, there are a number of reasons which would explain the results. First, water was not applied to the pit with enough frequency because the water

Table 4. A Comparison of Task Length Average-Respirable Dust Concentrations With and Without the Engineering Control Wetting for Excavation Jobs at Los Alamos National Laboratory

Job	Geometric Mean Concen. of Samples Taken in the Presence of Wetting (mg/m^3)	Number of Samples	Geometric Mean Concen. of Samples Taken in the Absence of Wetting (mg/m^3)	Number of Samples
All Scrapers	0.28	8	0.20	8
Bulldozers	0.48	8	3.18	1
Blade	0.21	1	1.76	1
Front End Loader	3.29	3	0.39	1

truck took 30 minutes to fill and only 15 minutes to empty. Also, the water truck had responsibilities away from the pit. As a result, only a small fraction of the day was spent spraying the pit with water. The climate of the area was another factor contributing to reduced effectiveness of the engineering control. The combination of the warm temperatures and low humidity facilitated rapid evaporation of the water.

C. Exposure in Relation to Increasing Depth of Pit

To determine if exposure increases with increasing depth of pit, regression analysis was performed. The results for the drillers were not included because they work in an area remote from the pit. The results for the front end loader were also omitted because the front end loader was used only during the preliminary phase of pit excavation. The results for the water truck and Cat scraper were also omitted because of the effects of air conditioning discussed previously. Regression was performed on all remaining results of exposure on depth of pit and each individual job on depth of pit. The regression plots and output are included in Figures 1 through 5 and the results are summarized in Table 5. To determine if variability in the data can be explained by the model, a t-test and a F-test were performed. The null hypothesis was the slope was equal to zero, thus indicating none of the variability in the data was explained by the model. The alternative hypothesis is that the slope is unequal to zero and some of the variability in the data was explained by the model. The assumptions for regression stated earlier in this paper are applicable.

For all groups of data, except the bulldozer, we reject the null hypothesis and conclude the model does not provide a good fit for the data. The bulldozer data, however, suggests the model provides a good fit for the data ($p<0.005$). Consistent with our assumption, the positive slope indicates the exposure increases with increasing depth of pit.

The bulldozer is the best representative of exposure in the pit because the bulldozer operator had responsibilities only in the pit, whereas the other pieces of equipment have responsibilities outside of the pit. For this reason, it could be concluded that exposure increases with increased depth of pit for machinery which work predominantly in the pit.

Consistent with the results of the t-test and the F-test, the R^2 values, except for the bulldozer, are small indicating that very little of the variability in the results are explained by depth of pit. The R^2 value of the bulldozer is 0.23, which indicated 23 percent of the variability in the data is explained by increasing the depth of the pit.

Figure 1. Regression Analysis for All Data on Depth of Pit for Excavation Jobs Performed at Los Alamos National Laboratory

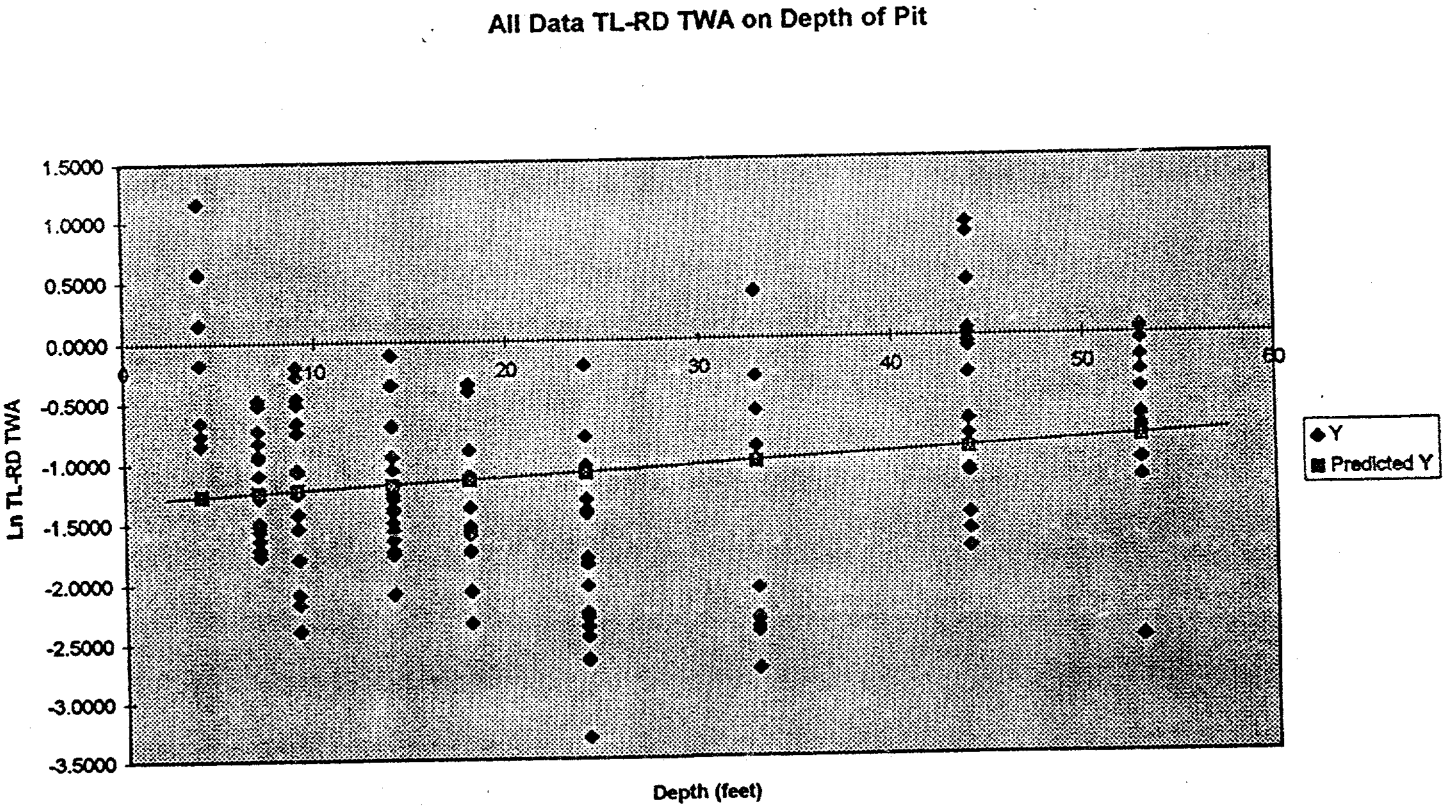

Figure 2. Regression Analysis for Terex and Fiat Results on Depth of Pit for Excavation Jobs Performed at Los Alamos National Laboratory

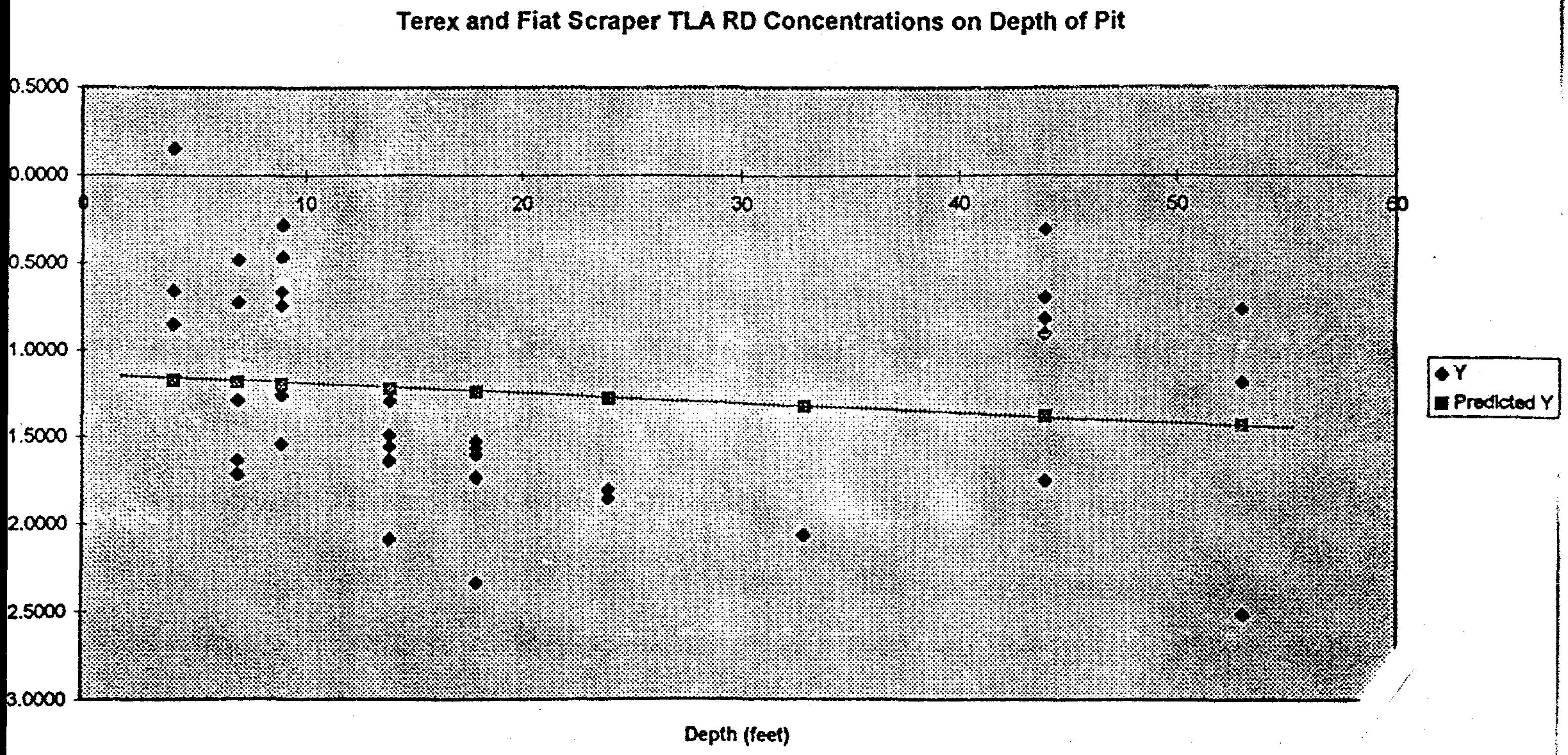

Figure 3. Regression Analysis for Blade Results on Depth of Pit for Excavation Jobs Performed at Los Alamos National Laboratory

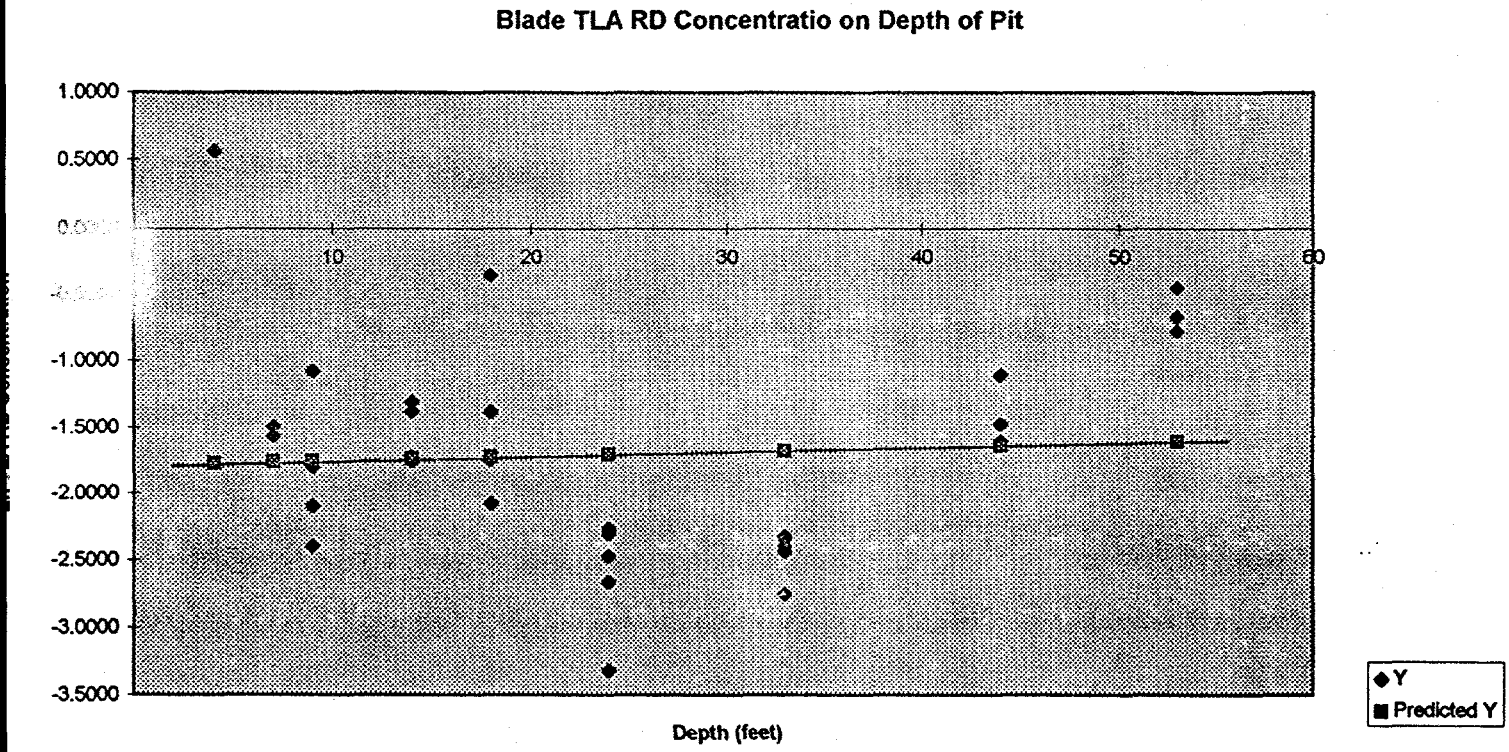

Figure 4. Regression Analysis for Backhoe Results on Depth of Pit for Excavation Jobs Performed at Los Alamos National Laboratory

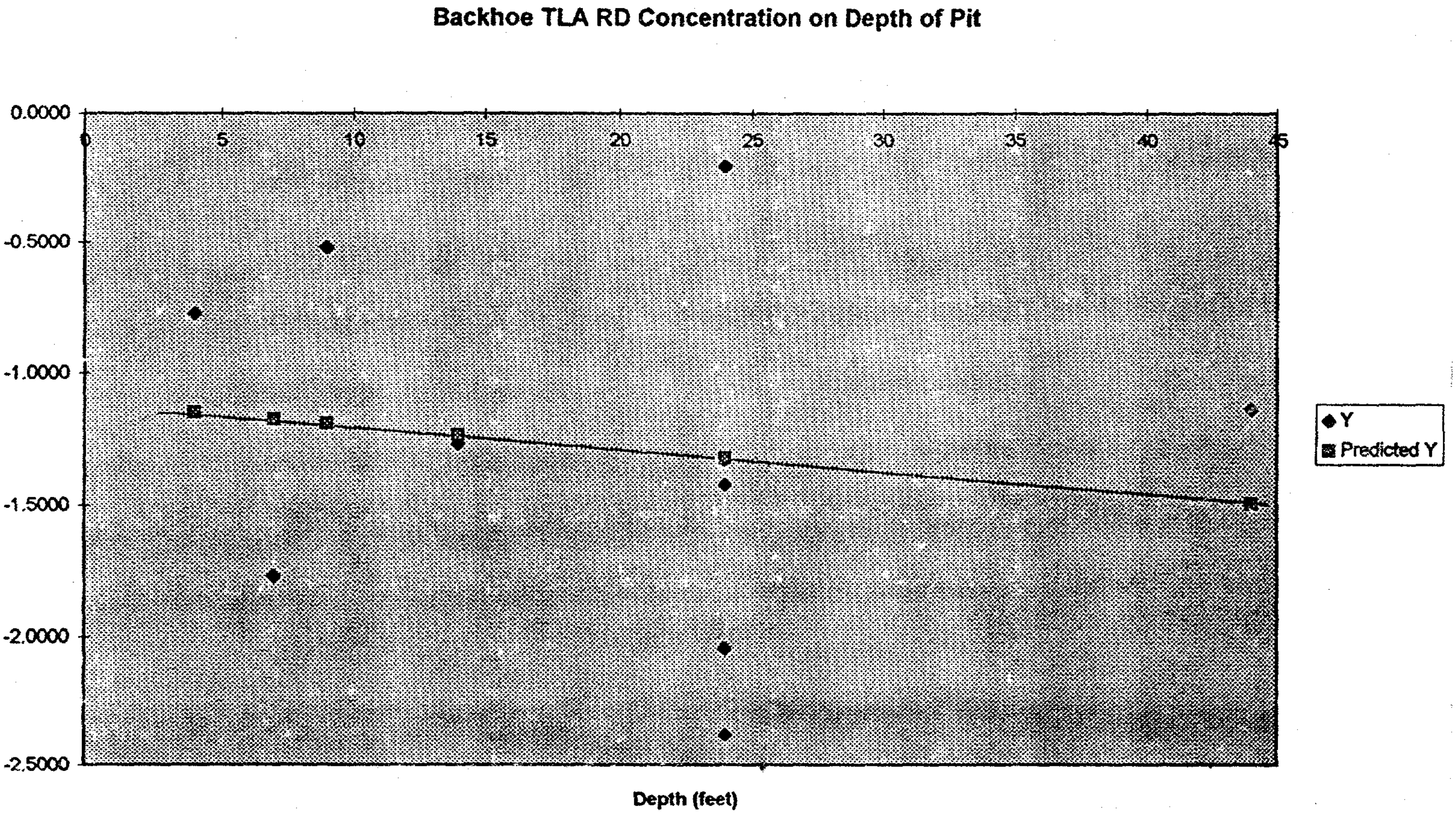

Figure 5. Regression Analysis for Bulldozer Results on Depth of Pit for Excavation Jobs Performed at Los Alamos National Laboratory

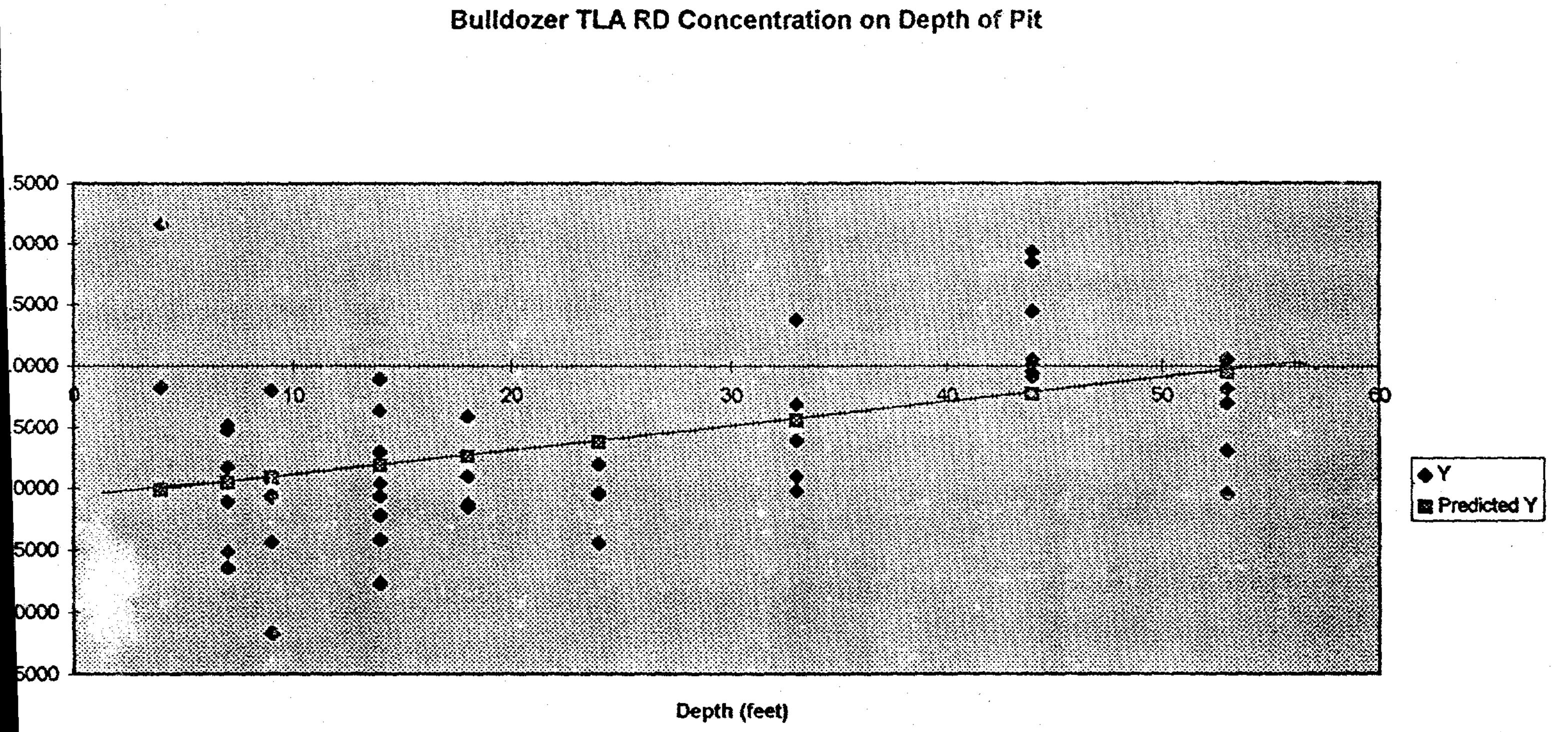

Table 5. Analysis of Respirable Dust Exposure Relative to Depth of Pit for Excavation at Los Alamos National Laboratory

Group	Computed t	Critical Value for t	Computed F	Critical Value for F	Slope	R^2
All Remaining Data	1.871	1.980	3.50	3.92	0.009	0.07
Other Scraper	-0.824	2.030	0.68	4.17	-0.054	0.02
Blade	0.010	2.045	0.10	4.18	0.003	0.00
Backhoe	-0.428	2.306	0.18	5.32	-0.009	0.02
Bulldozer	3.797	2.009	14.42	4.08	0.019	0.23

D. Full-Shift Respirable Dust Time Weighted Averages

Using the personal and area samples, the full-shift respirable dust concentrations were calculated as outlined in Appendix II and summarized in Table 6. In seven instances, the sum of the elapsed time on the pump (ELAP), break time (BREAK ROOM) and transportation time (TRANSP) exceeded the workday length (WKD LEN). In these instances, it was assumed the employee spent the entire day operating the machinery resulting in no time spent in the general area of the site (MISC). If this was still not sufficient, time was deducted from the transportation allowance. This was done because of the three area samples, this had the lowest respirable dust concentration and removal from this time period would result in a worst case scenario. If necessary, time was deducted from the break for the same reason. The results of these calculations are consistent with the results found earlier. The bulldozer operator experienced the highest full-shift respirable dust TWA concentration (0.40 mg/m^3) of any operator and the water truck and the Cat scraper both experienced the lowest full-shift respirable dust TWA (0.13 mg/m^3). Table 6 is a summary of these results.

Table 6. Summary of the Full-Shift Respirable Dust Time Weighted Average Concentrations for Excavation Jobs Performed at Los Alamos National Laboratory

Equipment Type	Geometric Mean Concentration (mg/m^3)	Geometric Standard Deviation
Bulldozer	0.40	1.93
Front End Loader	0.23	1.23
Backhoe	0.24	1.41
Other Scraper	0.26	1.57
Blade	0.20	1.76
Driller*	0.18	1.29
Asst. Driller*	0.17	1.48
Water Truck	0.13	1.26
Cat Scraper	0.13	1.34

To determine the full-shift polymorph specific TWA, it was necessary to determine the percent of each polymorph present. The results of the bulk soil samples indicate the percent quartz, cristobalite and tridymite were 7.59, 3.60 and 3.71, respectively. The laboratory results are summarized in Table 7.

Table 7. X-ray Diffraction Analysis Results from Bulk Samples of Soil From Los Alamos National Laboratory Radiologic Waste Disposal Site

Sample Number	Lab	Percent Quartz	Percent Cristobalite	Percent Tridymite
1	1	18.36	4.30	4.97
1	2	15.07	<0.04	<0.04
1	3	17.49	4.62	4.62
2	1	9.58	2.85	3.68
2	2	3.54	<0.23	6.55
2	3	32.92	1.71	1.71
3	1	0.58	2.27	6.82
3	2	0.20	<0.05	<0.05
3	3	5.43	5.96	5.96
4	1	1.59	11.88	4.99
4	2	<0.06	<0.06	<0.06
4	3	4.21	6.12	6.12
5	1	0.24	4.25	3.96
5	2	0.15	3.62	<0.03
5	3	4.51	6.16	6.16
AVERAGES:		**7.59**	**3.60**	**3.71**

To compare these data to the ACGIH guidelines, which are based on an 8 hour workday, the guidelines must be converted to the various workdays encountered in the study. The steps of this conversion are outlined in Appendix IV and the results are summarized in Table 8. Examination of the full-shift polymorph specific columns of Appendix I indicates that 7 exceedances of the ACGIH guidelines to quartz, 4 to cristobalite and 4 to tridymite occurred during the course of this study. The exceedances are marked with an asterisk. Two exposures to cristobalite and three exposures to tridymite were borderline. The borderline exposures are marked in Appendix I with a "B". One exceedance to the guideline for quartz occurred on the blade and all of the other exceedances occurred on the bulldozer operator. When there was an overexposure to cristobalite or tridymite, an overexposure to quartz was also present. These results provide further evidence that the bulldozer was the most potentially hazardous job on the site with respect to silica exposure.

Table 8. ACGIH Guidelines for Quartz, Cristobalite and Tridymite to Account for Workdays Which are not 8 Hours

	QUARTZ	**CRISTOBALITE & TRIDYMITE**
Workday Length (hrs.)	ACGIH Guideline (mg/m^3)	ACGIH Guideline (mg/m3)
8-1/2	0.09	0.05
9	0.08	0.04
10	0.08	0.042
11-1/2	0.07	0.03
12	0.06	0.03
12-1/2	0.06	0.03

VI Discussion and Conclusions

Analysis of the results indicated that the bulldozer exhibited the highest respirable dust concentration of any of the job classifications. This finding was partially explained by the nature of the bulldozer work. This study provided evidence that enclosed, air conditioned cabs result in lower respirable dust concentrations than do enclosed cabs without air conditioning. Since cabbed vehicles were operated with the windows opened, it was impossible to determine if enclosed cabs provide additional protection over open cabs. It would be useful to design a study to determine if the open cab contributed to the elevated levels.

The results suggest the engineering control, wetting, was not effective in reducing the respirable dust concentrations in the method it was used at LANL. Although 7 exceedances to the ACGIH guidelines support this finding, it should be noted that this is limited evidence. This finding is limited because the data were collected over only four days of no wetting and four days with wetting, resulting in small sample sizes and lowered statistical power.

When considering machines whose work is predominantly in the pit, 23 percent of the variability of the results is explained by increasing depth of the pit. This percentage is consistent with visual inspection of the area which indicated increased dust concentrations with increased depth. The evidence suggest the walls of the pit were blocking cross wind ventilation.

The full-shift polymorph specific TWA concentration calculations indicated 7 instances of an exceedance by the ACGIH guidelines. The exposures estimated during this study were lower than those estimated in other industries. The 5.1 percent possible exceedance rate found in this study compares favorably to the 40.6 percent exceedance rate found in a study of foundry workers (34).

Two differences between this study and the concrete and masonry study (35) will be discussed prior to comparing the results. First, our study used a metal cyclone whereas the concrete and masonry study used a nylon cyclone. While this difference makes comparison of the results problematic, the difference in the collection efficiency has been documented and is discussed in Appendix V. The second difference is the analysis technique used to quantify the concentration of quartz. The concrete and masonry study used Forurier Transform Infrared Analysis (FTIA) to obtain the results as mg/m^3 of quartz. How the efficiency of this method compared with the efficiency of gravimetric analysis is unknown and for purposes of this discussion, it will be assumed they are equal.

Summary statistics for the concrete and masonry study and this study for exposure to quartz are shown in Table 9. As can be seen from the table, the excavation workers can be expected to experience a lower exposure to quartz than construction and masonry workers.

While the results from this study provided information where the literature was lacking, they must be used carefully. The exposure to quartz, cristobalite and tridymite were calculated from bulk soil samples. This assumes that the percent of quartz, cristobalite and tridymite is the same in the bulk sample as it would be in respirable, airborne concentrations. To achieve a more accurate exposure assessment XRD analysis on the dust in the sampling media is required. XRD analysis on the sampling media, was not used because of the quick turn-around time needed. Also, as noted earlier, OSHA and NIOSH recommend using a nylon 10 mm cyclone for sampling. This study used a metal cyclone therefore, when comparing the data obtained during this study and similar studies, it is important to account for this difference.

Further studies on this subject area should include more data in the presence and absence of wetting where water is applied to the pit more frequently, an analysis of the dirt collected in the grit cups and exposure calculations to quartz, cristobalite and tridymite which are based on XRD analysis of the sampling media.

Table 9. Summary Statistics for the Concrete and Masonry Industry and the Construction-Excavation Industry With Respect to Exposure to Quartz

Statistic	Concrete and Masonry[35]	Construction-Excavation
Minimum (mg/m3)	<0.06	0.01
Maximum (mg/m3)	8.70	0.26
Geometric Mean (mg/m3)	0.49	0.02
Geometric Standard Deviation	3.85	1.86

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List Of Appendices

Respirable Dust and Exposure Data Collected During Excavation at Los Alamos National Laboratory

ATE	DEPTH	JOB	PID	PRE	ELAP	POST	LOAD	VOL	EXP	FLD BLK	WT	TLA RESPIRABLE DUST CONCENT.	NOTES	WKD LE
/17/94	4	F1	26	1916	109	1952	74	210.81	0.3510	B28	8	0.3890		48
/17/94	4	A2	28	1898	81	1923	72	154.75	0.4653	B28	8	0.5170		48
/20/94	4	A2	28	1926	506	1878	1115	962.41	1.1585	B42	5	1.1637		48
/21/94	4	E4	27	1931	443	1930	1503	855.21	1.7575	?	4.37	1.7626		48
/22/94	4	B4	26	1903	515	1889	3094	976.44	3.1687	B54	10	3.1789		48
/23/94	4	A1	20	1918	223	1887	62	424.26	0.1461	B51	6	0.1603		48
/23/94	4	A2	20	1918	64	1887	46	121.76	0.3778	B51	6	0.4271		
/23/94	4	D1	26	1909	169	1879	142	320.09	0.4436	B51	6	0.4624		48
/23/94	4	B1	27	1901	129	1889	199	244.46	0.8141	B51	6	0.8386		48
/24/94	7	A2	20	1900	202	1923	70	386.12	0.1813	B79	5	0.1942	AM	48
/24/94	7	A2	20	1900	39	1923	25	74.55	0.3354	B85	11	0.4829	PM	
/24/94	7	D1	26	1898	31	1892	5	58.75	0.0851	B79	5	0.1702	AM	48
/24/94	7	F1	26	1898	50	1923	17	95.53	0.1780	B85	11	0.2931	PM	
/24/94	7	B1	27	1902	210	1873	126	396.38	0.3179	B79	5	0.3305		48
/24/94	7	B2	27	1902	57	1873	36	107.59	0.3346	B85	11	0.4369	PM	
/27/94	7	C1	17	1905	193	1916	23	368.73	0.0624	B78	12	0.0949	AM	72
/27/94	7	C1	17	1898	165	1911	64	314.24	0.2037	C05	11	0.2387	PM	
/27/94	7	A1	18	1911	302	1915	63	577.73	0.1090	C05	11	0.1281	PM	72
/27/94	7	A2	20	1927	203	1917	95	390.17	0.2435	B78	12	0.2742	AM	72
/27/94	7	A2	20	1902	332	1905	380	631.96	0.6013	C05	11	0.6187	PM	
/27/94	7	F1	26	1919	223	1915	56	427.49	0.1310	B78	12	0.1591	AM	7
/27/94	7	B1	27	1917	201	1942	217	387.83	0.5595	B78	12	0.5905	AM	7
/27/94	7	B1	27	1909	311	1880	246	589.19	0.4175	C05	11	0.4362	PM	
/28/94	7	C1	17	1903	373	1908	18	710.75	0.0253	C12	4.37	0.0315	PM	7
/28/94	7	C1	17	1889	103	1886	13	194.41	0.0669	C14	24	0.1903	AM	
/28/94	7	A2	20	1889	153	1882	55	288.48	0.1907	C14	24	0.2738	AM	7
/28/94	7	F1	20	1970	291	1949	338	570.21	0.5928	C12	4.37	0.6004	PM	
/28/94	7	B4	26	1943	63	1970	52	123.26	0.4219	C14	24	0.6166	AM	7
/28/94	7	B4	26	1886	78	1891	52	147.30	0.3530	C12	4.37	0.3827	PM	7
/28/94	7	B4	27	1903	63	1903	23	119.89	0.1918	C14	24	0.3920	AM	7
/28/94	7	E1	27	1882	289	1879	109	543.46	0.2006	C12	4.37	0.2086	PM	
/29/94	7	C1	17	1925	306	1933	26	590.27	0.0440	C40	13	0.0661	PM	7
/29/94	7	B1	20	1895	283	1959	107	545.34	0.1962	C40	13	0.2200	PM	7
/29/94	7	F1	20	1936	191	1925	54	368.73	0.1465	C31	9	0.1709	AM	
/29/94	7	A1	26	1916	175	1825	26	327.34	0.0794	C31	9	0.1069	AM	7
/29/94	7	B1	27	1924	160	1943	51	309.36	0.1649	C31	9	0.1939	AM	7
/29/94	7	E1	27	1919	274	1894	104	522.38	0.1991	C40	13	0.2240	PM	
/29/94	7	A2	28	1915	90	1919	22	172.53	0.1275	C31	9	0.1797	AM	7
/30/94	9	B4	20	1917	125	1902	52	238.69	0.2179	C46	5	0.2388	AM	7
/30/94	9	B4	20	1906	214	1940	138	411.52	0.3353	C57	3	0.3426	PM	
/30/94	9	A1	26	1921	148	1891	11	282.09	0.0390	C46	5	0.0567	AM	7
/30/94	9	A1	26	1902	314	1955	11	605.55	0.0182	C57	3	0.0231	PM	
/30/94	9	E4	27	1918	119	1954	16	230.38	0.0694	C46	5	0.0912	AM	7
/30/94	9	E4	27	1916	243	1964	157	471.42	0.3330	C57	3	0.3394	PM	
/30/94	9	A3	28	1916	148	1949	56	286.01	0.1958	C46	5	0.2133	AM	7
/30/94	9	A3	28	1916	243	1949	352	469.60	0.7496	C57	3	0.7560	PM	
7/1/94	9	B1	20	1933	295	1923	73	568.76	0.1283	C58	-8	0.1143		4
7/1/94	9	A1	26	1931	275	1999	19	540.38	0.0352	C58	-8	0.0204		4
7/1/94	9	E4	27	1907	170	1917	48	325.04	0.1477	C58	-8	0.1231		4
7/1/94	9	F1	28	1915	234	1944	176	451.50	0.3898	C58	-8	0.3721		4
7/5/94	9	C1	17	1911	280	2000	20	547.54	0.0365	C96	2	0.0402	PM	7
7/5/94	9	C1	17	1895	168	1854	26	314.92	0.0826	C71	6	0.1016	AM	7
7/5/94	9	A1	26	1894	244	1912	108	464.33	0.2326	C96	2	0.2369	PM	7
7/5/94	9	A1	26	1915	188	1894	30	358.05	0.0838	C71	6	0.1005	AM	7
7/5/94	9	A2	28	1927	281	1944	277	543.88	0.5093	C96	2	0.5130	PM	7
7/5/94	9	A3	28	1930	127	1927	63	244.92	0.2572	C71	6	0.2817	AM	

N	RK R	TRANSP	MISC	FS-RD TWA		QUARTZ	CRISTOB	TRIDYM		
0	75	40	149	0.1235		0.01	0.00	0.00		
				s						
0	75	40	193	0.4680		0.04	0.02	0.02		
0				s						
0	75	40	182	0.1468		0.01	0.01	0.01		
0				s						
0	75	40	221	0.3322		0.03	0.01	0.01		
0				s						
0	75	40	286	0.3686		0.03	0.01	0.01		
0				s						
0	75	40	298	0.1607		0.01	0.01	0.01		
0				s						
0	75	40	133	0.6126		0.05	0.02	0.02		
0				s						
0	75	40	186	0.1106		0.01	0.00	0.00		
0				s						
0	75	40	469	0.2149		0.02	0.01	0.01		
0	75	40	486	0.2118		0.02	0.01	0.01		
0	60	30	300	0.1567		0.01	0.01	0.01		
0	60	30	96	0.2588		0.02	0.01	0.01		
0	60	30	116	0.0890		0.01	0.00	0.00		
0	60	30	212	0.1832		0.01	0.01	0.01		
0	60	30	104	0.1887		0.01	0.01	0.01		
0	15	20	43	0.0891		0.01	0.00	0.00		
0	15	20	63	0.3933		0.03	0.01	0.01		
0	15	20	67	0.1889		0.01	0.01	0.01		
0	15	20	66	0.2216		0.02	0.01	0.01		
0	15	20	51	0.0760		0.01	0.00	0.00		
50	75	40	545	0.2156		0.02	0.01	0.01		
50	75	40	533	0.2012		0.02	0.01	0.01		
50	75	40	525	0.2080		0.02	0.01	0.01		
50	75	40	517	0.1725		0.01	0.01	0.01		
50	75	40	349	0.2377		0.02	0.01	0.01		
50				s						
50	75	40	350	0.1934		0.01	0.01	0.01		
50				s						
50	75	40	466	0.2000		0.02	0.01	0.01		
50				s						
50	75	40	399	0.1449		0.01	0.01	0.01		
50				s						
50	75	40	325	0.1851		0.01	0.01	0.01		
50	75	40	359	0.1861		0.01	0.01	0.01		
50	75	40	414	0.1631		0.01	0.01	0.01		
50	75	40	609	0.2151		0.02	0.01	0.01		
50	75	40	377	0.1601		0.01	0.01	0.01		
50	75	40	254	0.1158		0.01	0.00	0.00		
50	75	25	0	0.3004		0.02	0.01	0.01		
50	75	40	184	0.1360		0.01	0.00	0.01		
50	75	40	213	0.4744		0.04	0.02	0.02		
50	75	40	150	0.2023		0.02	0.01	0.01		
50	75	14	0	0.2957		0.02	0.01	0.01		
50	75	40	342	0.1367		0.01	0.00	0.01		
50	75	40	158	0.1452		0.01	0.01	0.01		
50	75	40	278	0.1981		0.02	0.01	0.01		
50	75	40	8	0.3614		0.03	0.01	0.01		
50	75	40	144	0.0890		0.01	0.00	0.00		
50	75	40	434	0.2099		0.02	0.01	0.01		
50	75	40	404	0.1963		0.01	0.01	0.01		

Respirable Dust and Exposure Data Collected During Excavation at Los Alamos National Laboratory

ATE	DEPTH	JOB	PID	PRE	ELAP	POST	LOAD	VOL	EXP	FLD BLK	WT	TLA RESPIRABLE DUST CONCENT.	NOTES
/17/94	4	F1	26	1916	109	1952	74	210.81	0.3510	B28	8	0.3890	
/17/94	4	A2	28	1898	81	1923	72	154.75	0.4653	B28	8	0.5170	
/20/94	4	A2	28	1926	506	1878	1115	962.41	1.1585	B42	5	1.1637	
/21/94	4	E4	27	1931	443	1930	1503	855.21	1.7575	?	4.37	1.7626	
/22/94	4	B4	26	1903	515	1889	3094	976.44	3.1687	B54	10	3.1789	
/23/94	4	A1	20	1918	223	1887	62	424.26	0.1461	B51	6	0.1603	
/23/94	4	A2	20	1918	64	1887	46	121.76	0.3778	B51	6	0.4271	
/23/94	4	D1	26	1909	169	1879	142	320.09	0.4436	B51	6	0.4624	
/23/94	4	B1	27	1901	129	1889	199	244.46	0.8141	B51	6	0.8386	
/24/94	7	A2	20	1900	202	1923	70	386.12	0.1813	B79	5	0.1942	AM
/24/94	7	A2	20	1900	39	1923	25	74.55	0.3354	B85	11	0.4829	PM
/24/94	7	D1	26	1898	31	1892	5	58.75	0.0851	B79	5	0.1702	AM
/24/94	7	F1	26	1898	50	1923	17	95.53	0.1780	B85	11	0.2931	PM
/24/94	7	B1	27	1902	210	1873	126	396.38	0.3179	B79	5	0.3305	
/24/94	7	B2	27	1902	57	1873	36	107.59	0.3346	B85	11	0.4369	PM
/27/94	7	C1	17	1905	193	1916	23	368.73	0.0624	B78	12	0.0949	AM
/27/94	7	C1	17	1898	165	1911	64	314.24	0.2037	C05	11	0.2387	PM
/27/94	7	A1	18	1911	302	1915	63	577.73	0.1090	C05	11	0.1281	PM
/27/94	7	A2	20	1927	203	1917	95	390.17	0.2435	B78	12	0.2742	AM
/27/94	7	A2	20	1902	332	1905	380	631.96	0.6013	C05	11	0.6187	PM
/27/94	7	F1	26	1919	223	1915	56	427.49	0.1310	B78	12	0.1591	AM
/27/94	7	B1	27	1917	201	1942	217	387.83	0.5595	B78	12	0.5905	AM
/27/94	7	B1	27	1909	311	1880	246	589.19	0.4175	C05	11	0.4362	PM
/28/94	7	C1	17	1903	373	1908	18	710.75	0.0253	C12	4.37	0.0315	PM
/28/94	7	C1	17	1889	103	1886	13	194.41	0.0669	C14	24	0.1903	AM
/28/94	7	A2	20	1889	153	1882	55	288.48	0.1907	C14	24	0.2738	AM
/28/94	7	F1	20	1970	291	1949	338	570.21	0.5928	C12	4.37	0.6004	PM
/28/94	7	B4	26	1943	63	1970	52	123.26	0.4219	C14	24	0.6166	AM
/28/94	7	B4	26	1886	78	1891	52	147.30	0.3530	C12	4.37	0.3827	PM
/28/94	7	B4	27	1903	63	1903	23	119.89	0.1918	C14	24	0.3920	AM
/28/94	7	E1	27	1882	289	1879	109	543.46	0.2006	C12	4.37	0.2086	PM
/29/94	7	C1	17	1925	306	1933	26	590.27	0.0440	C40	13	0.0661	PM
/29/94	7	B1	20	1895	283	1959	107	545.34	0.1962	C40	13	0.2200	PM
/29/94	7	F1	20	1936	191	1925	54	368.73	0.1465	C31	9	0.1709	AM
/29/94	7	A1	26	1916	175	1825	26	327.34	0.0794	C31	9	0.1069	AM
/29/94	7	B1	27	1924	160	1943	51	309.36	0.1649	C31	9	0.1939	AM
/29/94	7	E1	27	1919	274	1894	104	522.38	0.1991	C40	13	0.2240	PM
/29/94	7	A2	28	1915	90	1919	22	172.53	0.1275	C31	9	0.1797	AM
/30/94	9	B4	20	1917	125	1902	52	238.69	0.2179	C46	5	0.2388	AM
/30/94	9	B4	20	1906	214	1940	138	411.52	0.3353	C57	3	0.3426	PM
/30/94	9	A1	26	1921	148	1891	11	282.09	0.0390	C46	5	0.0567	AM
/30/94	9	A1	26	1902	314	1955	11	605.55	0.0182	C57	3	0.0231	PM
/30/94	9	E4	27	1918	119	1954	16	230.38	0.0694	C46	5	0.0912	AM
/30/94	9	E4	27	1916	243	1964	157	471.42	0.3330	C57	3	0.3394	PM
/30/94	9	A3	28	1916	148	1949	56	286.01	0.1958	C46	5	0.2133	AM
/30/94	9	A3	28	1916	243	1949	352	469.60	0.7496	C57	3	0.7560	PM
7/1/94	9	B1	20	1933	295	1923	73	568.76	0.1283	C58	-8	0.1143	
7/1/94	9	A1	26	1931	275	1999	19	540.38	0.0352	C58	-8	0.0204	
7/1/94	9	E4	27	1907	170	1917	48	325.04	0.1477	C58	-8	0.1231	
7/1/94	9	F1	28	1915	234	1944	176	451.50	0.3898	C58	-8	0.3721	
7/5/94	9	C1	17	1911	280	2000	20	547.54	0.0365	C96	2	0.0402	PM
7/5/94	9	C1	17	1895	168	1854	26	314.92	0.0826	C71	6	0.1016	AM
7/5/94	9	A1	26	1894	244	1912	108	464.33	0.2326	C96	2	0.2369	PM
7/5/94	9	A1	26	1915	188	1894	30	358.05	0.0838	C71	6	0.1005	AM
7/5/94	9	A2	28	1927	281	1944	277	543.88	0.5093	C96	2	0.5130	PM
7/5/94	9	A3	28	1930	127	1927	63	244.92	0.2572	C71	6	0.2817	AM

N	RK R	TRANSP	MISC	FS-RD TWA		QUARTZ	CRISTOB	TRIDYM		
0	75	40	149	0.1235		0.01	0.00	0.00		
				s						
0	75	40	193	0.4680		0.04	0.02	0.02		
0				s						
0	75	40	182	0.1468		0.01	0.01	0.01		
0				s						
0	75	40	221	0.3322		0.03	0.01	0.01		
0				s						
0	75	40	286	0.3686		0.03	0.01	0.01		
0				s						
0	75	40	298	0.1607		0.01	0.01	0.01		
0				s						
0	75	40	133	0.6126		0.05	0.02	0.02		
0				s						
0	75	40	186	0.1106		0.01	0.00	0.00		
0				s						
0	75	40	469	0.2149		0.02	0.01	0.01		
0	75	40	486	0.2118		0.02	0.01	0.01		
00	60	30	300	0.1567		0.01	0.01	0.01		
00	60	30	96	0.2588		0.02	0.01	0.01		
00	60	30	116	0.0890		0.01	0.00	0.00		
00	60	30	212	0.1832		0.01	0.01	0.01		
00	60	30	104	0.1887		0.01	0.01	0.01		
00	15	20	43	0.0891		0.01	0.00	0.00		
00	15	20	63	0.3933		0.03	0.01	0.01		
00	15	20	67	0.1889		0.01	0.01	0.01		
00	15	20	66	0.2216		0.02	0.01	0.01		
00	15	20	51	0.0760		0.01	0.00	0.00		
50	75	40	545	0.2156		0.02	0.01	0.01		
50	75	40	533	0.2012		0.02	0.01	0.01		
50	75	40	525	0.2080		0.02	0.01	0.01		
50	75	40	517	0.1725		0.01	0.01	0.01		
50	75	40	349	0.2377		0.02	0.01	0.01		
50				s						
50	75	40	350	0.1934		0.01	0.01	0.01		
50				s						
50	75	40	466	0.2000		0.02	0.01	0.01		
50				s						
50	75	40	399	0.1449		0.01	0.01	0.01		
50				s						
50	75	40	325	0.1851		0.01	0.01	0.01		
50	75	40	359	0.1861		0.01	0.01	0.01		
50	75	40	414	0.1631		0.01	0.01	0.01		
50	75	40	609	0.2151		0.02	0.01	0.01		
50	75	40	377	0.1601		0.01	0.01	0.01		
50	75	40	254	0.1158		0.01	0.00	0.00		
50	75	25	0	0.3004		0.02	0.01	0.01		
50	75	40	184	0.1360		0.01	0.00	0.01		
50	75	40	213	0.4744		0.04	0.02	0.02		
50	75	40	150	0.2023		0.02	0.01	0.01		
50	75	14	0	0.2957		0.02	0.01	0.01		
50	75	40	342	0.1367		0.01	0.00	0.01		
50	75	40	158	0.1452		0.01	0.01	0.01		
50	75	40	278	0.1981		0.02	0.01	0.01		
50	75	40	8	0.3614		0.03	0.01	0.01		
50	75	40	144	0.0890		0.01	0.00	0.00		
50	75	40	434	0.2099		0.02	0.01	0.01		
50	75	40	404	0.1963		0.01	0.01	0.01		

	CTR	TRA[illegible]P	MISC	TWA		QUARTZ	CRISTOB	TRIDYM		
		40	188	0.0938		0.01	0.00	0.00		
[illegible]	75	40	423	0.1693		0.01	0.01	0.01		
750	75	40	295	[illegible]		0.01	0.01	0.01		
750	[illegible]	40	375	0.1958		0.01	0.01	0.01		
750	75	40	333	0.2095		0.02	0.01	0.01		
750	75	40	200	0.1077		0.01	0.00	0.00		
750	75	40	366	0.1543		0.01	0.01	0.01		
750	75	40	254	0.2268		0.02	0.01	0.01		
750	75	40	286	0.1742		0.01	0.01	0.01		
750	75	40	50	0.3846		0.03	0.01	0.01		
750	75	40	159	[illegible]		0.01	0.00	0.00		
750	75	40	120	0.1026		0.01	0.00	0.00		
750	75	40	301	0.2131		0.02	0.01	0.01		
750	75	40	219	0.1230		0.01	0.00	0.00		
[illegible]	75	40	378	0.1616		0.01	0.01	0.01		
750	75	40	309	0.4612		0.04	0.02	0.02		
750	75	40	259	0.2709		0.02	0.01	0.01		
750	75	40	171	0.0877		0.01	0.00	0.00		
750	75	40	360	0.1354		0.01	0.00	0.01		
750	75	40	251	0.1388		0.01	0.00	0.01		
750	75	40	281	0.2708		0.02	0.01	0.01		
750	75	40	449	0.1537		0.01	0.01	0.01		
750	75	40	111	0.1398		0.01	0.01	0.01		
750	75	40	460	0.1715		0.01	0.01	0.01		
600	60	30	444	0.2430		0.02	0.01	0.01		
600	60	30	49	0.3496		0.03	0.01	0.01		
600	60	30	438	0.2035		0.02	0.01	0.01		
600	60	30	89	0.1133		0.01	0.00	0.00		
750	75	40	447	0.1824		0.01	0.01	0.01		
750	75	40	230	0.3801		0.03	0.01	0.01		
750	75	40	446	0.1735		0.01	0.01	0.01		
750	75	40	196	0.1328		0.01	0.00	0.00		
750	75	40	102	0.4523		0.03	0.02	0.02		
750	75	40	92	0.1023		0.01	0.00	0.00		
750	75	40	325	0.2591		0.02	0.01	0.01		
750	75	40	323	0.2080		0.02	0.01	0.01		
750	75	9	0	1.3110		* 0.10	* 0.05	* 0.05		
750	75	40	212	0.1165		0.01	0.00	0.00		
690	75	40	250	0.1429		0.01	0.01	0.01		
690	75	40	219	0.3165		0.02	0.01	0.01		
690	75	40	230	0.1293		0.01	0.00	0.00		
690	75	40	71	0.8138		* 0.06	0.03	0.03		
510	60	30	188	0.1298		0.01	0.00	0.00		
510	60	30	99	0.5278		0.04	0.02	0.02		
510	60	30	187	1.2590		* 0.10	B 0.05	B 0.05		
510	60	30	184	0.4101		0.03	0.01	0.02		
510	60	25	0	1.9633		* 0.15	* 0.07	* 0.07		
750	75	40	400	0.1861		0.01	0.01	0.01		
750	75	40	190	0.6719		0.05	0.02	0.02		
750	75	40	198	0.2680		0.02	0.01	0.01		
750	75	40	169	0.1155		0.01	0.00	0.00		
750	75	40	439	0.1895		0.01	0.01	0.01		
750	75	40	270	0.1489		0.01	0.01	0.01		
750	75	40	247	0.5818		0.04	0.02	0.02		
750	75	40	589	0.2005		0.02	0.01	0.01		
750	75	40	160	0.1091		0.01	0.00	0.00		
750	75	40	20	0.3573		0.03	0.01	0.01		
750	75	40	206	0.2626		0.02	0.01	0.01		

LEN	JCI R	TRANSP	MISC	TWA		QUARTZ	CRISTOB	TRIDYM		
750	75	40	188	0.0938		0.01	0.00	0.00		
75	75	40	423	0.1693		0.01	0.01	0.01		
750	75	40	295	0.1627		0.01	0.01	0.01		
750	75	40	575	0.1958		0.01	0.01	0.01		
750	75	40	333	0.2095		0.02	0.01	0.01		
750	75	40	200	0.1077		0.01	0.00	0.00		
750	75	40	366	0.1543		0.01	0.01	0.01		
750	75	40	254	0.2268		0.02	0.01	0.01		
750	75	40	286	0.1742		0.01	0.01	0.01		
750	75	40	50	0.3846		0.03	0.01	0.01		
750	75	40	159	0.0931		0.01	0.00	0.00		
750	75	40	120	0.1026		0.01	0.00	0.00		
750	75	40	301	0.2131		0.02	0.01	0.01		
750	75	40	219	0.1230		0.01	0.00	0.00		
750	75	40	378	0.1616		0.01	0.01	0.01		
750	75	40	309	0.4612		0.04	0.02	0.02		
750	75	40	259	0.2709		0.02	0.01	0.01		
750	75	40	171	0.0877		0.01	0.00	0.00		
750	75	40	360	0.1354		0.01	0.00	0.01		
750	75	40	251	0.1388		0.01	0.00	0.01		
750	75	40	281	0.2708		0.02	0.01	0.01		
750	75	40	449	0.1537		0.01	0.01	0.01		
750	75	40	111	0.1398		0.01	0.01	0.01		
750	75	40	460	0.1715		0.01	0.01	0.01		
600	60	30	444	0.2430		0.02	0.01	0.01		
600	60	30	49	0.3496		0.03	0.01	0.01		
600	60	30	438	0.2035		0.02	0.01	0.01		
600	60	30	89	0.1133		0.01	0.00	0.00		
750	75	40	447	0.1824		0.01	0.01	0.01		
750	75	40	230	0.3801		0.03	0.01	0.01		
750	75	40	446	0.1735		0.01	0.01	0.01		
750	75	40	196	0.1328		0.01	0.00	0.00		
750	75	40	102	0.4523		0.03	0.02	0.02		
750	75	40	92	0.1023		0.01	0.00	0.00		
750	75	40	325	0.2591		0.02	0.01	0.01		
750	75	40	323	0.2080		0.02	0.01	0.01		
750	75	9	0	1.3110		* 0.10	* 0.05	* 0.05		
750	75	40	212	0.1165		0.01	0.00	0.00		
690	75	40	250	0.1429		0.01	0.01	0.01		
690	75	40	219	0.3165		0.02	0.01	0.01		
690	75	40	230	0.1293		0.01	0.00	0.00		
690	75	40	71	0.8138		* 0.06	0.03	0.03		
510	60	30	188	0.1298		0.01	0.00	0.00		
510	60	30	99	0.5278		0.04	0.02	0.02		
510	60	30	187	1.2590		* 0.10	B 0.05	B 0.05		
510	60	30	184	0.4101		0.03	0.01	0.02		
510	60	25	0	1.9633		* 0.15	* 0.07	* 0.07		
750	75	40	400	0.1861		0.01	0.01	0.01		
750	75	40	190	0.6719		0.05	0.02	0.02		
750	75	40	198	0.2680		0.02	0.01	0.01		
750	75	40	169	0.1155		0.01	0.00	0.00		
750	75	40	439	0.1895		0.01	0.01	0.01		
750	75	40	270	0.1489		0.01	0.01	0.01		
750	75	40	247	0.5818		0.04	0.02	0.02		
750	75	40	589	0.2005		0.02	0.01	0.01		
750	75	40	160	0.1091		0.01	0.00	0.00		
750	75	40	20	0.3573		0.03	0.01	0.01		
750	75	40	206	0.2626		0.02	0.01	0.01		

DATE	DEPTH	JOB	PID	PRE	ELAP	POST	LOAD	VOL	EXP	FLD BLK	WT	TLA RDC	NOTES
8/10/94	44	G1	20	1918	55	1937	-3	106.01	#####	G65	-8	-0.1038	
8/10/94	44	B1	26	1917	369	1930	1117	709.77	1.5737	G65	-8	1.5625	
8/10/94	44	E3	27	1928	164	1924	71	315.86	0.2248	G65	-8	0.1995	
8/10/94	44	G2	28	1911	25	1975	0	48.58	0.0000	G65	-8	-0.1647	
8/10/94	44	A2	30	1921	515	1898	497	983.39	0.5054	G65	-8	0.4973	
8/10/94	44	B3	32	1921	393	1948	702	760.26	0.9234	G65	-8	0.9128	
8/11/94	53	B1	26	1905	203	1940	330	390.27	0.8456	G93	-6	0.8302	
8/11/94	53	E3	27	1918	258	1930	323	496.39	0.6507	G93	-6	0.6386	
8/11/94	53	A2	30	1917	195	1934	181	375.47	0.4821	G93	-6	0.4661	
8/11/94	53	B1	32	1926	370	1938	534	714.84	0.7470	G93	-6	0.7386	
8/12/94	53	G1	20	1917	129	1940	18	248.78	0.0724	H14	-10	0.0322	
8/12/94	53	B1	26	1929	333	1966	628	648.52	0.9684	H14	-10	0.9529	
8/12/94	53	E3	27	1922	246	1929	227	473.67	0.4792	H14	-10	0.4581	
8/12/94	53	G2	28	1928	200	1938	12	386.60	0.0310	H14	-10	0.0052	
8/12/94	53	B2	32	1921	67	1983	56	130.78	0.4282	H14	-10	0.3517	
8/15/94	53	G1	20	1914	222	1957	52	429.68	0.1210	H36	-4	0.1117	
8/15/94	53	B1	26	1911	293	1933	286	563.15	0.5079	H36	-4	0.5008	
8/15/94	53	G2	28	1912	253	1929	16	485.89	0.0329	H36	-4	0.0247	
8/15/94	53	A2	30	1927	449	1921	268	863.88	0.3102	H36	-4	0.3056	
8/18/94	53	G1	20	1907	33	1943	126	63.53	1.9835		4.37	2.0523	
8/18/94	53	B1	26	1901	402	1916	808	767.22	1.0532		4.37	1.0589	
8/18/94	53	E3	27	1906	300	1909	288	572.25	0.5033		4.37	0.5109	
8/18/94	53	G2	28	1906	283	1916	117	540.81	0.2163		4.37	0.2244	
8/18/94	53	A2	30	1910	112	1927	13	214.87	0.0605		4.37	0.0808	
8/18/94	53	B3	32	1909	435	1911	866	830.85	1.0423		4.37	1.0476	
											4.37	AVE FLD BLK WT	

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N	JCI R	TRANSP	MISC	TWA		QUARTZ	CRISTOB	TRIDYM		
50	75	40	580	0.1764		0.01	0.01	0.01		
50	75	40	266	0.8644		* 0.07	B 0.03	B 0.03		
50	75	40	471	0.1970		0.01	0.01	0.01		
50	75	40	610	0.1870		0.01	0.01	0.01		
50	75	40	120	0.3961		0.03	0.01	0.01		
50	75	40	242	0.5673		0.04	0.02	0.02		
50	75	40	432	0.3671		0.03	0.01	0.01		
50	75	40	377	0.3466		0.03	0.01	0.01		
50	75	40	440	0.2658		0.02	0.01	0.01		
50	75	40	265	0.4598		0.03	0.02	0.02		
50	75	40	506	0.1688		0.01	0.01	0.01		
50	75	40	302	0.5289		0.04	0.02	0.02		
50	75	40	389	0.2806		0.02	0.01	0.01		
50	75	40	435	0.1446		0.01	0.01	0.01		
50	75	40	568	0.2121		0.02	0.01	0.01		
40	60	30	228	0.1578		0.01	0.01	0.01		
40	60	30	157	0.3559		0.03	0.01	0.01		
40	60	30	197	0.1114		0.01	0.00	0.00		
40	60	30	1	0.2773		0.02	0.01	0.01		
50	75	40	602	0.2805		0.02	0.01	0.01		
50	75	40	233	0.6540		0.05	0.02	0.02		
50	75	40	335	0.3195		0.02	0.01	0.01		
50	75	40	352	0.2046		0.02	0.01	0.01		
50	75	40	523	0.1801		0.01	0.01	0.01		
50	75	40	200	0.6847		0.05	0.02	0.03		

Appendix I a - Codes for the equipment type used for excavation at Los Alamos National Laboratory

CODE	JOB
A1	Cat Scraper
A2,3	Other Scraper
B1,2,3	Bulldozer
C1	Water Truck
D1	Backhoe
E1,2,3	Blade
F1	Front End Loader
G1	Driller
G2	Assistant Driller

Appendix I b - Legend for Respirable Dust and Exposure Data Collected During Excavation at Los Alamos National Laboratory

HEADING	UNITS	FORMULA	EXPLANATION
DATE	N/A	N/A	Date the sample was collected.
DEPTH	Feet	N/A	Depth of the pit as measured by the weekly site survey.
JOB	N/A	N/A	Type of machinery the operator was running while the sample was collected. The codes are shown below.
PID	N/A	N/A	Personal Identification Number.
PRE	ml/min	N/A	Flow rate of the pump at the start of the sampling period.
ELAP	min	N/A	Time the pump ran during the workday.
POST	ml/min	N/A	Flow rate of the pump at the end of the sampling period.
LOAD	ug	(Pre weight of filter - Post weight of filter)	Amount of respirable dust collected on the filter.
VOL	liters	$\frac{\{(PRE + POST)/2 * ELAP\}}{1000}$	Volume of air collected by the pump.
EXP	mg/m3	LOAD/VOL	Respirable dust concentration in the breathing zone of the worker
FLD BLK	N/A	N/A	Field blank identification number.
WT	ug	(Pre weight of filter - Post weight of filter)	Weight change of the field blank
TLA RESPIRABLE DUST CONCEN.	mg/m3	(LOAD-WT)/VOL	Respirable dust concentration adjusted for the field blank. Abbreviated TL-RD TWA.
NOTES	N/A	N/A	Indicated if the sample was taken before of after lunch.
WKD LEN	min	N/A	Length of the workday.
BREAK ROOM	min	N/A	Time spent in the break room
TRANSP	min	N/A	Time spent commuting to and from the break room.
MISC	min	N/A	Time spent doing miscellaneous tasks at site.
FULL SHIFT-RD TWA	mg/m3	See Appendix 2	The TWA exposure as calculated over the entire work shift. Abbreviated FS-RD TWA
FULL SHIFT-	mg/m3	(TWA*0.0759)	Exposure to quartz
POLYMORPH	mg/m3	(TWA*0.0360)	Exposure to cristobalite
SPECIFIC TWA	mg/m3	(TWA*0.0371)	Exposure to tridymite

Appendix II Formula Used to Calculate the Full Shift-Respirable Dust Time Weighted Averages (FS-RD TWA)

FS-RD TWA=

$$\frac{\text{(ELAP*ADJ EXP)+(BREAK ROOM*0.1575)+(TRANSP*0.0960)+(MISC*0.2110)}}{\text{WKD LEN}}$$

NOTE: * Where AM and PM data was used there were two components of the ELAP*ADJ EXP.

* The 0.1575, 0.0960 and 0.2110 mg/m^3 are ambient respirable dust concentrations at the break room, transportation area and general site area respectively as measure by the area samples.

EXAMPLE:

Date:	6/24/94
Job:	A2
ELAP$_{\mathrm{AM}}$:	202 min.
TL-RD TWA$_{\mathrm{AM}}$:	0.1942 mg/m^3
ELAP$_{\mathrm{PM}}$:	39 min.
TL-RD TWA$_{\mathrm{PM}}$:	0.4829 mg/m^3
WKD LEN:	480 min.
BREAK ROOM:	60 min.
TRANSP:	30 min.
MISC:	149 min.
NOTE:	* This sample contains AM and PM data * Refer to Appendix I for Raw Data

$$\text{FS-RD TWA}=\frac{(202*0.1942)+(39*0.4829)+(60*0.1575)+(30*0.0960)+(149*0.2110)}{480}$$

$$= 0.2122 \text{ mg/m}^3$$

Appendix III Formula Used to Calculate the Full Shift-Polymorph Specific Time Weighted Averages (FS-PS TWA) for Quartz, Cristobalite or Tridymite

FS-PS TWA = (Full Shift Respirable Dust-Time Weighted Average * (X/100))

Where X= Percent Quartz =7.59
Percent Cristobalite = 3.60 or,
Percent Tridymite = 3.71
Depending on the polymorph in question.

EXAMPLE:

Date:	6/24/94
Job:	A2
FS-RD TWA:	0.2122 mg/m^3
Note:	*Refer to Appendix I for Raw Data

FS-PS TWA = (0.2122 * (7.59/100))
= 0.02 mg/m^3 for Quartz

= (0.2122 * (3.60/100))
= 0.01 mg/m^3 for Cristobalite

= (0.2122 * (3.71/100))
= 0.01 mg/m^3 for Tridymite

Appendix IV Conversion of Permissible Exposure Limits and Threshold Limit Values to Account for Workdays Which are not Eight Hours

Exposure limits, set by various agencies, refer to airborne concentrations of substances where repeated exposure day after day will result in no adverse effect for nearly all workers. Implicit in these exposure values are an 8 hour workday, 40 hour work week. The exposure limits for this work regime assumes the body burden of the contaminant will increase during the 8 hour workday. While away from work, where there is presumably no exposure, the contaminant will be eliminated. While this is true for many chemicals, any toxicologist will point out there are exceptions to this rule. To adjust for a longer exposure period and hence a shorter recovery period, the exposure limits are adjusted according to the OSHA model discussed next.

Based on a health classification developed by OSHA, the substance is adjusted according to a corresponding formula. For chronic toxins such as crystalline silica, the formula is based on a work week and is shown below:

$$\text{Equivalent Exposure Limit} = \text{8 hr. Exposure Limit} * \frac{\text{40 hours}}{\text{Work week length}}$$

As mentioned previously, the ACGIH TLVs were used to evaluate silica exposures during this study because they are widely accepted and concise. It is assumed that the above OSHA formula can be applied to the ACGIH values and still result in exposure limits which are more stringent than no adjustment thus providing additional protection to the worker. While this model accounts for the chronic nature of silica toxicity, other models are possible. The reader is referred elsewhere for a more complete discussion (33). Sample conversions are shown below.

EXAMPLE #1:

Substance:	Respirable Dust
Work Shift Length:	10 hours or 50 hours/week
OSHA PEL:	5 mg/m^3

$$\text{Equivalent PEL} = 5.00 * \frac{40}{50}$$
$$= 4.00 \text{ mg/m}^3$$

EXAMPLE #2:

Substance:	Quartz
Work Shift Length:	8-1/2 hours of 42-1/2 hour/week
ACGIH TLV:	0.10 mg/m^3

$$\text{Equivalent TLV} = 0.10 * \frac{40}{42\text{-}1/2}$$
$$= 0.09 \text{ mg/m}^3$$

Appendix V Discussion of Metal Cyclones verses Nylon Cyclones

Cyclones available for personal exposure monitoring are designed for the respirable dust criteria which they will approximate. The NIOSH and OSHA methods recommend using a nylon cyclone at a flow rate of 1.7 lpm. This cyclone was designed to meet the sampling criteria set forth by the ACGIH where the median cut size is 3.5 um. This study utilized the metal cyclone which was designed to meet the British Medical Research Council (BMRC) respirable dust criteria with a median cutoff of 5 um. The flow rate of 1.9 lpm was used as suggested by the manufacturer. Comparative analysis indicates that differences exist between the respirable dust cyclones. A relationship between the two has been found and is shown in the table below (32). A study comparing cyclones and cascade impactors has been completed (33) but, the results are beyond the scope of this paper.

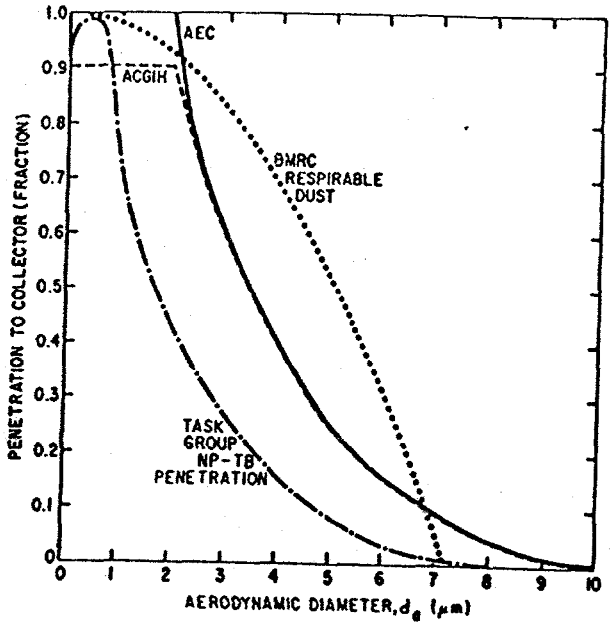

Figure 4.B-10 — Respirable particulate mass (RPM) and respirable particulate mass fraction (RPMF) criteria tolerance band given as penetration efficiency to sample collector of those particles that penetrate a separator whose size collection efficiency is described by a cumulative lognormal function with median cut size of 3.5 ± 0.3 μm in aerodynamic diameter and with geometric standard deviation, σ_g, of 1.5 ± 0.1. Also shown are the assumed penetration values of pharyngeal (NP) head airways and the tracheo-bronohial (TB) airways representing effective penetration to the gas exchange region (GER) based upon the recommendations of the ICRP Task Group on Lung Dynamics.(6)